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the imminent peak of global oil production

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Humanity has already burned nearly half of its endowment of oil and, within the next five years, its most convenient form of energy will become increasingly scarce.

The world's economic prosperity over the best part of the last century was driven by an abundant supply of cheap oil-based energy. This energy source has also played a critical and increasing role in agriculture, which has successfully fed a rapidly growing population. Given this dependency on oil, it is surprising that more attention has not been given to studies of its endowment in Nature, including its distribution, and above all, its depletion. All finite natural resources are subject to depletion which follows a general bell-shaped curve, starting and ending at zero with a peak in between.

The oil industry has made great technological advances since exploration began 150 years ago. These achievements have not, however, been matched in properly defining oil and gas or reporting discovery and production. The unreliable database has given many vested interests the opportunity to mislead and confuse. Explorers have a vested interest in exploration; economists have a blind faith in market forces; engineers have a belief in technology; managers have no alternative but to sing to the investment community, whose interest is confined to short-term financial gain; and governments rely on voters with a thirst for good news. So far, this obfuscation and denial has not particularly mattered as oil production from past discovery continued to grow, although it has indirectly led to damaging fluctuations in oil price. But now the moment of truth approaches as the peak of discovery in the 1960s delivers the corresponding peak of production. The world is ill-prepared to face this historic turning point.

It is now too late to make many useful preparations, and the effort has to concentrate on education. Governments and the people at large need better information if they are to react sensibly.

THE GENERATION OF OIL AND GAS

Advances in geochemistry over the past twenty years have made it possible to relate the oil in a well with the source-rock from which it came, and to map the productive trends, once the critical information has been gathered from key boreholes. In fact, the bulk of the world's oil comes from only a few epochs of extreme global warming, which caused the proliferation of algae, effectively poisoning seas and lakes. The resulting organic material was preserved in favourable plate-tectonic settings. Thus, most of the oil from the United States to northern South America, including the vast degraded deposits of Venezuela, comes from a few hundred meters of clay, deposited 90 million years ago. Another such event, 140 million years ago, is responsible for most of the oil in the North Sea, the Middle East, and parts of Russia.

Gas was more widely generated in Nature than was oil, but this is offset by its tendency to leak from geological traps. Salt and permafrost form the most effective seals. The presence of salt is an important factor contributing to the preservation of large amounts of oil and gas in the Middle East.

The world has now been so extensively explored that virtually all the productive trends, at least in the accessible parts of the world, have been identified, leaving much less scope for surprise than was previously the case.

The world is not about to run out of oil, but it is about to face the peak of production. To determine the date and size of peak involves identifying the many different categories of oil and gas to see how each can contribute. Each category has its own endowment in Nature, its own costs and characteristics, and above all, its own depletion profile. There is obviously a world of difference between a Middle East well flowing at 30 000 barrels per day and processing a few barrels a day from a tar-sand or oil 'shale'.

It is convenient to distinguish *Conventional* oils, which have produced most oil to-date and will continue to dominate all supply far into the future, *from Non-conventional* oils, but there is no standard definition by which to do so. Here, the following categories are treated as Non-conventional:

- Oil from coal and 'shale' (actually immature source-rock)
- Bitumen (defined by viscosity)
- Extra-Heavy Oil (less than 10o API. API is an index which measures viscosity - the lower, the thicker)
- Heavy Oil (10-17.5o API)
- Deepwater oil and gas (more than 500 m water depth)
- Polar oil and gas
- Coalbed methane, gas in tight reservoirs, gas in geopressured aquifers, hydrates etc

Gas liquids, comprising condensate, liquids from processing and new Gas-to-Liquids technology, belong to the gas domain and should be treated apart from crude oil, although the industry's database does not distinguish these adequately.

Economists tend to picture a seamless transition driven by market forces, such that as the production of one category becomes expensive another will take its place, making it difficult to measure anything. It is therefore better to base measurements on physical attributes, although economic and technological factors do influence extraction.

Since peak production is controlled mainly by Conventional oil, we will concentrate on it here.

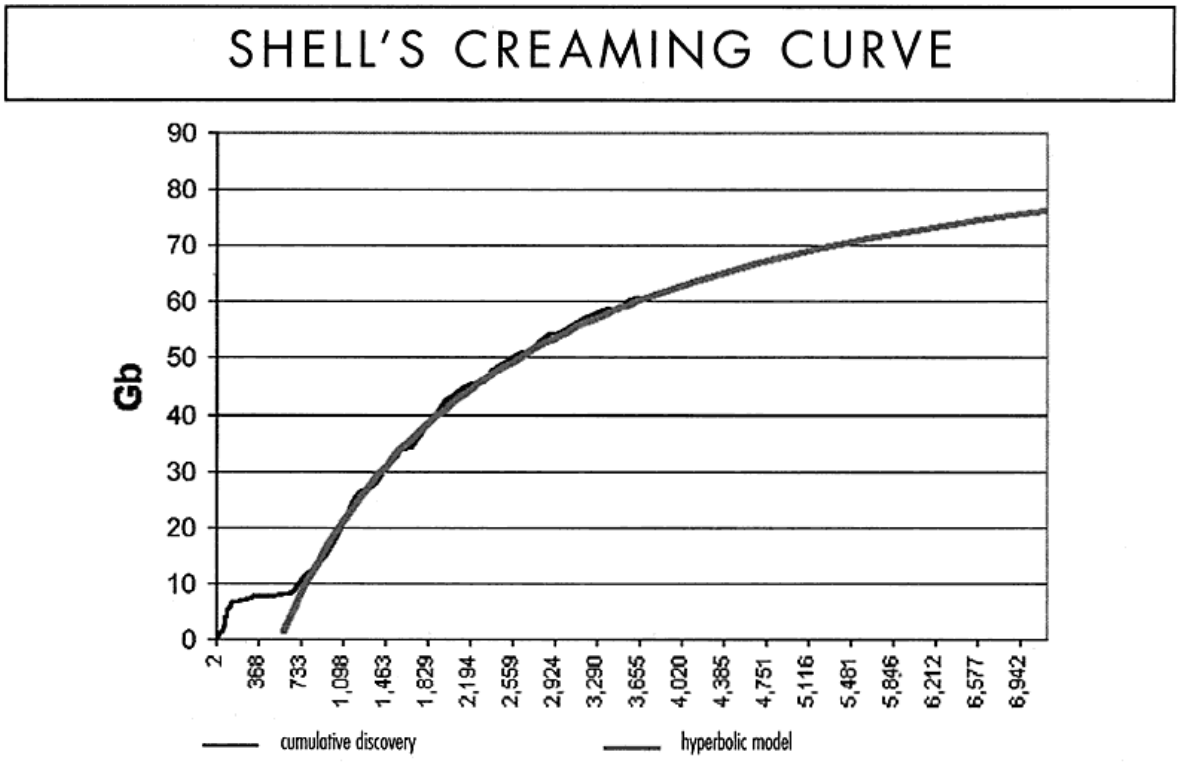
THE SIZE OF DISCOVERY

An oilfield contains what it contains, having been filled in the geological past. Its size will be known exactly only on the day of its final abandonment, but reasonable estimates may be made earlier. The terminology and practices of reserve estimation and reporting are subjects in themselves. But to simplify greatly, we need to use the estimate most likely to result in revisions being statistically neutral: the best estimate for this purpose is that commonly termed *Proved & Probable*. Published reserves are generally reported as *Proved*, although in reality they are closer to *Proved & Probable*, save in the onshore USA. Revisions have to be backdated to the discovery of the field containing them to obtain a valid discovery trend. The amount discovered at any given reference date is the sum of Cumulative Production and the Reserves.

THE ILLUSION OF 'RESERVE GROWTH'

Many claims are made that technology will extract more oil from known fields, giving what is termed Reserve Growth. However, plotting annual production against cumulative production for most major fields shows unequivocally that technology barely affects the reserves. The observed upward revision of reserves is primarily an artefact of reporting practices.

THE SIZE OF THE YET-TO-FIND



The number of exploratory wells - wildcats - drilled by the Shell oil company are plotted on the horizontal axis and the cumulative amount of oil they discovered is shown in billions of barrels (Gb, or giga-barrels) on the vertical one. The graph makes it clear that recent drilling has discovered much less oil per wildcat than in the early days.

It is possible to obtain a good estimate of what is yet-to-find in mature basins by extrapolating the discovery curve with a so-called creaming curve that plots cumulative discovery against cumulative wildcats or over time. The plot of a particular geological province is hyperbolic because the larger fields are found first, being too large to miss. Other statistical techniques involving size distributions and geological habitats also contribute to the estimate. Given that the

world has now been thoroughly explored, most future discovery will be in ever smaller fields in currently producing basins.

ULTIMATE RECOVERY The sum of *Cumulative Production*, the *Reserves* and the *Yet-to-Find*, comprises the *Ultimate Recovery*.The key parameters of the world's oil based on a realistic assessment of each country's conventional crude oil for end 1999 are follows (Gb stands for billion barrels):

Cumulative Production to date	822 Gb
Remaining Reserves	+ 827 Gb
Discovered	= 1649 Gb
Yet-to-Find	+ 157 Gb
Ultimate	= 1800 Gb
Used to date	- 822 Gb
Yet-to-Produce	978 Gb

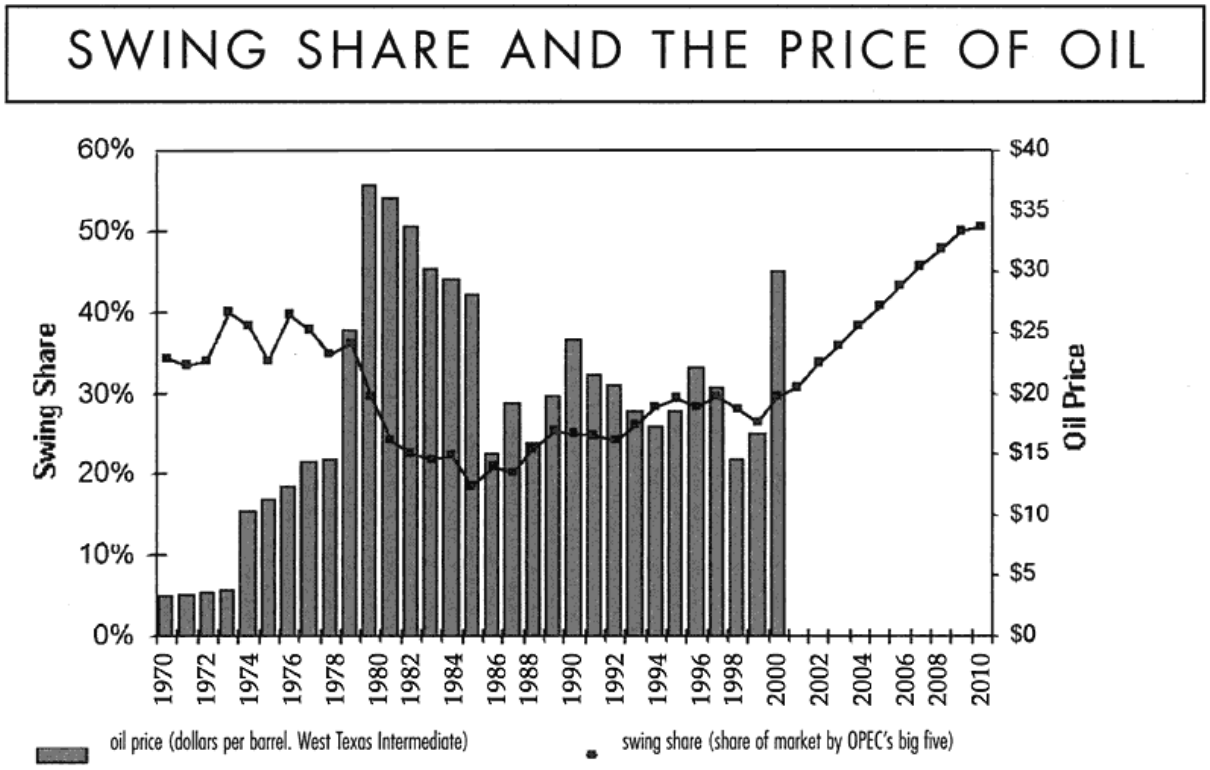
These numbers are quoted as computed but need to be generously rounded, given the inaccuracy of the input. In principle, they apply to conventional crude oil only, but it is recognised that they include some condensate and *non-conventional* heavy oil, which cannot be properly identified in the industry's database.

MODELLING DEPLETION

There are several ways to model depletion once the resource base has been established to within at least reasonable limits. A simple practical model distinguishes five Middle East countries as swing producers, making up the difference between world demand, under various scenarios, and what the non-swing countries can produce. Peak production comes close to the midpoint of depletion, when half the *Ultimate* has been consumed. The non-swing countries may in turn be divided into post- and pre-midpoint groups. In the post-midpoint group, production is assumed to decline at the current *Depletion Rate*, which is annual production as a percentage of the *Yet-to-Produce*. In the pre-midpoint countries, production is assumed to rise to midpoint on the current trend or as otherwise determined. Since midpoint in most such cases is now close, alternative assumptions about the rate of increase have little overall impact. The treatment of

the individual swing countries is more complex, but generally, it is assumed that each country produces in relation to its share of the regional *aggregate Yet-to-Produce* to midpoint, when production declines at the then depletion rate, with the balance being made up by Saudi Arabia.

The base case scenario assumes that demand grows at 1.5% a year until swing share passes 35%. That is taken to mark a price shock sufficient to curb further demand increases, leading to a plateau of production until share reaches 50%, when the swing countries can no longer meet the demands made upon them as they themselves are approaching their own depletion midpoints. World production thereupon falls at the then depletion rate.



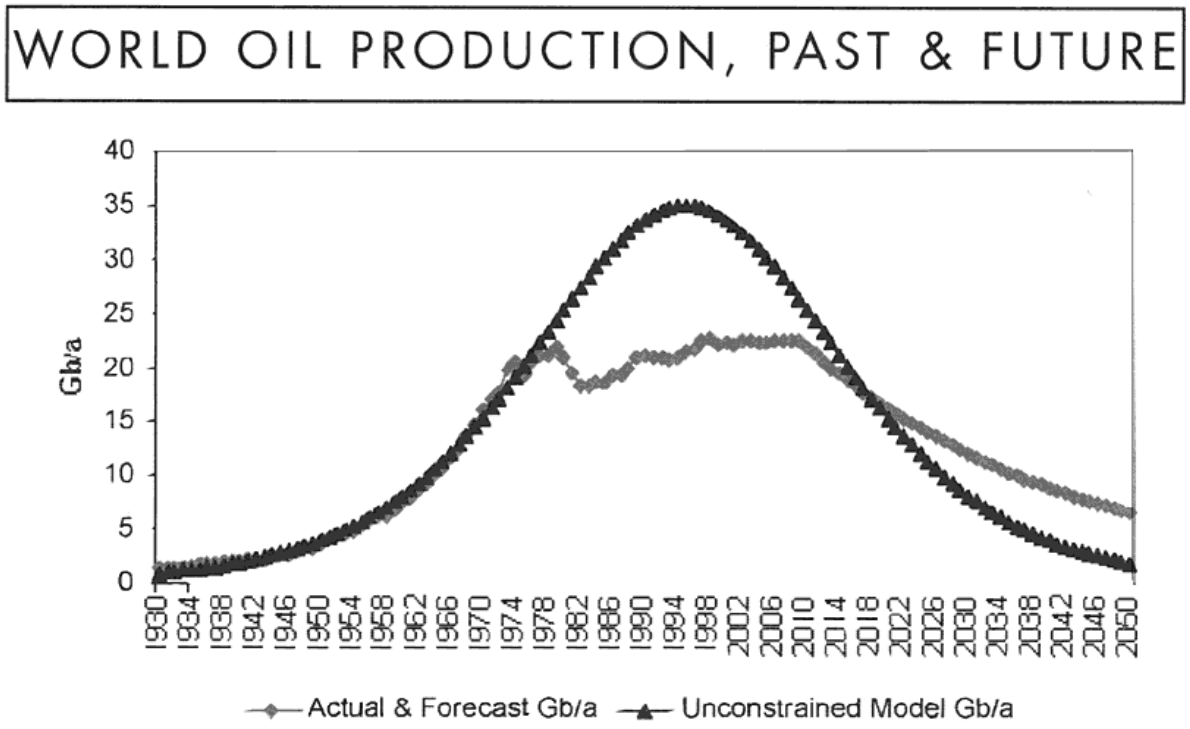
Whenever the share of the world oil market held by the five big OPEC producers in the Middle East has exceeded 30%, they have had the power to push oil prices up sharply - and have done so.

Swing share is an important element. It was 38% the time of the First Oil Shock in 1973, but sank to 18% in 1985 because new provinces, such as the North Sea, were flooding the world with flush production from giant fields, which are found early in the exploration process. It is stressed that these new provinces had been found before the shock, and were not a consequence to it, as is so often claimed. Share

has been rising since 1985 to reach about 30% by end 1999. This time, it is set to continue to rise because there are no major new provinces ready to deliver, or indeed in sight, save perhaps the Caspian, whose potential has been much exaggerated.

SCENARIO

Applying the model to the database, summarised above, gives a price shock in 2002 and the onset of terminal decline in 2009. The intervening plateau is likely to be anything but flat as it will be a time of tension and volatility. A general peak for conventional oil at about 61 Mb/d (million barrels per day) can be said to arise in the middle of the plateau, namely around 2005. Adding non-conventional oil and gas-liquids will delay the overall peak by about five years, when production may total about 85 Mb/d. Gas itself, which is not considered in detail here, is likely to peak around 2020.



The darker line in the graph above is the so-called Hubbert curve and shows how oil production would have expanded and then contracted if it had been governed solely by physical constraints. The lighter line shows the amount of oil actually produced until today and what is likely to be produced in the future. As can be seen, the actual curve followed the theoretical curve very closely until the early 1970s when the five powerful Middle Eastern OPEC producers gained control of more than 30% of the world market. They took advantage of their situation and pushed up prices, thus limiting oil demand. High oil prices can be expected to cause world oil

demand to stay on a plateau until around 2010. After that, output will fall whatever the price because fields will be becoming exhausted.

There are of course other scenarios that could advance or delay peak, but the onus rests on their proponents to demonstrate exactly where they expect the necessary production to come from and at what rate and cost. The deepwater areas, whose oil is here treated as non-conventional, are not as well known as the rest of the world. It appears, however, that deepwater oil prospects depend very much on divergent plate-tectonic settings as found principally in the Gulf of Mexico and South Atlantic, where reservoirs are underlain by effective oil-source rocks. In other areas where delta fronts have extended into deepwater, the prospects are likely to be gas-prone. Overall, the deepwater domain is likely to yield about 85 Gb, peaking with heroic effort at about 9 Mb/d by 2010.

DENIAL AND OBFUSCATION

The foregoing scenario is based on a realistic assessment of the reserves as known to the oil industry with the yet-to-find estimate coming from an extrapolation of past results. The industry has indeed made remarkable technological progress in virtually all spheres of operation, and it has systematically searched the world for the biggest and best remaining prospects. It is, therefore, very reasonable to give weight to the past record in predicting the future, and to treat with skepticism claims that some remarkable and unforeseen technological breakthrough might open unknown doors. In any event, it is better to base plans on realism and not dreams.

It is worth examining how and why governments, international institutions and oil companies are reluctant to look reality in the face. It is difficult to penetrate the many layers of denial and obfuscation that envelope their pronouncements. We need the skills of a detective to determine whether we are dealing with ignorance, culpable ignorance, or fraud and deception.

OIL COMPANIES

One major company overcomes its reluctance to admit to depletion by claiming that its record of forecasting has been poor, so that it prefers to develop a range of well-reasoned scenarios to cover the spectrum of possibility. In effect, it evades the issue on the grounds that it has no single viewpoint, although it does confess that at least one of its scenarios contemplates an Ultimate of about 2600 Gb for all liquids with a peak around 2010. This is close to the above assessment.

Another major oil company, BP Amoco, has made a public presentation showing that discovery peaked in the 1960s, even if failing to draw the obvious conclusion that peak production must follow. It has changed its logo to a sunflower and says that its initials stand for 'Beyond Petroleum', which is a very oblique reference to the depletion of its principal asset. Its chairman and chief executive sit on the board of an investment bank, Goldman Sachs, which in 1999 commented:

'The rig count over the last 12 years has reached bottom. This is not because of low oil price. The oil companies are not going to keep rigs employed to drill dry holes. They know it but are unable and unwilling to admit it. The great merger mania is nothing more than a scaling down of a dying industry in recognition of the fact that 90% of global conventional oil has already been found'

It would be surprising if this did not convey the opinion of the BP board. At the time it was making large acquisitions, the company stated that oil prices would remain low for the foreseeable future, but now admits that the world depends on the Middle East.

Still another chief executive comments: *'So technology is one of the key reasons why I am excited about the prospects of our industry. Our raw resources may be the same, but our processes and technology are truly state-of-the-art'*. In other words, he admits that technology does not change how much oil a field contains, with all that that implies.

In shining contrast are the chief executives of Arco and Agip who, when they felt free to speak on leaving office, both stated that they expected global production to peak by 2005.

GOVERNMENT INSTITUTIONS

The US Geological Survey has made periodic assessments of the world's oil and gas endowment, the latest of which was issued in 2000. In a press release on the eve of a critical OPEC meeting, it claimed *that 'there is still an abundance of oil and gas in the world'* and announced an estimated Undiscovered of 649 Gb for the world outside the USA and 612 Gb of 'Reserve Growth'. The report itself later revealed a very wide range from 239 to 1376 Gb for the Undiscovered with for example a *Mean* expectation from East Greenland of 49 Gb on the basis of a comparison with mid-Norway, which has yielded about 10 Gb after many years of search. To attribute five times more to an undrilled, unknown province

demonstrates an absence of common sense. The reserve growth claim also ranges from 192 to 1031 Gb based mainly on onshore US experience, failing to appreciate that most 'growth' is a reporting phenomenon, primarily related to large onshore fields. Only the low end of the ranges can be taken at all seriously. At the same time, the Geological Survey separately released an unpublicised poster that did depict an imminent peak of production accompanied by a text stressing the consequential crisis. It has diplomatically covered the full spectrum of possibility with a wide range of estimates and contradictory material.

The International Energy Agency was established by the OECD governments in the aftermath of the oil shocks of the 1970s to monitor supply and demand. In 1998, it presented a report evaluating a so-called 'business as usual scenario' whereby demand grew to 112 Mb/d by 2020 with prices rising to $25/b. It showed how this demand would be met, admitting that the non-Middle East peaked and declined, while the Middle East share grew to 62% by 2020. Even this was not enough, causing the IEA to introduce a 'balancing item' of unidentified unconventional oil, whose production miraculously rises from zero in 2010 to 19 Mb/d ten years later, while the identified unconventional makes a ceiling of only 2.4 Mb/d by 2010. A moment's reflection tells us that oil will not be $25/b when the Middle East supplies 62%, and that the 'balancing item' is a euphemism for rank shortage.

These few examples illustrate the scale of denial and obfuscation that surrounds this subject.

CONCLUSIONS

There is no particular technical difficulty in assessing the size of a field's reserves or in assessing the world's undiscovered potential. It is easy to see that the true impact of technology is to hold production as high as possible for as long as possible, without materially affecting the reserves themselves, which are set by Nature. The relationship between peak discovery, which is a matter of historical fact, and a corresponding peak of production is also evident from a moment's thought

So far, the world has been reluctant to admit that the production of one of its principal fuels is close to peak without sight of any substitute that can come close to matching its convenience and low cost. It is now too late to make any useful preparations, but much remains to be done to inform. Governments need to

understand, so as to react better, and the people at large have to know, so that they will be willing to give governments the mandate for tough decisions.

The world is not about to run out of oil, but production is about to peak. The sky does not fall in at peak, but the perception of the future changes. It is likely to lead to severe political and economic tensions, including economic recession, a stock-market crash, and financial instability from the huge flows to the Middle East. There are obvious dangers of misguided military intervention as the United States, Europe and the East vie for access to Middle East oil. The inequality between rich and poor nations will be more severe. Agriculture is at risk because it is now heavily dependent on synthetic nutrients and irrigation, both directly and indirectly dependent on petroleum. The global market may wither from high transport costs.

This is not necessarily a doomsday picture, for the end of cheap oil-based energy may carry long-term benefits. Countries will have to become more self-sufficient and self-reliant, finding ways to live in closer harmony with their environments. The excesses of capitalism that seem to have created a virtual economy, based on the notion of perpetual growth, may be curbed, and the kleptocrats who run it may be reined in. The risks to the climate from human activity may recede.

It is time to wake up, for the alarm has sounded.

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Biographical Sketch :

Colin Campbell obtained his doctorate in geology from Oxford University in 1958 and has worked since then as a petroleum geologist with companies including BP, Texaco, Fina and Amoco. He was exploration manager for Aran Energy, Dublin, in 1978-9. More recently he has been a consultant to the Norwegian and Bulgarian governments, and to Shell and Esso.

In 1998, he and a colleague, Jean H. Laherrère, were largely responsible for convincing the International Energy Agency that the world's oil output would peak in the next ten years. He is the author of two books and numerous papers on oil depletion and has lectured and broadcast widely on the topic. He lives in Ballydehob.

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