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The Oil Supply Mountain:

Is the Summit in Sight?

Philip Barnes

1993

Oxford Institute for Energy Studies

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EXECUTIVE SUMMARY

World oil consumption over the next twenty-five years could be almost as much as the total amount of oil produced in the entire existence of the oil industry. This high demand for what is a finite resource makes it necessary to assess where the continuing need for oil stands in relation to latest views on the size of the overall resource base and its potential utilization. This has less to do with uttering doomsday warnings than putting future technological, political and economic decisions relating to energy into their fundamental context.

Views on the potential global supply of oil are usually formed by isolating and using as a basis for quantification a number of factors and assumptions. These include the likelihood of enhancing estimates of existing reserves, the potential for discovering additional conventional oil, the rate at which this oil could be brought into production, the scope for additional volumes from enhanced oil recovery, natural gas liquids and unconventional liquid fuels. This paper critically examines these and other key elements and uses the results to build up a quantified view on the likely shape of the oil supply mountain.

One view is that a steady climb to a peak production of 90 million barrels per day by the end of the first decade of the next century could be achieved on an ultimately recoverable resource base for conventional oil of some 2,200 billion barrels. Thereafter, world production would inevitably decline rapidly, falling to below 10 million barrels per day by 2065. However, the shape of the mountain could vary considerably; it may well be flattened by efficiency improvements on the demand side and by substitution by other fuels. On the other hand, the production peak could also be brought forward and foreshortened considerably if growth in oil demand accelerates and discoveries are disappointing. A build-up of production to 100 million barrels per day by the year 2005 would be supportable on a resource base of 2,200 billion barrels, but it would involve a sharp decline after just a few years at peak production.

The paper describes and quantifies what would be necessary for the expansion and extension of the oil supply mountain through the exploitation of additional conventional and unconventional resources, and assesses the probabilities involved. There is still great uncertainty about how much oil is actually in place, what volumes can be sensibly recovered and at what cost. Nevertheless, this paper concludes that there could still be a long way to go before the summit of the oil mountain is reached even on fairly conservative assumptions.

1. INTRODUCTION

During much of the 1980s world demand for oil was stagnating or even falling. Although the oil price collapse of 1986 encouraged demand, growth only averaged 1.4 per cent per annum between 1987 and 1991. Demand for oil in 1992 increased by a very modest 0.5 per cent to reach 66 million barrels per day (mb/d). Even the most bullish of forecasters seem to have difficulty now in envisaging demand growing at annual rates of much more than 1 or 2 per cent for the rest of the 1990s. The contrast between these rates of growth and the 8 per cent or more per annum that used to obtain in the 1950s and 1960s is striking.

The deep pessimism on the future of oil supplies which emerged in some quarters in the late 1960s/early 1970s was induced by the relentless increases in world oil consumption over many years. The perceptions have now changed radically and there is little inspiration for the kind of articles and speeches warning about the finite nature of oil resources that were once so common. The need to switch to alternative fuels away from oil and particularly to renewables is now more likely to be promoted on environmental grounds than through fear of looming oil scarcity. The ritual cry of 'what shall we do when the oil runs out?' is still heard occasionally but, even then, only in a local context. Amongst organizations that specialize in energy matters the once outspoken consensus on coming scarcity and particularly the decline in non-OPEC oil supplies is now muted.

Nevertheless, the modest rates of growth that are expected for future oil demand should not distract attention from the important fact that this demand would still be *growing*. And it could grow much faster under quite a number of realistic assumptions, in particular if there is rapid economic expansion in the large developing economies such as China. If oil demand were to continue to grow at, say, an average of 1.5 per cent per annum, the world would be consuming a total of 90 mb/d by the year 2015. This means that the world would consume almost as much oil over the next twenty-three years as has been produced during the previous hundred or so years — that is since the beginning of the oil industry.

This significant demand for liquid fuels, which are after all finite resources, means that questions about the world oil supply potential will inevitably become once again the focus of attention. The issue of where the world requirements for oil stand in relation to the latest available views on the size of the overall resource base and its potential utilization is, and will always remain, topical. There is no need, however, to utter doomsday warnings but it is important to put future technological, political and economic decisions relating to energy into a fundamental context.

The standard measure used to calculate and indicate how high production levels can go and how long they can be maintained is the size of the ultimately, or the original, recoverable resource, sometimes abbreviated to URR. This may also be labelled as the ultimate resource or UR. These concepts are not to be confused with the total amount of *oil in place* within the earth before production, not all of which is recoverable. Neither are they to be confused with the undiscovered recoverable resource, also sometimes abbreviated to URR. These and other concepts of resources and reserves, which often involve confusion, are discussed in the next chapter.

If a reasonable indication of the amount of oil that can ultimately be recovered happens to be available, it would be easy to work out the time-span over which the resource will be exhausted at various levels of future production.

The use of a time-curve to exhaustion to illustrate the finite nature of the world's oil first came to prominence as a result of the work of M. King Hubbert, a geophysicist from Texas. In a paper published in 1956 Hubbert predicted that oil production in the lower 48 US States would peak in 1969 and decline steadily thereafter. This was at variance with the consensus at the time that production would continue to rise for the rest of the century. Production in the lower 48 States did, indeed, peak in 1970 although at a rather higher level than forecast by Hubbert.

The potential production from Alaska which enabled overall US production to be maintained through the 1980s was apparently not considered.

Hubbert considered that the logistic or S curve displayed a good fit with the life cycle of cumulative oil discoveries and production. He felt that it provided a useful tool for estimating the size of the ultimately recoverable resource and for projecting potential levels of production and their limits.

According to Hubbert, oil discoveries are sporadic and generally limited in size when the oil industry is in its infancy. As more discoveries are made the industry's knowledge and techniques improve considerably, and this leads to more discoveries and to the further accumulation of expertise. In this expansionary phase the discovery rate rises and the largest fields tend to be discovered and developed first. However, there must inevitably come a stage when both the rate and the size of discoveries reach a peak and start to decline. Discoveries will

Table 1: USA Crude Oil Production in the Lower 48 States. 1900-91. Million Barrels Per Day

Year	Actual	Hubbert's Forecast
1900	0.17	
1910	0.57	
1920	1.21	
1930	2.46	
1940	3.70	
1950	5.41	
1960	7.04	
1965	7.77	
1966	8.26	
1967	8.73	
1968	8.93	
1969	9.04	(8.0)
1970	9.41	
1971	9.24	
1972	9.24	
1973	9.01	
1974	8.58	
1975	8.19	(7.0 - 7.5)
1976	7.96	
1977	7.78	
1978	7.48	
1979	7.15	
1980	6.98	(6.5 - 7.0)
1981	6.96	
1982	6.95	
1983	6.97	
1984	7.16	
1985	7.15	
1986	6.81	
1987	6.40	
1988	6.14	
1989	5.75	
1990	5.60	(4.0 - 5.0)
1991	5.62	

Note: Oil production includes field condensates

Sources: DeGolyer and McNaughton; *Basic Petroleum Data Book*, various issues; Cleveland & Kaufmann (1991).

continue to occur but they will require more effort and obtain at an ever decreasing rate. Cumulative discoveries therefore follow an S curve over time, approaching asymptotically an upper limit which represents the amount of the ultimately recoverable oil resource. Hubbert hypothesized that cumulative production followed a similar shaped curve to discoveries although with a lag to allow for the time it takes to develop the oilfields that have been discovered.

In his 1956 paper Hubbert assumed that the size of the ultimately recoverable resource in the USA was 150 billion barrels (which he later increased to 171 billion barrels). This was the consensus view at the time. A symmetric, bell-shaped, curve with historical data fitted against it, was used to forecast future levels of production based on these views of the recoverable resource base. Later, however, he inferred the most likely size of the recoverable resource from the logistic curve that fitted the data.

There were, naturally, critics of Hubbert's methods, who were healthily sceptical about any attempt at predicting production by this type of mathematical modelling. It was argued that market forces and technical change strongly influenced oil discoveries and that the future impact of these forces could not be inferred and quantified solely by an historical approach.

None the less, Hubbert's methodology and particularly the resultant bell curve of production captured the imagination of many at the time and has frequently been used to illustrate the limits to global oil production. For obvious reasons it has not been mentioned too frequently in recent years although, coincidentally, it has been referred to recently by both the Centre for Global Energy Studies (1992) and the Massachusetts Institute for Technology (Lynch, 1992).

Production forecasts using the Hubbert method rely explicitly on a current estimate of the size of the ultimately recoverable resource to determine future production. Thus, every change of views about the volume of oil that is recoverable means that the production curve must be revised and production peak and life expectancy of the depletable resource shown by the curve must be changed. The limitations of this approach are illustrated in later chapters.

In the USA, production according to Hubbert's curve should by now be around 4 mb/d. It is actually nearer to 5.4 mb/d, without the additional 1.7 mb/d or so from Alaska.

Production in the lower 48 States has been maintained largely through squeezing more oil out of existing fields. However, it is interesting that in this, the most intensely drilled and analysed region in the world, the US Geological Service view of undiscovered oil increased by 33 billion barrels between their 1975 and 1991 estimates. That is by some 2 billion barrels per annum.

The final shape of the Hubbert curve, or 'Oil Mountain', is frequently used to show that global oil production is nearing the summit only a few years from the time the calculations were made. Thereafter there is a seemingly inevitable and rapid descent down the other side of the mountain. Not the least value of this kind of approach to world oil supply is its use as a public relations tool. Oil-producing countries wanting higher oil prices and status, oil companies wanting both higher prices and better terms and everybody with a vested interest in promoting other forms of energy than oil have all found it useful.

The amount of oil that can actually be recovered out of the ground is, indeed, ultimately of paramount importance in building up a picture of future production possibilities, whether for a country or for the world as a whole. However, there are many other factors that have to be considered in looking at potential oil production levels. Clearly, the producers' price expectations, the financial needs of the countries with an oil resource, upstream taxation and political and strategic attitudes play a significant role. These have a bearing on, and are themselves influenced by the rate of turning the undiscovered resource into reserves, the eventual rate at which these reserves are produced, the speed at which production is built up and the extent of improvements in the recovery rate that could be achieved from the oil physically in place.

Estimating the long-term global, or country, potential for oil production is still very much an art open to many interpretations. But it will always be vitally necessary despite the many uncertainties and the likelihood of getting the estimate wrong. In judging the value of any production forecasts one would need to know what elements have been taken into account and particularly the basic assumptions made on the way in which the resource will be developed. The substantial degree of flexibility and bias that these assumptions allow always has to be borne in mind when considering pronouncements on the potential for future oil supplies from whatever source.

Chapter 2 looks in some detail at the different types and definitions of resource and reserve concepts that are used as a basis for production estimates and at the confusion that frequently surrounds them.

Chapter 3 looks closely at some of the more basic factors to be considered in determining the eventual pattern of oil production and at some of the key and fundamental elements involved in developing national and global oil supply profiles.

These various elements are then brought together in the final chapter in the form of an illustrative global 'Oil Mountain'. This global view of oil supply potential, as a complement to the Oxford Institute for Energy Studies country-by-country analysis (Barnes, 1990), attempts to provide some answers to the broad question facing the future of conventional oil: is the summit near or not?

2. RESERVES VERSUS RESOURCES

Despite the enormous growth in our knowledge of the earth's resources, there is still considerable uncertainty about the volume of oil available as a resource. Adding some confusion to the issue is the variety of terminologies in use when various agencies or companies classify and report reserves in relation to resources. Such confusion, especially in the different concepts (and therefore estimates) of reserves is not just prevalent outside the oil industry, but sometimes within it as well. Within a company, an estimate from the team charged with exploration may be quite different from that made by development engineers from another department of the same corporation.

In this paper, when discussing the 'Oil Mountain', we have used as far as possible the following terms in relation to the definitions indicated:

Total resource: The total volume that was formed and trapped in place within the earth before production.

Recoverable resource: Accumulations of sufficient size and quality that could be produced with conventional recovery technologies but *without regard to economic viability*. They include both discovered and undiscovered resources.

Undiscovered recoverable resource: As above, but excluding those recoverable resources whose location is known and have already been produced or counted as reserves.

Proved reserves: The estimated quantities of all liquids defined as crude oil, which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs *under existing economic* *and operating conditions.*

The above may seem admirably clear cut or at least reasonably concise, but it is salutary and, we feel, necessary to look more closely at these definitions and at the many variants used in practice.

An indication of the relationship between some of the terms commonly used for petroleum resources and reserves is given in Chart 1 derived from the US Energy Information Agency (EIA). The terms used apply equally well to gas as to oil.

The *Concise Oxford Dictionary* gives a definition of resource as 'means of supplying what is needed, stock that can be drawn on'. As defined by the EIA, the total resource of oil and gas is the total volume that was formed and trapped in place within the earth before production. This is not necessarily 'stock that can be drawn on' in the sense of the dictionary definition. A large part of these hydrocarbons is found at very low concentrations throughout the earth's crust and cannot be extracted short of mining or some other technique that consumes more energy than it produces. An additional portion of the total resource base cannot be recovered because current production techniques are unable to extract all of the oil and gas in place even when it may seem to be present in commercial quantities. This is not to say that one day, with new or improved techniques, some of these additional volumes may not be recovered. However, a substantial portion of this total resource base is unrecoverable by current or foreseeable technology.

When such terms as the total resource, the overall resource base, oil in place or hydrocarbons in place, abbreviated to OIP, HCIP, HIP and so on are used it may not always be clear what is actually being covered. They may at times refer to the total resource base as defined by the EIA, but at other times they seem to refer only to those resources that are believed to be present in what could currently be considered as commercial volumes. For the purposes of this paper we have used the term 'total resource' as defined by the US EIA.

The concept of 'recoverable resources' indicated in Chart 1 clearly excludes those parts of the total resource that cannot be recovered. There are, naturally, other terms in common use which generally mean the same thing, for example 'ultimately recoverable resource', 'ultimate economic recovery', 'expected ultimate recovery'.

However, it is important to recognize that the proportion of oil that can be recovered is susceptible to change over time and place because of new technology and changes in economic conditions.

Some estimates of the volumes recoverable, such as those of the US Department of the Interior, specifically disregard economic viability although restricting recovery to the use of conventional technology. Other sources such as the American Association of Petroleum Geologists specify a price range for their estimates. A considerable difference to the volumes involved would be made, for example, by including or excluding oil extracted by high-cost enhanced recovery methods. However, the overall uncertainty and the reliability of the different methodologies is so great that such differences of definition may not prove to be very serious for global forecasts.

A concept used by the Royal Dutch/Shell Group of companies perhaps uniquely, also brings in the concept of changing regulatory patterns. 'Expected ultimate recovery' is defined as 'the total volume of hydrocarbons which may be expected to be recoverable commercially from a given area at current or anticipated prices and costs, under existing or anticipated regulatory practices and with known methods and equipment' (Shell, 1969). However, the addition of a proviso on regulatory practices in such a broad definition makes little difference to the estimate.

We have used the term 'undiscovered recoverable resource' in this paper in the sense of the US Department of Interior definition taken up by the EIA.

The proportion of oil that can be recovered from the total resource, i.e. the recovery rate, is usually said to be around 30 per cent on a global basis. It can be much higher in individual areas and fields. For example, the latest investment plans for the UK North Sea Brent field envisage that, when the field is ultimately abandoned, some 55 per cent of the oil in place, i.e. the total resource, will have been recovered. Even though our view of the original total resource may not change, the perception of what can be commercially recovered clearly does. This is of real significance. An increase in recovery from say 29 per cent to 35 per cent on a global basis could, on an estimate of total oil in place of around 8,000 billion barrels, mean an extra 500 billion barrels added to the ultimately recoverable resource.

The recoverable resources that are quoted by institutions, companies and governments usually refer to the technical and economic conditions prevailing when the estimates were made. They do not normally include oil recoverable by enhanced methods such as Enhanced Oil Recovery (EOR) or unconventional oil resources such as tar sands and heavy oil.

As Chart 1 indicates, recoverable resources include both those resources that have been discovered and those that have yet to be discovered. The discovered recoverable resources include all the oil that has been produced to date, i.e. the cumulative production. The other component is the reserves which, obviously, should not contain oil that has already been produced.

These overall reserves are usually volumes estimated to exist in known deposits and believed to be recoverable now or in future through the application of current or anticipated technology.

There are numerous classifications and labels for reserves such as proved, proven, measured, indicated, inferred, discounted, demonstrated, identified, probable and possible. Although clear in specific context and immediate use, when employed on a wider scale or in aggregations these classifications seems almost designed to confuse.

'Proved reserves' are defined by the US Energy Information Administration as the estimated quantities of all liquids defined as crude oil, which 'geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions' (DOE/EIA, 1991:3). A similar definition is used by the American Association of Petroleum Geologists.

The most commonly used concept for reserves that are almost certain to exist, is generally that of proved or proven reserves, although this sometimes tends to be a 'catchall' term. The definition that is described above being used by the EIA and the American Association of Petroleum Geologists is probably the most common and accepted one for general purposes. It is this concept that we have used in this paper.

Reservoirs are considered proved if economic producibility is supported by actual production or conclusive formation test, or if economic producibility is supported by core analysis, electric or other log interpretations. The area of an oil reservoir considered to be proved includes (1) that portion delineated by drilling and defined by gas-oil and/or oil-water contacts, if any; and (2) the immediately adjoining portions not yet drilled, but which can be reasonably judged as economically productive on the basis of available geological and engineering data.

Reserves of crude oil which can be produced economically through application of improved recovery techniques, such as fluid injection, are included in this 'proved' classification under certain conditions. It is not necessary that production, gathering or transportation facilities be installed or operative for a reservoir to be considered proved.

Another definition of reserves is that of the US Department of the Interior (DOI), which defines 'measured reserves' as 'the part of the identified economic resource that is estimated from geological evidence supported directly by engineering data' (DOE/EIA, 1991:3). They represent volumes demonstrated with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions. They are generally equivalent to 'proved reserves' as defined by the EIA.

A further category of 'indicated additional reserves, included in 'other reserves' in Chart 1 is defined by the EIA, as 'quantities of crude oil, other than proved reserves, which may become economically recoverable from existing productive reservoirs through the application of improved recovery techniques using current technology' (Ibid). Indicated additional reserves are not included in proved reserves due to their uncertain economic recoverability. When economic recoverability is demonstrated the indicated additional reserves are transferred to the proved reserves as positive revisions.

The DOI, in turn, defines 'inferred reserves' as 'that part of the identified economic resources, over and above measured and indicated reserves, that will be added through extensions, revisions, and the addition of new pay zones in discovered fields' (Ibid). These 'inferred reserves' are often also considered as 'probable reserves'.

'Discounted reserves' are usually reported on the basis of the probability of them materializing. The latest UK 'Brown Book' (Department of Trade and Industry, 1993), for example, does not actually call its estimates discounted. However, it provides a matrix of 'initially recoverable reserves' set against 'proven', representing those with a better than 90 per cent chance of being produced, and of 'probable' and 'possible' reserves. The latter represent above 50 per cent and below 50 per cent chances of being produced respectively. The 'maximum possible' of 'total remaining reserves' is the sum of proven, probable and possible, less cumulative production to date.

Some official country estimates may only report a single volume for reserves, and others just provide a little more information that may or may not be related to the probability of more oil being available. The Indonesian government, for example, gives volumes for 'proven' and 'potential' reserves separately and another undefined volume for 'resources'.

The World Energy Council defines 'proved recoverable reserves' as the 'tonnage of the proved amount in place that can be recovered in the future under present and expected economic conditions and existing technological limits' (World Energy Council, 1992). This appears to mean the same as the US definition of proved reserves. There is another category of 'estimated additional reserves recoverable' defined as 'the tonnage of additional amount in place which geological and engineering information indicates with reasonable certainty might be recovered in the future'.

There is, with the definition of proved reserves, and even more with some of the other reserve concepts, considerable scope for uncertainty and confusion particularly when these concepts are used for international comparisons.

Quite why there needs to be such a proliferation of terms and why there is not a common and acceptable usage, particularly for international comparisons, is not clear. Certainly, when many definitions are being used it seems sensible to give discount factors related to the availability of oil at different volumes if some comparative structure is to be achieved. The authoritative and widely copied World Oil and Oil and Gas Journal estimates very sensibly use the single terms 'proven' and 'proved' respectively. This seems, in both cases, to be the same as the US EIA 'proved' definition. On a worldwide basis this is probably the best that can be done.

The turning of undiscovered resources into reserves is fundamentally a continuing function of investment allied to technology. Chart 2 attempts to illustrate the movement that takes place and the relationship between reserves and undiscovered resources and between sub-economic and economic resources.

Clearly oil that is not economic to produce at any one time can become economically recoverable oil if prices or returns rise or costs fall. In addition there is a flow into reserves from the undiscovered, speculative, element as new fields are proven up. The reverse can also happen as some discovered or undiscovered resources become uneconomic with falling prices or if technical costs or fiscal payments prove higher than anticipated.

These kinds of movements also give rise to confusion. Quoted estimates of the volume of economically recoverable oil may have been made against, say, a background of higher prices than at present; some downward adjustment ought to be made but often is not. The estimates may also have been made before many present, cost reducing, technologies were known, in which case, for example, additional infill drilling or secondary recovery becomes economic and should increase estimates of volume available.

Particularly in the case of specific fields and countries, changes in fiscal terms will also have a major impact. A recent example is the change in the UK Petroleum Revenue Tax (PRT) in April 1993. This is likely to encourage further development of existing fields, thus moving sub-economic reserves to the economic reserve category. According to its critics, the abolition of exploration incentives will also tend to reduce the amount of oil moving from the speculative category into the proved category. It has been said that, where under the previous fiscal regime a 15 million barrel field would be economic to prove up, the tax changes will move the threshold to as far as 60 million barrels.

These processes of discovery and proving up reserves, and the reclassification of uneconomic reserves into an 'economic' category are, however, not always directly related to new economic conditions or the application of new technology. Commercial, fiscal and political influences and procedures also have a significant effect on the way in which reserves and resources are treated and reported.

3. ELEMENTS OF THE GLOBAL OIL SUPPLY PROFILE

In order to build up a profile of potential global oil supply, and more fundamentally to prepare production profiles for individual countries, it is necessary to obtain reliable and consistent reserve and resource estimates.

We have prepared from a variety of sources a detailed country-by-country compilation of cumulative production, proved reserves and undiscovered resources, including additions from Enhanced Oil Recovery methods. One hundred and eleven individual countries are covered by the compilation. The uncertainties attached to these estimates and to the other basic technical elements which should be incorporated in any view of potential production are described below.

3.1 Existing Fields and Revision of Reserves Estimates

Proved reserves estimates at any particular date are usually an understatement of the amount of oil that is ultimately recovered from a field or from a country as a whole. This is particularly true for a recently discovered field. Although this is well-known, it is a factor that is rarely taken into account when considering production potential on an aggregated basis. It is probably one of the main reasons for the seemingly perennial underestimation of, for example, non-OPEC oil potential.

Estimates for the discovered volume of proved reserves can be made when an exploratory well penetrates an oil-bearing zone or reservoir. Such estimates are based on the initial flow data, the thickness of the reservoir found and the apparent size of the area it covers. Electrical and other measurements taken inside the hole also provide information about reservoir rock porosity, permeability, fluid saturations, pressures and temperatures. The initial estimate of proved reserves is based, of necessity, on the limited amount of data available from this exploratory drilling and from the interpretation of any seismic or other geophysical and geological data. The first discovery well may not be sufficient to determine the commercial nature of the reserve and this may only be known after the drilling of appraisal wells. In addition, there may be pressing commercial, fiscal and political reasons for initially understating reserve positions.

The estimates made after the initial drilling can only be preliminary judgements as to the amount of oil and gas in place and the amount that could eventually be recovered economically. A field may contain a single reservoir or many reservoirs in its proved area. As more wells are drilled and placed on production, data on reservoir performance becomes available. The additional wells also provide more information on the thickness, size and other properties of the reservoir. Production and pressure data obtained from actual field measurements can be built into reservoir engineering 3D computer simulation models. At the same time much additional geological information becomes available following drilling of the development wells, and this may lead to the increasing of reserves estimates.

Conversely, drilling may reveal a gap in the reservoir or a water-bearing section, indicating that the field is more limited in scope than previously thought. This may well result in the reserves estimates being decreased. Proved reserves are continually revised as additional knowledge is gained and improvements are made in the technology available or in the economic and operating conditions.

Proved reserves are by definition economic to produce. Economic considerations are important through most of the life of a field but can be most pronounced towards the end of its anticipated life. At that time capital costs have depreciated, so that field profitability at low production rates is then highly geared to operating costs and crude oil prices and the returns from them. A marginal upward price movement at the appropriate time can therefore have a marked effect on the timespan of the economic production profile and thus on enhancing reserves. This is because the higher price encourages the drilling of more infill wells or the application of secondary or tertiary recovery methods. Even after many years of production there is often substantial scope for additional investment to offset the depletion of the field. Naturally, the longer the production history the closer to reality the proved reserve estimate becomes. About four or five years after discovery the estimated ultimate recovery volumes may be fairly close to the final value. The exact amount of recoverable oil will not be known, however, until the field is permanently abandoned and the cumulative production added up.

According to Shell International, more than three-quarters of the annual additions to the world's total reserves of oil are obtained by optimizing the recovery from producing fields. The discovery of new fields contributes only one quarter (Pink, 1992). Certainly, according to US DOE statistics 88 per cent of the average amount of crude oil reserves added each year in the USA now comes from revisions and extensions to existing fields.

An example of the changes in reserves that have occurred in the USA between 1977 and 1990 is shown below. Over that period, of the total increase in reserves of 33 billion barrels only 2 billion barrels were obtained from the discovery of new fields.

Table 2: USA Crude Oil Reserve Changes. 1977-90. Million Barrels

	Volume	Average Per Year	Per Cent
New field discoveries	2,000	143	6.0
New reservoir discoveries in old fields	1,908	136	5.7
Extensions	7,649	546	23.0
Total discoveries	11,557	826	34.7
Revisions and adjustments	21,751	1,554	65.3
Total reserve increase	33,308	2,379	100.0

Source: US DOE EIA (1990)

It is of interest that, in the particular case of the USA, production over the period totalled 40.5 billion barrels resulting in a fall in net reserves of 7.2 million barrels. However, it is clear then that in order to develop sensible estimates of future production potential, the reserve estimates for a newly discovered field generally need to be revised upwards.

Attempts have been made to estimate the multiplier that on average would need to be applied to a new field. This could be in the range of two to three times the first year estimate of reserves and would mean that the apparent additions to the reserve base from a new field would be at most 50 per cent of their final true value. This kind of correction has a significant effect on the short-term production profile, particularly as these additions are relatively quickly connected to the production facilities.

To estimate the reserves for a country as a whole is even more difficult given that each individual field which contributes to the total will be of a different age. As indicated earlier, new fields form only a small addition to the total proved reserve base each year. None the less, particularly for near term production levels, the impact on overall proved reserves of enhancing the initially reported reserves of new fields is still important. The appropriate correction could, perhaps, amount to an average of between 7-8 per cent for the world as a whole. This is indeed significant; on the latest reserve position such an adjustment could add some 80 billion barrels or three to four years of global production at current levels.

The proved reserves that have been used as part of the basis for the global 'Oil Mountain' and for the OIES country production profiles (Barnes, 1990) have been largely derived from published material in the *Oil and Gas Journal*. This journal as well as *World Oil* are widely used as authoritative sources of national reserves data. Indeed the information they provide is more consistent and reliable than the global compilations made by bodies such as the UN or the World Energy Council.

These published reserves estimates have been supplemented or enhanced wherever possible by other more direct sources. But they have not been fully adjusted for likely understatement by a broad enhancement factor, and consequently they represent a conservative view for the shorter term.

The oil reserves quoted by the *Oil and Gas Journal* are almost entirely reported as proved reserves recoverable with present technology and prices. They usually include condensates and exclude natural gas liquids although there is some inconsistency on this score. Both the *Oil and Gas Journal* and *World Oil* base their estimates on private and governmental national sources, industry associations, oil companies and the work of organizations such as Petroconsultants SA. The estimates for some countries, for example China, are from necessity, based on what appear to be very broad guesses presumably related to very old or restricted field data.

Net additions to global reserves, i.e. after taking production into account, have been substantial over many decades. Between the end of the Second World War and 1970, estimated reserves as reported grew by some 420 billion barrels despite a cumulative production of over 175 billion barrels. As Table 3 shows, increases in reserves also more than kept pace with production through much of the 1970s and 1980s. In the twenty years between 1970 and 1990, net reserves increased by nearly 40 billion barrels more than in the previous twenty-five years. As Peter Odell has pointed out (1991), this effectively undermines the oft-repeated comment that more oil is being used each year than is being added to reserves. On the contrary the world has been 'running into oil rather than out of it'.

The very substantial increases in reserves that took place for a few years during the 1980s were largely the result of revisions in estimates for the Middle East. Saudi Arabia in particular announced a substantial reassessment of the country's proven reserves in 1988. These apparently increased by 85 billion barrels between 1987 and 1988 with substantial additional probable reserves through the development of existing fields and extensive exploration. Iranian reserves also apparently nearly doubled between 1984 and 1989 and in the case of Iraq reserves more than doubled, increasing by 62 billion barrels.

Table 3: World Additions to Reserves. By Period. Billion Barrels

	Net Reserve Increase	Total Production	Gross Reserve Increase
1946-54	58	35	93
1955-59	101	32	133
1960-64	86	44	130
1965-69	175	65	240
1970-74	52	94	146
1975-79	57	106	163
1980-84	71	101	172
1985-89	268	104	372
1990	8	22	30
1991	-4	23	19
Total to end 1991	872	626	1,498

Sources: *World Oil,* various issues; DeGolyer and MacNaughton (1992)

These reserve revisions may in part represent a statistical sleight of hand applied to known data for a variety of political and commercial reasons. Nevertheless, overall global reserves are currently estimated to stand some 870 billion barrels higher than they did in 1946 despite a cumulative production of oil to date of some 700 billion barrels.

This picture of reserve replacement being more than adequate to make up for produced oil is not, however, merely a function of vast, low-cost, Middle East reserves being brought at will into published estimates. If the Middle East is excluded, net reserves have still increased by over 300 billion barrels since 1946, despite a cumulative production of over 400 billion barrels. Reserves were being proved up much faster in the late 1970s and throughout the 1980s than in previous periods. This continued in 1990 although 1991 additions to reserves did not cover production.

As shown in Table 4, most of the major regions of the world have seen substantial additions to their reserves over the last twenty years or so. Particularly large increases have occurred in Latin America, especially Mexico. Only in the USA, Canada, the CIS and the former Eastern Europe have net reserves fallen.

Table 4: Net Additions to Reserves. By Region and Period. Billion Barrels

	1970-1979	1980-1989	1990	1991
Central and South America (excluding Mexico)	2	44	-1	5
Mexico	25	21	-	-
Far East	25	17	-1	2
Africa	12	-	3	15
USA/Canada	-4	-	-1	-1
CIS/Eastern Europe	2	7	-4	-3
Western Europe	15	5	1	-1

Source: *World Oil*, various issues.

Although commercial deposits of oil have been found in around eighty countries, the distribution in terms of volumes currently recognized as reserves is fairly narrow. Approximately 66 per cent of proved reserves are in the Middle East with an additional 26 per cent being concentrated in just seven countries with reserves of over 10 billion barrels each. However, these countries range from Nigeria to Russia and represent a broad spectrum of physical and political conditions.

Table 5: Distribution of Proved Reserves at 1 January 1993. Per Cent	
Middle East	66
Latin American	12
Africa	6
CIS	6
Far East	4
N. America	4
Europe	2

Source: *Oil & Gas Journal*, 28 December, 1992

Table 6: Non-Middle Eastern Countries with Reserves Greater than 10 Billion Barrels at 1 January 1993	
Venezuela	63
Russia	57
Mexico	51
USA	25
China	24
Libya	23
Nigeria	18

Source: *Oil and Gas Journal*, 28 December, 1992

A commonly used yardstick for measuring the life of the world's oil is the ratio of reserves to current production. On a global basis this also emphasizes the improvement in the reserves position. For many years the world reserves to current production ratio was approximately thirty years although it is now, on a total reserve of 1,000 billion barrels, over forty years. It can, however, be misleading to use this yardstick when looking into future levels of production where the daily and annual volumes are likely to be increasing.

3.2 Undiscovered Oil and New Discoveries

The extent of new discoveries and their impact on proved reserves is a function of expectations of how much oil remains to be discovered and the likely rate of finding and developing it. The amount of oil still to be discovered is the difference between the size of the ultimate recoverable resource base, whatever that turns out to be, and cumulative past production plus estimated proved reserves.

There have been, and will continue to be, many different opinions on how much of the world's oil remains to be exploited. Estimates of the ultimate size of recoverable oil resources made during and just after the Second World War were usually under 600 billion barrels. These now appear absurdly low in the light of current knowledge; they are less than cumulative production to date!

Throughout the 1950s, estimates tended to put the volume at well under 2 trillion barrels. By the 1960s and 1970s it was considered to be around 2 to 2.5 trillion barrels of conventional oil and this still seems to be the current consensus. However some estimates, such as those by Modelevsky (in the late 1980s) put it at least 50 per cent higher.

Many estimates of the size of the world's recoverable resources of oil are not reliable. They often consist of bald numbers, with little disaggregation by country or region, little if any description of the reasoning behind them and with only a few explicitly incorporating uncertainty. In truth the amount of effort required for a comprehensive, uniform and reliable estimate of even the known world recoverable resources of oil is enormous. This would be so even if the necessary field data were publicly available to allow such an exercise; which they are not.

In his 1982 paper on 'Prospects for Conventional World Oil Resources' based on work completed in 1978 for the CIA, the highly respected geologist Richard Nehring advocated a median value for 'ultimately recoverable world oil resources' of 1,800 billion barrels with an 'ultimate total' of 2,400 billion barrels with improvements in oil recovery technology (Nehring, 1978, 1982).

This estimate was arrived at by examining the world's giant fields, those with 500 million barrels or more of recoverable oil. These were said to contain 75 per cent of known recoverable resources in the world at the time Nehring was writing. They included thirty-three 'super giant' oilfields, defined as fields that contain at least 5 billion barrels or more of recoverable oil. Nehring estimated that these contain 51 per cent of the world's known recoverable oil resources.

A recent study by MIT (Lynch, 1992) looked at the forty-two giant fields in the USA that Nehring had examined and found that twenty-two of the thirty-three still listed in the *Oil and Gas Journal* are now shown, in terms of past production and remaining reserves, to have more oil than Nehring estimated for the top of their range. This is without allowing for any future growth in reserves. In aggregate the major fields, according to MIT, now contain slightly more oil than the higher end of the estimates. The fact that so many of these fields - most of them decades old in a country with a very long and intense history of exploration and development - are still growing and already contain more oil than was thought possible only some fifteen years ago is an example of the weak basis on which long-term projections of supply potential are made.

It seems sensible to assume that for many of the other giant fields that Nehring used which are much less developed and under-reported, similar and possibly even more conservative estimates were made.

Methods of petroleum resource assessment are usually divided into two basic types depending primarily on the type of data used by each. Geological methods involve geological, geochemical and geophysical data, and historical and statistical approaches employ drilling and discovery data. The various geological methods include both direct and indirect approaches to resource assessment. Indirect methods rely on assessment by analogue of the areas being evaluated to already explored, geologically similar reference areas. In some cases estimates are based solely on expert opinion.

Use is often made of the published works of C. D. Masters and others of the US Geological Survey who have, in the past, provided estimates of world crude oil resources and their distribution (Masters et al, 1987). It not clear whether the Masters' estimates have been updated since the mid-1980s in the light of the latest experience and information. Certainly little if any original, fundamental and comprehensive work on global oil resources appears to have been done in recent years.

There will inevitably always be considerable uncertainty concerning the size of the overall resource base. This is likely to continue despite the rapidly growing knowledge of world oil occurrences and the potential for increased recovery. None the less, the US Geological Survey estimates appear to be the most comprehensive and detailed available and we have used them, with some adjustment, in our development of the 'Oil Mountain' as well as for our individual country profiles. These estimates are said to represent economically recoverable resources although that seems likely to mean under the conditions of the early 1980s when they were made rather than at current prices and technology.

For some estimates, such as for oil from Antartica or in very deep water, eventual economic recovery of large field occurrences was assumed by Masters even though the technical capability had not yet been demonstrated. His estimates fall into three categories. These relate to a 95 per cent probability, a 5 per cent probability and a 'modal' or most likely estimate of the quantity of resource associated with the greatest likelihood of occurrence. It is this later estimate, slightly adjusted to take into account subsequent discoveries, that we have used as an initial basis for our global and individual country profiles.

As Table 7 shows, a change in status of sub-economic resources to economic would nearly treble the total volume available.

Table 7: World Undiscovered Recoverable Resources. Billion Barrels

	Probability Range		
	95%	**Mode**	**5%**
Economic	322	553	1414
Sub-economic	623	1071	2751

Source: Masters et al (1987)

Some indication of the uncertain nature of these estimates can be illustrated by the development of oil production in the Yemen. The modal ultimately recoverable oil resource in the category 'Other Middle East' estimated by Masters et al and quoted at the 1987 World Petroleum Congress was 0.7 billion barrels. This 'Other Middle East' category included not only Yemen but all other Middle East countries apart from Iran, Iraq, Kuwait, Saudi Arabia and the UAE. Production began in the Yemen in 1984 and proved reserves plus cumulative production by the end of 1992 were 4.3 billion barrels. This is some six times the Masters' estimate and future reserves and cumulative production seem likely to increase in the Yemen considerably over the next few years.

It seems clear that a new comprehensive look at the likely volumes of oil still awaiting discovery is required to take into account the enormous gains in knowledge of recent years.

3.3 The Rate of Discovery

The rate at which new reserves are found from the pool of undiscovered oil is obviously related to the exploration effort. Both the number of active rigs and seismic crews peaked in 1981 and fell through much of the 1980s. In 1991 the number of active rigs were below 2,000 worldwide compared with 5,500 at the peak of activity (see Chart 3).

However, this apparent decline masks a number of changes. In particular, rigs are now worked harder and with greater success than in previous years with the aid of new technology. A recent Shell Briefing Paper (1993) indicated that at present one in seven wells drilled finds oil compared with one in ten in the early 1970s. Nevertheless, a decline in activity does not augur well for future discoveries, although the long lead times involved mean that it will take some time to work through to the production record.

Exploration within a province or a basin is usually characterized by a 'creaming off' process whereby the larger fields are found in the early stages of exploration. This is partly due to sheer chance, because larger fields statistically have larger productive areas and are therefore easier targets for a random driller. Other reasons are the growing sophistication of geophysical surveys and geological understanding which guide the driller to the best places.

At some point in time as the cumulative level of drilling an area increases, the return in terms of discoveries diminishes. Eventually the finding rate will decline to zero as the total amount of oil discovered approaches the area's ultimate potential. The 'creaming' curves for fields typically show a convex upward line of cumulative discovery against a cumulative number of exploration wells drilled. This 'creaming' process may take place on a small play level, a province or basin. Several plays may be simultaneously explored in a basin, causing a fuzzy overall creaming curve for the basin. In so far as there is choice, one play may not be as attractive as another. Individual, entire plays are creamed as well and this may give a fractal aspect to the curves at a basin level.

Globally, one might expect to see some creaming off by now but this does not appear to be the case. It is difficult to disentangle discoveries from appreciation of existing fields. But the constant opening up of new countries, basins and plays as well as substantial improvements in exploration technology and the accumulated knowledge of previous explorations seems to have allowed a substantial discovery rate to be maintained. For example, in the USA, total discoveries of crude oil per exploration well increased steadily through the 1980s and in 1990 reached 1.2 million barrels per well which was nearly twice that of the mid-1970s (see Chart 4).

Exploration has occurred in most countries of the world although to a greatly varying extent. The remaining areas include Antartica and several small countries in Polynesia and so on which may not necessarily provide attractive exploration targets. The common wisdom based on detailed analysis, is that the chances of opening up major new oil provinces like the North Sea are very slim indeed. In recent years this seems to have been confirmed, for example when the practically virgin Argentine and China offshore were explored with disappointing results. But recent discoveries such as the 2 billion barrel Cusiana field in Colombia and the enormous potential for the vast Tarim Basin onshore in China's Sinkiang Province offer an antidote. The Cusiana field reserves could add at least over half a million b/d to world production within five years solely on the basis of two initial wells.

The larger share of small fields, more remote and often in deeper water will make new development projects more sensitive to low oil prices and margins. For example, the daily drilling costs for wells offshore in the harsh conditions of the Northern North Sea can be five times those for drilling onshore in the USA. At current prices it seems likely that future discovery volumes would be lower than in the past although technology and better fiscal arrangements may work in the other direction.

In looking at future production on a global basis, we have assumed that 5 per cent of undiscovered resources is proved up every year well into the next century. This 'discovery rate' represents around 24 billion barrels of new reserves per annum, compared with an average of some 33 billion barrels per annum since 1946, and is roughly comparable to the average over the first two years of the 1990s.

3.4 Production Profiles

A textbook production profile for an oilfield has three phases. First there is the start-up phase with a rapid build-up of production as the operating company seeks to recoup its investment as quickly as possible. Then there is the plateau with the field in full production. This continues, with cash flow stabilizing, until the pressure reaches a point where it cannot support full production any longer and production begins to decline slowly over a long period. Chart 5 represents an ideal profile. The reality is usually different as Charts 6a and 6b illustrate. It is of interest that, in the case of the Argyll field, peak production in 1975 was estimated to reach 1.8 million tonnes. This has never been achieved and the field is clearly well into a stage of decline, so overestimation can also take place. However, in many major discoveries the plateau phase is quickly overtaken by a succession of increasingly higher build-ups and peaks as new wells are brought on stream and the wider extent of the resource is realized.

In the early stages of production the initial reservoir pressure will usually be sufficient to drive the oil to the surface. As the oil is produced, the reservoir pressure will decline. However, the rate of production may be maintained at satisfactory levels by natural drive mechanisms. These include the displacement of oil by water underlying the field, by the expansion of a naturally occurring gas cap overlying the reservoir or by the formation and merging of gas bubbles. These natural drive mechanisms account for more oil production than all other recovery methods combined.

Primary recovery can be enhanced or extended by a variety of methods.

These include artificial lift and well stimulation, water and steam drive, generating heat underground using a small amount of the oil in place, gas injection and chemicals as well as directional and lateral drilling, all of which can help to keep production up in old fields.

In many producing areas the rationalized use of the existing infrastructure of pipelines and other facilities also permits trimming of unit costs. The result is that the third phase of gradual run-down often occurs much later than that forecast at the time of the original economic estimates.

The main uncertainties in building up a production profile for the future are the height of the plateau level and the speed with which it is reached, the location of the point of decline and the speed of the decline. For some fields the build-up phase may be very short, as little as a year or two. The Wych field, onshore in the UK, took twelve years to reach peak production whilst Eider in the North Sea took only one year.

For countries, representing an aggregate of fields, the period to maximum offtake hinges on the overall maturity of the country's oil development. The whole combination of years to maximum offtake and the actual maximum offtake proportion will vary considerably; from, say, fourteen years to reach a maximum offtake of 23 per cent in the USA to twenty-one years to reach a maximum offtake of 7 per cent in Oman. (over a period 1970 to 1986).

The 'offtake rate' represents the proportion of oil produced in relation to the remaining reserves. During the build-up phase, the offtake rate increases from nil to a certain level; during the plateau phase it continues increasing and then remains constant in the declining phase (see Chart 7). The level of offtake chosen is a key element in modelling the development of the production profile and the changes assumed in it can have a significant effect on the pattern of production. However, with a finite reserve volume, production must inevitably decline sooner or later.

For any given year, the aggregate offtake rate for the existing fields in a country is a weighted average of what happens in the individual fields. The offtake rate for the world as a whole is the aggregate of all the fields in the world; which at any one time are all at different stages of development. Aggregate maximum offtake rates for individual countries vary widely between 5 per cent and 25 per cent but may tend towards the lower end of the range.

3.5 Enhanced Oil Recovery

Conventional recovery uses the natural drive from the reservoir alone or in conjunction with injected water or natural gas to displace the oil in place. As mentioned earlier, on a worldwide basis, these conventional methods recover an average of around 30 per cent of the oil originally in place although the recovery rate can be higher in individual fields and areas. The remaining 70 per cent or so of the oil in place is left behind either because it is trapped by capillary forces or because it is bypassed by the displacing fluid.

Enhanced Oil Recovery (EOR) aims to recover part of the oil that is left behind by conventional methods. The recovery methods used involve injection into the reservoir of fluids differing significantly from the natural reservoir fluids in their chemical composition or energy state. Many different EOR processes are available but each is applicable only to a limited range of reservoir conditions and oil types. The ranges are largely complementary so that for almost every type of liquid hydrocarbon accumulation there are known processes which might potentially recover additional oil.

Many of the currently known EOR processes can be most effectively applied at a very early stage of a field's life, that is as secondary processes. However, the majority of such applications are applied at much later stages in the field's development, i.e. in a tertiary role to recover oil left behind by exhausted primary or secondary development schemes.

The EOR methods currently available have a considerable range of technical costs, from around \$10 to \$ 30 per barrel produced using steam soak and steam drive to up to \$40 or more for surfactant flooding (Barnes, 1991). The benefits of each proposed scheme clearly have to be compared with the benefits obtainable from an improved conventional recovery scheme. Most of the latter techniques can recover a significant amount of additional oil at a relatively low cost compared with EOR methods. As a result, EOR is at present not widely employed and the majority of projects are located in the USA where there are a large proportion of reservoirs in an advanced state of depletion.

Overall, use of EOR methods at present probably contributes only a little over 1 mb/d to the world's supply of oil. None the less, with higher prices or fiscal incentives, EOR methods seem likely to make an increasing contribution to maintaining the 'Oil Mountain' in the long term. The recovery efficiency of individual technologies appears to range very widely, by as much as 2 to 40 per cent of remaining oil in place. On a more general basis, it was assumed at one time that 10 per cent or so of oil originally in place could be accessible to EOR. This view now seems to have been moderated to a recovery rate of between 4 and 8 per cent.

The complications of bringing EOR projects into operation mean a fairly slow rate of development even when the price and the fiscal and commercial conditions are right. There are several strategies that can be followed when prices are low or uncertain. One example is the strategy adopted by Exxon for developing the Cold Lake Tar Sands in Canada. A very long pilot phase was conducted, beginning in 1964. Production was then expanded gradually to 15,000 b/d and subsequently progressed in small stages of 10,000 b/d to produce about 75,000 b/d. The low incremental costs involved meant that the additional stages could be implemented even though the outlook for oil prices was poor after the oil collapse of 1986.

For the purposes of our individual country projections and the 'Oil Mountain', we have generally assumed that 4 per cent of oil originally in place is open to EOR. On a global basis this could represent some 300 to 400 billion barrels of additional oil. It could, of course, be much more or much less depending on the view taken of the real volume of oil in place and the economic and technical climate.

3.6 Natural Gas Liquids

In any attempt to project oil availability it is unwise to ignore the increasing potential from natural gas liquids (NGLs). There are difficulties in even getting a reasonable line on the current position, accurate data is scarce, often fairly unreliable and sometimes treated in a confusing manner. This may explain why they are often ignored in supply projections.

NGLs consist broadly of those hydrocarbons which can be extracted in liquid form from natural gas as produced. In addition to ethane there are two main categories, Liquefied Petroleum Gas (LPG) and natural gasoline. Both NGLs and condensates are usually traditionally viewed by the industry as liquids produced as the unintentional co-products of natural gas production. The NGLs can be removed from the wet gas only by lower temperatures and higher pressures whereas the condensates, the heavier components of natural gas, become liquids under normal atmospheric conditions at the surface. The latter usually consist of a mixture of hydrocarbons ranging from light distillates to butane, recovered from non-associated gas reservoirs. They are often included in crude oil or NGL data.

There is confusion on the treatment of NGLs and condensates, of which some is perhaps deliberate. Currently between 5 and 6 mb/d of NGLs appear to be produced, thus contributing 8 or 9 per cent to total oil supplies. However, some reports put the quantity much lower, at around 2 to 3 mb/d. Although apparently modest at present, volumes seem likely to continue to grow substantially in future with the faster and wider development of gas production and LNG schemes.

A moderately increasing contribution has been assumed for NGLs in our oil supply projections. These have been taken up in terms of barrels rather than in terms of crude oil equivalent.

3.7 Syncrudes and Synfuels

Unconventional oil resources are usually excluded from the basic resource estimate but could represent an enormous addition to the world's supply of liquid fuels.

Synthetic crudes from tar sands, bitumen and oil from shale and so on are far less attractive under today's price conditions than they seemed to be in the 1970s. The same is true of liquid fuels such as alcohol from biomass, methanol, gasoline and middle distillates from natural gas and coal.

Examples of most of these alternatives to conventional oil are currently in operation - the substantial tar sands programmes of Canada, alcohol from sugar cane in Brazil, oil from coal in South Africa and single demonstration plants such as those producing a range of liquid fuels from natural gas in Malaysia and New Zealand. However, in total, the contribution from all these unconventional sources together is under 1 million barrels of oil equivalent per day (boe/d) of liquids.

As a resource base, the potential from tar sands, heavy oil and shale oil alone is enormous. Estimates vary considerably depending on price assumptions and the degree of practicality involved. At oil prices giving a netback of around $30, a reasonable range might indicate a resource of some 1,000 to 2,000 billion barrels. At the upper end of the range this is twice the level of current estimates of conventional oil reserves. Theoretically, and at much higher netbacks, there is a lot more available. As much as 2,000 billion barrels of heavy oil from the Orinoco Basin and an enormous 14,000 billion barrels of oil shale of all grades have been indicated, for example.

These syncrudes and synfuels will continue to be of some significance in countries such as Canada, Brazil and South Africa although even in these countries their importance has diminished in recent years. Overall, they are not expected to make more than a very minor contribution on a global scale for many years to come.

Nevertheless, in the longer term these fuels represent a substantial potential addition to world oil supplies. Given the right economic incentives they could be a realistic means of pushing the 'Oil Mountain' beyond the end of the next century.

4. THE OIL MOUNTAIN

The foregoing chapters have emphasized the uncertainty, and sometimes confusion, that is involved in all the component parts of any projection of production potential. This uncertainty and the scope for large variation in projections apply equally to natural gas.

As a result, it may seem rather foolish to even attempt to look at the potential for world oil supplies for more than a few years ahead. However, for the reasons mentioned in the introduction, such an exercise is of value, not least because of the misuse to which estimates of the future global oil position are put in making partisan claims for one form of policy action or another. A major proviso has to be that the numerous uncertainties described earlier, and on which any views must necessarily be based, are borne in mind and the assumptions made clear. Certainly, on a global scale any view of oil supply potential can only be illustrative and far from definitive.

In order to develop a global supply profile on the basis of current views on the amount of oil available and to demonstrate how its peak can be pushed forward into time, we have developed a number of illustrative cases.

Case 1 in Chart 8 is based on an ultimately recoverable resource base of some 2,200 billion barrels of conventional oil, together with some 350 billion barrels from EOR. A modest but steady climb to peak production of 90 mb/d is assumed. It can be seen from the chart that after the year 2012, production declines rapidly. By the year 2065, production has fallen to below 10 mb/d and by 2080 only 4 per cent of the ultimately recoverable resource is left.

Case 2 assumes another 500 billion barrels of undiscovered conventional oil, which is well within a feasible range. This would extend the peak by another fifteen years. By 2080, 95 per cent of the ultimately recoverable resource would be used up.

Case 3 assumes an ultimately recoverable resource base of 3,200 billion barrels and makes it possible to sustain production of 90 mb/d almost until 2050.

The volume of conventional oil assumed as ultimately recoverable in Case 3 is at the high end of most current estimates. However, it does not appear an impossibility given the tendencies described in earlier chapters.

The price needed to bring forward these amounts of oil is uncertain although it seems likely that the bulk of the oil could be produced at technical costs well below US $30 per barrel. Technical costs may well continue to come down over time and changes in fiscal terms are likely to be as important as the actual trading price.

It would also be quite likely, given a clear and sustained perception of future scarcity, that the enormous resources of unconventional oil could be mobilized. On current views, prices would need to be of the order of $30 per barrel or more. However, it is also probable that advances in technology will bring down the costs of liquids from these unconventional sources by the time they are needed.

If unconventional oil brought in another 2,000 billion barrels, then production at a peak of say 90 mb/d would be assured until well into the twenty-second century. This would surely be long enough to pacify even the most fainthearted doomsday prophet!

Table 8: The Oil Mountain. Billion Barrels

	Proven	EOR	Undiscovered	URR	Peak Year	Peak Production (Million b/d)
Case 1	1000	320	480	2500	2015	91
Case 2	1000	320	980	3000	2020	93
Case 3	1000	320	1480	3500	2020-2040	95

Source: OIES Projections

Obviously the shape of the mountain could be, and probably will be, very different from that which we have shown. It might well be flattened considerably by efficiency improvements on the demand side and with substitution by other fuels. In this way more modest, but adequate, production levels could be extended for many years.

In contrast, the production peak could also be brought forward and shortened considerably if growth in oil demand accelerates and discoveries are disappointing. If demand for oil grew at an annual average rate of 3.5 per cent, a production level of 100 mb/d by the year 2005 would be necessary. This would be feasible on a resource base of 2,200 billion barrels but would mean a steep decline after only a few years.

The shape of the 'Oil Mountain' as illustrated does not take into account the geopolitical considerations of the location of the oil resource. In particular, that well over 60 per cent of the world's current proven reserves are in the Middle East, with around 55 per cent in Saudi Arabia, Kuwait, Iraq and Iran alone. Nor does it take into account the many other individual elements of investment and other policy decisions that could give it a very different shape. It is solely an illustrative background to any considerations of future world oil supply.

The actual level of global production capacity available to meet actual demand at any one time will depend on the ability, and willingness, of a large number of very different countries and companies to make the necessary investments. Apart from specific conditions of a physical, political or fiscal nature, the main actors will generally be influenced at the same time by the same expectations of growth in global economic and oil demand and particularly by the common perspective on oil prices and the netback available from them. The delays in translating a favourable or unfavourable view of the climate for exploration and development into actual physical volumes of oil can take several years.

Thus, there will undoubtedly continue to be short to medium fluctuations in the relationship between producing capacity and actual demand for oil. As in the past, these will lead to significant price fluctuations and to glut and shortage despite the long-term adequacy of the overall resource base.

The price collapse of 1986 was a result of more oil production capacity being available than was warranted by demand. This capacity had partly been put in place in expectation that the high prices of the 1970s would continue alongside steady demand growth.

If the growth in demand for oil towards approximately 90 mb/d, is to be met from conventional oil sources, it will increasingly depend on the willingness of a few individual Middle Eastern countries to make the necessary investments.

A continuing period of low demand growth and low expectation on prices may well lead to a reluctance to invest scarce capital in exploration and new production capacity. If growth in demand accelerates, perhaps because of much faster growth than currently expected in the CIS and former East European countries and in the developing countries, then oil prices will rise. However, given the very substantial volumes yet to come from the 'Oil Mountain', it seems unlikely that higher prices could be sustained for more than two or three years solely on the basis of impending global scarcity. The stimulus of higher prices and better fiscal terms would soon put new capacity in place. Until we really slide down the far slope of the mountain, only a succesful cartel of the four main Middle Eastern producing countries is likely to be able to sustain high prices. This does not, at the moment, seem a realistic proposition.

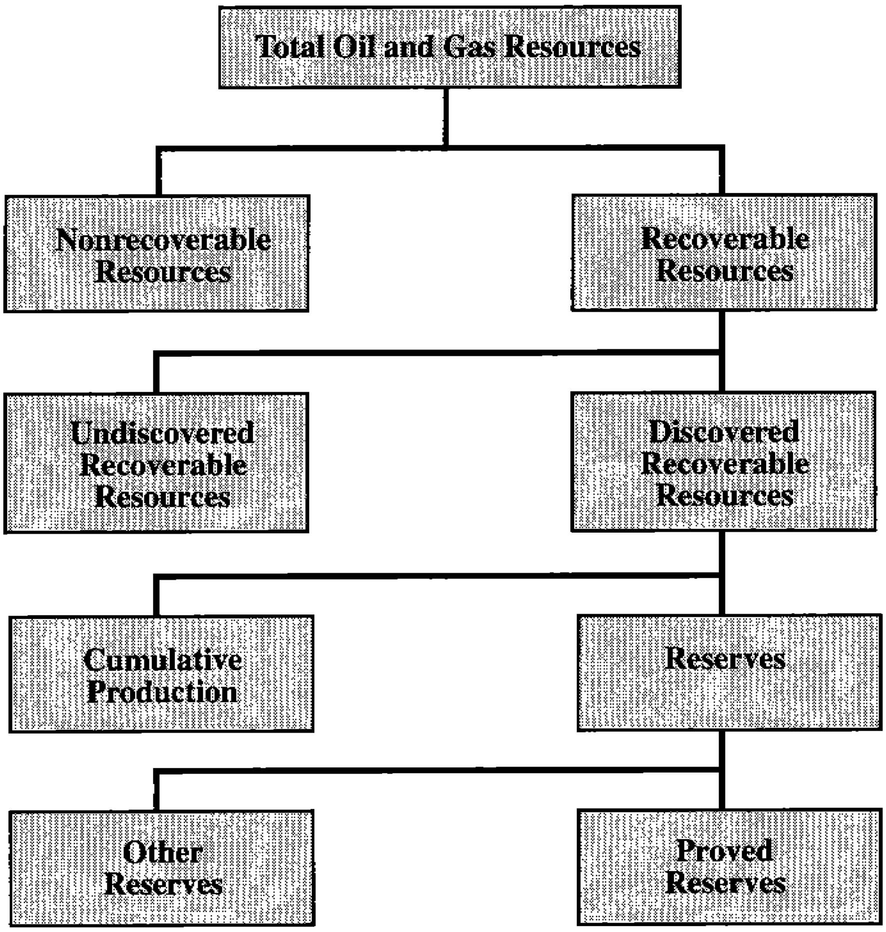
Despite the best efforts of the experts we are still very uncertain about how much oil is in place, what volumes can be sensibly recovered and at what cost. As discussed earlier, there are many uncertainties of a technical nature alone without the usual economic and political uncertainties that bedevil any major enterprise. However, given a continuing need for oil it would seem that there is still some way to go before the summit of the 'Oil Mountain' is reached, even on the relatively conservative assumptions made in this paper. The summit can be pushed even further forward if unconventional oil sources are taken into account.

Finally, it is worth bearing in mind what most walkers and climbers know: just when you think you are nearing the summit, another one always appears over the horizon.

APPROXIMATE CONVERSION EQUIVALENTS

boe	= barrels of oil equivalent = 5.8 million British thermal units
boe	= 5.7 gigajoules
boe/d	= 50 toe

Chart 1 Relationship of Petroleum Resource and Reserve Terms



Source: adapted from US DOE EIA, *Annual Report*

Chart 2 Resource to Reserve

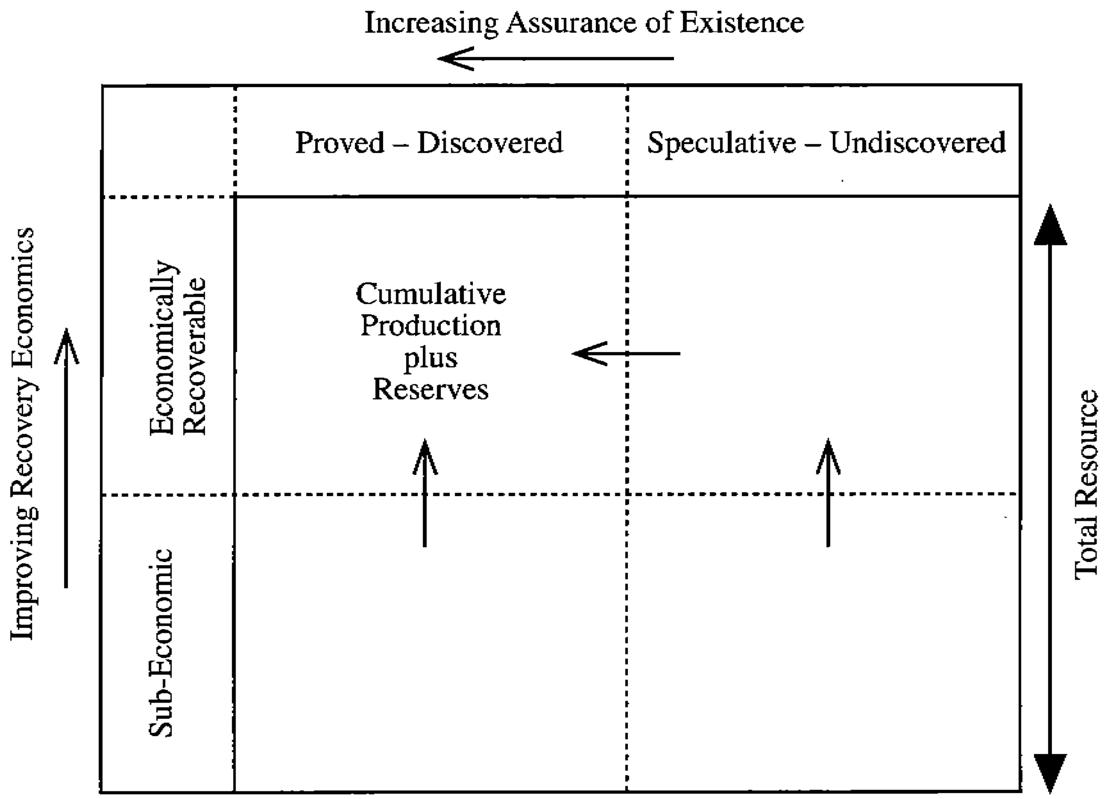
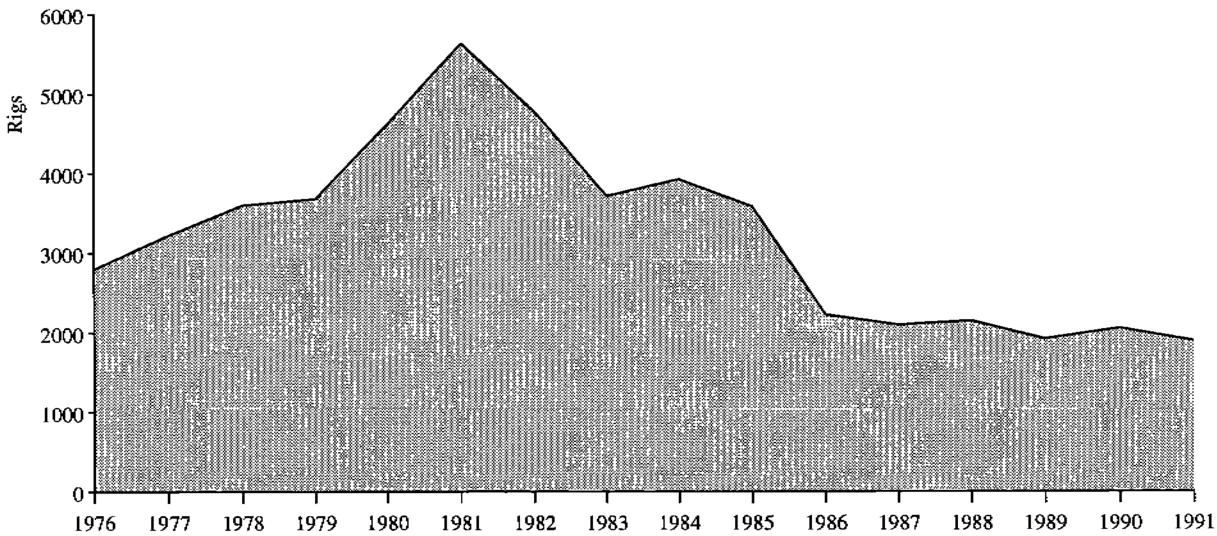
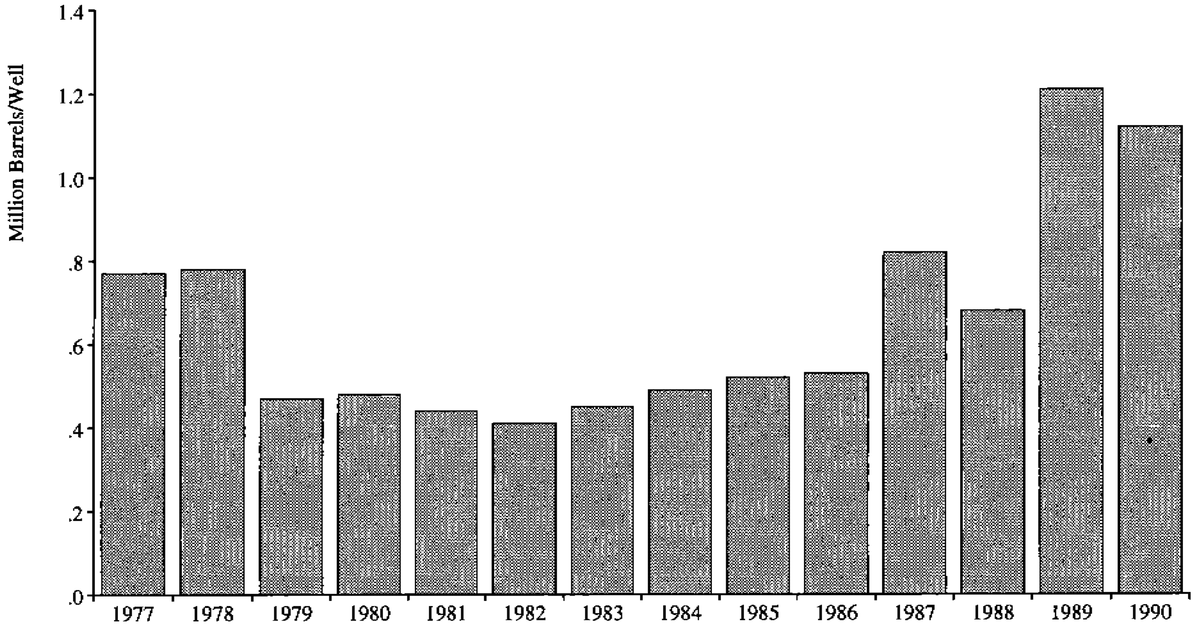


Chart 3 International Active Rig Count



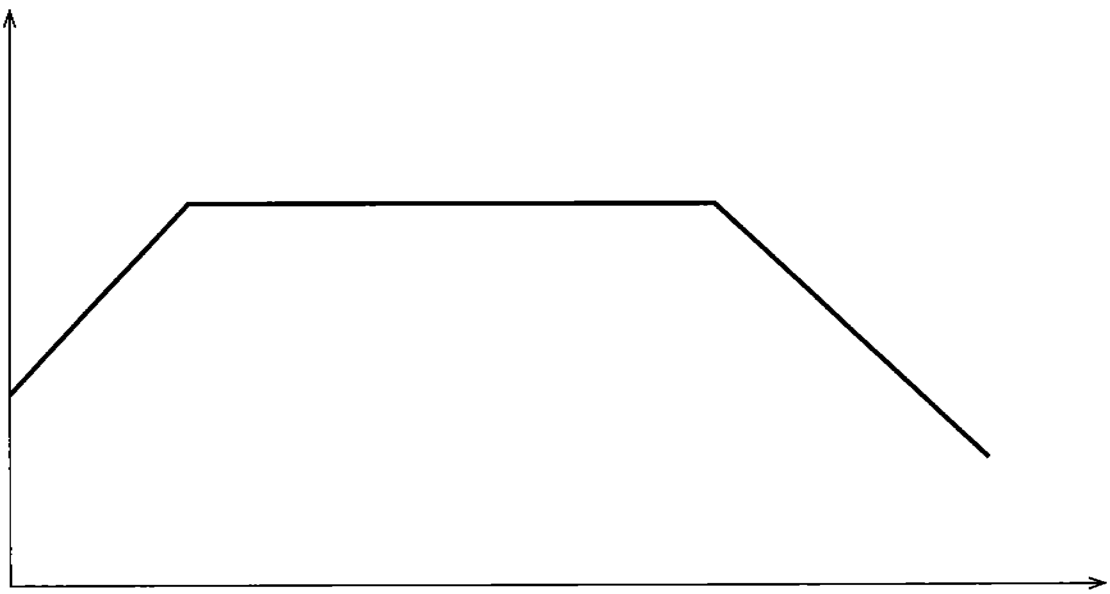
Source: *International Petroleum Encyclopedia*, various

Chart 4 US Total Discoveries of Crude Oil per Exploratory Oil Well Completion



Source: US DOE EIA 1990 *Annual Report*

Chart 5 Idealized Production Profile



Source: Stenslad/Tjøsthein (8/90)

Chart 6a Annual Production from the Argyll Field (UK North Sea)

Source: UK Department of Trade and Industry, 'Brown Book' various years

Chart 6b Annual Production from the Montrose Field (UK North Sea)

Source: UK Department of Trade and Industry, 'Brown Book' various years

Chart 7 Simple Production Profile Model of a Field with 200 Million Barrels

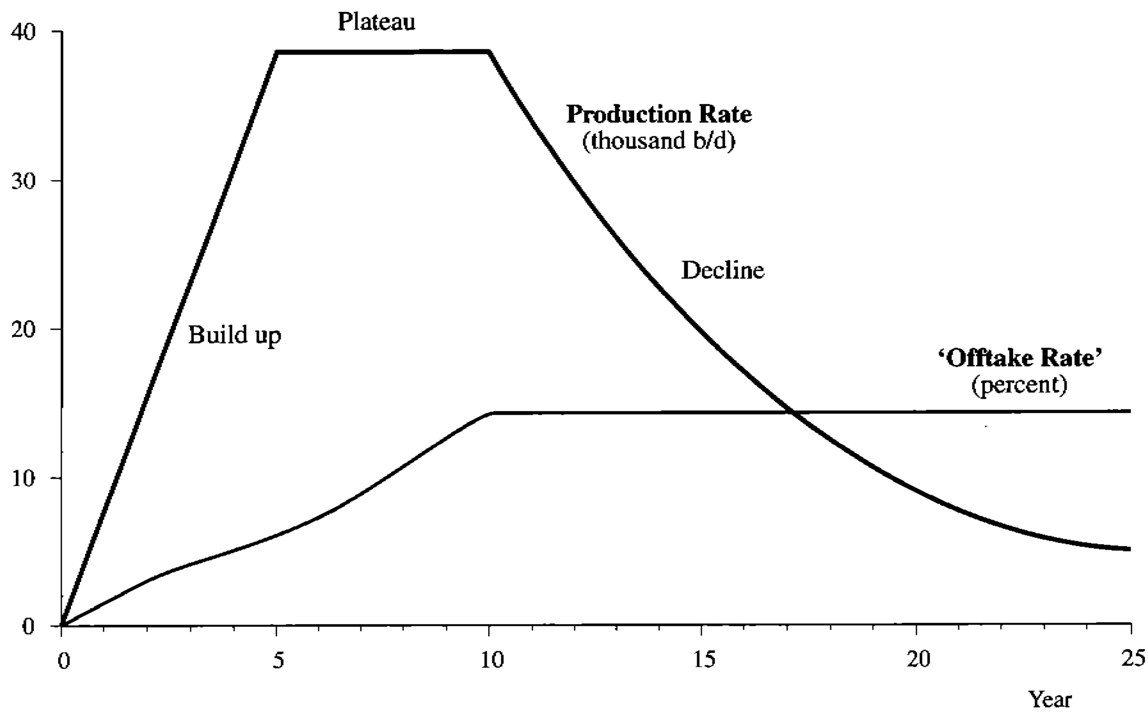
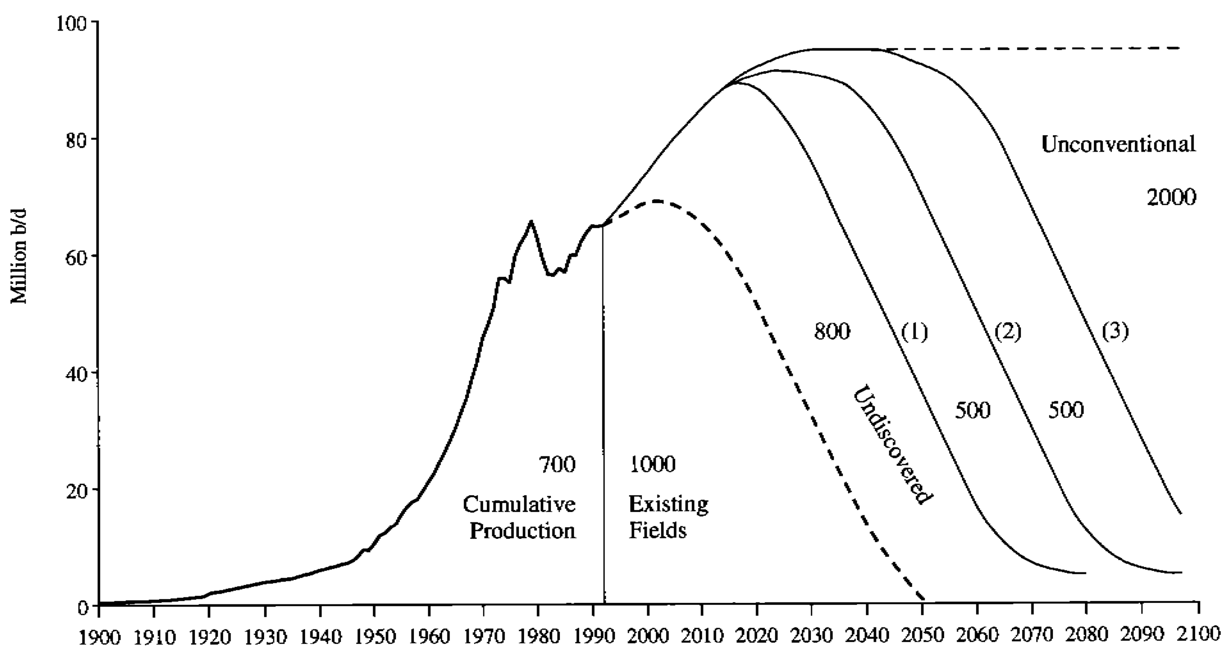


Chart 8 World Oil Production - 'The Oil Mountain'



Source of historical data: *Oil Economist Handbook;* De Golyer and McNaughton, *Twentieth Century Petroleum Statistics*; *Petroleum Economist*, various editions

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