Future world oil supply

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Future World Oil Supply

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"Everybody hates this topic but the oil industry hates it more than anybody else."

Colin J. Campbell

1 Introduction

This paper tries to explain the basic facts and mechanisms of discovery and production of oil, leading to a better understanding of its future availability. Oil is the most important fossil fuel, and the world economies are dependent on it. A detailed assessment of the topic is given in (GCN 2002).

2 The Imminent Turning Point

The future supply of crude oil is only indirectly governed by the amount of reserves still available; it is much more determined by future production capabilities. An eventual future supply crisis will not be the result of the production of the "last drop" of oil; long before this ever happens the peaking of the world wide oil production will mark a turning point for our energy economies. Then a period of time which has seen ever growing production volumes will be followed by a time with steadily shrinking production volumes year after year.

The peak of world wide oil production will be a unique historic event. It has never occurred before and it will never occur again. Due to the singularity of this event we have not developed an intellectual or emotional sensitivity that could help us in coping with it.

The production peak does not send an advance signal to the markets as to when it will happen (and anyway by no means 10, 20 or even 30 years in advance). In fact there are no long term signals to which the crude oil markets and the consumers can react. The markets react only to short term imbalances between supply and demand; it is therefore futile and dangerous to attempt to assess the future supply situation on the basis of current prices.

3 The Life Cycle of Oil Production

3.1 The Three Phases

The production profile over the life cycle of any oil region can be divided into three phases: The first phase is a phase of continual production increase ("pre-peak"); in the second phase production is stagnant ("at peak" or "plateau"); and finally we have a phase of continually declining production ("decline").

These three phases of oil production constitute a general trend. In the following we will explain this production profile by taking the Norwegian oil production as an example and then we will sketch the worldwide situation.

Figure 1 shows the Norwegian oil production where the production profile of each individual field

is presented in chronological order.

Phase 1: "pre-peak"

No oil company in the world is holding production from its oilfields in reserve to take advantage of improved economic prospects in the future. The largest and most productive oilfields are brought on-stream first. These fields have the highest production rates, and will produce oil for the longest time. In the early phase of production in any basin an expansion of the production is quite easily done by adding new wells within already producing fields or by developing further fields.

Phase 2: "at peak"

The longer the production goes on, the more the pressure in the oil field drops while the water level rises. Then at some point in time the production rate begins to decrease. In this situation the addition of further wells within an already producing field leads to a further drop of pressure and therefore succeeds only for a very short time in upholding the rate of production. Modern state-of-the-art production methods (e.g. increasing the pressure of the field by water or gas injection, or reducing the viscosity of the oil by chemical or thermal treatment) which now have been successfully applied for almost 20 years, can postpone and sometimes soften the decline a little, but they cannot reverse it.

As soon as the large oilfields of a region have passed their production maximum, an ever-increasing number of new smaller fields have to be developed to compensate for the decline of the older, already producing fields. In such a situation it becomes increasingly difficult to extend the production of the whole region. Since more and more small and less attractive fields enter the production, the "treadmill" situation of having to develop ever more fields is aggravated by the concurrent faster depletion of these smaller fields. In Norway this phase started about 1995 or 1996.

Phase 3: "Decline"

Then at some point in time the production decline in the already producing fields gets so steep that it can no longer be compensated by the development of new fields. This is the time when the production of the whole region starts to enter the decline phase. To a certain degree oil companies and oil producing states can influence this decline pattern by their production strategies. Thus the longer the producers try to uphold the production maximum, the steeper the following decline will be.

Example 1: The oil production of Norway

Figure 1 shows the production profile of Norway. The decline phase presumably started in 2002.

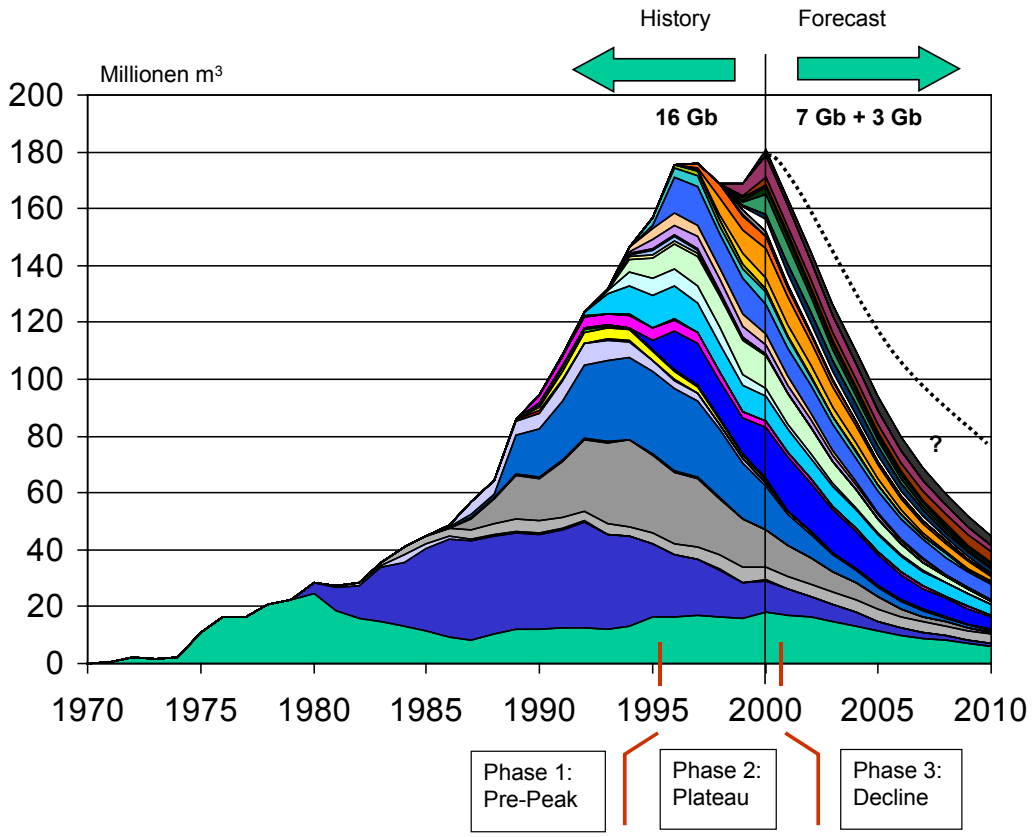


Figure 1: Norwegian oil production profile showing individual fields. The broken line indicates the expected future production profile - taking into account the already known, but not yet developed fields. An Estimated Ultimate Recovery of 26 Gb is assumed. (LBST 2001)

Example 2: The oil production of the UK

Figure 2 shows the production profile of the UK. There production peaked in 1999. The production of all the big fields has been declining for many years, but for the first time in the year 2000 this decline could not be compensated by bringing new fields into production. Since then total production has also been declining: in the year 2000 production was 8 % lower than in 1999; the year 2001 saw a further reduction of 10 % compared to the year before. The sharp decrease in production after 1985 shown in the figure was a consequence of the Piper Alpha accident which led to stricter safety regulations and required some time for the industry to adapt. The subsequent production increase was possible because of the existence of the then already known finds – but this is different from the present situation.

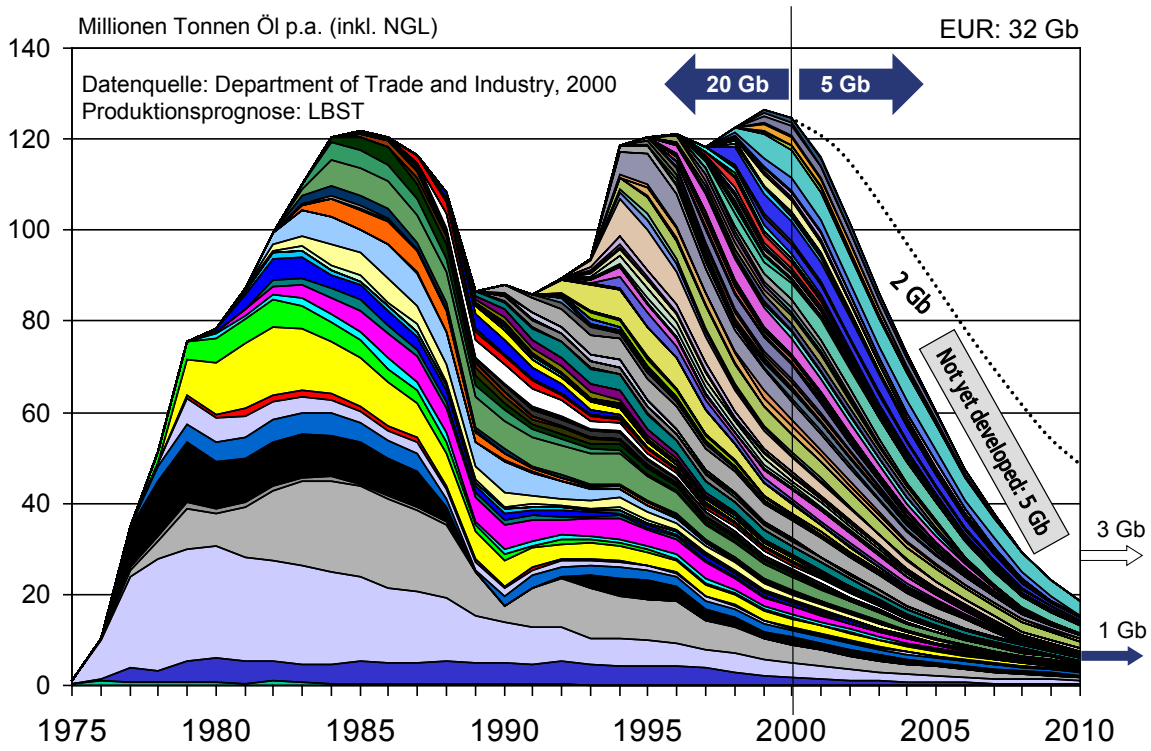
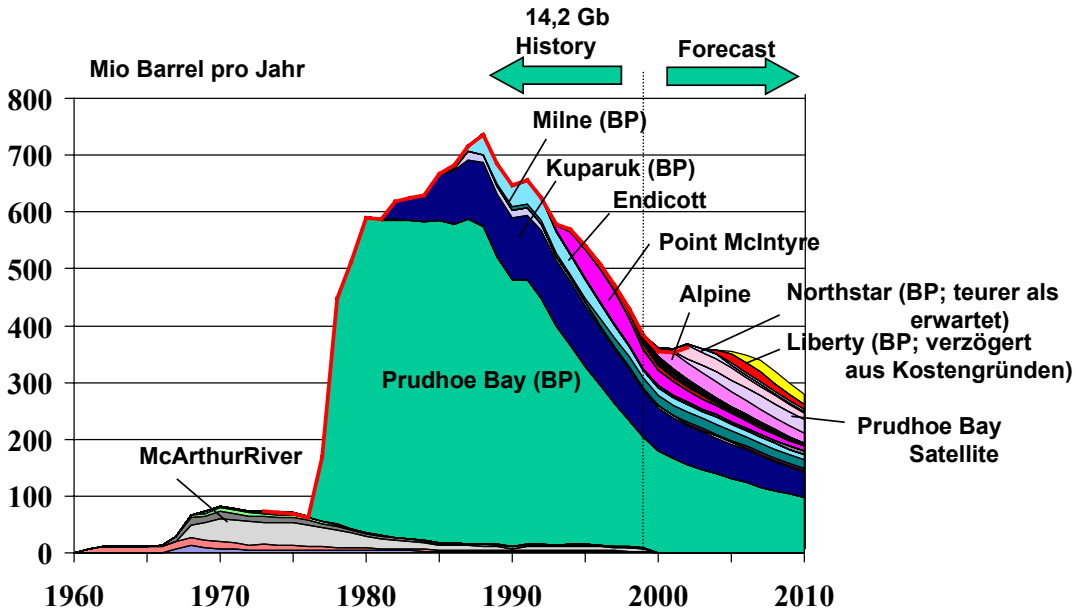


Figure 2: UK oil production profile showing individual fields. The broken line indicates the expected future production profile - taking into account the already known, but not yet developed fields. An Estimated Ultimate Recovery of 32 Gb is assumed. (LBST 2001)

Example 3: The oil production of Alaska

The future oil production of Alaska can be taken from the forecast of the Department of Natural Resources in Alaska, upon which the following figure is based.

The decline of the large fields might be offset for some time by the development of already known smaller fields, but it is more likely that delays in commencing the new projects will lead to a continuing overall decline in production.



Quelle: **Department of Natural Resources, Division of Oil and Gas 2000 Annual Report**

Figure 3: Field by field analysis of oil production in Alaska. The peaking oil production from Prudhoe Bay in 1989 set the scene for the unavoidable decline in production in the following years. Production from the small fields has succeeded in halting the decline at less than half the level of peak production, but this can last for only a few years, and at much higher costs than in the early production phase.

Example 4: USA - Decline analysis of regional production profiles

"Excessive activity" can stop the production decline for a short while – but, according to all experience, only at the cost of even higher decline rates in subsequent years. This can be demonstrated by the production profile of the USA which is shown in figure 4. The US reached its production peak in 1970. Even the growing production in Alaska in the following years could only compensate for the decline of the old fields for a short while. In the early 1980s there was excessive activity in bringing new wells into production caused by high oil prices. This resulted in a slight increase in the production of the "Lower 48" states. But within a few years the production then started to decline again at even higher rates than before – and the long term decline trend was approaching the values one would have expected from the experience of the 1970s.

Nor could the prevailing trend of a declining domestic oil production and rising imports be reversed in 2001 and 2002 – in spite of an economic situation which dampened the rise of oil demand and favoured exploration and production of oil, and also in spite of the announcement of a new energy policy by the new administration aimed at increasing American oil production.

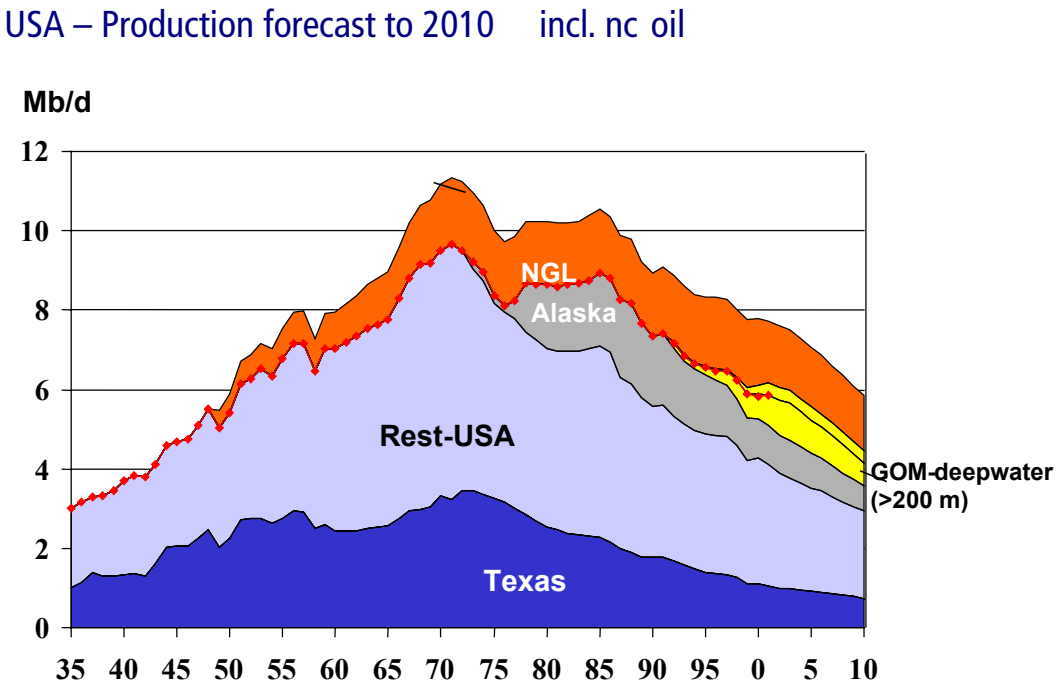
The following figure shows the historical oil production of the United States of America.

Alaska passed its maximum more than ten years ago. Texas passed its maximum thirty years ago.

Today, Texas produces no more than it did in the 1930s. The other states passed peak production in the early 1970s and are declining year by year.

Average oil production per well has decreased in Texas to about 6 barrels/day, while in Pennsylvania – where the oil boom started 140 years ago – it is even lower.

These production rates can be compared with the generation of renewable energy: an average oil well in Texas produces about the same amount of energy as might be provided in the form of thermal energy by solar collectors of 1,800 m^2 in size, i.e. less than 45 meters square.



Source: Texas Railroad Commission, US Energy Information Administration

Figure 4: The future oil production profile for the declining oil regions of Texas and Rest of the USA is controlled simply by the physics of depletion, allowing a straightforward extrapolation of existing trends.

Only in the deep water area in the Gulf of Mexico can production still be increased, as all other areas have already passed their production maxima. Even production from the shallow water parts of the Gulf of Mexico is already declining.

Of special importance is the field *Thunder Horse* which holds about one billion barrels of reserves and is by far the largest discovery in recent years. A study by the US–Department of the Interior in May 2001 suggested that the production might still increase to 1 – 1.2 Mb/d by 2005 (see the report "Gulf of Mexico Outer Continental Shelf; Daily oil and gas production rate projections from 2001 to 2005"; Department of Interior, Minerals Management Service , May 2001, OCS-Report MMS 2001-044). Unless major new discoveries are made this year and next, of which there is at present little sign, production even in the deepwater areas of the Gulf of Mexico will start to

decline after 2005 or soon thereafter.

Most official forecasts predict an increasing NGL production in the near and medium term future, but there is reason for serious doubt. It is much more likely that NGL production will strongly decline in the coming years, in response to the tight natural gas supply which is even more severe in the USA than in Canada.

3.2 Enhanced Oil Recovery (EOR) from Ageing Fields

So called secondary and tertiary measures are often cited as a viable source of enhanced future oil recovery rates and as a reason to blame forecasters for being too pessimistic regarding future oil production. Indeed, these measures are widely used and have the potential to enhance the oil production rate. When the pressure in the oil field has decreased to a level where the viscosity of oil dominates the production profile, leading to smaller extraction rates, pressure can be raised artificially by water or gas injection, or by reducing the viscosity with the injection of steam or a chemical surfactant.

However, for various reasons we should not overestimate the influence of these measures:

- EOR measures have already been applied for more than twenty years, and these measures are accounted for in production forecasts. There will not be any sudden jump in the future – continuous progress is and was always part of the production forecasts. There are two major examples for this: (1) One is the production profile of German oil. After its peak in 1968 the production continuously declined despite efforts to implement enhanced oil recovery techniques. (2) Another example is the production of Prudhoe Bay as already explained in figure 3. This field is at the technological forefront and every possible new measure was exploited to enhance production and to avoid a decline, with almost no success. Today more water is extracted from the wells than oil, water which was injected into the field to increase the pressure.
- EOR measures are only applicable beyond peak production when the pressure level is low. These measures cannot revert a decline into an upward production profile for any substantial period of time.
- EOR measures are most effective in certain fields with complex geology which exhibit a low recovery factor.
- These measures are only effective in the sense that more dollars are gained with the extra oil than have to be spent for the measure.
- Usually these measures increase the production rate for a short period of time, but enhance the decline in the long term – they are only intended to extract the oil faster, but not to increase the overall oil recovery.

To illustrate this, the influence of EOR measures at one of the largest US fields is investigated in figure 5. The Yates field, which was found in 1926 in Texas, has produced since 1929. Since peak production in 1970 the production rate has declined by more than 75 percent. In 1993 hot steam and chemicals were injected to enhance the production rate. This measure was successful for about 4 years. Afterwards the decline was even steeper, exceeding 25 percent per year instead of 8.4 % as before. Today the production rate is even below the level it would be without these measures.

To assess the overall influence of this measure, out of the 1.4 billion barrels of oil which were produced since 1929, only 40 million are due to enhanced oil recovery – an increase of about 3 percent.

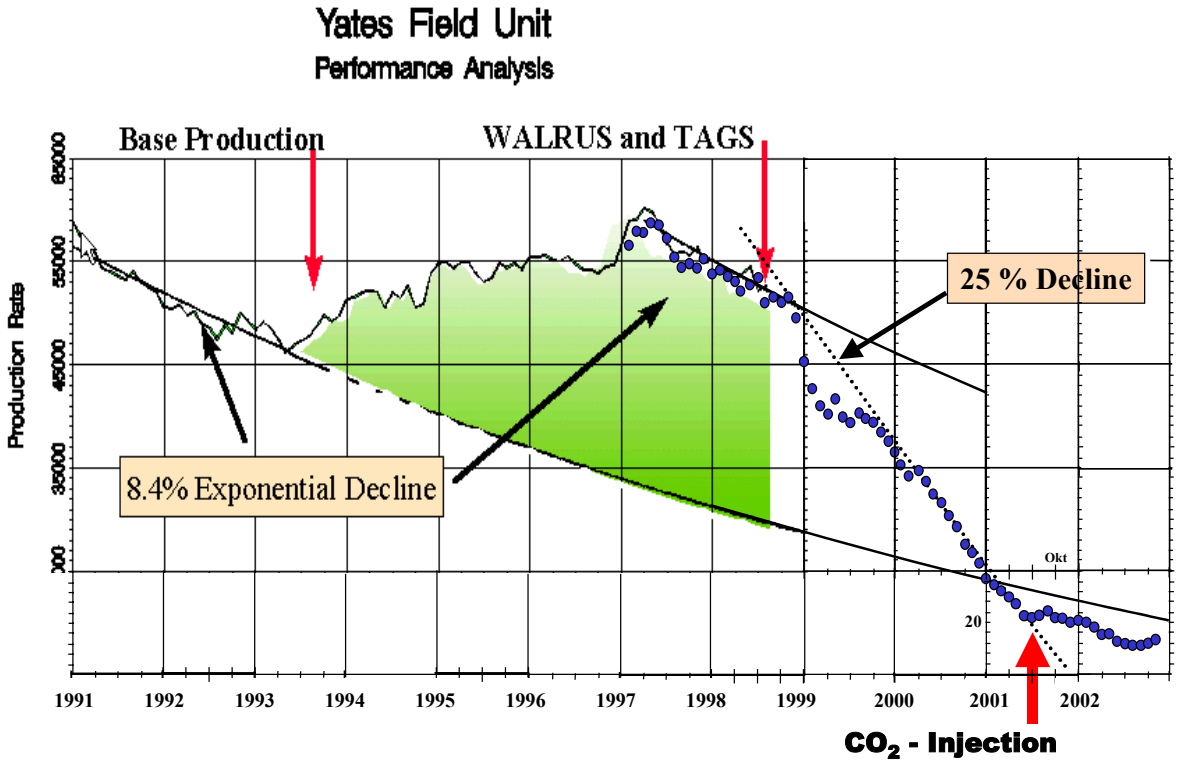


Figure 5: Yates field: total output increase was 40 million barrel with respect to total output since production start of 1.4 billion barrels (an increase of 3 percent). If the initial recovery rate was 20 percent, these EOR measures would have shifted the recovery rate to 20.6 percent. (RRC 2003)

4 The Influence of Non Conventional Oil

Example 1: Oil production of Canada

Very often one hears the argument that the depletion of *conventional* oil supply will be offset by the production from *non-conventional* sources, mainly oil from tar sands. It is relatively easy to evaluate the potential of *non conventional* oil production in North America. Because of the long lead times and the necessary huge investments the planning has to be nearly completed today. These plans, which are documented, allow a reasonable forecast of what is possible over the medium term at least.

Figure 6 shows the history of the oil production in Canada. *Conventional* oil production reached a maximum about 30 years ago. The downward trend has been reversed in recent years, due to production from the offshore Hibernia field, several hundred kilometres east of Newfoundland. Hibernia was discovered in 1978 and is believed to contain about 600 million barrels of oil. The field was brought into production only a few years ago, because of difficult operational conditions.

Heavy oil production in Alberta and Saskatchewan has been increasing in recent years, with the production of synthetic crude from tar sands from Alberta starting as early as 1967. Up to now, production has come from only a few localities where the tar sands are close to the surface, allowing a relatively cheap extraction. Only about half of the recovered bitumen is processed to synthetic crude.

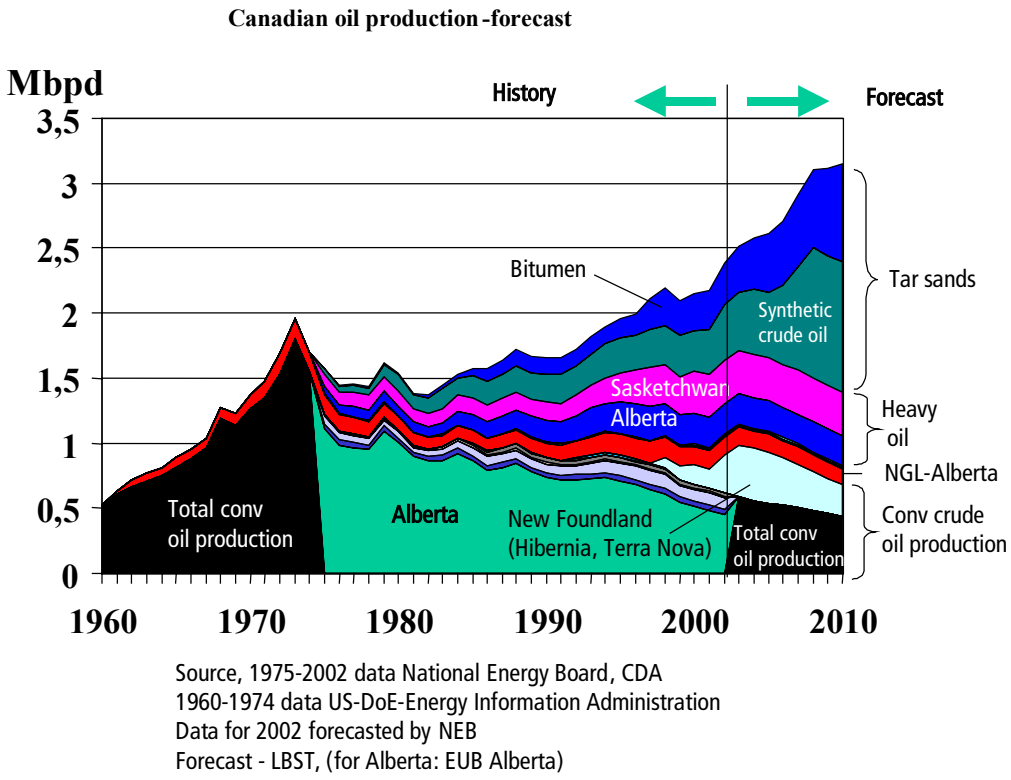


Figure 6: Total oil production in Canada including conventional oil and non conventional oil

The onshore crude oil supply from conventional sources will continue to decline over the next years, following a standard pattern which is already well established. Natural gas liquids (NGL) are another important element, but production is more likely to decline than increase in the near future as most Canadian gas wells have shown substantial decline rates over the last years.

It looks as if North America as a whole will run into severe gas supply problems. Due to increased gas prices, the operators are likely to market the NGL blended with the natural gas rather than extract the liquids by processing. This practice occurred during the winter of 2000/2001 when gas prices in the USA skyrocketed; NGL production declined by some thirty percent, since NGLs were left in the natural gas instead of being marketed separately.

The best hope for increasing Canadian oil production rests with the offshore areas, mainly east of Newfoundland. Hibernia itself has already reached maximum capacity but can continue to produce in declining amounts for some years to come. Terra Nova is another large field in the vicinity with reserves of about 400 million barrels. It was brought into production late in 2002 and is expected to reach a maximum production plateau of about 150 kb/d. The third large discovery in that area, White Rose, was found in 1984 with an estimated reserve of about 230 million barrels. It is scheduled to start production in 2005 with an estimated peak production close to 100 kb/d.

Most *Non-conventional* oil comes from the tar sands of Alberta. The financial plans of the large

companies have already been announced, and form the basis for the forecasts by the Alberta Energy and Utilities Board.

The production of synthetic crude oil (SCO) will roughly triple by 2010, as will the production of non-upgraded bitumen, resulting in a total oil production in Alberta of 2 Mb/d in 2010, an increase of about 1.5 Mb/d from 2000.

Adding these sources together gives a forecast for total Canadian oil production as shown in figure 6.

Example 2: Oil production of Venezuela

The other location of non conventional oil resources with worldwide importance are the extra heavy oil deposits in Venezuela. The development and production from these deposits started already 15-20 years ago. In the late 1980s BP invented a method of mixing oil, water and chemicals in a type of synthetic crude called Orimulsion. Although this method facilitates extraction somewhat, the environmental impacts are tremendous, and many countries refuse it. Today several projects have been completed or under construction which will increase the total production capacity in 2010 to about 1 Mb/d, up from 0.4 Mb/d in 2002. The location of these projects is shown in figure 7.

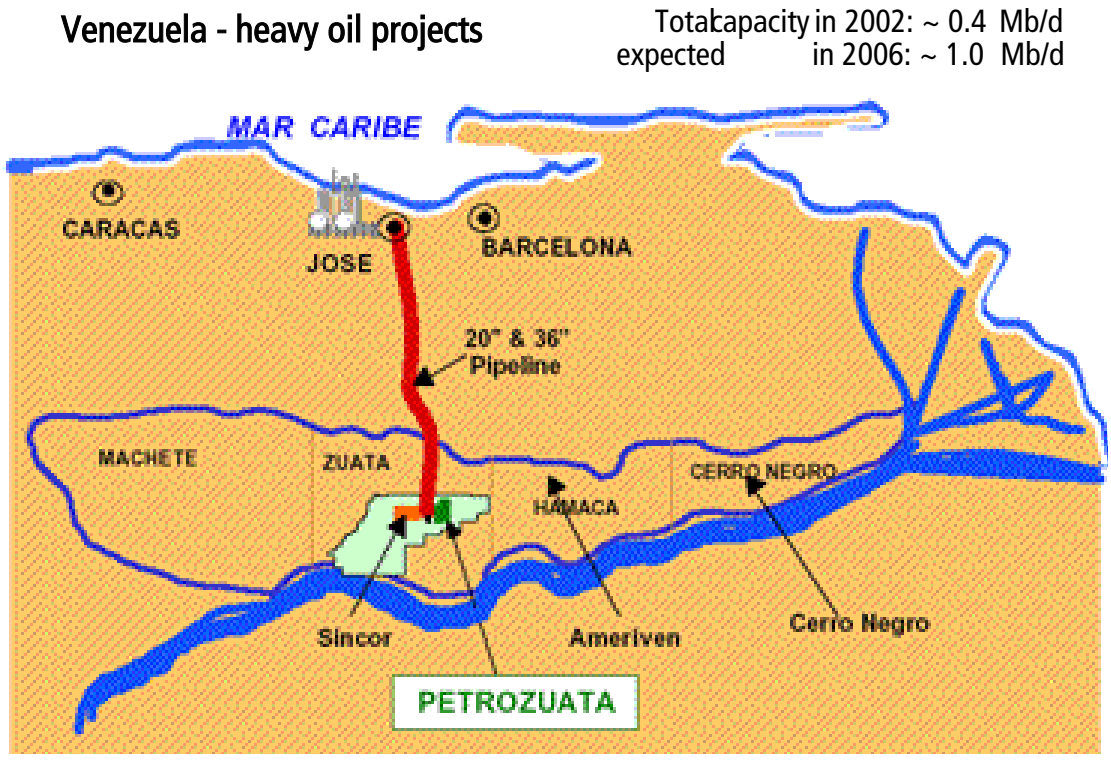


Figure 7: Location of non conventional heavy oil deposits in Venezuela and explicit citing of the projects (PdV 2003)

Though theoretically a huge resource, tar sands and extra heavy oil in Canada and Venezuela will have only a low impact on the worldwide supply situation for at least the next decade. This is due to the fact that only a small amount of the reserve is economically feasible. These projects are already planned; further extensions will be much more difficult. The long planning and construction

times and the long return of investment times ties up capital for long periods, which hinders fast reactions and fast enlargements. Furthermore the low extraction rate makes any production increase very slow and subject to long term planning.

Finally one should not forget the energy and water resources which are needed to extract the oil from the ground. Just to give an idea of the size of these efforts: today a quarter of all water used in Alberta is directed to the oil and gas industry. Canadian Natural Resources Inc (CNR) is investing about 5 billion Canadian dollars to push the production rate of the project horizon to 235 kb/d by 2011. Within that project there are plans to divert a river for several miles and to use the water to allow on-site extraction of 3.5 cubic meters per second. Large extensions of these projects are simply not realistic when one considers the needs for other resources and the environmental side effects.

5 Signs of the Imminent Peak of Production

The fact that the oil industry is spending much money and using all available high technologies to explore for oil in unfavourable areas (like polar, Caspian, Deep Sea) might be interpreted as the industry's admission of the fact that ever less oil is found at other (easier to access) places. Otherwise industry would look for that oil first.

As one can see in detail from figures 8 and 9 ever more oil producing countries are reaching their peak of production in spite of very favourable economic conditions i.e. high prices of crude oil.

The aggregate production peak of all countries outside OPEC occurred somewhere around the year 2000.

In 2002 the OPEC share of world oil production was about 33 % and thus had reached roughly the same size as at the beginning of the 1970s when the power of OPEC over the markets (or at least the public awareness of it) enabled it to trigger an oil price shock. But in contrast to the situation in the 1970s the OPEC share will not decrease again in future but will only increase further because of limited reserves outside OPEC.

Table 1 shows the assignment of all the important oil producing countries to the three production phases defined in chapter 3. This assignment is done according to our assessment with regard to the production profile in the past and the ratio of reserves/discoveries (i.e. the share still available for production). Basic data are taken from the industry database. The detailed assignment country by country is given in [LBST 2001a].

Table 1: Production in the year 2000, cumulative discoveries and reserves (= cumulative discoveries minus cumulative production) of all countries grouped by phase of production

Region	Production 2000 Mb/d	Share of World Production %	Cumulative Discoveries Gb	Reserves 2000 Gb	Still available %
Decline	37,8	51,4	897	337	38
At Peak	12,4	16,8	293	156	53

Pre-Peak	23,4	31,8	840	610	73
Total	73,6	100	2026	1103	54

Only about 30% of the world's oil production is coming from the few countries still able to increase their production substantially (these are the countries at Pre-Peak). Those countries own more than half of the world's remaining oil reserves and have to date used only one quarter of their reserves. Nearly half of the world's known oil reserves have already been produced.

5.1 Scenarios of the Future Oil Production

For the discussion of the question of annual production growth in the future, we group the oil producing countries according to phase of production (as in table 1) and then we make assumptions regarding possible and necessary production rates. For this purpose we make projections for the years 2005, 2010 and 2020.

We concentrate our discussion on two scenarios: the first scenario assumes oil demand remaining constant over the next two decades; the second scenario assumes a (moderate) increase of future oil demand. It is our purpose to keep these scenarios very simple in order to make it easy to follow the argument and to enable the reader to make his own assessments.

Scenario 1: Constant Demand

This scenario rests on the following assumptions: The world demand remains constant until 2020. The average yearly production decrease of the countries in "Decline" is assumed to be 2.5 % p.a. Countries now in the "At Peak" group are expected to start their decline in year 2006 (this is a rather optimistic assumption). The production gap caused by the declining countries has to be compensated for by increased production of the countries in the "Pre-Peak" group and/or by the additional production of non conventional oil (NC).

Table 2: Scenario 1 - Average daily production in Mb per day

Year	2000	2005	2010	2020
Decline	37,8	33,3	29,3	22,8
At Peak	12,4	12,4	10,8	8,4
Pre-Peak + NC	23,4	**28**	**33,5**	**42,4**
Total	73,6	73,6	73,6	73,6

Scenario 2: Rising Demand

Assumptions are: The future demand growth will average 1.5 % p.a. (i.e. about the average growth rate since 1975). The average yearly production decrease of the countries in "Decline" is assumed (again) to be 2.5 % p.a., and countries now in the "At Peak" group are expected to start their decline in year 2006. The production gap caused by the declining countries has to be offset by the countries in the "Pre-Peak" group and/or by the production of more non conventional oil (NC).

Table 3: Scenario 2 - Average daily production in Mb/d

	2000	2005	2010	2020
Decline	37,8	33,3	29,3	22,8
At Peak	12,4	12,4	10,8	8,4
Pre-Peak + NC	23,4	**33,9**	**45,7**	**68,9**
Total	73,6	79,5	85,8	100,1

We think that both scenarios are rather on the optimistic side because the average decline rates of the countries in "Decline" are assumed to be only 2.5 %. This decline rate equals about the average decline rate experienced in the US in individual basins after passing the peak. In off-shore basins however decline rates of 5 – 10 % p.a. are more likely. As illustrations of this: Alaska has halved since 1989, and in the UK production fell by 20 % in the first two years after passing the peak - and for Norway similar decline rates are expected.

Figure 8 shows the production profile of the three groups for the two scenarios.

Scenario 1 shows how much the "Pre-Peak" countries would have to increase their production over the next 20 years to ensure constant supply.

In scenario 2 the task for the "Pre-Peak" countries (including increased production of non conventional oil) is even tougher: in order to offset the decline in the other regions, their production would have to increase by 2 Mb/d every year (equivalent to 6 – 7 % p.a.) for 20 years!

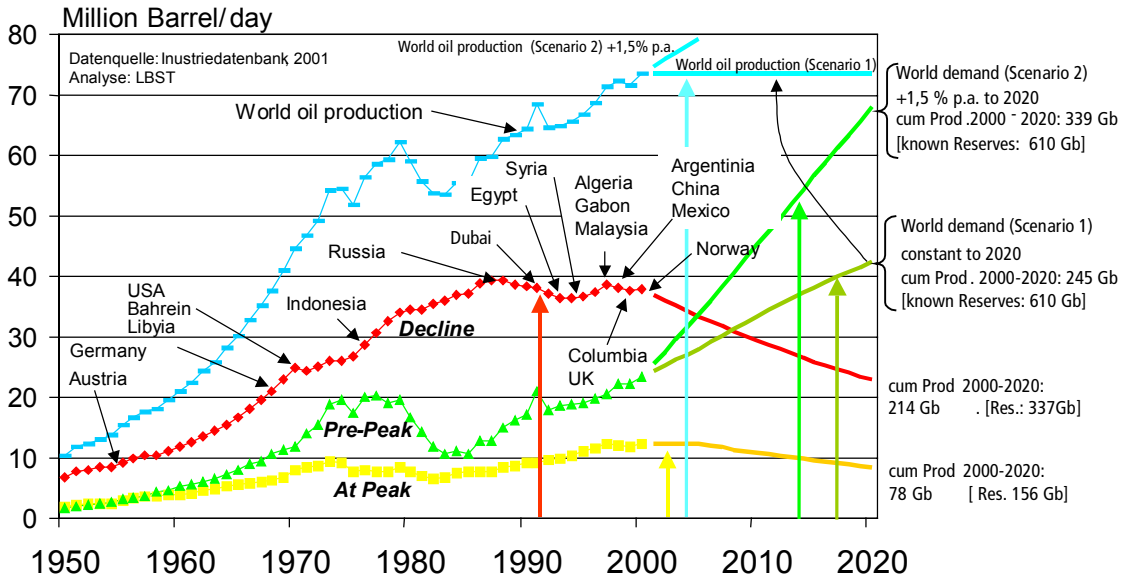


Figure 8: World oil production scenarios. All oil producing countries are assigned to one of the groups "Decline", "At Peak" or "Pre-Peak", according to the phase in which they are producing. For the countries in "Decline" (red curve) there is also the year

marked in which important countries reached their production peak. The coloured arrows indicate for each group the year of the aggregate "mid-depletion" point at which half of the recoverable oil has been produced. [Source: Industry database]

How probable are the developments described in these scenarios? The following considerations may be helpful in assessing the situation:

- The United States EIA estimates that production from the Caspian Sea under favourable conditions can grow by 2.7 Mb/d to 4 Mb/d by 2010 and can possibly reach 6 Mb/d in 2020. (EIA 2001) As discussed below, an increase of about 1 - 1.5 Mb/d is much more likely.
- Oil production in the deep sea off Angola was until recently expected by the industry to grow to about 2.5 Mb/d by 2015. This would amount to an increase of production of 1.8 Mb/d over the next 15 years. Already today these forecasts are deemed to be too optimistic (Luanda 2000) and an expected increase of about 1 – 1.5 Mb/d seems more realistic.
- All known projects up to 2010 dedicated to produce non conventional oil from Canadian oil sands add up to an expected production of 2 Mb/d. This amounts to an expected production growth of 1.6 Mb/d within the next 8 years.
- If one adds the above increases in production regarded as possible by industry one arrives at about 6 Mb/d in the very optimistic case. But if demand grows according to scenario 2 there remain more than 15 Mb/d in 2010 which have to come from other sources. If those 15 Mb are to come from the Middle East then production capacities there would have to double within the coming 10 years. This seems impossible with regard to the necessary long lead times and the investment made to date.
- One should also note that the assumed production increase of 1.5 % p.a. in scenario 2 is well below the increase assumed by the IEA in its Energy Outlook 2000. There the IEA forecasts an increase of production by the year 2020 to about 120 Mb/d.(IEA 2000)
- The chairman of BP, John Browne, was reported saying alongside of the G8 gathering in Davos in spring 2001 that he expected the maximum production capacity of the industry to be somewhere around 90 Mb/d.

We very much doubt that even the peak capacity of 90 Mb/d as estimated by John Browne can actually be reached and think it much more likely that world peak production will eventually lie somewhere in the region of 80 Mb/d.

Worldwide experience shows that the production peak in an oil region happens when about half of the ultimately recoverable oil has been extracted. However, due to the poor data base available, these figures have to be seen only as a rough estimate. But with regard to this estimate and together with the above considerations and further arguments as listed below we are very confident that the world wide production peak is very close.

In contrast to other estimates, the USGS uses in its assessments different definitions for resources. (USGS 2000) The USGS assessment leads to the observation that the US oil production peaked in 1970 when only 1/3 of the USGS estimated ultimate recoverable oil was extracted. If we translate this relation to the worldwide situation – where the USGS estimated ultimate recoverable world resources of 3,000 Gb – than the world wide oil production should peak when about 1,000 Gb of oil are consumed.

The geologist Colin Campbell estimates that about 2,000 – 2,200 Gb of oil (including crude, NGL and heavy oil) can ultimately be extracted. He forecasts that the world wide production maximum will occur around the year 2005 based on a Hubbert model.(GCN 2002)

To develop a better understanding of this assessment, the following chapter focuses on the same topic, but from a slightly different point of view. Also the following subchapters give further hints and circumstantial evidence regarding the imminent peak of oil production.

5.2 Oil Production Outside OPEC and Outside the Former Soviet Union

Over the years, membership of the *Club* of countries that have passed their production peak has grown. Figure 9 lists the countries outside OPEC and outside the Former Soviet Union in the order of their peak production date. Indonesia is the only important representative of OPEC on the list, having passed its peak production twenty-five years ago. Algeria or Libya could have been added but are left in the "OPEC" group. Countries which still might increase their production are given at the right hand side of the figure. The most important ones are Angola, and Brazil. There is a degree of uncertainty whether China and Mexico have already passed their production peak or whether they are still a few years before it. However, this does not change the general pattern much.

The data for North America are taken from figures 4 and 6, but excluding heavy oil and tar sands as non conventional oil. The non conventional oil is added explicitly in figure 10.

The future production pattern of the countries in decline is easily calculated from trend extrapolations. After adding in possible production increases mainly confined to Angola and Brazil where new deepwater finds have been made, we get an overall estimate of decline by some 7 – 8 Mb/d over the next decade.

Unless demand is cut, the world will depend on additional supplies from the Former Soviet Union (including the Caspian) and the Middle East OPEC countries, and on additional *non conventional* sources in Alberta (as outlined above) or Venezuela. Canada might provide about 1.5 Mb/d of additional oil until 2010. Another million could come from other unconventional oil projects in Venezuela under optimistic assumptions. According to predictions by the US-DoE (Energy Information Administration) the Caspian region could eventually supply 1.5 Mb/d additionally in 2010.

The missing 3.5 – 4.5 Mb/d would have to come from Russia and the Middle East OPEC countries.

It remains to be seen if this is achievable, as the available data about these countries are of poor quality and do not allow reliable forecasts. However, an increasing demand for oil would need even further resources. Another 4 Mb/d would be needed if world demand were to rise by a moderate 0.5 % per year on average up to 2010 (which is far less than the growth rates during the last two decades).

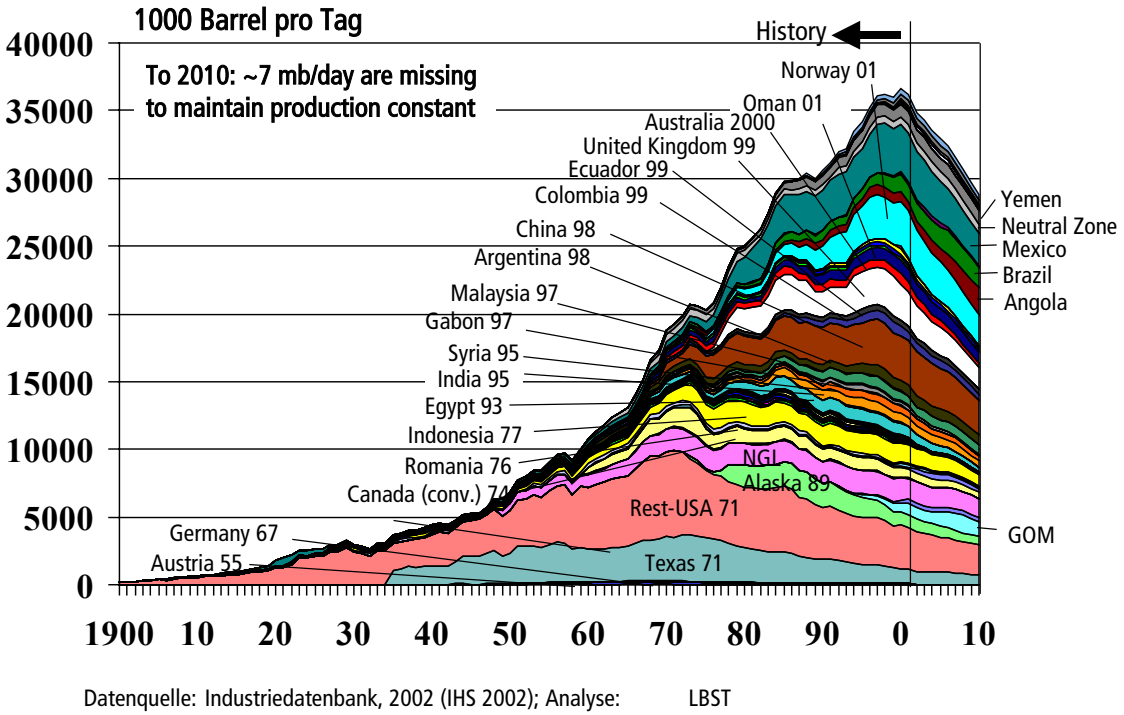


Figure 9: Oil production summing up all countries outside the Former Soviet Union and most of the OPEC- countries (only Indonesia is included having passed its production peak in 1977)

5.3 More Oil from Russia and the Caspian?

The Russian oil production reached its peak in 1987 with about 11.4 Mb/d. Some years later production fell to 6 Mb/d in 1996. This decline was partly due to the breakdown of the country's economy, but also due to having passed peak production in important Russian oil fields.

E.g. the largest oil field, Samotlar, with a reported size of 28 Gb, had reached peak production in the mid 1980s when it produced 1.3 Mb/d. Today its production rate is down to 100 kb/d. Recent data indicate that the ultimate recovery of the field is overestimated in official documents by about 8 Gb, leaving only 20 Gb as ultimate recoverable - an overestimate of about 30 percent. Even the second largest field, Romashkino, holding 18 Gb, has already passed peak production and seems to be overestimated by 10 percent. Further analysis shows that Russian oil discoveries in general are overestimated by about 20-30 percent. And most of the large fields already have passed peak production.

In the last 5 years, oil production has recovered to about 7 Mb/d. Official statements claim that further production increases will shift the level close to or even above the record levels of the 1980s. However, some scepticism might be allowed. First of all, the reported production volumes cannot be checked. Only exported quantities are measurable for outside observers. It is also possible that oil is removed from the domestic market and exported instead to gain hard currency. Secondly, once the largest fields are beyond peak production the gradual decline has to be

compensated with ever rising new discoveries and field developments. Though there is some potential for further discoveries in Russia, it is very likely that the best opportunities were taken first in these early years after the economic transition. It is very likely that the recent upward trend will be disrupted soon and turn into a decline as experienced earlier during the 1990s.

Many people believe that the Caspian Sea area holds huge amounts of still undiscovered or undeveloped oil. But actually, only four super giants are worthwhile to be mentioned: Tengiz, Karachaganak and Kashagan in Kazakhstan, and the complex Chirag-Azeri-Guneshli in Azerbaijan. In total, these fields hold about 20 Gb of oil or condensate. But surprisingly, big oil companies which took part in the early development of these discoveries withdrew from operational consortia or postponed their plans: BP and Statoil from the latest discovery Kashagan, Chevron at the already producing field Tengiz, Exxon after drilling a dry hole in Azerbaijan while having spent about $1 billion for its exploration, or even the Russian company Lukoil which - as a surprise to observers - sold all its assets in Azerbaijan. The withdrawal of several billion dollars of investment makes it very doubtful whether the envisaged future production levels are still realistic.

In view of all these facts and considerations we conclude that for the whole former Soviet Union a production increase of about 1 – 1.5 Mb/d is still possible up to 2010. Some early extensions of Russian developments in the next years will most likely turn into decline after 2005, while on the other hand the development of additional Caspian oil will come into production mainly after 2005.

5.4 Frontier Areas

Some people also hope for huge undiscovered oil in the deep sea of the oceans. However, looking somewhat closer these people might find themselves disappointed in a few years, just like the oil companies which are looking for it.

Only very rare combinations of events in the geological past are responsible for the accumulation of oil in ultra deep waters. These conditions are found in front of Palaeozoic river deltas, e.g. east of Northern Brazil, west of Angola and Nigeria, in the Gulf of Mexico, and in the Southern Chinese Sea. Within the last 20 years about 30 Gb of oil have been found in these areas, and the discovery rate in most deep sea areas is already slowing down during the last two years. Therefore one can hope to find maybe another 20 - 30 Gb in the future.

Angola, and Brazil together produce about 2 Mb/d at present with some potential to double that rate in 5 – 10 years for a very short period before the inevitable decline sets in.

5.5 A "Profit Warning" for Future Oil from OPEC Countries

The Middle East countries are the "wild card" in future oil production. Indeed, many people believe that their reserves will feed the rising world oil demand for many decades to come. But on looking a little closer one notes that Saudi Arabia's large oil fields have already been producing for many decades and are close or beyond peak production. More expensive offshore oilfields already contribute 25 percent of the country's oil output. One should not be surprised to find that production in Saudi Arabia cannot be increased substantially any more.

It turns out that only very few countries still have the potential to rise their production capacity by several million barrels per day. These countries are probably Iraq, Abu Dhabi and perhaps Kuwait.

Even in these countries production growth is only possible if large investments take place.

However, there is as yet no sign that this is happening. This makes it very doubtful whether these countries will be able to offset a future oil scarcity resulting from the decline in other countries. This task becomes even harder because within this decade the production decline in other regions will accelerate.

5.6 World Oil Production

Figure 10 summarises the history of world production distributed among the different producing regions. OPEC is counted without Indonesia, FSU includes the Caspian Region. *Non Conventional* production from Canada and Venezuela is shown explicitly, and "Rest of the world" (ROW) is the same as given in figure 9.

Forecasts to 2010 are made in line with the data and figures as discussed above. Since future production data for the "Rest of world"- countries are probably quite accurate, any further demand increase above today's levels would have to be supplied by OPEC or Russia.

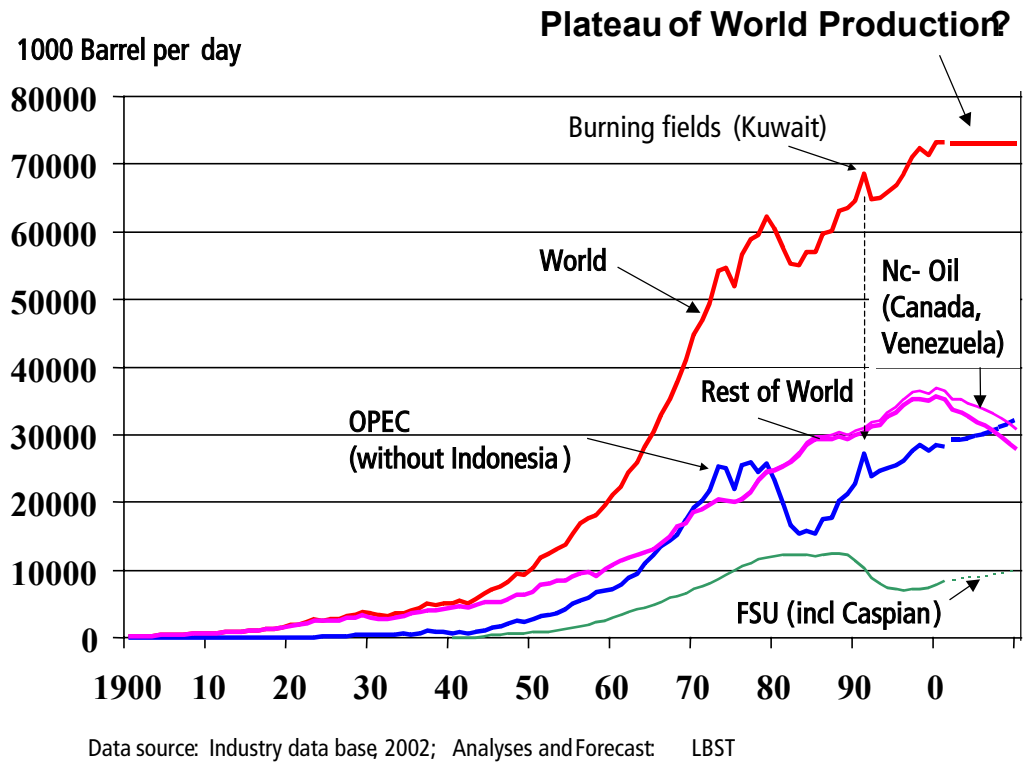


Figure 10: World Oil production split into OPEC (without Indonesia), Former Soviet Union (FSU) and the Rest of World. Explicitly shown is the rising contribution from tar sands and heavy oil from production in North America and Venezuela, not included in "ROW"-production. The forecast is based on the assumption that total world oil production might stay flat. To offset the decline in ROW-countries, an increase of oil production by 1.5 Mb/d is assumed for FSU; the rest has to be contributed by OPEC countries – summing up to an increase of 3 Mb/d for these countries. If oil demand were to rise above the given level, oil production in these countries would have to rise further – which would need investments which are not yet visible.

5.7 The Economic Situation of Oil Companies is Indicating Imminent Problems

Future oil production rates are limited by geological and technical constraints. But also economic factors influence future spending on exploration and production. And vice versa, once a growing industry arrives at a turning point due to diminishing assets, this will influence the economic situation of individual companies and of the industry as a whole. This chapter draws together economic indicators which further support the evidence of an imminent peak of world oil production.

Example 1: Norsk Hydro

Expenses for oil and gas exploration tremendously increased over the last year at Norway's second largest oil company Norsk Hydro, as can be seen from figure 11 which compares income from oil and gas production and expenses for exploration since the first quarter of 1997. In 2002 several large projects turned out to be ultimately unsuccessful, forcing the company to completely write off these efforts. In the third quarter of 2002, about 1.3 billion Kroner were spent on exploration of which 480 million Kroner were spent on dry holes in Angola, 300 million Kroner went into dry holes in the Gulf of Mexico and smaller budgets were lost with dry holes in Denmark and the Caribbean. The only successful exploration well was drilled in Canada. Looking at figure 11, the huge increase in earnings in 2000 was due to higher oil prices and to the production expansion in Canada (Hibernia oil field in 2000 and Terra Nova oil field in 2002). However, exploration expenses increased to a share of about 50 percent of the income in the 3rd quarter of 2002. If these trends continue, the company will run into serious problems. (NH 2003)

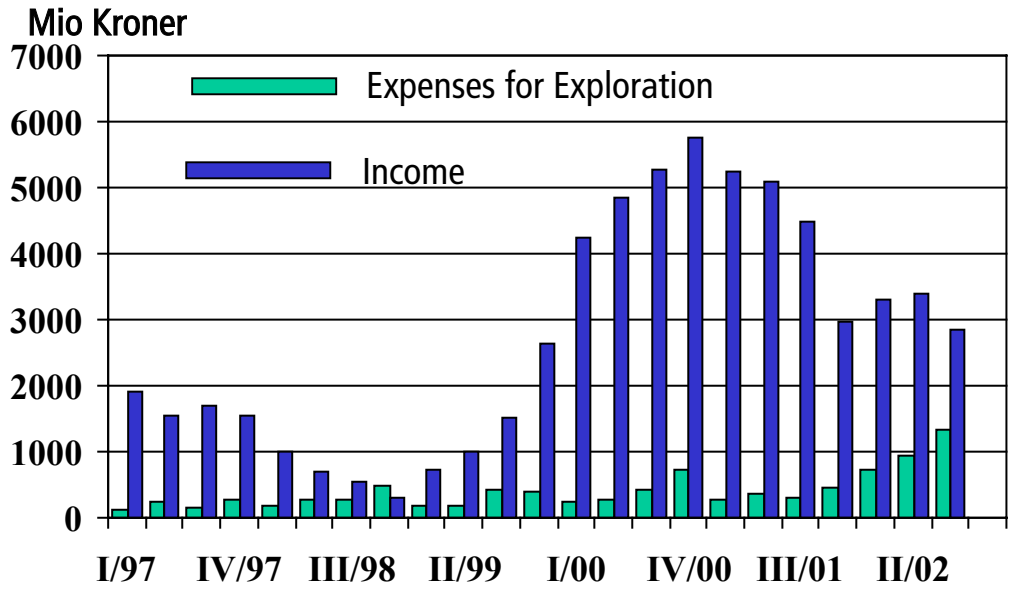


Figure 11: Earnings from oil and gas production (blue bars) of Norsk Hydro and exploration expenses (green bars). In 2002 costs increased by at least a factor 4. This was mainly due to disappointing exploration activities in Angola, the Gulf of Mexico, the Caribbean and Denmark.

Example 2: Amoco

The Amoco company spent a lot of money on unsuccessful exploration efforts as can be seen from

figure 12. Entering the business as a late starter, the good oil prospects were explored very fast with the first hundred wildcats. With the next three hundred wildcats only another 4 Gb were discovered. Five to six hundred further explorative drillings could only add about 1 Gb, all discoveries summing up to 16 Gb. This poor success was the main reason for financial problems of the company and the eventual merger with BP. Later on the same story happened to Atlantic Richfield Corporation (ARCO). Both companies merged with BP to the joint company BP-Amoco-ARCO, which now is downsized again to BP, both in the name and in the staff. In other words these mergers were nothing more but a downscaling of the industry hidden to the public.

What happened to Amoco and to ARCO soon might also happen to Norsk Hydro if the trends sketched above continue.

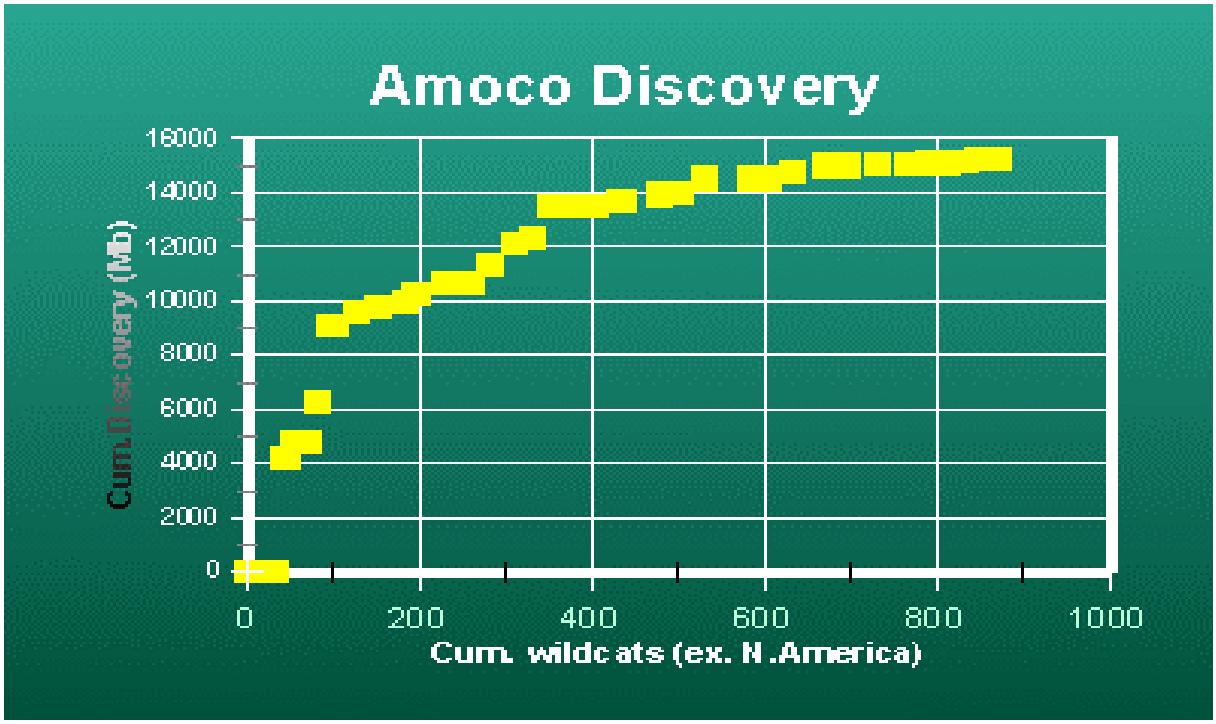


Figure 12: The disappointing oil exploration of AMOCO exhibited in the cumulative discoveries resulting from new wildcats (Source: Colin Campbell)

Example 3: BP

The whole industry comes under severe financial pressure soon as investment in new exploration fails to maintain the same return of investment as in former years. The only remaining possibility for companies to increase their production volumes is via mergers and acquisitions.

This situation is completely different from five years ago and is already reflected in the market and illustrated by recent profit warnings. E.g. BP downscaled its production goals three times within the last year. More and more big companies are changing their reporting habits and only publish their output and financial results combining oil and gas. This obscures the change in the production portfolio namely a declining oil business and a growing share of the gas business.

Looking at BP's present assets, about 70 percent of the oil production comes from the North Sea and from the United States of America (Alaska). In both areas production is declining year by year. Therefore it is only consistent to sell these assets as was announced very recently. The company

argued that the new liquidity will be used to reinvest in more profitable projects. But it will be interesting to see where these are going to be. Recently the most important large scale projects were the involvement in Chirag-Azeri-Guneshli (offshore Azerbaijan) and Thunderhorse (Gulf of Mexico). But these require huge development costs. Other attempts to establish new projects are less successful. In 2000 the company withdrew its shares from the largest discovery in the Caspian Sea (Kashagan) for being unprofitable. More and more BP has to turn to less profitable assets (compared to past performance) or to turn to completely new areas such as renewable energy.

Example 4: Exxon

Exxon is the leading privately owned oil (and gas) company which until recently completely ignored the problems with which oil companies are confronted: Climate Change was seen as an issue where the oil industry must not take action; depletion didn't seem to exist according to their profits and behaviour; renewable energies are considered to be decades away from now, thus prohibiting any investment in this area.

However, in the last year (2002) there have been signs of change. For the first time high ranking managers made several speeches in which they communicated to the public that the whole industry is facing new and fundamental problems:

- Exxon has published a graph which shows the historical pattern of oil discovery which first was compiled and published by Colin Campbell and Jean Laherrère. This graph is based on the industry database and makes use of backdating reserve reassessments of known fields to the date of the original field discovery. It shows the historical fact that peak discovery took place in the 1960s of the last century.
- Exxon admits the fact that discoveries fell in the last two decades despite strongly increased oil prices. There is no empirical correlation between oil prices and discoveries.
- Exxon states that depletion in producing fields is a fact. Therefore in order to maintain today's production level, about 40 Mb/d of new capacity will have to be developed within this decade.
- Exxon states that the oil industry is facing a new situation which is completely different from the past: To increase production by 2010 to those levels to which the oil demand will rise (according to IEA estimates) requires expenses for exploration and development in the order of 100 billion $ per year, a total of $1000 billion by 2010. This is substantially more than in the past.

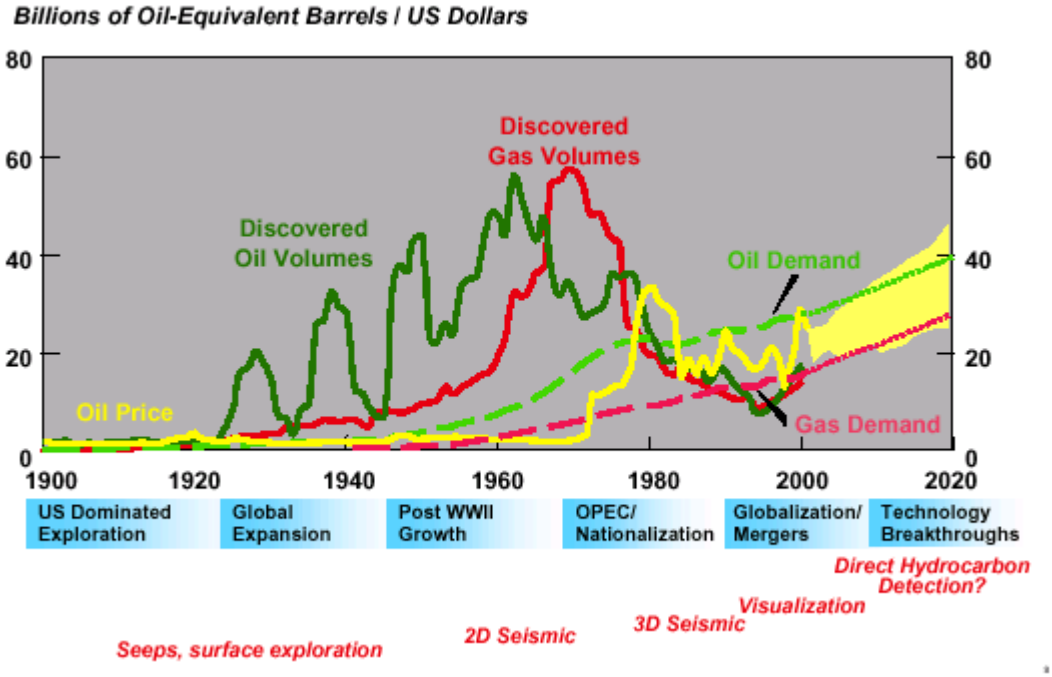


Figure 13: Smoothed annual discoveries of oil and gas as seen by Exxon. This figure is well in line with data from the industry data base and in striking contrast to public domain information sites. It is interesting to see Exxon expecting a rising oil price in coming years. (Exxon 2002)

It is also interesting to see world wide gas discoveries peaking only a few years later than oil did, though world wide interest in gas assets increased over the last two decades tremendously. Can this be read as a signal that in the long run Exxon also doesn't believe in natural gas as a substitute for oil?

6 Difference between Reserves in Public Domain Statistics and Industry Databases

Diminishing oil assets are in striking contrast to public communications stating that oil reserves are growing, and have been doing so for decades without any sign of a reverse trend. What sources are these different views based on?

6.1 The "Economist's" Point of View

This view is based on annual reserve statistics which are published each year by oil companies (e.g. BP Statistical Review of World Energy). Those statistics are based on two completely different facts:

- On the one hand new discoveries which are made during the course of the year are added to reserves.
- On the other hand the estimated recoverable amounts of oil in ageing fields are re-evaluated and systematically increased year by year. These field revisions are due to an early underestimate in annual reports. This guarantees that year by year proved reserves are increasing, thus hiding the real situation regarding new discoveries.

This is common practice for the reporting of reserves by private oil companies. With the help of these systematic upward revisions, years with disappointing exploration success can be hidden, .and the produced quantities smoothly replaced in the company statistics. This accounts for the fact that oil reserves have almost continuously increased for more than 40 years, though each year about 25 Gb or 2 percent of known reserves are removed by production.

The reserve figures used in financial contexts and shareholder meetings, are completely different from those which address the question of how much oil has already been found and how much oil still will be found.

The main reason, however, for the apparently unchanged world reserves year after year is the reporting practice of state owned companies. More than 70 countries have reported unchanged reserves for many years, despite substantial production.

6.2 The "Geologist's" Point of View

This view is concerned with the question of how much oil will still be found in a certain oil basin or worldwide. To address this question a clear distinction is necessary between new discoveries and the re-evaluation of the size of old fields.

First of all, in financial context, the reserve of a given field is given as "proved reserve" which usually has a probability of 80 – 90 percent that the field has at least the stated size. But experience shows that mature oil fields turn out in reality to be around the size which was originally estimated as their "proved and probable reserve" – an estimate which has equal probabilities that the field will ultimately turn out to be smaller or greater. In technical terms this is called the P50 reserve (50 percent probability). During the lifetime of a producing field the initially estimated "proved reserve" is re-evaluated several times and is finally very close to the value which in the beginning was internally known as P50-reserve.

To get a correct historical pattern of discoveries, reassessments of an old field are based on the year of discovery and not on the years of reassessment (as favoured by economists). The derived historical pattern of discoveries displays a trend which helps to extrapolate into the future and to assess the prospects for future discoveries in a given basin in coming years. Such an analysis is essential for the geologists' decision as to where it is still worth looking for oil and where not. In nearly all oil provinces, the same pattern can be observed: large discoveries are made early and with minimal effort. In later years the size of individual and annual discoveries gets smaller and smaller. The cumulative discoveries over the years saturate and approach an asymptotic value which might be seen as the estimated ultimate potential for the oil recovery of a region.

An important reason why reassessments of ageing oil fields do not influence the production pattern and the production peak is that they are mostly done for old fields after their production maximum. This leads to the paradoxical situation that the oil production in an individual field can decline even though the ultimate reserve in the field increases. In these cases the reassessment has no influence on the future production profile. This can be demonstrated with many examples. The reassessment of the largest UK oil field (Forties) is shown in table 4.

Table 4: Production rate of Forties, the largest UK oil field, and estimated ultimate recovery for the field as stated by the operator [after (Brown Book 2002) and (Laherrère 2001)]

Year	1980	1984	1987	1997	1999
Production (kb/d)	182	156	128	41	28
Estimated Ultimate Recovery (Gb)	1,8	2,0	2,4	2,5	2,7

Another example is the case of the reserve estimates for the USA which are reassessed each year resulting in almost constant oil reserves over many years, though each year oil is removed by production. Despite these reassessments, the US oil production has been in decline for 30 years (as shown above in figure 4).

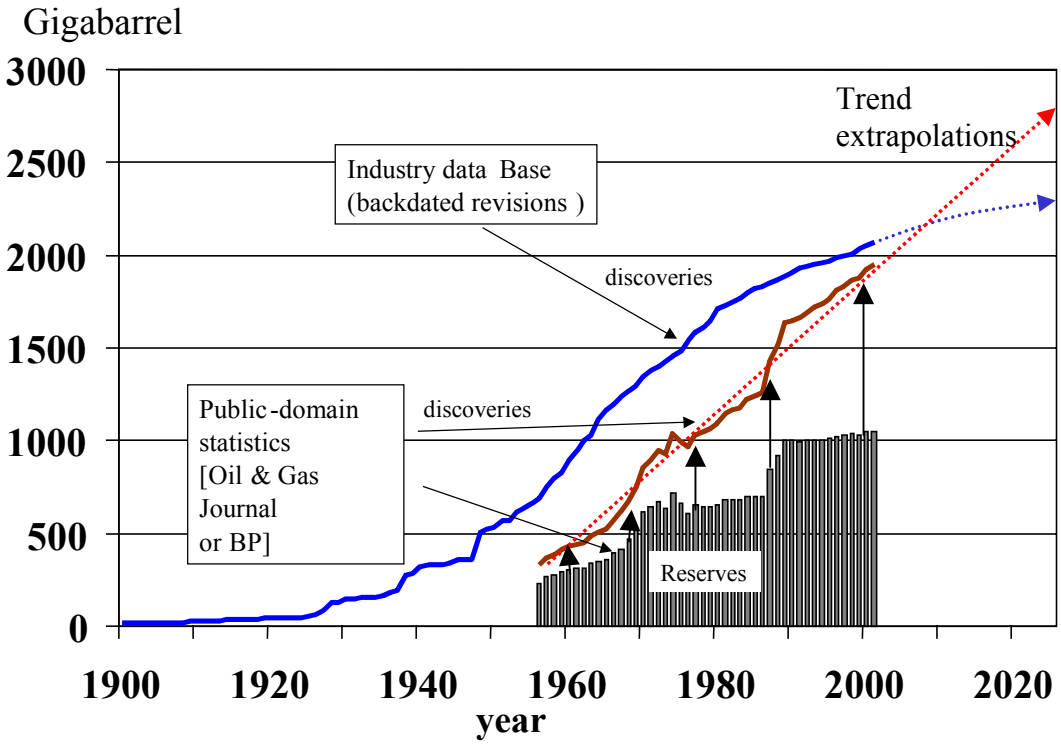


Figure 14: The difference between Industry data and public domain statistics of reserves. Though their absolute size is similar, the most striking difference is the backdating of reserve revisions to the discovery year. This gives a completely different historical pattern which changes the forecast for future discoveries considerably.

7 Some Comments on the Current Debate

Discussion of future oil and gas supply is dominated by two opposing positions.

Economically oriented observers base their knowledge mainly on information derived from the financial departments of their companies. They argue that market mechanisms are sufficient to guarantee future discoveries and production rates. Many therefore believe that also in the long term supply shortages can be avoided. Price increases will happen only for short times until supply and demand reaches an equilibrium again, driven by market forces and the panacea "technology".

In contrast, those who base their knowledge more on the "geologist's view" argue that the

historical peak in discoveries has to be followed by the peak of production. Many of these analysts have many years of personal experience in oil exploration with close ties to colleagues and with access to exploration and discovery statistics.

These opposing views might be concentrated in the following two statements:

" *The potential significance of the alternative theory of the origin of additional oil and gas potential is self-evident with respect to the issues of the longevity of hydrocarbons' production prospects and to production costs in the 21st century. Instead of having to consider a stock reserve already accumulated in the finite number of so called oil and gas plays, the possibility emerges of evaluating hydrocarbons as essentially renewable sources in the context of whatever demand developments may emerge*" Peter Odell, Economist [Odell 2001].

" *Geologists look for oil, engineers produce oil, economists sell oil. Beware of economists who tell you how much is there*." Colin J. Campbell, Geologist.

To give some orientation in this ongoing discussion it is also helpful to have a closer look at the type of arguments used by different groups and the motives and interests behind them.

7.1 Oil Industry

Oil companies frequently publish reassuring press releases, speeches and "studies" on the future availability of oil; the oil industry has a natural financial interest in doing this:

- The signal of diminishing resources could induce the consumers to reduce their oil consumption even faster than necessary. In such a case the oil industry would be left with more oil available on the market than consumers would want to buy. Certainly, this would be bad for business.
- The signal of diminishing resources and hints at "diminishing assets" could lead shareholders and investors to redirect their investments into new business opportunities with more growth potential. This also would be bad for business.
- It would be best if consumers and shareholders would stay loyal to oil even at declining production rates and rising prices. This would bring about the highest earnings at minimum costs. Therefore, the best communication is to convince the consumer that any current problems are only temporary – and thus to keep them dependent on oil even in worsening times.

Because of these motives the industry will never admit that the future availability of oil might be a problem and rather tends to communicate growing reserves. All this however does not necessarily prevent the oil industry from investing in new business areas.

7.2 Consumers and the Public

The consumer is interested in using cheap energy in everyday life to gain as much comfort as possible. Therefore disturbing messages are seen as endangering the present way of life and questioning the own behaviour, and it is therefore very likely that they will be discarded. On the other hand, messages which confirm the present lifestyle find open ears and are readily believed. So in a way the interests of all participants in the market point into the same direction: it is more comfortable not to be aware of the imminent problems caused by peak oil production.

7.3 Economic Institutes

Economists concentrate on the market mechanism which tends to balance demand and supply. The optimum price is reached when supply and demand are in balance. Imbalances between supply and demand are reflected in changing prices which in turn trigger enhanced production or demand until both are in balance again.

In this reasoning oil scarcity will lead to rising prices which in turn is an incentive for the oil industry to invest more into exploration and field development and consequently the oil supply will rise. The argument that every new exploration tends to be less successful because the amount of the remaining undiscovered oil is diminishing is countered with the argument that because of this efforts have to be intensified by spending still more on exploration. And once the prices for oil are high enough, the market mechanism will ensure that alternatives to oil are smoothly introduced into the market.

In short, the market perfectly regulates the economy and there is no need for political action with regard to energy supply.

Though this reasoning seems plausible at first sight, we criticise it as never being able to predict a critical supply situation; it does not take care of – among other things - the changing geological, geographic and physical conditions (resource depletion) and the long lead times for reactions which govern the real world. This "naive optimistic" economic view always results in a sufficient supply situation and therefore is "unfalsifiable". Within that thinking it is left to the engineers and technicians to provide the preconditions necessary for the proper working of the economic model. Whether and how this can be done is not considered but rather the fact that it can be done is deemed as self evident.

7.4 Ecology Institutes

The threat of global warming caused by the burning of fossil fuels dominates the present discussion on the necessity to change our energy economy by reducing the use of fossil fuels and by introducing renewables.

One can observe that ecologically oriented scientists and policy makers frequently give the impression that they think the whole debate on the possibility of imminent oil and gas supply crises is absurd. It even looks as if the topic of resource depletion is a cause of nuisance for them. These people seem to believe that the debate on resource depletion diverts the attention away from the predominant topic of climate change and thus reduces the urgency of actions. They seem to believe that in a few years oil prices will return to the low levels we have seen before and that the "wolf!" cries will again turn out to be without substance. They therefore think that this discussion might discredit the efforts to change the energy system and to reduce emissions.

But between the topics of climate policy and resource depletion of fossil fuels there is no antagonism. Both problems can be addressed by exactly the same measures. Therefore both topics together strengthen the pressure and also the willingness to reconsider our energy policy.

8 Early Investigations of Peak Oil Production

Very often one hears the argument that diminishing oil supply has been predicted several times

before, but each time the claims turned out to be false. The report "Limits of Growth" by the Club of Rome which was published in 1972 is cited in this context. Also it is pointed out that proved oil reserves remain at constant or even increasing levels, that the production to reserves ratio (P/R ratio) indicates that reserves will last at present consumption levels for more than 40 years, and that this value has not changed during the last decades despite rising consumption.

The discussion of P/R ratios based on proved reserves is nonsense for various reasons. As explained above, proved reserves (or P90 reserves) for systematic reasons always grow and therefore are the wrong measure when trying to assess future availability of oil. Instead "proved and probable" or P50 reserves are the better measure (the value to which proved reserves will converge ultimately). On the other hand the question "for how many more years will the oil last at present consumption rates?" is irrelevant since this R/P ratio is based on constant supply over time while actually the supply is growing in early phases and falling once peak production is passed. The cause for economic disruptions is not the date at which the "last drop of oil" will be consumed but the point in time where rising supplies are followed by continually declining supplies.

By the way, the report "Limits of Growth" used in its calculations five times the figure of the then known proved reserves. This resulted in a reserve estimate of about 2280 Gb which even today is well in the range of best estimates (even if only by chance ...).

But the only detailed historical analysis of the subject which was known to a wider public is the report "Global 2000" to the President of the USA, published in 1980 by US government agencies. The then estimated amount for ultimate oil recovery is well in line with today's knowledge. Even the estimated date of peak production is about accurate when one uses the factual growth rates of demand in the past two decades. In the report this date was estimated for different levels of demand growth. The considered annual growth rates of 2, 3 or even 5 percent would have led to a peak of production between 1985 and 1995. If we insert the average rate of 1.3 % per year since 1975 into the graph then peak production will take place around 2002 or 2003. This is well in line with today's (also our) estimates that peak production will happen sometime between 2000 and 2010. Maybe the peak already happened two years ago since world oil production in 2001 and 2002 did not exceed the production in 2000.

The geologist King Hubbert (then working for Shell) predicted as early as 1956 the peak of the US oil production to be reached around the year 1970 – a widely ignored statement at the time but which later turned out to be quite correct.

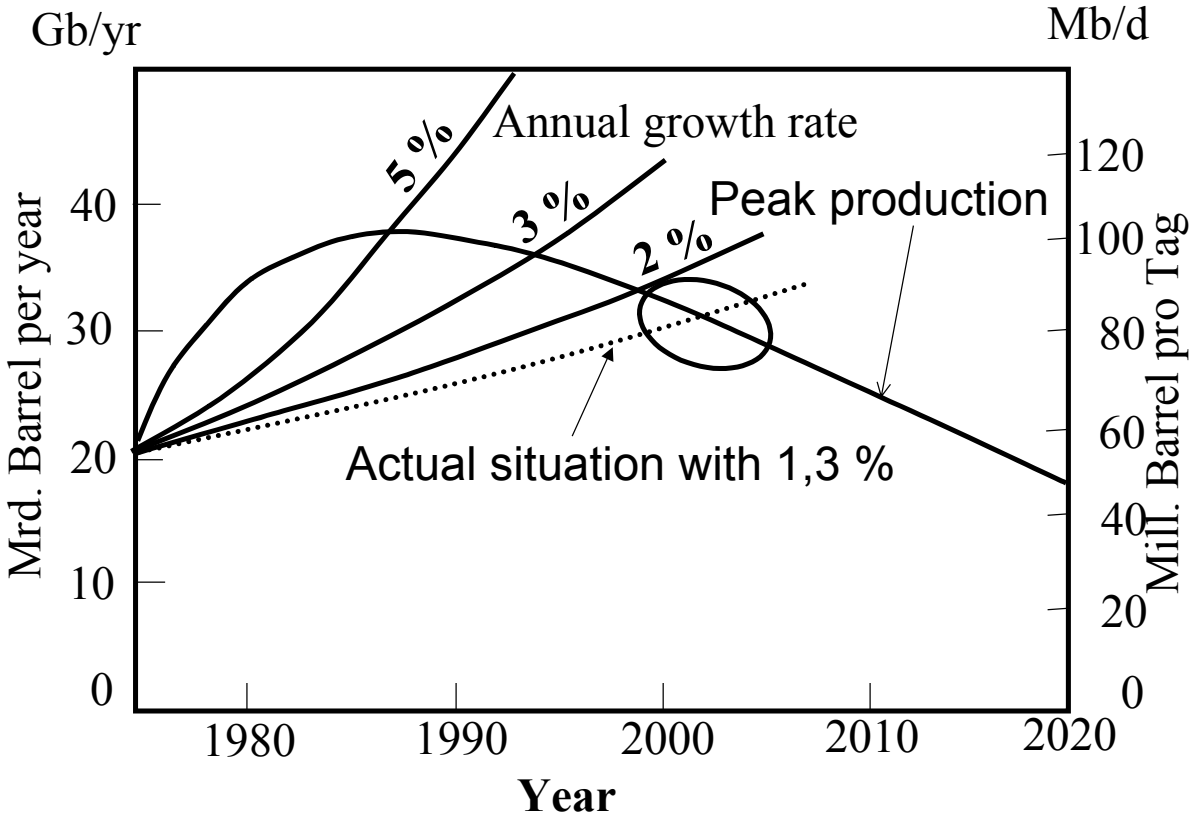


Figure 15: Early forecasts of the date of peak oil production, assuming various annual production growth rates. The forecasts from 1979 assumed 2, 3 or even five percent annual growth rate, given expected dates of peak production between 1985 and 1995. (Data taken from "Global 2000", published in 1980). The dotted line however shows the real production growth since 1975 with 1.3 % p.a., indicating peak production at around 2002. (Global 2000)

9 Summary

The main facts, theses and conclusions are:

- The peak of oil discoveries was reached in the 1960s. This is a historical fact.
- This peak in discoveries has to be followed by a peak in production, since we can only produce what has been found before.
- The production peak of individual fields is a historical fact, almost all large oil fields have already passed their production maximum and are in decline.
- The aggregation of the production profiles of individual fields (with their individual peaks) sums up to a production peak of individual oil regions. Historically peak production was reached e.g. in Austria in 1955, in Germany in 1968, in the USA in 1971, in Indonesia in 1977. Recent regions joining the club of countries with declining production rates are Gabon (1997), UK (1999), Australia (2000), Oman (2000) and Norway (2001).

- The aggregate decline of mature regions is getting steeper with every new "member of the club" . In order just to keep overall production flat ever fewer regions have to increase their production.
- This pattern can already be observed over more than thirty years. Even the quantitative estimates of peak oil production have been sufficiently accurate for more than 20 years. It is very likely that the peak of world oil production will be reached by 2010 at the latest.

Due to diminishing exploration successes, the financial situation of oil companies is deteriorating.

An escape out of this dilemma is only possible for a limited time. These are the main options:

- Companies merge to increase their individual production and reserve situation by simultaneously downsizing their staff.
- Discovery and or development of new large fields with a favourable return on investment. These fields are increasingly scarce and only available in regions which have already been known for decades, mainly in Iraq. The frontier areas (Caspian and deep sea drilling) do not belong to this category.
- Dramatic price increases to compensate for higher production costs. That might be a reason why Exxon has started to point out the fact of oil depletion: perhaps they want to prepare the public for higher prices in future.

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