THE EVOLUTION OF THE WORLD'S HYDROCARBON RESERVES

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by **J.H. Laherrère** e-mail: j.h.laherrere@infonie.fr
lecture given in French on June 17, 1998 in Paris to SPE France

Introduction

The reserves of an oil or gas field cannot be measured directly but only estimated on the basis of geological and engineering knowledge and principles. Like all estimates, reserve estimates are subject to uncertainty. Furthermore, many are confidential or subject to "political" pressures. Companies use different numbers for internal and external purposes, and different companies involved in a particular field may report different estimates. It is accordingly very difficult to obtain valid current estimates, and even more difficult to determine their evolution over time.

What are we talking about?

It is difficult even to clearly distinguish what is classed as an oilfield from what is classed as a gasfield. The US Department of Energy lists 46 000 fields in the United States but 4500 of them are classed both as oilfields and gasfields. Of the 18 000 fields in Petroconsultants' database, about a thousand lack reserve data, meaning for the most part that an announced discovery was not substantiated. Fields may have different names in different databases, and may change their names where they straddle concession or national boundaries. For example the North Field in Qatar was found in 1971, but an extension into Iran is known as the South Pars Field and attributed to 1991. Reports even of world production range widely. The 1996 production of what was termed "oil" was variously reported as 62.7 Mb/d for crude oil (IEA); 64.1 Mb/d for crude oil and condensate (EIA/DOE); and 74.4 Mb/d for "liquids" (EIA/DOE). Synthetic oil is sometimes included, sometimes not. For these reasons, Cumulative Production has an accuracy of no more than ten percent.
The proportion of liquids derived from gas ranges from 26% (including 21% of NGL) in the United States to 6% in the world as a whole.
There is confusion between *Initial Reserves*, namely the total discovered, and *Remaining Reserves*, namely the reserves as of a reference date. There is confusion between *Reserves* and *Resources*, as well as between *conventional* and *non-conventional* categories. There is no consensus on the definition of these terms. Reserves yield production, but much of the resource base will never achieve reserve status. Some are non-economic; some would take more energy to produce than they deliver; and some will remain undiscovered due to the practical limits of exploration activity in the foreseeable future.

The initial reserves of a field will be known absolutely only on the day when it is finally abandoned, when they will equate with the Cumulative Production. Prior to that they are known only within a range of uncertainty which should be expressed in terms of a probability range. The traditional method, known as the Determinist Method, is used mainly in the United States, and classifies reserves as Proved, Probable or Possible. It ignores the range of uncertainty, giving a single number for each class of reserves. Only the Proved class is accepted for financial reporting purposes.

Figure 1 Curves of probability

Fig 1 **Lognormal distribution: probability curves**

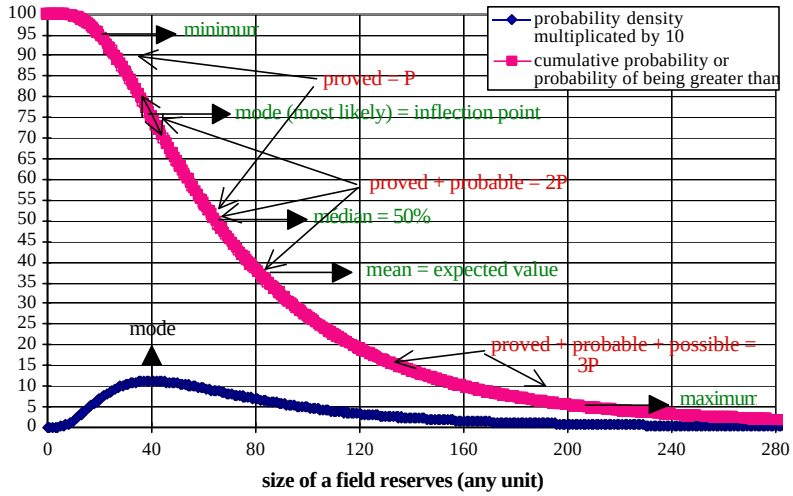


Figure 1 illustrates a probability curve that represents the uncertainty of reserves in a field. The probability ranking on the Y-axis is that the actual number is greater than the corresponding value on the X-axis. Thus, in this particular example, the low ("mini-") case, with a probability of 95%, is 20 Mb whereas the high ("maxi-") case, with a probability of 5%, is 200 Mb. It means that there is a 90% probability that the actual reserves will fall between 20 and 200 Mb. Refining the analysis further, we may recognize the Mode value of 40 Mb which is the most likely, coming at the point of inflection, with a 65% probability; the Median of 60 Mb with a 50% probability; and the Mean of 80 Mb with a probability of 35%.

Superimposed on Figure 1 are the ranges of what are termed Proved (P); Proved + Probable (2P) and Proved + Probable + Possible (3P). It is necessary to show them as ranges because there is no consensus on how to define them.

There can be no absolute ranking of probability because each field in unique, but the distribution of probability can be built up from an evaluation of the probability ranking of the several physical parameters, such as reservoir thickness and porosity, that control the size of the reserves.

In practice, there is a tendency to prefer the simpler determinist method, which allows the evaluator to deliver the desired results, rather than deal with the more correct but more complex probability method. In the real world, there are pressures to both over- and under-report.

Motives for declaring the minimum:

Explorer: to avoid being regarded as a dreamer

Engineer: to reduce the risk of being contradicted (a mean estimate implies being wrong 60% of the time),

Company: to secure apparent reserve growth over time which presents a more attractive financial image, may reduce tax, and in some cases facilitate its competitive position

Motives for declaring the maximum:

Explorer: to make a small prospect sufficiently economic to pass corporate hurdles

Company: to augment its share values; sale value; the stock options of its executives; overcome government constraints to depletion rate (Frigg)
Countries: to provide collateral f or debt (Mexico)
OPEC: to increase quota (large increases in the late 1980s)
Soviet Union: to show the maximum theoretical recovery ignoring economic constraints

Motives for declaring the mean (the expected value):

Those seeking a valid national total. The mean value of a large number of fields is the sum of the mean value of each individual field, despite the fact that, statistically, 60% of the cases will prove incorrect.

Most international companies are quoted on the American Stock Exchange and are subject to the rules of the Securities and Exchange Commission, which were designed to protect investors from unscrupulous promoters in the onshore environment of the United States. These regulations accept, for financial purposes, only Proved reserves, based on the catchment area of producing wells (normally 40 acres) as deemed "reasonably certain" in relation to the technology and economics, including oil price, in effect at the end of the year in question. This practice naturally gives rise to "reserve growth" over time as the fields are drilled up and as probable and possible reserves are converted to proved status. The concept of "reserve growth" is much misunderstood, being commonly attributed to technological progress, when in reality it is mainly an artifact of the reporting procedure. There are many vested interests that benefit from the ambiguity surrounding reserve estimation and the illusion of "reserve growth" which conceals the reality of depletion.

The weakness of the system has been the subject of comment by many experts:
"*There are currently almost as many definitions for reserves as there are evaluators, oil and gas companies, securities commissions and government departments. Each one uses its own version of the definitions for its own purposes*" DeSorcy 1993 (1)

"*The resource base [of the former Soviet Union] appeared to be strongly exaggerated due to inclusion of reserves and resources that are neither reliable nor technologically nor economically viable*" Khalimov 1993 (2)

"An industry that prides itself on its use of science, technology and frontier risk assessment finds itself in the 1990s with a reserve definition more reminiscent of the 1890s" "illegal addition of proved reserves" Capen 1996

"*Why our reserves definition don't work anymore*" Caldwell 1996

"*Virtual reserves - and other measures designed to confuse the investing public*" Tobin 1996

"*The term "reserves" often is treated as if it were synonymous with "proved reserves". This practice completely ignores the fact that any prudent operator will have, at least internally, estimates of probable and possible reserves"* Ross 1998 (3)

Defining Proved Reserves

The problem of defining what is meant by the commonly used term, *Proved Reserves*, has been addressed many times with a wide range of proposals. In fact, the term has been variously

applied to reserves having a probability ranking from 50% to 95%. Some of the approaches are listed below:

1961 API : Proved = "beyond reasonable doubt"
1977 SEC-FASB : Proved = "with reasonable certainty"
1979 Kalimov : USSR A + B +C1 reserves = Proved Reserves
1979 Esso : Proved (P) = 95% probability; Proved + Probable (2P)= 50% probability; Proved + Probable + Possible (3P) = 5% probability
1980 AAPG, SPE and API : uses SEC definitions
1983 WPC (Martinez) Proved = "reasonable certainty" or 90% probability
1985 Grossling : "expected value = 2.3 Proved for Non-OPEC; 1.5 Proved for OPEC
1985 Bourdaire (4) : Proved (P) = 95% (minimum); 2P = mode; 3P = 5% (maximum); mean = "expected value" = Proved + 2/3 Probable + 1/3 Possible
1987 WPC (Martinez) Proved = 85%-95% Probability = "high degree of certainty"
1990 Laherrère (5) : Proved(P) = 85%-95% ; 2P = 50% ; 3P = 5%-15%
1991 Ross notes that "reasonable certainty" is treated by some as having a probability of 65% or, even worse, 50%.
1991 Caldwell proposes that "reasonable certainty" equates with a 75% probability, between Proved and Probable
1993 DeSorcy : Proved = 80% probability; Probable = 40%-80% probability; Possible = 10%-40%; "Expected Reserves" = Proved + 0.6 Probable + 0.25 Possible; "Established Reserves" = Proved + 0.5 Probable
1994 Ross : Proved = 75% probability
1994 NPD drops Proved, Probable and Possible in favour of 90%; 50% (called Most Probable?) and 10%
1994 PdVSA (Roger) uses a probabilistic range of 80-50-20%
1996 SPE/WPC proposes a hybrid system whereby the Determinist terms are defined as follows : Proved = "reasonable certainty", but also having a "high degree of confidence"; Probable = "more likely than not"; Possible = "less likely than not"; and the Probabilistic terms are defined as follows: Proved (P) =80% probability; Proved + Probable (2P) = 50% probability; and Proved + Probable + Possible (3P) = 10% probability
1997 SPE/WPC final text : Proved = P90.

The issue of reserve definition has become the prime responsibility of the a committee formed by the World Petroleum Congress and the Society of Petroleum Engineers under the direction of A. Martinez. It has endeavoured, without much success, to find a compromise between the determinist and the probabilist schools of thought. One of the obstacles to progress has been the huge amount of work and re-education that would be involved in financial reporting if the traditional determinist method were to be changed. An obvious solution would be to persuade the SEC to follow the UK accounting procedure that requires reserves to defined as Proved + Probable, which is normally taken at a P50 value, although strictly speaking it should be the Mean, with a Probability of about 40%. A discussion with SEC is presently in progress (Martinez July 1998).

Summing reserves of more than one field

The way in reserves are defined has much impact on cases where reserves from more than one field are summed to give national or corporate totals. Adding the Proved reserves of individual fields under-states the total. The proper procedure is to sum the mean values.
In the case of determining the reserves of a field from the constituent parameters, such as reservoir thickness, porosity, saturation etc., also requires proper handling. Multiplying the low case value for each parameter does not give the Proved reserves for the field as a whole: thus multiplying five parameters each having a probability of 90% would give a total of 0.9 power 5, namely 59%. The Most Likely (mode) value for the field is obtained by multiplying the mode value for each parameter.
There has been a tendency to use Monte Carlo simulations to make probability calculations, but it is not necessary to go to this length if one makes the reasonable assumption that the distribution of the parameters is lognormal (6) (7).

Norwegian System

The Norwegian Petroleum Directorate operates a particularly thorough and sound procedure recognizing as many as twelve categories, of which only three are covered in the SPE/WPC classification, in all cases referring to initial reserves and resources.

0 Reserves where production is ceased
1 Reserves in production
2 Reserves with an approved development plan
3 Resources in a late planning phase (PDO approval within 2 years)
4 Resources in an early planning phase (PDO approval within 10 years)
5 Resources which may be developed in the long term
6 Resources where development is not very likely
7 Resources in new discoveries for which the evaluation is not complete
8 Resources from possible future measures to increase the recovery factor (measures which are not planned, possibly superseding present-day technology)
9 Resources in prospects
10 Resources in leads
11 Unmapped resources

The volumes declared (Feb.1997) by the NDP are:

	Oil M.m3	Gas G.m3	NGL Mt	Total M.m3 o.e.
0: Production ceased	0	41	0	41
1: In production	2702	1639	122	4499
2: Development approved	448	294	31	782
subtotal = reserves	3150	1974	153	5322
3: Late planning phase	540	365	23	935
4: Early planning phase	123	655	21	805
5: Can be developed in the long term	135	435	24	601
6: Development very uncertain	24	47	1	72
7: New discoveries	10	17	0	27
Total discovered (resources)	3982	3493	222	7762
Reserves as % of resources	79%	56%	69%	69%

It should ne noted that Norway accords Reserve status to no more than 69 percent of its discovered resources.

The U.S. oil resource agencies (Department of Energy , Department of the Interior Geological Survey and Mineral anagement Service) that are not bound by the SEC regulations do not use the terms Proved, Probable and Possible.

The Minerals Management Service, which is responsible for the offshore, explains its definitions:

"Cumulative probability distributions: A distribution showing the probability of a given amount or more occurring. These distributions include the values for the resource estimates presented throughout this report: a low estimate having a 95 percent probability (19 in 20 chance) of at least that amount (F95), a high estimate having a 5 percent probability (1 in 20 chance) of at least that amount (F5), and a mean (m) estimate representing the average of all possible values. Values of the fractiles are not additive. These distributions are often referred to as S-curves. Deterministic : a process in which future states can be forecast exactly from knowledge of the present state and rules governing the process. It contains no random or uncertain components" It is obvious that they regard the determinist method as stretching credulity, given the many uncertainties".

Recovery Factors

The growth of reserves is often taken as a reflection of an improvement in the percentage of the oil-in-place to be recovered. We must note that the uncertainty relating to the size of the reserves is large at the outset but reduces progressively until the abandonment of the field when all uncertainty has been removed. By contrast, the oil-in-place is estimated at an early stage from seismic surveys and other data, and the uncertainty does not improve over the life of the field unless additional seismic surveys and drilling are undertaken. Recovery factor is used to estimate reserves only at the beginning of the project: later estimates come from well performance and simulation techniques. This is illustrated, for example, by the fact that a manual on reservoir engineering issued by the Institut du Petrole Francaise (8) makes no reference to the use of recovery factor. The fact that recovery factors are commonly quoted in round numbers, such as 30%, 1/3, 40%, 50%, demonstrates what an imprecise method it is. NDP has taken 50% for its last oil estimates and 75% for its gas estimates.

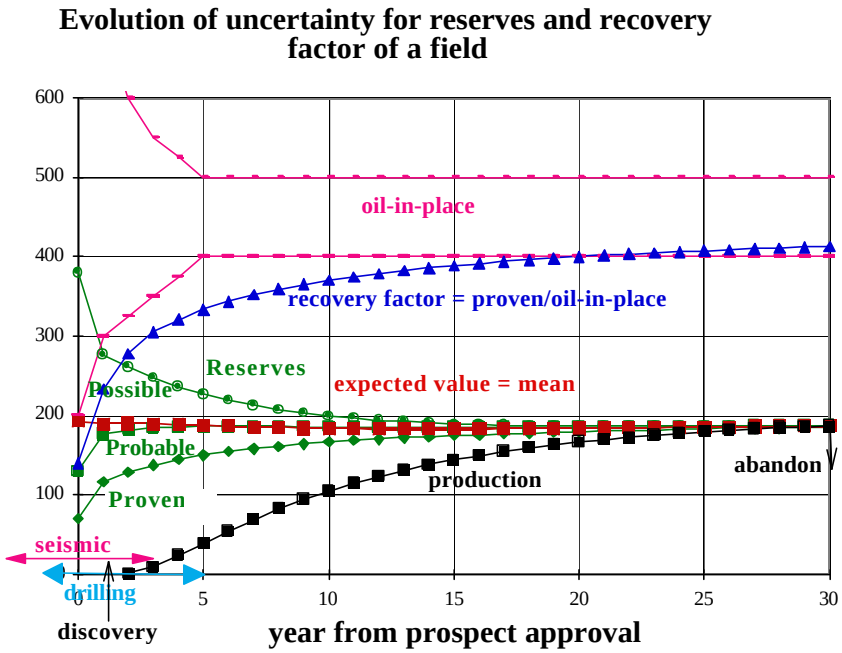
It is clear that, in the same way as reserves should be reported as a range, so should the even more uncertain values of oil-in-place. Furthermore, the probability ranking of the reserves should be match by an equivalent ranking of the oil-in-place. Knowledge of both improve over the life of a field but not necessarily proportionately.

For these reasons, an improvement in apparent recovery factor normally simply reflects the progressive addition of Probable reserves that were omitted from the initial estimate.

The notion of "reserve growth" largely reflects the bad practices widely used in reserve estimation. Figure 2 illustrates the position.

Figure 2. Evolution of the uncertainties of reserves and recovery factor

Fig 2



Published Reserves

Published reserve estimates range widely, and are commonly contradictory as reported by Greenpeace on Internet.

Table 1 Global and Regional Oil Reserves at the end of 1995 (Gb)

Regions	OGJ	World Oil	Petroconsultants	USGS
North America	77	77	64	103
South America	78	85	51	74
Europe	16	31	30	37
FSU	59	191	76	121
Africa	73	79	53	72
Middle East	660	590	439	583
Far East	42	51	38	62
Australasia	2	4	3	4
TOTAL	1007	1107	746	1056

Notes:
OGJ = Oil and Gas Journal - Estimated Proven Reserves at 1.1.96.
World Oil - Estimated Proven Reserves at 21.12.95.
Petroconsultants - Assessed Reserves, 1995.
USGS = United States Geological Survey - Identified Reserves at 1.1.93. adjusted for subsequent production from 1993 to 1995.

The US DOE/EIA (Annual Report 1996) gives in Table 5 these values that differ by factors of one to three (especially for Non-OPEC countries where there is a average discrepancy by 1.7), yet it does not comment on the discrepancies nor indicate a preference.

International Oil (Million Barrels) Reserves as of December 31, 1996
(major discrepancies in bold face)

Rank	Country	Oil & Gas Journal	World Oil	
1	Saudi Arabia	261 500	261 800	
2	Former U.S.S.R.	**57 000**	**183 831**	
3	Iraq	112 000	112 000	
4	Kuwait	96 500	94 700	
5	Iran	93 000	90 500	
6	United Arab Emirates	97 800	63 510	
7	Venezuela	64 878	72 603	
8	Mexico	48 796	48 472	
9	Libya	29 500	29 500	
10	China	24 000	34 055	
	Top 10 Total	884 974 (87%)	990 971 (85%)	
11	United States	22 351	22 050	
12	Norway	**11 234**	**26 874**	
13	Nigeria	15 521	20 800	
14	Algeria	9 200	12 960	
15	Indonesia	**4 980**	**9 241**	
16	Brazil	4 800	6 970	
17	Canada	4 894	5 537	
18	United Kingdom	4 517	5 003	
19	India	4 333	5 049	
20	Malaysia	4 000	5 170	
21	Angola	5 412	3 601	
22	Oman	5 138	3 614	
23	Qatar	3 700	3 916	
24	Egypt	3 696	3 700	
25	Yemen	4 000	3 100	
				Discrepancy
	Top 25 Total	**992 749 (97%)**	**1 128 556 (97%)**	14%
	OPEC Total	788 579 (77%)	771 530 (67%)	-2%
	Non-OPEC	**230 270 (23%)**	**388 574 (33%)**	69%
	World Total	**1 018 849 (100%)**	**1 160 104 (100%)**	14%

We may note that there is a discrepancy of 14 percent for the world as a whole and as much as 69 percent for the Non-OPEC countries. The uncertainties are evident, yet these estimates are quoted in exact numbers implying a more than justified accuracy. Such estimates should be quoted to no more than two significant figures.

Comparison of data from the Oil & Gas Journal and World Oil

The Oil & Gas Journal gives its data in the last few weeks of the year in question, and the figure can accordingly be no more than an estimate, whereas World Oil publishes its data in August of the succeeding year. Both journals publish what are reported as Proved Reserves. World Oil

corrects the data in their subsequent report but the Oil & Gas Journal does not.. We have compiled the data from these two sources and compared them with the backdated Proved + Probable (P50) data provided by Petroconsultants. Backdating attributes any reserve revisions to the discovery date of the relevant fields. It does not take into account the impact of subsequent investments but certainly provides a better picture of the discovery trend than accepting, on a current basis, the revisions, which are mainly due to flawed estimation procedures rather than any dynamic addition. It would be still better to backdate to the date of the commitment of investment rather than to the discovery itself, but to do so is beyond the available database.
Figure 3 compares the two data sets for the FSU. The abrupt fluctuations in 1968-71, 1980-85 and in 1991, shown by World Oil is as implausible as is the constant value reported by the Oil & Gas Journal.
Figure 4 shows equally implausible World Oil fluctuations for the United Kingdom. Figure 5 shows the other anomalies in Norway, where the data is in the public domain, and Figure 6 illustrates Iraq and Saudi Arabia where large spurious increases were announced for quota reasons.

Figure 3. FSU : Comparison of different data sets

Fig 3

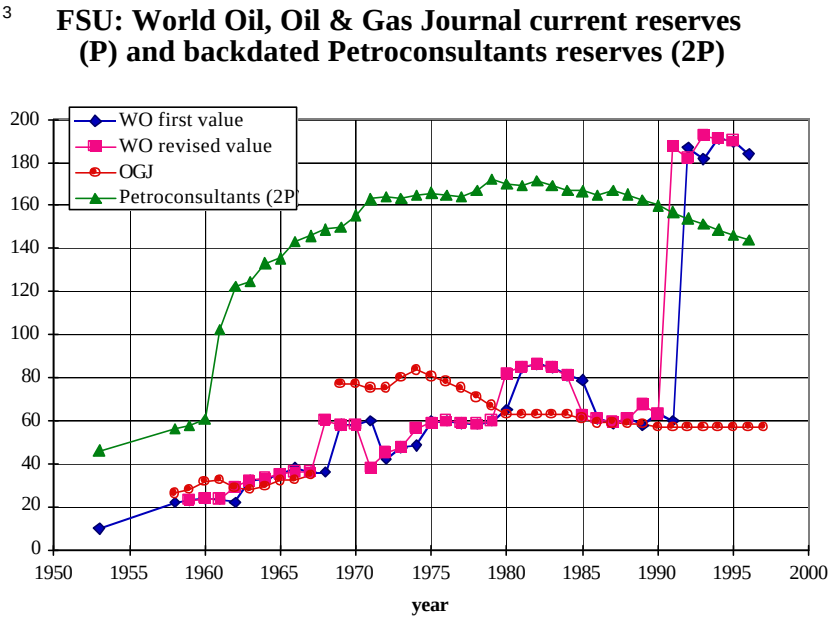


Figure 4 UK : Comparison of different data sets

Fig 4

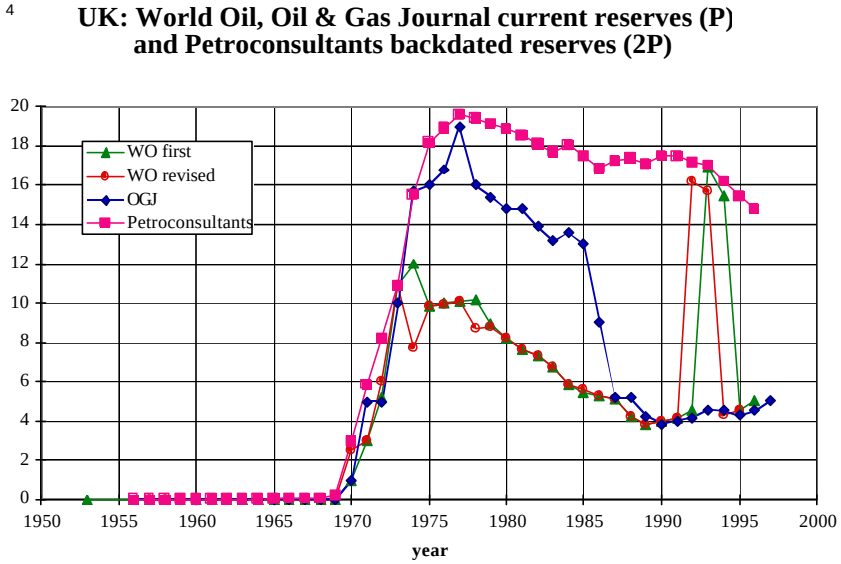


Figure 5 Norway : Comparison of different data sets

Fig 5

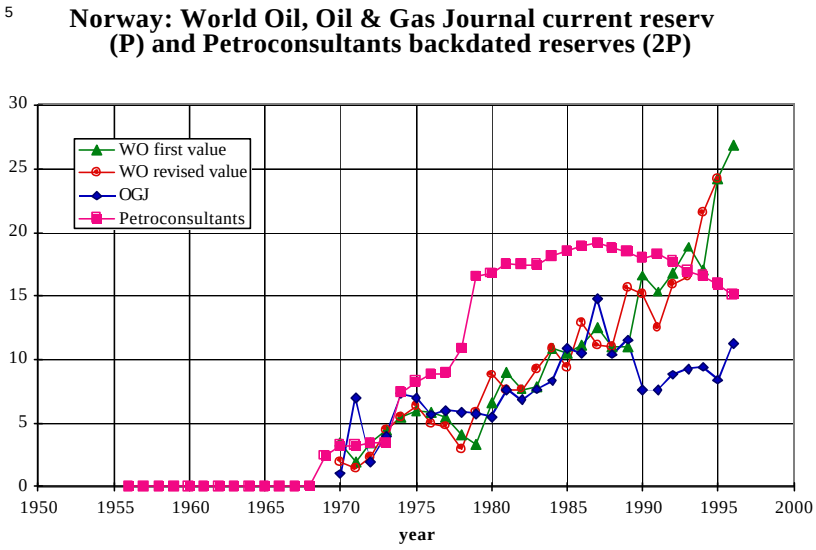


Figure 6 Iraq and Saudi Arabia : Comparison of different data sets

Fig 6

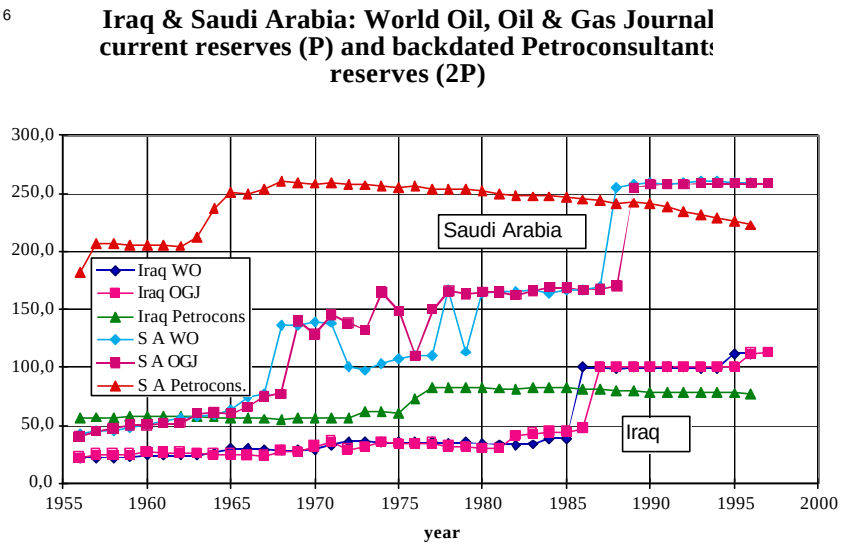


Figure 7 Trends of World data

Fig 7

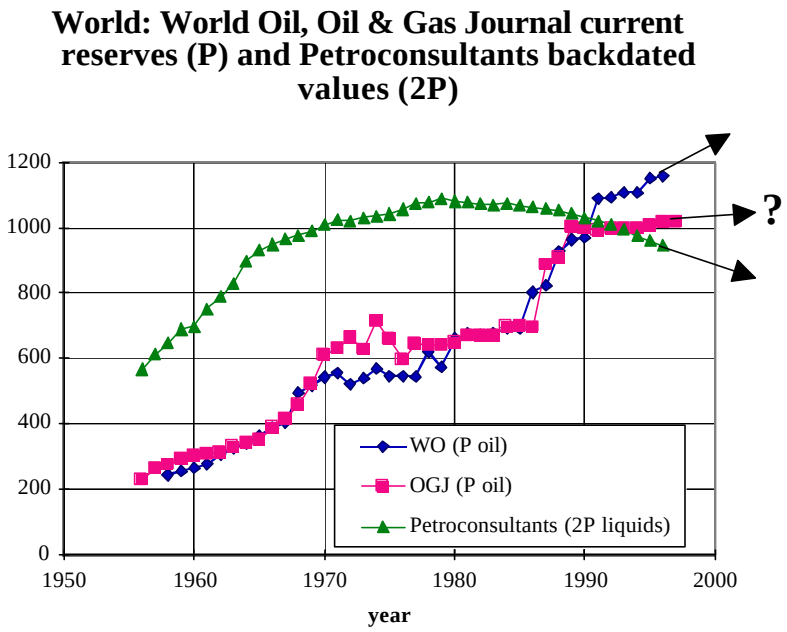


Figure 7 illustrates the three data sets for the world as a whole with the trends extrapolated. World Oil shows a rising trend; the Oil & Gas Journal shows a stable trend; and Petroconsultants, which records properly backdated Proved + Probable (P50) reserves, shows a plausible decline, remembering the production inexorably consumes reserves unless matched by new discovery. With the current discovery rate down to about 6 Gb/a, about a quarter of consumption, it can be no surprise that the reserves are declining.

Reserves reported by companies

Many companies provide reserve data on the Internet, and much useful information can be gleaned from analysing the reports in detail. The data are shown on the following table. It is revealing that Exxon admits that only 30% of its discoveries are booked as Proved, which explains why it attributes only 7% of the increase over the period quoted to "Improved Oil Recovery". This contrasts with Mobil which recognizes only Proved yet attributes 44% to IOR. Since all these companies have comparable worldwide positions and apply similar technological skills, the wide range in reporting procedure is truly remarkable, and a cause for serious concern.

http://www.	Proved oil/ Proved+Unproved	% Revision	% IOR	% Extension & Discovery	Period
exxon.com	0,3	48	7	44	87-96
total.com	0,8	23	0	78	91-95
saga.no	0,7	?	?	?	95-97
npd.no	0,8	?	?	?	96
statoil.com/english	only 2P	41	0	59	94-97
shell.com	1	41	20	39	92-96
bp.com	1	13	24	63	93-97
mobil.com	1	22	44	34	92-96
arco.com	1	52	5	43	95-97
bhp.com.au	1	66	0	34	95-97
chevron.com	1	?	?	?	
texaco.com	1	?	?	?	
amoco.com	1	?	?	?	
hydro.com	1	?	?	?	
conoco.com	1	?	?	?	
elf.fr	?	?	?	?	
eia.doe.gov	1	64	0	36	85-96

In the United States, the data show that the reserves, although reported as Proved (which should be with a probability of 90%), are in fact closer to Proved + Probable with only a probability of about 65% of being higher than indicated, which corresponds to the Mode or Most Likely case (see Figure 1). In effect, the DOE/IEA Annual Reports for 1995 and 1996 give the additions to Proved Reserves over the period 1977-1996:

US Proved Reserves of crude oil in Mb

Category	1977-1995 Average	% Additions	1996 Alaska	1996 48 States	1996 US
Adjustments	209	10%	3	172	175
Revisions increase	2522	116%	69	1654	1723
Revisions decrease	1348	-62%	-60	-926	-986
sub total Adjustments & Revisions	1383	64%	12	900	912
Extensions	508	23%	64	479	543
New Field Discoveries	137	6%	128	115	243

New Reservoirs Discoveries in old fields	139	6%	0	141	141
Sub total Extensions &Discoveries	785	36%	192	735	927
Total= Additions	2168	100%	204	1635	1839

US Proved reserves of gas in Gcf

Category	1986-1996 Average	% Additions	1988	1996	% Additions
Adjustments	1984	13%	2193	3785	14%
Revisions increase	20211	136%	23367	17132	64%
Revisions decrease	17162	-115%	38427	13046	49%
sub total Adjustments & Revisions	5033	34%	-12867	7871	29%
Extensions	6287	42%	6803	1451	5%
New Field Discoveries	1335	9%	1638	3990	15%
New Reservoirs Discoveries in old fields	2188	15%	1909	12318	52%
Sub total Extensions & Discoveries	9810	66%	10305	18861	71%
Total= Additions	14843	100%	-2562	26732	100%

US Proved Reserves of Condensate & NGL in Mb

Category	1986-1996 Average	% Additions	1996	% Additions
Adjustments	138	20%	474	44%
Revisions increase	918	134%	844	78%
Revisions decrease	702	-102%	669	-62%
sub total Adjustments & Revisions	354	52%	649	60%
Extensions	284	41%	451	42%
New Field Discoveries	43	6%	65	6%
New Reservoirs Discoveries in old fields	76	11%	109	10%
sub total Extensions & Discoveries	403	59%	625	58%
Total= Additions	687	100%	1076	100%

For more than twenty years, positive revisions to US oil reserves have exceeded negative revisions by a factor of two, giving an overall increase of 65 % (2522 out of 2522+1348). In addition, there has been an increase of 24% from field extensions; 6% from new reservoirs in old fields ; and only 6% from new discovery. In 1996, Alaska had as much negative revision as positive.

Gas revisions have been on average equally up as down over an eleven year period, due to a 25 Tcf downward revision of Alaskan North Slope gas in 1988. Prudhoe Bay's gas had apparently been declared as Proved initially but had to be downgraded when a proposed gasline did not materialise. In 1996, there were upward revisions of 8.4 Tcf and downward revisions of 6.7 Tcf,

meaning that only 55% of the revisions were positive. It demonstrates that in reality what is classed as Proved in fact has a probability not of 90% but of 54% (20 211 out of 20 211+17 162). In the case of Natural Gas Liquids, the revisions both in 1996 and over eleven preceding years were also only 57% positive (918 out of 918+702).

Grace (9) has commented on the US resources reported by the DOI

Resource	Onshore liq. Gb	Offshore liq. Gb	Total liq. Gb	Onshore gas Tcf	Offshore gas Tcf	Total gas Tcf
Cum. production	162	10	172	764	113	877
Reserves	26	3	29	135	28	163
Expected growth	73	4	77	322	39	361
Estimated undiscovered	37	46	83	259	268	527
Ultimate resource	298	63	361	1480	448	1928
% growth/discovered	39%	31%	38%	36%	28%	35%
% Undisc./Ultimate	12%	73%	23%	18%	60%	27%

At current discovery rates, it would take 615 years to find the 83 Gb of liquids and 400 years to find the 527 Tcf, which is hardly plausible even if 11Gb of liquids and 361 Tcf are attributed to what is called "Reserve Growth". This conclusion has been confirmed by the USGS when it comments "The US consumes 7 Mb/d more than it produces..... Last year in the entire United States less than four days of oil supply was found by new discoveries" (10)

The USGS has adopted a model whereby "field growth" one barrel onshore becomes seven barrels fifty years later. But the MMS has recently concluded that the factor is only 1 : 4 for the offshore.

The Use of the term Proved

Every company whose shares are traded on the American Stock Exchange has to respect its regulations in declaring reserves, but for internal purposes can use better methods of definition. The requirement imposed by the SEC to omit reserves in the Probable and Possible status, means that so-called Proved reserves increase over time as an artifact of reporting, and not from discovery or the application of new technology. It is clearly a very unsatisfactory system that has far outlived its purpose.

There is no consensus on how to define reserves because everyone in practice wants to retain the flexibility to report them in whatever fashion serves his purpose. In particular, American consultants, such as Scott Hickman (11), prefer to retain the "determinist" approach whereby Proved Reserves, which are supposed to have a 90% probability that the actual number is greater than quoted, in reality have a probability of around 65%. They themselves have a very limited understanding of modern statistical theory. The term "reasonable certainty", which is used to define Proved status, can mean anything with a probability of between 50% and 90%, and twenty years of US experience shows in fact that it has a probability of about 65%.That US "proved" oil reserve addition were split 65% (and gas and gas liquids 55%) increase and 35% decrease, demonstrates that the Proved status does not in reality have a 90% probability.

Outside the United States, most companies prefer the probabilistic method, using P90, P50 and P10 values to generate a mean or expected value. Also, the US government agencies, which are not bound by SEC regulations, avoid reference to Proved Reserves.
It is important to note that the sum of proved reserves of individual fields does not correspond to the proved reserves of a country or basin. It is also worth pointing out that quoting reserves to six significant numbers as is commonly done is misleading when the reserve estimates themselves rarely have an accuracy of better than ten percent and two significant numbers are enough.

In short, what is termed Proved for reporting purposes is close to Proved + Probable in a technical sense.

Examples of Reserve Revision by Field

North Sea

A 1998 study by the Department of Trade & Industry (1998) on UK oilfields shows both positive and negative revisions over the period 1986-1996 as given in the following table. The corresponding revisions as based on SPE/WPC guidelines is given in parenthesis.

Reserves	No. of fields	Positive Revision	No Revision	Negative Revision
3P >10 Mboe	144	70 (14)	7	72
2P>10 Mboe	86	46 (40)	5	35 (40)
P>10 Mboe	58	44	4	10 (5)
2P>50 Mboe	66	33 (31)	4	29 (31)

A number of observations may be made:

The low number of Proved (P) estimates shows that the US system is not applied in the North Sea;

The Proved + Probable + Possible (3P) estimates are too low, having been exceeded 70 times rather than the 14 times indicated by definition

The Proved (P) estimates are too high, having failed 10 times rather than 5 as indicated by definition

The Proved + Probable (2P) estimates are close to a 50% probability especially in the case of the larger fields (>50 Mboe)

Another study by BP (12) shows that there have been as many positive as negative revisions, and that the simple fields tend to be underestimated whereas the more complex ones are overestimated. A Statoil study (13) shows that the revision of Norwegian fields have been more or less random.

The case of the Forties Field is illustrated in Figures 8a and 8b, based on BP's data. Figure 8a shows the growth of cumulative production and published reserves. It is evident that the 1986 reserve estimate was too close to Cumulative Production and was due for upward revision, irrespective of the construction of a fifth platform and the application of gas lift in 1987.. Figure 8b shows annual production as a function of Cumulative Production with a straight decline trend demonstrating that the additional platform and gas lift temporarily increased production without affecting the reserves. It is a compelling argument against the widely promoted view that technology increases reserves.

Two billion barrels of reserves were reported in 1986 when it was already evident that they should be 2.7 Gb. (They were still understated in 1995 at 2.5 Gb).

Figure 8a Forties Field: Growth of Cumulative Production and Reserves

Fig 8a

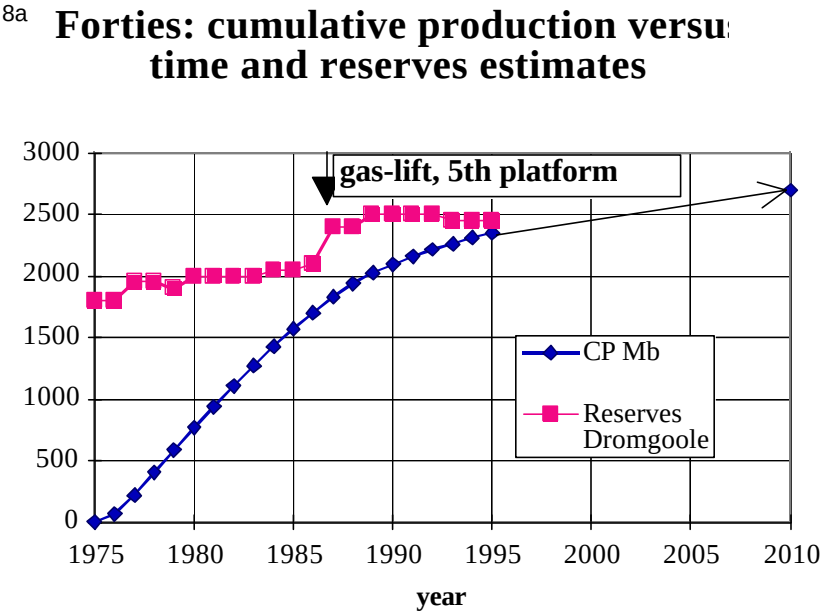
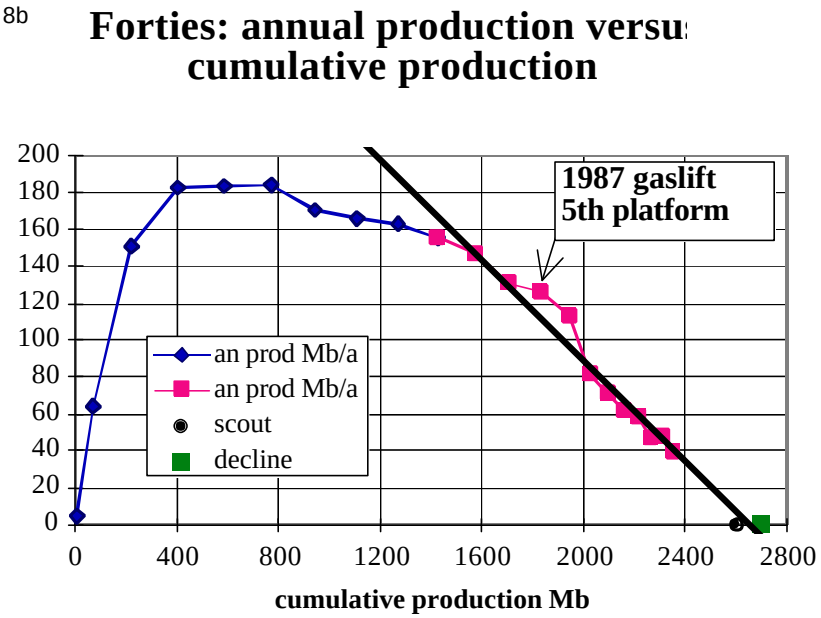


Figure 8b Forties Field: Annual Production versus Cumulative Production

Fig 8b



The United States

The production data given by the Oil & Gas Journal (last January issue) for the major US oilfields (>100 Mb) since 1960 may be used to estimate ultimate recovery and to compare that with the reported reserves. These 300 fields represent less than one percent of all fields but contain 66% of the total reserves. Figure 9 shows the growth of reserves as a function of discovery date, and presents a beautiful example of a historical creaming curve (a form of logistic curve) interrupted only by the late opening of Alaska. The standard creaming curve displays the cumulative discoveries versus cumulative New Field Wildcats (when available) and usually is hyperbolic.

Figure 9 USA : Cumulative Discovery by Year (major oilfields)

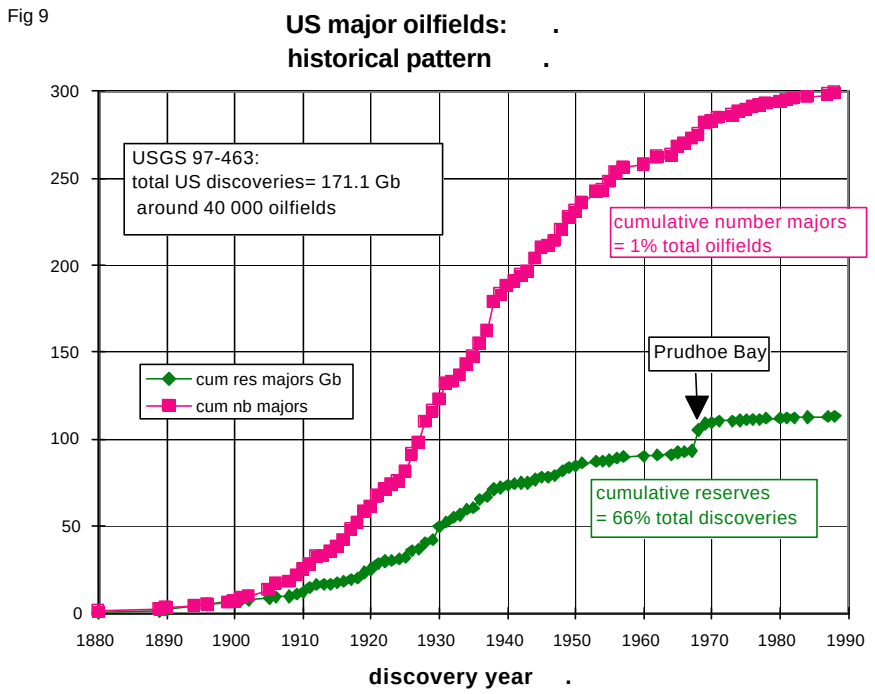
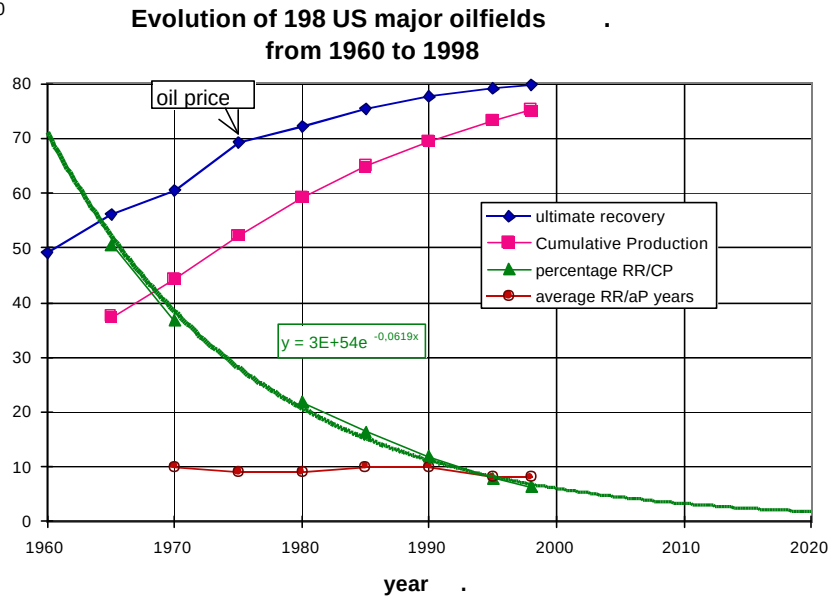


Figure 10 shows the evolution of 200 fields, on which there are continuous data, for the period 1960-1998. Cumulative production and reserves grew regularly save for an interruption in 1975, when the first oil shock caused a sudden increase in reported reserves. The percentage of remaining reserves to cumulative production shows that the United States will have depleted its reserves by around 2020 unless new provinces are found.

Figure 10 Evolution of US major oilfields

Fig 10



East Texas Field

Decline curves for East Texas and Wilmington, the two largest fields in the United States, are illustrated in Figures 11 and 12. The East Texas field with a 380 API at a depth of about 1100 m was found in 1930. Its reserves were estimated at 6 Gb in 1970, even though Cumulative Production was then close to 4 Gb. Its reserves were revised downwards to 5.4 Gb in 1992. Figure 11a shows Cumulative Production and ultimate recovery since 1970. Figure 11b shows annual production as a function of Cumulative Production with two very clear decline trends. The first was at 5%/a lasting until 1993, and the second from that date onwards is at 10%/a despite the possiblity of applying modern technology. Figure 11c shows the number of wells, which have declined regularly since 1960, together with daily production per well which has also declined regularly since 1975. It also shows the Reserve to Production Ratio which was high prior to 1992 but now stands at about five years, close to the US average. An extrapolation of the number of wells and production per well over the next twenty years indicates that there is about 110 Mb yet-to-produce, which is consistent with the decline curve and the Oil & Gas Journal data

Figure 11a East Texas Field: Cumulative Reserves and Production

Fig 11a

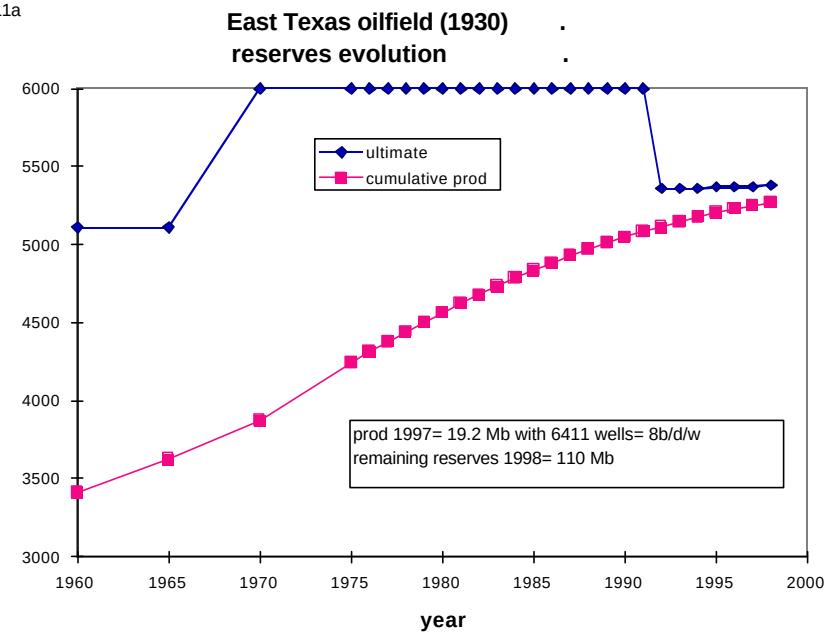


Figure 11b East Texas Field : Annual Production versus Cumulative Production

Fig 11b

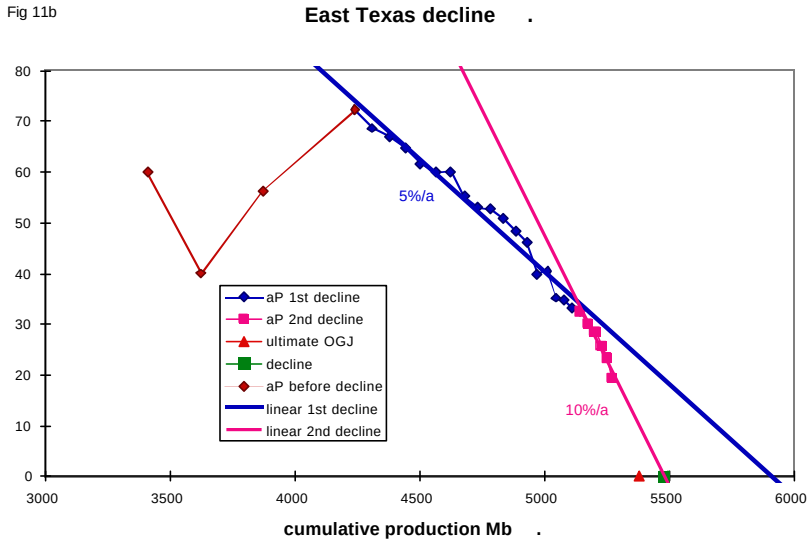
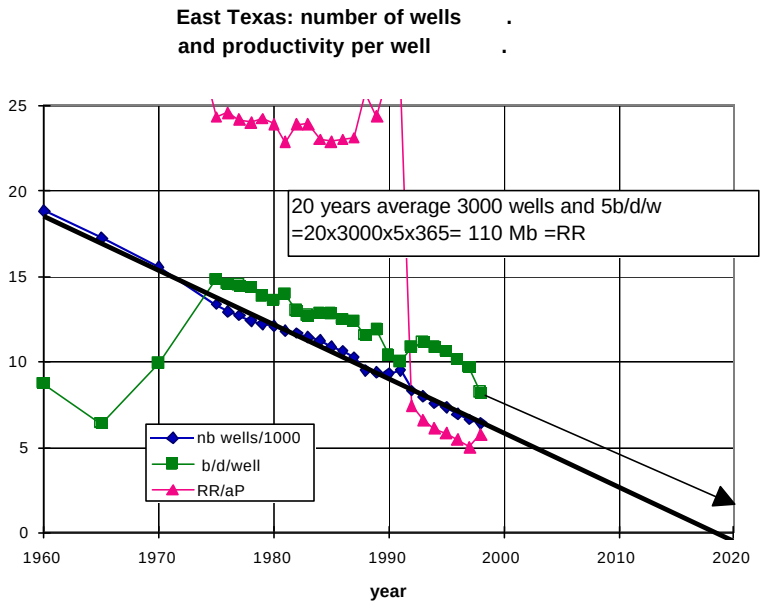


Figure 11c East Texas Field : Number of wells, daily production



Wilmington Field

The Wilmington Field was found in the Los Angeles Basin in 1932. It contains oil ranging in gravity from 120API to 340API at a depth of 600 - 1200m and has an estimated 8.8 Gb of oil-in-place. Figure 12a shows that the reserves had increased regularly to 2.8 Gb by 1985. Figure 12b shows a constant decline rate since 1970 also pointing to an Ultimate of 2.8 Gb. This decline rate has been constant despite the application of various new approaches, including water injection and unitization in 1960; steam injection from 1980 and horizontal drilling since 1993. (The extraction of oil has led to a surface subsidence of as much as 8 m by 1969). Enhanced recovery techniques have been tried for forty years without much success, and a current project sponsored by the Department of Energy has the objective of extracting no more than 28 Mb (0.3% of the Oil-in-Place). It is a sanguine commentary on the contribution that EOR can make to world supply.

Figure 12a: Wilmington Field: Cumulative Reserves and Production

Fig 12a

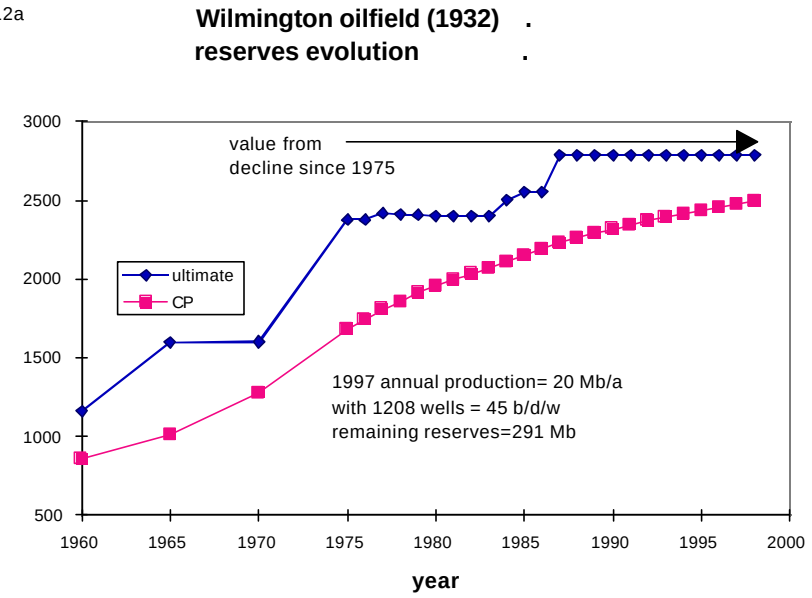


Figure 12b: Wilmington Field: Annual Production versus Cumulative Production

Fig 12b

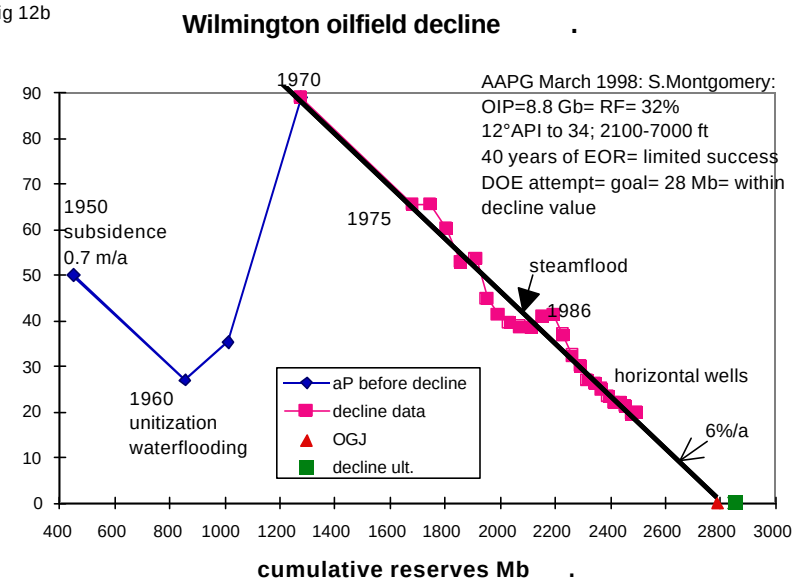
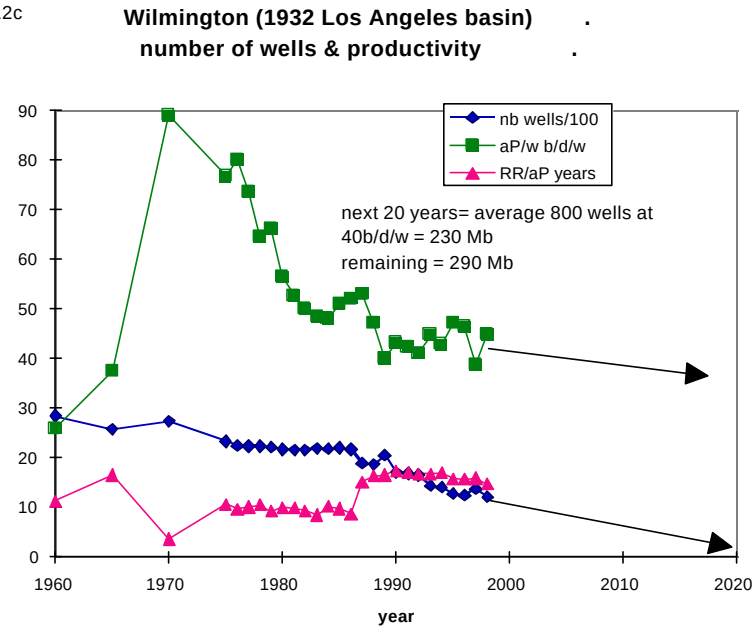


Figure 12c shows an extrapolation of the number of wells and productivity per well over twenty years, pointing to the extraction of 230 Mb, close the Oil & Gas Journal estimate of remaining reserves at 290 Mb.

Figure 12c: Wilmington Field: Number of wells, daily production

Fig 12c



We have studied a number of other large fields in several different basins. Their combined Cumulative Production is 13.7 Gb, their reported Ultimate is 14.3 Gb and their Ultimate based on decline analysis is 14.7 Gb. It suggests that the Oil & Gas numbers are 0.35 Gb too low, that is to say, 2.5% for the Ultimate and 50% for the remaining reserves. This 2.5% confounds the Department of Energy's estimate that a 38% addition will come from so-called reserve growth for the country as a whole. The two heavy oil fields, which should be treated as non-conventional, are Midway-Sunset with 2.8 Gb of 180 API oil and Kern River with 2 Gb of 13o API oil and do not indicate decline rates capable of extrapolation. They have accordingly have been ignored. New technology may prove effective for such non-conventional fields.

The World outside North America

Petroconsultants' records for 1993-1997

The Petroconsultants' database is a dynamic one, subject to continuous revision as more information come in. It is accordingly difficult to make comparisons over time without accessing the historic backup files. Instead, we may consult our two reports, based on 1993 and 1997 data (15) for a number of petroleum systems. The comparison over this four-year interval is mainly straightforward, although a few fields have changed their names or have been removed as unconfirmed discoveries.

The number of variations and the volumes involved are given in the following table

Oilfields in Petroleum Systems: variations from 1993 to 1997

Petroleum System	No. of fields	number of changes			Reserves change Mb	
		(+)	0	(-)	(+)	(-)

Niger delta	583	86	399	98	3299	2071
Arabo-Iranian	444	116	247	81	53063	43473
North Sea grabens	399	98	211	90	6029	2190
Sirte	223	23	174	26	4687	1317
Timan-Pechora	141	10	123	8	69	239
Paris	75	8	40	27	3	17
Saharian Triassic	70	14	51	5	696	265
Gippsland	35	9	23	3	200	10
total	1970	364	1268	338	68046	49582
% No. of fields	100%	18%	64%	17%		
% change in reserves					58%	42%
Giants	347	105	176	66	68398	65851
% No. of fields	100%	30%	51%	19%		
% change in reserves					51%	49%

Out of a total of almost 2000 fields, the 18% with positive revisions were almost exactly matched by 17% with negative revisions, but in terms of reserves there was a wider range with 58% up and 42% down. In regard to the giant fields (>500 Mb) the number with positive revisions is 30% compared with 19% for those with negative revisions, but the change in reserve volume is barely changed (51% up, 49% down)

It is interesting to note that the Niger Delta exhibits variations that are much influenced by the status of production. Most of the positive revisions both for number and volume apply to fields in production, whereas most of the negative revisions apply to discoveries awaiting development.

Changes in Niger delta from 1993 to 1997 versus production status

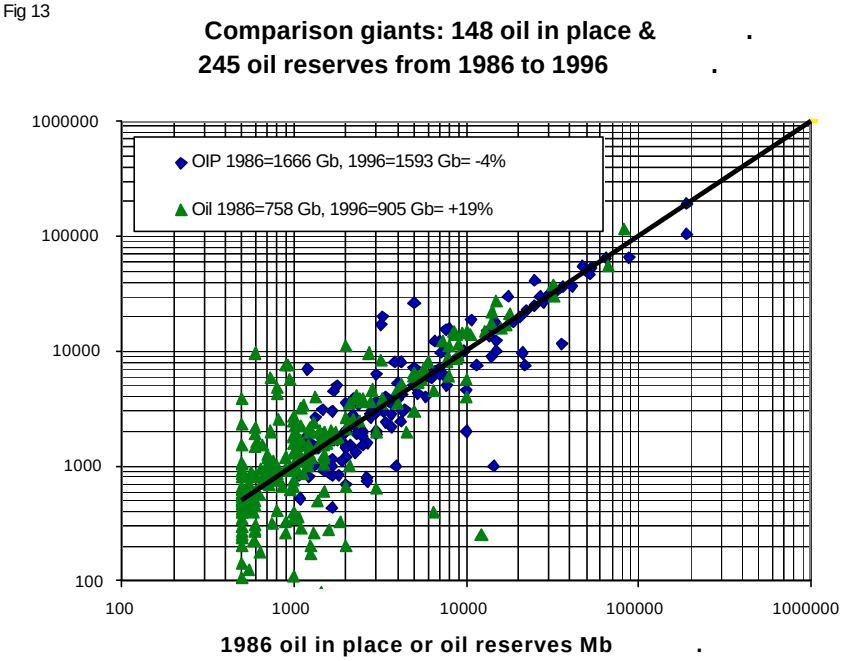
Production	Number	97-93	Change	no Change		
Status	of fields	Mb	reserves %	No.	nb %	category
Producing	225	1416	115%	95	24%	42%
Developing	19	148	12%	11	3%	58%
Discovery	339	-335	-27%	293	73%	86%
Total	583	1228	100%	399	100%	68%

Comparison of 1986 Mobil and 1996 Petroconsultants reports

Roadifer of Mobil published in 1987 a list of giant fields as of the end of the preceding year, giving reserves and oil-in-place. Figure 13 compares this data set with that furnished by Petroconsultants in 1996 in respect of the oil-in-place for 148 fields and the reserves for 245 fields. There is a wide range: reserves show a 19% increase whereas oil-in-place shows a 4% decrease. It shows that oil-in-place is not well known, confirming that the concept of recovery factor has little practical meaning.

Figure 13 1986 and 1996 data compared

Fig 13



Reserves in relation to the status of production

As shown in the following table, as many as 44% of reported discoveries that are not yet in production, which is a surprisingly high number. But in terms of reserves the amount reduces to 8% for oil and 19% for gas, suggesting that it is mainly small fields that are not yet in production.

World outside North America: Production status

	Producing	In Development	Discovery	Total
Number of fields	8900	745	7520	17165
% number	52%	4%	44%	100%
Oil reserves Gb	1251	83	115	1449
% oil reserves	86%	6%	8%	100%
Gas reserves Tcf	4035	724	1117	5876
%gas reserves	69%	12%	19%	100%

Synthesis

There are as many negative as positive revisions but globally the revision of reserves has been positive, by about 0.5% per year for oil (less for giant fields) and 2% for gas. But the number of fields awaiting development, which are presumably mainly small, may well reduce these numbers.

Comparison between reserves reported by Petroconsultants and those based on decline analysis

The production data in the Petroconsultants database is sufficient to allow the analysis of decline curves on a sample of large fields (>100 Mb). The results are given below. The greatest variation is in Russia, confirming the statements by Khalimov that the official reserves were exaggerated under the Soviet classification which ignored technological and economic factors. The decline curve for the Swing Producers of the Middle East has to be viewed with caution because these fields were not produced to capacity.
Decline analysis of the 528 fields evaluated showed that the estimated reserves are 80 Gb too high, namely 16% of the Ultimate and 42% of the Remaining Reserves. This is a significant number, remembering that the Yet-to-Find of conventional oil is estimated as less than 200 Gb.

Comparison of Petroconsultants reserve data and decline estimates

	No of	Estimated	Decline	Cum.	%.	%
	Fields	Reserves	Curve	Prod.	Ultimate	Remaining
		Gb	Gb	Gb		
Russia85	107	85	70	-20	-58	
Iran	14	61	52	33	-16 ?	-34 ?
Venezuela	45	53	47	38	-11	-39
Saudi Arabia	6	35	26	13	-24 ?	-39 ?
Libya	19	28	20	14	-30	-60
Iraq	5	22	18	17	-17 ?	-73 ?
Kuwait	4	21	4	3	-81 ?	-94 ?
Nigeria	57	17	15	10	-8	-21
Mexico	36	14	12	10	-16	-49
Algeria	13	13	15	8	11	32
U.K.	23	13	13	11	4	31
Indonesia	30	12	13	11	7	50
Other <10Gb	191	83	81	60	-2	-8
Total	528	478	401	298	-16	-42

Comparison of USGS estimates since 1981

In 1997, the USGS published two contradictory documents on the Internet (16). One recognizes the 1994 study by Masters, the other the successor study by Ahlbrandt for 1997. As much as 200 Gb has disappeared from the world numbers in the latter study.

USGS Report	145-97	145-97	145-97	145-97	97-463
Ref. Date	1/01/81	1/01/85	1/01/90	1/01/93	1995-6
	oil Gb	oil Gb	oil Gb	oil Gb	oil Gb
Cum. production.	445	524	629	699	
Discovered	724	795	1053	1103	
Total discovered	1169	1319	1682	1802	1608
Undiscovered	550	425	489	471	?
Total	1719	1744	2171	2273	?

Difference on total oil discovered					-194 Gb
USGS Rreport	145-97	145-97	145-97	97-463	97-463
Ref Date	1/01/85	1/01/90	1/01/93	1995-96	1995-96
	gas Gboe	gas Gboe	gas Gboe	gas Gboe	NGL Gb
Cum. production	196	266	292		
Discovered	651	750	856		
Total discovered	847	1016	1148	1126	109
Undiscovered	700	736	780	?	?
Total	1547	1752	1928	?	?
Difference on total gas discovered				-22 Gboe	

The USGS World Energy Programme, directed by Tom Ahlbrandt in Denver, is an ambitious project to evaluate world resources on the basis of petroleum systems as identified by a group of oil companies (17) and government agencies who plan to have quaterly meetings in 1998. The plan to use the databases of Petroconsultants and Dwights and choose a standard methodology. This is the same approach already followed by Petroconsultants in its Strategic Assessment Series of Reports.

Future Production

The world's endowment of oil comprises at any particular date the Cumulative Production, the Reserves and the Yet-to-Find, adding up to the Ultimate Recovery. The Yet-to-Produce is the sum of the Reserves and the Yet-to-Find.

M.King Hubbert of the USGS predicted in 1957 that peak production would come at the midpoint of depletion and that the production curve would be symmetrical. He was much derided at the time because individual fields tend to have an asymmetrical depletion, skewed to the left. But Hubbert's views were amply vindicated when production in the US-48 peaked in 1970, following a symmetrical curve. The explanation for the symmetry is provided by a law of statistics "The Central Limit Theorem" which states that the sum of many asymmetrical distributions becomes symmetrical. Furthermore, discovery is cyclical and production mirrors discovery after a time-lag.

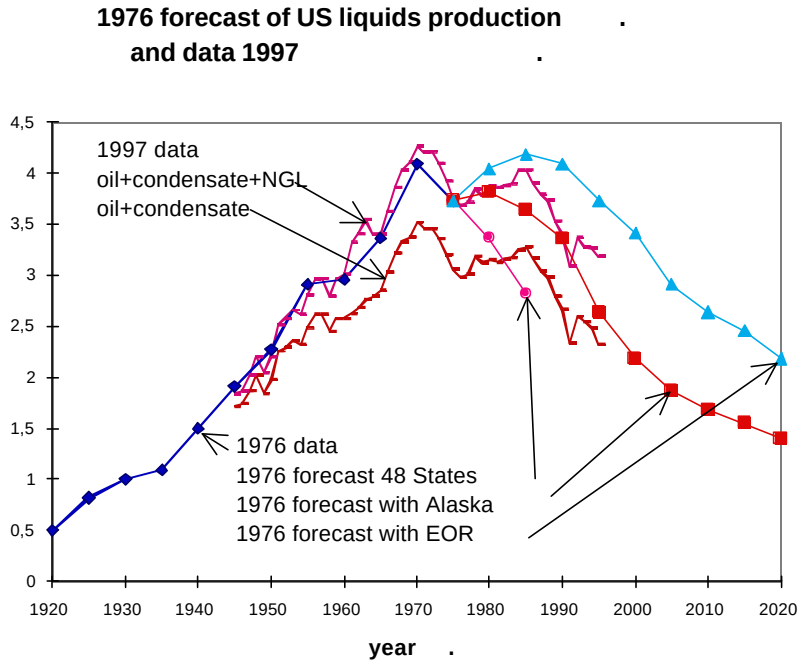
A single Hubbert curve applies well in countries having a large population of fields and basins, but in other cases it is better to model discovery and production with multiple curves, each reflecting different cycles (Laherrère 1996). Al-Jarri & Startzman have modeled the world prouction by country with Hubbert curves and found an Ultimate of 1760 Gb.

1976 US Forecast

The United States shows a single cycle with respect to the Lower 48 States and a subsidiary cycle for Alaska. In 1976, Hartnett published a forecast of oil and gas production for the United States anticipating cycles for Alaska and the proceeds of Enhanced Oil Recovery. There was a belief

then, as now, that new technologies, such as 3D seismic and steam injection would have a great impact. Figure 14 demonstrates that the hopes for EOR failed to materialize.

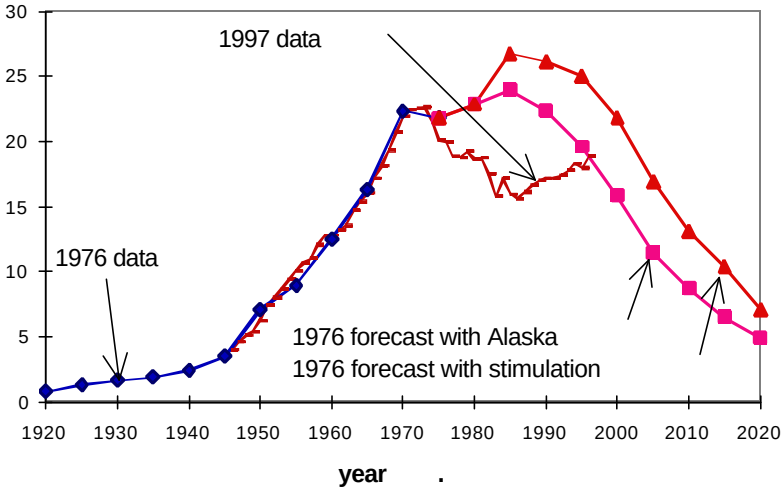
Figure 14 1976 Forecasts for EOR



The 1976 forecast (Figure 15) for gas assumed a contribution from Alaska that was not realised. Thus, the limited success of technological stimulation failed to compensate for the loss of Alaskan gas. It is much more difficult to forecast gas production than is the case for oil. Technology can have an important impact on non-conventional gas, despite the disappointing results of application to conventional types.

Figure 15 1976 Gas Forecasts not realised

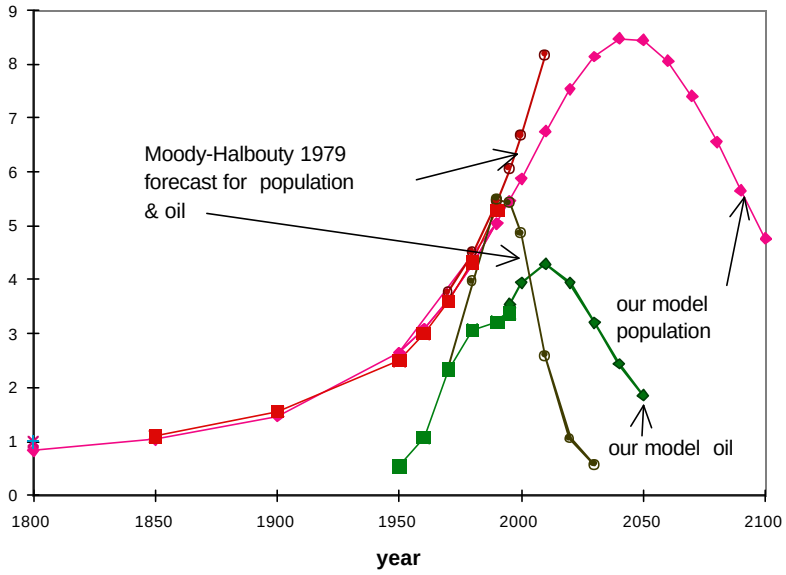
Fig 15 **1976 forecasts of US gas production and 1997 data**



Moody and Halbouty, two well known oilmen, presented forecasts of oil production and population at the World Petroleum Congress of 1979, as shown in Figure 16. They anticipated a production peak of 38 Gb/a in 1990 which was reasonable in resource terms, save that it failed to take into account the effects of the oil shocks of the 1970s which cut demand, such that 1979 production was not surpassed for fifteen years. So far as their population forecast is concerned, they assume exponential growth, which has not been experienced since.

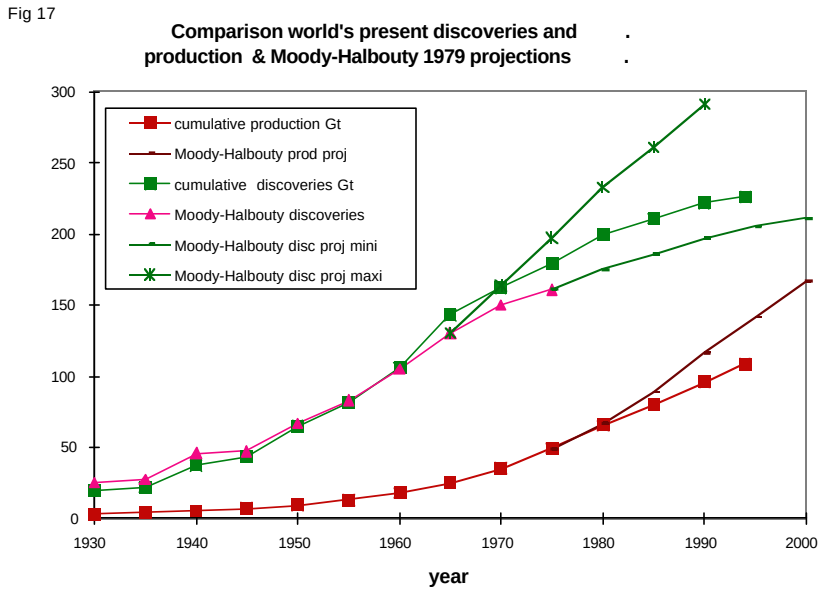
Figure 16 1979 Forecasts of oil and population

Fig 16 **1979 forecast for oil production & world population and our forecast**



The Halbouty-Moody forecasts are superimposed in Figure 17 on the discovery and production trends. The forecast of cumulative discovery is placed within the maxi- and mini- curves. The reality is that the 1965-74 estimates were too low, whereas the subsequent ones were valid but closer to the low end of the range of uncertainty. The curve of Cumulative Production is too high because the impact of the oil shocks was under-estimated.

Figure 17 1979 Forecasts of discovery and production

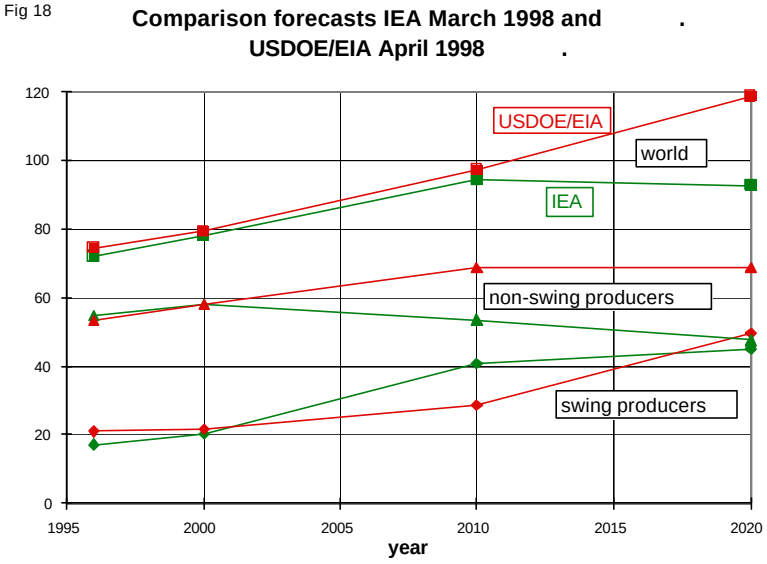


Comparison of IEA and DOE forecasts

The International Energy Agency (IEA) submitted a report to the G8 Ministers on March 31st 1998 showing a peak in oil production by around 2010. By contrast, the DOE forecast reaches a similar level by 2010 but continues to grow thereafter (Figure 18). Even more striking is the difference in the estimates for the non-swing producers (world outside the Persian Gulf) which peak in 2000 according to the IEA and in 2020 according to the DOE.

Figure 18 IEA and DOE Forecasts

Fig 18

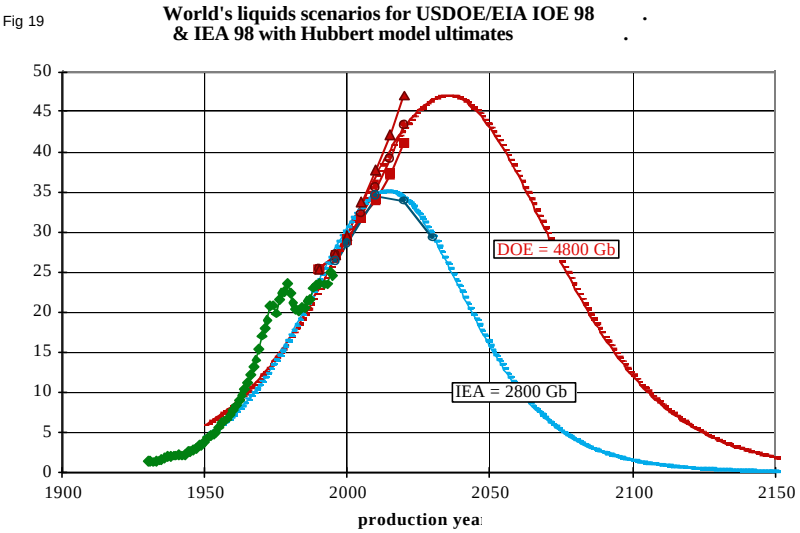


The IEA forecasts a shortfall of 17 Mb/d by 2020, which it euphemistically suggests will be made up by "unidentified unconventional". Considering that most heavy oils and tarsands lie at or close to the surface, it is indeed unrealistic to assume that more deposits remain to be identified.

Figure 19 shows the extrapolation of the IEA and DOE forecasts to depletion using Hubbert curves (18) . The DOE forecast implies a minimum Ultimate of 4700 Gb, which is a number far in excess of all known conventional and non-conventional reserves (19), and is absolutely implausible. The IEA forecast implies an Ultimate of 2700 Gb.

Figure 19 Ultimates needed for IEA & DOE/EIA forecasts

Fig 19



A recent study published by the Petroleum Economist (20) gives the following estimates

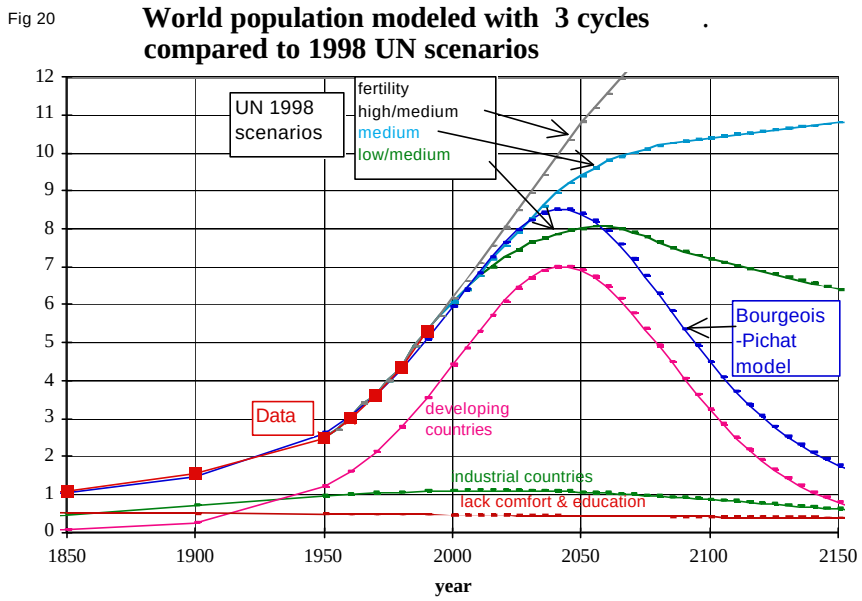
Gb	low	mean	high
Conventional oil	1700	1800	2200
Conventional gas liquids	200	250	400
Non-conventional liquids	300	700	1000
Total	2300	2750	4000

Population

It is obvious that world oil production will affect and be affected by population levels, and it is accordingly instructive to consider population in relation to oil.

In 1988 Bourgeois-Pichat (21) modelled the growth of world population with the help of two symmetrical curves (similar to Hubbert curves). The first referred to industrial countries with a fertility rate of 1.7, which is below the replacement level of 2.1, and it peaked around 2010. The second related to developing countries where the fall in fertility is delayed. In Figure 20 we have added a third curve for a notional basic simple population, such as represented to-day by for example the descendants of the once glorious Maya civilization. Also shown is the recent UN forecast (February 1998).

Figure 20: World population model and UN scenarios



UN forecasts for the next fifty years have consistently reduced since 1990 the estimated size and date of peak. World population growth as a percentage of total population peaked in 1964 at 2.1%/a and is now down to 1.4%/a ; and in absolute terms peaked in 1990 at 90 million.

Date of Forecast	Average forecast for 2025 in millions
1980	8195

1982	8177
1990	8504
1994	8294
1998	7900

Conclusions

The size of the reserves of a field is uncertain, but the range of uncertainty declines as the field is produced. This uncertainty must be expressed by quoting a range of estimates, either stated or implicit. By using a single number without specifying its position in the range, the author can express whatever value meets his purpose.

The regulations of the Securities and Exchange Commission in the United States were designed to protect investors. By rejecting, the Proved and Probable categories, they lead to the understatement of reserves, which accordingly are subject to upward revision over time. The new classification proposed by the SPE/WPC is a compromise that scarcely represents an improvement. The only solution is to persuade the SEC to update its requirements, and discussions to this end are in progress. In reality, lax definition is found attractive to many vested interests. It is of no particular consequence for normal financial reporting, but is a serious obstacle to studies of future production.

The apparent "field growth" is an artifact of reporting due to the unsatisfactory procedures, and is not due to technological advances as is often claimed.

Internally, most companies do use probabilistic methods in economic studies, although the correct theoretical procedures are not always applied. To be statistically correct, it is necessary to use the mean or "expected value". Reported reserves of countries range over a factor of one to three, and are often quoted with a precision that masks their true uncertainty, which is in the order of 10%. US reserve estimates already include provision for the impact of technological advances save in the case of non-conventional resources.
Estimates of Proved + Probable reserves of oil show as many positive as negative reserve revisions, but overall there has been a slight upward revision of initial reserves of about 0.5% per year, but less in the case of giant fields. It is mainly due to the over-estimation of small and difficult fields (fear to be rejected) and the under-estimation of the large and simple fields (fear to appear too optimistic). The increase in reserves of about 5% over ten years has to be offset against the inclusion of numerous discoveries (44% of the fields by number and 8% by reserves) that fail to be developed because they are marginal or unsubstantiated. A comparison between reported reserves and the evidence of decline curve analysis shows that reserves are overstated, especially in the FSU.
Estimates of Ultimate recovery are of little interest except when used as a basis for forecasting production. The estimates of oil production by the DOE and the IEA differ significantly. The DOE estimate is unrealistic, implying an ultimate far in excess of both conventional and non-conventional reserves, foreseeable under any remotely plausible scenario.
World liquid production is likely to peak at latest around 2015-2020, whereas world population is likely to peak around 2040-2050. The alarmist forecasts of a population explosion are unlikely to

be realised, and accordingly the tensions associated with peak oil will be less severe than would have otherwise been the case. Mankind will always adapt itself to Nature, both having their limits.

Petroconsultants is thanked for permission to use their confidential database.
Dr C.J.Campbell assisted with the translation.

Sources of Data

US : Fields>100 Mb:	O&GJ Forecast Review each January 1960-1998
US Federal:	USDOI/MMS: Internet
Country and World:	O&GJ each December 1960-1997
	WO (World Oil) each August 1960-1997
	USDOE/EIA (Energy Information Agency): Internet reports
Norway:	NPD Internet
Companies:	Internet annual reports
World:	IEA (International Energy Agency) Internet
World outside N.America	Petroconsultants database (18 000 fields) 1993-1997

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NOTES

(1) Canadian Standing Committee on Reserve Definition
(2) Khalimov AAPG 1993 and WPC Budapest 1979
(3) Ross of Gaffney Cline & Associated 199! who incidentally himslef confuses the P50 and the mode (right only for normal distribution but wrong for any asymmetrical distribution)
(4) Oil & Gas Journal of June 10, 1985
(5) Oil & Gas Journal of August 13, 1990
(6) Bourdaire 1985 (estimate OIP from distribution of area, pay, porosity, water saturation, volume factor): mini= 95%, mode = most likely (near 65%), maxi= 5%; x= product minis; y= product modes; z= product maxis; m= 1/2 (ln x + ln z); -? 2 = 1/2 (ln x + ln z) -ln y = m-ln y; -Mini OIP = Exp (m-1.65?); -Mode OIP = y ; -Maxi OIP = Exp (m+1.65?); -Standard deviation = 1/3 (Maxi - Mini); -mean = 1/3 (mini + mode + maxi) = proven + 2/3 probable + 1/3 possible
(7) Capen 1993 : (estimate reserves from distribution of area, pay and recovery per acre-foot): m= 1/2 (ln X90 + ln X10); ? 2 = ((lnX90 - ln X10)/(2x1.28))2; -m(res) = m(area)+ m(pay) + m(rec); -? 2 (res) = ? 2 (area) + ? 2 (pay)+ ? 2 (rec); -Mean reserves = Exp (m+ ? 2 /2); -Mode = Exp (m+ ? 2); -R10 = Exp (m-1.28?); -R50 = Exp (m); -R90 = Exp (m+1.28?)
(8) Cossé 1993 "Basics of reservoir engineering" Editions Technip
(9) Grace 1998
(10) T.Ahlbrandt USGS Fact sheet FS-007-97 (http://energy.cr.usgs.gov/energy/worldenergy/WEvision.htm)
(11) President of the Society of Petroleum Engineers 1996-1997
(12) Dromgoole 1997
(13) Hermanrud 1996
(14) Montgomery S. AAPG March 1998
(15)see Strategic Assessments series http://www.petroconsultants.com/products/hydro_strat.htm
(16) USGS Fact Sheet 145-97 and USGS Open File Report 97-463 (http://energy.cr.usgs.gov/energy/worldenergy/OF97-463/97463.html)

(17) Exxon, Amoco, Mobil, Conoco, Phillips, Oryx, Shell, Petroconsultants, DOE/EIA
(18) Starztman of the University of Texas A&M
(19) Oil shales are to be excluded, being neither shale nor oil but immature hydrocarbon source rocks that have to be retorted to give up hydrocarbons. They have more in common with coal, which can be also used to produce liquid hydrocarbons, than oil
(20) Perrodon A., J.H.Laherrere & C.J.Campbell 1998 "The world's non-conventional oil and gas"
(21) Former director of INED Institut National des Etudes Demographiques