THE RELIABILITY OF OIL AND GAS RESERVES DATA

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1. Introduction

The economic prosperity of the best part of the last century was fuelled by an abundant supply of cheap oil-based energy. The size of the reserves left for the future is therefore an issue of critical importance. Although the technical assessment of reserves is fairly straightforward, the reporting of reserves is another matter, being surrounded by much misunderstanding and confusion. Stated simply, reserves may be defined as estimated future production from known fields. Such estimates are based primarily on the size of the resource in the ground, but economic and technological factors affect the amount that can be profitably extracted from a field prior to its abandonment.

Public data on reserves are atrociously unreliable. The industry has systematically under-reported the size of discovery for good commercial reasons, and several countries have exaggerated their reserves for political reasons. This article will explain the situation.

1.1 Units of Measurement

Oil and gas are variously reported under different units of measurement—barrels, cubic meters, tons, cubic feet, joules, kilowatt-hours, and Btu, or as various equivalents thereof. The absence of standard procedure and the lack of a central authority able to audit the reports mean that there is plenty of latitude, so that the oil- and gas-producing community may report reserves as best suits their purpose.

Oil is generally measured in terms of barrels, following US practice, but since it is not a recognized official unit of measurement, it has to be qualified in terms of gallons. A barrel of oil contains 42 US gallons, whereas a barrel of whale oil contains only 30. There is not even a standard abbreviation for barrel with b, B, or bbl being in common usage. In fact, bbl actually stands for blue barrel, a color used in early years to distinguish crude oil from the refined product that was sold in red barrels. The industry has generally failed to adopt the International System of Units (S.I.), although it is legally mandatory in all countries other than Liberia and Bangladesh. Canada and Australia, however, do report in metric terms (1b = 0.159 m^3; 1 m^3 = 6.3 b and 35 cf).

Crude oils have different specific gravities, which complicates the matter when amounts are quoted by weight (tons). Furthermore, the calorific value of oil and gas varies depending on their composition, with an equivalence of 1 boe (barrel of oil equivalent) being variously quoted as 6 or 5.6 kcf. In terms of value, an equivalent of 1 boe to 10 kcf (30$/b equals 3$/kcf) better reflects the fact the gas costs five to ten times more than oil to transport, and is perhaps the better practical equivalent.

The issue of equivalence becomes particularly important in connection with studies of energy consumption related to population or gross domestic production (GDP), on which demand forecasts are often based. It is important to take into account the efficiency of energy conversion, which varies greatly from country to country, variously considering either the input or the output. In France, for example, 1000 kWh equates with 0.22 tons of oil equivalent (toe), whereas the International Energy Agency (IEA) and World Energy Council (WEC) apply a general equivalence of only 0.08 toe.

Total Primary Energy Supply (TPES) is reported by the IEA in terms of oil equivalent (toe), based on all energy sources used. Again, there is little consistency between different sources. The IEA reports a total of 10 Gtoe for 1999, whereas the BP Statistical Review reports 8.5 Gtoe, omitting non-commercial biomass, which forms a large component of the energy used in less developed countries. The WEC omits the energy used by humans in the form of food, which is about 0.6 Gtoe: walking being treated differently from driving a car.

The following table shows the WEC estimate, illustrating, amongst other things, the wasteful use of energy in North America, where per capita consumption is about double that in Europe, although the respective standards of living are comparable.

Region	TPES Gtoe	Population G	TPES/capita toe
North America	2.5	0.31	8.1
Japan/Australia/New Zealand	0.7	0.15	4.7
West Europe	1.8	0.52	3.5
FSU	1.1	0.35	3.4
Middle East	0.4	0.17	2.4
Latin America	0.6	0.52	1.2
China	1.1	1.26	1
Other Asia	0.8	0.96	0.8
Africa	0.5	0.79	0.6
India	0.5	1	0.5
World for 2000	10	6.03	1.7

Table 1 : Total primary energy supply (usage) for selected countries and continents

1.2 What is Measured?

There is often obscurity as to what is actually being measured. Crude oil supply may include: condensate, a liquid, which condenses from gas at the wellhead; natural gas liquids (NGL), which are extracted from gas by processing in a plant; non-conventional oil, variously defined; synthetic oil produced by processing other oil; and even refinery gains.

Natural gas may, or may not, be associated with oil; and it may be gross or marketable, “wet or “dry, with or without any associated inert gases. Gas that is flared in the course of operations is commonly ignored. Even the US practice of referring colloquially to gasoline as “gas” may add to the confusion.

For example, world oil production is variously reported as 65 Mb/d when referring to crude oil only, and as 75 Mb/d when referring to all liquids. The BP Statistical Review includes synthetic oil from oil shales and tar-sands in the production statistics, but excludes it from the reserves. The amount of gas liquids ranges from 26% of the total liquids in the United States to only 6% in the world as a whole. It is accordingly difficult to determine how much of these different substances have been produced to date, never mind assessing their reserves or potential for future discovery.

1.3 Reporting Agencies

Many different agencies are involved in the reporting of oil and gas production and reserves. The oil companies, which are directly involved, hold the information confidential, except to the extent to which they are required to report it to stock exchanges and governments. These reporting requirements range widely, and generally provide the companies with much latitude. The principal sources of global data are:

- American Petroleum Institute (API);
- *Oil and Gas Journal*;
- *World Oil*;
- *Petroleum Intelligence Weekly* (PIW);
- NRG Associates;
- *Petroleum Review* (Institute of Petroleum, London);
- International Energy Agency;
- US Department of Energy.

The International Energy Agency was established by the OECD governments in the aftermath of the 1973 Oil Shock with a mandate to monitor supply and demand. But it has a questionable reputation, having been accused of contributing to the 1998 collapse of oil prices by mis-reporting the supply by 300–600 Mb, the so-called “missing barrels” (Simmons, 2000).

By far the most comprehensive database, which includes information on individual fields and exploration drilling, is the industry database, maintained by Petroconsultants in Geneva, which is now part of the IHS Group. It has compiled this information for many years on a consistent basis through contacts with the oil companies, who find it expedient to exchange information in this manner. The costs of maintaining the database are considerable, and access is normally out of reach for academic and other institutions operating on limited budgets.

A few government agencies report field data too, including the NPD in Norway, the DTI in the UK ("Brown Book"), the DOE/MMS in the United States, and the provincial governments of Canada. Detailed examination of this material, however, often reveals glaring anomalies; for example in the case of the MMS, which reports declines in cumulative production for certain fields which cannot be other than flawed.

2. Reserve Definition

There is much confusion over the meaning of the term "reserves" (or "remaining reserves"). Stated simply, they are the estimates, at any given reference date, which should be stated, of what remains to be produced from a known oilfield from that date to the date of abandonment. The term "recoverable reserves" is widely used, but is tautologous because reserves have to be recoverable to qualify as such. The size of a field (termed "ultimate recovery" or "initial reserves" or "original reserves" or often "reserves without date") is known precisely only on the day of its abandonment, being the total production extracted from it. Until then, some uncertainty inevitably attaches to the estimate of its reserves. The degree of uncertainty, however, diminishes over the life of a field as knowledge of its geology and production capability improves. The IEA gives a good general definition of reserves as "that portion of the resource that is believed to be recoverable with current or prospective technology and oil price" (World Energy Outlook, 1998).

To clarify the position we may define the key elements as follows:

- *Cumulative production* is the sum of production to the reference date;
- *Reserves* are the estimated amounts yet to be produced; and
- *Estimated ultimate recovery* (EUR) is the sum of cumulative production and reserves (the terms "original" or "initial reserves" are synonymous with EUR)

While there is naturally an implicit or stated range in the estimates, it is in practice expedient to work with a single number for planning and reporting purposes. In fact, different numbers are commonly used for different purposes. Conservative estimates are needed for financing and sometimes tax purposes; best estimates are needed for internal technical planning; and optimistic estimates are sometimes used for promotional purposes. Often different companies with interests in the same field report different estimates. Those involved are under many pressures: some are cautious, fearing the consequences of unfulfilled claims; others may be forced to exaggerate to secure funding against internal competition.

Governments are not immune either. Several OPEC countries announced huge unsubstantiated reserve increases in the late 1980s to increase their quotas, which were based partly on reserves. Mexico, facing a peso crisis, secured collateral for international debt by the inclusion of non-conventional resources. It may be assumed that it did so with the connivance of the bankers concerned who desired to stabilize financial markets. In any event, the reserves were later reduced by as much as 20 Gb.

Furthermore, there are inconsistencies in the treatment of gas, and gas liquids, as already discussed, and in drawing the boundary between conventional and non-conventional categories.

Of particular relevance is the US Securities and Exchange Commission, which in earlier years issued strict regulations for financial reporting to prevent fraud, limiting *proved reserves* to those in the catchment area of a producing well that are deemed economic with current technology and the price at the end of the reporting year. Most international companies are quoted on the New York stock exchange and find themselves subject to these archaic and inappropriate regulations. They have allowed, indeed forced, the companies to systematically under-report the size of discoveries, which have consequently been subject to progressive upward revision. It allowed them to present an unrealistic image to the stock market, concealing the inevitable grip of depletion, to which all fields are subject.

The appalling weaknesses of the system have been emphasized by many experts, as the following quotations confirm: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)

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)

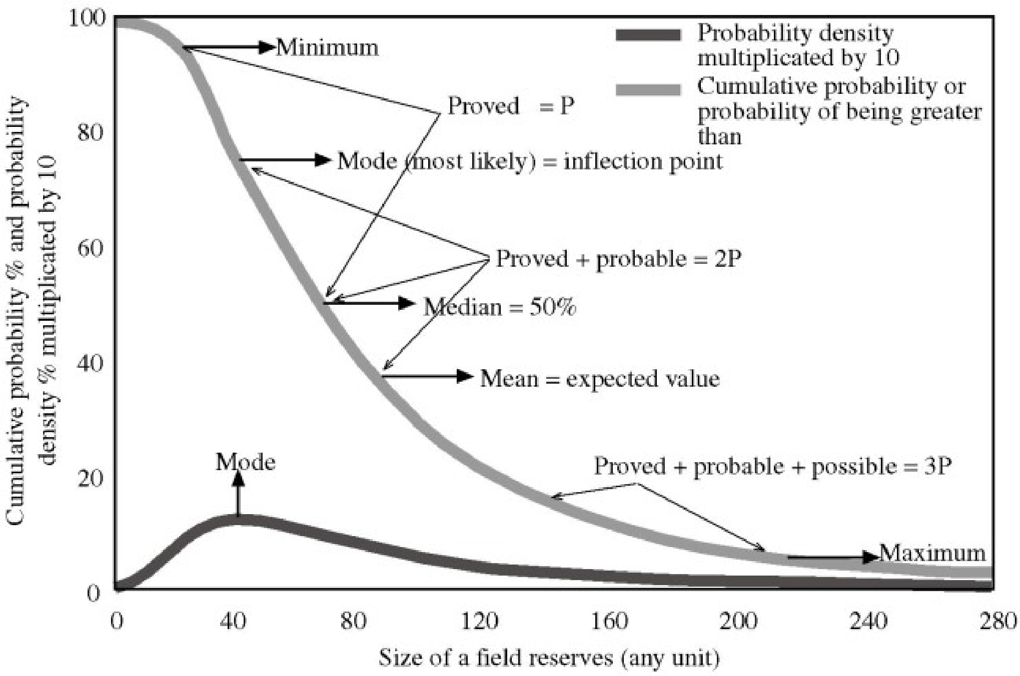

Figure 1:Probability curve (lognormal distribution)

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 definitions 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)

Figure 1 illustrates the various systems in use in terms of probability. They comprise the following:

1. The mini-, median, and maxi- range, with respectively 95–50–5% probability values.
2. The 1P–2P–3P range, referring to proved (1P); proved + probable (2P); and proved + probable + possible (3P). 1P may variously range in practice from 95–50% probability; 2P from 60–35%; and 3P from 15–5%.
3. The mode value is the most likely case, or the peak in frequency: in other words, it is the best estimate, with a probability of about 65%.
4. The median value is simply the 50% probability value, and is perhaps the most widely used.
5. The mean is the average probability ranking, corresponding to a probability of about 40%. Statistically it is the only value to use when adding reserves.

Efforts to properly quantify the degree of probability are admittedly difficult because each field is unique, but advances have been made by assessing the probability distributions of the several physical parameters, such as reservoir thickness, porosity, saturation, and recovery factor. The respective professional bodies (SPE, WPC, AAPG) are making progress in developing improved guidelines for universal application. They could do worse than follow the Norwegian system, which is particularly thorough and sound:

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

11. Resources in leads;
12. Rnmapped resources.

The volumes declared (Feb.1997) by the NDP are shown in Table 2. It should be noted that Norway accords Reserve status to no more than 69 percent of its discovered resources.

	Oil	**Gas**	**NGL**	**Total**
	M.m^3	**G.m^3**	**Mt**	**M.m^3 oe**
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

Table 2: Oil and gas reserves in Norway

2.1 Application of Probability Theory

Although the application of probability theory to reserve estimation is clearly desirable, there are certain pitfalls. Perhaps the most important is the recognition that it is statistically incorrect to sum other than the mean values. It means that the sum of the Proved Reserves of individual fields will be less than the proved reserves of a country as a whole. Likewise, in multiplying the probability values for the parameters taken into account in assessing the reserves of a field, it is necessary to use only the mode (most likely) value.

There are numerous models of probability distribution. The most often used to describe the probability distribution of the parameters of a specific field (area, net pay, etc.) is lognormal distribution. This corresponds with a random normal (Gauss) distribution, but is skewed at the lower limit, as a physical value cannot be negative. By contrast, the distribution of the sizes of fields in a petroleum basin is different, because there are fewer larger fields than smaller fields and the distribution is close to a parabolic fractal (Laherrère 1996).

2.2 Recovery Factor

As is well known, only a percentage of the oil in the reservoir of a field is recoverable. The oil occurs in pore space between the grains of sand (or other rock fragments) making up the reservoir, which are coated by a film of water. This water may coalesce blocking the pore throats between the spaces preventing the movement of oil.

The explorers estimate the oil-in-place of a prospect from seismic surveys and regional knowledge, and, if drilling is successful, later refine the estimates on the basis of information from the wildcat and delineation wells. An assumed recovery factor, based primarily on the characteristics of the oil, is applied to derive an initial estimate of the reserves. Interest in oil-in-place and recovery diminishes over the life of the field as actual well performance gives a progressively better indication of the size of the remaining reserves. Whereas actual production can be accurately measured and extrapolated, estimates of oil-in-place are inevitably subject to much greater uncertainty. It follows that the real recovery factor can be known only within broad limits, which explains why they are usually reported in round numbers.

There are many reports of improved recovery that do not bear close analysis. In many cases, apparent improvement reflects nothing more than the correction of initially under-estimated reserves based on the initial oil-in-place estimates that tend to remain unchanged on the files, no one having any particular reason to reevaluate them.

A particularly good example is provided by the Statfjord Field, whose oil-in-place forms the basis of determining the proportion of the field falling in UK and Norwegian jurisdictions. An early estimate of oil-in-place was based on the western flank of the structure, which could be easily mapped. As development proceeded, the wells were found to deliver much more than anticipated, which led to claims of very high recovery factors that were widely attributed to technological advances. But later, improved seismic coverage and outstep drilling showed that the complex, faulted and slumped eastern flank of the structure contained substantial additional oil-in-place, which had the effect of reducing the notional recovery factor back to close to what it was initially.

Most modern fields are developed to maximize recovery from the outset, with all appropriate measures being taken early during its life, when they are most effective. For example, miscible gas drive was applied from the beginning in the giant Hassi Messaoud field in Algeria, and various procedures were applied to the Prudhoe Bay field in Alaska in 1982. There does however remain a certain scope for extracting more oil from certain old fields by changing the characteristics of the oil in the reservoir by such methods of enhanced recovery as steam injection. In the United States, where such activities are more advanced than elsewhere, enhanced recovery can be applied to about ten percent of the fields, yielding perhaps 6–10 percent more oil. It is a decidedly tail-end activity. Infill drilling is a related practice. In the United States, the normal well spacing has been 40 acres, but in certain fields, more production can be won by reducing the spacing to 20, 10, and eventually 5 acre spacing. Chinese fields are, for example, produced on a very close spacing, which compensates for any technological limitations.

Figure 2 illustrates how oil-in-place is normally determined early in a field’s life, with the range in the estimates of ultimate recovery closing towards abandonment. In earlier years, a 30% recovery factor was taken as a rule-of-thumb, but it now averages about 40%. Claims that improving the recovery factor will release vast amounts of new oil, as voiced from time to time, as for example by Yamani, are spurious, failing to give due credit to the great technological advances of recent years.

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Biographical Sketch

Jean H. Laherrère was born on 30 May 1931. After graduation from the Ecole Polytechnique and Ecole Nationale du Pétrole in Paris, he participated with Compagnie Francaise des Pétroles (now TOTAL) in the Sahara exploration with the discoveries of two supergiant fields: Hassi Messaoud and Hassi R'Mel. He went on to explore Central, Southern, and Western Australia. He was in charge of exploration in Canada for TOTAL in Calgary where he started exploring the Labrador Sea and Michigan. After 15 years overseas, he went to TOTAL headquarters in Paris where was in charge of new ventures negotiation, technical services, research, basin exploration, before finally becoming deputy exploration manager. He has been a member of the Safety Panel of the Ocean Drilling Program (JOIDES). Before retiring in 1991, he was President of the Exploration Commission of the Union Francaise de l'Industrie Pétrolière, where he directed the piblication of a dozen manuals. He was also Director of Compagnie Génerale de Geophysique, Petrosystems, and various TOTAL subsidiaries. He is now writing articles and gioving lectures. His graphs are used in the International Energy Agency 1998 report "World Onternational Outlook" and in the World Energy Council 2000 report "Energy for Tomorrow's World".