Chapter 7
What Do We Know About "Peak Oil" Today?

We do not inherit the Earth from our fathers, we are borrowing it from our children. [However] we're not borrowing from our children, we're stealing from them –and it's not even considered a crime.

–David R. Brower, 1995 (Let the Mountains Talk, let the Rivers Run)

In this chapter we will analyze data to support the claims about the basic limited nature of the global oil resources that underpin this entire book. Due to the very nature of the task, but also to the prevailing disinformation practices that permeate oil debates, the estimates presented here have a degree of uncertainty, which we acknowledge. However, we believe that current events are proving Campbell, Laherrère, and the "peakists" to be right in general. We leave the discussion about appropriate policies to others.

This evidence has compelled us, and many before, to speak out against the failures of companies and governments in addressing or communicating the problem. According to our arguments, these shortcomings could be threatening the future of communities and entire nations in some cases. We think the problem is serious and that neither the state nor the private sector is reacting in an appropriate way; we must insist, to the risk of being repetitive or pretentious, that awareness about "peak oil" (and EROI) needs an increased level of attention from the media and society in general, at least comparable to that of global climate change. We believe that our role as scientists is to collect and interpret the data to the best of our knowledge and communicate our findings to society in general.

7.1 Technology and Uncertainty in the Oil Industry

The biggest problem anyone faces when trying to assess the future of oil production is uncertainty. It is amazing to us that one of the most important industries for the modern society, having large resources and access to the best possible technologies,

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still relies on unscientific practices coming from the nineteenth century. Jean Laherrère likes to point out the role of technology in the oil industry by quoting the Greek fabulist Aesop, according to whom the tongue is both the best and the worst tool: it is the key to all knowledge and philosophy, the instrument to establish trade and contracts, the means to pronounce eulogies and marriages; but also, the tongue is responsible for all the wickedness in the world, causing the ruin of empires, cities, and relationships; wars and misdeeds are perpetrated only after being discussed, debated, resolved, and communicated, all by words.

The oil industry uses also the best and the worst tools. While the best technology is used in seismic exploration, extracting and logging, the worst technology is often used in defining the units and measurements, in reporting and communicating important issues about oil resources, and also in accelerating the present production to increase current profits to the detriment of future production and future generations. It is embarrassing to see a trillion-dollar industry hiring some of the best engineers all over the world on the one hand, but still following outdated practices and emitting reports that would be unacceptable for undergraduate students. Some of the most salient issues that Jean Laherrère has detected are the following (Laherrère, personal communication):

- Reports are issued with unofficial units different from the universally accepted metric system: e.g. feet..., barrels, and tons.
- Symbols are used to denote different things in the same document: "M" has been used for "thousand," "million," and "metric."
- Assessment of probabilities is incompetent: P90 reserves from oil fields are added to calculate the P90 reserves of countries, and then added again to calculate global reserves. This aggregation underestimates P90 national reserves and the growth of reserves is partly due to this mistake.
- Quantities are reported with irrelevant significant digits: twelve digits are reported when even the first is uncertain.
- Forecasts are done for long periods into the future using insufficient data from the past: estimations for a certain period should report historical past data for a period of about twice the period that is being forecasted.
- Important data is now inaccessible: incredibly, data from USGS was lost or became inaccessible because it was stored in outdated digital mediums that either degraded to a point that they could no longer be read, or a suitable computer or software which could read the data could not be found.

There is a smokescreen of numbers that could and should be avoided. The task is difficult by itself and having to account for all the artificial uncertainty only makes things worse. Governments are not addressing the issue publicly and the industry is running under a business as usual scenario. Meanwhile, oil supplies have not increased significantly since the year 2005 despite enormous increases in the price of oil. That is why we think that some national and international agreements should be implemented in order to guarantee accurate information. Definitions, symbols, and techniques should be standardized on the basis of the best scientific knowledge available.

7.2 Fossil Fuels Have No Apparent Substitute

Many people believe that renewable energies have the capacity to displace fossil fuels and are the solution to an eventual depletion of the latter. That may not be true at all. Renewable energies are not displacing fossil fuels; instead the *increase* in use of oil, gas, or coal in most years is greater than the *total* amount of wind and photovoltaic output, the so-called "new solar energies" (Fig. 7.1). These new energies are just adding to the mix. Before 2008, the new solar was growing more rapidly from a much smaller base; if it is to overtake fossil fuels, it would have to grow much faster from a larger base. As of this writing, growth in all fuels has decreased since the financial crisis of 2008 and the subsequent recession; this decrease has been especially true for the new solar technologies (wind and photovoltaic).

It is not difficult to find very different accounts about whether or not we should be worried about the immediate availability of oil. Many authors (e.g., Ivanhoe, Deffeyes, Hubbert) have indicated that as of 2010 humanity would have burned about half of the oil it will ever burn, everything else remaining equal. On the other hand, other studies (see Sects. 9.2–9.4) suggest that we have not burned a significant amount of the oil we will ever burn. Beyond that, some analysts (e.g., Simon (1998), Lynch 1998, 2001, 2008, 2009; see references) say we will never run out of oil, that the economic process itself will always find more oil and if not, it will provide substitutes. Probably the majority of Americans believe that, essentially, there should

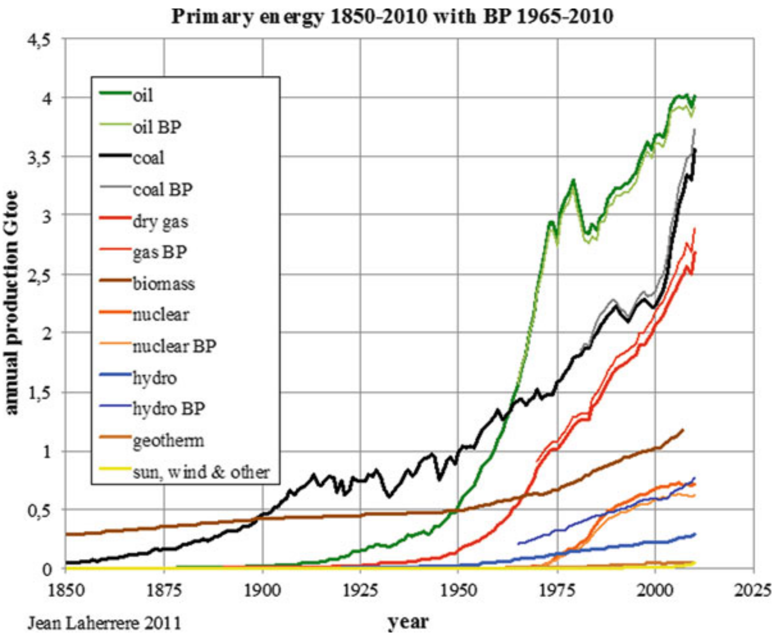

Fig. 7.1 Production of primary energy from different resources in billions of tons of oil equivalent (Gtoe). The difference in hydropower is due to the conversion factor used in BP's statistical review BP (2012)

be no concern about future oil because "scientists and engineers will come up with something." How can we evaluate the veracity of these very different statements? How can we know how much oil is yet to be extracted from the ground? Which assumptions do we have to make in order to produce such figures?

7.3 Ultimate Recoverable, Cumulative Production, and Discoveries

In order to forecast future oil production, we need to estimate the following items:

1. Ultimate recoverable—the volume of oil that can be recovered from worldwide reservoirs at a profitable rate (both in terms of energy and dollars) under the current technology.
2. Past cumulative production—the amount of oil that the industry has pumped out of the ground in the past.
3. Future cumulative production—the difference between the previous two quantities yields the remaining amount of oil that is likely to be extracted in the future.

The total volume of future cumulative production (3) cannot be pumped in one day or in a single year. Therefore, in order to forecast annual production, we also need to estimate the path that oil production is likely to follow year by year—for example, stationary process, exponential growth, exponential decay, logistic pattern, and bumpy plateau—and allocate the future cumulative production according to this path. Hubbert, for example, chose the derivative of a logistic curve (see Sect. 5.3).

Even though the previous calculations seem to be straightforward, keep in mind that the estimation of each of these quantities requires vast amounts of other estimates, each of which have some degree of associated uncertainty. For example, the estimation of the ultimate recoverable requires historical data on discoveries around the world, while past cumulative production involves historical data from extraction rates worldwide.

7.3.1 The Use of Creaming Curves to Estimate the Global Ultimate Recovery of Oil

The oil that we can expect to find and extract in an already exploited region—so-called "mature province"—can be estimated by exploiting the regularities that arise when an experiment—such as finding an oil field—is repeated a large number of times as described by the law of large numbers in statistics. Empirically, the larger fields tend to be discovered earlier, so when a province is mature, the volume brought by new discoveries declines year by year, and future discoveries would almost

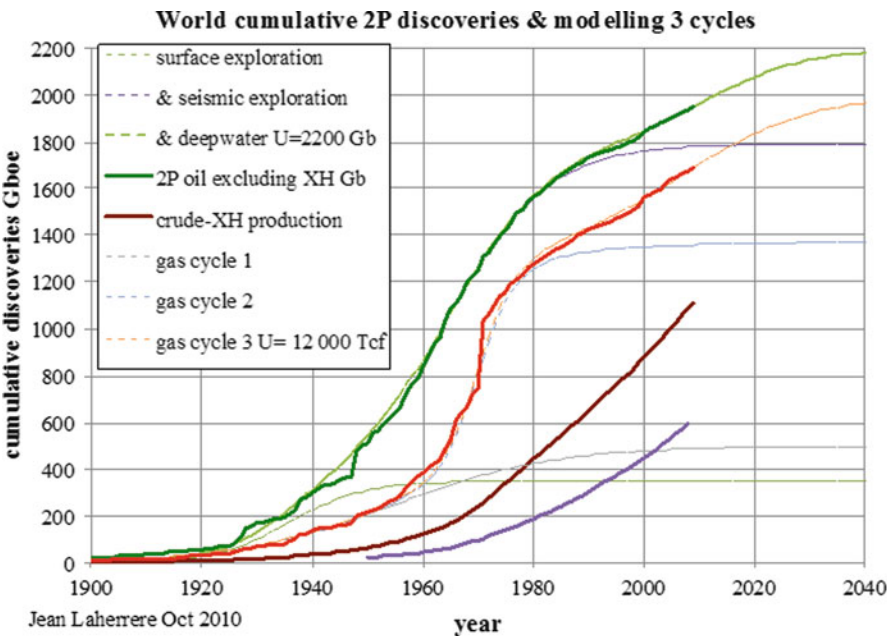

Fig. 7.2 Creaming curve for oil and gas world discoveries under different exploration cycles. Ultimate recoverable seems to be around 2,200 Gb for oil and 2,000 Gb (equivalent to 12,000 Tcf) for gas

certainly be smaller than the ones achieved already unless a groundbreaking technology opens new possibilities for exploration, an event that is becoming less and less likely as the current technologies are already on the edge of our geophysical knowledge. According to a report issued by the US National Petroleum Council in 2007, there are "five core exploration technology areas in which future developments have the potential to significantly impact exploration results over the next 25 years (20 years now). Although the future of these technologies is bright, it is still likely that the trend of decreasing volumes of hydrocarbons discovered with time will continue, although the exploration success rate may continue to improve" (US NPC 2007).

The pattern going from larger to smaller fields can be readily understood through the use of the "creaming curve," a very useful tool designed by Shell in the 1950s for examining the ultimate yield of oil—or natural gas—from any reasonably well-explored region under a given technology. Figures 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, and 7.9 show this pattern emerging throughout the globe, most clearly in the Middle East and Europe. The original version of the creaming curve depicted the cumulative discoveries versus the cumulative number of exploratory wells or "wildcats"—an index of exploration effort in the industry. Hyperbolas seem to fit wildcat data nicely; however, information on wildcats is hard to get and old data is not very reliable. On the other side, if we plot time (in years) or the cumulative number of oil fields instead of wildcats, we get the same pattern roughly, though the curve is not very smooth.

Using cumulative discoveries and hyperbolas, Jean Laherrère has model future discoveries and estimated ultimate recoverable several times. In Fig. 7.2, he used three hyperbolas to model discoveries achieved under different exploration cycles: surface surveys (from 1900 to 1950), seismic surveys excluding deepwater (starting in 1930), and deepwater exploration (more than 500 m or 1,600 ft; starting in 1990). It is worth comparing seismic against deepwater exploration: the current deepwater cycle will probably find some extra 150 billion barrels (Gb) in the following 30 years, while the seismic cycle boosted available crude from some 400 Gb found before the year 1950 with surface exploration to 1,700 Gb in the year 1990.

In Figs. 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, and 7.9, natural gas discoveries are plotted side by side with oil and condensate (O+C) discoveries. In this context, "condensate" refers to a liquid mix of hydrocarbons that is recovered from natural gas in separation facilities. Since it is a liquid fuel and a substitute for gasoline, Jean Laherrère and many other analysts consider these condensates should be included in the crude oil supply.

Gas reserves are usually measured in trillion cubic feet (Tcf; the T comes from the prefix "tera" which means 10^{12} in the International System of Units). Natural gas has a lower calorific power than oil, so a cubic foot of natural gas has less energy than a cubic foot of oil. The most common equivalence between oil and gas is the following: the energy of one barrel of oil equals the energy of 6,000 cubic feet of gas (in the USA, the exact number is 1 barrel = 5,620 cubic feet); this means 1 Gb (billion barrels of oil) = 6 Tcf (trillion cubic feet of gas). Therefore, in these plots, the volume of natural gas has been divided by six, rendering the energy in gas comparable to that in oil.

It is interesting to notice the amount of new fields that "need" to be found in order to increase oil reserves significantly. The case of the Middle East is illustrative: if the number of fields in the region were to double to 3,000 (a 100% increase), it is not likely for ultimate recoverable in the region to increase more than 5%. The other regions analyzed have not yet reached the flattest part of their curves, but we cannot expect them, by any means, to deliver any volume increase of the size of the discoveries made in the second half of the past century.

A way to check if the global hyperbola provides a reasonable estimation of ultimate recoverable is to add up the estimations provided by the hyperbolas of the regional creaming curves (Figs. 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, and 7.9). The global estimate is 2,200 Gb, while the sum of the different regions outside the USL48 and West Canada yields an ultimate of 2,010 Gb, leaving 200 Gb for USL48 and West Canada. Additionally, there are different estimations for deepwater potential. Jean Laherrère has estimated that the deepwater cycle would yield around 150 Gb, while Colin Campbell has calculated 100 Gb. In any case, the 2,200 Gb seem to be not too far from the mark.

Creaming curves give us an idea about how much oil can ever be extracted, but do not tell us when the oil will be produced, if ever. In other words, creaming curves are not production forecasts. However, we can estimate future production using the information of ultimate recoverable obtained from creaming curves together with the cumulative discoveries and production data.

There are only two places from which we can produce more oil: (1) the oil fields discovered in the past or (2) the oil fields that remain to be discovered in the future. The oil fields discovered in the past can be divided further as follows: (a) depleted, (b) producing oil, or (c) not yet developed. Aggregating the latter two together with

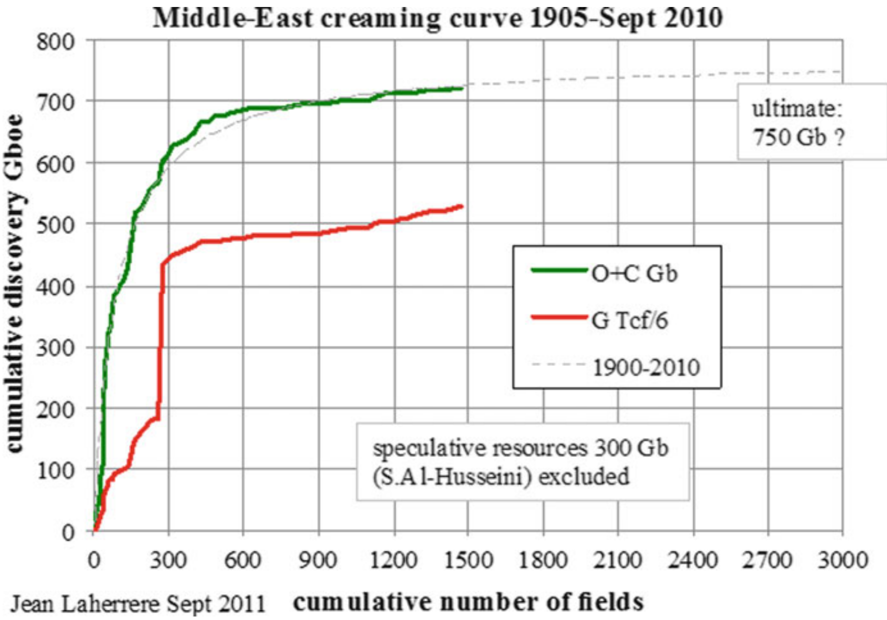

Fig. 7.3 Creaming curve for the Middle East with estimate of ultimate recoverable oil and condensate (O+C) at 750 Gb and excluding the 300 Gb from "political reserves"

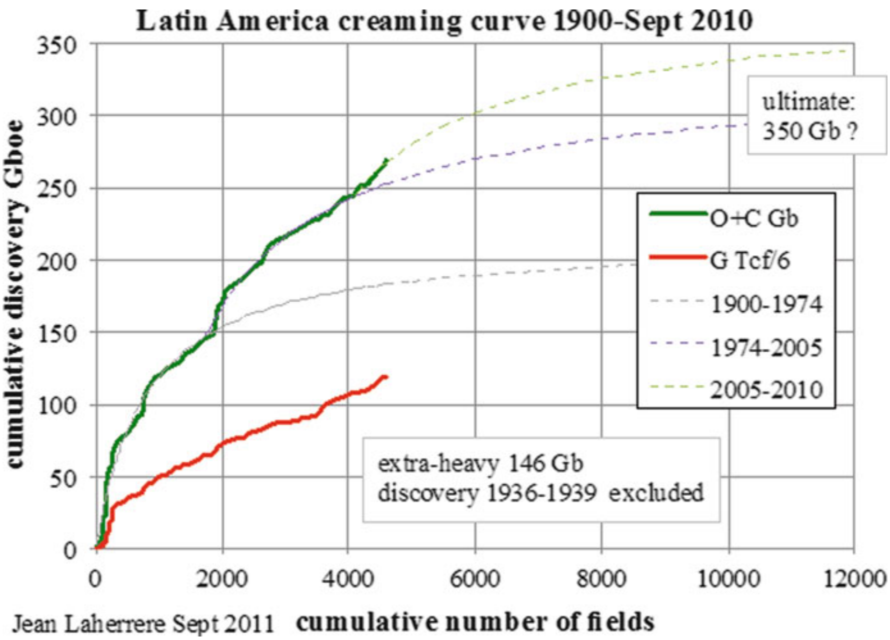

Fig. 7.4 Creaming curve for Latin America with estimate of ultimate recoverable oil and condensate (O+C) at 350 Gb

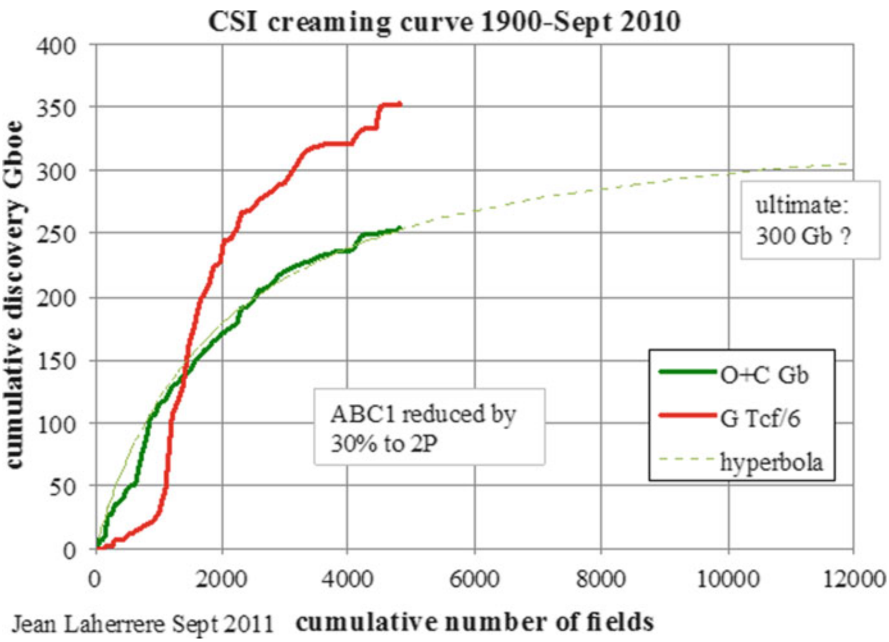

Fig. 7.5 Creaming curve for the Commonwealth of Independent States (CIS) of the former Soviet Union with estimate of ultimate recoverable oil and condensate (O+C) at 300 Gb. Not even this historically prolific region rivals the hydrocarbon wealth of the Middle East

future discoveries would yield the ultimate recoverable oil. Since the creaming curves have provided us with an estimation of ultimate recoverable and we can calculate past cumulative production from reports of national agencies around the world, we can estimate the total amount of oil that remains to be produced (Fig. 7.2):

$$\text{Future Cum Prod} = \text{Ultimate Recoverable} - \text{Past Cum Prod} \tag{7.1}$$

$$\text{Future Cum Prod} = 2{,}200\,\text{Gb} - 1{,}140\,\text{Gb} = 1{,}060\,\text{Gb} \tag{7.2}$$

7.3.2 *Discoveries and Production Cycles: For Oil to Be Extracted, We Need to Discover It*

These 1,060 Gb cannot be pumped out of the ground immediately (some of them lay in oil fields that are not yet developed and others in reservoirs that have not been

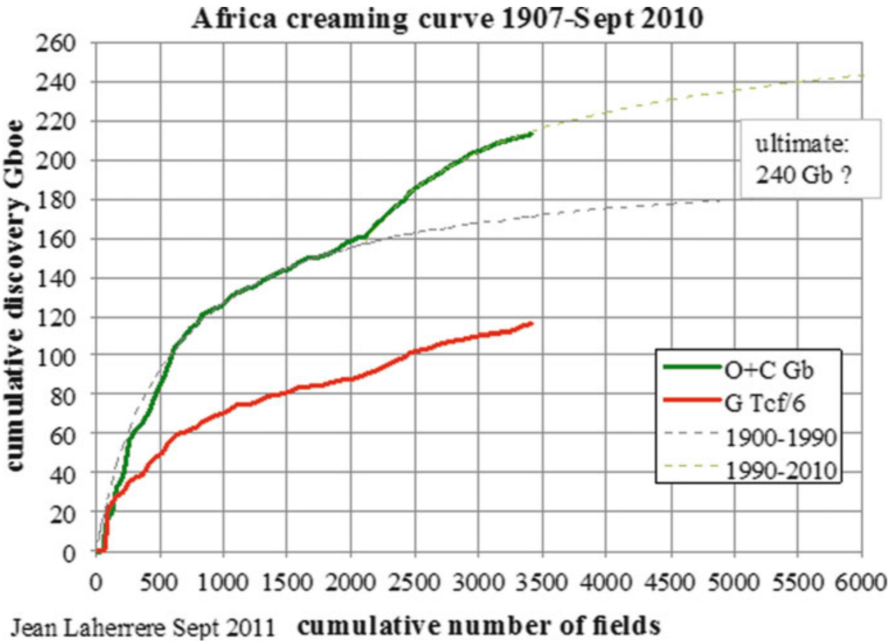

Fig. 7.6 Creaming curve for Africa with estimate of ultimate recoverable oil and condensate (O+C) at 240 Gb

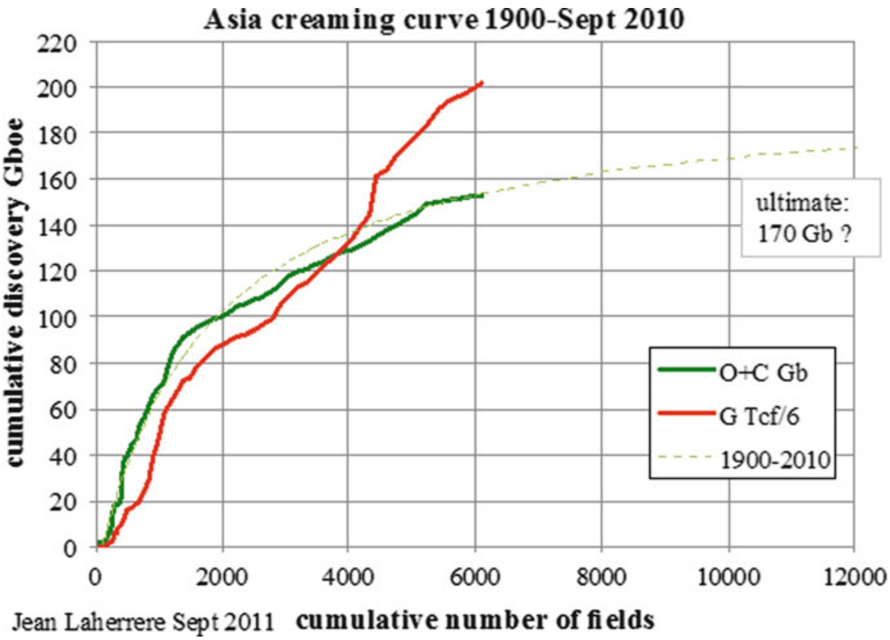

Fig. 7.7 Creaming curve for Asia (except Middle East and CIS) with estimate of ultimate recoverable oil and condensate (O+C) at 170 Gb

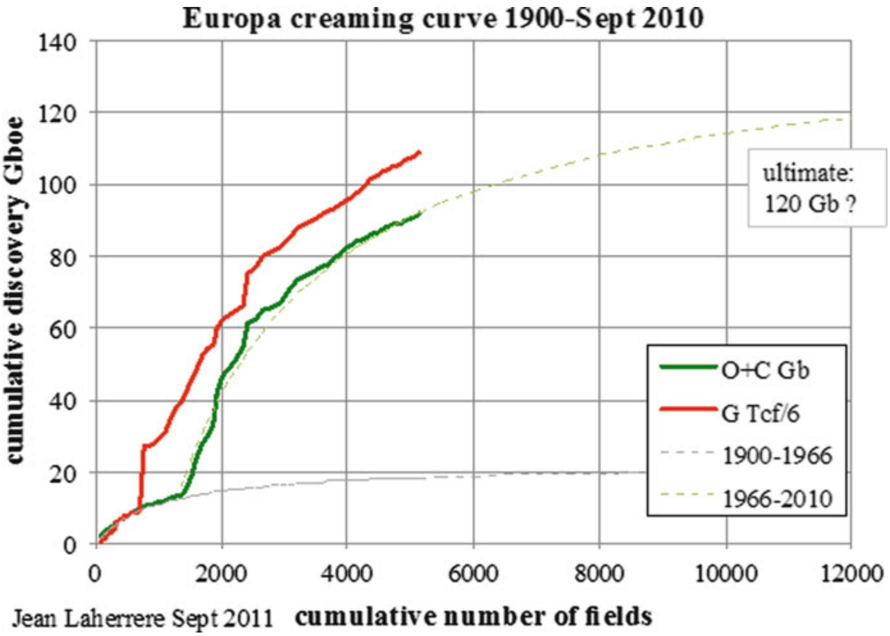

Fig. 7.8 Creaming curve for Europe with estimate of ultimate recoverable oil and condensate (O+C) at 120 Gb

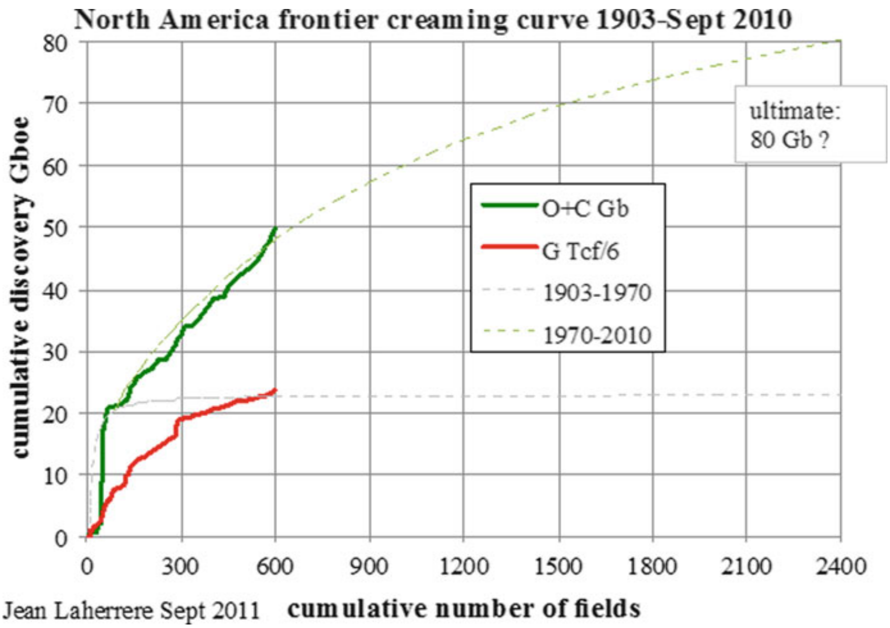

Fig. 7.9 Creaming curve for North America frontier (Gulf of Mexico, Newfoundland coast, Scotian shelf, Alaska) with estimate of ultimate recoverable oil and condensate (O+C) at 80 Gb

discovered); the industry will extract them in the decades to come. What shape will production have in the following years? Is it likely to grow, decline, or stabilize? To answer these questions, there are two pieces of information that we need to consider: (1) the discovery trend in the past and (2) the historical behavior of oil fields.

New discoveries become current reserves or, equivalently, future production, allowing for the uncertainties discussed elsewhere. A large share of today's production is limited by the amount of oil discovered in the recent past. If the discovery trend is increasing now, we need not be concerned about the future for some years, but if discoveries are dropping, we may be worried about a scarcity of oil in the next decades. Moreover, once an oil reservoir is discovered, it needs to be developed; depending on the size and complexity of the project, it may take several years to arrange the legal agreements and build the required infrastructure. So there is a lag between the discovery of an oil field and the point when production begins.

The lag between discoveries and production appears also at the national and global levels. France is one of the best examples to illustrate the relation between discovery and production cycles (Fig. 7.10). The first discovery cycle in France started in the late 1940s and finished in the 1960s, providing the reserves that were exploited during the first production cycle, starting in 1950 and finishing in the late 1970s. Around the same time, the second discovery and production cycles started, but the former peaked and finished earlier than the latter.

While the lags between the discovery and production cycles were different, it is clear that production cannot grow beyond the limit previously imposed by the discovery cycle. In geometrical terms, the area below the production curve in Fig. 7.10—that is, cumulative production—cannot be larger than the area below the discovery curve at any point in time. This is why the oil industry operating in France could not prevent the decline in production during the 1970s; the oil from the previous discovery cycle had been already extracted, so the height of the production had to go down.

Thus, a way to forecast annual production is to look at the discoveries of the past decades. Nevertheless, we must be aware that there are several issues to consider when characterizing discovery trends. For example, discoveries do not follow a smooth path through time; major discoveries occur sporadically and there are many years that are not successful at all. There is, however, a clear decreasing trend in global oil discoveries since the 1980s. In the four decades between 1940 and 1980 the industry made vast discoveries that have become our current production (Fig. 6.3). Despite the growing demand for fossil fuels (Fig. 7.1), and the high prices that have been reached in the last years (Fig. 7.11), the trend of discoveries has been declining during the last 30 years as compared to the previous decades.

In other words, we are extracting more oil than the oil that we are finding. For each barrel produced in the years 2007–2009 less than 0.5 barrels have been discovered. This trend has led to a situation—as in the French case—where past discoveries are not large enough to support either an increase in production or even to maintain the current level for a long time.

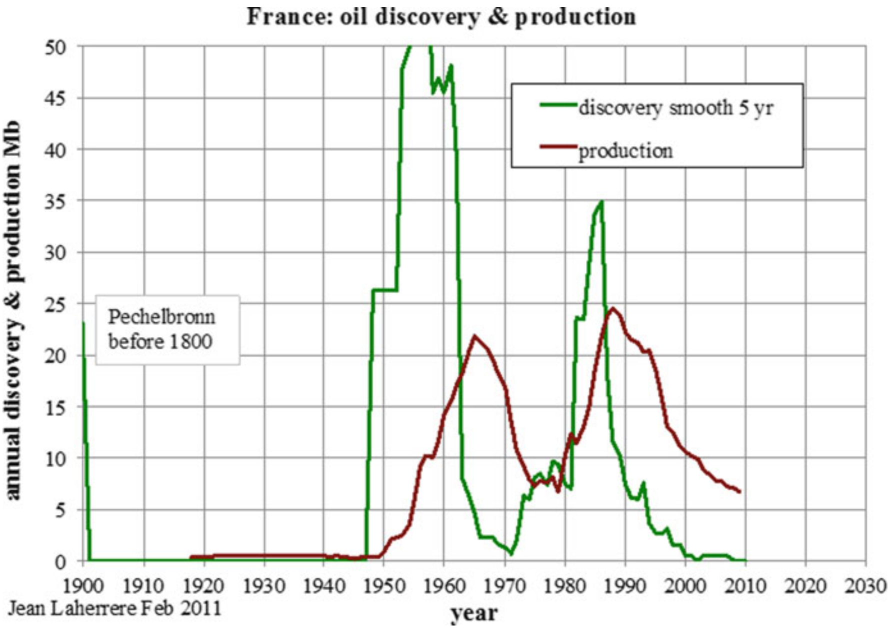

Fig. 7.10 Discovery (5 years average) and annual oil production in France. The two discovery cycles were clearly followed by two corresponding production cycles

7.3.3 Production Data of Active Oil Fields

Estimates for ultimate recovery of currently producing but declining oil fields are straightforward to obtain in general because their production cycle is more advanced and a simple extrapolation will tell you when the field is finished and the quantity of oil you can expect from that field. If an oil field has not reached the decline stage, this extrapolation is not so reliable.

Figures 7.12, 7.13, 7.14, 7.15, 7.16, and 7.17 show the decline of some emblematical oil fields after they enter their decline stage. It is not hard to see that these oil fields have long passed their maximum production rate. Most of them have been placed under enhanced oil recovery (EOR) techniques. From numerous examples we can say that "technology" is useful to accelerate the production cycle allowing companies and governments to pump oil more rapidly than before, but usually without increasing the initial estimation of ultimate recovery in any consistent pattern. In addition, as we stated previously, the effect of technology is already taken into consideration when oil companies calculate their estimates.

As you can see, the great uncertainties around energetic issues can be better understood by examining data. According to Campbell, Laherrère, ASPO, and our own interpretation of the available data, it seems that increasing global oil supply is becoming more and more difficult year after year. Data quality is everything, and with good data you can get a good estimate of how much oil we are likely to produce in the future. International agreements on definitions, symbols, and estimation

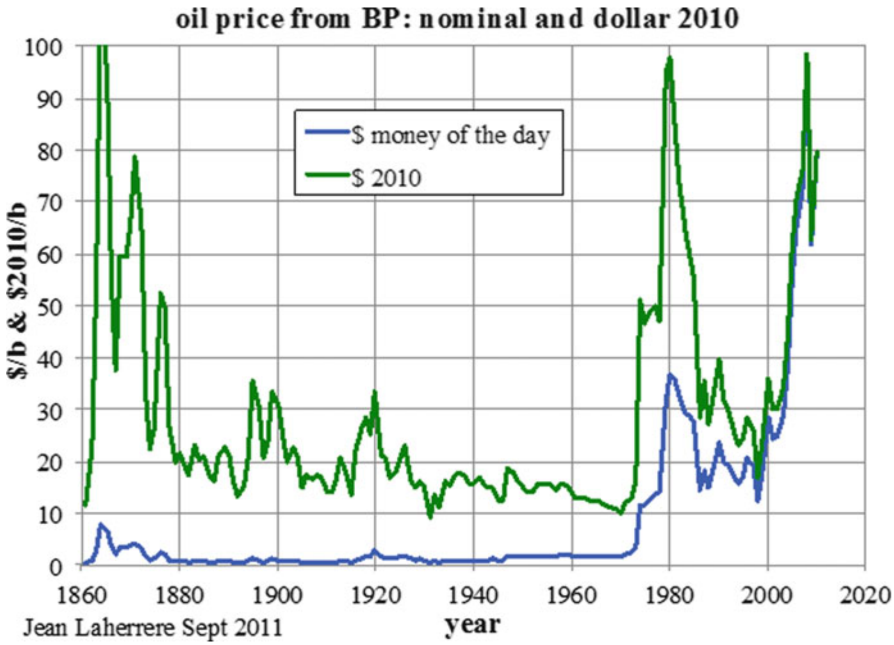

Fig. 7.11 Oil prices since 1860. The recent increases are comparable to those of the oil crises in the 1970s. The low prices in the mid-1980s and 1990s was related to important discoveries like Prudhoe Bay in Alaska, Cantarell in Mexico, or the North Sea

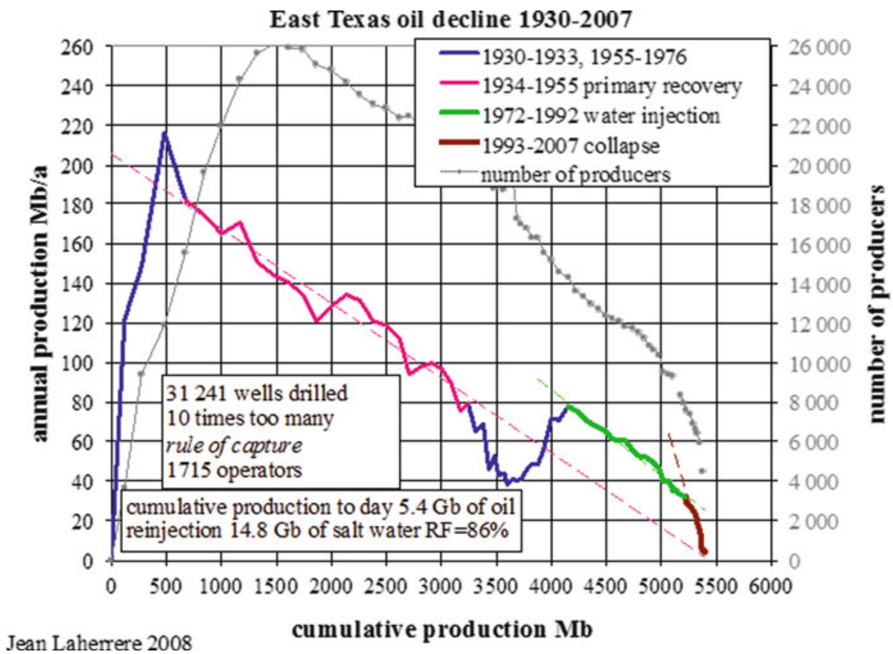

Fig. 7.12 Oil production of the East Texas oil field throughout different epochs. East Texas is famous because of the number of operators allowed to drill due to the “rule of capture” in the USA. Due to overexploitation, this prolific field started declining very soon in 1933

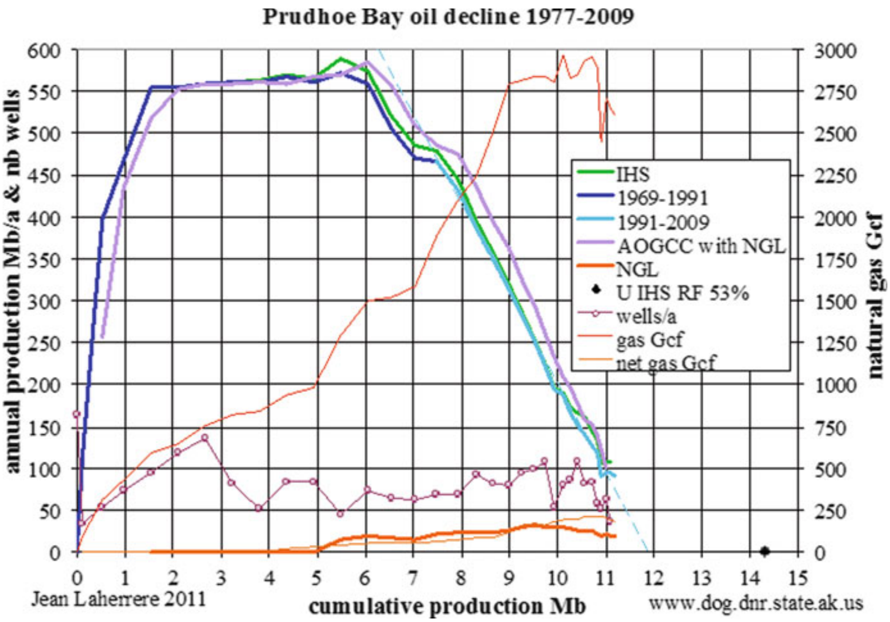

Fig. 7.13 Oil and gas production of Prudhoe Bay, Alaska throughout different epochs. The ultimate recoverable estimated by IHS consultancy at a recovery factor of 53% was too high. Operated by BP, Prudhoe Bay produced a second peak in the national US production, helping to disrupt OPEC's dominance during the 1980s and 1990s

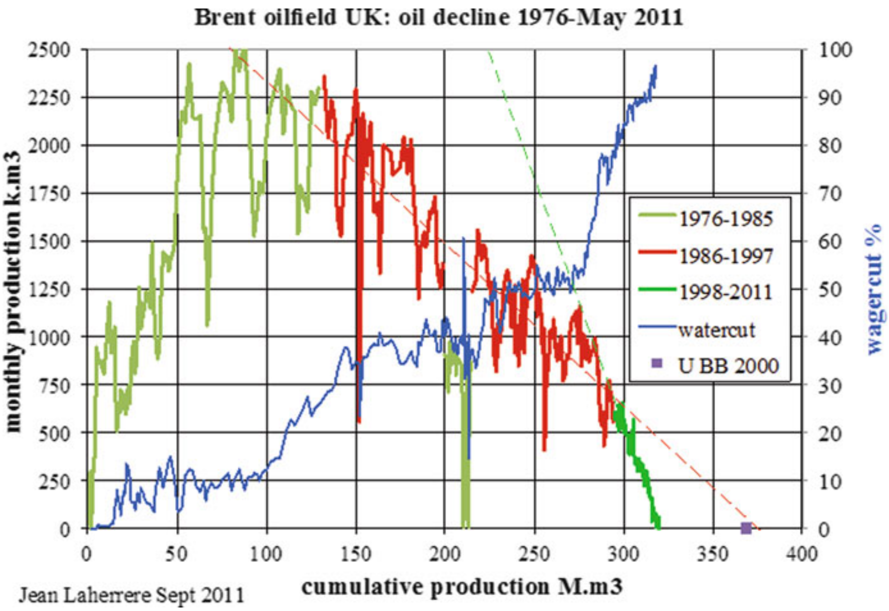

Fig. 7.14 Oil and gas production of the Brent oil field, in the UK North Sea, throughout different periods, showing the ratio of water produced compared to the volume of total liquids produced or watercut. The ultimate recoverable published in the Brown Book (BB) was too high. Once regarded as a standard of quality around the world, Brent oil is now in terminal decline

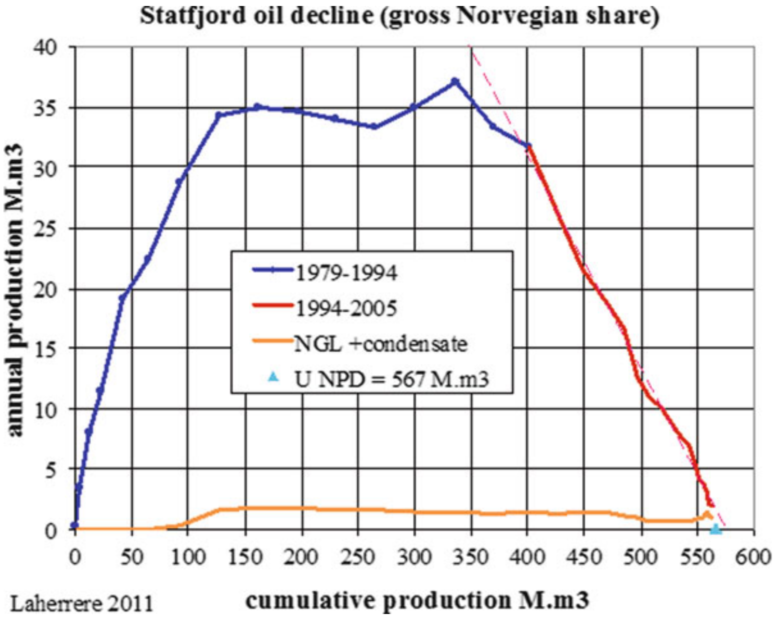

Fig. 7.15 Oil and gas production of Norway's Statfjord oil field, in the North Sea, in two different periods. Statfjord was Norway's largest oil field only after Ekofisk; both fields are now in terminal decline

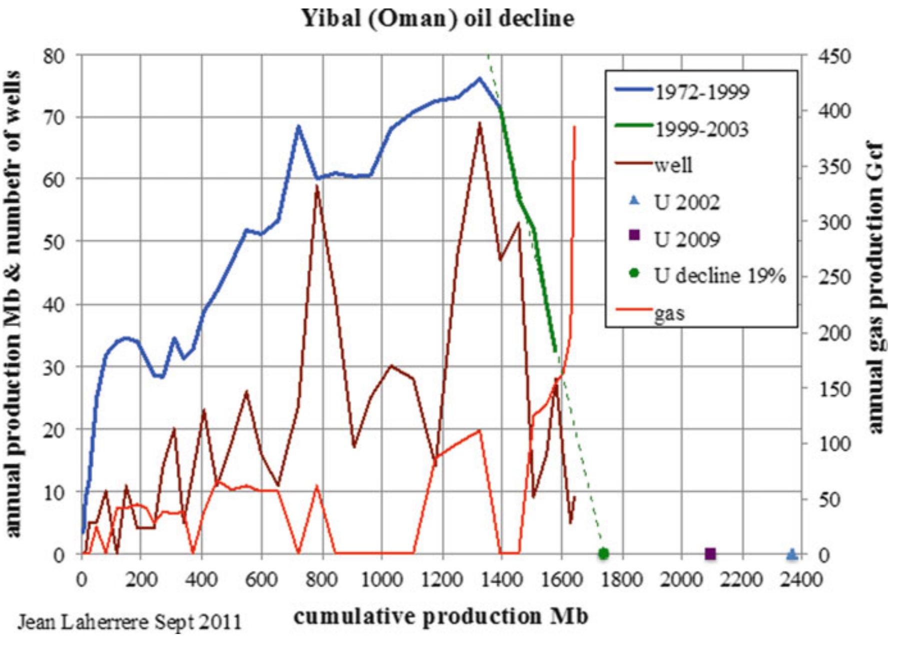

Fig. 7.16 Oil and gas production and number of wells in the Yibal oil field in Oman, with estimates of ultimate recoverable (*U*) calculated in 2002 and 2009. These estimates were too high because extraction was accelerated to increase short-term profits in detriment of future production

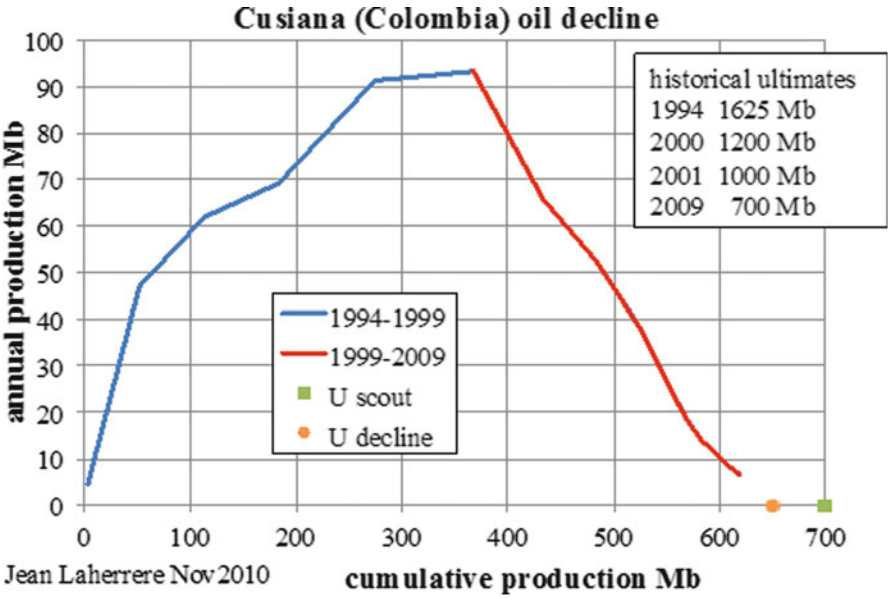

Fig. 7.17 Oil production in the Cusiana oil field in Colombia before and after decline. Cusiana was discovered in a joint venture between total and BP where Jean Laherrère participated. The legend shows BP’s overestimations about Cusiana

techniques, as the ones that Jean Laherrère is proposing in a book of this same collection, would help to guarantee more accurate information. Quality information, in turn, would reduce the uncertainty that prevails today, enabling our societies to take better decisions.

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