Chapter 6
The End of Cheap Oil

In 1998, Colin Campbell and Jean Laherrère published an article in the *Scientific American Magazine* where they estimated the amount of oil that remained to be produced. Campbell got interested in the study of oil depletion around 1969, in Chicago, when he was part of a team making a world evaluation for Amoco (now part of BP). Later, as the manager of the Norwegian branch of the Italian company Fina, he had the company and the Norwegian authorities sponsored a research project on the subject using public reserve data, which later proved to be very unreliable.

These results, published as *The Golden Century of Oil 1950–2050* (Campbell 1991), attracted the interest of Petroconsultants, a company based in Geneva that gathered privileged information from international oil companies to assemble a reliable database on oil activities around the world, including the size of discoveries and drilling statistics (we will return to the history of Petroconsultants in Section 9.4). They invited Campbell to redo the study, but this time using their comprehensive database. Jean Laherrère joined Campbell in the project. The resulting study was published at 50,000 USD a copy but was later suppressed under pressure from a major US oil company. However, Petroconsultants copublished a book, *The Coming Oil Crisis* (Campbell 1997), and agreed that Laherrère and Campbell should accept an invitation to write an article for the *Scientific American*. Thus, "The End of Cheap Oil" was published in March 1998. This paper reawakened scientific and public interest in the precarious position of modern society relative to its necessary oil supplies, a practical and intellectual concept that had lain dormant for more than two decades.

That paper and other related efforts have had considerable impact on reawakening interest in M. King Hubbert's analyses on "peak oil" and its ramifications such that, for example, the Association for the Study of Peak Oil (ASPO) now has 23 national chapters, and four more are in the process of being formed. According to Google Scholar, "The End of Cheap Oil" has more than a thousand recorded citations, ranging from popular science magazines and textbooks to peer-reviewed papers in scientific journals, all of the previous coming from a large diversity of disciplines, not only oil and energy studies but also political science, psychology,

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and cultural anthropology. Fourteen years after its publication, we can say that the article has stood the test of time: it is cited still in numerous works. In this chapter, we present Campbell and Laherrère's (1998) article with some minor modifications in order to make it readable today.

Before moving forward, we would like to recall the importance of defining what we are talking about when we say "oil" or "oil production." Since oil is used mostly as a fuel, the definition of "oil production" usually includes the supplies of *all liquid substances* associated with petroleum or chemical feedstocks, that is, crude oil, extra-heavy and shale oil, natural gas liquids, "refinery gains" (the difference between the volume of total output and the volume of crude oil and other feedstocks that go into refineries), and biocarburants (corn, sugar cane, and cellulose ethanol). This is the definition that Jean Laherrère uses today. Whenever you hear or read any news about "oil," ask which substances are being considered in the definition for there is some confusion with the use and misuse of the term. In 1998, Campbell and Laherrère used the term "conventional oil" as crude oil coming from any source that does not require production technologies significantly different from those used in the mainstream reservoirs exploited at the time. However, experts could never agree on a standard definition of the term, so "conventional oil" has lost its previous significance as extraction technologies have changed in the last decades. Hence, it would be meaningless—and perhaps misleading—to update estimations for conventional oil. The updated data we provide here refers to the most accepted definition today, that is, the supply of all the liquids listed lines above (US EIA 2012). In Chap. 7, we will explore publicly available data collected and corrected by Jean Laherrère.

6.1 Revisiting the End of Cheap Oil

In 1973 and 1979 a pair of sudden price increases rudely awakened the industrial world to its dependence on cheap crude oil. Prices first tripled in response to an Arab embargo and then nearly doubled again when Iran dethroned its Shah, sending the major economies sputtering into recession. Many analysts warned that these crises proved that the world would soon run out of oil. Yet they were wrong. Their dire predictions were emotional and political reactions; for even at the time, oil industry insiders, such as Campbell and Laherrère, knew that they had no scientific basis. Just a few years earlier, oil explorers had discovered enormous new oil provinces on the North Slope of Alaska and below the North Sea off the coast of Europe. By 1973, the world had consumed, according to many experts' best estimates, only about one eighth of its endowment of readily accessible crude oil (i.e., "conventional oil"). The five Middle Eastern members of the Organization of the Petroleum Exporting Countries (OPEC) were able to hike prices not because oil was growing scarce but because they had managed to corner 36% of the market. Later, when demand sagged, and the flow of fresh Alaskan and North Sea oil weakened OPEC's economic stranglehold, prices collapsed.

The oil crunch that we are experiencing now is not so temporary. In 1998, Campbell and Laherrère analyzed the discovery and production of oil fields around the world. Their findings suggested that within the first decade of this century, the supply of "conventional oil" would be unable to keep up with demand. This conclusion contradicts the picture one gets from oil industry and official reports. For example, the US Energy Information Agency (EIA) boasted 1,340 billion barrels (Gb) of oil in "proved" global reserves at the start of 2009. Dividing that figure by the current production rate of about 32 Gb a year as reported by the same agency suggests that crude oil could remain plentiful and cheap for 41 more years (US EIA 2012)—probably longer, because official charts show reserves still growing. It is noteworthy that this last figure, around 40 years of oil to go, has remained the same since 1998.

Unfortunately, this appraisal makes three critical errors. First, it relies on distorted estimates of reserves. A second mistake is to pretend that production will remain constant. Third and most important, conventional wisdom erroneously assumes that the last bucket of oil can be pumped from the ground just as quickly as the barrels of oil extracted from wells in the past. In fact, the rate at which any well—or any country—can produce oil always rises to a maximum and then begins falling gradually back to zero. This is the basic Hubbert analysis that has been used to study oil-producing countries. In some of these countries, oil production exhibits a symmetrical shape with one single maximum resembling the bell curve that M. King Hubbert used to study the USL48, but oil production in many other countries exhibits curves with multiple maxima.

From an economic perspective, when the world runs completely out of oil is not directly relevant: what matters is when production begins to taper off. This is because all of our economic and financial processes are based essentially on an expanding supply of energy, and oil is the most important source of energy for the world. Beyond the tapering point, prices will rise unless demand declines commensurately. This appears to be happening for the world in the first decades of the new millennium: oil prices have climbed to the highest level in history. Many countries are facing severe financial difficulties to repay their debt, not only in the developing world but also among the developed, due in part to high oil prices.

Using different techniques to estimate the reserves of conventional oil and the amount still left to be discovered, Campbell and Laherrère concluded in 1998 that the decline would begin before 2010. According to official figures, global oil production seems to have reached what Jean Laherrère called a "bumpy plateau" around 86 million barrels per day (Mb/d) plus or minus 2 Mb/d since 2005 (Fig. 6.1). This variation of 2 Mb/d, or 2.3% of total production, is less than the difference between the data reported by the US Energy Information Administration (EIA) and the data reported by the International Energy Agency (IEA). Moreover, in 2006, 2007, and 2009 annual production levels stayed below 2005 figures. On a monthly basis, the largest production was reached in January 2012 at 89 Mb/d; between 2005 and 2009, the largest production had occurred in July 2008, right before the Olympic Games in Beijing (Fig. 6.1).

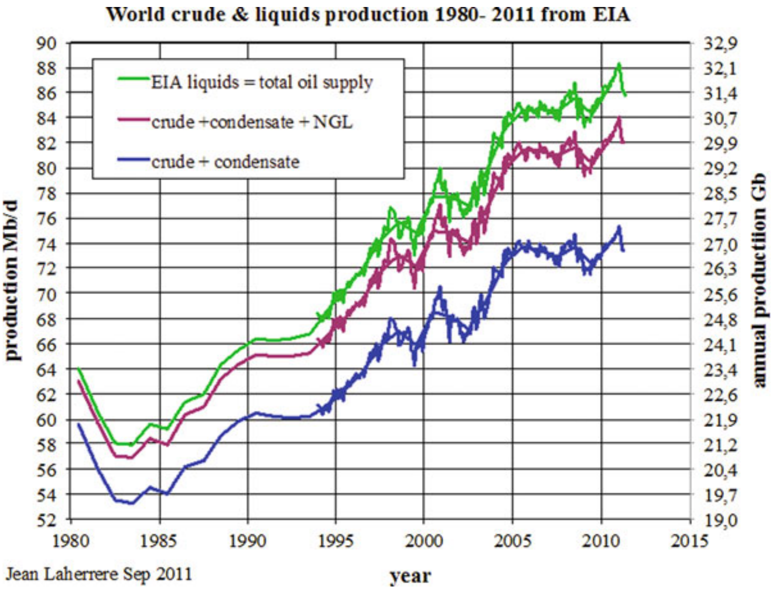

Fig. 6.1 Production of crude oil, condensate, and natural gas liquids (NGL). Crude oil and condensate have remained around 74 Mb/d since 2005; NGL and other liquids have become increasingly important, from less than 6 Mb/d in 1986 to 12 Mb/d in 2011

6.2 Digging for the True Numbers

Campbell and Laherrère spent most of their careers exploring for oil, studying reserve figures, and estimating the amount of oil left to discover, first while employed at major oil companies and later as independent consultants. Over the years, they have come to appreciate that the relevant statistics are far more complicated than they first appear to be.

Consider, for example, the three vital numbers needed to project future oil production. The first is the tally of how much oil has been extracted to date, a figure known as cumulative production. The second is an estimate of reserves—the amount that companies can pump out of known oil fields before having to abandon them. Finally, one must have an educated guess at the quantity of oil that remains to be discovered and exploited. Together they add up to ultimate recovery, the total number of barrels that will have been extracted when production ceases many decades from now (see Sect. 7.3). The obvious way to gather these numbers is to look them up in any of several publications. That approach works well enough for cumulative production statistics because companies meter the oil as it flows from their wells. The record of production is not perfect (e.g., the 2 Gb of Kuwaiti oil wastefully burned by Iraq in 1991, or the oil stolen in many producing countries is usually not included in official statistics), but errors are relatively easy to spot and rectify. The US Geological Survey has estimated that the industry had removed around 1,000 Gb from the earth by the end of 2005, which means some 1,150 Gb after adding production of crude, condensates, and natural gas liquids up to the end of the year 2010.

Getting good estimates of reserves, however, is much harder. Almost all the publicly available statistics are taken from surveys conducted by the entities that publish the *Oil and Gas Journal* and *World Oil*. Each year these trade journals query oil firms and governments around the world. They then publish whatever production and reserve numbers they receive, but they are not able to verify them.

The results, which are often accepted uncritically, contain systematic errors. For one, many of the figures reported are unrealistic. Estimating reserves is not an exact science to begin with, so petroleum engineers assign a probability to their assessments. For example, if, as geologists estimate, there is a 90% chance that the Oseberg field in Norway contains 700 Mb of recoverable oil but only a 10% chance that it contains 2,500 Mb, then the lower figure should be cited as the so-called P90 estimate (P90 for "probability 90%") and the higher as the P10 reserves (Campbell and Laherrère 1998).

In practice, companies and countries are often deliberately vague about the likelihood of the reserves they report, preferring instead to publicize whichever figure, within a P10 to P90 range, best suits their interests. Large estimates can, for instance, help to raise the price of an oil company's stock. On the other hand, sometimes it is advantageous to report lower amounts in order to secure some increases to report in the future, even if no real discoveries are made. Thus, reports are part of the financial strategy of the companies.

The members of OPEC have faced an even greater temptation to inflate their reports because, based on their own internal agreement, the higher their reserves, the more oil they are allowed to export. National companies, which have exclusive oil rights in the main OPEC countries, need not (and do not) release detailed statistics on each field that could be used to verify the country's total reserves. During the late 1980s, 6 of the 11 OPEC nations increased their reserve figures by colossal amounts, ranging from 42% to 197% (Fig. 6.2). The result was the addition of 300 Gb for OPEC members without making any significant discovery. Campbell and Laherrère claimed in 1998 that this increase in reserves was likely to be political instead of geological, and ASPO has insisted the same. The extra amount would boost the production quotas of the countries, allowing them to produce more. It was only in 2007 that Sadad Al-Husseini, former vice president of ARAMCO (who was retired because he wrote a report on peak oil), stated in London that these 300 Gb were indeed speculative resources unlikely to be produced (Al-Husseini 2007).

Previous OPEC estimates, inherited from private companies before national governments took over, had probably been conservative, P90 numbers. So some upward revision was warranted. But no major new discoveries or technological breakthroughs justified the addition of a staggering 287 Gb. That increase is 40% more than all the oil ever discovered in the United States. Non-OPEC countries, of course, are not above fudging their numbers either. For example, in the report of the *Oil and Gas Journal* for 2009, the reserves of 70 nations—including the United States, Russia, China, and India—show no change from 2008 because national agencies did not report changes, even though companies in these countries were extracting

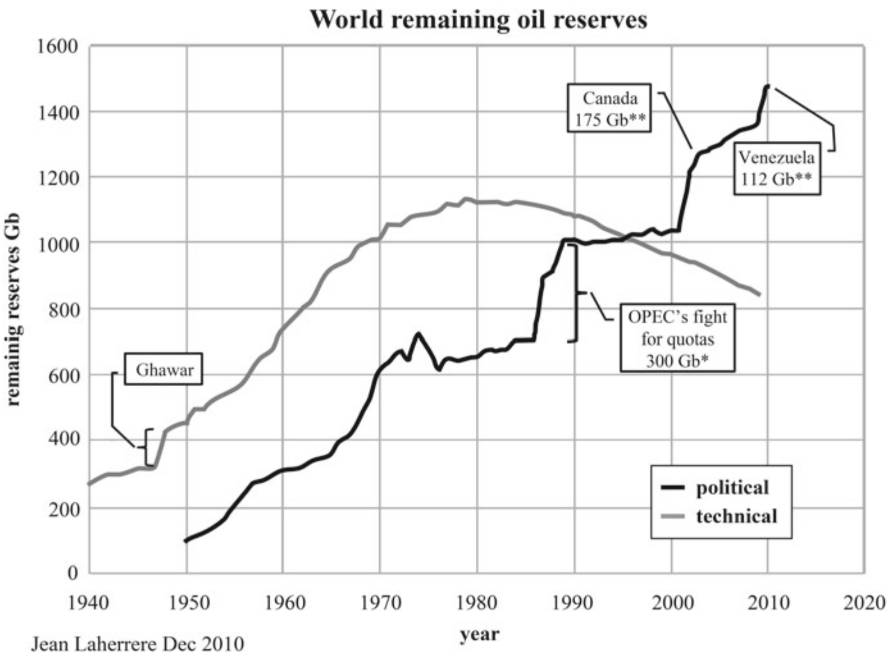

Fig. 6.2 Remaining oil reserves from technical and political sources showing OPEC fight for quotas (*) and the addition of Venezuelan and Canadian tar sands (**). Laherrère defines technical reserves as the addition of proven plus probable reserves (2P) dated back to the original date of discovery without extra-heavy oil; political reserves comprise only proven reserves (1P), include extra-heavy oil, and are not backdated; the initial difference between both curves comes from the omission of probable reserves in political sources and from the incorrect aggregation of reserves. Technical reserves peaked around 1980

oil regularly (US EIA 2012). Because reserves naturally drop as old fields are drained and jump when new fields are discovered, perfectly stable numbers year after year are highly implausible.

6.3 Unproved Reserves

Another source of systematic error in the commonly accepted statistics is the definition of reserves, which varies widely from region to region. In the USA, the Securities and Exchange Commission (SEC) allowed companies to call reserves "proved" only if the oil lies near a producing well and there is "reasonable certainty" that it can be recovered profitably at current oil prices, using existing technology. So a proved reserve estimate in the USA is equal to roughly a P90 estimate. We might consider these to be conservative estimates, as the eventual amount extracted will almost certainly be greater than these numbers. In 2010, the SEC changed the definition of reserves. Now instead of restricting proved reserves to the oil near producing wells, companies can use models to estimate the so-called proved reserves; for reasons of trade secrecy, the companies do not have to disclose precise details about the technology they used to estimate reserve sizes. It is interesting to consider the effect of this change of rules for the shale gas companies in the USA. The big breakthrough in shale gas does not come only from horizontal drilling and hydraulic fracturing technologies but also from the financial rules that allow overestimation of reserves. The goal of promoters becomes not only to produce gas but also to sell part of its interest to major companies such as Exxon, Total, Statoil, and the Chinese CNNOC. The majors, lacking new discoveries to compensate for their production, need "new reserves" on their financial report to prevent the fall of the price of their shares.

Regulators in most other countries do not enforce particular oil-reserve definitions. For many years, the former Soviet countries have routinely released wildly optimistic figures—essentially P10 reserves, which are equal to 3P reserves, that is, the sum of proved, probable, and possible reserves. Yet analysts have often misinterpreted these as estimates of "proved" reserves. *World Oil*-reckoned reserves in the former Soviet Union amounted to 190 Gb in 1996, whereas the *Oil and Gas Journal* put the number at 57 Gb (60 Gb at the end of 2010). This large discrepancy shows just how elastic these numbers can be.

Using only P90 estimates requires additional considerations that are not addressed in many cases. Adding what is 90% likely for each field, as is done in the USA, does not yield what is 90% likely for a country or for the entire planet. On the contrary, summing many P90 reserve estimates always understates the amount of proved oil in a region because the only correct way to total up reserve numbers is to add the mean estimates in each field. The mean estimates can be added because the sum of means yields the mean of the sum, or the total mean; this is not true for P90 estimates because the sum of numbers that occur with a probability 0.9 does not yield another number that will be observed with probability 0.9. For example, if you throw two dices, the probability of a five in each is 1/6, but the probability of getting two fives is 1/36, not 1/6. Moreover, there are several ways to get a ten from the sum of two dices (i.e., a four in the first dice and a six in the second, and vice versa), so a ten occurs with probability 1/12. Adding P90 values is equivalent to adding two fives, a shamefully flawed exercise.

In practice, the median estimate, often called "proved and probable," P50 or 2P reserves, is more widely used and is good enough for a decent estimate. The P50 value is the number of barrels of oil that are likely to come out of a well during its lifetime with probability 0.5—assuming prices remain within a limited range. Errors in P50 estimates tend to cancel one another out, although it is worth noticing that P50 values should not be added, due to the same reasons exposed previously for P10 and P90 values.

In 1998, Campbell and Laherrère were able to work around many of the problems plaguing estimates of conventional reserves by using a large body of statistics maintained by Petroconsultants in Geneva. This information, assembled over 40 years from a myriad of sources, covers some 18,000 oil fields worldwide. It, too, contains some dubious reports, but many errors were detected and corrected.

According to this information, the world had, at the end of 1996, approximately 850 Gb of so-called conventional oil in P50 reserves—substantially less than the 1,019 Gb reported in the *Oil and Gas Journal* and the 1,160 Gb estimated by *World Oil*. The difference was actually greater than it appeared because the value obtained by Campbell and Laherrère represented the amount most likely to come out of known oil fields, whereas the larger numbers were supposedly cautious estimates of proved reserves.

For the purposes of calculating when oil production would crest or peak, the size of ultimate recovery—that is, all the cheap oil there is to be had—is even more critical than the size of the world's reserves. In order to estimate that number, we need to know whether, and how fast, reserves are moving up or down. It is here that the official statistics become dangerously misleading.

6.4 Diminishing Returns

According to most accounts, world oil reserves have marched steadily upwards over the past 30 years (Fig 6.2). Extending that apparent trend into the future, one could easily conclude, as the US Energy Information Administration has, that oil production will continue to rise unhindered for decades to come, increasing almost two thirds by 2020.

As Campbell and Laherrère have explained, such growth is an illusion. About 80% of the oil produced today flows from fields that were found before 1973, and the great majority of these fields are declining. For example, in the 1990s, oil companies discovered an average of 7 Gb a year; in 1997, they extracted more than three times this amount. Yet official figures indicated that proved reserves did not fall by 16 Gb, as one would expect, but rather that they expanded by 11 Gb. One reason is that several dozen governments opted not to report declines in their reserves, perhaps to enhance their political cachet and their ability to obtain loans. A more important cause of the expansion lies in revisions: oil companies corrected earlier estimates of the reserves left in many fields with higher numbers, in particular P90 estimates that by definition were 90% likely to be exceeded. Operators decide to develop a field on the base of net present values (see Sect. 9.1.2) using mean reserves, whose probability is about 40–45%. Shareholders, however, like to have a 90% chance to recover oil, not the 40–45% that operators have to deal with. For financial purposes, such amendments are necessary, but they seriously distort forecasts extrapolated from published reports.

To judge accurately how much oil explorers will discover in the future, one has to backdate every revision to the year in which the field was first discovered—not to the year in which a company or country corrected an earlier estimate. Doing so reveals that global discovery peaked in the early 1960s and has been falling steadily ever since (Fig. 6.3). By extending the trend to zero, we can make a good guess at how much oil the industry will ultimately find.

Campbell and Laherrère used other methods to estimate the ultimate recovery of conventional oil for each country (see Sect. 6.8) and calculated that the oil industry

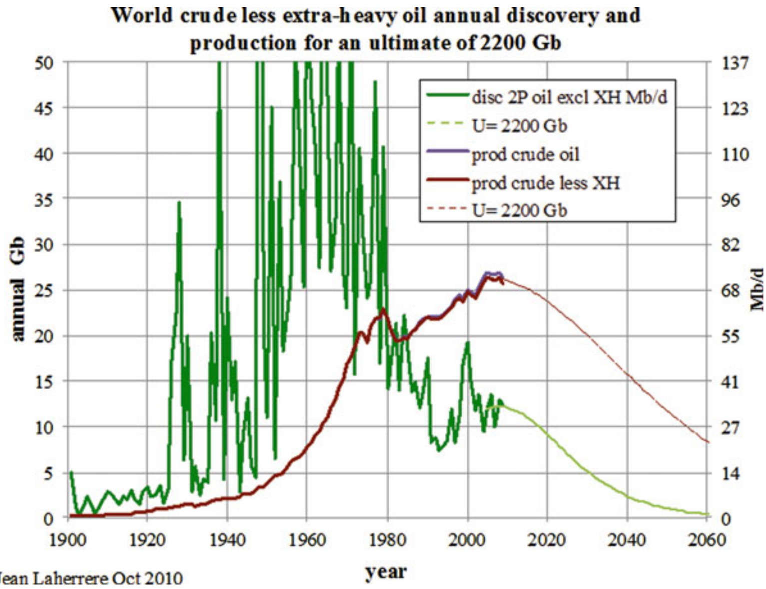

Fig. 6.3 Discovery, production, and projections for an ultimate recoverable (*U*) of 2,200 Gb. At any given year, the area beneath the production curve cannot be greater than the area under the discovery curve. Since the 1960s, discoveries have been decreasing, leaving small room for production to increase

would be able to recover only about another 1150 Gb of "conventional oil." This number, though great, is similar to the lower estimate of the oil that had already been extracted in 2005 (1,050 Gb).

It is important to realize that spending more money on oil exploration will not change this situation necessarily. After the price of crude hit all-time highs in the early 1980s, explorers developed new technology for finding and recovering oil, and they scoured the world for new fields. They found few: the discovery rate continued its decline uninterrupted. There is only so much crude oil in the world, and the industry has found about 90% of the oil lying in fields significantly large to make their exploitation energetically feasible. While there are locations that have not been well explored (e.g., Greenland, ultra-deep water) it is likely that the energy costs of much of this oil (if it is there) would be prohibitive, as the EROI of global oil and gas appears to be declining substantially already (Gagnon et al. 2009).

6.5 Predicting the Inevitable

Predicting when oil production will stop rising is relatively straightforward once one has a good estimate of how much oil there is left to produce; we simply apply a refinement of M. King Hubbert's technique. The global picture is more complicated

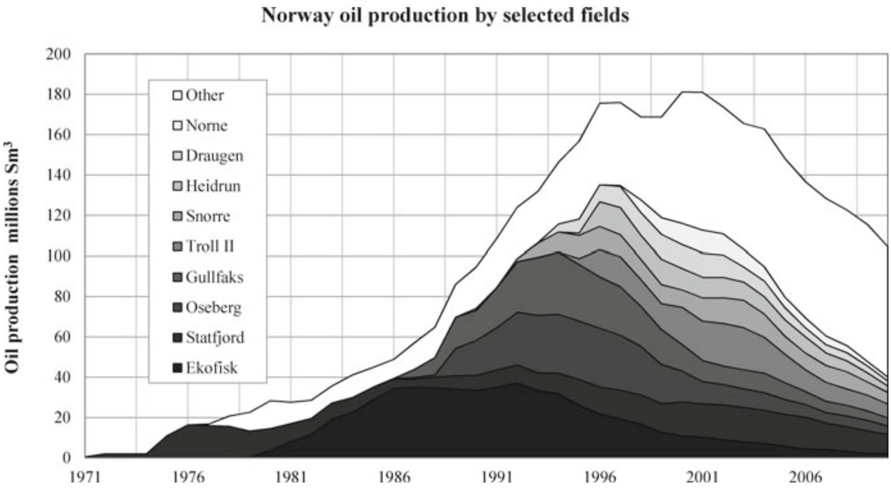

Fig. 6.4 Oil production in Norway showing production of selected fields. Norwegian oil helped to keep oil prices low in the 1990s; the decline of the Norwegian North Sea could not be replaced with other reservoirs after the year 2000

than is the case for an individual field or a nation because the Middle East members of OPEC deliberately reined back their oil exports in the 1970s, while other nations continued producing at full capacity. It is worth mentioning that, since 2002 or so, the world relies principally on Middle East nations, particularly five states near the Persian Gulf (Iran, Iraq, Kuwait, Saudi Arabia, and the United Arab Emirates), to fill in the gap between dwindling supply and growing demand.

The analysis of Campbell and Laherrère predicted that a number of the largest producers, including Norway and the UK, would reach their peaks around the turn of the millennium unless they sharply curtailed production. They did not, and the peak indeed has come to pass (Figs. 6.4 and 6.5). Campbell and Laherrère also had predicted that once 900 Gb had been consumed, production must soon begin to level off or even fall, and this has occurred indeed (Fig. 6.1). World production of oil indeed peaked during the first decade of the twenty-first century, as Campbell and Laherrère—and even Hubbert—had predicted. The situation has been complicated by the global recession and related financial issues, which have greatly decreased demand. So now we bounce along a bumpy plateau, with national economies contracting at about the rate of the oil wells so that "supply and demand" are maintained in approximate balance.

Perhaps surprisingly, the prediction of a peak sometime in the first 10 years of the new millennium does not shift much even if the estimates are a few hundred billion barrels high or low. Craig Bond Hatfield of the University of Toledo, for example, conducted his own analysis in 1997 based on a 1991 estimate by the US Geological Survey of 1,550 Gb remaining (55% higher than the figure of Campbell and Laherrère). Yet he concluded, similar to Campbell and Laherrère, that the world would hit maximum oil production within the 15 years following the year 2000.

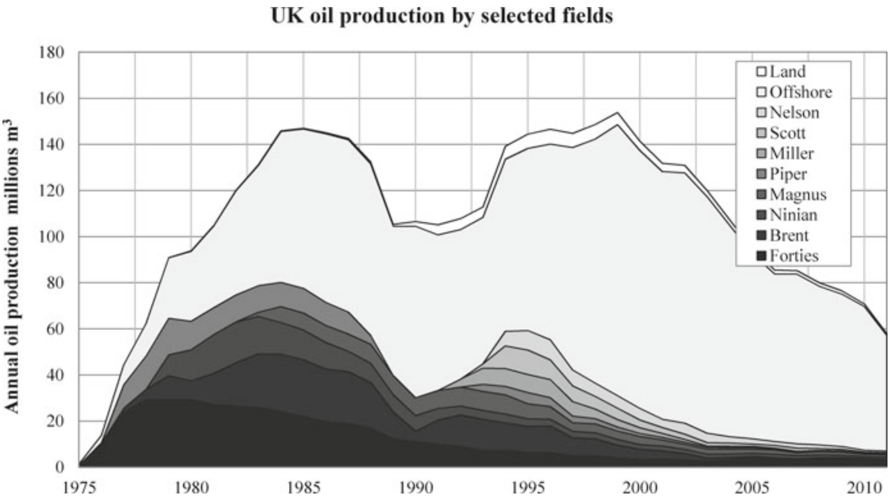

Fig. 6.5 Oil production in the United Kingdom showing production of selected fields. British oil contributed to bring the world out of the oil crises in the 1980s; despite the recovery in the mid-1990s, smaller reservoirs could not compensate for the decline of the British North Sea after the year 2000

John D. Edwards of the University of Colorado published, in 1998, one of the most optimistic estimates of oil remaining—2,036 Gb—although he conceded that the industry has only a 5% chance of attaining that very high goal. Even so, his calculations suggested that "conventional oil" would top out in 2020. At this time what is clear is that oil production, especially that of conventional crude oil, has ceased increasing since about 2005 despite growing prices. This is a remarkable fact and has many implications.

6.6 Smoothing the Peak

Factors other than major economic changes could speed or delay the point at which oil production begins to decline. Three in particular have often led economists and academic geologists to dismiss concerns about future oil production with naive optimism.

First, some argue, huge deposits of oil may lie undetected in far-off corners of the globe. In fact, that is very unlikely. Exploration has pushed the frontiers back so far that only extremely deepwater and polar regions remain to be fully tested, and even their prospects are now reasonably well understood. Advances in geochemistry and geophysics have made it possible to map productive and prospective fields with impressive accuracy. As a result, large tracts can be condemned as barren. Much of the deepwater realm, for example, has been shown to be absolutely non-prospective for geologic reasons.

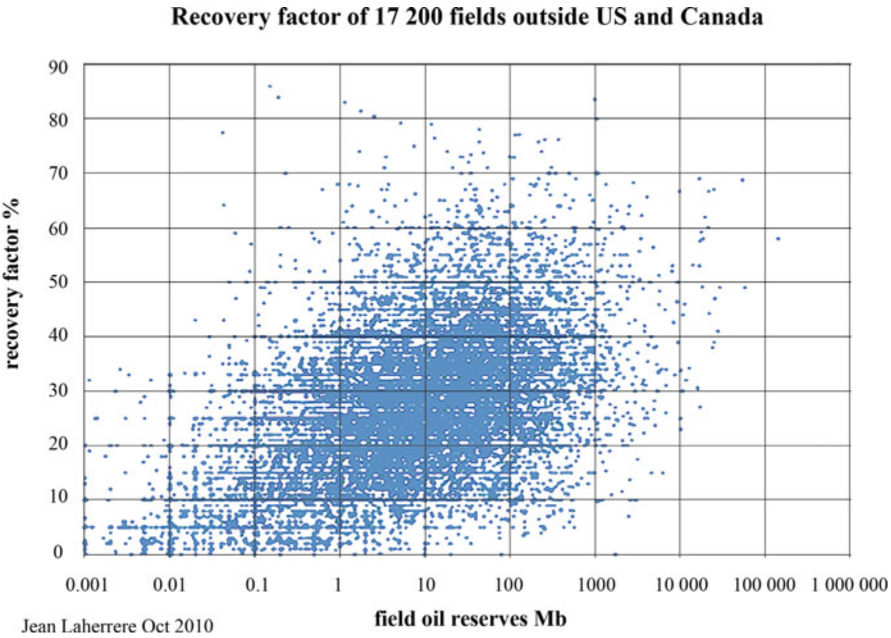

Fig. 6.6 Recovery factors (RF) and reserves by field; the horizontal axis is in logarithmic scale. RFs below 40% are more common than above 40%; also the RF in the smallest fields tends to be small too. Both variables have great dispersion with no apparent grouping around a single value

A second common rejoinder is that new technologies have steadily increased the fraction of oil that can be recovered from fields in a basin—the so-called recovery factor. In the 1960s oil companies assumed as a rule of thumb that only 30% of the oil in a field was typically recoverable; now they bank on an average of 40% or 50%. That progress will continue and will extend global reserves for many years to come, the argument runs. Recovery factors are often unreliable because the volume of oil in the reservoir is very hard to check even when the field is depleted. The range of recovery is huge, from less than 1% to almost 90%, with good fields being around 50%—as in the North Sea—but no apparent grouping around any value (Fig. 6.6). Hence, neither the mean nor the median is significant.

The dream of boosting recovery factors using technology is unrealistic: a poor field, which has a compact and tight reservoir with less than 3% porosity and about 1–2% recovery factor, cannot be transformed into a porous reservoir with a recovery factor of 50%. Technology allows us to extract oil at faster rates in poor reservoirs with horizontal drilling and hydraulic fracturing, but cannot change the geology of a rock. In other words, we may squeeze some oil drops from a bad reservoir but at a high cost. The ultimate limit for rational exploitation would not be any monetary index, but the amount of oil derived from a reservoir relative to the amount of oil—that is, oil-derived energy and materials—invested in it.

Of course, advanced technologies will buy a bit more time before production starts to fall. But most of the apparent improvement in recovery factors is an artifact of reporting. As oil fields grow old, their owners often deploy newer technology to slow their decline. The fall off also allows engineers to gauge the size of the field more accurately and to correct previous under- or overestimation.

Another reason not to pin too much hope on better recovery is that oil companies routinely count on technological progress when they compute their reserve estimates. In truth, advanced technologies can offer little help in draining the largest basins of oil, those onshore in the Middle East where the oil needs no assistance to gush from the ground.

Last, business analysts like to point out that the world contains enormous caches of "unconventional oil" that can substitute for crude oil as soon as the price rises high enough to make them profitable. There is no question that the reserves are ample: the Orinoco oil belt in Venezuela and the tar sands and shale deposits in Canada and the former Soviet Union contain a vast amount of recoverable hydrocarbons. However, their exploitation is not as profitable as that of regular oil, and even the prospects to develop them support the main thesis: cheap oil is over.

Theoretically, these unconventional oil reserves could quench the world's thirst for liquid fuels as conventional oil passes its prime. But the industry is under hard pressure to get the money needed to ramp up production of unconventional oil quickly enough. An excellent assessment of these and other possibilities for replacing oil was undertaken by Hirsch and colleagues in 2005, who concluded that the time to undertake any such transition would be so long that such a replacement needs to start well before the peak even if any replacement is possible and the enormous capital investments are made available.

Additionally, most substitutes for crude oil would exact a high environmental price. Tar sands typically are extracted from strip mines. Extracting oil from these sands and shales creates a great deal more air and water pollution than oil. The environmental costs of extracting Canadian tar sands are already restricting its expansion. The Orinoco sludge contains heavy metals and sulfur that must be removed, so governments may exercise their right to restrict these industries from growing as fast as they could. In view of these potential obstacles, Laherrère's estimate is that only 500 Gb will be produced from unconventional reserves, a significant amount, to be sure, but not enough to be a game changer.

6.7 On the Downside

Until 2008 global demand for oil was rising at more than 2% a year. Much of the increased demand has been in developing countries. Since 1980, oil consumption is up about 50% in Latin America and 100% in Africa and Asia, according to the Energy Information Administration. In its *2010 International Energy Outlook*, this agency, in the "reference case," forecasts further growth in consumption of liquid fuels in non-OECD Asia, North America, Central and South America, and the Middle East, all of which amount to a 30% increase by 2035 (110 Mb/d) from the levels of 2007. The International Energy Agency made a similar statement for "oil"; in the "Current Policies Scenario" analyzed in the *2010 World Energy Outlook*, the demand for "oil" is more than 107 Mb/d in 2035, an increase of 28% from the 2009 levels (IEA 2010). In our opinion this demand will be too difficult to fill.

The switch from growth to stasis in oil production already has created economic and political tension, such as the economic crisis of 2008 whose effects are still felt throughout the world. Unless alternatives to crude oil quickly prove themselves, the market share of the OPEC states in the Middle East will continue to rise rapidly. These nations' share of the global oil business passed 50% in 2005, way beyond the level reached during the oil price shocks of the 1970s. While there have been many calls for reducing energy dependence in the USA and elsewhere (indeed by the last eight US governments) the fact is that oil and gas provide almost the same percentage of fuel for the USA as they did in 1970, except this time there is more and more oil and gas coming from overseas.

As Campbell and Laherrère forecasted in 1998, the world has seen radical increases in oil prices, changes far beyond what most had thought within the realm of possibility. That alone was sufficient to curb demand, flattening production into the bumpy plateau where we are now, vindicating their previous arguments. Demand fell more than 10% after the 1979 oil shock and took 17 years to recover; it is impossible to guess when it will recover this time, but by now, many Middle Eastern nations are themselves facing their own midpoint of production. We are quite certain that, should economies recover, world oil production will be unable to grow to any significant extent. As the US National Petroleum Council stated in 2007, "the new dynamics may indicate a transition from a demand-driven to a supply-constrained system" (US NPC 2007).

The transition to the post-oil economy need not be traumatic. If advanced methods of producing liquid fuels from natural gas can be made profitable and scaled up quickly, gas could become the next source of transportation fuel. Indeed, it is possible to power automobiles from natural gas, although it can cover only about half the distance that gasoline-powered cars can cover. Safer nuclear power, cheaper renewable energy, and oil conservation programs could all help postpone the impacts of the inevitable decline of oil. A serious problem is time, for countries should have begun planning and investing some years ago. As of 2012, the vigorous initiatives that are required have not appeared either from the governments or from the private sector. At this point, it seems that the burden will be deposited on the civil societies.

The world is not running out of oil—at least not yet. What our societies are facing is the end of the abundant, cheap, and expanding oil supplies on which all industrial nations have come to depend.

6.8 The Methodology Used by Campbell and Laherrère in 1998

In 1998, Campbell and Laherrère combined several techniques to conclude that about 1,000 Gb of conventional oil remained to be produced. First, they extrapolated published production figures for older oil fields that had begun to decline (see Sect. 7.3.3). According to these calculations, the Thistle field off the coast of Britain, for example, would yield about 420 Mb. In May 2011, the cumulative production of

Thistle was 412 Mb; the field is still producing a mix of oil and 96% water. Second, the amount of oil discovered so far in some regions was plotted against the cumulative number of exploratory wells drilled there. Because larger fields tend to be found first—they are simply too large to be missed—the curve rises rapidly and then flattens, eventually reaching a theoretical maximum (see Sect. 7.3.1). Third, Campbell and Laherrère analyzed the distribution of oil-field sizes in the Gulf of Mexico and other provinces. Ranked according to size and then graphed on a logarithmic scale, the fields tend to fall along a parabola that grows predictably over time (Laherrère 2000). Interestingly, galaxies, urban populations, and other natural agglomerations also seem to fall along such parabolas (Laherrère 1996). Finally, the estimates were checked by matching the projections for oil production in large areas, such as the world outside the Persian Gulf region, to the rise and fall of oil discovery in those places decades earlier (Campbell and Laherrère 1998).

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