PANORAMA 2010

a look at ...

Update on hydrocarbon resources

1 - Petroleum liquids*

The level of current oil reserves would not be able to sustain the present pace of world production in the long run. Even in an energy transition context, it remains vital to mobilize new reserves to prevent a sharp decline in production. This requires the convergence of a number of technical, human, financial and political factors.

Hydrocarbons continue to be major energy sources

Today, oil and gas represent more than 60% of the primary energy supplied to the 6.5 billion inhabitants on earth. Whether used for energy production, heating, transport or as a source of raw materials, they are not easily or massively replaced. In the years to come, the world population and average per capita income are expected to rise, which will increase world demand for energy and therefore hydrocarbons. In light of the slow development of alternative energies, oil and gas will remain dominant in the next few decades. Under these circumstances, the matter of ultimate recoverable reserves continues to be of vital concern.

Review of basic concepts

Reserves and resources: clear definitions and very restrictive concepts

We will use the following terms, consistent with the definitions adopted by the Society of Petroleum Engineers (SPE) and the World Petroleum Congress (WPC):

- ultimate reserve, the quantities generated over geological time and contained in the terrestrial subsurface. The quantities inside a geological formation are referred to as "resources in place". This includes what has been, what is going to be and what will never be produced. The evaluation of ultimate reserves involves carrying out material balance calculations for sedimentary basins, to estimate the status of exploration there, and also for geological formations, to estimate the quantities in place, quantify the recovery rate and undertake (or not) to improve it,
- contingent ressources, the producible quantities contained in current discoveries not yet programmed for production,
- potential resources, the producible quantities contained in undiscovered accumulations,
- current ressources, the volumes remaining to be produced, located exclusively at geological formations under production or about to come onstream, which are subject to existing economic and technical conditions. They make up only a portion of the volumes contained in said geological formations. The remaining quantities are known as non-producible resources; a portion of the latter will never be produced and be referred to as "trapped",
- additional reserve, the volumes that have become producible to the detriment of resources initially classified as non-producible. They reflect improvements made in the recovery rate by implementing methods of production that offer better performance,
- new reserve, these quantities are obtained by bringing new fields into production. In other words, they change categories, from "contingent and/or potential resources" to "reserves".

Any change in technical or economic conditions leads to changes in the announced figures, which are revised up as soon as a change improves exploration or production performance.

Quantities are estimated, not measured

It is quite a challenge to determine, with exactitude, the reserves and resources contained in the more than 25,000 hydrocarbon accumulations disseminated across the surface of the earth. Published figures are estimates that are even more subjective because they are based on partial data and announced by hundreds of different operator companies that may or may not be obliged to have them certified.

** Petroleum liquids are defined as crude oil and condensates (the heaviest natural gas liquids or C_{5+})*

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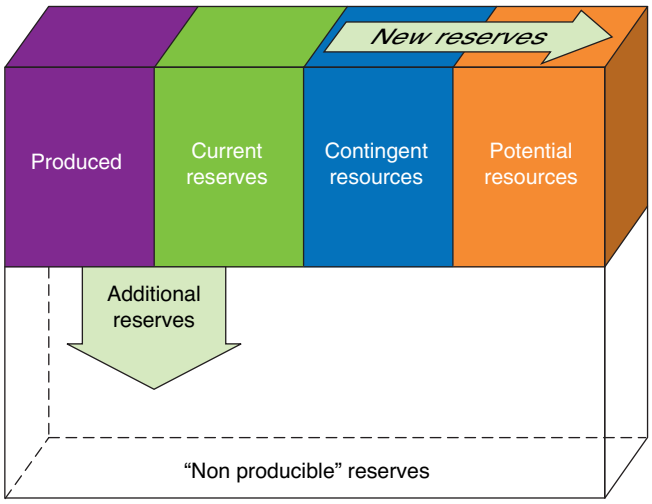
Fig. 1 - The categories of reserves and resources that make up ultimate resources



Source: IFP, from JPG and WPC

Resources and reserves are calculated using parameters about which knowledge is limited and uncertain, such as: the exact geometry of the traps, the quality of the reservoir rock, the hydrocarbon content and the rate of recovery.

Estimates are made using two methods of calculation: the deterministic and the probabilistic. The deterministic method yields a single value that, according to the oil companies, corresponds to high-certainty values for resources and reserves. The probabilistic method provides the continuum of all possible values ranging from the minimal values for the various parameters (100% chance of existing) to the maximum values (0% chance of existing), and therefore a succession of values that increase as the probability of their existence decreases. The calculated reserves are called:

- 1P (proved). These reserves, associated with a high degree of certainty, are referred to as P90 when using the probabilistic method, because they correspond to quantities that have a 90% chance of existing,
- 2P (proved + probable). The quantities computed are larger and the degree of uncertainty is higher. These reserves are known as P50 when, using the probabilistic method, they have a 50% chance of existing,
- 3P (proved + probable + possible). They are called P10 when they only have a 10% chance of existing when using the probabilistic method.

For a field under development, the reserves announced corresponds, according to the oil companies, to the proved reserves or 1P, i.e. quantities with reasonable certainty of being recovered under current economic and technical conditions. As development proceeds, more and more data become available so that initial estimates can be refined and 1P reserves updated. Experience shows that this process of revising estimates yields final numbers that are close to the initially computed 2P reserves.

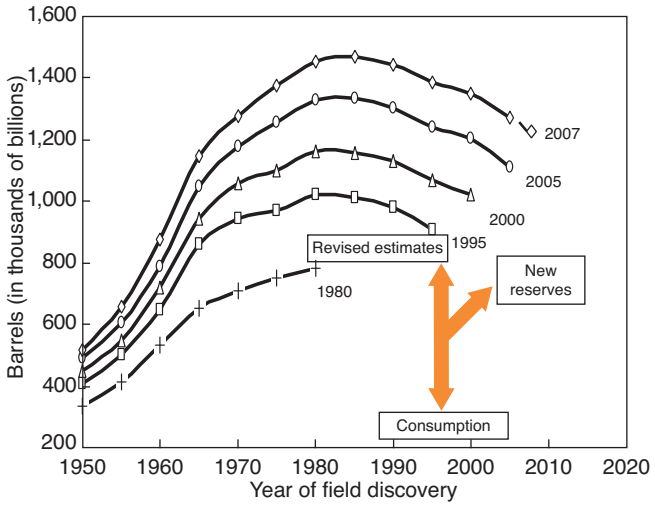
Reserves are in a constant state of change

Reserves are calculated and not measured. For any given accumulation, they will depend on the means of production implemented. In other words, they are revised with each technical and economic advance and are subtracted from produced volumes. Reserves are always the product of the competition between produced volumes and the volumes added when revising estimates. Added volumes might originate in gains from a positive revised estimate of economically extractable volumes, improved recovery rates (additional reserves) or production starts at new fields (new reserves).

For oil, these conditions are repeated at more than 15,000 fields operated by about a hundred oil companies in more than 133 countries. It is impossible to arrive at figures presenting a high level of certainty. The published figures are estimates at a specific point in time and will inevitably change. This can be seen in Figure 2, which shows the curves for extractable resources (current reserves + contingent resources) estimated in different years, depending on the dates of field discovery. This manner of grouping liberates one from the changes incurred when contingent resources are transformed into reserves. Figure 2 underscores that:

- the bulk of resources still extractable were discovered before 1970,

Fig. 2 - Trends in extractable quantities of oil for different periods, depending on the date of discovery



Source: IHS

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- published estimates are always being revised, even for the volumes contained in accumulations discovered more than 50 years ago,
- quantities announced today must be revised tomorrow. It is thought that initial estimates are always low by more than 100 billion barrels (Gbbl), at the very least,
- extractable resources peaked in about 1980 according to estimates made in 1995, but estimates revised in 2007 situated the peak in about 1985. These maximum values show that, since then, production has exceeded the replacement of reserves.

Reserves of petroleum liquids at the end of 2008

The term "petroleum liquids" covers crude oil and condensates, i.e. the heaviest natural gas liquids (or C_{5+}).

Reserves with a strong strategic connotation

World demand for energy, hence oil and gas, is growing. The possession of reserves and resources in large quantities confers economic and strategic weight of the first order upon owner countries. Some countries may be very tempted to blur the distinction between reserves and contingent resources, or to simply overestimate their reserves, which is why published figures are often disputed.

Reserves, disputed but not exaggerated

There are many and various reasons to dispute reserve estimates, including issues relative to quantification, qualification and certification:

- quantification can be refined as more is learned about a field, i.e. the further the field proceeds in its development and life span,
- as for qualification, the biggest problem lies in the lack of distinction between current reserves and contingent resources. It may be that the published reserves are overestimated in anticipation of the investments required for their production,
- for most oil companies, the certification of reserves is not mandatory. 80% of all extractable reserves are held by national companies, which generally are under no obligation to have their published figures certified.

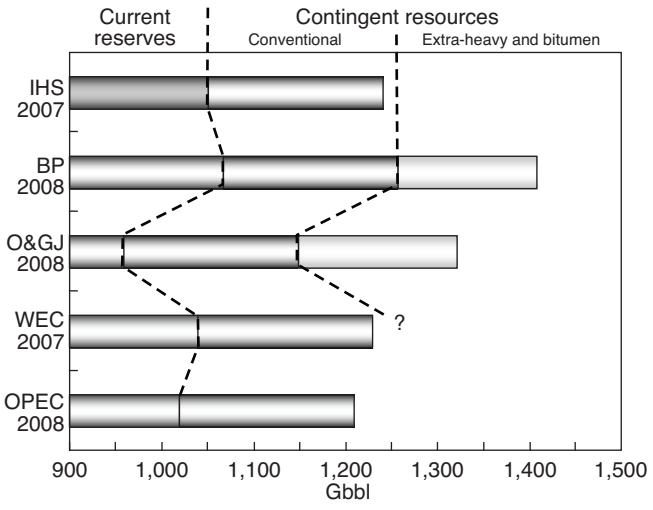
This situation is the source of many disagreements over the relevance of reserves declared by some of the OPEC countries. This impression was reinforced in the late 1980s when the Emirates, Iran, Iraq, Kuwait and Saudi Arabia revised their reserves up massively following the collapse of oil prices. The purpose of increasing their reserves was to boost their export potential following the introduction of production quotas, calculated pro rata based on the reserves of each country. Does this mean that announced reserve estimates are unrealistic? Not at all. It must be remembered that these countries have changed from a restrictive method of calculating reserves – only counting recoverable quantities at fields provided with production installations – to a broader one.

Estimates of world extractable resources published by the main sources of information vary tremendously (Figure 3). After cross-referencing the data and making extrapolations based on past production, we have good reason to think that current world reserves (not including contingent resources) are situated somewhere between 960 Gbbl (*Oil & Gas Journal*, or O&GJ) and 1,060 Gbbl (BP), equivalent to 32 to 35 years of production at actual levels of consumption. If we include the contingent resources contained in new discoveries, these estimates would exceed 1,150 Gbbl and attain 1,240 Gbbl, respectively. If we then factor in extra heavy crudes and Canadian tar sands, they would exceed 1,300 and might reach 1,400 Gbbl.

Reserves, concentrated in a small number of countries

More than the controversy over estimates, it seems important to stress that these reserves are concentrated in a small number of countries. Saudi Arabia ranks first with more than 20% of reserves, followed by Iran, Iraq and Venezuela, four countries holding more than half of the world's reserves. Three-quarters of world reserves are found in only 11 countries, including the largest consuming country, the United States. The remaining quarter is distributed among 122 countries (Figure 4).

Fig. 3 - Published estimates for reserves and contingent resources



Source: IFP, from IHS, BP, O&GJ, WEC and OPEC

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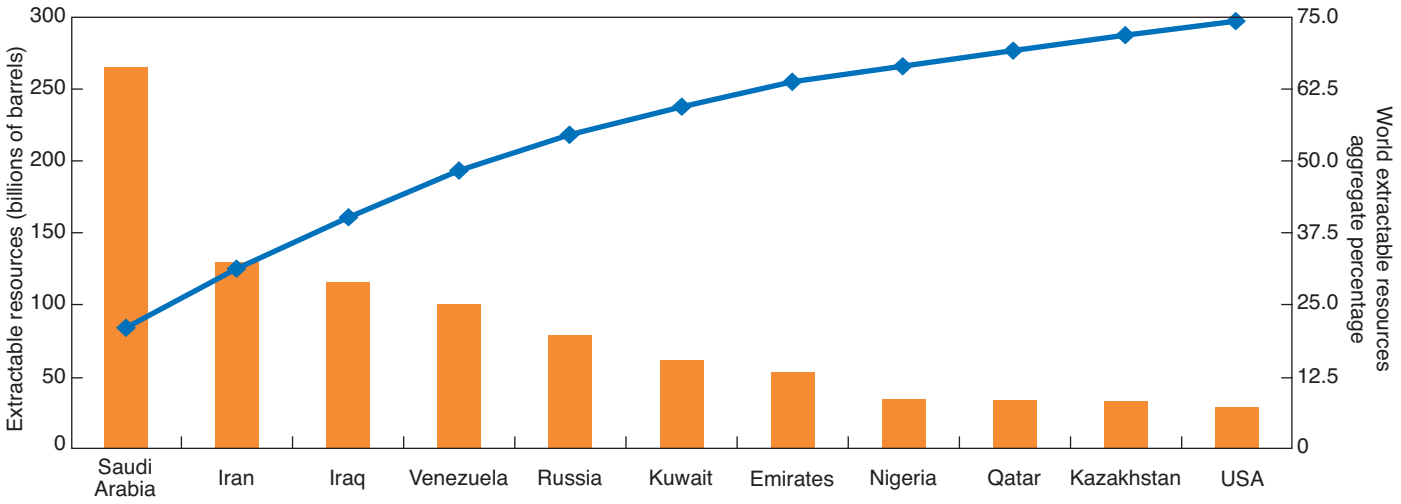
Fig. 4 - The 11 countries richest in extractable petroleum liquid resources



Source: IFP, from IHS

The Middle East, taken as a whole, holds about 54% of world reserves, followed by Russia and Central Asia (15%), South America (10%), Africa (8%), North America (6%), Asia-Pacific (5%) and Europe (2%). Using another mode of segmentation, OPEC contains 67% of the extractable resources, the CIS 15%, OECD countries 8% and other countries (e.g. Brazil, China, India and Pakistan) about 10%.

The escalating search for future reserves

Additional reserves

With the exception of regions to which access has been gained only recently (e.g. deep offshore, sedimentary formations buried at very great depths), the discoveries of the last 30 years have been located in geological formations that are increasingly small, deep and complex and therefore increasingly hard to detect. Not since the 1980s have world reserves been replaced by new discoveries alone (Figure 5). Today, more than two-thirds of the annual renewal of world reserves comes from revising up the reserve estimates for existing fields. By simply revising the 1P reserve estimates for fields already under production or in the process of coming onstream, one would be likely to obtain an increase of 100 to 200 Gbbl. The increase is expected to come from drilling new wells (e.g. straight, horizontal, multi-drain and multiple completions) and from implementing modes of recovery offering better performance. It is important to recall that today, on average, only one-third of the oil contained in a reservoir is recovered. A one-point increase in the world rate of recovery is equivalent to nearly two years' worth of consumption. There are a number of ways to improve this rate: gain more knowledge about the characteristics of a reservoir and its heterogeneities, simulate flow more systematically or inject various products. There are three main categories of production:

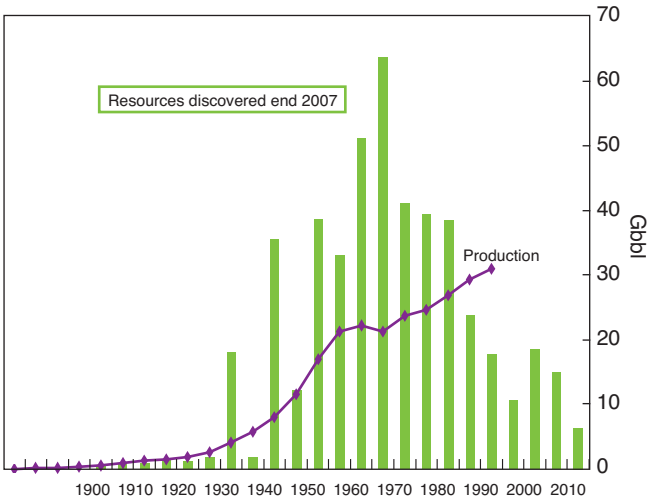
- primary production consists simply of pumping oil. The recovery rates are variable but average less than 20%. One-fifth of the world's oil production falls into this category,
- secondary production involves injecting water, which brings the average recovery rate up to 30%. Two-thirds of the oil produced in the world is extracted using this technique,
- tertiary production calls for adding chemicals to the water or injecting gas (air, carbon dioxide or gas produced). It brings the average recovery rate up to 33% and is only used at 15% of existing oil fields. In some cases, it boosts the recovery rate to 70% (Ekofisk).

The general shift from primary production to secondary, and then to tertiary, is expected to contribute additional reserves in non-negligible quantities. However, this shift is limited by two criteria: the availability of products to be injected and the extra-cost incurred. Today, many specialists estimate that there are roughly 200-300 Gbbl in additional reserves.

New reserves

The potential for new discoveries of conventional oil remains high, because some regions of the world have seen little or no exploration: the Arctic, deep offshore and ultradeep zones (onshore and offshore), but also reservoir traps that have never been explored because they were difficult to detect (e.g. tectonically complex

Fig. 5 - Discovered resources and five-year production averages



Source: IFP, from IHS

areas and stratographic traps). Improvements in seismic prospection tools and advances in our knowledge of sedimentary basins and their modeling, used to reconstitute the geological and development history of oil-bearing basins, have broadened the scope of exploration. A case in point: the fabulous discoveries off the coast of Brazil (e.g. Tupi and Carioca) would not have been possible only a few years ago. Each of these discoveries, made at depths of more than 2,000 meters of water and located beneath 5,000 meters of sedimentary cover, contain announced reserves of several billion barrels oil equivalent.

The so-called "unconventional" oil should also permit access to large new reserves:

- tar sands and extra-heavy oil, very dense and viscous hydrocarbons, represent nearly 4,000 Gbbl of resources in place, nearly 600 of which could eventually be recovered. They are already developed in Venezuela and Canada and may eventually be in other parts of the world (e.g. Russia and Nigeria). However, large quantities of energy and water are required to mine and process these resources to produce a syncrude suitable for use at any type of refinery. Their future production will be constrained by the availability of water and energy. Considering the additional costs incurred and the environmental challenges involved, the development of the 600 Gbbl of extractable resources proceeds at a slow pace. BP, the *O&G Journal* and a few others have announced reserves of between 151 and 173 Gbbl, but these figures are heavily disputed. The great majority of the quantities announced, which have been located and therefore discovered, are contingent resources and not reserves. New techniques will have to be developed to reduce the cost of exploiting these oils as well as their environmental impact,
- other important resources: bituminous shales whose development involves producing from immature source rock, i.e. completing (*via* pyrolysis) what Nature has left unfinished. With 3,000 Gbbl equivalent in place, these shales could eventually yield large quantities of hydrocarbons. In the past, they have been used locally and on a temporary basis to produce motor fuels and, especially, to fuel thermal power plants (Estonia). Today, the development of these resources is highly problematical because it is very expensive (>$100/bbl) and has some of the most negative effects on the environment (e.g. it destroys the landscape, pollutes the air, generates ash particles and pollutes the environment with heavy metals). However, new projects are under study, especially the Green River project in the United States, where they may contribute to the effort to reduce energy dependence.

In conclusion, current reserves – situated between 960 Gbbl (O&GJ) and 1,060 Gbbl (BP) – could, with the various other resources, exceed 1,600 Gbbl or even reach 2,000 Gbbl. The breakdown of these 1,600 or 2,000 Gbbl in the future would be practically the same as it is today (Figure 6), with the Middle East showing a marked predominance. The Middle East would nevertheless see its share decline from 57% to 48% in favor of Africa, South and North America and Asia-Pacific, whereas the reserves of the CIS countries and Europe would weigh in at similar levels.

The question here is: What constraints may limit the transformation of these resources into reserves?

Constraints likely to limit future reserves

The transformation of resources into reserves is subject to different constraints:

- geopolitical and regulatory: the right political, legal and tax conditions must exist. Political risk can substantially inhibit exploration and production starts at new accumulations, as has been the case in Iraq for the last 30 years. Furthermore, it must be feasible to build systems for shipping hydrocarbons to consumer markets. The fact that pipelines must sometimes routed through unstable countries in order to get oil and gas out of landlocked countries can significantly hinder resource development (e.g. countries on the Caspian Sea),
- affecting the level of investment: the discovery, development and shipping of oil and gas absorb very large

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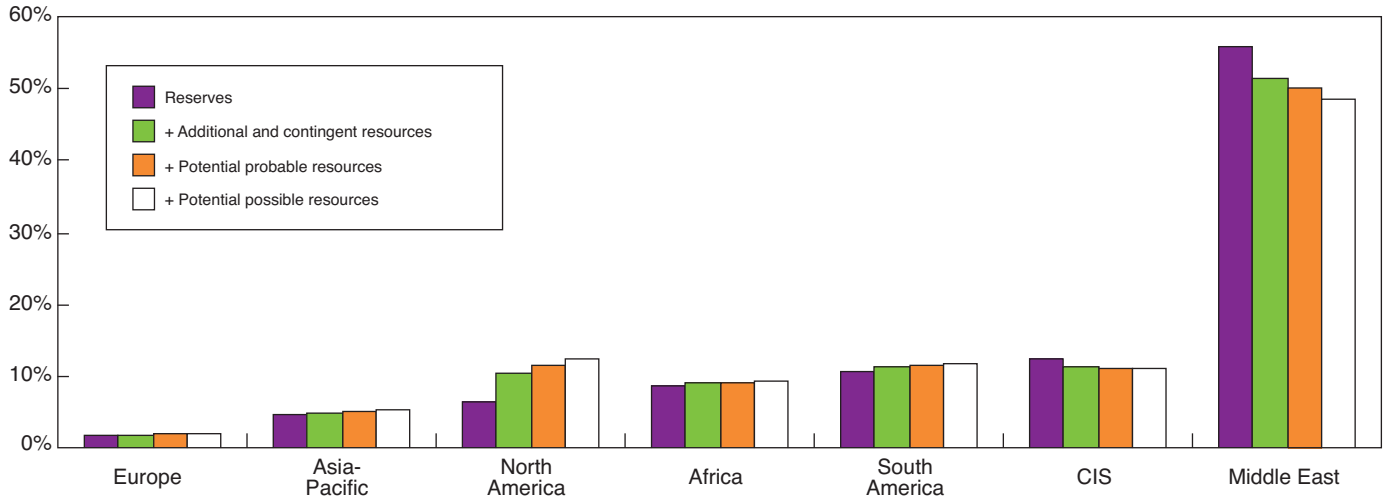
Fig. 6 - Breakdown of current reserves and the future anticipated reserves for major geographic regions



Source: IFP

amounts of capital, estimated at $410 billion for 2009 (see Panorama article: "Activities and Markets in Exploration-Production"). In many countries, the availability of local financing is not assured or is inadequate. Only an injection of foreign funds could make it possible to undertake the desired developments. This raises a question about the extent to which these countries are actually open to foreign investors,

- technical and humain: increasingly sophisticated technical know-how and expertise are needed to develop oil resources, conventional or unconventional, which have become harder to find and produce,
- market: the oil price situation has a strong influence on the level of investment and the development of reserves,
- environmental: Alaska and the unconventional crude sector are cases in point.

What will the oil production curve look like?

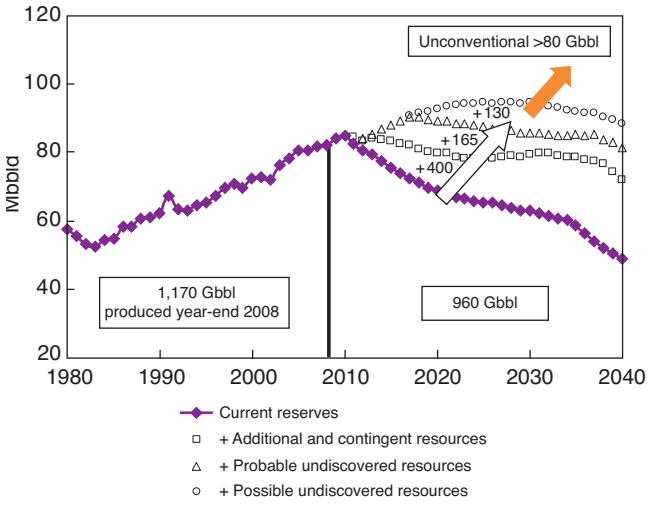
Given the number of parameters and unknowns, it is not easy to come up with a world production curve for the decades to come. A number of profiles have been published, some bell-shaped and others following a more or less dissymmetrical plateau, with production peaking at 85 million barrels a day (Mbbld) in 2010 according to the more pessimistic scenarios (Campbell) and 107 Mbbld in 2030 in the more optimistic ones (IEA).

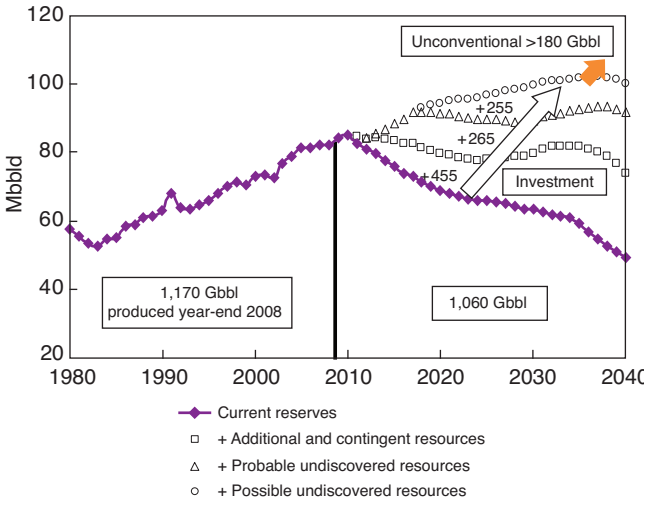
Production scenarios fall into two main groups. Those in the first group are based on conservative hypotheses for current and future reserves: 960 Gbbl and 695 Gbbl, respectively (Figure 7), while those in the second group rely on more optimistic figures: 1,060 Gbbl and 975 Gbbl, respectively (Figure 8). In both instances, the production scenarios presented are aggregates of production scenarios for the top 97 producing countries. For countries that have not yet reached their production peak, production was calculated to reach its maximum with annual pre-peak growth not exceeding 2% on average.

These two types of scenario underscore the strong interaction between production and the replacement of reserves:

- if reserves are not renewed, production is expected to decline in about 2011. This is perfectly logical, because it takes constant investment to produce more or as much, which is what oil companies are doing. This scenario corresponds to a halt in exploration, i.e. a reduction in capital expenditure of 15 to 20%,
- if reserves are renewed, it may be possible to defer decline. To do so, the level of investment would have to be maintained, or steadily increased, as has been done historically (see article: "Activities and Markets in Exploration-Production"). It is estimated that bringing additional reserves and contingent resources onstream would maintain the 2008 level of production through 2014, then keep daily production in the vicinity of 80 Mbbld through about 2035 (Figures 7 and 8). Production could only be augmented by calling on new reserves. Bringing undiscovered probable resources into production could help boost extracted resources to 90 Mbbld by about 2017 (Figure 7) or 91 Mbbld by 2018 (Figure 8). Bringing possible resources onstream would yield, in both cases, a slight rise in the world production plateau that could reach 94 Mbbld by 2027 (Figure 8) or 101 Mbbld by 2034. Finally, it is thought that producing unconventional oils on a more massive scale would, in both instances, serve more to slow down the decline of production than to increase its level.

Fig. 7 and 8 - Conservative scenarios for the production of oil and condensates, depending on the efforts undertaken to produce them





Source: IFP

Conclusion

Current world reserves (oil and condensates) are situated between 960 and 1,060 Gbbl. They are lower than the reserves already produced, which suggests an imminent decline in world production (consistent with results obtained by countries having observed similar remaining/produced reserves ratios). The expected decline in current reserves is not surprising; however, unlike the situations occurring in the past, it can only be deferred by the arrival of high-tech oils. Rates of recovery must be improved; new reserves must be extracted from geological formations that are smaller, deeper and more complex; and the proportion of unconventional oils is on the rise. To develop these new reserves, the level of capital investment and sophisticated technical expertise must be maintained or increased. Depending on the intensity and speed of their implementation, world production of petroleum liquids could be maintained at 80 Mbbld until about 2035 (pseudo plateau), or slightly increased (bumpy plateau) through 2027 (94 Mbbld) or 2035 (101 Mbbld). These forecasts cover the supply derived exclusively from oil and condensates. To meet demand, petroleum liquids will have to be produced from other sources as well, such as biomass, gas (GTL) or coal (CTL), which are not covered in this paper.

It is important to recall that variations in the world oil production profile depend not only on the availability of reserves and resources, but also on major changes in demand, which can have a strong impact. For all scenarios considered, it will not be possible to step up the pace of daily production unless reserves from new discoveries make a rapid appearance on the scene.

Finally, the efforts to mobilize new resources and the attendant investments are crucial to ensuring an energy transition period that is globally acceptable as well as politically and economically desirable.

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