Update on hydrocarbon resources

2 - Natural gas

Current gas reserves could sustain a slight increase in world production until 2020. The development of all existing conventional resources would bring them up to about 4.5 Tm^3 by 2030. The effect of a generalized development of unconventional gas resources would be to slow down rather than postpone the decline in production.

Natural gas reserves at year-end 2008

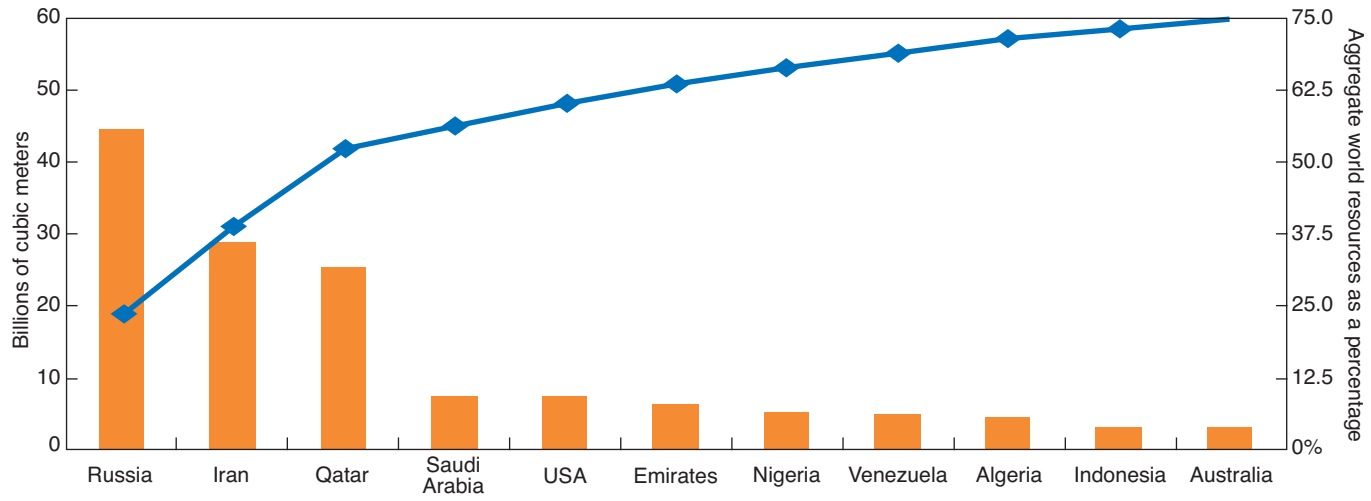
Undisputed estimates

The announced volumes for natural gas, compared to those for oil, are much more reliable and therefore estimates only differ slightly. There is little controversy because, thanks to a basic difference in behavior between gases and liquids, these volumes can be determined. Natural gas is produced by decompressing the gas in place. As soon as the volumes produced cause pressure to decrease by a sufficient amount within the geological formation, the remaining extractable quantities can be determined with precision. It follows that revised estimates differ only slightly from the original ones and these differences generally account for the discovery of initially unsuspected extensions (satellite fields or new levels of the reservoir). According to IHS, the world's extractable resources stand at 200 Tm^3 (tera cubic meters or 10^{12} m^3), which includes 182 Tm^3 of current reserves. This number is close to other published estimates: 175 Tm^3 (Oil and Gas Journal), 189 Tm^3 (Cedigaz) and 185 Tm^3 (BP Statistical Review 2009). The low figure of 175 Tm^3 represents large reserves, representing nearly 60 years of consumption at the 2008 level. These estimates vary according to technical and economic conditions.

Unevenly distributed resources

For natural gas, like oil, 11 countries possess 75% of world gas resources (Figure 1). Russia holds nearly one-quarter of the total, followed by Iran and Qatar with 15% and 14%, respectively. The 111 other countries only have 25% of the world's extractable resources.

Fig. 1 - The 11 countries richest in extractable gas resources



Source: Cedigaz, 2009

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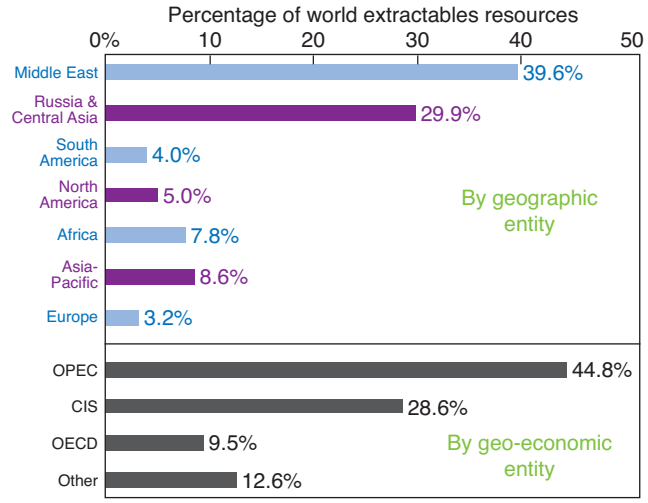
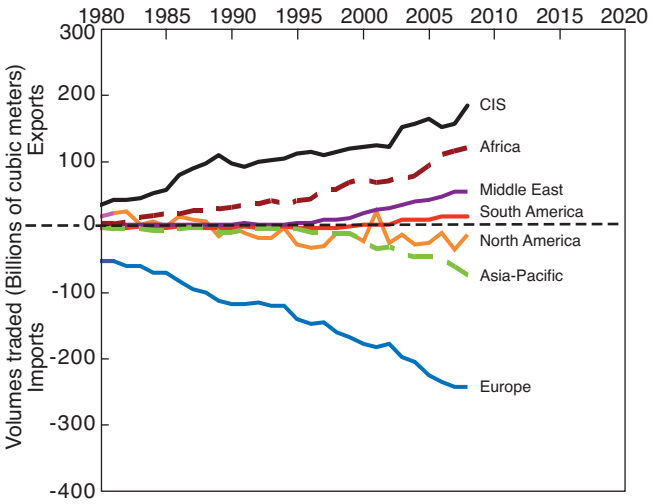
Fig. 2 - Breakdown of extractable gas resources by large geographic or geo-economic entity



Source: Cedigaz

Fig. 3 - Volumes traded over time between major geographic regions



Source: IHS

Resources are distributed very unevenly: the following breakdown by large geographic or geo-economic entity (Figure 2) shows that most are located in the Middle East and the OPEC countries, followed by member states of the CIS.

This disequilibrium of resource distribution means that large volumes must be traded between major geographic regions (Figure 3). By producing unconventional gas, North America has managed to keep its natural gas imports to the same level, but the same cannot be said for Asia-Pacific and especially not for Europe. The other regions are exporting more and more gas.

Considering the growth rate expected for world demand, what can be said about the quest for future reserves and the evolution of interregional flows?

The search is on for future reserves

Although the largest fields were discovered more than 30 years ago, there is still high potential for the discovery of new accumulations, hence new reserves. At the time, discovering gas fields was not a top priority for a good number of geographic regions and countries. Gas exploration was long inhibited by the absence of local or regional markets to make it commercially attractive. The only objective was to discover oil: finding water was vexing and finding gas was often a major constraint. Therefore, exploration operations tended to be sited far from gas-bearing regions. One example is the fabulous North Field in Qatar (more than 150 Tm^3), discovered in 1971 by Shell and returned to Qatar due to the lack of commercial outlets.

While the potential for new discoveries remains high, expectations of obtaining additional reserves by improving the recovery rate are significantly lower for gas than for oil. Production by fluid expansion and pressure reduction ensures about 80% recovery on average. The small quantities contained in these anticipated additional reserves will be located in:

- new, previously unsuspected levels of reservoirs that are found when drilling development wells,
- oil fields of the dissolved gas type, which can yield larger amounts of associated gas along with the oil recovered,
- small, lateral extensions at working oil fields that had not been initially detected.

There is also large potential for new reserves in the unconventional gas that could be recovered from reservoirs of poor quality (e.g. coal beds containing Coalbed Methane, sandstone or carbonate reservoirs containing Tight Gas, and shales containing Shale Gas). Not much is known about resources located outside the United States. Today, they stand at an estimated 900 Tm^3 with one-quarter in North America (under active study) and one-third in the member states of the CIS and Central Asia, including China. Unconventional gas resources are already under development in the United States: they represent about 50% of domestic output and about 9% of world production. It should be possible to recover these resources in other countries as well, thereby adding a few dozen supplementary Tm^3 to future reserves. Since they are contained in reservoir rock of poor quality, recovering them will require tight well spacing (200 m) and the use of stimulation techniques (fracturing). All of this will increase production costs and reduce their real

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potentialities accordingly. Unconventional reserves that are technically and economically accessible represent about 4% of total proven reserves. Unless major technical improvements are forthcoming or the price of gas goes up, this percentage is expected to remain small.

The development of methane hydrates is even more complex. Frequently located in polar regions or deepwater acreage, these resources have been estimated at between 2,500 and 20,000 Tm^3. The potential energy would exceed all of the energy contained in coal, oil and conventional natural gas combined (produced + unproduced + unproducible). Although production tests have yielded positive results at Malik in Canada, the technical difficulties of delimiting favorable areas as well as the economic constraints and the environmental risks associated with exploiting gas hydrates, reduces all or part of their tremendous potential to zero for the time being. A few ideas about how to proceed have been put forward but, for now, the development of these resources remains very much at the conceptual level. One of these ideas is to inject carbon dioxide to produce the methane contained in the hydrates by replacing it with carbon dioxide hydrates. This would produce the methane without producing water while sequestering the carbon dioxide and also maintaining the mechanical stability of the hydrates bearing series under development, which would substantially lower the risks.

Ultimate conventional gas reserves: no change anticipated in the breakdown by region

Given the difficulty of computing future undiscovered unconventional gas reserves, only the potential conventional gas reserves have been estimated. The figure for current reserves, 175 Tm^3, would increase progressively to 213 Tm^3 with the addition of contingent resources and potential "certain" undiscovered resources, then to 244 Tm^3 with the potential probable undiscovered reserves; it would approach 261 Tm^3 if the potential possible undiscovered reserves were included.

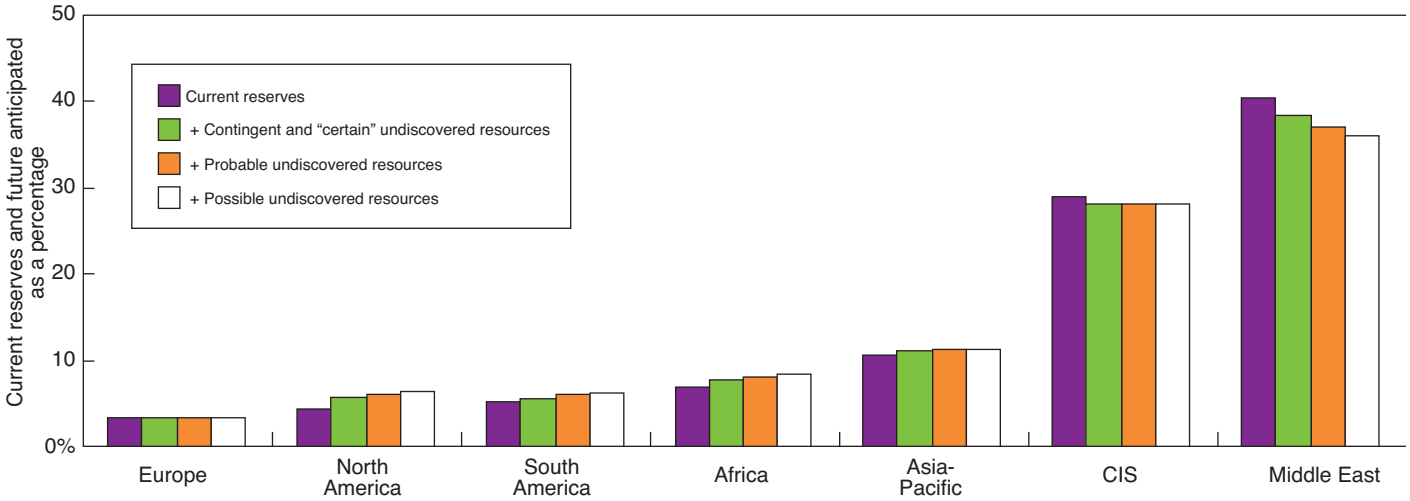
This anticipated increase in reserves should not significantly change the geographic breakdown existing today (Figure 4). However, the proportion of gas reserves contained in specific parts of the world are expected to grow slightly: in North America (with unconventional gas) as well as South America, Africa and Asia-Pacific (offshore zones). The Middle East should see its percentage decrease, because finding another North Field will be impossible. The figure for the CIS, like Europe, should remain more or less stable. Only the exploitation of gas hydrate resources, if and when that happens, could significantly alter the breakdown of the world's future gas reserves but, for now, nothing indicates that this will happen within a reasonable time frame.

If one adds the unconventional gases (Coalbed Methane, Tight Gas and Shale Gas) contained in poor quality reservoirs outside the United States that have not been previously included, ultimate world reserves could reach 300 Tm^3. It is likely that the percentage would rise for the CIS countries and other regions, except the Middle East, where the prospects appear to be dimmer.

What will the gas production curve look like?

World gas production scenarios depend on the same uncertainties about future conditions as the oil production

Fig. 4 - Breakdown of current and future anticipated conventional gas reserves by major geographic region



Source: Cedigaz, IFP

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scenarios (see the Panorama article "Update on hydrocarbon resources - 1 - Petroleum liquids"). However, there are greater constraints involved in shipping gas, which requires heavy infrastructure and equipment (e.g. gas pipelines, liquefaction plants and regasification installations).

Few scenarios predicting the evolution of the world gas production profile have been published. According to the most optimistic, issued by the IEA, production will exceed 4.5 Tm^3 by 2030. Other forecasts indicate that production will top out at 4 Tm^3.

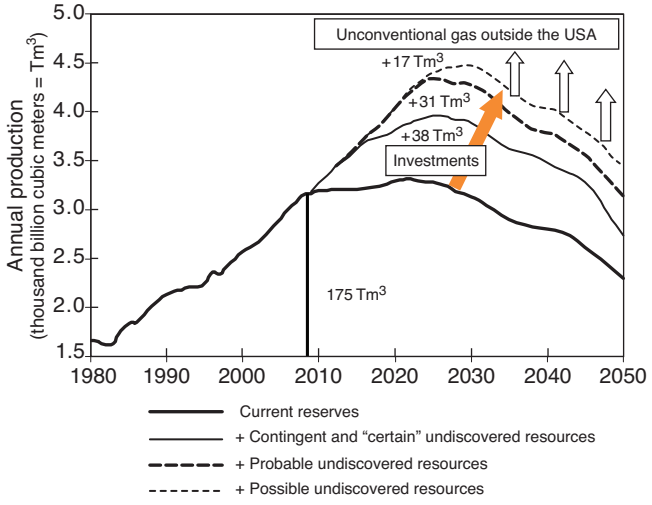
The production scenarios presented (Figure 5) were based on the following assumptions:

- world demand will grow by 1.7% on average,
- countries provided with both gas and oil (mostly countries in the Middle East and on the Caspian Sea) will seek complementarity in producing these resources,
- exporting countries will set maximum export levels for 20 years to amortize the infrastructure that will have to be built (e.g. Iraq and Iran).

The scenarios presented show anticipated trends rather than actual conditions.

Based on current reserves and existing shipping/construction capability, world production will peak at about 3.3 Tm^3. It continues to be constrained by export capacity. Nearly one-third of current and future reserves are located in countries located far away from consumer markets (Qatar and Iran) and some of these countries are landlocked (Azerbaidjan, Turkmenistan and Kazakhstan), which poses serious problems.

Fig. 5 - Gas production scenarios as a function of efforts undertaken to produce them



Source: IFP

If contingent resources and anticipated "certain" discoveries are brought onstream with *ad hoc* shipping infrastructure and equipment, world production could reach 4 Tm^3 by about 2025.

The discovery and development of the gas contained in complex accumulations could boost output to 4.3 Tm^3 by 2025 (including probable resources) or 4.5 Tm^3 by 2030 (including possible resources).

With the unconventional gas resources located outside the United States, it might be possible to briefly postpone these peaks and, more importantly, to cushion the production declines that follow them.

Conclusion: natural gas

The figure of 175 Tm^3 for current reserves, which is not disputed, is still sufficiently high (nearly 60 years of current consumption) to obviate the fear that world production will decrease due to a scarcity of reserves in the next ten years. The prospects of discovering further large volumes are real, both in key producing regions and in areas that have seen little or no exploration (e.g. in ultradeep zones onshore and offshore and in the Arctic). The current figure for current reserves of 175 Tm^3 could climb to 213 Tm^3 by taking into account the contingent resources and "certain" undiscovered resources and to 244 Tm^3 by adding the probable undiscovered resources. If one were to go further and add the several dozens of Tm^3 of unconventional gas, outside the United States and Canada, the estimate could be as high as 261 Tm^3. For the latter, a great deal of research is needed to get a clearer idea of what resources are there and what their real potential might be.

Although the approximately 300 Tm^3 of anticipated ultimate reserves corresponds to about 100 years of consumption at the current rate, world production will grow in step with the construction of large shipping infrastructure. The production scenarios show that gas production might peak at 4 Tm^3 by 2025 or at 4.5 Tm^3 by 2030. The recovery of unconventional gas in importing countries could prove to be a growing trend in the years to come. As for methane hydrates, it does not seem likely that they will be developed to any significant extent in the next two decades.

Conclusion: hydrocarbons (oil and natural gas)

Given the dominance of fossil energies in the world energy balance and the inertia inherent to energy systems, it is imperative to keep mobilizing new reserves in the

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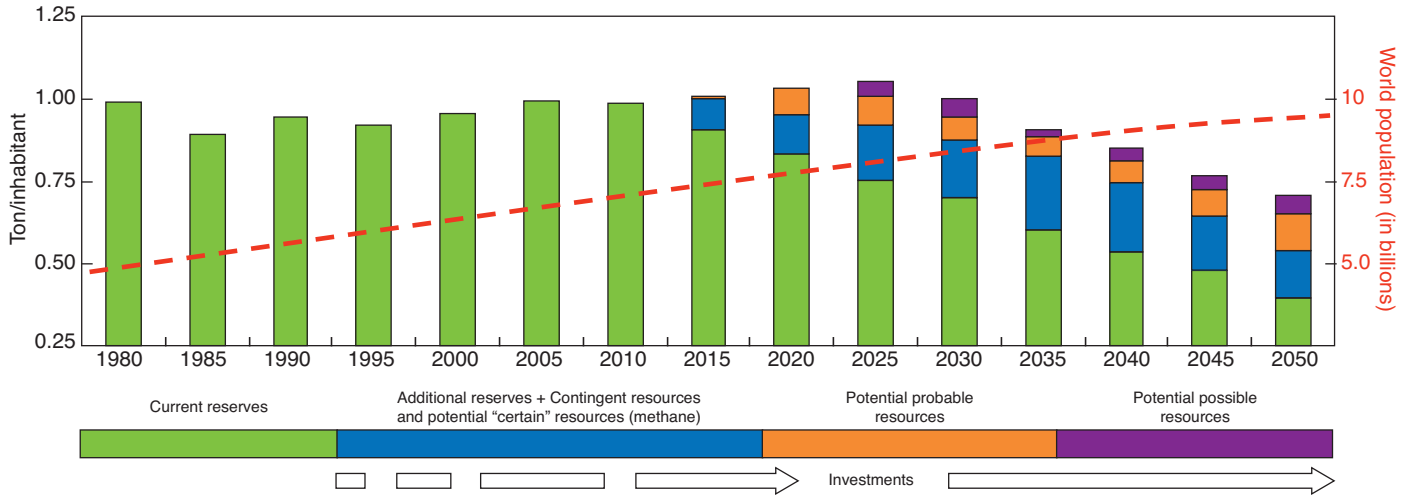
Fig. 6 - World hydrocarbon availability, average per capita 1980 to 2050



Source: IFP

decades to come. The 21st century will be a period of energy transition during which our society, highly dependent on fossil fuels, will develop the diversity of its energy supplies. The transition will have to be controlled (without shocks to the economy) and will continue to make a substantial call upon oil and gas.

The availability of reserves continues to be a matter of vital concern. It's a fact that the supply of fossil resources beneath the surface of the earth is finite and that production cannot keep growing at the same rate forever. Reviewing the current reserves of petroleum liquids and methane, as well as the estimated future unproduced reserves, shows that nearly half of all hydrocarbons will continue to be concentrated in three countries: Saudi Arabia, Iran and Russia. The published production scenarios indicate that the world production profile will evolve as a function of the efforts undertaken to mobilize different types of reserves. The effect of recovering unconventional resources will be to slow down the decline of production more than to raise its maximum level.

Today, world hydrocarbon availability averages one ton per capita. Between 2015 and about 2030, this average can only be sustained by tapping new reserves (Figure 6). After 2030, unconventional resources should arrive more or less massively on the energy scene and help slow the decline of the hydrocarbon supply.

It has become crucial to bring future hydrocarbon reserves into production. This would gain time for the development of alternative energy sources and help ensure a controlled energy transition.

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