Gas Reserves, Discoveries and Production

Between 2000 and 2004, new discoveries, located mostly in the Asia/Pacific region, permitted a 71% produced reserve replacement rate.
The Middle East and the offshore sector represent a growing proportion of world gas production
Non-conventional gas resources are substantial but are not exploited to any significant extent, except in the United States, where they account for 30% of U.S. gas production.

Reserves and Discoveries

On January 1, 2005, world gas reserves came to 180 Tm^3 (10^{12} m^2), or about 162 btoe. They have been rising steadily since 1975, at which time they totaled 60 Tm^3. Current reserves can cover production for 59 years. Their localization is highly concentrated, with three countries in possession of more than half of the total: Russia, Iran and Qatar hold 26%, 15% and 14%, respectively (Fig. 1).

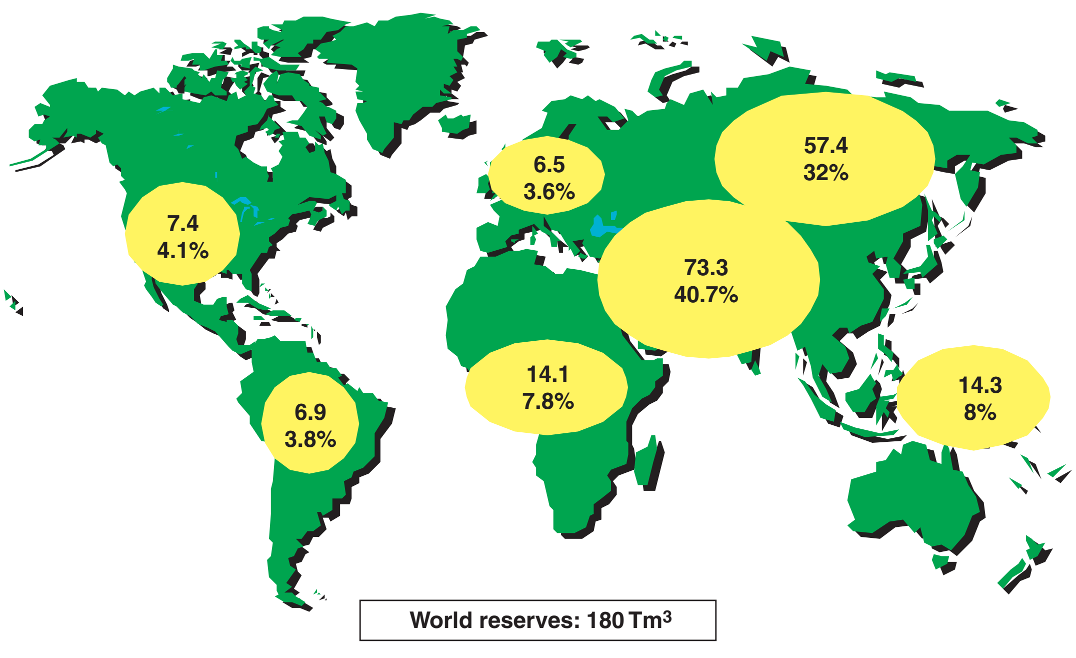
Reserves on the Rise

Since 2000, world gas reserves have increased by 15%. Of this, 38% was due to new discoveries and 62% to the revision of estimates for existing fields. The Middle East saw the largest increase (33%), mainly owing to the revision of estimates for Qatar in the wake of drilling campaigns. Reserves in the Asia/Pacific region were up 25% for the same period, mostly due to new discoveries (Fig. 2). This region is where most of the recently discovered large fields are located. Finally, Africa saw its gas reserves climb 25% between 2000 and 2005, following discoveries in Nigeria, Egypt and Angola. Conversely, gas reserves in Europe have declined by 20% since 2000.

Reserve Replacement

Between 2000 and 2004, 12,700 bcm of gas were produced. During this period, new discoveries represented 9,100 bcm, enabling the replacement of 71% of the global

Fig. 1 Breakdown of proven reserves of natural gas on 1/1/2005 (Tm^3/% of world total)



Source : CEDIGAZ.

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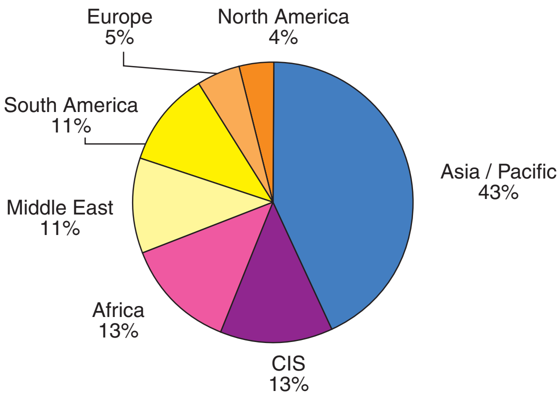
volume consumed during this interval. The remainder of production was replaced as a result of revising reserve estimates for existing fields.

There are substantial regional disparities relative to the replacement of production by new discoveries. Some areas presented a large surplus: new discoveries in Asia/Pacific, South America and Africa led to replacement rates of 260%, 187% and 180%, respectively. Other zones ran a deficit for this period: new discoveries in North America, Europe and the CIS countries yielded rates of renewal of 8%, 31% and 34%. The Middle East, with a rate standing at 85%, was close to the world average.

Revised estimates represented nearly twice world production volumes. The biggest revisions took place in the Middle East, North America and the CIS countries.

Fig. 2 Geographical breakdown of gas volumes discovered between 2000 and 2004



Offshore Reserves

Current offshore reserves amount to 70 Tm^3 and account for 39% of proved world reserves. This proportion has increased over time: the 1995 offshore reserves were estimated to be 39 Tm^3 or 26% of the global figure. Nearly two-thirds of offshore gas reserves are in the Middle East, where over half of offshore reserves are located in two giant fields: North Field (Qatar) and South Pars (Iran). The Number Two region for offshore gas reserves is Asia/Pacific, with 16%. This is where 43% of new offshore gas finds occurred in the last five years. The CIS countries (especially the Caspian Sea area), and Africa each represent 13% of the new offshore gas discoveries made between 2000 and 2004.

In addition, the size of offshore gas discoveries is rising. Nine of the fifteen largest fields discovered between 2000 and 2004 were offshore; they represent 64% of the reserves discovered during this period.

Production

World marketed gas production amounted to 2,777 Tm^3 in 2004 (see Fig. 3). Russia and the United States are by far the largest producers: together, they represent 42% of world output. Canada is number three with 6% of the volumes put on the market. Next come about ten countries that produce between 50 and 100 bcm/yr: the United Kingdom, Iran, Norway, Algeria, the Netherlands, Indonesia, Saudi Arabia, Malaysia, Turkmenistan and Uzbekistan. As for geographical distribution, one notes that the Middle East

Table 1
List of the largest gas fields discovered since 2000 (reserves exceeding 100 bcm)

Country	Field	Reserves (bcm)	Location	Year of discovery
Australia	Jansz	550	DW Offshore*	2000
Australia	Brecknock South	110	DW Offshore	2000
China	Sulige	450	Onshore	2000
Indonesia	Abadi	130	DW Offshore	2000
Myanmar	Shwe	120	Offshore	2004
Kazakhstan	Kashagan	560	Offshore	2000
Russia	Kamennomyskoye	180	Offshore	2000
Russia	Khvalynskoye	120	Offshore	2000
Iran	Lavan	180	Onshore	2003
Iran	Homa	130	Onshore	2000
Iran	Day	100	Onshore	2001
Oman	Khazzan	120	Onshore	2001
Bolivia	Incahuasi	200	Onshore	2004
Brazil	Mexilhao	210	DW Offshore	2001
Brazil	1-RJS-587	120	DW Offshore	2003

* Deepwater offshore, i.e. over 500 m deep.

Sources: Various.

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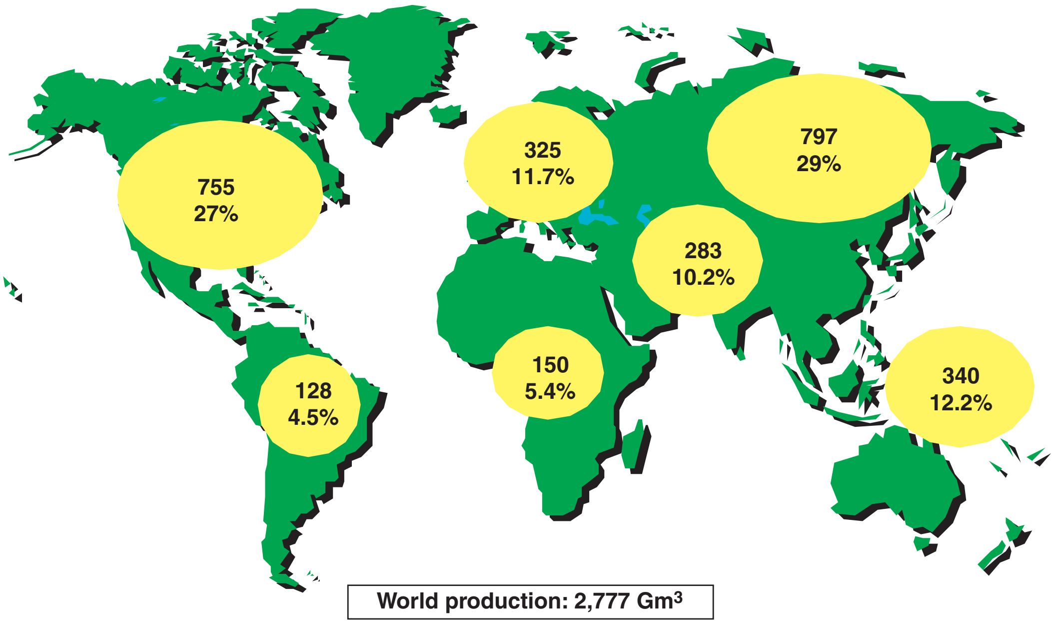
Fig. 3 Breakdown in marketed gas production in 2004 (bcm)



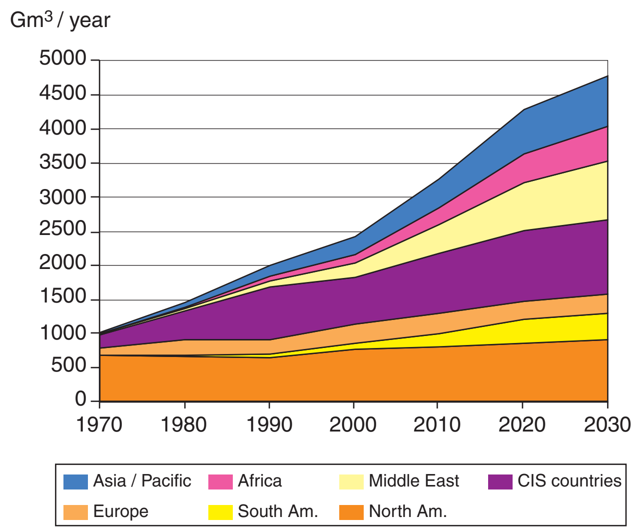
Source: CEDIGAZ.

accounts for about 10% of gas production compared to one-third of oil production.

According to forecasts by the International Energy Agency (IEA), world gas demand is expected to rise by 2.1% a year by 2030 and reach 4,790 bcm (at the same time, oil demand should increase by 1.3%/yr), driven by the electricity sector. Gas is preferred to other energies for economic and environmental reasons. The largest rates of consumption growth should be reported for China, India and Africa (5.1%, 4.7% and 4.3%, respectively).

Production trends will vary according to the region. **Gas production should increase in all areas except Europe** (see Fig. 4), where producing fields are old and there are too few new developments to compensate for the decline. The largest production increases in volume terms should occur in the Middle East, Asia/Pacific, Africa and the CIS countries, which contain the bulk of reserves. The share of the CIS countries and North America should decrease, although they will continue to be the top producing zones: by 2030, they will respectively represent 23% and 19% of world production. The Middle East should account for a larger share of world production (up from 10% to 18%) and Asia/Pacific will also see an increase, from 12.2% to 15%. Africa's share should rise from 5.4% to 10% between 2004 and 2030, while Europe sees a downtrend.

Fig. 4 Gas production trend per geographic area



Source: IEA WEO 2004

Offshore Production

Offshore production currently represents 26% of the volumes extracted (722 bcm) and is primarily localized in Europe, Asia/Pacific and North America. It is expected to develop rapidly in the years to come, especially in the Middle East, Asia/Pacific and the CIS countries, driven by the development of newly discovered fields. For instance, production at **Jansz Field** in Australia should start in 2012 and top out at 7 bcm/yr. **Gold Field** in Myanmar and **White Lion** in Vietnam are expected to produce 13 bcm/yr. In the CIS countries, **Shtokman Field** in the Russian Barents Sea contains 3,200 bcm of gas, or 2% of world reserves. At this field, development should begin in 2006 and reach peak production in 2011, topping out at 67.5 bcm/yr (10% of current Russian production). In 2007, development will start at **Shah Deniz** in Azerbaidjan, which should be producing 17.3 bcm/yr by 2015. In the Middle East, the biggest contributions to the increase in offshore production should be the final phases of the giant South Pars Field in Iran and the buildup of volumes for export extracted in Qatar. Europe's biggest project is the development of the Norwegian **Ormen Lange Field**. Production will start in 2007 and should last for more than 30 years. According to predictions, its production will peak at 25 bcm/yr, which is 30% of Norway's current output. Despite this high level of production, this field will not be able to offset the overall decline of gas extraction in the European zone.

Looking ahead to 2020, the median scenario by Cedigaz predicts a 52% increase in offshore gas production, which could reach 1,100 bcm.

Technological Progress Imperative to Ensure Economic Access to Resources

According to estimates, 30 to 35% of gas reserves are located in very small onshore or offshore accumulations that are quite remote from their potential markets. This is known as "stranded gas". No real solution is currently available for the exploitation of stranded gas, but research is underway on the following subjects:

– The use of LNG production barges to exploit offshore and near-shore accumulations.

– Chemical conversion of gas to liquids (see specialized paper). It is expected that cost reductions will eventually make this technology a realistic alternative. Barge-mounted applications are also under study.

– Reducing the cost of gas pipe transport (overland or marine).

– Seeking new transport solutions, such as using tankers to ship compressed gas.

We also saw that production will be developing most intensively in the Middle East, Asia/Pacific, the CIS countries and Africa. In the first three of these regions, the gas is especially acid either due to the presence of sulfur (Middle East, Caspian Sea) or CO_2 (Asia/Pacific). Research programs are underway to develop higher-performance, more economical production and processing techniques for fields where the natural gas contains high levels of acid gases and/or contaminants such as mercaptans.

The increase in production is paralleled by the development in transport capacity. Many long-distance pipe construction projects are under consideration, especially projects to supply Europe with gas. There are also numerous gas liquefaction projects underway, particularly in Qatar, Nigeria, Australia and Libya, and the first large-scale developments of gas to liquids technology (GTL) have been undertaken (see specialized reports).

Non-Conventional Resources

In addition to conventional resources, there are large potential non-conventional reserves: coalbed methane, tight gas sands, shale gas and methane hydrates. According to estimates, these reserves represent substantial volumes that remain underdeveloped (see table below). The industry has mastered the recovery of coalbed methane and gas from tight sands or shales, but not the techniques for developing and producing gas hydrates. Today, there are no projects underway that aim to produce these resources on an industrial scale.

Table 2
Gas resources and world production

Type of gas	Resources (Tm^3)	Production (bcm/yr)
Conventional	180 (reserves)	2,587*
Coalbed methane	100 to 260	≅ 50
Tight gas	402 to 442 min**	100 - 150
Shale gas	42 to 45 min**	17
Hydrates	13,000 to 24,000	ε

* This figure is obtained by taking the world gas production figure as given in the statistics (2,777 bcm), and subtracting the non-conventional gas production for 2004, or about 190 bcm.
** min.: values considered to be minimum.

• *Coalbed Methane*

Coalbed methane (CBM) designates the methane contained in coal layers. This methane was initially generated during the phase when the organic matter — which would subsequently become coal — was buried and remained trapped in the coal layers where coal would form. It is adsorbed onto coal particles. Very large quantities of methane are trapped: given the same volume of rock, the concentration is 6 to 7 times greater than at conventional gas fields.

Estimates for world methane resources of this type range from 100 to 260 Tm^3. Collectively, Canada, Russia and China represent 80% of world resources. The largest coal producing countries are also endowed with coalbed methane resources, namely, Australia, the United States, Ukraine, Germany and Poland.

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In principle, the production of coalbed methane involves depressurizing the accumulation by extracting water from rock fractures. Thus, the methane is naturally de-adsorbed and rises to the surfaces via drilled wells. Since average well productivity is low (20,000 m^3/day), the profitability of this technique requires a large well density. This mode of production also generates large quantities of process water of highly variable quality that must be recycled. Often, it contains saline compounds. To be profitable, a coalbed methane basin must contain between 14 and 17 m^3 of methane per ton of coal. For some basins, the figure may be as high as 220 m^3/ton.

The United States is not the world's most CMB-rich country, far from it. However, it is the most advanced in terms of CBM development and production. In 2003, **CBM production in the U.S. amounted to 45 bcm** or 8% of total gas production. Ever since CBM production began there in 1983, it has steadily increased. The CBM is located mainly (88%) in the Rocky Mountains. **China also produces CBM (1.5 bcm were extracted in 2002)** and plans to increase this volume to 10 bcm by 2010. The other key producing countries are Russia, India, Ukraine, Poland, Canada, Australia as well as Germany and the United Kingdom.

The environmental impact of CBM is favorable in that injecting carbon dioxide into deep coal layers can improve methane recovery while sequestering CO_2 to some extent. Gas is a "cleaner" energy than coal and can replace it for energy applications. Finally, methane can be captured before or after the mine is exploited, thus preventing it from being released into the atmosphere, where it would add to the greenhouse effect.

The downside of CBM technology is it uses tremendous quantities of water that must be treated. This major disadvantage strongly inhibits the development of this activity.

- *Tight Gas Sands*

No formal definition for "tight gas sands" exists and different authors use it to mean different things. However, there seems to be a consensus that tight gases are found in tight sands with a permeability lower than 0.1 millidarcy. As a result, gas mobility within the formation is poor and production by conventional means is not economically viable. Specific recovery technologies, such as fracturing or acidification of the formation, must be deployed to increase reservoir porosity and facilitate gas mobility. These techniques require a particularly high density of wells and represent a fairly elevated cost.

World gas reserves contained in tight sands reservoirs have not been quantified with any degree of accuracy. The biggest producing countries, namely, the United States and Canada, have made estimates. In Canada, the National Energy Board thinks there are between 2.5 and 42 Tm^3 of gas in tight gas sands. As for the USA, the Energy Information Administration estimates these resources to be about 400 Tm^3; recovery is technically feasible for 7 Tm^3, a volume that exceeds domestic conventional gas reserves.

Tight gas production started in the 1970s in the United States and is **currently estimated to be 100 bcm/yr.** This represents 13% of the production of the "Lower 48" (U.S. not including Alaska, Hawaii and offshore). The United States numbers about 40,000 wells producing tight gas from 1,600 reservoirs and 900 fields. Canada, Australia, Argentina, Egypt and Venezuela also produce tight gas, but little information containing statistics has been published on the subject.

- *Shale Gas*

Shale is particularly impermeable rock in which gas is stored in two forms: as free gas in the pores or fractures in the rock and gas adsorbed onto organic particles (as in the case of CBM). For shale gases, like coalbed methane, the shale serves as source rock, reservoir rock and methane trap.

These formations are under study, especially in the **United States where shale gas resources** are estimated to be **between 14 and 17 Tm^3. The estimate for Canada** mention 28 Tm^3. To produce these gases, as in the case of CBM or tight gas sands, the rock must be fractured to increase permeability. In the U.S., there are approximately 35,000 wells producing 17 bcm/yr of shale gas.

- *Methane Hydrates*

Methane hydrate is a crystalline substance composed of water molecules organized in cage-like structures that trap methane molecules in very high concentrations. By way of an indication, one cubic meter of gas hydrate can contain 160 to 180 m^3 of gas under standard temperature and pressure conditions.

Gas hydrates form at low temperatures and high pressures and with very precise gas concentrations. All of these conditions exist naturally below the surface of the earth: over 1,000 m below frozen Nordic permafrost or over 500 m below the floor of the ocean deeps. Permafrost gas hydrates have been found in Siberia, Alaska and the Mackenzie Delta in Canada. Offshore hydrates have been found in the Gulf of Mexico, California, the Black Sea, the Caspian Sea and the Okhotsk Sea, but also at great water depths in the ocean trenches of Central America and Japan and even off the coast of New Caledonia.

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Despite increasingly intense research, the size of gas hydrate accumulations is still primarily based on theoretical conditions of stability rather than on direct measurements to ascertain the presence and concentration of hydrates in reservoirs. Therefore, the quantification of resources is accompanied by great uncertainty. Actually, **the methane resources contained in hydrates are estimated to be between 13,000 and 24,000 Tm^3, i.e. 70 to 130 times the proven reserves of conventional natural gas. It is still difficult to estimate what proportion of these resources is likely eventually to become economically viable; this is quite a controversial subject.** Many international or more local research programs have been undertaken to develop techniques for the recovery of methane contained in hydrates. Canada, the United States, India, Japan, Australia and France are involved in this hydrate research.

- *The Importance of Non-Conventional Gas in the United States*

The United States, a major gas importer, early recognized the strategic importance of non-conventional gases. In 1980, the U.S. government granted a tax credit as an incentive to develop non-conventional resources. Production of CBM, tight gas and shale gas, which represented 15% of U.S. gas output in 1990, now accounts for 37% of the total and should reach 40% by 2025 according to the DOE. Domestic gas production should increase by 14% between 2005 and 2025. This should be possible thanks to production in new areas such as Alaska (+470% for the period) and more particularly to production of non-conventional resources, which should rise by 17%. At the same time, conventional gas production should drop by 4 to 5%.

Table 3
U.S. gas production breakdown, 2003

Type of gas	Production (bcm/yr)	Share of total production
Conventional	372	70%
Coalbed methane	≅ 45	8%
Tight gas	≅ 100	19%
Shale gas	≅ 17	3%
Total	534	100%

Conclusion

In the last five years, there have been many new gas discoveries enabling reserve replacement of 71%. In the years to come, gas production should grow quickly (2.1%/yr by 2030 according to the median scenario of the IEA), driven by electricity demand. China, India and Africa will represent a particularly significant component of the increase in demand. To satisfy demand, it will be necessary to bring new discoveries into production, develop existing fields that have never before been developed because they did not have a market, and exploit non-conventional resources, which the United States is already doing. The development of technologies for transport (LNG) and for valorization (GTL) make it possible to transport gas, under different forms, over long distances just like oil, and to broaden its range of sales outlets. The gas market is going international.

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