Natural gas

Introduction

Natural gas is the last fossil source of energy to be used on a global scale. For over a century, when the gas was discovered in areas that were far from the places where it could be utilized, it was preferably burnt at the gas well or freed into the atmosphere, because harnessing it in a pipeline and making it travel for many kilometres was too expensive. The situation has changed over the past forty years and today natural gas ranks third in world consumption of energy and is the fossil source with the best growth prospects. In the Seventies with the creation of transport infrastructures for importing natural gas, the producer countries and the consumers defined typical contract agreements that are reference models still today. From the Seventies up to date world consumption of gas has tripled, growing from 100 billion cubic metres to approximately 3,444 cubic meters in 2014. Data updated to 2014, indicate that Italy produces 6.98 billion cubic metres of natural gas per year and consumes 60 billion cubic metres a year.

(*Source: eni, World Oil and Gas Review 2015*)

Natural gas knowledge

What is it

Natural gas is a fossil fuel like oil and coal. It is a mixture of hydrocarbons, mostly methane, and other gaseous substances such as carbon dioxide, nitrogen, hydrogen sulphide and, in some cases, helium. The mixtures that are mainly composed of methane are called dry mixtures, whereas those mainly containing hydrocarbons such as propane, and butane are called wet mixtures.
Before being distributed for use, natural gas is treated to eliminate carbon dioxide and nitrogen, which make it less flammable, and hydrogen sulphide, a corrosive and toxic gas. The result is mainly methane. Methane is the simplest gaseous hydrocarbon and is characterised by the smallest molecule, including one carbon atom and four hydrogen atoms (CH4). It is lighter than the air (at a 15°C temperature and 1013.25 millibar pressure its specific weight is 0.678 kg/m3), it is colourless and odourless and not toxic.
It was very common in the primordial atmosphere of the Earth and probably contributed to the synthesis of the first amino acids and the creation of life on our planet. Mixed with the air, methane becomes flammable only if its concentration ranges between 5 and 15%. Below 5% the quantity of natural gas is insufficient to start the combustion, whereas above 15% the oxygen is insufficient. At temperature of 15°C and atmospheric pressure 1 cubic metre of methane produces over 8 thousand calories. In those conditions one cubic metre of methane has an energy content equivalent to 1.2 kg of coal and 0.83 kg of oil.
Methane becomes liquid at a critical temperature of –83°C and a pressure of 45 bars. The transformation into the liquid state can take place by decreasing temperature or increasing pressure. For example, at –161°C methane becomes liquid at room pressure.
The critical temperature of wet natural gases such as propane and butane, including 3 and 4 carbon atoms respectively, is higher than room temperature, therefore they become liquid simply by increasing pressure.

The origins of natural gas

On our planet hydrocarbons, including methane, are mainly located on rock pores that constitute the higher part of the Earth's crust and result from chemical and physical processes that have taken place during the history of the Earth.
The action of atmospheric agents provokes the erosion of mountains whose debris, transported by water courses arrive at the sea, where sand and clay layers deposit. As well as the debris, sea-origin materials deposit on the seabed: salts

that precipitate due to evaporation, and above all animals and materials that live in the sea. With time passing, due to crystallization of salts, sediments transform into compact rocks that still have some tiny holes occupied by water and organic substances. Subject to the micro-organisms disintegrating action, these organic substances convert into hydrocarbons like methane and oil. This process is called mineralization: plants and animals become gas, oil and coal, and these fuels are called “fossil” because they originated from the fossilization of plants and animals.

Where it is

The geographic location of gas reserves obviously mirrors that of oil: Russia, Iran and Qatar approximately have 53.4% of the total. Just like oil, the exploitation of gas fields takes place in a non-uniform way. For example, the Middle East countries extract little gas as compared to the reserves available. They have 40% of the world reserves and only produce 16.3% of the natural gas consumed in a year world-wide, whereas the U.S. and Western Europe show high levels of extraction (as compared to the available reserves). In fact, he U.S., despite possessing only 4.9% of the world's proven reserves of natural gas, produce more than 20.7% of the gas produced in the world.
This means that, if the current production level remains unchanged and if no other fields are discovered, those countries (14 years for North America and approximately 19 for Europe) will deplete their reserves in a few years and will need to resort to imported gas only.
(*Source: eni, World Oil and Gas Review 2015*)

The reserves

World natural gas reserves total 201,771 billion cubic metres approximately (data refer to 31st December 2014). Such reserves include the currently known fields that can be exploited through the technology available to obtain an economic profit. They are not the actual total underground resources still unknown to mankind or the extraction of which would be too expensive. Nevertheless, they can be a good indication of the rate at which resources are being exploited (and depleted). If the currently known reserves are divided by the yearly world consumption of natural gas (in 2014, amounted to 3,444 billion cubic meters), at the current exploitation rate reserves will be depleted in approximately 58 years. There are certainly still unknown field which may extend the use of this fossil fuel, however the obvious conclusion is that natural gas, just like oil, is a resource bound to be depleted.
(*Source: eni, World Oil and Gas Review 2015*)

A bit of history

In a manuscript by the Chinese historian Chang Qu dated 347 B.C. a strange gas is described that can be used for illumination purposes. Approximately 200 years ago, Alessandro Volta “re-discovered” the energy potential of natural gas noticing small gas bubbles which formed when the muddy bottom of the Maggiore lake was stirred. If a lit match was approached, the gas contained in the bubble produced a bluish flame.
Between 1840 and 1850 gas lights became common in many American and European cities and changed the lifestyle of citizens: well illuminated streets at night were an obstacle for thieves, ballrooms and clubs flourished even for less well-off people (since gas lights were cheaper than candles). Thos advantages were limited to where the natural gas came to the surface spontaneously, since no adequate technology was available to search for, extract and convey natural gas.
For a long time the methane coming out of oil wells was burned by means of a torch when it reached the surface. Several billion cubic metres of natural gas were burnt in the process: the biggest waste of resources in the history of mankind. Italy is one of the few countries where methane has been enhanced as an energy resource since the very discovery of fields in the Po valley and in the Adriatic sea. Natural gas, as a national energy source, remarkably contributed to the industrial development of Italy in the 1950s and 1960s.
The exploitation of natural gas is a recent achievement: in Europe it started a little more than 50 years ago thanks to the development of technology which made its extraction economically viable and a pipeline network (i.e. the pipes to convey

natural gas from the place of extraction to the place of consumption) to achieve a more efficient distribution. Pipelines currently run across the whole of Europe and make up the ideal transportation system because they have a low environmental impact: they do not increase surface traffic and are invisible, thanks to the restoration of the surrounding area after the digging to lay pipelines.

Extraction and distribution

The extraction

Often, albeit not always, natural gas is extracted from the same fields as oil. Just like oil, natural gas is the result of the transformation of organic substances deposited at the bottom of ancient seas and lakes (sedimentary basins). Therefore, there is no search for natural gas distinct from that of oil, but a single research activity for hydrocarbons: only after exploration wells are drilled is it possible to ascertain the nature of the deposit. The term “associated gas” is used when natural gas is dissolved into oil or makes up the top layer of the oil field; the expression “non-associated gas” is used when the field contains almost exclusively natural gas (for example, the large field of the North Sea or the Netherlands). Extracting natural gas from underground is quite easy. Usually it is trapped together with oil under a rock layer. Due to the big pressure, as soon as drilling is finished, the gas comes out and it is necessary to “direct” it into a pipe and guide it towards its final destinations or storage centres. The latter are not tanks like the ones containing oil, but they are exhausted natural reserves that once contained natural gas, oil or water and that are used today as real “warehouses” for the gas.

The treatment

If the natural gas from the field is wet, it undergoes a preliminary conditioning to separate methane from the other gaseous hydrocarbons such as propane, butane and ethane. The separation is simplified by the fact that methane is marked by a much lower critical temperature (above which gas cannot be liquefied). The amount of wet gases available on the market is very large since gas extracted along with oil is always wet. After being liquefied, humid gases are bottled for household uses in 10/15 kg containers or bigger bottles for industrial purposes. Methane is distributed through the pipeline networks
Albeit rarely, the methane from some fields needs to be purified. The most damaging impurity undoubtedly is sulphur because it produces sulphur dioxide during combustion and when the weather is humid it causes acid rain, responsible for lung diseases, the deterioration of plants and anything being exposed to it. Sometimes the gas extracted contains precious substances too, such as helium, used to make airships fly and mixed with oxygen in scuba-diving bottles. Although extraction is simple and the quality of natural gas as a fossil fuel is high (also from the environmental viewpoint), up to the second world war the use of methane was very limited.

The transport

The long distance transport of natural gas started in 1958 when natural gas was imported from Canada into the U.S. At present natural gas is transported in the gaseous state through gas pipelines, else by means of natural gas carriers in the liquid state (Liquefied Natural Gas).
Gas pipelines allow the transport of a large quantity of natural gas directly from the place of production to the place of consumption without any loading or storing operation.
After the safest and more effective route is identified, a trench is dug to lay previously welded together steel pipes. To prevent any leak, each welding is x-rayed to check it is perfect. To prevent corrosion, the pipe is covered by a layer of bitumen, tar and synthetic resins and protected by means of dedicated electronic devices. Finally, the gas pipeline is buried and the landscape is restored. The presence of the gas pipeline is signalled by special signs. Every 100/200 km compression stations are installed to restore a sufficient pressure to make the natural gas move at a speed of 20-30 km/h. Gas pipeline networks also comprise storage stations where the natural gas is kept available in case of

emergency. Depleted fields near the place of consumption are preferably used as deposits. Their geological features ensure maximum safety against possible leaks.
The whole of Europe is crossed by long gas pipelines that run underground. In this way the landscape is not spoilt. When resorting to gas pipelines is impossible – because the distance to be bridged is excessive or an excessively long sea route needs to be covered - natural gas is liquefied and transported by LNG carriers.
At present 25% of natural gas is transported via LNG carriers. Natural gas is liquefied at –161°C and its volume is reduced by 600 times as compared to the original natural gas. A LNG carrier on average carries 130,000 m3 of liquefied natural gas, i.e. 78 million cubic metres in the gaseous state. Transport costs are higher in the case of LNG carrier is because different transhipments are necessary. The first takes place from the field to the coast via a gas pipeline. Then the gas is liquefied and loaded onto an LNG carrier equipped with heat proof tanks. Finally, after it has been unloaded from the LNG carrier it is turned into gas and conveyed into the gas pipeline. During the maritime transport part of the natural gas evaporates and contributes to keep the temperature low, part of it is used as fuel for the LNG carrier itself.

Natural gas storage

The storage of natural gas plays an important role in regulating the supply in order to meet the great seasonal variation in demand. Consumption of natural gas is much greater in winter than in summer, while the supply of gas is relatively stable throughout the year. The excess supplies of natural gas produced or imported in the summer months are generally stored in depleted reservoirs and can be withdrawn in winter when demand is greater than supply. The storage of natural gas is implemented through an integrated infrastructure system that consists of depleted reservoirs, gas processing plants, gas compression stations and operational dispatching systems. The underground storage of gas has played and continues to play a significant role in the development and stabilisation of the gas market. Storage is called conventional when depleted or partially depleted gas production reservoirs are used, semiconventional when depleted oil reservoirs or aquifers are used and special when it takes place in caverns created in underground salt formations or in abandoned coal mines.
At present there are 10 natural gas storage fields in Italy with a total capacity of 16 billion cubic metres. In Italy, storage fields are obtained exclusively from nearly depleted gas reservoirs. This choice is a consequence of the geological characteristics of the country and of the fact that the depletion of some gas fields has provided structures that are suitable for use as storage facilities.

The distribution

From the large pipes of the national distribution network, thousands of kilometres of smaller pipes are derived to convey natural gas to industrial plants and households. In the city networks managed by the distribution firms the gas pressure is maintained at lower levels than the large transport networks for technical and safety reasons. In 2014, 42% of the natural gas distributed in Italy is used in the civil sector, 30% in thermoelectric power plants and about 24% in industry (Source: Bilancio Energetico Nazionale 2015 - Ministero dello Sviluppo Economico).
Before being conveyed to the distribution network, natural gas is added odour, i.e. it is mixed with a substance characterised by a strong smell called “mercaptans”. Therefore users immediately realise if there is a leak. In indoor environments, (e.g. a room), natural gas is mixed with the air and if an igniting factor is present (a flame or a spark caused by switching on the light), it explodes. Therefore, if we come back home or walk indoor and smell a strong odour, we need to avoid switching on the lights or starting any fire. Rather, we have to open doors and windows (natural gas is not toxic) and let it be dispersed outside. For those who cannot smell odours, ad hoc devices were created to signal any leak through visual or acoustic signals. Since natural gas is lighter than the air, such devices ought to be placed near the ceiling.
Environmental impacts associated with the transportation and distribution phases are of two kinds:

- Uncontrolled release of gas into the atmosphere as a result of leakage;
- Loss of water and gasoline deposited at the bottom of the pipeline.

In order to prevent gas leaks, gas pipelines are monitored constantly and the pressure along the entire distribution line is controlled so that leaks can be detected promptly. It has been estimated that over a distance of 4000 km, less than 1% of the gas transported by pipelines is lost. Generally, leakages are greater in the low-pressure urban distribution networks that carry gas to the residential areas, because often the pipes are old. The substitution of old distribution networks and the use of innovative materials is the best solution to drastically reduce leaks.

The distribution of gas in Italy

In Italy, imported natural gas is introduced into the national network at seven entry points, where the network connects to the import pipelines (Tarvisio, Gorizia, Passo Gries, Mazara del Vallo, Gela) and at the LNG regasification terminals (Panigaglia, Cavarzere). Italy's major supplier is Russia; 51% of natural gas imports originate from Russia and is injected into the national network at the entry point of Tarvisio and Gorizia. The second most important exporter is Libya with 13% and Algeria (13%); natural gas from Libya and Algeria is injected into the national network at the entry point of Mazara del Vallo in Sicily. The imports from Netherlands (8%) and Norway (5%) follow. Natural gas produced in Italy is injected into the national network at 51 entry points from the production facilities or from their collection and treatment plants; natural gas storage facilities are also connected to the network.

The gas distribution network reaches cities on the plains and in numerous valleys, bringing natural gas directly into the vast majority of homes. The transport of natural gas in Italy occurs at two main levels. The first, called “primary distribution”, involves transport at a national scale through large pipelines. The second level or “secondary distribution” supplies gas locally through a widespread system. Primary distribution is guaranteed by a 29,300 kilometre-long gas pipeline network that spans the whole of Italy, with the exception of Sardinia. A new gas pipeline is being built to transport natural gas from Algeria to Italy via Sardinia. This new pipeline, called Galsi (the acronym of Gasdotto Algeria Sardegna Italia) will be completed in 2018.

In Italy natural gas is distributed for civil use (42%) and for industrial and thermoelectric uses (around 52%). Secondary distribution is carried out by municipal companies, local governments or private companies. The local companies that receive natural gas at delivery points outside the cities oversee its distribution through their networks in over 5,000 municipalities, delivering natural gas to families, commercial businesses and small industries.

Decommissioning

When a gas field is depleted, the decommissioning of the production facilities follows. The activities carried out during the decommissioning phase include the safe removal of the pre-treatment plant, the platform structures, the compression structures and the hydrocarbon dispatch facilities and the removal of the wellheads and the pipelines that connect to the collection points. Following the dismantling of the production facilities, there is the environmental restoration phase. The areas where the wells and the treatment facilities were located are reclaimed and restored to pre-mining conditions, with the planting of grasses and trees. As far as the decommissioning of offshore facilities is concerned, operations to safely plug and abandon the well must be carried out and the installations and pipelines that connected the platform to treatment facilities on land must be removed. These operations are very delicate and require specialised personnel in order to avoid adverse environmental impacts. Once the installations have been removed, suitable sites must be identified for materials that cannot be reused and for the disposal of potentially polluting products. An alternative to the dismantling and removal of offshore installations envisages the reuse of disused platforms in-situ as artificial barriers, for example. In fact, it has been observed that many artificial structures placed in open water are soon colonised by benthic macrofauna and by a large number of fish species that find a suitable habitat to reproduce. Another alternative is the installation of offshore wind turbines on the disused platforms. In fact, these offshore platforms can support wind turbines with the advantage that they are far from the coast, where the winds are strong and constant, and where there they do not have a negative effect on the landscape. The option of leaving disused offshore platforms in place must be carefully evaluated from an environmental and a legislative point of view.

Uses

The production of electric power

Thanks to its several economic and environmental benefits, in the latest years natural gas has converted into the main fossil fuel for the production of electricity. During the 70s and 80s, energy production was oriented towards coal and nuclear plants, but a series of economic, environmental and technological factors has provoked a shift towards the gas.

Vapour plants

Natural gas can be used as a fuel in vapour electric plants in order to produce vapour that, at a high pressure, activates a turbine, which makes the alternator turn. In order to create high- pressure vapour, water is superheated in a boiler: by hemertically closing the container, the vapour pressure increases and then violently gets out towards the turbine. With reference to the performance of these plants, approximately 40% of the energy contained in the fuel is transformed into electricity. The remaining 60% is lost during energy conversion from chemical to thermal, mechanical and electric.

Turbo-gas plants

Natural gas can also be used in turbo-gas electric plants. These thermoelectric plants directly exploit the energy produced during methane (or gas oil) combustion and work without boiler, in order to transform the water into vapour and without condenser in order to reconvert the vapour into water. A turbo-gas plant consists of:

- **A compressor**: it sucks air up from the atmosphere, compresses it and sends it to the combustion chamber
- **Combustion chamber**: this is where the combustion between the air and the fuel occurs (methane or gas oil)
- **Gas turbine**: the air and gas mixture, at high temperature, gets into a turbine where the expansion of combusted gases makes the rotor blades rotate and subsequently activates the alternator therefore generating electricity.
  The advantages of turbo-gas plants are: the low costs of the plant, they start rapidity even if there is no energy in the network and the fact that these plants do not need cooling water. It is possible to build them in any place, even far from the rivers and the sea. The disadvantage is the very low output (around 30%) and therefore the very high energy cost.

Combined-cycle plants

Combined-cycle and co-generation systems are the most efficient technologies to produce electricity from natural gas. Both use the heat that would normally be lost. Combined-cycle plants exploit the heat they generate to produce electricity. These systems associate a turbo-gas plant with a vapour group: the residual heat of fumes going out from the turbo-gas group is used to produce vapour, increasing the performance by 56%. Moreover combined-cycle plants have lower building and maintenance costs, and a higher functioning reliability.

Cogeneration

Among the innovative implementations of natural gas mention has to be made to cogeneration, i.e. the combined production of electric energy and heat. Cogeneration is the combined use of a primary energy, like natural gas, to produce heat and electricity.

The concept is based on the recovery and the use of heat residues produced during electricity generation that in other plants would be lost, being therefore less efficient than cogeneration.

For example, a methane engine produces electricity and exhaust emissions are then used as a thermal source, i.e. to heat water. In this way electric energy and thermal energy are produced in a combined way. If they were produced through separate processes, larger quantities of primary energy would be needed. This process optimises the use of energy resources with significant economic and environmental benefits.

Natural gas is the most economically advantageous fuel with reference to industrial and commercial cogeneration applications, above all due to the lower fixed and management costs and because it is the cleanest fossil fuel.

At the moment a wide series of cogeneration technologies is being used, including small pre-packaged units that comprise all the components that are needed for a cogeneration system.
These systems are available from 2.2 kW to several hundred MW format. These are cases of micro-generation, which means simultaneous and localised production of thermal energy and electric energy.
Thanks to the technological development of new and more efficient natural gas turbines and machines, cogeneration, which was only used by the large industrial sector, is now spreading to small and medium-sized industries and the third sector. In particular, cogeneration systems represent an efficient solution to reduce the costs of electric energy and heating for paper mills and the pharmaceutical, textile, oil refining industry, and in particular petrochemical industries, as well as hospitals, universities, hotels, calculation centres and shopping centres.

Transportation sector

Natural gas can also be used to fuel vehicles. Natural gas presents numerous advantages respect to other fuels for vehicles: the first of these is that it is an ecological fuel. In fact, it has a low carbon content and does not contain aromatic hydrocarbons, sulphur nor lead. Respect to petrol powered cars, natural gas powered vehicles produce around 25% less carbon dioxide and more important, they do not emit particulate matter (made of particles that are dark enough to seem smoke or soot, but so small that they can only be detected using a microscope), benzene or other aromatic hydrocarbons. Moreover, they emit less carbon monoxide, nitrogen oxides and unburned hydrocarbons (these unburned hydrocarbons prevalently consist of methane). In addition, there are negligible emissions of sulphur dioxide, the primary cause of acid rain. Natural gas does not have the harmful effects on human health that many hydrocarbons have. In particular, those hydrocarbons that are more reactive in the presence of nitrogen oxides and sunlight can generate low level ozone, a gas that can cause irritation to the respiratory system and that can generate photochemical smog. Benzene and other polycyclic aromatic hydrocarbons (PAHs), instead, are considered potential carcinogens. Car traffic contributes in great measure to total PAH emissions in urban areas with heavy traffic, especially where the traffic structure (traffic lights, crossroads, etc.) forces car engines to constantly operate under transient conditions. Thanks to current engine technologies, emissions of these substances by natural gas powered vehicles are greatly reduced or almost absent (as in the case of benzene). However, to carry out a complete evaluation of natural gas powered cars respect to those powered by traditional fuels, one must assess the environmental impacts along the entire energy transformation life cycle; in other, words, analyse all the stages including extraction, production and transport of the fuel. The analysis should also take other factors into consideration, such as the availability of energy resources in the near future. The purpose of these studies is to direct consumption towards a more efficient use of energy sources, both from an energetic and from an environmental point of view. Besides the above-mentioned characteristics, the natural gas life cycle displays other features that make it more advantageous respect to other fuels. In fact, natural gas can be used directly as fuel upon extraction, after normal processing, it does not require refining. It is transported by a network of pipelines which are connected directly to methane refuelling stations, and which supply them uninterruptedly, without requiring storage in deposits and without affecting traffic nor road transport. Contrary to liquid fuels, the refuelling system, being pressure-tight, has practically no evaporative losses. Among the four vehicle fuels currently used (petrol, diesel, LPG and methane), methane is definitely the cheapest. To cover the same distance, the use of methane allows you to save up to 65% respect to petrol, up to 45% respect to diesel and up to 30% respect to LPG.
Germany, Italy, Switzerland, Sweden and Austria are among the European countries that use methane the most.
Methane system
The methane system for engine propulsion is simple. Vehicles are usually built to be supplied both with methane and petrol. The methane is put into bottles (located on the vehicle) in a “compressed” gaseous state, at high pressure (200 bar). The methane gets, through special pipes, to a reducer that supplies the injectors of internal combustion engines at low pressure. A pressure sensor sends the signal to the methane-quantity indicator and to the electric board that controls the fuel injectors and the bottle opening/closure valves. The vehicle is provided with a methane-petrol commuter that can be activated at any time.

The vehicle usually works with methane, but if, while running, the gas pressure inside the bottles is lower than the minimum pressure, the engine electronic control automatically converts the functioning to petrol. Once the petrol has been supplied, the bottle pressure is restored and the car starts to work with methane.
In order to guarantee the maximum reduction of exhaust emissions, methane vehicles must use an adequate catalyser to eliminate residual hydrocarbons deriving from the methane combustion. In fact, the methane oxides have more difficulty to oxidize than hydrocarbons and therefore it is necessary to adopt a catalyser characterized by a higher quantity of noble metals (which act as catalysers) than the most standard catalysers.

Industrial purposes

Industries make use of natural gas not only to heat or cool environments, but also to make production processes more efficient, cheaper and ecological.
The most important productive uses are:

- **food industry**: malt and coffee roasting, meat processing (cooking, salami seasoning), cooking of bakery products (bread, bread-sticks, sweets)
- **metallurgic industry**: the most frequent applications are related to iron and its alloys, cast iron and steel. It is used in kilns for thermal treatments, for processes where controlled atmosphere is required, etc;
- **tiles and ceramics**: the gas is mainly used for the production of coating tiles and floor tiles, as well as in the sector of crockery and glassware and art ceramic. In the field of bricks (bricks, tiles), drying and cooking kilns working with natural gas allow to provide products with a more pleasant aesthetic aspect as compared to other techniques. The use of gas made the “fast cooking” possible, significantly reducing production times;
- **glass**: the absence of combustion residues and the easy temperature regulation make gas very suitable to supply continuous cycle kilns for both “sheet” and “pit” glass production;
- **jewellery**: thanks to its flexibility and flame purity, natural gas is widely used for the construction and welding of precious objects;
- **weaving**: natural gas supplies the energy needed to hair shaving and thermal fixing;
- paper industry: the methane is used to rapidly dry the ink.

Other uses

Use in the commercial sector

The commercial use of gas includes cooling (conditioning and refrigeration), restaurant services (kitchen), motels and hotels (heating of interiors), hospitals, public building sites and retailing.
Thanks to their high energy-efficiency, natural gas air-conditioners represent the most valid alternative to traditional electric systems and are used both to guarantee high comfort levels in civil buildings (houses, hospitals, hotels, buildings, offices), as well as to satisfy the needs of the industrial sector (air-conditioning of the workplace, productive processes, food preservation, etc).
Gas cookers are very popular in the restaurant sector: thanks to them it is possible to measure the heat in the best way, by varying the flame intensity. Moreover, during oven cooking, the combustion of methane releases water vapour, which softens the food preventing it from drying. These characteristics, as well as guaranteeing supply continuity, convert the methane into the most appreciated source both for household and professional purposes.

Household purposes

Natural gas is an excellent fuel used for both household purposes (gas ovens, heating, hot water), as not only is it the cleanest of all fossil fuels, but it is also the most convenient thanks to the relatively low costs of the equipment. Future estimates forecast an increase by 30% of the household consumption of gas in 2020. The main household use of natural gas is for heating. 35% of Italian families have central heating systems that supply heat to several houses.

Distributed generation

For many years people have been talking about “distributed generation” and “energy self-production”, i.e. energy production physically close to users. Recently the following concepts have become more relevant and up-to-date:

- The liberalization of the gas and electric energy market.
- The fact that electric energy is unable to satisfy the high demand and the subsequent planned black out.
- The problem of reducing pollutants emissions into the atmosphere.
- The community support towards renewable energy sources or sources that improve the efficiency of fossil sources.
- The possibility, by producing energy close to the users, to plan cogeneration, which leads to a better energy efficiency, reduced transmission losses and distribution and a sensitive reduction of emissions into the atmosphere.
- Lower costs of investments thanks to the smaller size of plants.
- The chance to electrify remote areas.
- The possibility to make a Country less vulnerable to the fluctuation of fossil fuel value (it was calculated that in Italy, by doubling cogeneration by 2010, 20% of imported gas would be reduced)

It is more and more important to develop, as well as an energy-centralized production, small power plants (i.e. micro-generation), located on the territory and built with technologies that combine efficiency and low emissions with cheap investments and excellent reliability.

Methane hydrates

Special ice

At the beginning of the Nineties, in marine geology research environments, word began to spread about a particular substance present under the ocean floor: it was the first information on methane hydrates that had up to then received scarce attention because they were considered not much more than a mere geological curiosity and lacking any commercial value.
The so-called biogenic methane is released during decomposition processes of organic matter and accumulates within sediments where it may concentrate and eventually rise towards the surface. If the surface is a sea bed, the gas that is released mixes with the cold water of the deep sea and forms a sort of ‘ice’. The water molecules crystallize forming a ‘cage-like’ structure inside which methane molecules are trapped. On freezing, the water squeezes the gas and the mixture’s density increases greatly. Chemically, methane hydrates are made up of a molecule of methane and 6 molecules of water (CH_46H_2O) and belong to the ‘clathrate’ family, that comprises compounds whose crystalline solids occur when water molecules form cells closed in a ‘cage-like’ structure. For this process to take place, two simultaneous factors are necessary: a low temperature (-15°C) and high pressure all around (20 bar, that corresponds to a sea depth of a little less than 200 m), in addition to an abundant supply of methane and water molecules, of course.

Where do you find them?

Due to the particular conditions required for these compounds to form and remain stable, their presence is limited to three environments: ocean floors, terrains covered by permafrost and the deeper polar ice.

The conditions that are more favourable to the formation of methane hydrates are to be found on a large scale beneath the sea beds at depths ranging from 300 to 3,000 – 4,000 m. Above this depth the pressure is not sufficient for the formation of methane hydrates and below it instead, there are optimal pressure and temperature conditions but the organic matter that originates methane is scarce: in other words, at this depth, the 'raw material' is absent. It is for this reason that methane hydrate deposits seem to concentrate along the continental slope that divides the continental platform from the deep abyssal plains: here great amounts of sediments accumulate that are often rich in organic matter and slide from the continents towards the open sea along the slopes. However, if the temperatures are very low, methane hydrates can form at lower pressures, as, for example, on shallower sea beds (in polar regions) or in the frozen soil covered with permafrost found in vast regions of Alaska and Siberia.
The greatest amount of methane hydrates, however, are found in the oceans. They occupy the porous spaces in the sediments for a thickness of several hundreds of metres. At deeper levels within the sediments where the temperature increases due to the geothermal gradient, the methane hydrates dissociate into water and methane gas and, as in the case of normal deposits, they constitute a sort of 'crust' that envelops methane in its gaseous state.

An original behaviour

Methane hydrates, made as they are of ice 'cages' that trap gas molecules, are stable compounds only when simultaneous very low temperature and high pressure conditions occur. If the temperature increases or the pressure decreases, the ice melts and methane is released in its gaseous form: methane hydrates, at room pressure and temperature, survive for only a couple of seconds. It is for this reason that to collect a sample of this substance is very difficult because, on bringing it to the surface, the majority of the methane is lost and only a minor part can be recovered in solid form. This characteristic is one of the main limitations to the extraction of methane stored in this way and also one of the possible sources of serious environmental hazards connected to its exploitation.
Methane hydrate ice found under the ocean floors can melt for various reasons, but the main one is surely the increase in the water temperature. The release of methane in its gaseous form brings about the formation of gas bubbles that expand on rising, and on reaching the surface they scatter in the atmosphere. This gives rise to a characteristic bubbling of the waters where the phenomenon is taking place.

Methane: a 'clean' fuel

Among fossil fuels, currently methane seems to be the one that will be exploited more and more in the near future, thanks to its relative abundance and thanks to the fact that it is relatively 'clean'. Its molecule is made up of 4 atoms of hydrogen and one of carbon (CH_4): on burning, it is the hydrocarbon that releases the smallest amount of carbon and it is for this reason that it is less harmful for the environment. Its CO_2 emissions are 25% lower than petrol, 16% lower than Liquid Propane Gas, 30% lower than diesel and 75% lower than carbon. Its capacity to form ozone is 80% less than petrol and 50% less than diesel and Liquid Propane Gas. Moreover, the combustion emissions do not contain carbonaceous residues, benzene and microscopic dusts (PM10), contrary to petrol and diesel oil. Among all the fossil fuels, methane is surely the most 'ecological'. The use of methane is expected to increase greatly in the near future.
The natural gas reserves that are of 'geological' origin are estimated to be sufficient for 60-70 years and they are mostly concentrated in the areas surrounding the Persian Gulf.
Much smaller amounts are currently obtained from waste products of zooculture, with the use of anaerobic digesters that enable the production of methane from animal sewage. Other small quantities can be obtained from self-produced methane in abandoned carbon mines; here, this naturally produced gas is tapped and at the same time is prevented from dispersing in the surroundings.
Immense reservoirs
Methane hydrates could be the energy source of the future. A cubic metre of methane hydrates can contain from 160 to 180 m3 of methane gas.
It has been calculated that beneath the ocean floor and in areas of permafrost more than 100,000 million billion cubic

metres of methane are present, trapped in the form of hydrates. Some estimates state that the ‘reservoirs’ contained in the permafrost of Alaska and Siberia are 5 x 10^{13} m^3 while those contained beneath the ocean floor are 5-25 x 10^{15} m^3. The amount that can be exploited could be at least two orders of magnitude greater than the amount of methane present on the planet and could supply about twice the amount of energy that can be obtained from all the fossil fuel deposits known to date.

Limits of methane hydrates

The exploitation of such quantities of natural gas is not possible today: present day technologies are not yet able to collect the hydrates so as to extract the gas, without losing it in the environment.
The first problem that has to be solved is that of finding the deposits. The research for methane hydrates utilizes geophysical methods that make use of the particular property of layers rich in hydrates to reflect seismic waves. Appropriate systems (usually compressed air ‘cannons’, for investigation in the sea) provoke the propagation of seismic waves that, passing through the rocks beneath the sea floor, are reflected at particular levels (the so-called Bottom Simulating Reflectors). This phenomenon occurs also for levels rich in hydrates: the so-called ‘seismic profiles’ are thus obtained and are real ‘ultrasound scans’ of the rocks that make up the sea floor. Italy is in the forefront in this type of research that is carried out by the Istituto Nazionale di Oceanografia e Geofisica Sperimentale (National Institute for Oceanography and Experimental Geophysics) with the research ship, OGS-Explora.
The second problem is that not much is known about these compounds: currently studies continue both for scientific research purposes and for commercial reasons. The GEOMAR Institute of Kiel, one of the major institutes of marine research, has created a laboratory in which the temperature and pressure conditions required for the conservation of methane hydrates have been recreated: in this way they can be studied in a laboratory at controlled conditions. Other research institutes, like the Brookhaven National Laboratory (USA), are carrying out experiments regarding the creation of these substances in a laboratory.
As far as commercial research is concerned, in March 2005, an expedition set out, financed by the American Energy Department and by the oil company, Chevron-Texaco. During the 35 days spent in the Gulf of Mexico, hydrate samples, collected with the additional aid of mini submarines at a depth of 1,300 m, were studied. Laboratory tests will enable us to understand in what way the methane trapped in ice can be released, recovering the maximum amount possible without losing it in the environment: extractive technologies, in fact, will have to consider the separation and collection of the gas directly in the sediments.

Hydrates and climate changes

Methane is much more opaque to infrared radiation than CO_2 and consequently it produces a greenhouse effect 20 times greater than that of carbon dioxide. It is a gas whose effect on the atmosphere is much more dangerous than that of CO_2: its effects are not very important because, at the moment, it is found in very limited quantities. Geological evidence in Antarctic ice cores show, however, that periods when the climate was warmer are always associated to increases in the methane concentration in the atmosphere.
The exploitation of methane hydrates potentially creates the risk of releasing great amounts of methane, either accidentally or as an undesired consequence of the extractive process. What must be avoided is that the exploitation of this enormous energy source should happen in an irresponsible way: the release of great quantities of methane could cause an increase in the greenhouse effect and, consequently, a warming of the oceans. This would bring about the melting of great amounts of hydrates beneath the ocean floor, in the land covered with permafrost and in the polar ice causing a further release of methane: this would trigger off a series of processes whose final effects are difficult to foresee. Man’s contribution to the greenhouse effect as a result of the burning of all the fossil fuels available, would be of ‘only’ 200 billion tonnes of CO_2: nothing, when compared to the possibility that hydrates could release 10,000 billion tonnes of methane ‘spontaneously’!
Moreover, when hydrates are absent, the sediments of continental slopes are made up of loose and unstable elements.

Therefore it is likely that the melting of hydrates could trigger off landslide phenomena, even on a large scale, in the areas where extraction is taking place.

A look at the past

Some geological evidence proves that there have been climatic ‘crises’ on a large scale that have modified the distribution of creatures living on Earth. Recent geological and paleontological researches seem to indicate that in at least one of these crises the role played by methane hydrates could have been very important.
55 million years ago, between the Paleocene and the Eocene, on our planet a climatic and environmental catastrophe of enormous proportions took place, known to researchers as the Paleocene-Eocene Thermal Maximum (PETM).
The global warming, that involved the whole planet, brought about migrations of animals on the mainland from subtropical zones to higher latitudes, while 70% of the creatures living on the ocean floor died out. As a consequence of conditions that have not yet been understood (but probably a result of a period of intense volcanic activity) the oceans got warmer provoking the release of enormous quantities of methane from the ocean floor that then entered the atmosphere. The amount of gas is in the order of billions of tonnes released in the time interval of a couple of millenniums, or perhaps, even a few centuries. The melting of the hydrates made the continental slopes unstable and these, sliding and falling, released more methane creating a cyclic process that was self-powered for a period that lasted between 80,000 and 200,000 years.
The greenhouse effect that the released methane triggered off, heated the oceans more and more, bringing about the release of other methane and a reduction of the oxygen dissolved in sea water causing serious damage to sea life. In the Nineties, the analysis of marine sediments and of their paleontological content has led to estimate the rise in temperature of the oceans as having been around 8-10°C. This resulted in a modification of both oceanic and atmospheric circulation bringing about intense climate modifications and the extinction of numerous forms of life.
Other ‘crises’ of this kind are documented in the geological history of the Earth, for example, 250 million years ago, in the Permian or at the beginning of the Jurassic. For these events that are so far back in time, there are no geological proofs to indicate a relationship with methane hydrates. In a more recent past, instead, the analysis of ocean sediments and the study of the presence of bacteria that feed on methane show that in different parts of the world, the warmest spells of the last glacial period always correspond to the presence of great quantities of methane, released from beneath the sea floor (70,000 to 12,000 years ago).
Some scientists who are studying the problem of global warming, fear that an increase in temperature on our planet can in turn trigger off a sudden release of the methane contained in the hydrates.

Other consequences

Now that methane hydrates have been discovered, they are proving to be present on sea floors in enormous quantities. As already mentioned, some researchers suppose that it is the very methane hydrates that act as the ‘adhesive’ that allows the stability of the sediments that are deposited along the continental slopes. Therefore the rapid melting of methane hydrates would have the immediate effect of destabilising the sediments that have accumulated along these slopes. This could set off underwater landslide phenomena, even on a vast scale, that could in turn bring about the propagation of anomalous waves.

What can be done?

What is known about methane hydrates, about their behaviour and their distribution along with the geological data of the past, suggest caution in the race to utilize these compounds for the production of methane. The exploitation of these enormous energy reserves could temporarily solve many energetic problems and help in the difficult transition phase between the utilization of fossil fuels and the use of renewable energy sources. However, the environmental risks connected to an indiscriminate exploitation that does not respect the environment seem very high. Commercial exploitation must therefore be postponed till when state of the art technologies can protect us from the most serious risk: the release of great quantities of methane into the sea and the atmosphere.

Moreover, the possible risk of triggering off great underwater landslides on a vast scale must not be forgotten.
The presence of compounds with such particular and unstable characteristics, that are so sensitive to the slightest variation in temperature keeps us on guard as far as man's contribution to the greenhouse effect is concerned: it is true that geological data show that climate changes on a large scale and environmental and climatic 'crises' at a planetary level have occurred in the geological past without any involvement on man's part, but our behaviour could give a decisive contribution to sparking off these processes that, once started, could prove to be irreversible.

Environment and territory

Impacts on air

The extreme flexibility of natural gas makes it one of the fuels easier to use, whereas the low content of pollutants makes it an environmentally friendly fuel. During combustion natural gas produces carbon dioxide and nitrogen oxides (NOX), albeit to a lesser degree than other fuels.
Moreover, coal and oil by-products also produce sulphur oxides and sulphur dioxide (SO_2), two pollutants toxic for mankind and the atmosphere. Sometimes the natural gas can be burnt with coal or oil (co-firing): this process can significantly reduce the emissions of SO_2 e NOX. Cogeneration allows to consume 25% less of energy as compared to a traditional plant and to reduce by 1% the emissions of SO_2 and by 50% NOX emissions, as compared to a coal or oil-based plant, even if it makes use of anti-pollution equipment.
As regards carbon dioxide in particular, the International Energy Agency (IEA) assessed that, if the same amount of energy is produced, carbon dioxide emissions caused by the combustion of natural gas are smaller by 25% and 40% as compared to those produced by the combustion of oil and coal by-products.
Finally, methane presents the advantage of being virtually "invisible" both during ground transport and when it is distributed in cities (it travels through underground pipes and only pumping stations are at ground level), a feature only few other energy sources share.
Moreover, since it is gaseous at room temperature (20°C), should any leak occur during transport, it disperses into the air, does not dirty, or pollute waters or the soil.
Natural gas can damage the environment if it is dispersed in its natural state because it is one of the greenhouse gases. In other words, after reaching the top layers of the atmosphere, it stops and stays there for many years, contributing to the formation of a gas layer that prevents the solar heat reflected by the earth's surface from being dispersed and leads to global warming (i.e. the greenhouse effect).
Therefore leaks of natural gas during its transportation should be reduced to a minimum or eliminated: not only is it a waste of a precious resource, but there is also the risk of contributing to a potentially dangerous phenomenon for mankind.

Gas flaring and gas venting

In an oil field, oil is almost always associated with a certain quantity of natural gas: newer oil wells are equipped for the recovery of both oil well gas and crude oil and hence the gas is an additional resource of the oilfield. However, the recovery of this gas presumes that there are the transportation infrastructures required to move it to the points of consumption: these infrastructures, which are both costly and often difficult to implement, are not finalised when the quantity of gas recovered from the oilfield as a "secondary" product is limited, since the potential revenue would not cover their cost. Hence the problem arises of what to do with the associated gas.
The term gas flaring indicates the combustion of gas (without energy recovery) in an open flame that burns unceasingly at the top of flare stacks in oil production sites. This practice has resulted in the burning of large quantities of gas with the consequent production of huge amounts of carbon dioxide together with sulphur dioxide and nitrous oxide, which have contributed substantially to atmospheric pollution. In order to better understand the scale of the problem, it is sufficient to observe nocturnal images of Earth from space: the gas flaring activity in regions corresponding to the major petroleum-producing areas are a proof that cannot go unnoticed! Consider that in Italy today (where the practice of gas flaring is

limited not only because there are fewer oil fields respect to gas fields, but also because Italy attempts to use all the natural gas produced) one million tonnes of carbon dioxide are produced every year as a result of gas flaring, while in Nigeria, where this practice is still greatly utilised, hundreds of millions of tonnes are produced!
Besides the practice of gas flaring, there is also that of gas venting. Gas venting is the discharge of unburned gases into the atmosphere, often carried out in order to maintain safe conditions during the different phases of the treatment process. During venting operations methane, carbon dioxide, volatile organic compounds, sulphur compounds and gas impurities are released. In many cases gases that are being vented could be burnt rather than dispersed into the atmosphere; this would partially reduce the environmental impact in terms of greenhouse gases, because the gases would be oxidised to form carbon dioxide, which has a global warming potential 21 times lower than methane.
Currently, the above-mentioned practices are subject to strong restrictions, both for economic (the gas produced could be sold and consumed rather than wasted!) but especially for environmental reasons. Under the Kyoto Protocol, there are incentives for the construction of plants that have minimum environmental impact and which, at the same time, do not waste precious resources. In more developed countries, this practice has been almost totally abandoned because it is a waste of an important resource and the infrastructures required to utilise the gas in situ are not difficult to implement. On the contrary, in many developing countries the gas is often not required at the production site and the costs of transportation are very high. For this reason, there are incentives to implement practices that are more feasible and less costly such as, for example, natural gas reinjection into the reservoir to increase its pressure and consequently its efficiency, small-scale natural gas liquefaction plants on the production site, the generation of electricity in situ, the distribution of natural gas to neighbouring urban areas, its use for transportation, etc. while costly operations, such as the construction of pipelines, are carried out only when the natural gas extracted justifies the high costs.