

NATURAL GAS KNOWLEDGE

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NATURAL GAS KNOWLEDGE

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.

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 (CH_4). It is lighter than the air (at a 15°C temperature and 1013.25 millibar pressure its specific weight is 0.678 kg/m^3), 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 52.2% 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 39.9% of the world reserves and only produce 16.6% 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, the U.S., despite possessing only 6.5% of the world's proven reserves of natural gas, produce more than 23.4% 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 will deplete their reserves in a few years and will need to resort to imported gas only.

(Source: eni, World Energy Review 2022)

The reserves

World natural gas reserves total 202,179 billion cubic metres approximately (data refer to 31st December 2021). 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 2021, amounted to 3,851 billion cubic meters), at the current exploitation rate reserves will be depleted in approximately 52 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 Energy Review 2022)

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). Those 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.

Uses of gas

Natural gas supplies are mainly used to generate electricity in many types of power plants where it fuels the burners that produce steam to drive turbines. It is also used in gas turbine power plants where, however, it is directly burnt in internal combustion turbines. Gas-fueled thermoelectric power stations are the best power plants because they combine a gas turbine (first stage) with a steam turbine (second stage) whose boiler is fueled by the flue gases leaving the gas turbine. These plants are known as combined cycle power plants. Natural gas is also now used for heating via district heating networks or in homes, businesses and industrial plants, for example for cooking, domestic hot water, and building heating or cooling systems.

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 hermetically 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 rapidly 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 localized 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 centers and shopping centers.

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.

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.

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