

GAZPROM EXPORT

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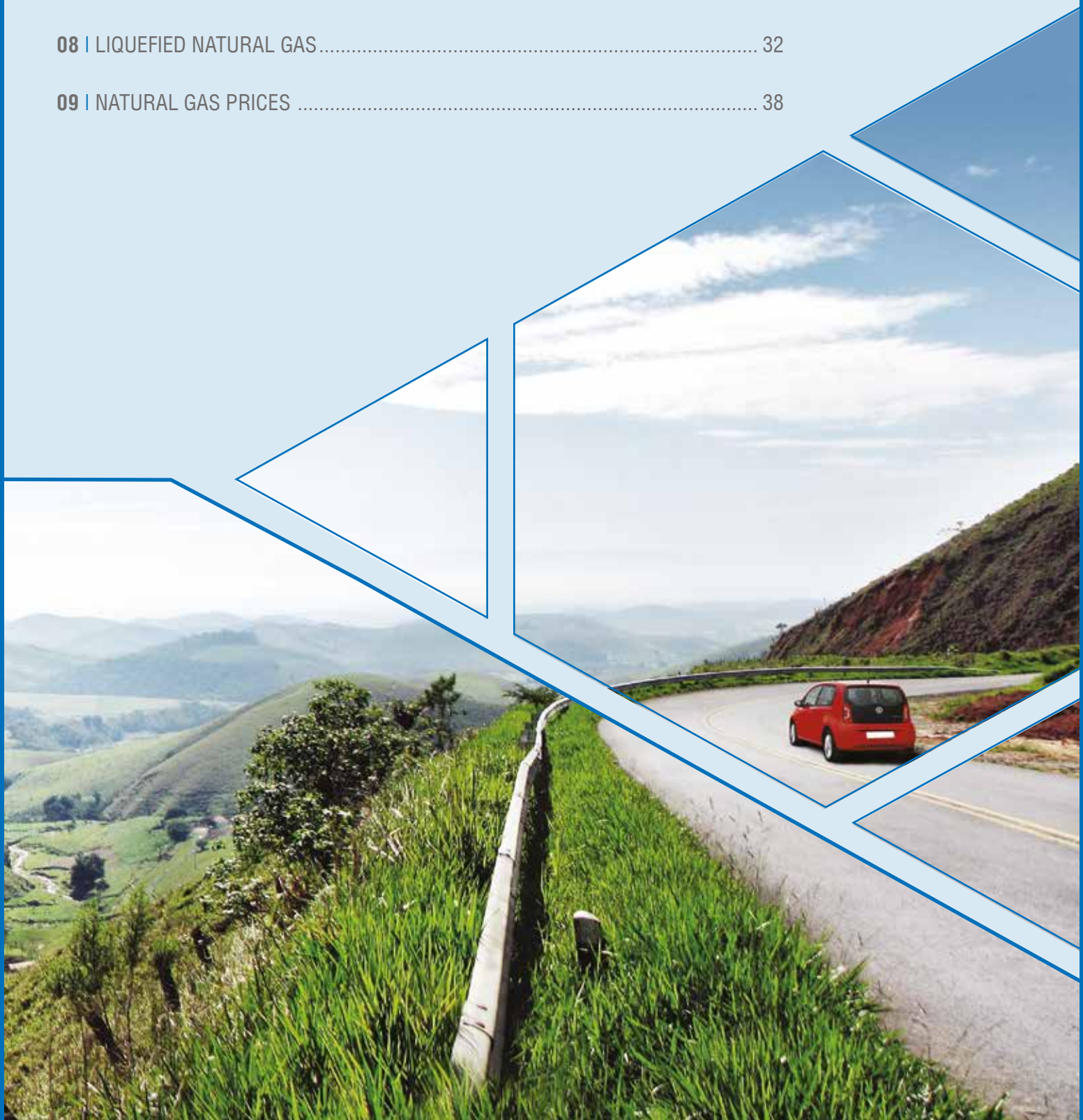
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01

GAZPROM IN THE GLOBAL TRANSPORTATION FUEL NGV MARKET



Today, the involvement of energy companies is essential to the development of the global transportation fuel NGV market and its European segment. The world's top energy brands are encouraging global transport industry to adopt natural gas instead diesel and gasoline. Many have their own programs for developing CNG and LNG filling infrastructure, natural gas liquefaction plants, and sea or river bunkering facilities.



Gazprom is no exception. Gazprom's production, research, and engineering subsidiaries have been not only building and operating CNG filling stations. They are directly involved in creating Russia's NGV industry: developing new gas-consuming and gas-fuelling technologies for CNG and LNG, building up regional filling networks, improving national regulatory environment, proposing tempting federal and regional incentives for NGV market stakeholders.

Gazprom is directly involved in launching the NGV programs in aviation (creating the world's first LNG airplane), railway industry (creating the world's most powerful LNG locomotive), water transport (converting tourist boats to use CNG), and agriculture (testing and certifying prototype CNG- and LNG-fueled wheel tractors and caterpillars). Domestically-produced compressors and cylinders for CNG, as well as cryogenic hardware for LNG, valves and other components, locally built CNG trucks and buses – all these equipment have been in Gazprom's focus.





Gazprom Export is one of the Gazprom Group subsidiaries active in the global NGV market. Its task is to expand number of customers, and increase export of Russian gas that can be used for greener mobility. To achieve this goal, Gazprom Group is coordinating activities of Gazprom's outlets worldwide, marketing methane for vehicles. Gazprom Group is represented in European NGV market through its 100% subsidiaries Gazprom NGV Europe and NIS (part of Gazprom Neft Group) which sells CNG in Serbia. In 2017 the number of CNG filling stations operated by Gazprom Group in Europe totaled 60 units. Gazprom also operates two LNG filling stations in Poland.

- In Germany, Gazprom Group owns 49 CNG filling stations.
- In the Czech Republic, Gazprom Group runs 8 CNG fueling sites.
- In 2013, Gazprom Group and Solbus delivered 11 LNG buses to the city of Olsztyn in northern Poland. Another 35 LNG buses were commissioned in Warsaw in 2015. To fuel them, Gazprom Group has erected a private LNG station at the premises of the MZA bus company. The new Euro 6 environmental standards being introduced from 2015 made eco-friendly LNG buses even more competitive against diesel buses.
- In Serbia, NIS company affiliated with Gazprom Neft operates 2 CNG stations.
- In Italy, Gazprom subsidiary Gazprom Italia is aiming for a solid position in the market of the European NGV fuel segment leader. The company is engaged in market research, partner selection, cooperation with national and EU authorities, and technology exchange. These operations cover not only CNG for passenger vehicles, but also LNG for trucks and shipping.

Gazprom Group's expansion of its transportation fuel NGV market operations is not confined to Europe alone. In 2015, Gazprom and PetroVietnam established a joint venture PVGazprom NGV. The new company will produce gaseous transportation fuel for on-road vehicles in Vietnam.

BLUE CORRIDOR

The Blue Corridor NGV Rally has become an international brand-name event associated with the use of natural gas for transportation.

Eleven rallies of this series since 2008 are part of the eponymous project blending theory (2003 UNECE study), public relations (holding the actual NGV races), and practice (the EU country's programs for creating a network of LNG/LCNG filling stations and a fleet of LNG-fueled vehicles).



The Blue Corridor project was proposed by the V.I. Vernadsky Nongovernmental Ecological Foundation in 1999 and since then patronized by Gazprom.

At the time, there was no global or European transportation fuel NGV market in today's sense of the term. There were under a million NGVs worldwide, with market growth sluggish and confined to just a few countries. In this situation, a new and arguably revolutionary approach was proposed.

For the first time, the issue of using natural gas as a transportation fuel was considered from the standpoint of transnational, trans-sector (gas industry + automotive + logistics), and trans-institutional (political entities + business + consumers) cooperation.



An international experts group organized by Gazprom, the Russian and European NGV Associations, and the UN Economic Commission for Europe, was established, and developed a theoretical concept for using CNG and LNG in vehicles transporting passengers and freights along European major transport corridors. In 2003 UNECE made the final report on The Blue Corridor Project public.

The concept was based on international transport corridors (Crete corridors). Over time, this notion matured into the European Union's key transport corridors (TEN-T Core Corridors). These corridors link Europe's main cargo and passenger traffic hubs across all transportation modes.



In 2006, the G8 summit in St. Petersburg endorsed the Blue Corridor Project. Eight national leaders confirmed their support in the Global Energy Security Action Plan that included natural gas mobility.

The Blue Corridor Project's public stage started from 2008 when Gazprom organized the first NGV rally from St. Petersburg to Moscow. This and subsequent rallies were aimed at demonstrating the environmental and economic advantages of natural gas and the diversity of OEM NGVs. The rallies became an annual event.

Since 2010, Germany's Uniper SE (former Ruhrgas and E.On) joined Gazprom in organizing the Blue Corridor NGV Rally. The Rally routes cover the territory of European countries as well as Russia.

Over the years, Blue Corridor rally crews have driven across all of Europe (and even a bit of Asia) from Yekaterinburg to Lisbon, from St. Petersburg to Sochi, and from Göteborg to Belgrade. In a number of the tours, the rally teams and their gas vehicles traveled between Turku and Stockholm on the LNG ferry Viking Grace.



In 2016, Gazprom expanded the Blue Corridor agenda by complementing the showcase for the use of gas in on-road transport with the topic of bunkering marine and inland water ships with LNG. The Blue Corridor Rally 2016 has proven that European businesses and countries have huge interest in LNG use for water vessels.

The 11th annual natural gas rally 'Blue Corridor - 2017' took place in September and October 2017. The route of the Rally, designed to promote the use of natural gas in transportation, crossed 12 European countries from Portugal to Russia and totalled to 5,5 thousand kilometers one way. The Rally was focused on the use of liquefied natural gas (LNG) on trucks.

Blue Corridor rallies are accompanied by public displays of natural gas vehicles and roundtables including gas and automotive industry representatives, leaders of national and municipal authorities, transportation companies, the European Commission and the European Parliament.

Over 150 originally-equipped (OEM) NGVs, running on compressed and liquefied natural gas (CNG and LNG), have taken part in the project over its lifetime: from the smallest Volkswagen Eco Up to Iveco Stralis and Volvo FM heavy duty trucks, Solbus LNG buses, and KAMAZ racing truck. Over the years of the project, 11 rallies have been held and the participants drove more than 50 thousand kilometers across Europe.

It should also be added that similar NGV rallies are held in Latin America and the Asia-Pacific.

For the sake of historical accuracy, it should be noted that the Blue Corridor NGV rally is not the first event of its kind aiming to promote the use of natural gas as a transportation fuel.



Indeed, the first rally looked more like vehicle testing. In the early 1860s, Étienne Lenoir drove his gas powered prototype vehicle for the first time from downtown Paris to the suburb of Joinville-Le-Pont.



However, in September-October 1946, Academician Evgeny Chudakov organized a real rally involving 18 gas vehicles (five running on CNG and 13 on LPG) along Berlin – Kiev - Moscow route of 2,603 kilometers.



The next rally arrived in Moscow on 2 September 2002 in conjunction with the 11th meeting of the Russian government's NGV Commission. This rally involved a total of over 30 vehicles from various remote Gazprom subsidiaries. The CNG- and LPG-fueled vehicles gathered in Moscow from various directions including Yekaterinburg, Kazan, St. Petersburg, and Stavropol.



02

NATURAL GAS IN BRIEF



Natural gas is one of the world's most widespread and demanded primary energy resources. According to the latest forecast of the International Energy Agency's, global natural gas consumption may pass 4 trillion cubic meters mark as early as in 2022.

This energy carrier, unique in its environmental and economic properties, is used efficiently in heat and power generation, cooking, air-conditioning, and lighting, and as a fuel for vehicles and stationary engines.

The basic component of natural gas (up to 98%) is methane (CH4). This is a colorless and odorless gas, lighter than air; it is chemically inert and readily soluble in gaseous and liquid states such as air, water, or oil. Natural gas is mostly of organic origin.

The formation of resources of this fuel had taken hundreds of millions of years, at high temperatures, enormous pressures, and anaerobic conditions.

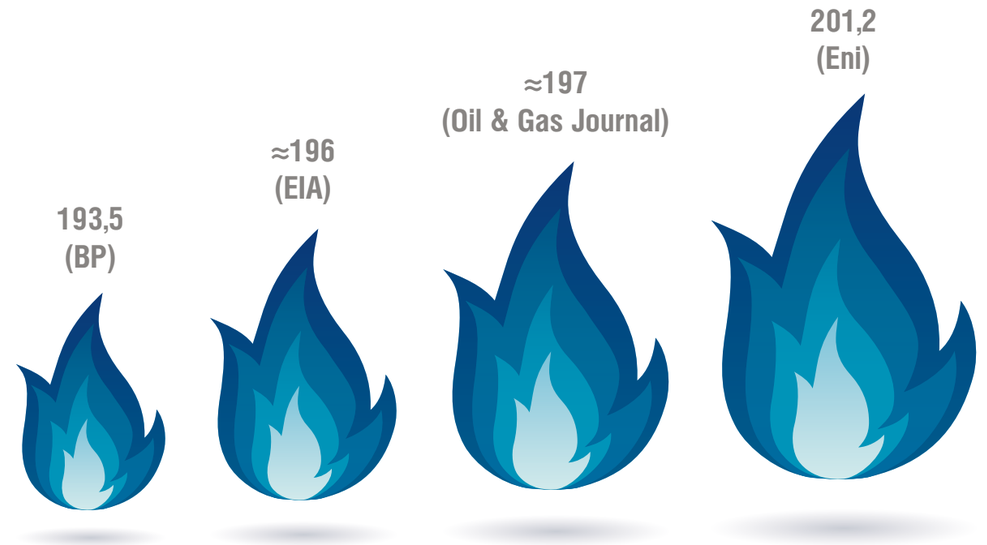
Methane-based natural gases are found alongside deposits of other fossil fuels: associated gas comes with oil, coal deposits have coal bed methane, and wetlands generate marsh gas.

Extraction of methane from shale, known as 'shale gas', has become widespread in the United States recently.

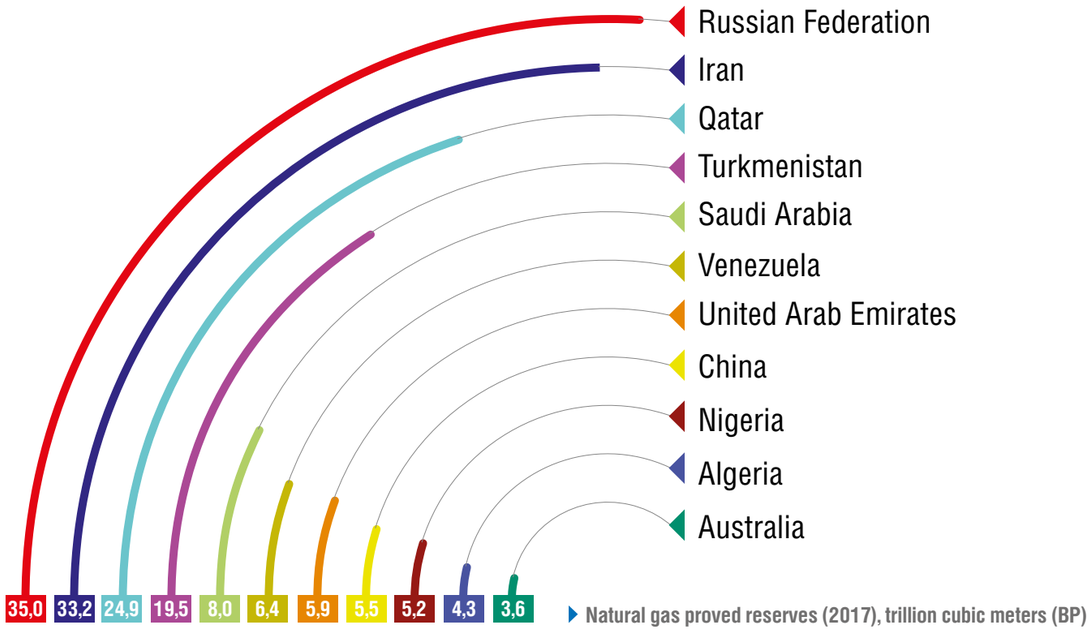
Natural gas can be produced artificially. For instance, biogas is produced from sewage or at landfills, cattle and poultry farms. There are also a number of techniques for synthesizing natural gas.

EXPLORED OIL AND GAS RESERVES

There are diverse estimations on the extent of global oil and gas reserves. Various methodologies are used to calculate this. However, overall experts' estimates of various organizations are fairly similar.

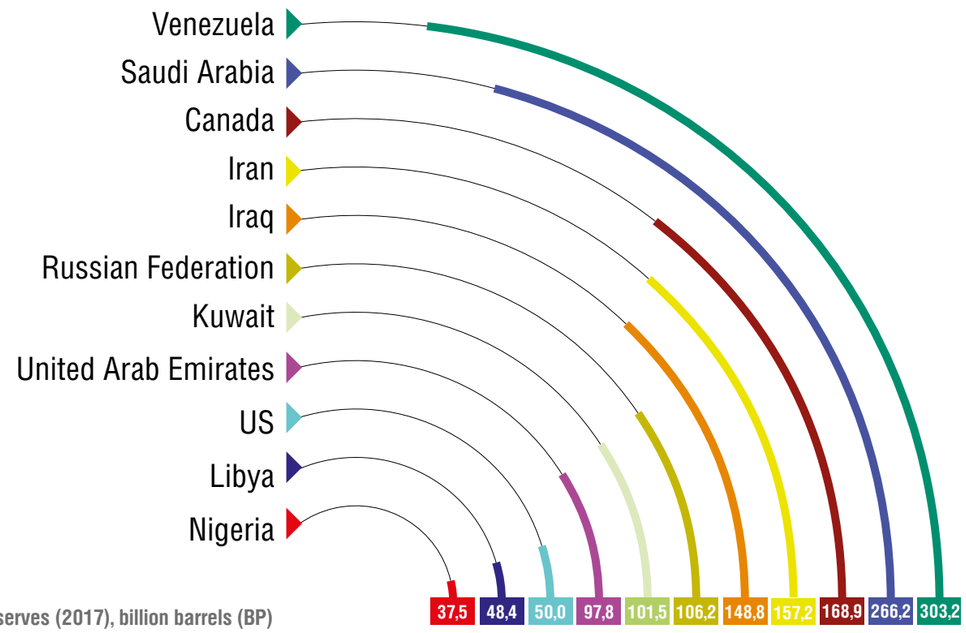


World gas reserves various estimates in 2017 (trillion cubic meters)



Natural gas proved reserves (2017), trillion cubic meters (BP)

The distribution of oil and gas reserves across different countries is very uneven. Some countries have more oil, some have more gas, some have a bit of both, and some have neither. The question of for how many years the reserves of a particular fossil fuel will last also lacks a definitive answer. Factors to be taken into account include the actual volume of reserves in various categories, production levels, demand and its dynamics over time, and other parameters. At present-day production levels, the world's proven hydrocarbon reserves should last an average of 50-55 years for oil, and up to 60 years for natural gas. It should be noted that the natural gas reserves in question include only conventional resources, not shale gas or other sources.



Oil proved reserves (2017), billion barrels (BP)

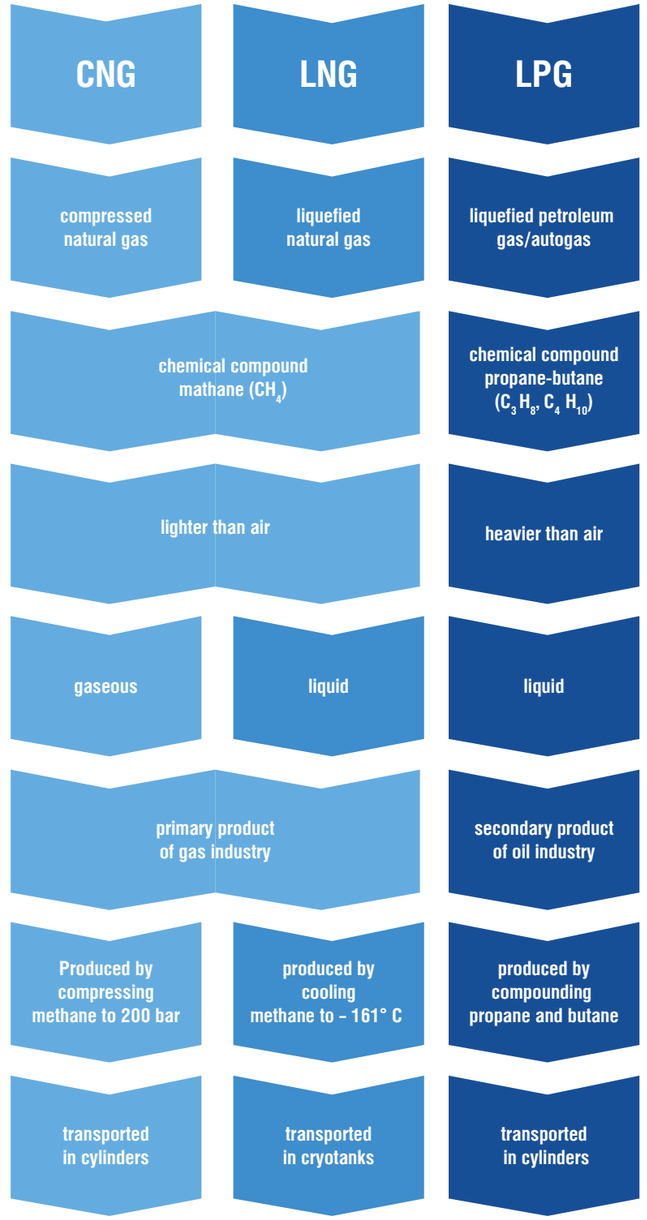
USE OF NATURAL GAS FOR TRANSPORTATION

The widespread availability of natural gas, along with its environmental and economic advantages make it a valuable fuel for the transportation industry. On-board a vehicle, natural gas can be stored either in gaseous form (compressed natural gas, or CNG), or in liquid form (liquefied natural gas, or LNG).

CNG and LNG are "blood brothers". All the same, as is common in families, they each have different personalities or, technically speaking, physical and chemical properties. These variations determine the design of fuel management and storage systems for NGVs, as well as that of filling stations.

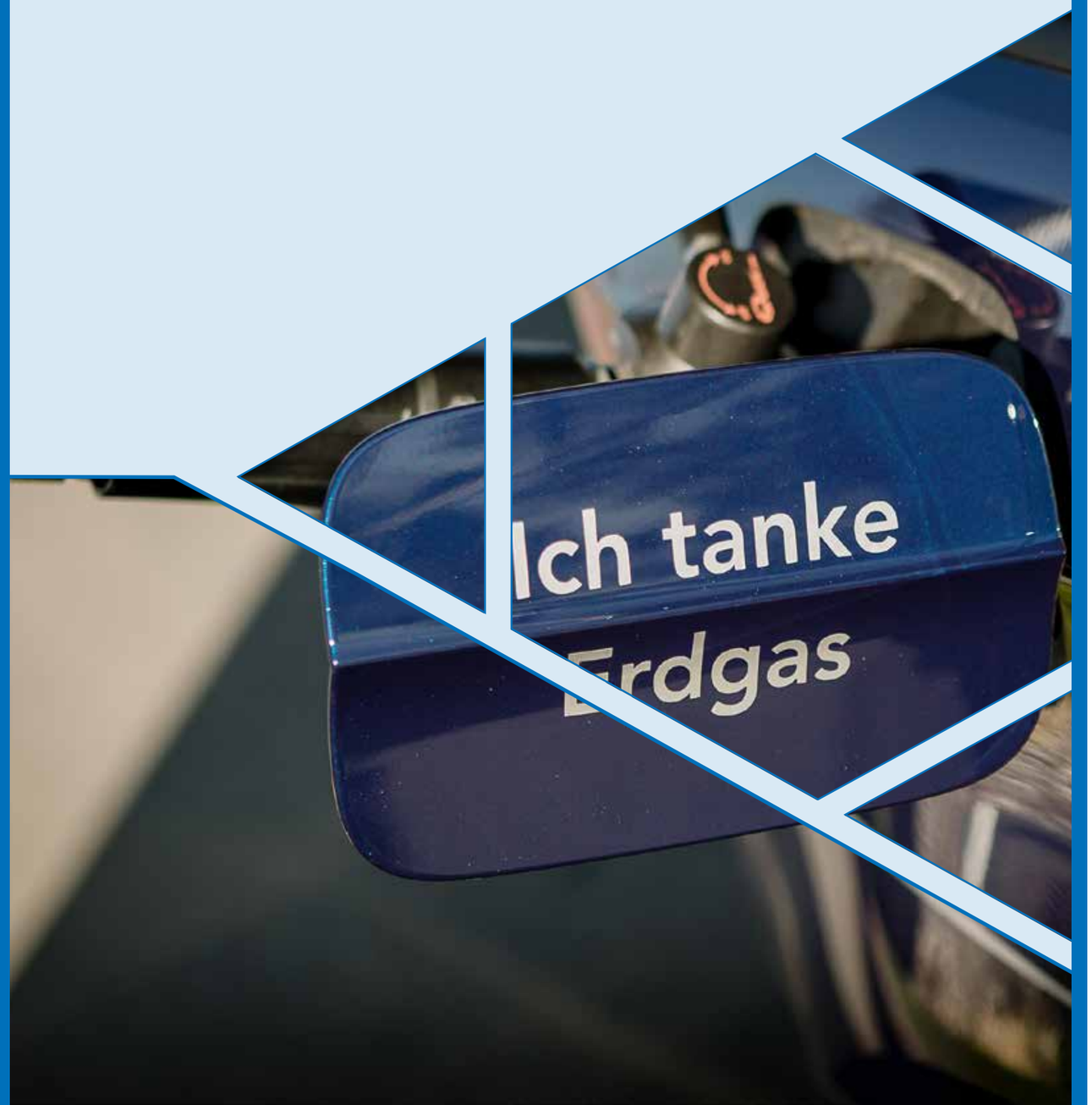
Liquefied petroleum gas (LPG) is also a very popular fuel around the world. LPG is a mixture of propane and butane, while natural gas is mostly methane. For simplicity's sake, therefore, LPG is often called "propane" while CNG and LNG are called "methane." In some countries, propane is also called "autogas."

Methane is lighter than air, and if released, it rapidly dissipates in atmosphere. Propane is heavier than air, and tends to sink to the ground. It can fill garage service pits or drain trenches and form explosive mixtures with air. A single spark is enough to trigger an explosion.



03

NATURAL GAS IS A CLEAN FUEL



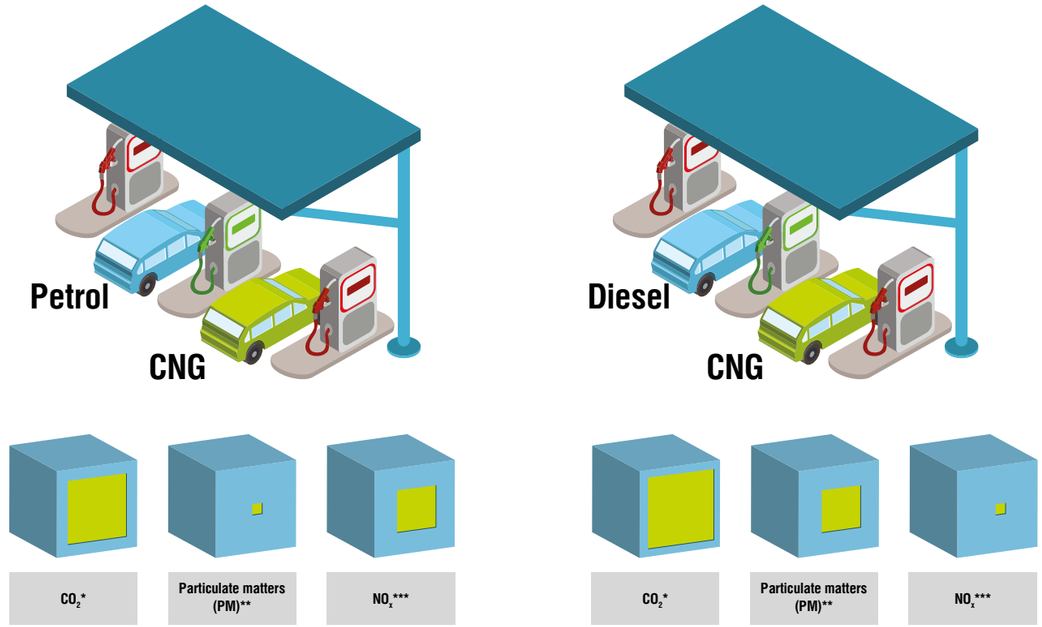
Gas is a key solution to ensure improved air quality in a cost-effective way



The use of natural gas represents one of the key and most effective solutions to fight climate change and improve air quality in a cost-efficient way, particularly in the transport sector. Today transportation contributes to about 85% of harmful emissions in big cities. Both CNG and LNG are viable and scalable solutions that allow an immediate reduction on greenhouse gas (GHG) emissions and pollutants.

Growing popularity of natural gas use in public and municipal transport not only helps to reduce costs, but to improve air quality in cities and to achieve the targets needed to decarbonise the transport sector. Gas engines are also characterized by low noise level, adding flexibility to municipal use.

A study conducted in 2017 on the greenhouse gas intensity, under the well-to-wheel approach, proved that CNG allows to reduce greenhouse gas emissions by 23% compared to petrol or by 7% compared to diesel for the passenger vehicles. When used in heavy-duty vehicles, results are even more impressive, allowing up to 16% GHG decrease compared to diesel.



Comparison based on actually measured real emissions

Source: *Taking into account the share of biomethane at 20% (see the 3rd interim report by dena Initiative Erdgasmobilit t, 2015);
**PM calculation at ADAC EcoTest 2017
***ADAC ExoTest 2017, EMPA 2017

Comparison of emissions from internal combustion engines on CNG, petrol and diesel (Euro 6)

Taking other emissions besides the greenhouse gas, methane as a vehicle fuel performs even better. It emits up to 95% less PM and up to 70% less NOx compared with the very strict European emission standards for new heavy-duty vehicles (Euro VI) and light-duty vehicles (Euro 6) using petrol or diesel. Exhaust gases from natural gas engines are free of other harmful and carcinogenic pollutants.

Even when considering non-regulated emissions (like ozone promoters or aldehydes), natural gas is the best fuel to improve air quality, particularly in urban areas. In the maritime sector, natural gas also provides a concrete solution with regard to pollutant emissions, particularly in curtailing sulphur oxides (SOx).

According to NABU research, cruise ship passengers could be exposed to pollution levels that are up to 60 times higher than in fresh air. The use of LNG as bunkering fuel reduces potential harm almost to zero.



Gas can be green

Both CNG and LNG can also be produced from a variety of renewable energy sources, or through different pathways:

- organic waste and biomass processed through anaerobic digestion develop to biogas which is then upgraded to biomethane;
- in the gasification processes, organic waste with high carbon content is converted into carbon monoxide, hydrogen and carbon dioxide, then combined to produce synthetic methane;
- power-to-gas is a process in which excess electricity gained from renewable sources is used to produce hydrogen which is then upgraded via methanation to methane.

All renewable gas can be blended with natural gas and used as fuel for NGVs. With this, even moderate blend levels allow to further enhance the beneficial environmental effects of using natural gas, already a low-carbon fuel, thus enabling substantial reductions of total GHG emissions. Use of renewable gas obtained from the excess of electricity can offer a zero-emission option for vehicles.



04

MYTHS ABOUT METHANE



Loss of engine power



Among the most widespoken myths is the allegation that a vehicle converted to natural gas loses up to 20% of its power. This is only partly accurate. Vehicles used to lose power in the early stages of NGV market – in the 1970s - 90s.

Original equipment manufacturing (OEM) of NGVs was limited back then, and most NGVs on the road were converted vehicles; fuel management systems were mechanic; auto-makers bore responsibility only for the vehicle, while the CNG equipment was the responsibility of third-party suppliers; and there was no qualified servicing system for gas technology.

In such conditions, not only mechanical performance of the engine, but its emissions could worsen.

Electronic engine control OEM production of NGVs took these problems away. Performance–wise, a natural gas vehicle is not different from its gasoline or diesel modification: they have the same power, torque, speed, load capacity, and passenger capacity. However NGVs are quieter, their emissions are cleaner, and fuel expenses are lower.

Shorter mileage per fuel tank

This was another disadvantage of NGVs a few decades ago, mostly affecting passenger vehicles. It was hard to equip them with enough cylinders to travel a fair distance on methane. A 50-liter cylinder tank pressurized to 200 atmospheres holds 10 to 12 m3 of natural gas. With an engine consuming 7-10 liters of petroleum fuel per 100 km, a converted car could drive 150-200 km. Trucks and buses could be fitted with more cylinders. Since their fuel consumption was also higher than that of passenger cars, however, they also went only 200-300 km between refueling stops.

Modern cars with CNG tanks integrated into their bodies, and with fuel consumption of 5-6 liters/100 km can travel up to 450 km on methane. And given that practically all models also carry a reserve supply of gasoline, the total distance traveled on one fill up (methane + gasoline) can reach up to 900-1,000 km. Trucks and buses with multiple tanks can travel 400-1,400 km between natural gas refueling stops.

LNG-fueled trucks and buses are even more distance-efficient, since LNG takes up about 1/600th the volume of CNG. Volumetric density of LNG is 2.5 times greater than that of CNG, which translates into 2.5 times longer mileage on LNG compared to CNG.

Longer refueling time

Modern natural gas refueling equipment allows that filling a car, bus, or truck with CNG takes just negligibly longer time compared with filling the conventional vehicles with gasoline or diesel. NGV1 nozzles are used to fill passenger cars with CNG. For faster filling, heavy vehicles use NGV2 nozzles with higher throughput.

Filling bus or truck with LNG will take exactly the same time as their diesel modifications – around 10 minutes.

Time issues at CNG filling stations can only arise when it becomes necessary to fill heavy duty vehicles through nozzles designed for passenger vehicles.

Driving on high pressure gas is like having a bomb in a car

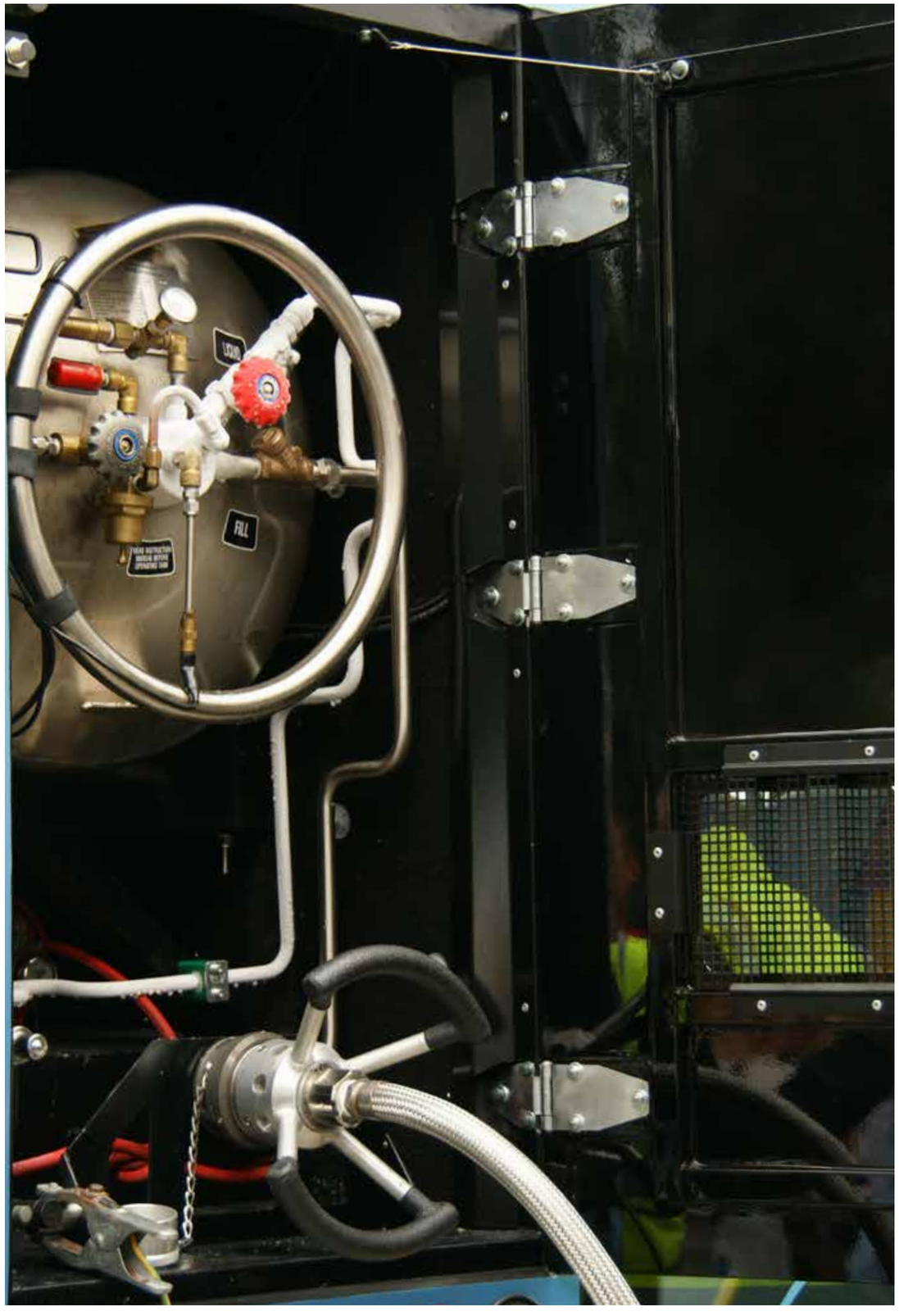
Some say that driving around with CNG tank is “like having a bomb in your car.” It’s no secret that methane is a flammable and explosive gas. It requires respectful attitude and skilled handling. Although NGV accidents are extremely rare – far more rare than for cars running on propane or other oil fuels – they do happen sometimes.

Still, natural gas is not that easy to ignite. Its concentration in the air has to be 5-15%. Besides, its auto-ignition temperature of 540°C is very high. Comparing these figures for natural gas to propane, gasoline, and diesel shows that it is still the safest form of transportation fuel.

CNG tanks used in vehicles are very robust. In passenger cars, for instance, the cylinders are installed in the statistically least vulnerable parts of a car. According to BMW studies, cylinders integrated into a car body are much safer than gasoline, diesel or propane tanks.

In case of an accident, cylinders filled with natural gas often remain undamaged after a serious accident or fire. Their safety features are activated: safety rupture valves triggered by a sudden rise or drop of pressure, melting fuse valves activated by rising temperature; and the natural gas is released into the air.





05

HOW IS METHANE REFUELING PERFORMED?



Filling stations and vehicles are not only complementary, but mutually essential elements of a single system. Worldwide experience shows that the filling station shall go first. NGVs will not survive without refueling infrastructure.

The following principle categories of natural gas (CNG and LNG) fueling equipment are available:



Stand-alone CNG filling stations (mother and daughter)



Integrated CNG dispensers (at regular petrol stations)



Vehicle refueling appliances



LNG and LCNG filling stations (fixed and mobile)



Mobile CNG filling stations (self-propelled natural gas tankers)



Mobile CNG filling stations (towed refueling packages)

CNG filling stations

In terms of fueling speed, there are two types of CNG filling stations: fast-fill stations, generally equipped with cascading gas storage tanks; and slow-fill stations which can refuel one or more vehicles over a period of several hours, such as at a night stopover. Slow-fill systems can be economical in some cases and are used effectively by, for example, bus fleets.

In terms of gas sources, CNG filling stations can be divided into ‘mother stations’, where gas is piped in, and ‘daughter stations’, where vehicles are refueled with compressed gas delivered by tank trucks from a ‘mother’ station. In some countries, these gas tank trucks are called virtual pipelines. All LNG and LCNG station are basically ‘daughter’ stations.

In terms of capacity, there are several classes of CNG filling stations:

- mini and micro: under 50 nm3/hour
- small: 50-200 nm3/hour
- medium: 200-500 nm3/hour
- large: 500-1,000 nm3/hour
- very large: over 1,000 nm3/hour



Vehicles can be refueled at CNG filling stations by specially trained and certified personnel. Some countries permit self-service, with drivers performing the filling process themselves.

Mainstream trend today is to build small automated CNG filling stations with one or two dispensers, equipped with a telemetric monitoring system, no staff at all, serviced on schedule by offsite technicians. Such stations need very short construction time (under a month, including all engineering work) and reasonable costs (€250,000-300,000).

One of the main problems with CNG filling station network development is a lack of suitable sites and unjustifiably complicated bureaucratic procedures in acquiring them.

Vehicle refueling appliances (VRA)

These refueling devices are also called home fills, since they can be installed in private houses. As a rule, VRAs are slow-fill systems. They are connected to the local natural gas distribution systems. As yet, not all countries have established the regulatory framework on installation and use of VRAs.

VRAs can also be used to supply gas at small corporate car parks: office parking lots or garages are equipped with these appliances, to refuel company fleet overnight and private cars of the employees during the day.

‘Daughter’ stations without compressors

These CNG fueling sites have no compressors, being in fact only a gas storage equipped with a dispenser. They are installed at the customer’s sites. Their gas reserves are refilled from a mobile CNG tanker, or by replacing the multiple tank racks.

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Mobile CNG filling stations

Mobile CNG filling stations have various capacities, from 50 ncm to 14,000 ncm. They can refuel vehicles independently by using booster compressors or pressure differences. From a commercial point of view it is better to use CNG tankers with boosters. In this case 95% of transported gas may be filled into the NGVs. Otherwise, when mobile unit has no compressor, only 65% of gas in the container is commercially available, with the rest of gas just staying inside.

LCNG filling stations

LCNG filling stations are a special class of refueling stations, with natural gas being delivered and stored in liquefied form. It can be dispensed into vehicles in liquefied form, or, it can be regasified and compressed to a filling pressure of 240-250 atmospheres, to be used as CNG.

Liquefied/compressed natural gas stations (LCNG) make it possible to have a wider range of customers, since such stations can fill both LNG and CNG vehicles.

Mobile LNG units can also fuel locomotives and ships.



06

THE GLOBAL NGV MARKET



Demand for natural gas as a transportation fuel continues to grow steadily. Along with already established consumers like on-road vehicles of various classes and purposes, natural gas is also becoming an attractive fuel for railway and water transport. Further new projects of this nature are emerging worldwide. One can expect that the methanization of aviation will resume soon.

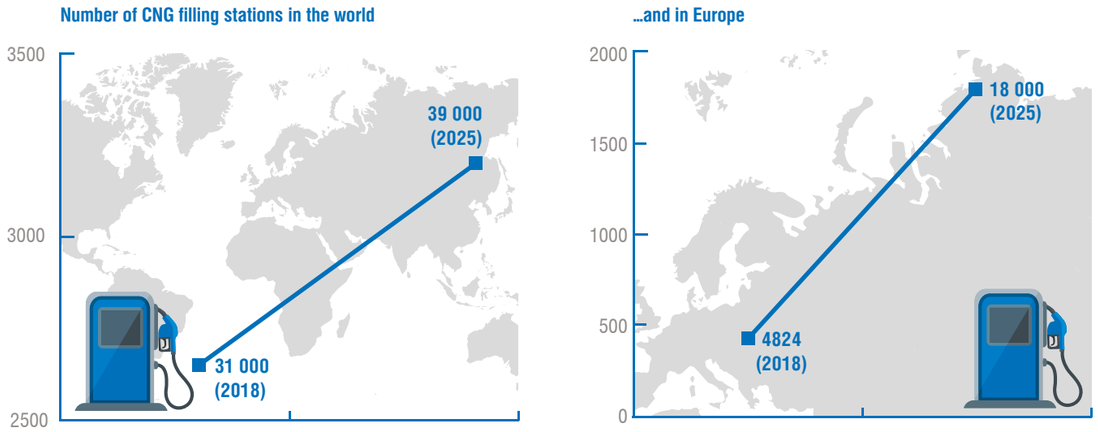
According to NGV Communications Group, by the end of 2017, the key indicators of the global NGV market were as follows:

- population of NGVs: 26 million (the number of vehicles running on CNG or LNG worldwide has grown almost six fold through the past decade);
- number of CNG filling stations: over 31,000;
- reported demand for CNG/LNG: 35 billion cubic meters;
- estimated actual demand: at least 40 billion cubic meters.

The figures might be even higher, as not all countries, and not all major players report on their domestic markets.

Europe has 1.8 million NGVs; over 4,000 filling stations have been built, and recorded consumption of natural gas for transport amounted to 5.6 billion cubic meters in 2017.

Development of filling station networks for natural gas is an issue in every region of the world. For instance, uninterrupted NGV travel through Europe using methane alone, without switching to gasoline or diesel, is not possible as yet. But the need to create natural gas refueling infrastructure has been recognized at the level of the European Union, which on October 1, 2014, resolved that the governments of EU member-states would be required to develop specific programs for building natural gas filling stations along trans-European highways at 150 km intervals; and LNG filling stations at intervals of 400 km. The European Commission declared its readiness to share the construction costs.



Current and future numbers of CNG filling stations

Today auto manufactures like Volkswagen, Audi, Mercedes-Benz, BMW, Ford, Volvo, Skoda, Fiat, Seat, etc. offer around **70 CNG-fuelled car models**





Fiat, Iveco, Mercedes-Benz, Opel, Volkswagen serially manufacture around **15 models of light commercial vehicles running on CNG**

Iveco, Mercedes-Benz, Scania offer around **10 models of heavy trucks on CNG and LNG**





Iveco, Man, Scania, Solaris, Volvo manufacture more than **50 models of city buses on CNG and LNG**

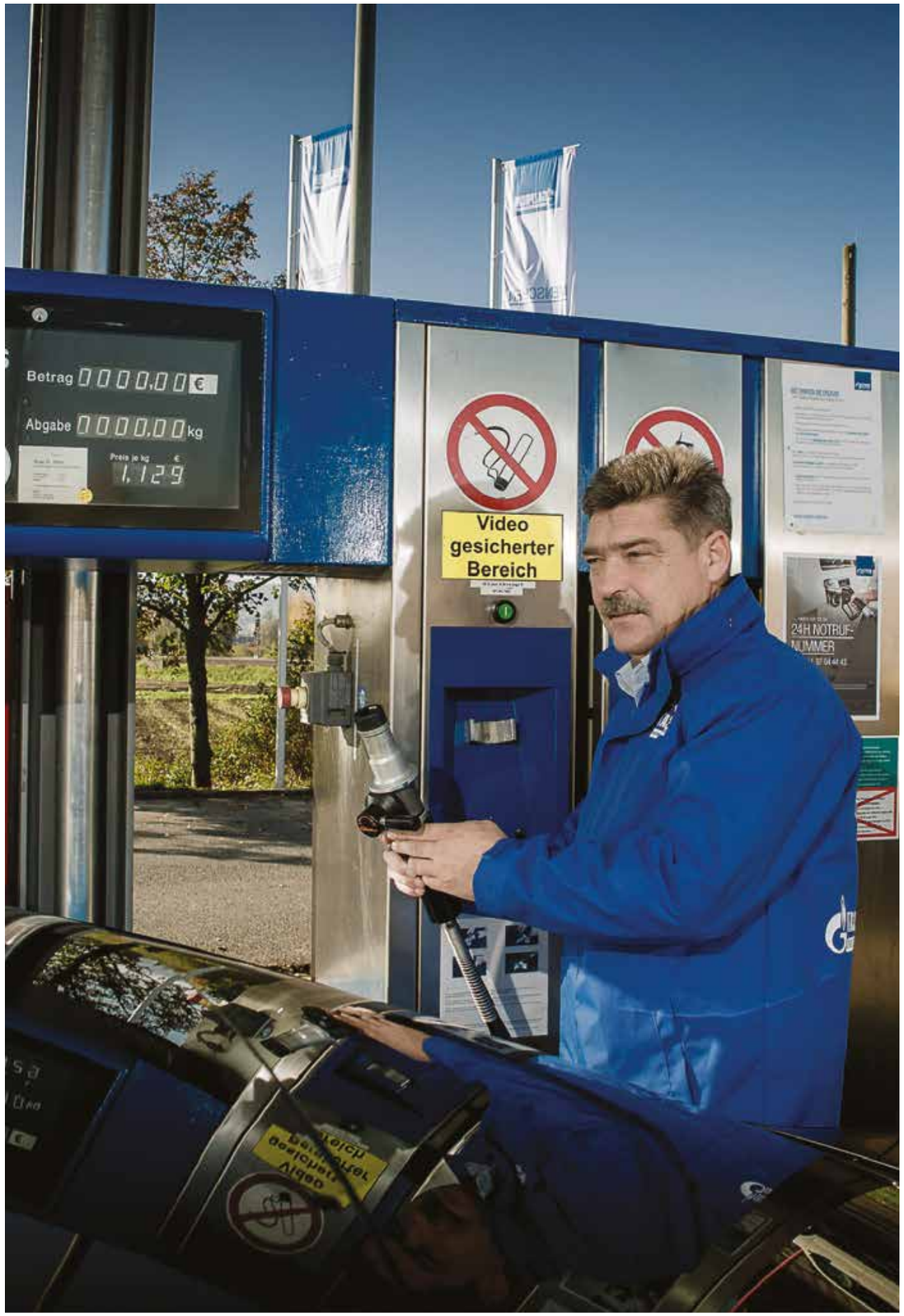
Assuming that demand for methane grows at an average annual rate of 16.5% (with a 10-year horizon), annual global consumption in transport could reach 75 billion cubic meters by 2020 – not counting gas used for bunkering vessels.

Natural gas is now used to fuel vehicles in 85 countries. CNG and LNG filling stations have been built in over 31 000 locations around the world. The available variety of OEM NGV models embraces about 190 cars, trucks, buses, municipal and specialized vehicles and still growing. The global NGV fleet counts over 26 million of vehicles, according to NGV Global.

The popularity of natural gas keeps growing not only due to its environmental and economic advantages. With LNG, biomethane, coal bed methane, gas hydrates, and shale gas coming on the market, the resource base and availability of natural gas is improving significantly, several times larger than oil reserves.

Better refueling convenience is facilitated by the growing number of home fills (VRAs). There are now about 10,000 of these devices in use worldwide.

It should also be noted that the global NGV market has already created over 800,000 technical and blue-collar jobs.



07

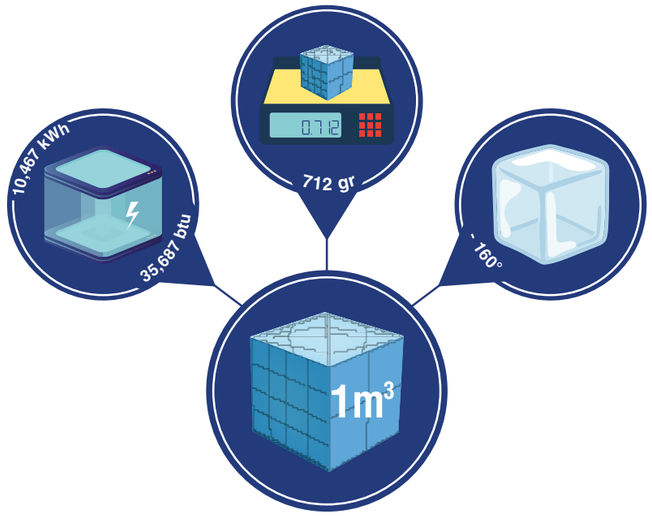
COMMERCIAL GAS METERING





Different countries use different measurement units for natural gas. While in one country CNG filling station customers may be charged for cubic meters (m^3) of gas, in a neighboring country they would pay per kilogram (kg). That is, natural gas is sold by volume in the former case, or by mass in the latter.

Natural gas metering also uses energy value measurement units, which could be kilowatt hours (kWh), British thermal units (Btu), or gigajoules (GJ).



- One cubic meter of natural gas weighs 712 grams.
- One cubic meter of natural gas is the energy equivalent of 10.29 kilowatt hours or 35.687 British thermal units.
- Liquefaction reduces the storage volume of natural gas by a factor of 600. A cubic meter of natural gas in liquid form weighs around 720 grams. A kilogram of regasified LNG occupies 1.38 cubic meters of space. LNG at LNG filling stations is priced in kilograms.

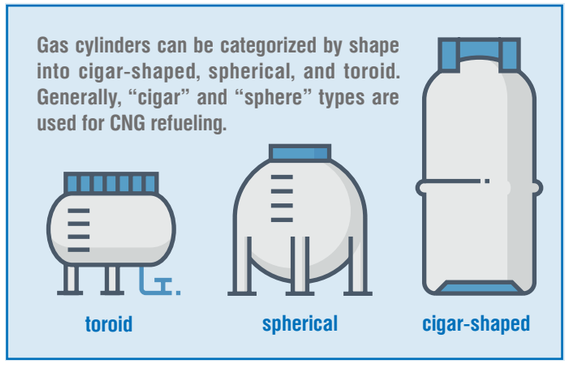
For a quick estimate of how many cubic meters of gas will fit into a cylinder, the cylinder's water capacity should be divided by 4.5. To calculate how many kilograms of gas it is, the capacity should be divided by 6.3.

1 m^3	=	712 grams 10,47 kWh 35,687 btu

1 kg	=	1,4 m^3 14,4 kWh 49,96 btu

Cylinders

There are two competitive, effective, and time-proven methods for storing natural gas inside vehicles: in a gaseous state, at high pressures; or as a liquid, at low temperatures.



CNG is stored onboard in cylinders – high-pressure tanks under a maximum operating pressure of 200 bar. This pressure is necessary to maximize fuel reserves and distance between refueling stops. The cylinders are such an important component of the NGV technology that most countries have special standards and rules regulating their production and use. Only specialized and certified organizations may manufacture cylinders. Compressed natural gas may not be stored in cylinders intended to hold other gases or gas mixtures. In order to ensure safe use, CNG cylinders undergo a complex array of tests for resistance to exposure of various factors.

Gas cylinders can be categorized by shape into cigar-shaped, spherical, and toroid. Generally, “cigar” and “sphere” types are used for CNG refueling.

CNG cylinders may have different design and materials. Four types of cylinders are recognized internationally. Type 1 cylinders – all metal (steel); Type 2 cylinders – metal liner hoop wrapped (reinforced) by composite (glass, carbon, basalt or other fiber); Type 3 cylinders – all wrapped metal liner reinforced by composite; Type 4 cylinders – all composite cylinder. The choice of material directly affects the cylinder’s weight and cost.

The most popular cylinders have a capacity of 40 to 90 liters for passenger cars, or up to 300 liters for buses and trucks. The distance a vehicle can travel before its next refueling stop is directly dependent on the volume of gas filling its cylinders.



Occasionally manufacturers raise the issue of increasing the operating pressure of CNG cylinders to 320 bar or more. International practice confirms that it is possible to work with higher pressures of 320, 400, 600, 800 bar or even more. In NGVs, however, this was limited to prototypes so far. There have also been proposals to permit refueling cars with replaceable cylinders or accumulator racks. This idea originated in Italy in the 1950s. Like the proposals to increase operating pressure, this idea has few supporters at present.

Refueling nozzles

It is often claimed that natural gas is allegedly more dangerous due to the high pressure in cylinders; that car cabins smell of gas that could be hazardous for drivers and passengers; and that it may cause loss of power and detonation of engine. Some of these claims were only true at the dawn of widespread NGV adoption – about 30-40 years ago.



These days, all that some drivers know about their fuel, is only that their cars run on “gas”. Such attitude can lead to ill-advised attempts to fill propane-fueled cars with methane. There have been cases of this causing fatal destruction of cylinders or entire cars.

It is likewise impossible to refuel a car that runs on LPG or CNG with liquefied methane or hydrogen.

Another problem with refueling nozzles is the use of adaptors. These adaptors came into use after the industry adopted a new type of NGV nozzle, but many old CNG filling stations still had the old type of receptacles. So drivers started using adaptors.

Some countries have banned adaptors completely, while others allow only certified adaptors owned by CNG filling stations. In such cases, only qualified station personnel may refuel NGVs through adaptors.

Restrictions on adaptor use are mostly driven by the industry’s track record of incidents involving attempts to fill methane-fueled cars with propane – not a great safety hazard – or, worse, LPG cars with CNG, risking destruction and fatalities. LPG cylinders are not built to withstand the pressures used for CNG.

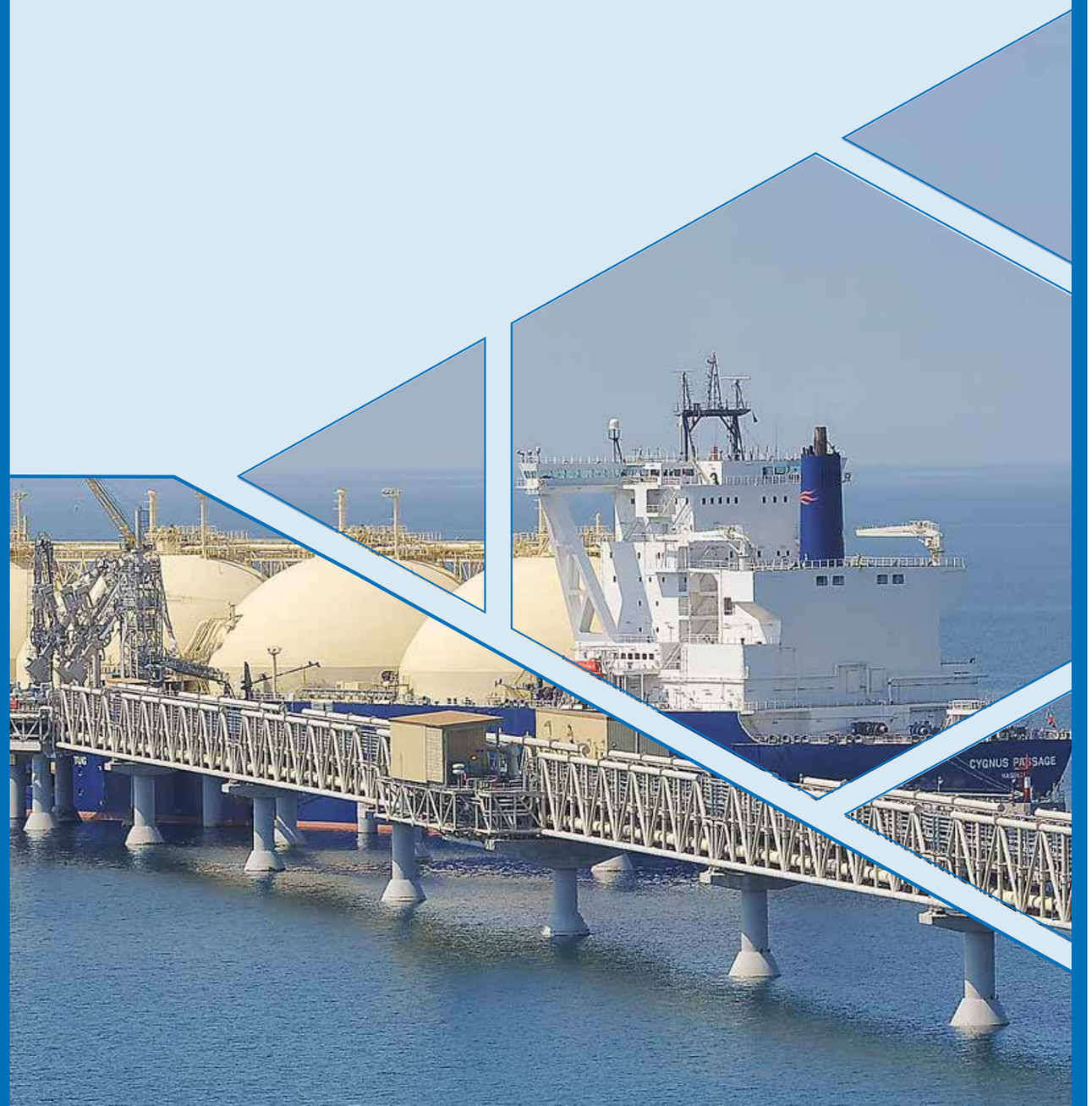
The problem of refueling adaptors has taken on an extra dimension recently. Now there is also an issue of heavy duty vehicles (trucks and buses) using refueling nozzles that were initially designed for passenger cars.

Dispenser nozzles for HDVs have a larger outlet than nozzles for light duty vehicles, in order to speed up refueling for buses and trucks that fuel more natural gas than cars in each refueling session.

High-pressure onboard cylinders have an operating pressure of 200 bar (3,000 psi). As a rule, dispenser nozzles can handle pressures of 250 bar (3,600 psi).

08

LIQUEFIED NATURAL GAS



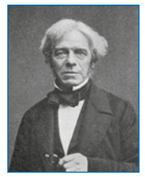


Liquefied natural gas (LNG) is a colorless, odorless cryogenic liquid with a density half that of water. LNG is nontoxic. Its boiling point is -158 to -163°C. LNG as transportation fuel contains at least 95% of methane; the remaining 5% include ethane, propane, butane, and nitrogen. LNG production process includes removing impurities from natural gas – primarily, from carbon dioxide.

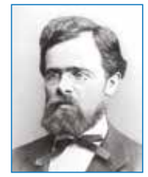
Compression and liquefaction of natural gas both intend to minimize storage container volumes. Under normal conditions (at 1 bar pressure, 0°C temperature), a container with water capacity of 1,000 liters can hold one cubic meter of natural gas (Nm^3); the same container can hold around 220 Nm^3 at 200 bar, and 600 Nm^3 at -162°C.

In other words, an LNG-fueled vehicle can travel 2.5 times further than a CNG-fueled vehicle with equal fuel reservoir capacities. For long-distance vehicles, this is a critical factor.

LNG is now an established independent segment of the gas market, with its own regulations, technologies, industry, resources, and infrastructure. One in three cubic meters of gas traded in the global marketplace is sold in liquefied form.



In the early 19th century, British scientist Michael Faraday first proved it was possible to liquefy gases, establishing the basics of the refrigeration cycle: as pressure rises, at ambient temperature, gas turns into a liquid; as the liquid evaporates, reverting to a gas, cold is generated; when recompressed, the gas turns to liquid again. And so on.



In the late 19th century, German engineer Carl von Linde, regarded as the founder of refrigeration technology, invented the first industrial-scale air separation machine and became the first to liquefy air, oxygen, and nitrogen. He started "making money out of thin air," literally: his company produced and sold liquid oxygen. Incidentally, he also invented the oxyacetylene torch.

Other milestones in LNG history:



- 1886: Polish physicist Karol Olszewski produces the first liquefied natural gas;

- 1915: US industrialist Godfrey Lowell Cabot patents technology for storing liquefied gases at very low temperatures;

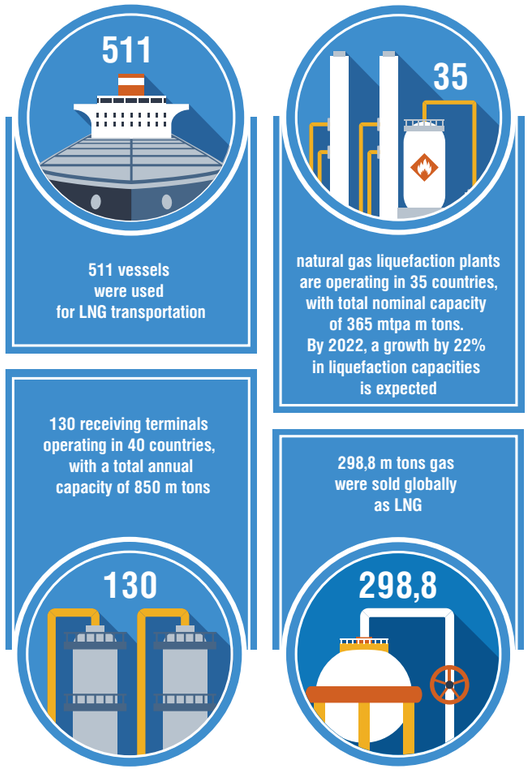


- 1917: the first commercial LNG production facility is constructed in West Virginia;

- 1957: the world's first methane transport tanker, the Methane Pioneer, starts operating and delivers the first commercial shipment of LNG from the US to Britain.



▶ By 2017, the global LNG market was characterized by the following indicators:



Source: GIIGNL

The greatest commercial effect from using liquefied natural gas can be achieved in heavy-duty transport: sea and river vessels, railway locomotives, freight trucks, mining trucks, and airplanes.

At present, 75% of international trade goods are shipped by sea. Global cargo fleet has over 50,000 vessels with a total load capacity of around 1.4 billion tons.

All of them damage the environment, with the major adverse impacts being dumped water ballast and solid or liquid waste, greenhouse gas emissions, oil spills, and noise.

The International Maritime Organization has calculated that unless urgent measures are taken, maritime transport's share of global industrial CO_2 emissions could rise from 2.7% in 2007 to 8.1% in 2050.

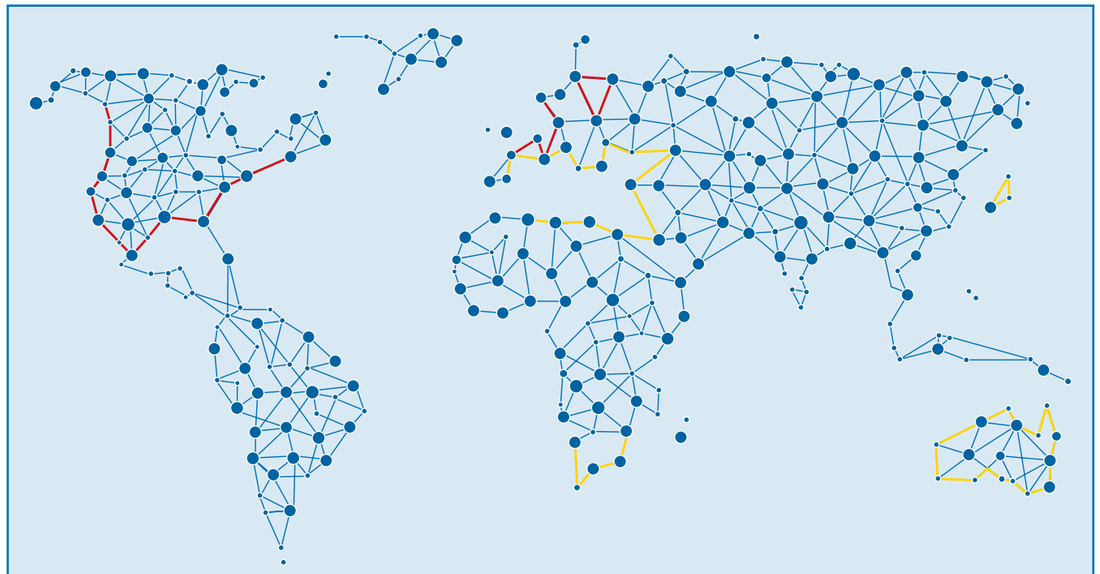
Natural gas makes it possible not only to comply with set requirements, but also to reduce fuel costs, thus covering the additional costs of converting vessels to this type of fuel.



The promising LNG market for bunkering seagoing vessels in Europe through to 2030 is estimated at around 8 – 10 bcm per year.

With the aim of reducing emissions, a concept Emission Control Areas has been developed. Within the framework of the International Convention for the Prevention of Pollution from Ships (MARPOL), the following environmental zones are being established:

▶ International Convention for the Prevention of Pollution from Ships (MARPOL) emission control areas



▶ EXISTING ZONES

- North American area (Pacific and Atlantic coasts), from 2012; restricts emissions of SOx, NOx, and particulate matter (PM);
- US coast on the Wider Caribbean Region, from 2014; restricts SOx, NOx, and PM;
- Baltic Sea and North Sea, from 1 January 2015; restricts SOx only;

▶ FUTURE ZONES

- Mediterranean and Black Sea; restricts emissions of SOx, NOx, and PM;
- Southern African area;
- Asia-Pacific area;
- Australian area.

In 2016, in an effort to reduce greenhouse gas emissions, the IMO announced that under the new global cap with the effective date 2020, ships will have to use marine fuels with a sulphur content of no more than 0.5% S against the current limit of 3.5% S.



AIDA Nova LNG vessel

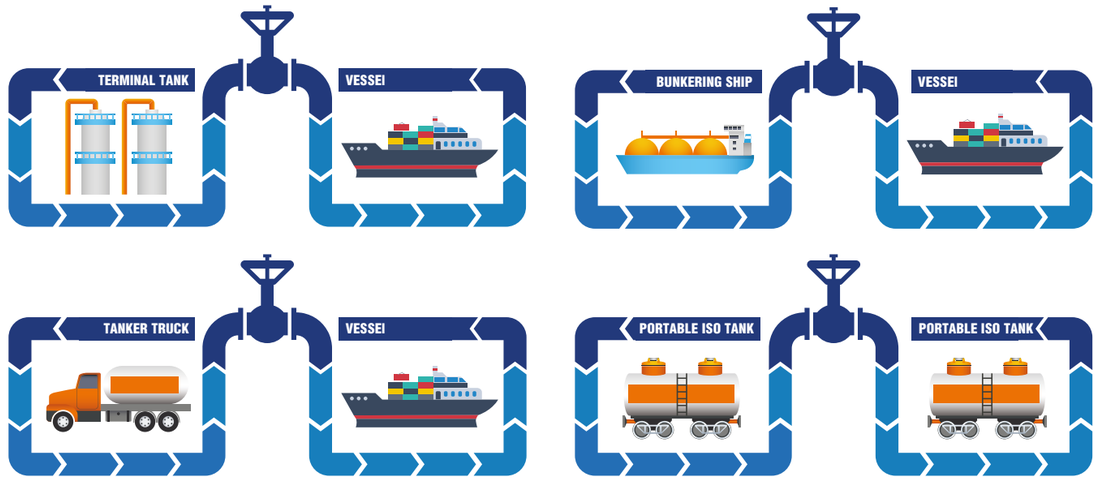
Construction of seagoing vessels that use LNG as their main fuel began several years ago.

The Viking Grace, a Finnish seagoing ferry, is a vivid example of the new class of LNG-fueled ships. It started operating on the Turku-Stockholm route in January 2013. This vessel can carry 3,000 passengers and has a crew of 200. The ferry is equipped with four Wärtsilä gas/diesel propulsion systems. Bunkering 60 tons of LNG takes less than an hour.

A new high-speed LNG-fueled passenger ferry Megastar, operated by Tallink cruise company, went on her maiden voyage from Tallinn to Helsinki on January 29, 2017. The vessel uses Russian LNG produced at small-scale LNG plants in Pskov for its propulsion system. The LNG-powered Megastar launched on the Tallinn-Helsinki route has carried more than 2 million passengers in its first year. This is the highest ever number of passengers carried on any vessel on the Baltic sea in one year.

Vessels on internal waterways have also started using LNG. The Greenstream barge (a Shell project) is operating successfully in the Netherlands and Germany. A major project has been proposed by China Natural Gas for the Yangtze River in China.

▸ **Arrangements for bunkering ships with LNG are no different from refueling with conventional forms of fuel:**



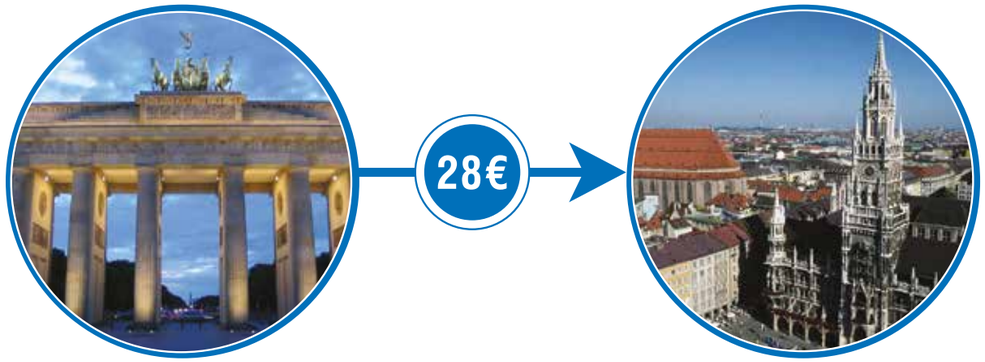


AIDA Nova LNG vessel

09

NATURAL GAS PRICES





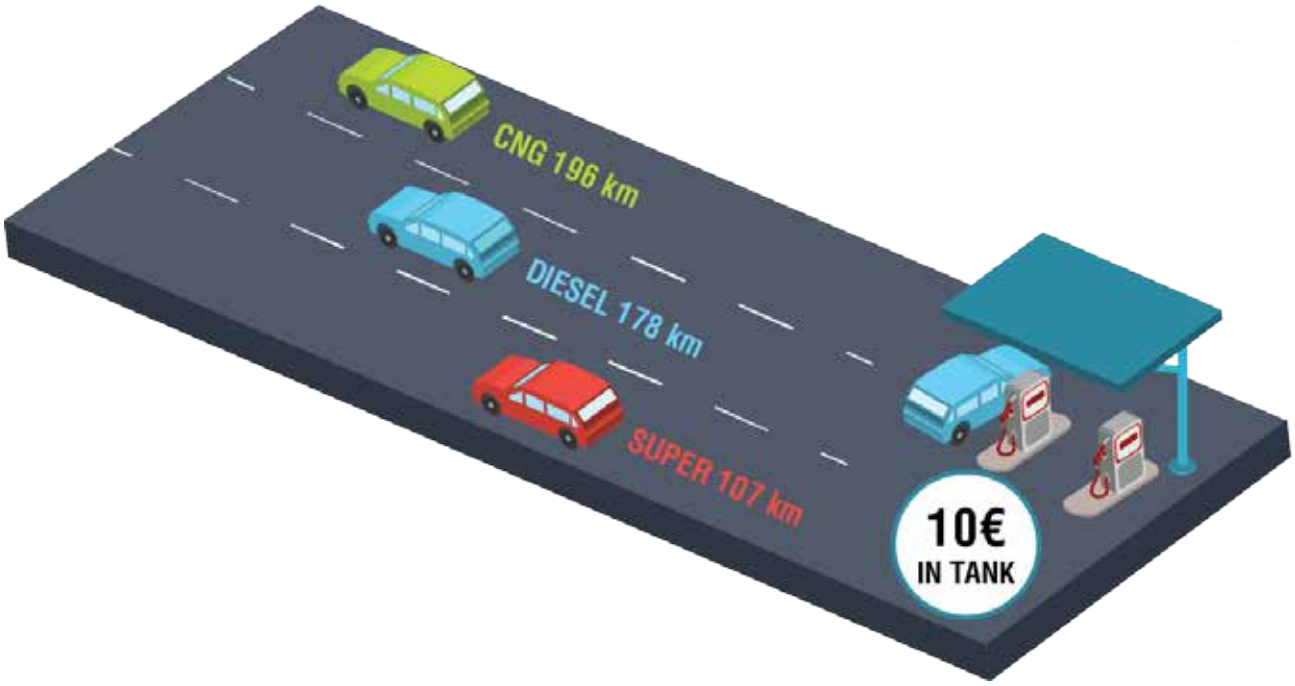
Gasoline and diesel are the primary natural competitors of natural gas. The economic rationale for converting transport to natural gas is the price difference between oil-based and gaseous fuels. The greater this difference, the more attractive natural gas becomes – and the greater is its competitive advantage.

Over the past decade, average retail prices for gasoline with an octane rating of 95 (95 RON) have fluctuated between US$1.20 and $2.06 per liter, while diesel prices have ranged from $0.99 to $1.91 per liter. According to Erdgas Mobil, as of April 2018, average retail prices for gasoline in Germany were €1.39 per liter; for diesel – €1.21 per liter; for CNG – €1.09 per 1 kg.

In 2017, the annual average CNG price in Europe was 45% below the price of 95 RON gasoline and 30% below diesel.



How far can you drive for €10?



With oil prices dropping significantly in 2014, there have been claims that advantage of natural gas is waning. But even though engine fuel price dynamics in the early 21st century are still characterized by rise-fall cycles, there is an overall rising trend. In other words, fuel prices in general are still rising, despite brief periods of decline.

All the same, history of the NGV market over the past two decades evidences steady growth of NGV population and demand for CNG and LNG, for readily apparent reasons: determination to cut fuel costs.

According to Erdgas Mobil, a German NGV association, an Opel Zafira car driver who spends €10 on fuel would be able to drive almost twice as far on CNG as on gasoline.

The lower price of natural gas relative to oil-based fuels is due to the fact that the technological chain from wellhead to dispenser nozzle is much shorter. Moreover, importer countries buy natural gas, on average, for only half of what they pay for gasoline and diesel fuel.