Werner Hermeling

Compendium for the LNG and CNG Practitioner

Liquefied Natural Gas in Application

Springer

Compendium for the LNG and CNG Practitioner

Werner Hermeling

Compendium for the LNG and CNG Practitioner

Liquefied Natural Gas in Application

Springer

Werner Hermeling
Neusiedl am See, Austria

ISBN 978-3-658-38257-5 ISBN 978-3-658-38258-2 (eBook)
https://doi.org/10.1007/978-3-658-38258-2

This book is a translation of the original German edition "Handbuch für den LNG- und CNG-Praktiker" by Hermeling, published by Springer Fachmedien Wiesbaden GmbH in 2020. The translation was done with the help of artificial intelligence (machine translation by the service DeepL.com). A subsequent human revision was done primarily in terms of content, so that the book will read stylistically differently from a conventional translation. Springer Nature works continuously to further the development of tools for the production of books and on the related technologies to support the authors.

This Springer imprint is published by the registered company Springer Fachmedien Wiesbaden GmbH, part of Springer Nature.
The registered company address is: Abraham-Lincoln-Str. 46, 65189 Wiesbaden, Germany

Preface

This book is intended to provide the practitioner, the plant engineer, the investment decision-maker and the plant fitter with technical and economic findings and considerations on LNG and CNG, as well as bio-LNG and bio-CNG, which I was able to gather in general for cryogenic liquefied and compressed gases during my work at Messer Griesheim, now the Messer Group and its subsidiaries. In addition to LNG, many statements also apply to air gases and ultra-pure gases, regardless of whether they are liquid or gaseous.

The energy carrier LNG is a new product in the German market, among others. Therefore, special care in the processing of projects and the construction of plants is one of the most important requirements. Together with my teams, I have been considering occupational safety issues that I consider necessary. In part, they have not yet been reflected in the regulations. We have developed devices that have been tested with the best results and must be introduced to the market, because they make processes safer and also more economical. The reader learns about my personal experiences, some of which are described in a number of my patents.

Unfortunately, I had to hear about terrible accidents, all of which could have been avoided if cryogenic liquefied gases had been handled correctly. Preventing similar accidents is another important concern of the book. That is why I have devoted a separate section to training recommendations. I am aware that much has not been mentioned or described, but at one point I had to make a point. The practitioner who is new to the subject of LNG and CNG will now and in the future acquire more in-depth knowledge in the relevant specialist literature and the specialist working groups.

As far as I know, the potential of LNG is only being exploited to a limited extent in the Central European region and almost certainly beyond. Therefore, it should inspire to face the challenges of LNG and not to put the critical thought aside with the reasoning – "because it has always been done that way".

I would now like to take the liberty of thanking my direct and indirect helpers in particular. My special thanks go to Mr. Peter Suchy, who bore multiple findings as an extremely innovative investor with unique generosity, to Mr. Thorsten Hoppestock, a gifted technician, who contributed significantly to the success of the introduction of a new system with his knowledge and to Dr.-Ing.

I was particularly lucky with my editor at the publishing house Springer Vieweg, Dr. Fröhlich, who taught me, as a novice writer, in a very motivating way how to design a book.

My wife Katharina always stood by me and helped over many passages to make my technical German understandable for everyone. It is a joint work of many other unnamed people, many thanks to all of them. Writing it has been a pleasure for me.

The statements I made must not necessarily be confirmed by the reader, but I have always supported my considerations with theoretical knowledge. I would be grateful if, despite all this, I should have assessed certain things differently, to inform me of this.

Neusiedl am See, Austria
August 2019

Werner Hermeling

Contents

LNG and Its Thermodynamics

1

Abstract

LNG is the abbreviation for liquefied natural gas, which in this form belongs to the cryogenic liquefied gases. At the source, i.e. in the gas or oil field, liquefaction from the gas phase takes place with a great deal of energy. From there, it is transported by ship at approx. −161 °C (boiling temperature at atmospheric pressure) to customers in Europe, Japan, China, etc. There, the LNG is temporarily stored in large tank facilities at atmospheric pressure or directly regasified for transport in the gas pipelines. (See [1].)

1.1 LNG

1.1.1 What Is LNG?

LNG is the abbreviation for liquefied natural gas, which in this form belongs to the cryogenic liquefied gases. At the source, i.e. in the gas or oil field, liquefaction from the gas phase takes place with a great deal of energy. From there, it is transported by ship at approx. −161 °C (boiling temperature at atmospheric pressure) to customers in Europe, Japan, China, etc. There, the LNG is temporarily stored in large tank facilities at atmospheric pressure or directly regasified for transport in the gas pipelines (see [2]).

Danger Note LNG is cryogenic and evaporates immediately in the environment to a suffocating, but non-toxic, odourless gas. This is lighter than air, rises and dilutes to an ignitable, explosive gas-air mixture!

W. Hermeling, *Compendium for the LNG and CNG Practitioner*,
https://doi.org/10.1007/978-3-658-38258-2_1

Biogas also belongs to the group of cryogenic liquefied gases, because its liquefaction also takes place exclusively through cold. Biogas is a gas mixture with an initially low methane content, which increases to up to 99% through purification. This makes biogas chemically and physically very similar to the gas that comes naturally from the ground. They differ in the formation and composition of the calorically effective components.

Cryogenic liquefied gases evaporate extremely quickly when energy is supplied. Therefore, the storage tanks must be very well insulated. If the liquid gas escapes uncontrolled from the tank, e.g. during the refuelling process at the coupling or via a leaky valve, it vaporises abruptly. The heat of vaporization required for this purpose is extracted from the environment. This is indicated by the formation of ice at the outlet points.

LNG and, like bio-LNG (liquefied biogas), is a mixture of different hydrocarbons whose main component is methane (CH_4) and which differs in its percentage composition depending on the source (see [3]). The molar weight of methane is around 16 g/mol, which makes it lighter than air (molar weight around 28.8 g/mol) (see [4]). This mixture is liquefied by cold.

The boiling temperature of approx. −161 °C is reached at ambient pressure, whereby the gas only occupies approx. 1/600 of the gaseous volume under atmospheric pressure (standard density of gas 0.671 kg/m^3, standard density of liquid 422.6 kg/m^3). The shrinking volume under atmospheric pressure is one of the main advantages of liquefaction. It allows large quantities to be stored and transported in a small space at low pressure (atmospheric pressure). The gas only changes to the liquid state through cold, not through pressure.

Methane forms an explosive mixture with air in a mixing ratio of between 4.4% vol. and 16.5% vol. Plants in which methane is used must be absolutely technically gas-tight and must be monitored accordingly. Otherwise, as the past has shown, extremely serious gas explosions are possible, because small traces (4.4%) lead to explosions when ignited.

The cryogenic liquefied gas has a temperature of −161 °C. This cold leads to the embrittlement of normal black steels. Therefore, austenitic steels or copper and its alloys should generally be selected for the construction of the plants for such applications. The exact alloy is determined by the subsequent load and use. Copper and its alloys are used especially in fittings, less as piping material.

Summary

LNG is a cryogenic liquefied gas and takes up about 1/600 of its gas volume in the liquid state. The gas is lighter than air. The ignition capability is between 4.4% vol. and 16.5% vol. Generally, austenitic steel or copper and its alloys are to be used for the construction of LNG plants. Compliance with occupational health and safety guidelines is a prerequisite for safe handling. Bio-LNG is liquefied biogas, which is very similar or equivalent to LNG in all physical parameters. The slightest traces of natural gas in the air can cause a gas explosion.

1.1.2 Biogas: Bio-LNG

Bio-LNG is liquefied using various processes, small quantities (over 1000 Nm^3/h) mainly with liquid nitrogen, larger ones with gas liquefaction plants. The gas is produced by anaerobic fermentation of organic substances, so-called biomass. This biomass includes residues from agricultural processes (manure, slurry, plant residues, food leftovers, meat and slaughterhouse waste, etc.). However, plants are also grown directly for fermentation and subsequently processed into corn, grass, beet pulp silage, etc., which is then fermented. During the fermentation process, 50–75% of the gas can be used for calorific purposes. The remaining part are calorically unusable accompanying gases, which are separated. By separating these non-combustible (so-called dead) associated gases, the gas is concentrated to over 99% vol. calorically effective fraction and is prepared for feeding into the grid (see [5]).

The DVGW rules and regulations deal with the issue of biogas in great detail. The feed-in conditions are described in [6], the entire complex is regulated in the following worksheets.

The economic viability of production depends very much on the world market price of internationally traded natural gas and the subsequent use of the biogas. The prices of the biogas derived from the production costs must be able to compete with the world market price for natural gas. This requires a favourable combination of different factors to make the process economically viable. This requires a mixed calculation. If, for example, the service of disposing of green cuttings and other waste is remunerated to the biogas plants, the processing of the fermentation residues into fertiliser is taken into account financially and the gas is sold as fuel, the overall process can be made more economical.

Note Biogas from animal fats, i.e. meat and slaughterhouse waste, may not be traded as fuel [1].

Converting biogas to electricity on site becomes economically interesting if the heat generated (approx. 2/3) can be put to good use. In contrast, discharging the upgraded gas into gas pipelines is rarely economically feasible due to the relatively small quantities in relation to the total cost of the discharge (Fig. 1.1).

The liquefaction of biogas into bio-LNG is technically feasible today without further ado. The advantage of liquefaction is that the gas can be transported to where the price can compete with that of natural gas from the pipeline. At present, this is only achievable when used as a fuel, provided that liquefaction has been carried out cost-effectively and the price of gas at filling stations is correspondingly high.

For biogas, it can be assumed that cryogenic liquefaction is currently economically feasible under the aforementioned sales conditions. Cryogenic liquefaction is generally done with liquid nitrogen. It takes about two to three parts by mass of liquid nitrogen to get one part by mass of bio-LNG. Due to the boiling points of the individual fractions, a purity of over 99% can be achieved (see [7]).

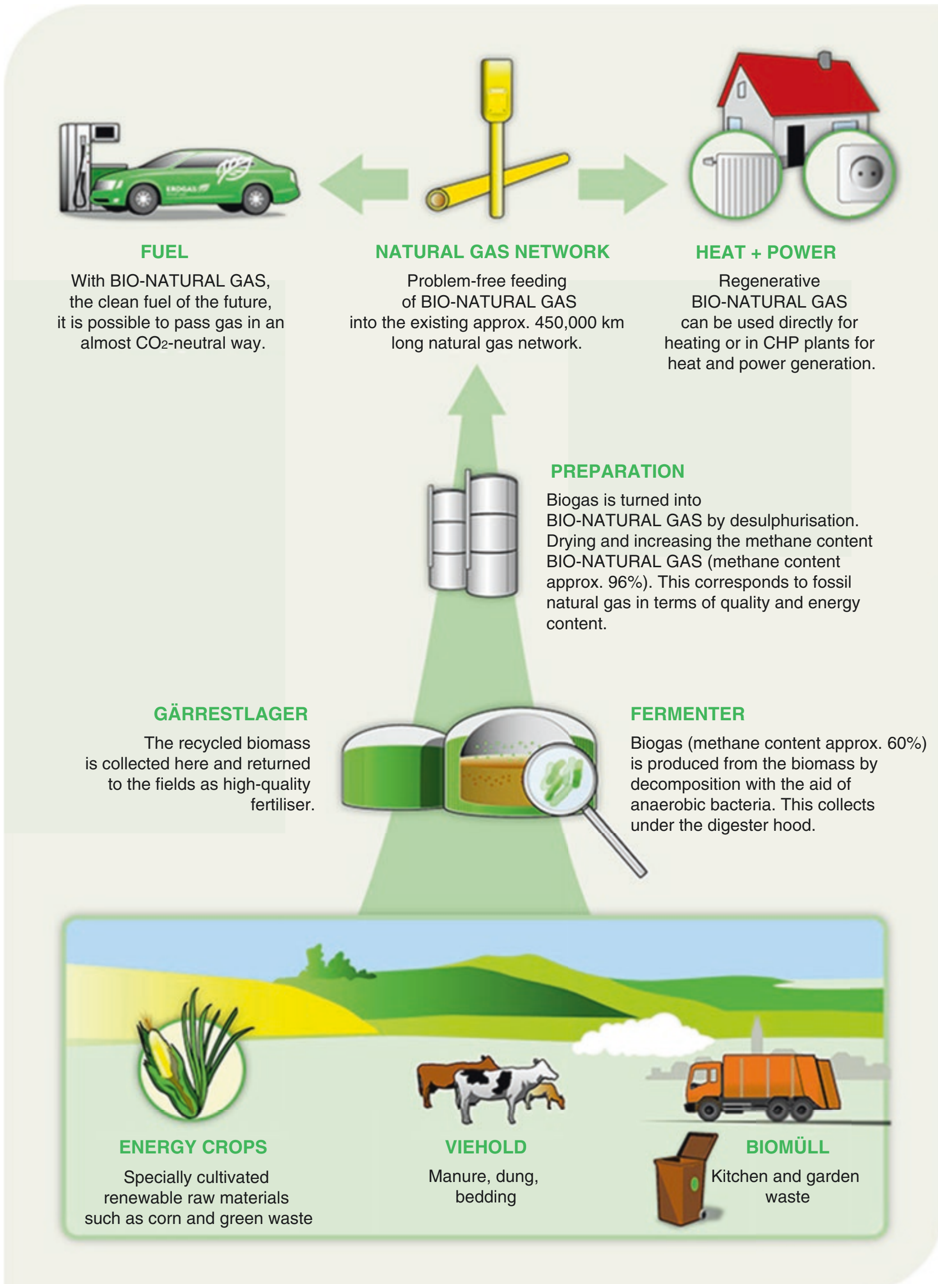

Fig. 1.1 Formation and use of biogas. (Source: Future natural gas)

Summary
Methane and other hydrocarbon components of biogas are produced by an anaerobic reaction. By separating dead accompanying gas, a high-quality biogas is obtained. It differs only in the formation of the calorically usable fraction, especially methane. The complex economic consideration of the whole process can make the biogas production competitive by liquefaction with nitrogen.

1.1.3 Origin of Natural Gas

Natural gas, like crude oil, is produced from the remains of animals, plants and microorganisms (organic matter), which are converted into a mixture of gases containing hydrocarbons in an anaerobic process under high pressure. Such gases are also referred to as organic gases. The predominant component of the caloric gas mixture is methane. This gas is mixed with caloric dead associated gas and water. The high pressure during the formation of the gas came from thick layers of earth and rock as well as heat. Over the course of 15–600 million years, the transformation took place and continues to this day. Current natural gas reserves exceed those of oil, so it is estimated that they will be available for 200 years [7]. The main natural gas deposits (see [8]) are located in:

- Europe 5.0 trillion m^3.
- CIS countries 57.3 trillion m^3.
- Middle East 72.7 trillion m^3.
- Africa 3.7 trillion m^3.
- Pacific region 11.9 trillion m^3.
- South America 6.8 trillion m^3.
- North America 6.8 trillion m^3.

Summary
Natural gas is created under extremely high pressure and heat over millions of years from organic source material. Crude oil is always accompanied by natural gas. The world's gas reserves are larger than its oil reserves.

1.2 Importance of LNG

In the past, natural gas escaping from oil production was considered a waste product and flared directly at the oil well.

Today, natural gas is an important and, above all, environmentally friendly energy source. Natural gas is a mainstay of the global energy industry. Figure 1.2 shows the geological structure of typical natural gas deposits. However, it is also extracted from its own natural gas sources in the course of oil production. It is a valuable by-product of oil production.

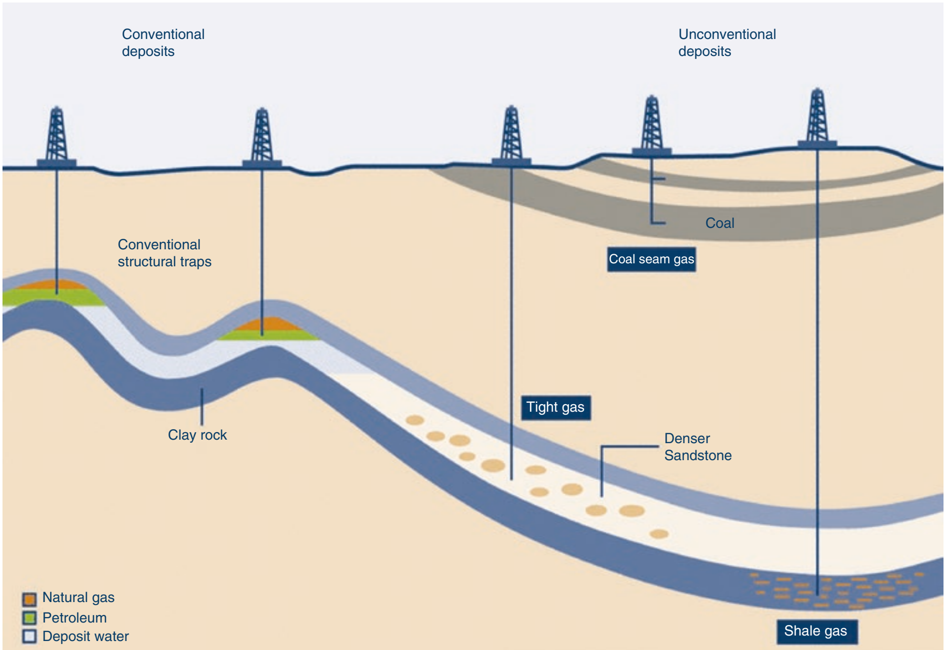

Fig. 1.2 Conventional and unconventional oil/natural gas deposits. (Source: National Cooperative for the Storage of Radioactive Waste)

From the continental fields of Russia, Azerbaijan and other countries, the gas is brought to Europe by pipeline.

As a result of the energy turnaround proclaimed in Germany, natural gas is gaining particular relevance, because energetically high-quality gas can be converted into electricity very advantageously and in an environmentally friendly manner in gas-fired power plants. Due to their process characteristics, gas-fired power plants are particularly suitable for supplementing alternative and, above all, volatile energy sources such as wind turbines and solar parks. These will gain in importance.

$$\text{Wind power} + \text{hydroelectric power} + \text{solar power} + \textit{natural gas} = \text{secure electricity}$$

> In order to avoid blackouts on the way to the green, renewables need a supplement that balances out these fluctuations flexibly and decentrally. This partner can and should be natural gas. Because of all the fossil fuels, natural gas has the best climate balance. When burned, it releases 25% less CO_2 than oil, 30% less than hard coal and 35% less than lignite. Modern gas-fired power plants have the highest energy efficiency values, especially in combined heat and power generation.

In addition, gas-fired power plants are decentralised and can be flexibly controlled. This means that energy from gas-fired power plants can be made available precisely when it is needed, and can be turned back as soon as enough electricity is available from the sun and wind. This is what makes even the most modern small-scale gas-fired power plants so attractive for municipalities and private households. In short, gas is the ideal backup system "on the way to green." [9].

Figure 1.3 clearly shows the importance and the share of natural gas in the energy supply. This share will continue to increase, because nuclear power and coal must be substituted. The gas can reach the power plants and the municipal grids quickly via high-performance pipeline systems. The only problem is that these pipeline capacities are not available in unlimited quantities, so pipeline-free transport will gain in importance. For this purpose, the natural gas must be liquefied into LNG.

The question arises why oil can not perform the function of the gas. The answer is relatively simple. According to current forecasts, global reserves of oil are lower than those of gas (see [10]).

Consequently, the statistical range of:

- Coal worldwide at 112 years.
- Crude oil worldwide at 54.
- Natural gas worldwide at 64.

Source: Southern Upper Rhine Regional Association [11].

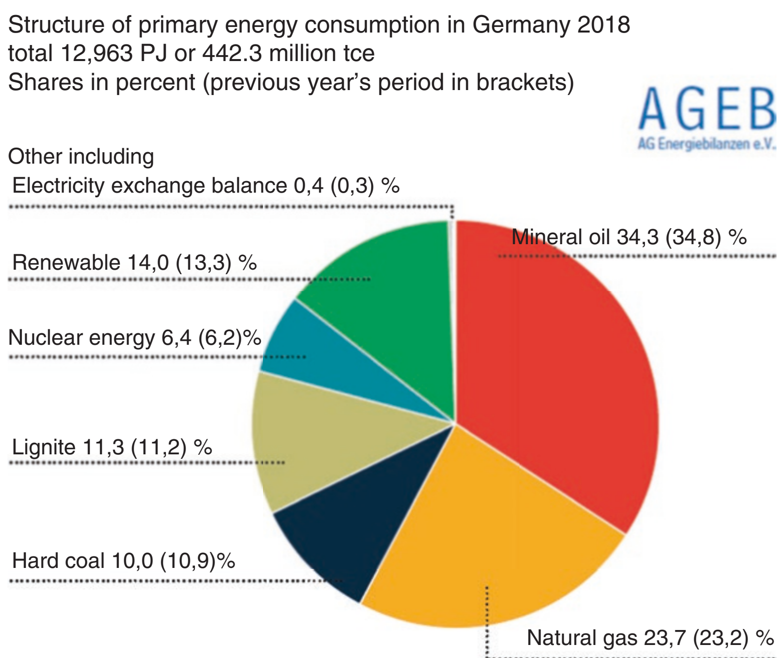

Fig. 1.3 Distribution of energy sources in Germany 2018. (Source: AG Energy balances e.V)

Every oil field has a not insignificant amount of natural gas. Natural gas fields do not necessarily have oil. Furthermore, the CO_2 emissions from the combustion of oil are greater than those of natural gas.

> The positive consumption forecasts for natural gas are also closely related to the natural gas reserve situation and the accessibility of deposits. Europe is strategically located among the world's largest natural gas reserves. It is technically and economically possible to make natural gas fields 6000 to 7000 kilometres away available to Western Europe. The technologies for transporting gas over these great distances are available. Thus, in the future, a pipeline (diameter 1,600 mm, pressure 120 bar) could transport about 50 billion m^3 of natural gas per year. (Source: [12])

The positive environmental balance, in particular the CO_2 emission during combustion, is another argument for the use of natural gas. During combustion, natural gas releases less CO_2 than crude oil and the environmentally harmful admixtures are lower.

At present, Germany has the primary energy mix graphically described in Fig. 1.3. The share of nuclear energy must be compensated for 100%, that of coal partially, because nuclear power plants are gradually being taken off the grid (see [13]).

Generation capacities must be compensated for elsewhere in order to maintain a reliable energy supply. Relying solely on renewable energies is not technically possible in an industrialized country like Germany. More details are given in Chap. 5, LNG applications. Coal-fired power plants are ecologically more questionable, their operation is not very flexible and they require very costly flue gas cleaning systems. The flue gas residues have to be disposed of at high cost. The situation is similar with crude oil, which is contaminated with more or less sulphur or other pollutants depending on the production area.

Natural gas is known to be the most environmentally friendly fossil fuel. Its composition depends on the respective deposit, although the main component is always methane. In addition to other hydrocarbon compounds that can be used for calorific purposes (including ethane, propane and butane), it also contains calorific dead gases such as air, nitrogen, carbon dioxide and, in some cases, hydrogen sulphide and water. All components vary in concentration and characterize the respective reservoir. When the gas is liquefied, the dead associated gases and impurities are completely separated, partly by thermodynamic processes and partly by other purification processes. The high purity is one of the main advantages of LNG.

Pipeline gas or pipeline gas has to be treated with complicated purification processes before it is injected into the pipeline (see [14]). Despite this purification process, pipeline-based gas transport is a very advantageous variant, as far as topographical, geographic and geological conditions allow. The economic viability is limited solely by the distance to the consumer.

1.3 Pipeline Gas and Its Significance

Pipeline gas is offered regionally in the qualities L-gas and H-gas (see [15]). L-gas is the low calorific gas which in Germany reaches the customer via the gas pipelines mainly in Lower Saxony, parts of Saxony-Anhalt and North Rhine-Westphalia. It has a methane content between 79% and 87%. The remaining quantity is dead associated gas. This gas quality is gradually being displaced by the higher-quality H-gas, which places technical demands on gas appliances and gas systems.

The higher calorific H-gas contains 87–97% methane. It does not reach the energy content of LNG. Therefore, vehicles fueled with LCNG (CNG regasified from LNG) have a longer range than those fueled with H-gas or L-gas.

The liquefaction energy is initially saved in pipeline transport, but in part energy is also required in pipeline transport for compression for transport. Due to pipe friction and flow losses, the pressure in the pipeline decreases. It has to be replaced repeatedly. A long-distance gas pipeline has a station for pressure boosting every 100–200 km (see Fig. 1.4). During the repeated pressure increase, the gas is treated. During this process, impurities such as moisture and oily contaminants are separated.

The pressure increase takes place via large compressors. To supply the customer with the same energy equivalent, more gas has to be transported in the case of pipeline gas than with LCNG or LNG. This is due to the dead associated gas. This expense is not

Fig. 1.4 ONTRAS compressor station Bobbau (Saxony-Anhalt). (Source: Ontrans – Photo: Peter Eichler)

insignificant, because the gas, including the dead associated gas, must be compressed to a pressure of up to 200 bar for transport in the long-distance pipelines. Up to 13% of the work performed cannot be used energetically and is lost in the energy balance of the gas.

Analogous to the electricity network, a distinction is also made in gas networks between high-pressure, medium-pressure and low-pressure lines. However, there are generally no standardised designations for the pressure levels of gas pipelines. There is also no standardised pressure-dependent classification. The pressure level is defined from the point of view of the available network. For example, if the gas pipeline is located in an urban area, the high-pressure pipeline is defined as 1–16 bar. The medium pressure line is then less than 800 mbar, the low pressure line up to 25 mbar.

If the consideration is made from the point of view of the long-distance gas pipeline network, the pressures are considerably higher. Long-distance pipelines are operated as high-pressure pipelines, which generally transport the gas at between 60 and 200 bar. This is also referred to as the high-pressure network.

Such high-pressure networks can supply large areas with natural gas and deliver gas via conversion stations to the medium-pressure network. This in turn covers a consumption area, e.g. a city, which is supplied via a few medium-pressure lines. Large consumers (e.g. heating plants, CHP plants, natural gas filling stations with high tapping capacity) must at least be connected to the medium-pressure network. If, for technical or economic reasons, the gas pressure available in the high-pressure lines or the medium-pressure lines were to be used in a CNG filling station, either long supply lines would be required or the consumers would have to be installed close to the lines. Both have to be weighed up economically.

Depending on the consumption characteristics in the local medium pressure networks, the pressure is reduced to a few *bar* and in the low pressure networks to a few *mbar*. The originally applied delivery pressure is lost. To reduce this obvious disadvantage, at some stations the gas is expanded via expansion turbines to generate electricity, which allows a small part of the compression work performed to be recovered.

Pipeline transport naturally also has many advantages, the continuity of supply and the low susceptibility to faults being one of the most significant. This high security of supply cannot be surpassed by any other system. The customer perceives it as very pleasant.

The "luxury" of a continuous supply is included in the gas prices. In addition to basic costs such as grid usage fee, connection fee, etc., gas is charged according to quantity (quantity price) and capacity (capacity price) (see example Tigas [16]). This means that fluctuations in demand are charged at the capacity price. Large fluctuations make the gas more expensive, while balanced offtake reduces the costs. This price structure is intended to encourage consumers to consume as constantly as possible. This is not possible in most cases. To avoid the fluctuations in offtake, the consumer would need to have large storage facilities to store gas at times of low demand and release it when demand increases. This sounds simple, but requires considerable technical effort. In the past, the municipal utilities operated retort or chamber furnaces and gasometers that could compensate for these fluctuations in demand.

LNG could be a welcome addition to pipeline supply for commercial customers. Instead of taking peak power from the grid, the customer could use gas from an LNG tank during peak periods to avoid expensive power peaks in the consumption curve (see Sect. 5.1.4). This injection must be made after the gas supplier has been connected, otherwise the consumer would be interfering with its system. This is not permitted. In this case, the responsibility for the feed-in would lie entirely with the customer. This option has rarely been used to date, as LNG is relatively unknown on the German market. The more expensive the power price of the supplier and the more extreme the power peaks of the consumer, the more likely an accompanying LNG supply can be economically viable. It should be noted that this supply also requires a processed gas. For example, the gas supplier's Wobbe number must be met to ensure that the burners, gas turbines/gas engines operate within the correct power and temperature range. The correct value is set by admixing nitrogen or caloric gases. It is a good idea to install a nitrogen tank next to the LNG tank, which forces nitrogen into the natural gas via an air vaporizer. The air vaporizer is adjusted to the feed pressure with the pressure booster vaporizer. A mass flow meter controls the mass flow to be added (see Sect. 5.1.4).

Summary

Pipeline gas offers the highest security of supply. Pressure losses in the pipeline during transport must be compensated for by increasing the pressure using compressors. The gas is treated before it is compressed again. Generally, one speaks of high-pressure, medium-pressure or low-pressure pipelines. There are no generally standardised ranges for the pressure stages.

Power peaks of the gas offtake are to be avoided. The costs of the power peaks could be avoided on the part of certain consumers by injections of LCNG. The Wobbe number of the injected gas should be adjusted to that of the gas supplier by adding nitrogen. The costs and benefits of own storage and injection must be weighed up.

References

1. https://www.gesetze-im-internet.de/bimschg/BimSchG.pdf, BImSchG, §37 b, Ziffer 8.
2. www.tugraz.at/fileadmin/user_upload/Events/Eninnov2014/files/lf/LF_Simmer.pdf
3. www.enercity-netz.de/pool/downloads/netze/kennwerte-erdgas-orientierungswerte%2D%2D2016.pdf
4. www.peacesoftware.de/einigewerte/methan.html
5. http://www.biogas-netzeinspeisung.at/anlagenbeispiele/pliening.html
6. DVGW – Arbeitsblatt G 262.
7. www.weltderphysik.de/gebiet/technik/energie/fossile-quellen/erdgas/
8. https://de.wikipedia.org/wiki/Erdgas/Tabellen_und_Grafiken#Nach_L%C3%A4ndern
9. www.wingas.com/rohstoff-erdgas/erdgas-im-energiemix.html/
10. www.bmwi.de/Redaktion/DE/Artikel/Energie/gas-erdgasversorgung-in-deutschland.html
11. http://www.bund-rvso.de/energievorraete-energiereserven.html
12. www.gwerbegas-online.de