Small-scale versus Large-scale LNG Plants

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This is the ninth article in a series of ten on natural gas (NG) and liquefied natural gas (LNG) by OTC specialists and partners.

The series comprises the following articles which have been published or are scheduled for publication on the dates listed:

1. Overview of the LNG industry – September 2020
2. Traditional gas transport modes – November 2020
3. Safe and clean storage of natural gas – January 2021
4. Alternative modes of natural gas transport – March 2021
5. Overview of LNG technologies – May 2021
6. Comparison of inland NG/LNG and imported LNG – June 2021
7. Outlets and applications for natural gas – August 2021
8. Natural gas for power generation – September 2021
9. Small-scale versus large-scale LNG plants – November 2021
10. Gas utilisation in transport – December 2021

These articles are published over a period of 16 months and are interspersed with articles related to aspects of project management and renewable energy.

Introduction

Consumption of natural gas (NG) has grown rapidly over the past three decades and today accounts for nearly a quarter of the world's primary energy supply. Although global primary energy consumption fell by 4,5% in 2020 due to the Covid-19 pandemic, the consumption of NG fell by only 2,3%, which caused the share of NG in primary energy to continue to rise, reaching a record high of 24,7% (BP, 2021). The use of gas is set to increase even further in the coming years due to population growth and the industrialisation of underdeveloped countries.

NG is mostly methane, a strong greenhouse gas, and emits carbon dioxide on combustion. Nevertheless, NG is relatively clean compared to crude oil and coal, provided methane emissions can be curtailed during the processing and transport thereof. NG can also underpin a rising reliance on renewable energy, as it provides a flexible back-up to intermittent energy supplies from solar and wind power generators. This was demonstrated in the recent past when adverse climatic conditions negatively affected the output from renewable energy sources in Europe and China.

Liquefied natural gas (LNG) is just a logistical means of getting gas from the source to the market. The preferred way to move gas will always be pipelines. Only if a pipeline is not a possibility (for practical or economic reasons) will LNG be considered. An LNG plant is merely a gas processing facility which cools down NG to below its boiling point of -162˚C to liquefy the gas to LNG. This results in a 600-fold reduction in the volume of the gas for ease of transport. LNG liquefaction plants are traditionally very large to achieve economy of scale. However, small-scale LNG plants have become increasingly popular in recent years to monetize isolated and smaller gas reservoirs.

In this article, we explore the terminology of smaller LNG plants, reflect on the cost of transporting natural gas, and consider the similarities and differences between small liquefaction plants, and conventional or large-scale liquefaction plants.

Defining small-scale LNG

Conventional liquefaction plants typically produce from 4 million to 8 million tpa LNG. The proliferation of smaller scale LNG plants over the past three decades, introduced terminology like micro-LNG, mini-LNG, small-scale LNG, and medium-scale LNG. This nomenclature was proffered by the technology suppliers to highlight unique aspects of their product. This implies that the current definitions of small-scale LNG relate to the technology or the equipment specifications and is not connected in any way to destination market size.

Small-scale LNG refers in general to LNG-related facilities (liquefaction plants, receiving terminals, storage units, vessels, etc.) of similar characteristics but with a lower capacity than conventional LNG infrastructure. However, there is not yet a clear, commonly accepted definition for small-scale LNG. According to the International Gas Union (IGU), small-scale projects are defined as anything less than 0,5 million tpa for NG liquefaction plants, 1 million tpa for LNG regasification units, and 60 000 m^3 for LNG vessels (IGU, 2018).

Based on these IGU guidelines, terminology used for existing small liquefaction plants, and the technology offerings in the marketplace, typical capacity ranges for micro-scale, small-scale, medium-scale, and large-scale (conventional) LNG plants are as shown in Figure 1.

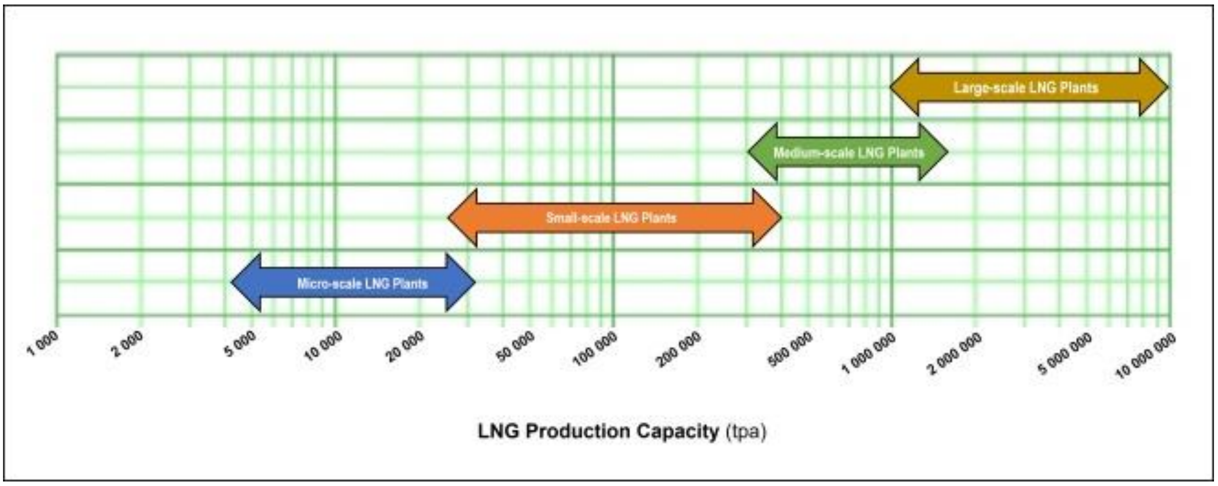

Figure 1: Terminology for liquefaction plant size

Figure 1 shows some overlap of the different capacity ranges. This can occur when using several parallel trains of, for instance, standardised small-scale LNG plants to reach a desired total production capacity.

Transporting natural gas

NG is moved through pipelines by compressors which increase the gas pressure to allow the gas to flow from areas of high pressure to areas of relatively lower pressure. Compressor stations on transmission pipelines are generally built every 200 to 300 km along the length of a transmission pipeline, allowing pressure to be increased as needed to keep the gas moving. Depending on where they are in a transportation system all NG pipelines are either:

- **Gathering pipelines:** These lines transport gas away from the well pad to another facility for further refinement or to transmission pipelines.
- **Production lines:** Production lines form part of the gas processing facilities, normally near the wellhead, used to prepare the gas for transport.
- **Transmission pipelines:** Large diameter lines (typically 6 to 48 inches) that move gas long distances around the country, at pressures up to 100 bar.
- **Distribution pipelines:** Distribution involves a system of low pressure mains and service lines that deliver NG to individual homes and businesses.

One of the toughest problems facing the gas industry is the high cost of gas transportation via transmission lines. In many cases, transport cost significantly exceeds the cost of gas production. For a pipeline to be economically viable, a baseload will be required to justify the capital expenditure on the pipeline. The longer the pipeline required, the bigger this baseload must be. A rough rule of thumb is that 10 million GJ/a baseload is required for every 100 km of pipeline. This implies that a pipeline of 30 to 35 km could be justified for individual customers requiring 60 000 tpa of gas.

If a customer is further away than 35 km or the market of 60 000 tpa is made up of several customers in different directions, then pipelines become uneconomical, and transporting gas as compressed natural gas (CNG) or LNG becomes preferable. CNG is generally more economical for distances below 300 km, whereas LNG becomes more economical beyond 300 km.

Another consideration is how far LNG can be transported overland which is the typical transport mode of LNG from small-scale LNG facilities. The constraint to transport distance is the prevention of LNG boil-off that vents to atmosphere. One way to avoid this would be to use LNG boil-off as fuel for the horse pulling the LNG tanker, but the practical implementation of this needs to be established. Venting of the boil-off must be prevented because NG/methane is a greenhouse gas.

The cost of moving NG is significantly higher than the cost of moving crude oil or even waterborne coal. Pipelining NG benefits from economy of scale, since large diameter pipelines are not that much more expensive to lay than smaller lines but carry much greater volumes of NG. Pipeline costs rise linearly with distance. LNG, requiring liquefaction and regasification regardless of the distance travelled, has a high threshold cost but a lower increase in cost with distance. Converting the NG to liquid fuels using a Fischer-Tropsch process (gas-to-liquids or GTL) has an even higher threshold cost, but a lower increase in cost with distance than LNG. These relationships are illustrated in Figure 2.

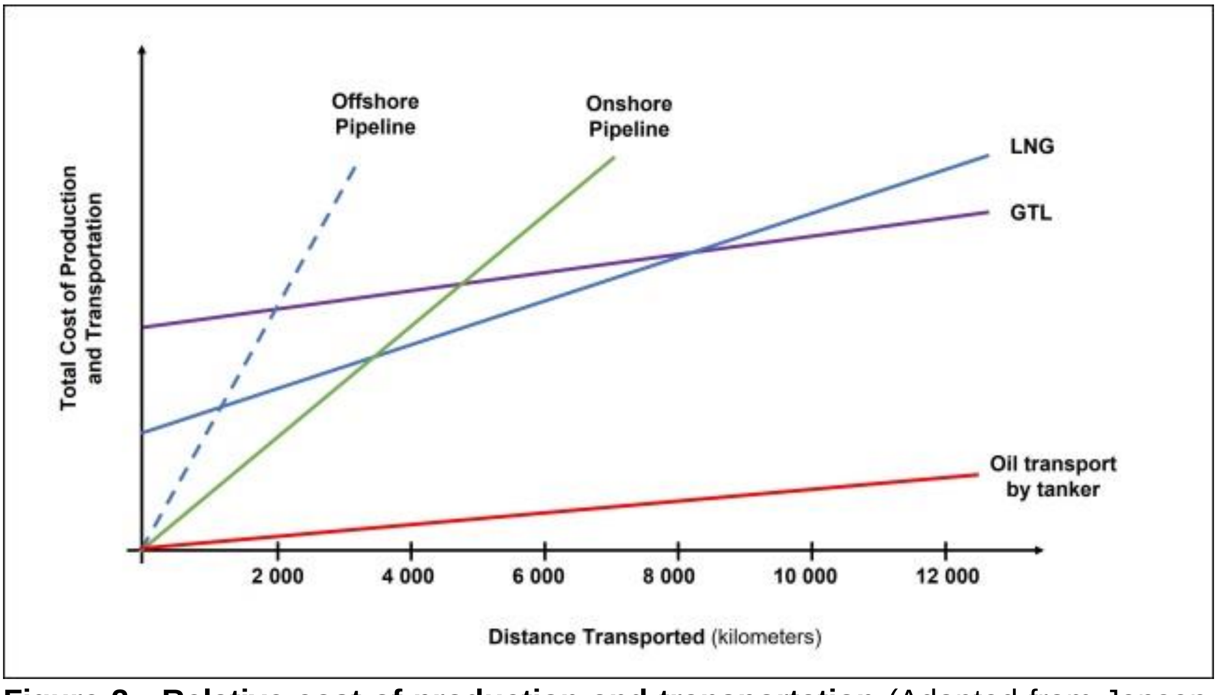

Figure 2: Relative cost of production and transportation (Adapted from Jensen, 2004)

From Figure 2 we see that shorter distances tend to favour NG pipelines, but longer distances favour LNG.

Comparison of small-scale and large-scale LNG plants

Opening remarks

A Venn diagram of properties of large-scale LNG plants (orange ellipse) and small-scale LNG plants (green ellipse) is shown in Figure 3. The intersection of the two ellipses represents areas of overlap or similarity between the two sets of properties. The areas which do not intersect, represent unique properties of the two categories of LNG plants.

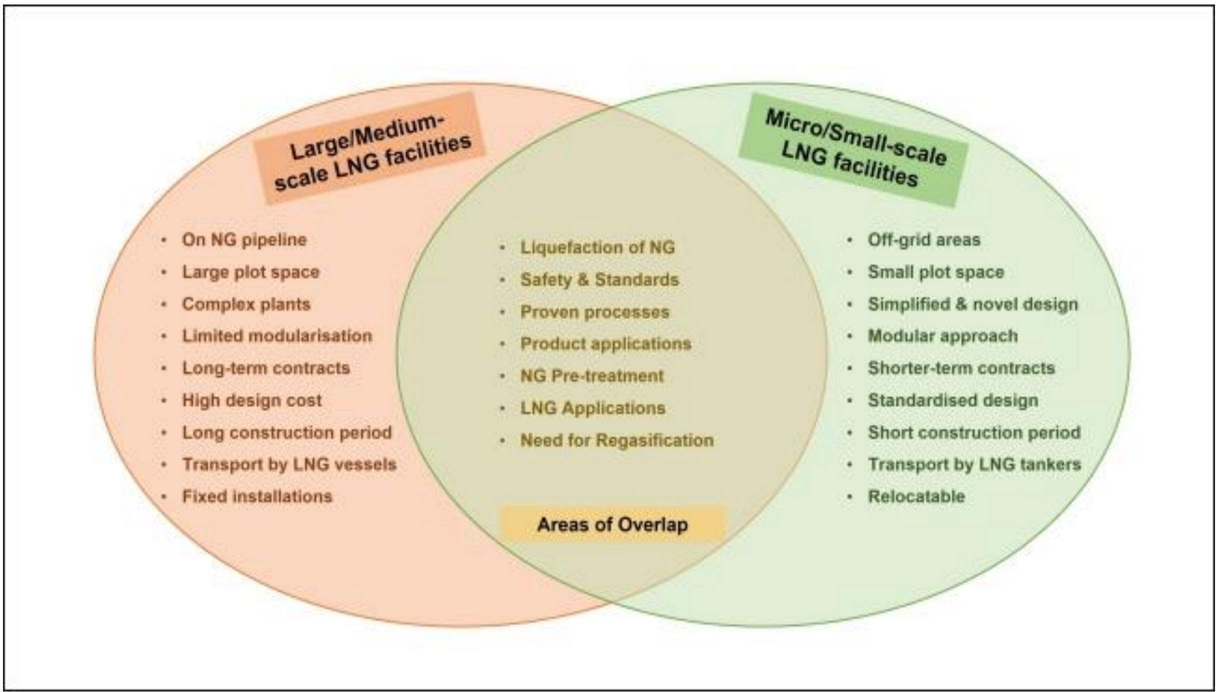

Figure 3: Comparison of small-scale LNG and large-scale LNG

In the following sections we first discuss the areas of overlap shown in Figure 3, which represent the similarities between small-scale LNG and large-scale LNG, followed by a discussion of the differences.

Similarities

Purpose and products

The objective of any NG liquefaction plant, irrespective of its size, is the same, namely to cryogenically cool down NG until it becomes liquid. This is done to facilitate the transportation of the gas over long distances when pipelines are impractical or uneconomical.

The composition of the natural gas defines how it will be processed for transport. Whether staying in its gaseous state or being transformed into a liquid, NG from the well must undergo separation processes to remove water, acid gases and heavy hydrocarbons. To produce LNG, additional processing is required before the liquefaction step to remove the threat of crystallisation in the heat exchangers in the liquefaction plant because of the extreme low temperatures involved.

The final product from small-scale and large-scale liquefaction plants is identical, namely LNG. LNG is a useful state in which to transport NG when pipelines are not justifiable. LNG customers can regasify and introduce the resulting NG into distribution systems for power generation, and other industrial, commercial, or domestic purposes. An overview of the applications of NG is available in an article by Steyn (2021), while the use of NG in power generation is covered by Thirion and Steyn (2021).

Proven technology

Construction of the first prototype LNG plant commenced in West Virginia in 1912 and beneficial operation started in 1917. The first commercial liquefaction facility entered service in Cleveland, Ohio, in 1941. The plant operated successfully for three years before a tank ruptured due to the cryogenic conditions and the plant burned down. The fire delayed further implementation of LNG facilities for many years. The LNG industry restarted in 1964 in Algeria. Several new large-scale plants were built during the mid-1960's in the USA. This means that the technology was proven more than a century ago and has been commercially operated for over fifty years.

LNG liquefaction plant capacity increased rapidly since 2000 and facilities above 5 million tpa are common. Small-scale LNG plants started to increase in number from about 2015 and shows sustained growth. The technology used is like that of large-scale LNG, but simpler and less complex. Advances in liquefaction equipment technology will continue to make small-scale LNG safer and more cost effective. Whereas most existing small-scale facilities are based on single mixed refrigerant technology and nitrogen expansion cycle technology, Gasconsult developed a zero refrigerant LNG technology for small-scale plants (Gasconsult, 2013).

Safety and standards

The LNG industry has an excellent safety record, irrespective of the size of the facility, apart from the Cleveland disaster mentioned above. Research has been done to specify the appropriate metallurgy for the cryogenic sections of an LNG plant to prevent a recurrence. The safety record is due to the combination of industry practice and regulations that are in place to prevent incidents from occurring and to reduce or mitigate the impacts of incidents if they occur.

The physical and chemical properties of LNG are well understood, and the plant designs are proven through many years of beneficial operation. Vapours released from LNG facilities, if not contained, will mix with surrounding air, which may create a vapour cloud that may become flammable and explosive. The flammability limits are 5 % and 15 % by volume in air. Outside of this range, the methane/air mixture is not flammable.

The LNG industry operates according to a set of standards, codes, and regulations to ensure safe and sustainable engineering, plant design, construction, and operation. These standards are continuously evolving and improving. Small-size LNG technology does not compromise on safety, reliability, robustness, or efficiency. Applied processes and equipment are proven in base-load service, comply with standards and overall safety philosophies, and are derived from large-scale LNG projects. However, based on standard industry risk acceptance criteria, necessary safety distances inside small-scale LNG plants are significantly lower than those of large-scale LNG plants. The main reason for the difference is the high hydrocarbon inventory in large-scale LNG plants due to the increased mixed refrigerant inventory and larger LNG storage tank sizes.

Regasification

Once it has reached its destination, the LNG is offloaded from the road/rail tanker or LNG vessel and either stored or regasified. Regasification is the process of converting LNG back to a gaseous state by passing the LNG through a series of vaporizers that reheat the fuel above the -160 ˚C mark. The resulting NG is then sent via pipeline to the end users.

Some customers of small-scale LNG facilities may use the LNG as is or rely on natural boil-off from the LNG storage tanks to supply their NG requirement. In this case, no regasification facility is necessary.

Differences

Application

Large-scale LNG facilities are inevitably linked to NG transmission lines which collect gas from large gas fields. These facilities are located at the coast and include LNG loading and unloading terminals to allow shipment of LNG by specially-built LNG transport vessels. This means that a country with an oversupply of gas can satisfy their own energy needs and export the excess to energy-poor countries.

Small-scale LNG facilities are more flexible in their application and are used to monetize isolated sources of gas. This refers to small gas reservoirs in areas not serviced by NG transmission lines, biogas from municipal solid waste disposal sites and anaerobic digesters, and flared gas from oilfields. Thousands of gas flares at oil production sites worldwide burned approximately 142 billion m^3 of associated gas in 2020 (World Bank, 2021). Stricter environmental regulations are forcing oil companies to drastically cut back on flaring.

Value chain

A typical value chain for small-scale LNG is shown in Figure 4. It comprises a gas source, processing (cleaning and liquefaction), LNG transport, LNG storage (including regasification), and consumption.

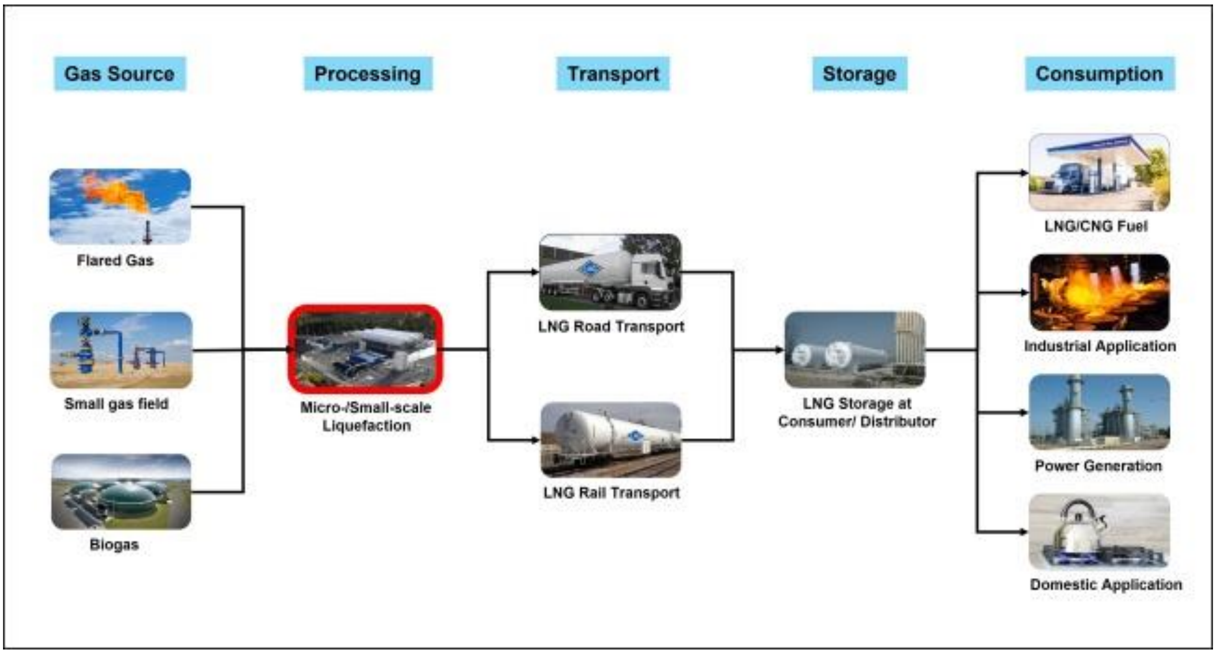

Figure 4: Value chain for small-scale LNG

Figure 4 illustrates some of the possible feedstock options, namely flared gas from oilfields, NG from isolated reservoirs, and biogas from landfills and animal waste. LNG transport by road and rail tanker is shown, but for small-scale plants along waterways, it is also possible to use LNG barges or small LNG carrier vessels.

The value chain for large-scale LNG is shown in Figure 5. In this case, the value chain is significantly longer and includes a gas source, NG processing (cleaning and compression), NG transmission, storage (if required), liquefaction, LNG transport, regasification, distribution, and consumption.

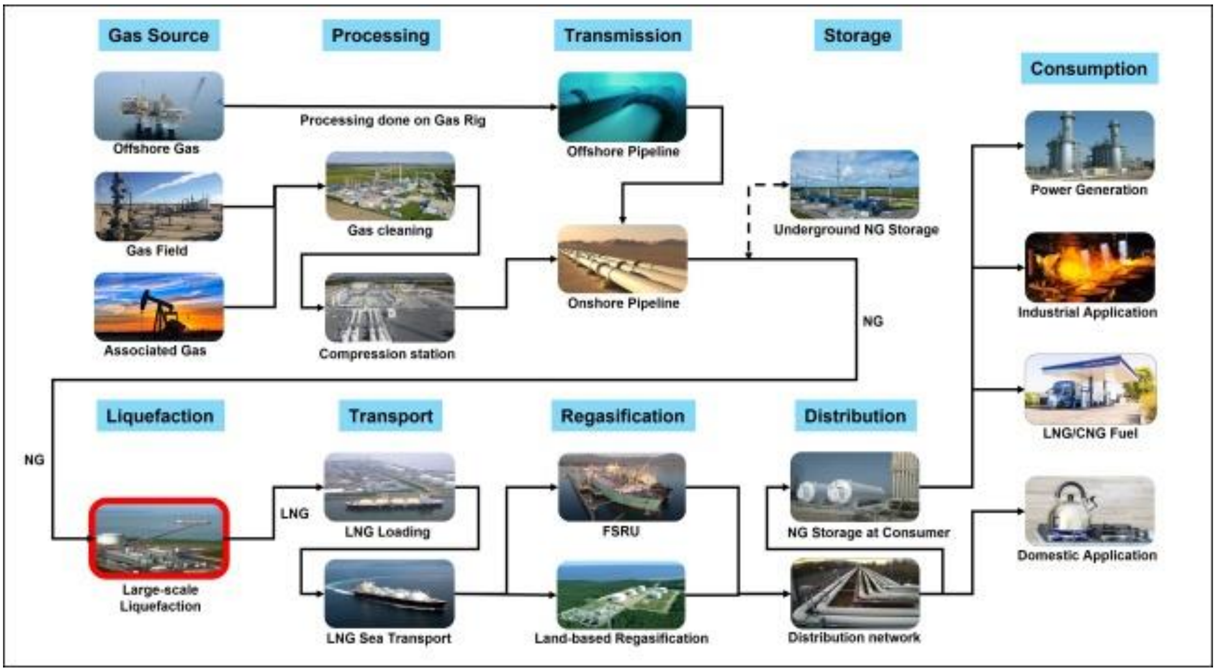

Figure 5: Value chain for large-scale LNG

LNG transport for large-scale LNG facilities is exclusively by sea, using custom-built LNG vessels. Regasification of the LNG is required to convert it back to NG before distribution to consumers. Regasification can be done in either a land-based storage and regasification facility, or in a floating storage and regasification unit (FSRU). FSRUs can be constructed and become operational in a shorter time than land-based facilities. A further advantage of an FSRU is the fact that it can be moved to other locations as desired.

Plot-space required

Plot space requirements of small-scale LNG plants differ significantly from large-scale LNG plants. Production capacity is obviously a determining factor, but the capacity to plot space required is not linear.

Small-scale LNG plants including buildings, flare, LNG tank and utilities requires a plot space of 10 000 to 20 000 m^2, while large-scale LNG plants require thirty to fifty times more plot space. In general, large-scale LNG plants do not benefit from economies of scale regarding plot space and require proportionally larger plot spaces than expected based on the sheer scale in capacity and equipment.

The increased hydrocarbon inventory in large-scale plants raises the potential fire and explosion loads which trigger additional requirements for keeping the risk as low as reasonably practicable. This either leads to increased investment cost for reinforcement of the equipment or to increased plot space requirements to limit the impact of a fire or explosion. Based on standard industry risk acceptance criteria, necessary safety distances inside of small-scale LNG plants are significantly lower than those of large-scale LNG plants.

Construction of a small-scale LNG plant requires far less area for lay down and work camps. The work force in a large-scale LNG project can exceed ten thousand men during peak times and poses a major challenge, especially when the plant is in a remote area.

Plant complexity

Large-scale LNG plants will opt for one of the multiple mixed-refrigerant vapour compression technologies with up to fifty major process units. If refrigerants for the mixed-refrigerant schemes need to be extracted from the incoming feed gas, the equipment count and expenditure for those processes will increase significantly. Lower capacity LNG plants, or smaller gas reserves, cannot sustain the high capital expenditure associated with these technologies and will opt for single mixed refrigerant or expander-based processes. Small-scale plants are usually expander-process based and has an equipment count of less than half that of a large-scale plant (Render & Howe, 2021).

Further technology optimisation can be expected for small-scale plants to lower the unit cost of producing LNG. Gasconsult's patented Zero Refrigerant LNG (ZR-LNG) uses no external refrigerants, using the NG feed as the refrigerant medium in an optimised system of expanders. This reduces major equipment count, capital expenditure and footprint. The absence of liquid hydrocarbon refrigerant also makes for a safer operating environment (Pekic, 2021).

Small-scale LNG liquefaction plants typically include a 'standard' gas pre-treatment train consisting of a mercury removal unit, an amine-based acid gas removal unit, and a dehydration unit with molecular sieves.

Supply contracts

The LNG Sale and Purchase Agreement (SPA) is the keystone of any LNG project and bridges the liquefaction plant to the receiving regasification terminal. The commitment made in a SPA, in its broadest sense, is that the seller will sell, and the buyer will purchase a specified amount of LNG. LNG SPAs are primarily founded on a 'take or pay' commitment, where the buyer agrees to pay for the committed volume of LNG, even if it is not taken, subject to the right of the buyer to take an equivalent make-up volume at a later stage.

Historically, LNG SPAs have been long-term contracts with terms of 20 to 25 years. These long-term contracts are essential for both the seller and the buyer to justify the significant investments required by the liquefaction project and by the receiving terminal and the natural gas end-users (US DoE, 2017). As much as possible of the liquefaction plant capacity must be tied into these long-term contracts to enable the developer to secure project finance.

Small-scale LNG plants can obtain finance with short-term SPAs of 5 to 10 years because of the lower capital requirement.

Cost & schedule

LNG liquefaction projects are some of the largest and most complex infrastructure projects undertaken in the world, with total project costs that can run into tens of billions of US$. A large-scale LNG plant costs about US$1,5 billion per 1 million tpa capacity. LNG terminal costs coupled with the cost for transportation vessels makes traditional LNG a very expensive option for users and financiers.

Small-scale LNG requires less capital investment due to lower plot space, less infrastructure, smaller equipment, and the use of standardised plant modules. Standardised modules eliminate redoing engineering and design for each plant to be erected. If a higher plant output is required, simply use two or more standardised trains. Modular plant construction also means that the bulk of the construction work can be performed workshop where the modules are built. This reduces construction work on the plant site and improves safety performance during construction.

Large-scale LNG liquefaction projects have always had long execution timelines with projects historically taking around 3 to 4 years to construct. This is over and above the time required to complete a bankable feasibility study, finalise the SPA, and do the detailed design of the LNG facility. Over the past 10 years, the trend has been for longer project execution times, namely 4 to 5 years, due to more difficult construction terrain (Zeal, 2019). In comparison, a standardised and modularised small-scale LNG plant can be built in less than 18 months.

Product transport

The transportation of LNG refers to any movement or shipping of natural gas while in its liquid form. LNG can be transported by pipeline, LNG carrier ships, or by trucks and trains equipped with special cryogenic containers.

LNG pipeline infrastructure takes the LNG between liquefaction facilities and storage facilities, from storage facilities to tankers, and from tankers to re-gasification facilities. Substantial insulation must be incorporated into LNG pipelines for it to maintain the LNG in its liquid form. This normally includes a combination of mechanical insulation, for example glass foam and a vacuum layer.

Most LNG exports take place at an intercontinental level, meaning that shipping LNG across the ocean is required. This mode of transport has been used for over sixty years. LNG from large-scale plants is transported by tankers called LNG carriers in large, onboard, cryogenic tanks. The tanks are not pressurised, and the LNG is maintained at its boiling point of -162˚C, which means that continuous boil-off occurs. Boil-off helps maintain the temperature in the tanks by evaporative cooling. Approximately 0,1% of the LNG inventory is lost through boil-off per day and this is used to power the carrier vessels.

For small-scale LNG facilities, LNG is transported in LNG tank trailers or in smaller ISO-compliant containers that can be placed on barges and on trucks. To maintain the temperature of the LNG, the tank trailers and containers are of double wall construction and insulated using high vacuum multi-layer insulation. Some small-scale liquefaction plants which are located along waterways, also distribute LNG using small carrier vessels, but this is the exception.

Transporting LNG by rail is a recent development. The ban on LNG transport by rail in the USA was lifted on the 24th of July 2020. However, the Biden Administration indicated its intent early on to review the LNG-by-rail rule (EELP, 2021). In Europe, the first LNG container was shipped by rail on the 10th of September 2020 from the Zeebrugge LNG terminal. China's National Offshore Oil Corporation is currently halfway through a two-year trial programme for delivery of LNG by rail. However, one of the industry's first is Japan's JAPEX LNG Satellite System which has been using rail to supply imported LNG to gas consumers in remote regions since 2000. LNG by rail is mostly used by small-scale LNG plants.

Permanency

Large-scale LNG facilities are typically designed for a 30-year operating life. Upgrades and additions can be made in this period to increase the production capacity or to extend the period of beneficial operation.

Whilst small-scale LNG plants are designed for a similar operating life, these facilities are more flexible due to their modular construction. This means that a small-scale plant can be deconstructed and moved elsewhere when the gas source stops producing.

Closing remarks

The increase in demand for LNG will require huge capital investments and the setting up of new large-scale LNG plants. However, small-scale LNG plants require less investment and provides returns much sooner because of the shorter construction time.

The production of LNG adds considerable cost to the NG value chain. This also explains why large-scale LNG facilities are getting bigger and bigger to benefit from economy of scale to drive down liquefaction unit costs. However, small-scale LNG has transformed the NG market by making stranded gas reservoirs an economic reality. NG reservoirs or biogas sources for which pipelines were too costly to construct, can now be produced, transformed into LNG, and transported via road or rail tanker and small-scale LNG vessels. In the case of small-scale LNG, the liquefaction plant (plus the ancillaries) will typically add US$5 per GJ to the cost or price of the LNG.

An ideal customer for an LNG liquefaction facility would be a remote mine using diesel for a variety of purposes such as yellow machinery, mine support vehicles, and even power generation. Another possibility would be a smelter using LPG for processing reasons and diesel for support vehicles. A small-scale LNG plant could supply such customers.

References

BP (2021) *Statistical review of World Energy, 70th Edition*. Available from Full report – Statistical Review of World Energy 2021 (bp.com). Accessed on 2 November 2021.

EELP (Environmental & Energy Law Program) (2021) *LNG by rail rule*. Available from LNG by Rail Rule - Environmental & Energy Law Program - Harvard Law School. Accessed on 10 November 2021.

Gasconsult (2013) *Gasconsult ZR-LNG™ technology*. Available from Gasconsult ZR-LNG™ Technology | Gas Consult LNG. Accessed on 10 November 2021.

IGU (International Gas Union) (2018) 2018 World LNG report – 27th World Gas Conference edition. Available from 2018 World LNG Report (27th World Gas Conference Edition) | IGU. Accessed on 10 November 2021.

Jensen, J.T. (2004) *The development of a global LNG market. Is it kikely? If so, when?* Oxford Institute for Energy Studies, Oxford.

Pekic, S. (2021) PolaireTech licences ZR-LNR for small-scale LNG plants. Available from PolaireTech licenses ZR-LNG for small-scale LNG plants - Offshore Energy (offshore-energy.biz). Accessed on 10 November 2021.

Render, C.L. & Howe, W. (2021) Overview of LNG Technologies. Available from Overview of LNG Technologies | OwnerTeamConsultation. Accessed on 15 October 2021.

Steyn, J.W. (2021) *Outlets and applications for natural gas*. Available from Outlets and Applications for Natural Gas | OwnerTeamConsultation. Accessed on 10 November 2021.

Thirion, C. & Steyn, J.W. (2021) *Natural gas for power generation*. Available from Natural Gas for Power Generation | OwnerTeamConsultation. Accessed on 10 November 2021.

US DoE (U.S. Department of Energy) (2017) *Understanding natural gas and LNG options.* Available from Understanding Natural Gas and Lng Options October 11 2017 1.pdf (energy.gov). Accessed on 10 November 2021.

World Bank (2021) *Gas flaring explained*. Available from What is Gas Flaring? (worldbank.org). Accessed on 10 November 2021.

Zeal, T. (2019) *Are LNG liquefaction projects taking longer to construct?* Paper presented at the 19th International Conference & Exhibition on Liquefied Natural Gas, held in Shanghai from 1 to 5 April 2019.