Traditional gas transport modes

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This is the second article in a series planned by OTC on natural gas (NG) and liquefied natural gas (LNG).

The originally planned series has grown to include two additional articles (nos. 3 & 4 below) and is 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 environmentally friendly storage of LNG – January 2021
4. Alternative modes of (gas) energy transport – March 2021
5. LNG technologies – May 2021
6. Comparison of inland gas and imported LNG – June 2021
7. Outlets for NG and LNG – August 2021
8. Gas for power generation – September 2021
9. Small scale versus large scale LNG – November 2021
10. Gas utilisation in transport – December 2021

These articles will be published over a period of 16 months (one month longer than originally planned) and will be interspersed with articles related to aspects of project management.

Introduction

The efficient and effective movement of natural gas (NG) from producing regions to consumption regions requires an extensive and elaborate transportation system. In many instances, NG produced from a particular well will have to travel a great distance to reach its final point of use.

Transportation of NG is intricately linked to its storage infrastructure. If produced NG is not immediately required, it can be stored for when it is needed. In addition, the handling of gas needs to be done safely and in an environmentally acceptable manner.

It is important to understand the different modes of gas transport when looking at the gas logistics chain and which mode of transport is suitable for different scenarios.

In this article, we discuss traditional gas transport modes. It covers the importance of gas logistics and how gas is traditionally moved from areas of production to areas of consumption, including by pipeline, as compressed natural gas (CNG), or liquefied natural gas (LNG).

Importance of gas logistics

The importance of gas logistics is evident when comparing gas prices in three of the largest gas markets in the world. These three markets are North America (representing 26.7% of global consumption), Europe (with 14,2% of global consumption) and China/Japan/Korea (with 12,5% of global consumption). In 2019 the gas price in North America was just over $2,50/GJ (average Henry Hub price for year), in Europe it was $5 to $8/GJ (prices at hubs such as NBP and Zeebrugge), and in China/Japan/Korea (landed LNG price) it varied from $5 to $12/GJ.

These 2019 prices were substantially lower than 2018 because of the LNG glut in the world. In 2020 the prices decreased further because of the global COVID-19 pandemic and the oil price war between Saudi Arabia and Russia. These prices are expected to recover over time and, in the medium to long term, gas prices are expected to range between $3 and $5/GJ in the USA, between $6 and $10/GJ in Europe, and between $8 and $15/GJ in Japan/Korea.

These significant discrepancies in gas prices around the world are largely driven by the logistic cost of getting the gas from source to market. In North America, gas is moved almost exclusively by pipeline and there is well-established pipeline infrastructure in place for this. In Europe most of the gas is delivered by long-distance pipelines from Russia, North Africa, and Norway, with spot LNG imports starting to play a more prominent role. In China, Japan, and Korea the gas is supplied via LNG imports, mostly on long-term contracts, but also increasingly on short-term contracts and spot.

The reason for these big price discrepancies amongst the regions is illustrated in Figure 1, showing how the cost of logistics (in this case LNG exports from the USA via LNG liquefaction, shipping and storage/regasification) adds to the price of the gas. As can be seen from Figure 1, the final price of gas exported as LNG from the USA, is substantially more than double the cost of gas at Henry Hub (HH). Similarly, the price of gas in Europe is roughly double the cost of gas at the sources in Russia or North Africa, to recover the cost of the long-distance pipelines used for transport. It is only in the USA (and other gas-rich constituencies such as Russia and the Middle East) that logistics costs represent substantially less than half of the price to the consumer.

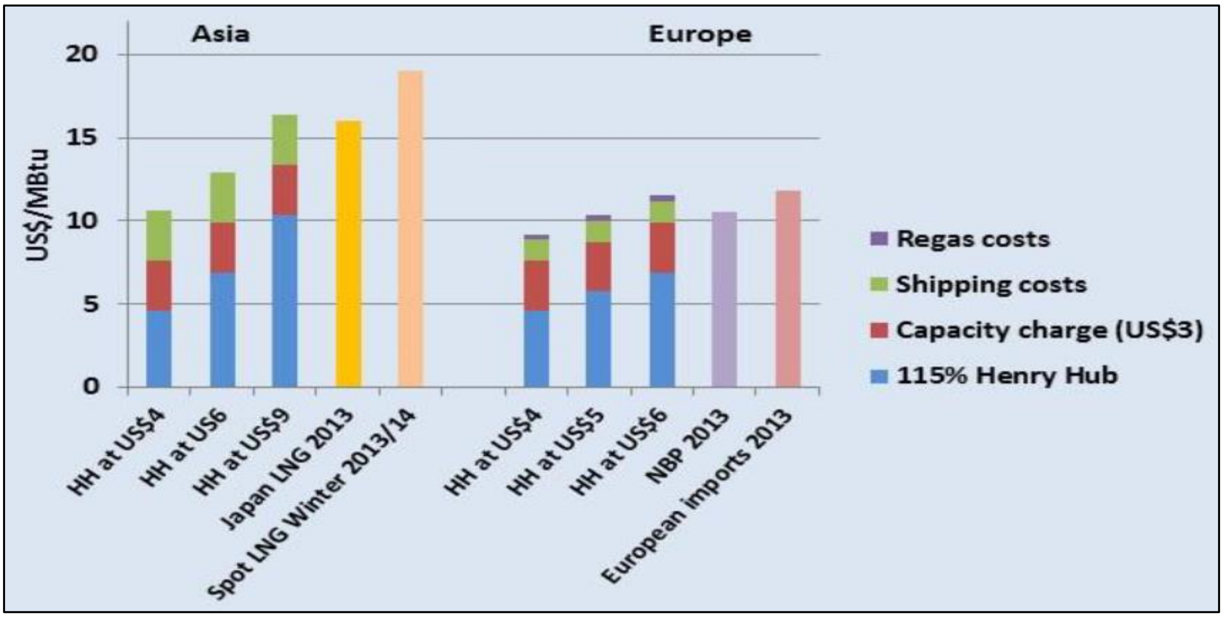

Figure 1: Delivered price of LNG to Europe and Asia (Cornot-Gandolphe, 2014)

Even though gas pipelines are typically the most economical means of moving gas, gas pipeline projects can still be expensive and add substantially to the price of the gas to the consumer. The examples of big gas pipeline projects given in the section on pipelines amply demonstrate this.

Proof of the importance of gas logistic cost is how prominently it features in global economic and trade battles. An example of this is the recent developments around the Nord Stream 2 project, an undersea pipeline to transport gas from the St Petersburg region in Russia to the Baltic coast in Germany. In June 2020, a bill was introduced into the US Congress to boycott entities involved in the pipe-laying activities on this pipeline, at a stage when the project was already 90% complete. Although the rationale of this bill is stated as maintaining the energy security of Europe, it seemed to be a thinly veiled attempt by the USA to protect its booming LNG export business to Europe against more pipeline competition from Russia. This move by the USA was heavily criticised by the EU Parliament and by the German government and the proposed legislation has not yet been signed into law in the USA. Ironically, both the EU and Germany are now proposing sanctions against Nord Stream 2 in retaliation for the alleged poisoning of the Russian opposition leader, Alexei Navalny, in August 2020, another example of how gas logistics across national borders has become a political tool.

Modes of transport of energy

Opening comments

Natural gas energy can be moved to market in various ways including pipelines, liquefied natural gas (LNG), compressed natural gas (CNG), gas to solids (GtS), i.e. hydrates, gas to wire (GtW), i.e. electricity, gas to liquids (GtL), with a wide range of possible products including clean fuels, plastic precursors, methanol, ammonia and gas to commodity (GtC), such as aluminium, glass, cement or iron or even in the form of adsorbed natural gas. In recent years, significant progress has been made in terms of distributed small and micro LNG technologies and systems to transport LNG and CNG in smaller volumes, both offshore and onshore in more economic ways. Technologies like hydrate transport, pressurised LNG and adsorption technologies are, at this stage, still more speculative.

Any gas energy export route requires a huge investment in infrastructure, and long-term 'fail-proof' contracts, covering perhaps 20 years or more.

Transportation of NG as hydrate or CNG is believed feasible at costs less than that for LNG under certain specific scenarios and where pipelines are not feasible. The competitive advantage of GtS or CNG over the other virtual pipeline transport modes is that they are intrinsically simple, so should be much easier to implement at lower capital cost, provided economically attractive market opportunities can be negotiated to the gas seller. LNG, being a well-established and growing mode of transport, is supported through an extensive infrastructure in place.

We elaborate on the 'traditional' modes of transport of the methane gas in pipelines, as CNG, and as LNG.

Pipelines

There are typically four types of pipelines along a NG transportation route:

- **Gas gathering systems:** The gathering system that transports the gas from the wellheads to the central processing and/or compression facility. These gathering systems can be quite extensive in the case of unconventional gas such as shale gas and coal-bed methane, in which case the system typically consists of low pressure, small diameter pipelines. If the gas from the wells is sour (high carbon dioxide and/or sulphur content), a specialised sour gas gathering system must be installed up to the processing plant due to the corrosivity of sour gas.
- **Transmission lines:** The transmission system that transports the gas at high pressure (typically above 20 bar) over long distances. The bulk of international and interstate gas transfers take place in transmission lines.
- **Distribution lines:** The distribution system that branches out from the transmission lines and transports the gas at medium pressure (typically 5 to 20 bar) over shorter distances, but normally not further than 200 kms.
- **Reticulation lines:** The reticulation system that transports gas at low pressure (below 2 bar) in a gas network. This is typically how town gas systems and gas supply systems in small industrial areas operate.

The capital cost for a steel pipeline can roughly be estimated at $65 000/inch in diameter per km (excluding any possible costs of servitudes). This figure can vary widely and will be dependent on a range of factors such as the terrain of the pipeline route, the seismic activity along the pipeline route, the number of river crossings, whether any mountains need to be crossed, and remoteness of the route from established infrastructure. Other factors include labour productivity and cost in the specific jurisdiction, environmental impact assessments, local content requirements, specific stakeholder aspects such as local community involvement, possible relocations, and owner's costs.

Pipeline tariffs for transmission lines are normally regulated. For distribution lines tariffs could be regulated or at least some oversight provided by regulatory authorities. In the case of reticulation pipeline systems, local authorities might regulate or have some oversight of the tariffs (although these tariffs are often included in the final price to the consumer and not specified separately). In the case of the USA, this means that over 70% of their 491 000 kms of gas pipelines is regulated since they are classified as interstate transmission lines. Normally the tariff for a regulated pipeline up to 1 000 km long will not exceed $1/GJ.

As NG consumption globally has grown strongly, so has the scale of pipeline projects to serve those needs. Following by way of illustration is information on two of the big pipeline projects currently in progress, namely the Power of Siberia pipeline and the Nord Stream 2 pipeline.

Power of Siberia pipeline

This pipeline connects gas fields in the east of Russia to the town of Blagoveshchensk on the China border (see Figure 2). In the first phase of this project, the 2 200 kms of pipeline from Chayandinskoye was completed at the end of 2019 and the second phase covering another 800 kms from Kovyktinskoye to Chayandinskoye is planned for completion before the end of 2022. A related project in China, called the East Russia - China pipeline will be completed in three phases (first phase to Jilin, second phase to Beijing and Tianjin, and third phase to Shanghai) and ultimately exceed 3 900 kms in length. The final cost of the 56-inch Power of Siberia pipeline is expected to be more than $15 billion (or roughly $90 000/inch/km). The remoteness of the region as well as the extreme climate conditions certainly contribute to the cost of the pipeline. The lowest ambient temperature along the route (and which had to be accommodated in the design) is -62°C, numerous river crossings had to be accommodated, as well as swamps, rocky terrain, permafrost and seismically active areas along the route. Figure 2 shows some of the gas developments, including the Power of Siberia, in the east of Russia. It is estimated that the Power of Siberia project, including the gas field development at Kovyktinskoye and the Amur gas processing plant, will cost north of $55 billion. This will be one of the biggest, if not the biggest, petrochemical development in history.

As shown in Figure 2, a 1 000 km pipeline link between Blagoveshchensk and the Sakhalin - Vladivostok pipeline is considered to move more gas east and this will probably be linked to a large LNG facility in Vladivostok for supply of LNG to Japan.

There is also talk of Power of Siberia 2 which will include several pipelines (shown in dotted lines) to connect the gas systems in the east with the gas systems in the west of Russia and then a second gas transmission line to China through Mongolia.

Figure 2: Gas development in eastern Russia (Gazprom, 2020a)

Nord Stream 2 pipeline

Nord Stream 2 is a 1 230 km undersea pipeline under construction from Ust-Luga in Russia to Greifswald in Germany, as shown Figure 3.

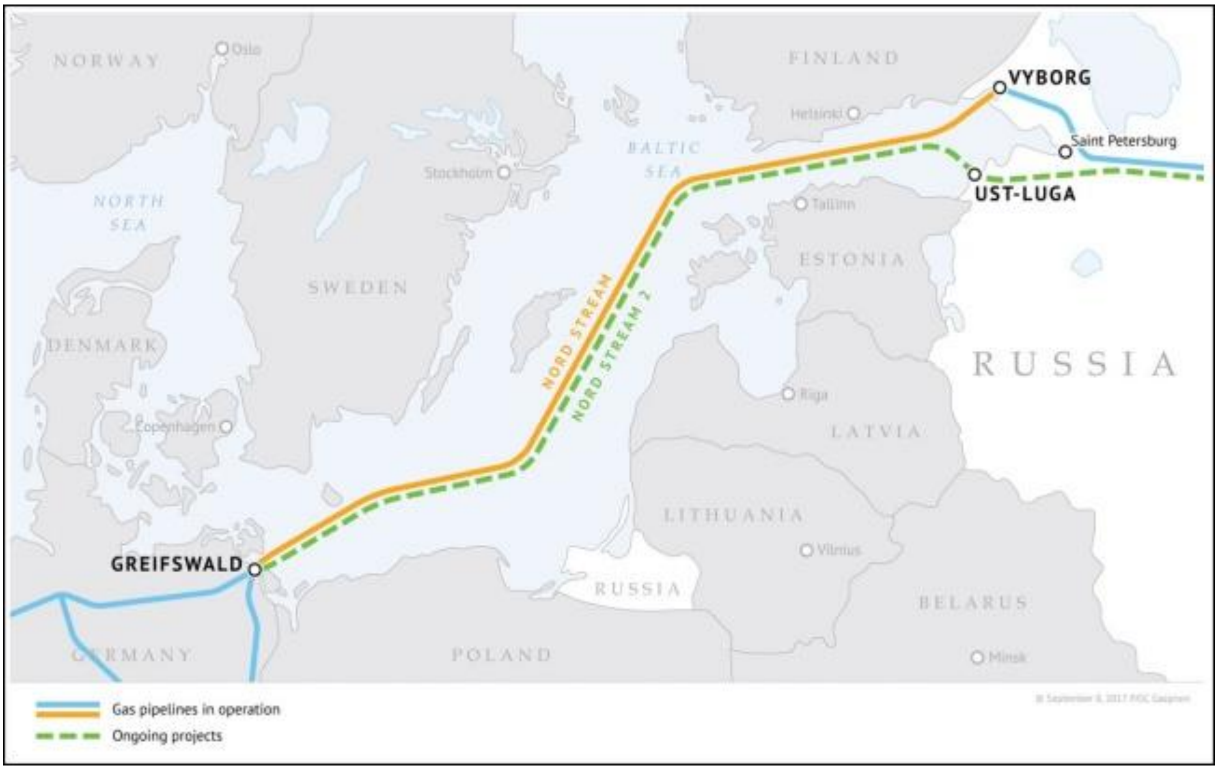

Figure 3: Nord Stream pipeline routes (Gazprom, 2020b)

Nord Stream 2 comprises two pipelines of 48-inch diameter each running parallel all the way. The project is expected to cost $11 billion which calculates to $93 000/inch/km. As to be expected for an undersea pipeline, this is higher than the typical value of $65 000/inch/km for steel lines. The expected completion date of Nord Stream 2 is early 2021, but this could be delayed because of political involvement as discussed above. For most of the route, the Nord Stream 2 pipes run parallel to the Nord Stream 1 pipelines. Nord Stream 1 was basically an identical project, also with 2 x 48-inch lines of which the first was commissioned in 2011 and the second in 2012. The cost of Nord Stream 1 was Euro 8,8 billion.

Pipeline projects in Africa

In Sub-Saharan Africa, three major natural gas pipeline projects were executed over the past 20 years:

- **ROMPCO pipeline:** The construction of this 26-inch 865 km pipeline from the Pande gas field in southern Mozambique to Secunda in South Africa was completed in 2004. In recent years, the capacity of this pipeline was extended through the addition of two loop lines covering about a quarter of the total distance.
- **West African Gas pipeline:** This offshore pipeline from the Escravos region of Nigeria to Benin, Togo and Ghana was completed in 2007. The 30-inch 678 km pipeline has a 569 km offshore section in water depths ranging between 30 and 75 meters. The total cost was about $970 million.
- **Mtwara-Dar es Salaam pipeline:** This onshore 36-inch 542 km pipeline stretches from the offshore gas fields in the south of Tanzania to the coastal city of Dar es Salaam in the northeast of Tanzania. The pipeline was completed in 2015 at a cost of $1,47 billion.

According to a World Bank report (Santley, Schlotterer & Eberhard, 2014) that looked at five different future pipeline concepts in Sub-Saharan Africa, there is little potential for major pipeline development in the medium term. The only concept that showed some potential was a pipeline from the Rovuma gas fields in the north of Mozambique to the South African industrial hub in the north of the country.

Compressed Natural Gas (CNG)

Compressed natural gas, or CNG, is produced by compressing NG down to less than 1% of its volume at standard atmospheric pressure. The CNG volume to be transported or stored can be from 150 to 300 times less than gas at atmospheric pressure. Producing CNG is a simple low-cost process and involves gas pre-treatment (depending on the gas source and quality) and compression. The NG arrives at the compression station at a low pressure from a local pipeline or truck, where it is compressed and stored in cylindrical or spherical storage containers at a pressure of 100 bar to 250 bar.

The main function of CNG is as an alternative for gasoline and diesel fuels for medium-duty vehicles travelling a moderate distance between refuelling. There are some other uses of CNG that include power generation and industrial consumers, however these are less developed due to the gas volumes required often being too high. CNG is typically used onshore for gas supply over short distances and in smaller volumes. Generally, CNG can be economically viable for volumes up to 140 000 m_s^3/day (5 million standard cubic feet per day (MMscf/d)), and distances up to 800 km.

The transportation of CNG can be onshore by truck or offshore by ship or barge. The largest cost in the CNG supply chain is the midstream transportation component, contributing up to 90% of the capital required. CNG onshore transportation by truck involves the facilities to load CNG into a pressurised transportable container at the compression site and the offloading facilities that includes the heating, let down and metering of the CNG at the customer site. The CNG offshore transportation by ship or barge involves a vessel with a containment system to transport the CNG from the source to the customer site. Figure 4 shows some of the different designs of trucks, ISO containers, and marine vessels for the transport of CNG.

Figure 4: Different options for transporting CNG

Cost analysis performed on the volume of CNG delivered and distances showed that for production capacities higher than 140 000 m_s^3/day (5 MMscf/d, equivalent to 8 000 GJ/d), delivery of CNG by truck becomes difficult, not only due to the substantial number of vehicles required (especially for longer distances), but also the significant extent of loading and offloading facilities required. The cost of transportation will depend on the project specific factors such as gas volume and composition, distance to consumers, storage and infrastructure requirements, geographical location. Figure 5 illustrates a case study performed for the World Bank (Tractebel Engineering, 2015) that shows the cost comparison between short distance and long-distance onshore transportation. Note the relatively large increase in transportation cost as the distance increases.

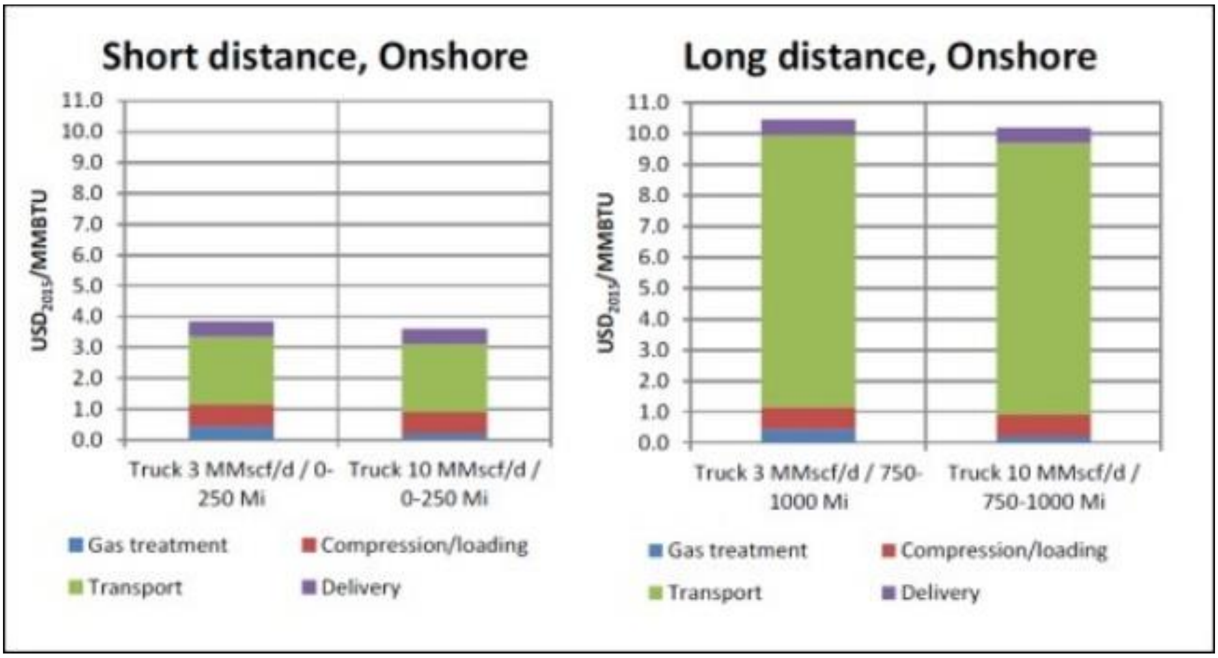

Figure 5: Comparison of CNG onshore transport costs (Tractebel Engineering, 2015)

The offshore marine CNG supply chain consists of three main components, namely:

- **Export onshore**: The upstream loading compression station with loading terminal (onshore or offshore)
- **Shipping:** The CNG carrier vessel, be it dedicated CNG ship, barge, or container vessel (offshore)
- **Import onshore:** The downstream unloading terminal (onshore or offshore) and the unloading decompression station.

The offshore transportation cost of CNG is directly proportional to the volume of gas and distance between the gas source and the consumers. This transportation method is best suited for medium distance projects: however, it is not well developed and has not yet been proven. The offshore transportation development to date is proposed to handle production rates between 1,4 million m_s^3/day and 19,8 million m_s^3/day (50 and 700 MMscf/d) and distances between 185 km and 3 700 km (100 nautical miles and 2000 nautical miles). For small volumes and distances barge shipping may be the appropriate method.

Tractebel Engineering (2015) performed a cost comparison between short distance and long distance offshore transportation in a case study, as illustrated in Figure 6. Note the increase in transportation cost when the distance increases.

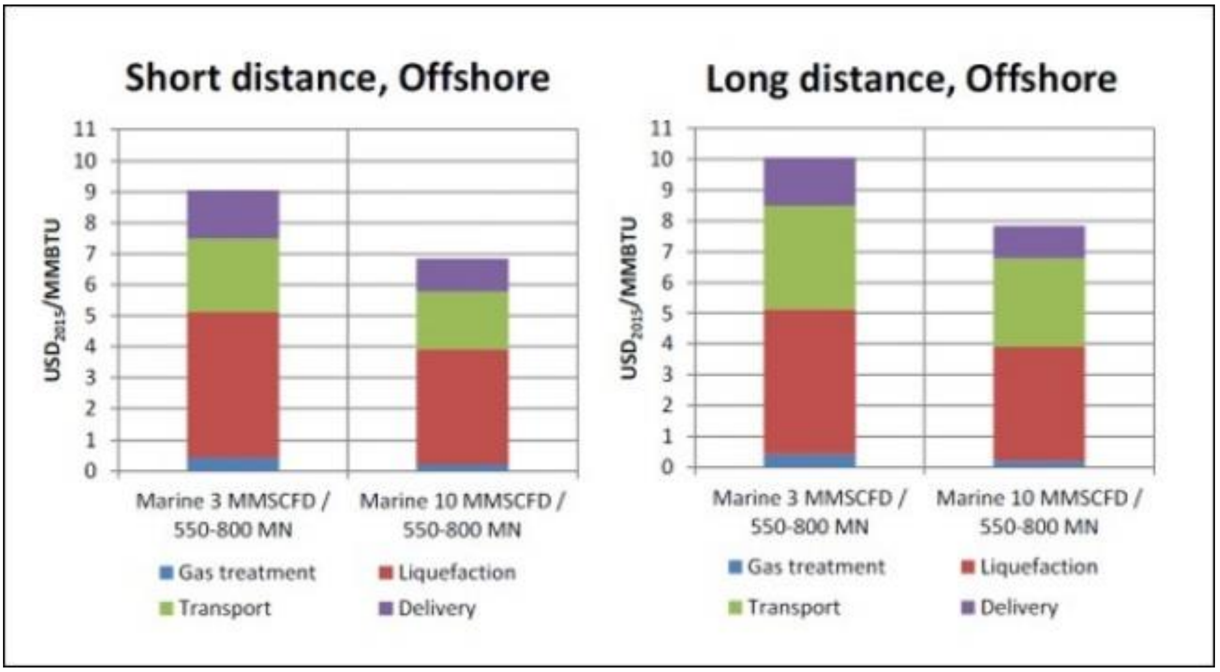

Figure 6: Comparison of CNG Offshore transport costs (Tractebel Engineering, 2015)

Liquefied Natural Gas (LNG)

Liquefied natural gas, or LNG, is gaseous NG that has been cooled down to the liquid phase at atmospheric pressure. The main application of LNG is as an alternative for gasoline and diesel fuels for heavy-duty vehicles travelling a long distance between refuelling, mine trucks, locomotives, remote power generation or marine vessels.

The LNG pre-treatment process will remove most water and any oxygen, carbon dioxide and sulphur compounds present in the NG, which will leave mostly methane (CH_4). The NG is then condensed into a liquid at close to atmospheric pressure by cooling it to approximately −162°C (-260˚F). The sources of the natural gas can vary from coal-bed methane (CBM) fields, biogas, or pipeline NG. The LNG takes about 1/600th the volume of gaseous NG and therefore makes it economical to transport over long distances. LNG is stored in cryogenic tanks to maintain it at the required temperature.

The transportation of LNG can be offshore by ship, or onshore by a truck and/or rail. LNG has been around for 50 years, primarily large-scale plants (>2 million t/annum) with the LNG being transported by sea. More recent developments are medium (2 million t/annum to 100 000 t/annum), small (100 000 t/annum to 10 000 t/annum) and micro (<10 000 t/annum) sized LNG plants. Micro-sized plants would typically be constructed inland for use locally at vehicle refuelling stations, or for the LNG to be transported by truck to other inland locations.

When the LNG is being transported offshore by marine vessel or barge, the vessel will have LNG tanks that are designed to store LNG at a cryogenic temperature of -162˚C. These LNG tanks are filled to 98,5% for the ability to have some room for expansion during transport. The natural evaporation from the tanks is known as boil-off, is unavoidable, and must be removed from the tanks to maintain the cargo tank pressure. The carrier vessel can use the boil-off as a fuel in the boilers and/or engines. LNG vessels can vary in size, with the larger vessels having a capacity between 125 000 m^3 to 250 000 m^3. Smaller LNG vessels typically have capacities between 1 000 m^3 to 25 000 m^3. Figure 7 illustrates the two different designs of marine LNG carriers, namely the Moss-type (round LNG containers) and the membrane-type (mostly box-shaped LNG containers).

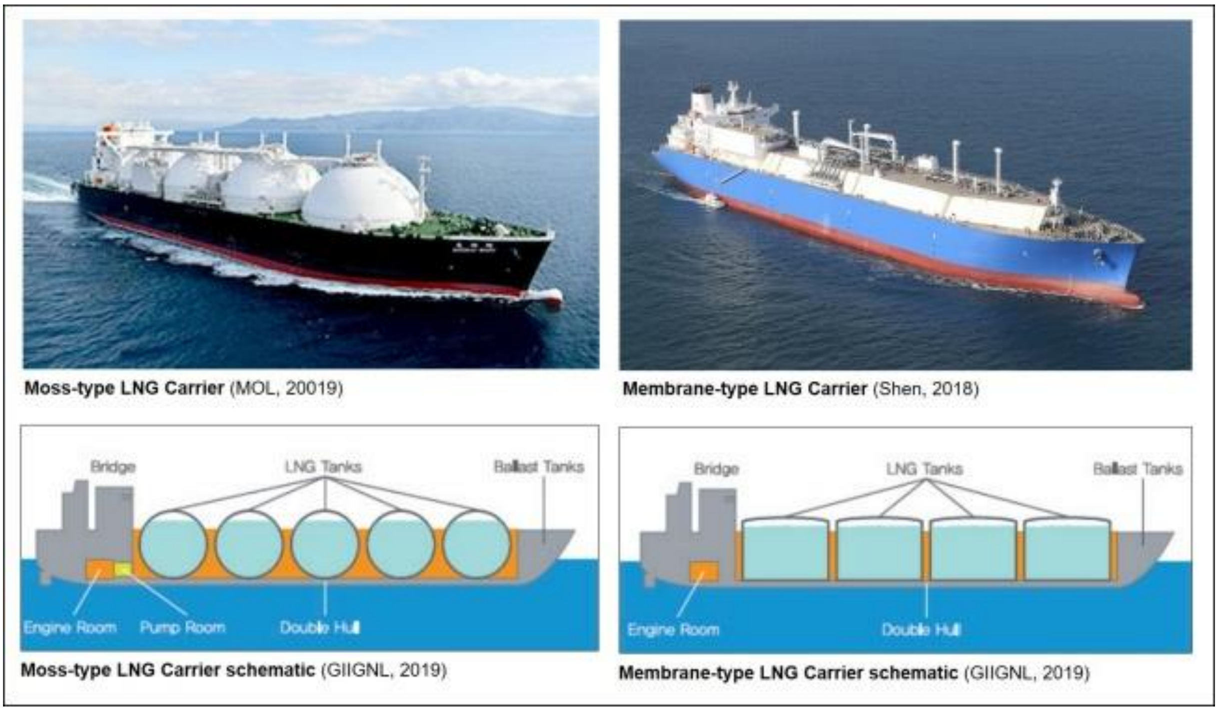

Figure 7: Moss-type and membrane-type LNG carrier vessels

The cost of the LNG logistics offshore by marine is largely dependent on the length of the logistics chain and the scale of the operations. The logistics chain can be large-scale, where the entire shipment is utilised by one end-user or medium-scale where the end-users are a few medium scale operators, or it can be small-scale where there are multiple small end-users.

Figure 8 shows an example of the increase in cost relative to the scale of the logistics chain. The cost of transportation will depend on the project specific factors such as volume and composition, distance to consumers, storage and infrastructure requirements, geographical location, etc. Moving from large-scale to small-scale LNG logistics adds nearly 65% to the final cost to the end-user.

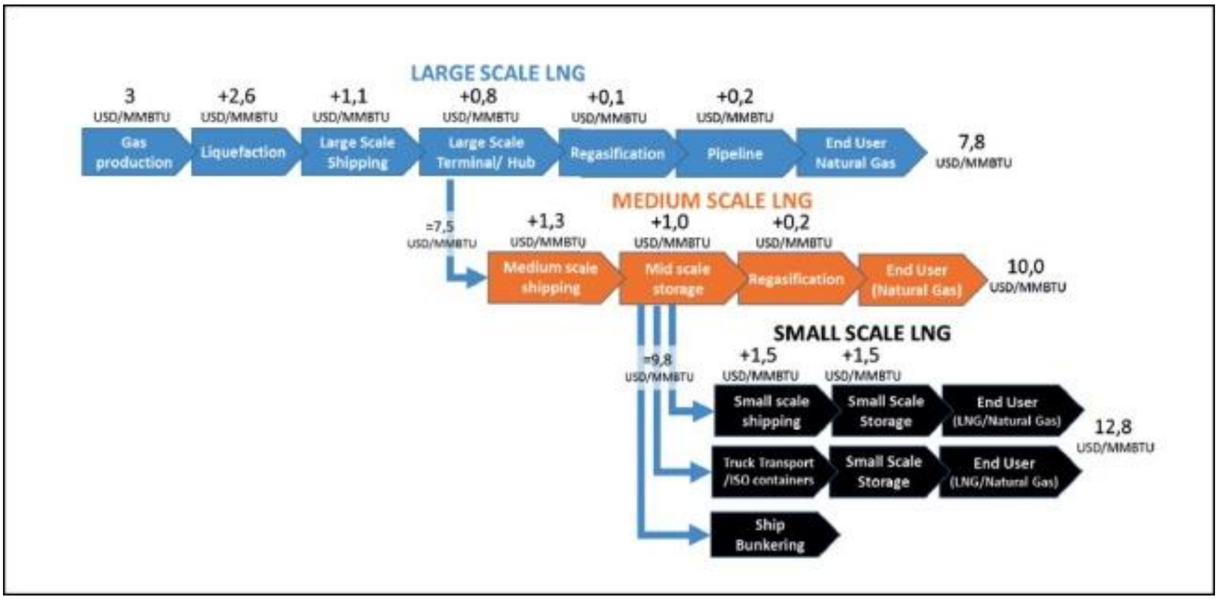

Figure 8: Offshore marine LNG logistics chain example (Wärtsilä, 2017)

In the case study performed for the World Bank (Tractebel Engineering, 2015) it was found that the transportation cost increases only slightly between short-distance and long-distance offshore transportation, as illustrated in Figure 9. The conclusion is that offshore transportation of LNG is an economical option.

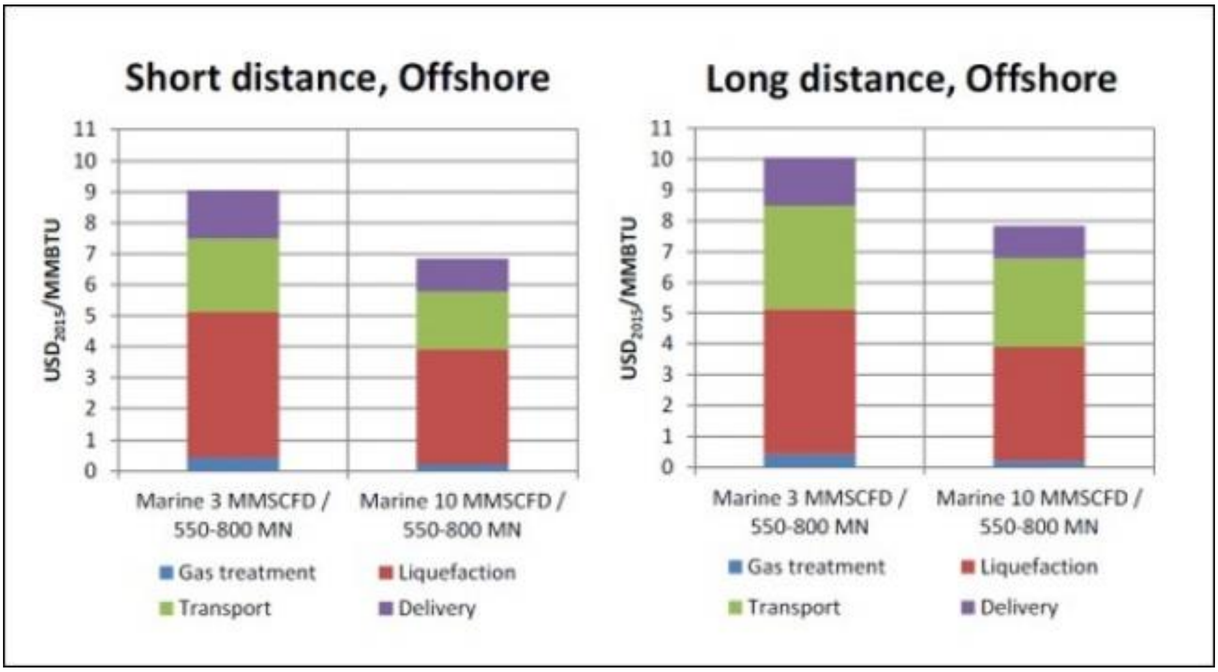

Figure 9: Comparison of LNG Offshore transport costs (Tractebel Engineering, 2015)

The LNG onshore transportation by truck can either be by LNG ISO container or by LNG transport trailer. The LNG ISO containers are 12 to 14m (40 to 45ft) long cryogenic containers that have an inner stainless-steel tank, an insulation layer and then an outer stainless steel tank. These types of containers have a 45 to 50 m^3 capacity. LNG ISO containers can be transported by truck, but also by ship and rail, as illustrated in Figure10.

Figure 10: Transport options for LNG with tankers and ISO containers

LNG transport trailers are vacuum-insulated, cryogenic semi-trailers that are designed to transport LNG by road. These are a similar design to the ISO container, as they have an inner stainless steel tank, then a layer of insulation and then an outer stainless steel tank. However, the LNG capacity is larger than the ISO containers as these trailers can hold 50 to 75 m^3 of LNG.

Transporting LNG by rail is another option and would be used to transport LNG to more remote inland areas. This mode of transport is currently being used in Japan but is not common in other areas of the globe. The intent would be that LNG ISO containers would be transported by truck to be loaded onto the rail cars or freight trains. Transport by rail can be more efficient and cost-effective than trucks if the distance is more than 200 to 250km, due to the ability to transport large quantities at once.

In the case study performed for the World Bank (Tractebel Engineering, 2015) it was found that the transportation cost increases sharply between short-distance and long-distance onshore transportation. Figure 11 shows the increase in transportation cost when the distance increases. Onshore transportation of LNG could be a feasible option, provided the transport distance is not too great.

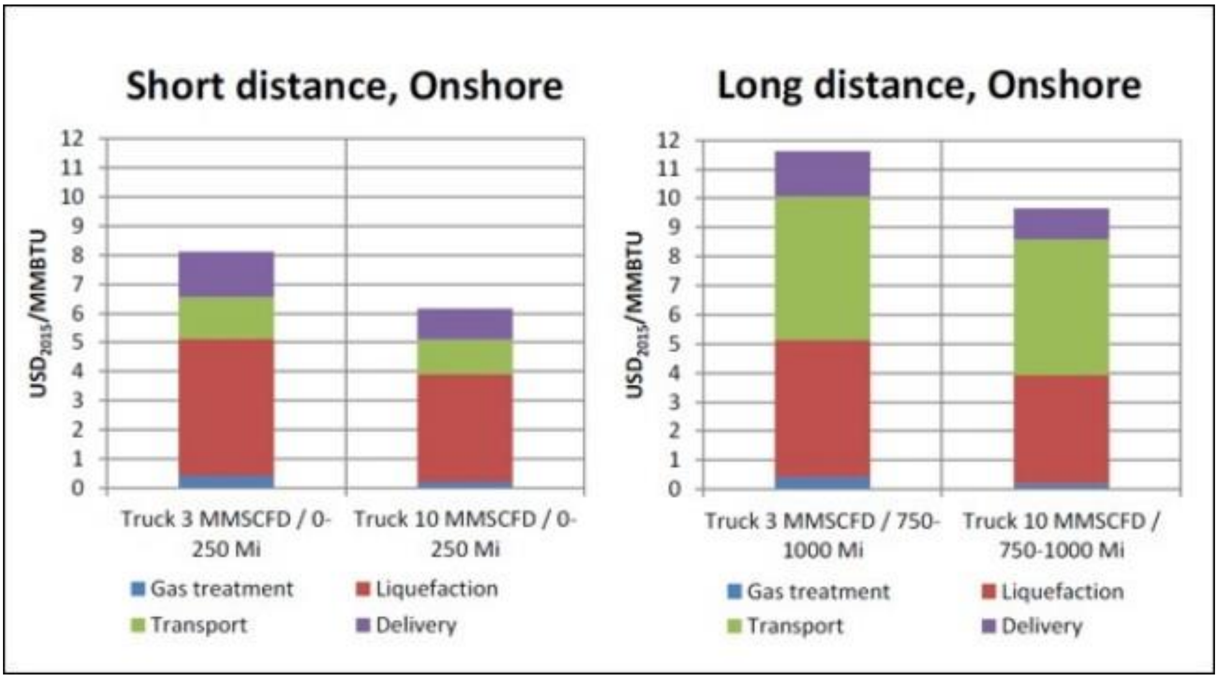

Figure 11: Comparison of LNG onshore transport costs (Tractebel Engineering, 2015)

Closing remarks

Depending on the specific application, transporting NG by pipeline, as compressed natural gas (CNG), or as liquified natural gas (LNG) are all applicable. Considering that the mode and thus the cost of transportation can add up to 50% to the eventual delivered cost, it is important to understand each mode of transport and the suitability of each option when considering the overall logistics chain. This is becoming increasingly important as smaller biogas sources are being exploited inland, utilising micro LNG and CNG plants.

The next two articles in this series focus on gas storage, safety and environmental considerations and the alternative modes of transport that include gas to liquids, gas to solids, pressurised LNG (PLNG) and adsorbed natural gas (ANG). There will also be discussion on the suitability for the different modes of transport in several scenarios.

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