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Alternative Modes of Natural Gas Transport

Freek van Heerden & Anton Putter

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

The series comprises the following articles which 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. LNG technologies – May 2021
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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 and will be interspersed with articles related to aspects of project management.

Introduction

The transport of natural gas (NG) using traditional transport modes was discussed in a previous Insight Article (van Heerden, Putter & Farina, 2020). In that article, the focus was on gas pipelines, compressed natural gas (CNG), and liquefied natural gas (LNG).

In this article we explore how energy from natural gas can be transported in other forms rather than directly as gas or liquefied gas. Some of these methods are more speculative than others and research and development is at an early stage. It is nevertheless interesting to note the developments in these areas.

Gas transport as a liquid

Opening remarks

Transport of gaseous energy as LNG is well-established and is supported by an extensive infrastructure in place (Putter, 2020). LNG pre-treatment removes 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). Maintaining the LNG at this low temperature during transport presents some challenges.

In this section we present two alternative options for the transport of gaseous energy as a liquid, namely pressurised LNG, and gas-to-liquids conversion.

Pressurised LNG (PLNG)

LNG liquefies, and remains liquid, at a higher temperature when kept under pressure. The pressurised LNG (PLNG) concept operates at higher pressure to increase the storage temperature of the liquefied gas. Liquefaction of LNG requires considerable pre-treatment and has large power requirements, and pressurising the LNG brings significant reduction of these requirements. The power required for liquefying the gas reduces to around 60% of that required for conventional LNG. The specifications on carbon dioxide and heavy hydrocarbon content are also less severe than for conventional LNG liquefaction.

The concept has been developed by ExxonMobil (Stone, 2001; Nelson et al, 2005), is still at the conceptual stage, and its economic viability is yet to be demonstrated. The PLNG concept utilises specially designed containers integrated into a ship to store LNG under moderate pressures. Conventional LNG ships transport gas with no applied pressure at -162ºC, whereas gas transported in a PLNG ship is under 17 bar of pressure at -115ºC. The potential benefits of PLNG would come from a significant reduction in the operating cost of gas treating units and liquefaction. The optimal PLNG conditions for transportation, compared to LNG and CNG, are indicated in Table 1.

Table1: PLNG conditions for transportation

Parameter	LNG	PLNG	CNG
Pressure (bar)	1	17	200-250
Temperature (°C)	-162	-115	25
Cargo density (kg/m^3)	440	350	188-223

However, the application of PLNG for natural gas transportation would require a whole new delivery chain: liquefaction plants, PLNG carriers, PLNG storage vessels, PLNG receiving and regasification facilities. Considering the significant investments already made in LNG facilities, the introduction of PLNG would need significant development, maybe in some niche applications to be able to make any significant impact.

Gas-to-liquids conversion

Gas-to-liquids (GTL) is a process that converts NG to liquid fuels such as gasoline, jet fuel, and diesel. The GTL process can also produce waxes. The most common technology used at GTL facilities is Fischer-Tropsch (F-T) synthesis. Although F-T synthesis has been around for nearly a century, it has gained recent interest because of the growing spread between the value of petroleum products and the cost of NG.

The first step in the F-T GTL process is converting the NG, which is mostly methane, to a mixture of hydrogen, carbon dioxide, and carbon monoxide. The syngas is cleaned to remove sulphur, water, and carbon dioxide, to prevent catalyst contamination. The F-T reaction combines hydrogen with carbon monoxide to form different liquid hydrocarbons. These liquid products are then further processed into liquid fuels using conventional refining technologies.

There are several large-scale commercial GTL plants in operation globally using Sasol, Shell, and Chevron technology. A further plant in Uzbekistan is nearing completion. The advantage of these plants is that dense liquid fuels are produced that can be stored and transported in liquid form at atmospheric pressure, resulting in favourable logistics costs as compared to LNG. An example of a GTL facility is shown in Figure 1.

Figure 1: Shell’s GTL plant in Bintulu, Malaysia.

A major disadvantage is the energy intensive nature of the GTL conversion process resulting in only about 60% of the energy input into the plant being exported as the final fuel while the balance is required to fuel the endothermic process. The result is that these GTL plants are large emitters of carbon dioxide, thus coming under scrutiny as major greenhouse gas sources. This can be compared to energy efficiency of typically more than 80% for an LNG facility.

Capital expenditure is higher for GTL than comparable LNG facilities. However, GTL makes higher value products so returns in terms of US$/GJ output can be considerably higher for a GTL project, even with its lower process efficiency than LNG. This applies even in the current low oil price environment, particularly if the plant is 'tuned' to produce high-value speciality chemicals. Also, capital expenditure does not end at a plant gate. For LNG, a significant component of the overall investment required sits with the ongoing value chain including storage, transfer systems, transportation to market via specially designed LNG carriers or road tankers, regasification, and import terminals. In contrast, the products of the GTL process, once converted to syncrude or to finished diesel or jet fuel, use standard petroleum transportation infrastructure (Lock, 2015).

There is an increasing move away from diesel-fuelled vehicles to direct LNG fuel and conversions of existing diesel engines to diesel/LNG dual fuel is gaining momentum. One of the main driving forces is the lower greenhouse gas emissions of LNG-fuelled vehicles, the lower price of LNG as compared to diesel, and the lower maintenance cost of these vehicles.

Gas transport as a solid

Opening remarks

Transport of gaseous energy as a solid does not mean that the NG is cooled down to its freezing point of −182.5 °C (−296.5 °F) to form blocks of solid NG. This would require specialised and expensive equipment to produce and to transport. However, it refers to the entrapment and enclosure of NG in a solid matrix, or the adsorption of NG onto a suitable solid matrix.

In this section we present two alternative options for the transport of gaseous energy as a solid, namely natural gas hydrates (NGH), and adsorbed natural gas (ANG).

Natural gas hydrates (NGH)

Gas hydrates are ice-like crystalline forms of water and low molecular weight gas (e.g., methane, ethane, carbon dioxide). On Earth, gas hydrates occur naturally in some marine sediments and within and beneath permafrost. At the molecular level, natural gas hydrates (NGH) consist of primarily methane molecules surrounded by cages of water molecules. Each water cage encloses a space of a particular size, and only a gas molecule small enough to fit within this site can be hosted in that specific hydrate structure.

The transport of NG in a hydrate form is attractive as the gas is transported in a solid state at moderate pressure and negative temperature. Direct cooling is required to maintain the low temperature required. When NGH is 'melted,' or exposed to pressure and temperature conditions outside those where it is stable, the solid crystalline lattice turns to liquid water, and the enclosed methane molecules are released as gas. Gas escaping from the melting ice matrix can be set alight, as illustrated in Figure 2.

Figure 2: A sample of methane hydrate burning.

The principle for a hydrate-based NG transportation system is to produce methane hydrate pellets, to transport the pellets to the destination, and to dissociate the pellets and recover the natural gas. The production of hydrate pellets is done by mixing natural gas and water under appropriate operating conditions. The crystals formed are then pelletised. NGH is in a solid state at -20°C under atmospheric pressure. The energy required to produce hydrate pellets is comparable to that required for the LNG liquefaction process. A 5 ton/day NGH plant constructed by Mitsui in western Japan is shown in Figure 3.

Figure 3: NGH plant in Yanai, Japan (Nakai, 2012).

A key issue to consider during transport is to control the pressure and temperature such that the hydrates stay in their solid form while minimising energy consumption. Energy required for NGH transport is comparable to that for CNG, but significantly higher than for LNG. The volume of NGH is about four times the volume of LNG for the same amount of gas.

At the reception facilities, the hydrates are dissociated through heating. The gas is compressed and fed into the pipeline network after drying, which is energy intensive as dissociation takes place at close to atmospheric pressure. NGH dissociation is not straightforward as the rate of dissociation varies significantly along the process. The NG composition also influences the rate of dissociation.

NGH is economically less favourable than LNG for the transportation of NG, primarily due to the lower energy density of NGH relative to LNG. However, NGH was found to be economically viable for small capacity peak-shaving plants and NG storage due to the lower costs associated with NGH synthesis (Mannel & Puckett, 2008).

Adsorbed natural gas (ANG)

Adsorbed natural gas (ANG) technology can be an economic alternative to expensive infrastructure to transport, transmit and distribute power from the source to the point of use, and can provide natural gas fuelling access to remote areas.

ANG involves the adhesion of gas molecules to a solid surface. This process creates a film of the adsorbate (methane) on the surface of the solid adsorbent. Activated charcoal is an excellent adsorbent because it has a large surface area per unit volume due to its porous nature. This gives it the ability to adsorb large quantities of natural gas at relatively low pressures (60 bar) compared to CNG (250 bar). In an ANG storage vessel, about one-third of the methane is stored as free gas and two-thirds as ANG. At 200 bar, ANG and CNG vessels store the same amount of methane per unit vessel: below 200 bar, ANG stores more.

Several operational issues must be addressed for ANG, namely:

- **Heat conductivity:** Significant heat is generated during adsorption, and desorption of the gas requires heating. The heat conductivity of the adsorbent material is therefore important.
- **Weight:** High performance carbons have higher densities, and a compromise must be found between the weight of the adsorbent and its capacity to store gas.
- **Attrition:** Storing and delivering the gas implies cyclic operations that, over time, have detrimental effects on the storage capacity and mechanical resistance of the adsorbent.
- **Output pressure:** The ANG is depressurised at nearly atmospheric pressure to maximize the net storage capacity and therefore requires a discharge compressor to achieve the required delivery pressure.

- **Gas composition:** Gas composition may be a serious issue as heavier hydrocarbon molecules are large compared to methane and may not be so readily adsorbed,
- **Contaminants:** The presence of contaminants, even in small quantities in the feed gas, can accumulate preferentially on the adsorbent.

ANG enables a natural gas fuelling solution for light-duty vehicles such as pickup trucks, SUVs and service vans, a segment that has traditionally been underserved by alternative fuel options. ANG is 50% less costly to operate than a gasoline-only vehicle; increases natural gas usage for a gas utility by more than 60%; and reduces greenhouse gas emissions by 25% compared to similar gasoline- and diesel-equipped vehicles (Green Car Congress, 2020). Figure 4 shows a Ford F150 converted to run on ANG. The vehicle is fitted with a 5.0ℓ V8 engine with CNG conversion kit, set up for bi-fuel (gasoline/natural gas) operation. The ANG storage tanks are operated at 62 bar.

Figure 4: ANG powered vehicle (Green Car Congress, 2020).

Gas transport by wire

Which is the preferable way to move energy: pipe (in the form of gas) or wire (in the form of electricity)? Although this sounds like an easy problem to resolve, it is not and a whole range of factors play a role in the decision. Every case is different and needs to be treated on its own merit.

The general perception is that wire is the way to go. This is probably driven by the general trend in the world towards electrification of energy supply, be that electric cars, all renewable energy that comes in the form of electricity, nuclear energy, etc. This relentless drive towards the final form of energy being electricity, does not answer the question on the best way to transport energy though. While gas remains one of the main sources of primary energy in the world, the question as to which is the best way to move the energy from the gas source to the market for the energy will be asked.

Up to now, the dominant choice between pipe and wire, has been pipe. This was probably driven by the economics of energy distribution, where it is typically significantly cheaper to distribute energy by pipe than by wire. This historic situation is also demonstrated by the actual situation on the ground in a historically gas-rich country such as the United Kingdom where the gas grid carries about four times more energy than the electric power grid (Elliott, 2019).

The contention above that pipe is the more economical choice (in the absence of any other factors) is supported by case studies in this regard. One such case study was performed jointly by the Bonneville Power Administration and the Northwest Gas Association (Buchanan & Christie, 2004) which concluded that the capital cost for an underground gas pipeline is 50% lower than the capital cost for an overland electrical transmission line. The basis of the study is shown in Figure 5. This study did consider the efficiency losses in converting gas to power and therefore the gas pipeline has substantial more energy transmission capacity than the competing electrical power line.

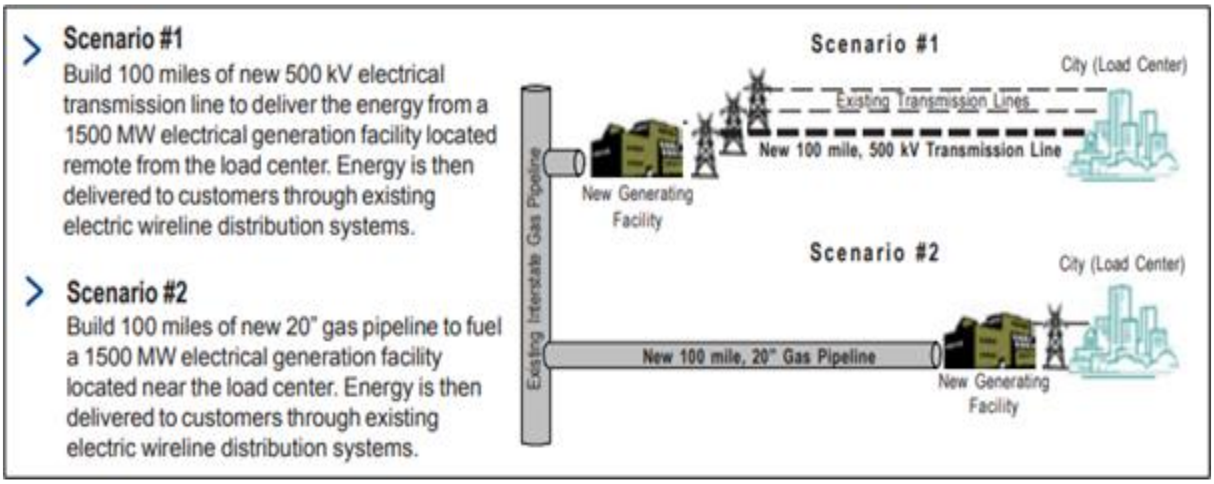

Figure 5: Basis for capital cost comparison of pipe versus wire (Buchanan & Christie, 2004).

Following is a short discussion on some of the more pertinent factors to consider when choosing between pipe and wire:

- **Capital cost:** This is normally the main determining factor and typically would favour pipe over wire as shown in the case study mentioned above. Some other case studies do not favour pipe as strongly as the case above, but almost always comes out in favour of the gas pipeline option.
- **Operating cost:** The operating cost for a wire is substantially lower than for pipe. The operating costs in both cases are low and play a small role in deciding between the alternatives. In the case of a pipeline, the operating cost would hardly ever reach 2% of the replacement value of the pipeline system and is mostly driven by compression stations and the fuel for those stations.

- **Existing infrastructure:** The decision of pipe versus wire is often strongly influenced by existing transport infrastructure in place, be that pipe or wire, or both. Normally there is some excess capacity available on such existing infrastructure that can then be used for at least the partial distribution of the gas or power. In countries or regions where gas has been in use for a long period of time, such as the USA, Iran and the United Kingdom, the existing gas pipeline system will normally favour a decision towards pipe. In countries where gas has only been introduced recently and the pipeline infrastructure is non-existent or very sparse, the existing power transmission and distribution network will normally then strongly favour a wire decision.
- **Storage:** If there is need for energy storage in the distribution system or at the market (endpoint of system), such a need would be better served by pipe. Pipelines themselves can provide some storage by increasing and decreasing the pressure inside the pipeline, and gas storage at the market (see article by van Heerden & Farina, 2021) is still a lot cheaper than power storage (normally in batteries).
- **Offtakes along the way:** For long-distance transmission lines (especially along new routes) there is often a need for offtakes along the route. Gas offtakes are quite simple (just a T-piece and probably a pressure reducing station) compared to the step-down transformer required for electricity. The gas offtake normally goes together with a small power station which would have some scale disadvantages compared to a single big power station at the source of the gas.
- **Losses during transmission:** Transmission and distribution systems for gas would have minimal, if any, gas losses during transport. On the other hand, transmission and especially distribution systems for electricity experience significant losses. In most cases, distribution systems for electricity would be needed even if the long-distance transport of energy is done by pipe; therefore, these electricity distribution losses do not normally play a role when comparing pipe and wire. The losses to be considered in a comparison of pipe and wire would typically be 1 to 2% for step-down transformers from electricity transmission to distribution and 7% for every 1 000 kms of alternating current electricity transmission (Vaillancourt, 2014).
- **Markets other than electricity:** Although the major outlet for gas is electricity generation, there are also a host of other uses for gas such as derivatives (such as fertiliser, methanol, hydrogen production, etc.) and heating. It is especially for heating that there are normally markets at the end and along a pipeline system where pipe has an advantage over wire. In all forms of heating (industrial, water and spatial) gas combustion is much more efficient than electrical heating.
- **Environmental considerations:** Probably the most serious environmental factor to be considered, is the negative visual impact of overland electricity transmission and distribution lines as opposed to the minimal visual impact of underground gas transmission and distribution lines. Fugitive gas emissions are undesirable due to

the strong global greenhouse effect of methane, but in the case of gas transmission and distribution lines this is a minor risk.

Closing remarks

Transporting gas in other forms remains speculative and applicable to smaller niche applications while gas pipelines and LNG remain the main methods of transportation of large volumes of gas. Improved LNG technologies are also facilitating the construction of small- and micro-scale LNG plants for localised distribution where piped gas is not available. This has resulted in ever increasing volumes of gas being transported as LNG where pipelines are not available. Construction of new pipelines is also continuing, making cheaper gas available to more and more consumers.

As a major portion of gas is eventually used to generate electricity, converting the natural gas at an optimum point to electrical energy and distributing the electricity to end users makes sense. However, the decision depends on the availability of existing infrastructure and the specific energy requirements of the end users.

The alternative NG transport options discussed in this article are complementary to the traditional transport modes (see van Heerden, Putter & Farina, 2020). Circumstances will dictate which transport mode is the most suitable for a specific application. It is expected that all the different NG transport modes will be in use for the foreseeable future.

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