WGCPARIS2015
WORLD GAS CONFERENCE
"GROWING TOGETHER TOWARDS A FRIENDLY PLANET"

26th World Gas Conference | 1-5 June 2015 | Paris, France

Small Scale LNG – From Concept to Reality

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Table of Contents

Background

Over the last 50 years since the Methane Princess carried the first cargo of Liquefied Natural Gas (LNG) from Algeria to Canvey Island, United Kingdom, the LNG industry has grown in scale. Increased size of plants, ships and terminals have improved economies of scale and the competitiveness of LNG into new markets.

Today, the LNG industry is focusing on a new challenge to make LNG work in smaller markets and as a transport fuel. Each of these applications may be small but has the combined potential of creating a significant new demand for the LNG industry.

Shell sees an estimated 430 million tonnes of global LNG demand by 2025. LNG for transport could possibly add 5 to 10% to our base case global LNG demand estimates by 2025. That is about 25 to 45 million tonnes per year by 2025. That is just transport. There is also potential for LNG to serve remote locations and regional markets if the supporting infrastructure can be developed to allow LNG to be competitive against existing liquid fuels.

This potential is creating a lot of interest and many concepts are being developed. The challenge lies in turning those concepts into the reality of viable, competitive supply chains.

This paper focuses on the development of such a supply chain, the challenges and how they are being addressed. It articulates that the success of small scale LNG is dependent on all elements of the supply chain being competitive and successfully integrated.

The International Gas Union (IGU) defines small-scale LNG as less than one million tonnes per annum (mtpa). In reality, many projects and terminals require deliveries at much lower rates. It is also worth noting that a number of what may be considered 'conventional' LNG import terminals, both existing and planned, have throughput volumes less than one mtpa.

The opportunity here is about being able to establish a chain that can successfully deliver a few hundred thousand cubic metres per annum into a terminal, a parcel of LNG into a ship or

a few hundred litres into a LNG powered truck.

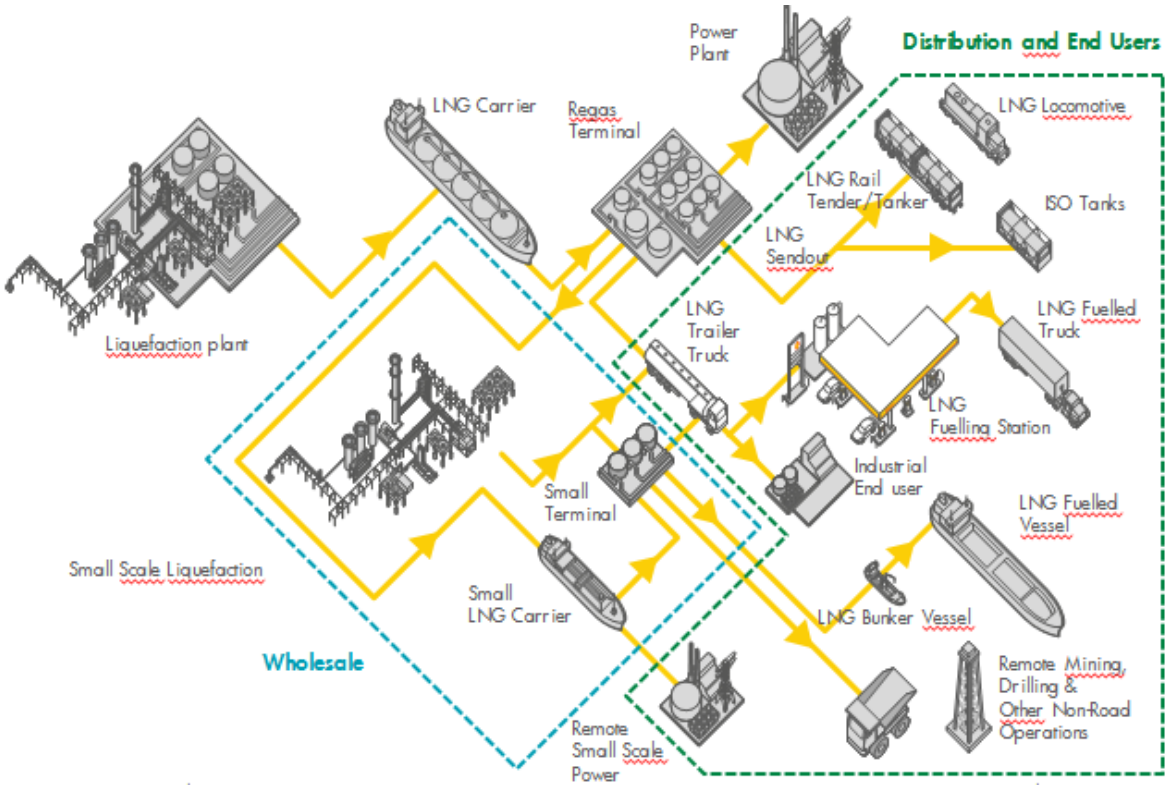

Figure 1 – Small-Scale LNG Value Chain

To date, there are two areas which have seen the development of small-scale LNG supply chains, the Baltics region, in particular Norway, and China.

In Scandinavia, there is now a network of LNG terminals that could be reasonably described as small–scale, supplying LNG into a range of customers with others under development.

This capacity has been developed by companies such as Skangass, Norway's leading supplier of LNG for marine fuel, with 300,000 tonnes of supply capacity, and Gasnor, a company acquired by Shell in 2012. These companies are now supplying LNG to ferries and other shipping, industrial consumers and supplying gas to more remote locations that would otherwise have to rely on more expensive liquid fuels. The experience in the likes of Gasnor

is providing invaluable customer, market and operational insights in small-scale LNG.

Figure 2 – Small Scale Terminals in Northern Europe

In China, small-scale LNG has grown at a significant pace, in part driven by domestic energy security concerns and to reduce emissions. It has also benefitted from the different pricing realized between regulated and unregulated markets. This has resulted in approximately 2,000 retail sites and 170,000 trucks being powered by LNG[1].

Plans are being progressed to develop small scale LNG terminals along the Yangtze River. There is opportunity to build on the experience of developing lower cost solutions in China, including LNG storage tanks, to be applied elsewhere in the world to support the competitive position of LNG.

Whilst small-scale LNG has developed in the Baltics and China, there is also potential for new small-scale markets to be developed for LNG in regions such as the Caribbean. This is to benefit from the production capacity under-development on the US Gulf Coast, as well as island markets in Mediterranean, South-east Asia and West Africa.

In many of these markets, expensive liquid fuels are being used for power generation and LNG has the potential to deliver a competitive alternative for these markets.

[1] Zhuo Chuang, Sublime China Information Group, http://intl.sci99.com/about/

Aims

LNG to transport, industrial and small-scale power markets is competing against liquid fuels, primarily gasoil, heavy fuel oil, and liquefied petroleum gas (LPG). The logistics which include terminal storage, shipping and truck distribution for these liquid fuels, are well established and customers are familiar with the products and handling of those products.

Whilst LNG as a fuel is competitive, the logistics of the total value chain need to be competitive for the customer. The additional costs of cryogenic handling are more expensive than conventional storage. However, we believe that if all aspects of the supply chain, including end user equipment, are properly managed, LNG can be a competitive alternative to today's fuels. Furthermore, LNG is cleaner than diesel and heavy fuel oil in terms of sulphur, particulates and nitrogen oxides, and can help reduce greenhouse gas emissions.

There is also a "chicken and egg" dilemma to be addressed. For customers to contemplate a switch to LNG they need to know that infrastructure is in place. This is particularly true for the development of LNG as a transport fuel. However, many infrastructure developers need to see the readiness of the market to receive LNG to invest in LNG infrastructure. Thus, there is a role for International Oil Companies such as Shell to work closely with customers, Original Equipment Manufacturers (OEM), partners, governments, and standardisation bodies to develop the market and the infrastructure.

To enable small-scale LNG value chains there is a need to focus on these key elements:

- Supply points including break bulk facilities and direct supply out of producers
- Small-scale shipping including provision of bunker vessels
- Small-scale LNG receiving facilities in particular storage
- Onward distribution of LNG by truck, International Standards Organization (ISO) containers
- Retail facilities
- End user equipment including engines and tanks
- Development of regulatory regimes and 'fit for purpose' standards

Once the infrastructure is in place, the ability to deliver LNG competitively will be equally dependent on the ability to optimize supply chains, including the management of potential losses and to utilize the infrastructure effectively.

Companies will look to leverage experience developed in the supply of liquid fuels and trading capabilities to do this. Further, the early experience developed in companies such as Gasnor will prove invaluable understanding of some of specific challenges associated with LNG.

Methods

Until recently, LNG was only being supplied from small scale liquefaction plants into the Baltic markets. Gasnor presently operates three such facilities and distributes 140,000 tons per year of LNG to Norway and Scandinavia. In 2014 there was a major step forward in enabling small-scale LNG value chains in Europe through the commitment to develop dedicated small-scale facilities, including a jetty able to handle ships up to 20,000 cubic metres (m^3), at the Gate LNG terminal in Rotterdam, Netherlands.

This enables small-scale LNG to benefit from some economies of scale offered by "conventional" LNG. We anticipate that the successful development of synergies between large-scale LNG facilities, either through direct supply of LNG in smaller parcels or out of break bulk facilities attached to conventional terminals will aid LNG being supplied in new smaller markets.

At the Gate terminal, conventional cargoes up to Q-Max in size can be received. Whilst the majority of this LNG will be re-gasified and dispatched into the European grid, the existing terminal facilities provide the capability for LNG to be re-delivered as smaller parcels. This is done either via the small scale jetty to regional markets and as bunker fuel or through a truck loading rack to serve small industrial, commercial (I&C) and road customers.

Such incremental investments are enabling internationally traded LNG to access a new set of customers and we expect more terminals to follow suit. This will not just include conventional onshore terminals but also Floating Storage and Regasification Units (FSRU) in future.

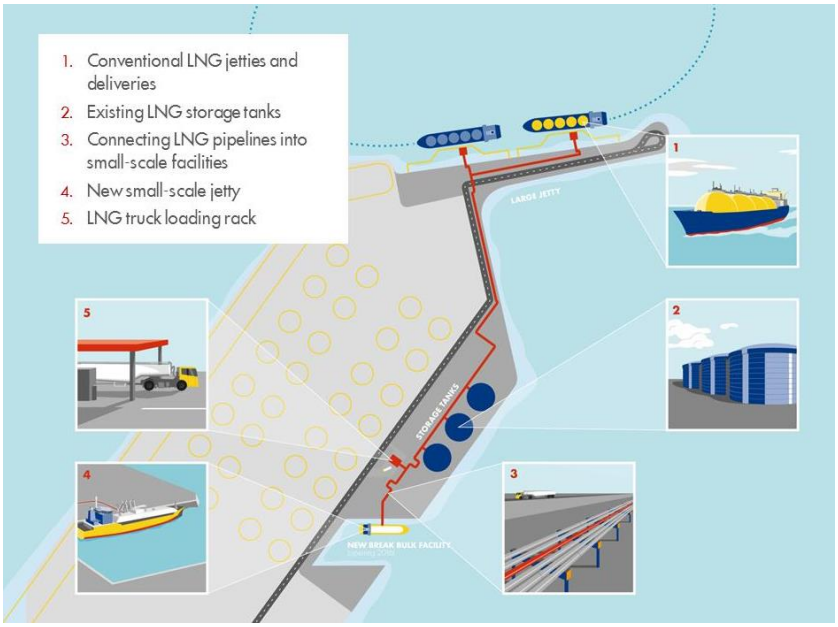

Figure 3 – Break Bulk at Gate Terminal, Rotterdam, Netherlands

Utilising existing terminals for break bulk is more cost efficient but also requires new operating models and considerations compared to existing terminals. In particular, two areas need to be considered. This includes the handling of boil off gas and quality management, as well as scheduling.

In general, LNG regasification terminals are set up to send gas out to grids and utilized for internal power rather than to store and reload LNG. If the intention is to reload the gas and sell as LNG, this can result in a value loss of gas delivered into the grid compared to being supplied as a transport fuel.

For smaller terminals, this will create issues if there is no ability to send out the gas or handle the pressure. The ability to handle pressure is less of an issue for sending out to power grids or loading into trucks. However, for future marine requirements where deliveries are required to be "cold" and at atmospheric pressure, this creates challenges. This

necessitates the installation of re-liquefaction facilities in the supply chain (at terminals and on bunker vessels) and flash drums to redeliver cold LNG.

The challenges for scheduling small scale loadings arise from a number of factors. For example, cargo sizes are of relatively a wider range, bunker deliveries are scheduled at a much shorter notice and with varying delivery patterns. Flexibility is needed to meet shipping operators' bunkering requirements. This means that large scale and small scale loading and discharges at single jetties do not mix well and small-scale LNG value chains are best served with dedicated facilities such as the new jetty being installed at the Gate Terminal, Rotterdam. However, if this is not carefully managed and optimized, it can add significant cost to the value chain.

The initial development of infrastructure in Europe is being supported by government hoping to support the development of small-scale LNG value chains and to reduce emissions in Europe. For example, the development of LNG bunkering in Norway has been supported by the development of the NOx fund. The overall development of LNG bunkering in the Emission Control Areas is driven by the requirement to reduce sulphur emissions to 0.1% this year. The European Union is providing financial support for the development of LNG bunkering infrastructure through its Trans-European Transport Networks (TEN-T) initiative.

These have become important drivers for seeing the timely delivery of the necessary infrastructure to support LNG bunkering and small-scale LNG. Subsidies are useful to help create a tipping point in demand so that the market develops and economies of scale are created.

Small-scale LNG shipping is presently a developing market with a handful of ship owners and approximately 21 distribution vessels globally. Vessels with sizes ranging from 1,000 to 30,000m^3 are mainly operating between small scale terminals in North West Europe and South-east Asia and with generally long term commitments.

Figure 4 – Pioneer Knutsen on charter to Gasnor

All these vessels are used for distribution purposes. However with LNG as a marine fuel and ship to ship LNG bunkering becoming a reality, we witnessed a number of new building orders for LNG bunkering vessels from Shell, GDF-NYK-Mitsubishi and Skangass in 2014. As the market for LNG as a marine fuel grows, the number of LNG bunker vessels or barges is expected to increase. This is expected to result in a new segment in LNG shipping industry. New LNG bunker vessels are also expected to be bigger in size as larger deep sea going vessels convert to using LNG as a fuel.

Figure 5 – Shell's Bunker Vessel to operate out of the Gate terminal (Artist's Impression)

Being a niche market brings a number of commercial, technical and operational challenges to small-scale LNG shipping. Availability in the market is very limited with nearly no spot market. This drives daily charter rates to a premium, which is comparable even with big scale LNG carriers. Standardization has been difficult due to project specific requirements and limitations. Fit for purpose solutions are common but raise long term utilization and residual value risks for the owners. Lead time for new vessel building projects is close or longer than two years, which is very similar to building standard LNG carriers. Since standard vessels designs do not widely exist, prices of new vessels still come with a premium.

These challenges could be addressed through long term supply deals, designing vessels with multiple product transportation flexibilities (multi-gas), pooling or cooperation

agreements between industry players and OEM. As the market grows, it is also expected that technology matures and standard designs develop. As a result, prices of building new vessels will decrease.

Whereas Korean and Japanese shipyards are the leading players for standard LNG carriers, FSU/FSRUs and FLNGs, these shipyards do not focus much on this niche market due to the size. Recent years showed a trend in new building projects going to Chinese shipyards. Some are under construction in China and others in Europe. This makes these shipyards a major player in the market because of competitive pricing and reasonable quality.

In the coming years, we anticipate an increasing amount of activity in this niche market as the market grows both in distribution and bunkering side of the business.

Historically the LNG business has developed through partnerships. The development of small-scale LNG is no different. It is also bringing a new set of partners to drive its development along the value chain. A good example is how Shell has been working with OEMs to develop reliable technologies that can utilize LNG.

Some sectors are more advanced than others. For example in the marine sector, all major OEMs, including Wärtsilä, Caterpillar and Rolls Royce, have developed engines across a wide power range and that portfolio continues to expand. However, in heavy duty trucking sector, the story is mixed with more limited engine offerings in Europe and US.

Through these partnerships, mutual assurance is developed on the availability of both equipment and supply. The partnerships create opportunity to develop a consistent approach to the development of standards and regulation, understanding of gas quality impact on engine performance and range, greenhouse gas emissions. This includes the important issue of managing methane slip and development of standard fuelling infrastructure.

A key challenge is to bring down the cost of LNG tanks for both trucks and ships, which is a key part in the investment cost of new trucks, new-build ships and conversions. A greater take up is expected to bring down these costs. Chinese OEMs are also expected to play an increasing role in bringing low cost equipment to the market.

This co-operation is not limited to working with OEMs. Shell is also working closely to implement small-scale operations with terminal operators such as Gate in Rotterdam. For example, we work together to develop appropriate infrastructure, as well as operating and scheduling procedures.

Shell is also working closely with major ports such as the Port of Rotterdam to support LNG bunkering. The company also works with shipping companies, ship yards and international

maritime organisations to develop standards and implementation of emission reductions, understanding of opportunities to reduce the costs of LNG handling on retrofits and new-build ships. It is also working closely with governments on enabling LNG as a transport fuel.

In the safety aspect, Shell has significant experience in minimizing potential LNG risks. We have 50 years' experience in handling, storing and transporting LNG. As small-scale LNG value chains extend the reach of LNG and bring LNG closer to more people, the industry needs to ensure that the safety record is maintained.

At the same time, appropriate, 'fit for purpose' standards and assurance processes that do not impose onerous costs on these emerging markets for LNG need to be developed.

Further, as an industry we need to ensure that the greenhouse gas emission potential for LNG is delivered by ensuring that methane slip is properly managed and temperature of the LNG fuel is maintained via boil off systems at retail sites. It also needs to be recognized that what works for large scale LNG does not always work well for smaller scale operations. The development of common standards and sharing of operational experience are going to be important drivers in making this a success.

Results

Shell is benefitting from its operating experience in Gasnor. Gasnor has been operating two LNG tankers, 22 trucks and to date has successfully completed over 70,000 LNG transfers. It has developed low manning concepts for LNG operations, including the remote operation of its liquefaction plants at night. Operating experience in managing and optimizing shipping is being developed. With that comes learnings and development of issues around boil off gas management, development of coupling and release systems that are fit for purpose for small scale applications.

Experience in both downstream and LNG helps develop the appropriate back office systems to support the timely deliveries and invoicing to customers and meet their delivery requirements. Repeatable terminal models are now being developed that can be applied in other locations and executed efficiently and cost effectively in different markets. These are also in line with market developments.

Elsewhere in the supply chain, early development of retail sites in North America is being applied in Europe with two new Shell LNG truck fuelling stations opened to date in The Netherlands. The learnings allow subsequent retail sites to be constructed in a shorter time and at a lower cost than the earlier ones. We work closely with our suppliers and partners constructing those sites, providing and developing the equipment and distribution companies delivering the LNG to the site. This will allow more to follow and more trucking companies to have access to competitively priced LNG.

Figure 6 – Shell's first LNG retail site in Alberta, Canada

There is also more experience in operating LNG fuelled shipping. In Norway, Gasnor and others are delivering LNG to ferries and regional shipping. Shell has now been operating two LNG powered barges transporting refined products along the Rhine since 2013.

In North America, Shell continues to look in to the commercial opportunity of supplying LNG fuel to customers in the region – both marine and road transport customers. In March this year, Shell chartered a special LNG-powered Offshore Supply Vessel for its deep water operations in the Gulf of Mexico.

Figure 7 – Developing LNG operating experience through LNG powered barges on the Rhine and Offshore Support Vessels in the Gulf of Mexico

What is consistent among these initial steps is balancing the need for customers to see the availability of fuelling infrastructure and to ensure an appropriate level of investment so that the industry is not over exposed to large scale investments. If the balance is not right, this will risk under-mining LNG's future as a transport fuel.

These "fit for purpose" supply chains are creating markets and experience is being gained. This is expected to enable future growth and new supply infrastructure to be put in place. Much of the growth will likely leverage existing facilities, which include LNG plants in the US, existing terminals in Europe and elsewhere in the world.

These investments are supported by the capability to effectively manage and optimize those supply chains to bring efficiency to the market. Traders in Europe are beginning to be involved in the development of the market. Opportunities are created through the large storage capacity availability in Northern Europe and different supply points.

Increasing liquidity in small scale LNG shipping and the customer base will only help. Further, LNG is being sold on an increased range of price indexations including against alternative fuels. The capability to risk manage will become an important capability and allow competitive LNG to be supplied to customers on indexes they are familiar with.

Conclusions

The development of these small-scale LNG supply chains is beginning to unlock LNG as a transport fuel. This brings LNG to more customers, including small-scale power that would not have been possible only a few years ago. These developments bring confidence to the market on its availability that will be essential to its take up.

However, we still need to recognize that it is early days and much more needs to be done to continue the development of small-scale LNG and to continue to bring down costs. In particular:

- Storage costs contribute a large component of the total value chain cost of supply and consumption. We expect Chinese manufacturers to play a role here as well as in market growth and work closely with OEMs. Confidence and familiarity needs to develop in ship construction yards so that the "LNG premium" can be eliminated from the total constructions costs.

- Standardisation will drive cost efficiencies through repeatability rather than scale which has been the focus of the conventional LNG industry. This will in part be driven by the development of low cost infrastructure that can be replicated elsewhere. It needs to be under-pinned by the development of common industry standards that are appropriate for small-scale LNG solutions. At present there is little consistency across countries and industries. This needs to change.

- Greater use of existing facilities whether liquefaction or LNG terminals. The potential for small-scale LNG as a potential market also needs to be considered early in the design stages of these facilities and the development of the commercial terms. The experience of break bulk facilities such as the Gate terminal will support this.

- Emissions legislation needs to be consistent.

- Finally, but most importantly, as an industry we need to ensure that LNG is delivered safely into these new markets.

With the continued and successful development of new small-scale LNG, the benefits will be brought to new markets and in particular support the adoption of LNG in the transport sector. Estimates vary on how significant LNG in transport use could be. We can see transport possibly adding 5 to 10% to our base case global LNG demand estimates by 2025. That is roughly 25 to 45 million tonnes per year by 2025. LNG in transport would then also move from "modest" to "mainstream". This is expected to bring a positive and welcome additional use to both the LNG market and sustainable transport mix.