# Completing the LNG value chain

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**The use of natural gas is already strong and will continue to increase. Wärtsilä's extensive expertise across the entire LNG value chain enables it to bundle together solutions that provide efficient energy production from gas.**

Most experts predict that natural gas demand will see strong growth in the future, growing at a compound annual growth rate (CAGR) somewhere in the region of 7-8 %.

According to the International Energy Agency, we could be entering "a golden age for gas". In its World Energy Outlook 2012, the agency projected gas demand to rise from 3.3 trillion cubic metres (tcm) in 2010 to 5.0 tcm in 2035, an increase of 50%. Its share of the global energy mix rises from 22% in 2010 to 24% in 2035, all but catching up with coal.

Meanwhile, ExxonMobil's Energy Outlook 2040 published in January 2013, forecasts that natural gas will emerge as the number one fuel for power generation within the next 30 years, accounting for 30% of global electricity generation.

The attraction of gas as an energy source – whether for heating, transport or power generation – is clear. Its price relative-to-energy content is favourable when compared with other fossil fuels, and it significantly reduces $SO_x$ and $CO_2$ emissions when replacing coal and oil in power generation.

With global LNG (liquefied natural gas) demand expected to show strong growth, LNG production is forecasted to jump from 270 million t/year in 2011 to 350 million t/year in 2016, according to the International Gas Union's (IGU) World LNG Report 2011. This growth in production will have to be accompanied by a similar expansion in LNG receiving terminal capacity, since gas production is often not in the same location as consumption.

Last year Wärtsilä took a significant step towards taking full advantage of this booming LNG business. In January 2012, the company gained expertise in small-scale LNG liquefaction, regasification, and LNG fuel systems through its acquisition of

Hamworthy plc. It is a move that strengthens its position as a total solutions provider, with a complete range of products, integrated solutions, and services to the marine and offshore industries.

These new capabilities go hand-in-hand with the company's existing expertise in ship propulsion and power plant/land-based design and construction. With capabilities now extending across the point of extraction, transport, regasification and onshore delivery, to user off-take in the form of power generation, Wärtsilä is able to integrate an LNG import terminal with a power plant with an integrated EPC solution. This can deliver a number of benefits to potential customers.

Fig. 1 – Small scale liquefaction plant at Snurrevarden, Norway.

### LNG production

Wärtsilä Oil & Gas has developed innovative LNG production plant solutions based on well-proven equipment and process control principles, which are suitable for small to medium size liquefaction capacities.

The LNG production facility in Snurrevarden, Norway was the first free-standing small scale LNG plant in Northern Europe. It is fully automated with remote monitoring and control capabilities.

Since then Wärtsilä Oil & Gas has delivered a number of complete onshore LNG production facilities, including the introduction of an improved liquefaction system with double expanders based on the reverse Brayton cycle. The LNG production plant for Gasum in Finland, delivered in 2010, uses surplus liquid nitrogen (LIN) for the LNG generation and incorporates new technology that reduces LIN consumption by 50%.

Wärtsilä Oil & Gas has also developed the energy efficient NewMR liquefaction technology for even lower capacities than its usual small and mid-scale LNG plants. For production capacities below 50 tonnes per day, the NewMR technology uses a mixed refrigerant in combination with standard equipment to achieve low investment costs and the rapid manufacture of the liquefaction unit. In the growing liquid biogas fuel market, this technology adds to the value chain. Wärtsilä Oil & Gas will deliver a biogas liquefaction plant to the Municipality of Oslo during spring 2013.

### LNG transport

Most of the growth in the global LNG market is expected to occur in large production plants – exceeding roughly 1 million t/year – in Australia, Asia, the US and parts of Africa, mainly Mozambique. There arealso a number of smaller scale plants that will make the LNG business more local.

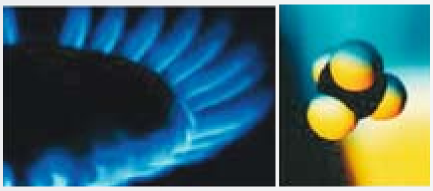
Typically, large LNG carriers transport →

Fig. 2 – Small scale liquefaction plant in Kollnes.

[ ENERGY & MARINE / IN DETAIL ]

### What is LNG?

- Liquefied Natural Gas (LNG) is Natural Gas that has been cooled below the bubbling point, where it is condensed to a liquid, which occurs at a temperature dependent of the gas composition, typically close to –160 °C at atmospheric pressure
- Consist mainly of methane
- Contains no sulphur or toxic elements
- Odourless



Methane ($CH_4$)

| Vol-% | Lean | Mean | Rich |
|---|---|---|---|
| Methane | 96.2 | 91.7 | 84.8 |
| Ethane | 3.3 | 5.7 | 13.4 |
| Propane | 0.4 | 2.2 | 1.3 |
| Buthane | 0.1 | 0.3 | 0.3 |
| Pentane | 0.0 | 0.0 | 0 |
| Nitrogen | 0.0 | 0.1 | 0.2 |
| MN | 87 | 76 | 71 |

Fig. 3 – LNG specifications.

### What is LNG?

- Solution to utilize natural gas where pipeline gas is not available
- Liquefaction reduces the volume by approximately 600 times, making it more economical to transport over long distances by specially designed semitrailers and ships
- 1 $m^3$ of LNG = 600 $m^3$ of natural gas
  Density of LNG: 450 kg/$m^3$

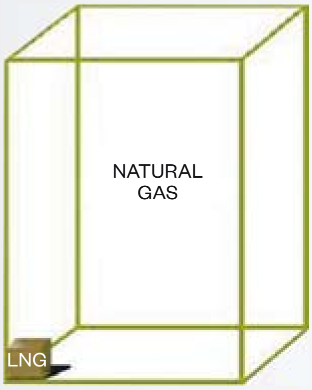



Fig. 4 – The relationship between natural gas and LNG in terms of volume.

Fig. 5 – The GdF Suez/HOEGH Neptune Shuttle Regasification Vessel (SRV).

LNG from the points of production to consumption locations. Wärtsilä 's strength in the ship power business has seen it heavily involved in this sector.

Since their introduction in 2006, 65%of all new LNG carriers have been fitted with Wärtsilä dual-fuel (DF) engines. Wärtsilä recently achieved the milestone of supplying DF propulsion engines to 100 LNG carriers, and has sold altogether some 720 DF engines to both marine and land-based applications, accumulating six million running hours of experience with the technology.

#### Wärtsilä regasification for offshore and onshore LNG storage

Regasification: The general idea of liquefying natural gas is to reduce the volume to make transport easier. LNG has a volume about 600 times less than natural gas. The LNG is then regasified at the receiving terminal by vaporising the LNG. The storage and regasification terminal can be either an onshore terminal, comprising a dedicated jetty regas unit (JRU) that makes use of a moored floating storage unit alongside to hold the LNG buffer stock, or a floating storage regasification unit on-board a ship.

#### Floating storage regasification units

In recent years there has been a growing interest in ship and jetty-based LNG regasification systems.

In a jetty regasification unit (JRU), the regas unit is mounted on a dedicated jetty while a floating storage unit (FSU) is moored alongside to hold the LNG buffer stock. Shuttles then bring the LNG to and from the FSU before being fed to the JRU in preparation for feeding to the gas grid or power plant. This was a solution that Wärtsilä Oil & Gas provided for Malacca in Malaysia (see box).

The ship-based option, more commonly known as a floating storage and regasification unit (FSRU), is essentially a LNG carrier converted by the addition of on-board storage and regas facilities. FSRUS present a strong economic case when compared with onshore import terminals. With no need to go through onshore planning procedures, they can typically be built in half the time – around two years – and at half the cost in some instances. FSRUS can also be built in remote areas with an associated subsea pipeline.

An increasing number of LNG importers want to take advantage of the cost and timing benefits offered by the jetty/regas vessels option, but they also want to be able to keep the ships on station in uninterrupted service for several years. They also want to be able to process larger quantities of LNG than converted FSRUs are capable of. This joint requirement has led to a number of orders for FSRU new builds.

New builds typically consist of a pair of vessels that together fulfill the same role as a FSRU. This configuration makes use of a barge-mounted regasification plant combined with an LNG carrier used as a floating storage unit. This approach obviates the need for a propulsion system on the barge floating regas unit. At the same time, a conventional LNG carrier can be easily prepared for its floating storage role.

The market for FSRUs is a growing one that Wärtsilä has been taking advantage of. So far, Wärtsilä has delivered 10 floating LNG terminals, representing a market share of about 40%.

Reconverting the LNG at import terminals requires a very large amount of energy in the form of heat for LNG vaporisation. Some FSRUs can actually provide the same amount of heat that could be supplied by a 1,000 MW nuclear power plant. To vaporise 14 million $m^3$ per day would require in the region of 100 MW of heat.

Many companies use seawater only to provide the heat for vaporisation but this can have drawbacks. Over the last several years, Wärtsilä has been developing its FSRU technology to increase the process efficiency, reliability and economics.

A key Wärtsilä LNG regasification technology utilises propane and seawater in cascade loops to warm the LNG. Wärtsilä built its first pilot to demonstrate propane loop technology in 2005.

Propane is used in the first stage to heat the LNG from -160°C to -10°C in a heat exchanger. In the second stage, the LNG can be heated further using seawater as a heating medium. Propane is a suitable heating medium as it does not freeze at the -160°C temperature of the LNG. Its use in the first stage reduces the risk of freezing the seawater in the heat exchanger.

Also, the latent heat from the propane is used for the vaporisation, which is more efficient and reduces the volume of the heating medium compared to competing technologies.

In the cascade system's first stage heat exchanger, heat is exchanged against the propane circulating in a closed loop. The propane enters the heat exchanger at →

Fig. 6 – A gas barge power plant.



Fig. 7 – An onshore gas power plant.

Fig. 8 – A gas cube.

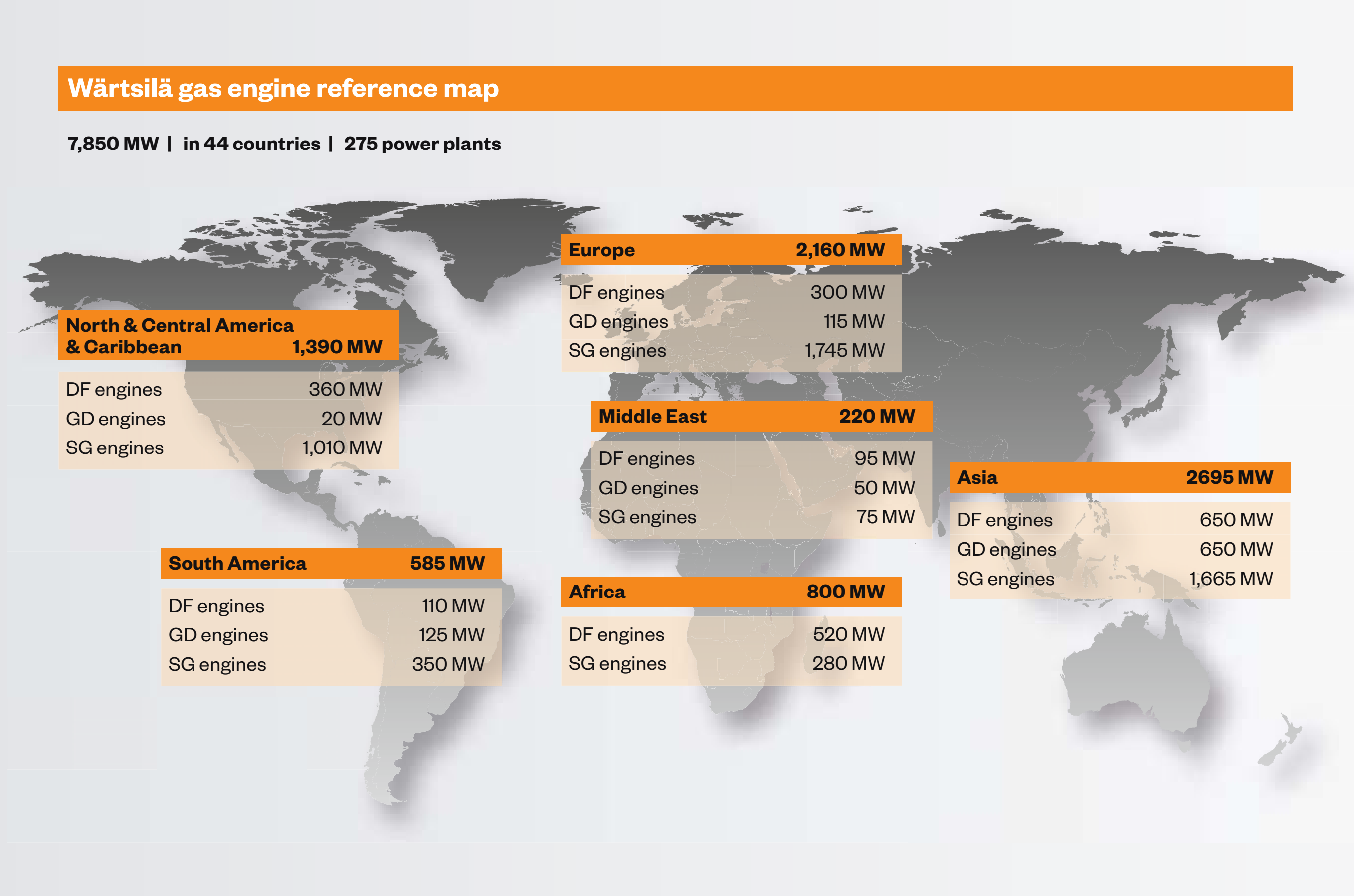



Fig. 9 – Wärtsilä's worldwide installations of gas fuelled power plants.

approximately 0˚C and 4.7 bar as gas. In the heat exchanging process, the propane is condensed and leaves the exchanger in a liquid state at about -5˚C.

The propane is then pumped by the circulating pump and heated against seawater in titanium, semi-welded-plate heat exchangers. Here the propane is evaporated and heated to 0˚C before returning as gas to the printed circuit heat exchanger.

Wärtsilä regas units use a type of printed circuit heat exchanger that allows for a compact unit capable of withstanding high pressures. The simplicity of control of the regas units using this technology has been proven at a demonstration plant. The robustness in terms of turndown capability, ramping up and ramping down, has also been demonstrated. Unlike other heat exchangers, the units are not susceptible to the fatigue caused by large changes in temperature.

Wärtsilä is also able to provide FSRUs for situations where seawater cannot be used. Here, steam from the ship's boiler system and cooling water from Wärtsilä's engines can be used for vaporisation.

The shipboard LNG regasification systems have capacities in the 50-1,100 tonnes per hour (tph) range, and send-out pressures ranging from 46 to 130 bar. As an example, a system based on the use of 630 tonnes/hour trains can provide a regasification capacity of 720 million standard cubic feet of gas per day, and discharge a 145,000 m$^3$ LNG carrier in approximately four days.

However, the fuel cost when discharging a LNG carrier provided with a propane/seawater regas unit can be up to seven times lower than for a similar size ship fitted with a steam/water-glycol unit.

### Onshore storage

Still, today most receiving terminals are built with onshore storage, which has certain advantages over FSRUs. Many of the smaller and medium size terminals will be onshore and for these Wärtsilä can be a supplier.

Onshore storage can either be a flat-bottom tank with a capacity ranging from 4,000 m3 to 200,000 m$^3$, or a horizontal or vertical, vacuum-jacketed, pressure tank for smaller amounts of LNG storage with less than 1,000 m$^3$/tank.

### Integrated receiving terminal and power plant

Wärtsilä has a long history in building power plants in the 1-500 MW range based on modular 1-20 MW engine units capable of running on fuel oil or gas, or on dual-fuel engines that can use both without modification. These power plants can be used to generate electricity only, or combined heat and power if there is also a requirement for heat as such in industrial applications.

There are a number of synergies between the power station and the regasification plant. Obviously the power plant can utilise the natural gas produced for power generation, but there are other opportunities for integration of the two systems.

When the LNG arrives at the country of destination, it is received at a terminal where it is stored and regasified before being fed into the gas grid or piped to a power plant for electricity generation.

The receiving terminal is designed

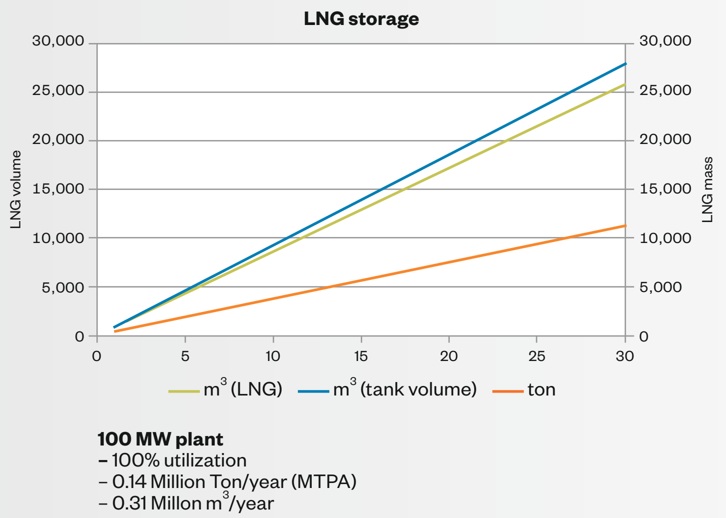
**LNG conversions and engine consumptions**

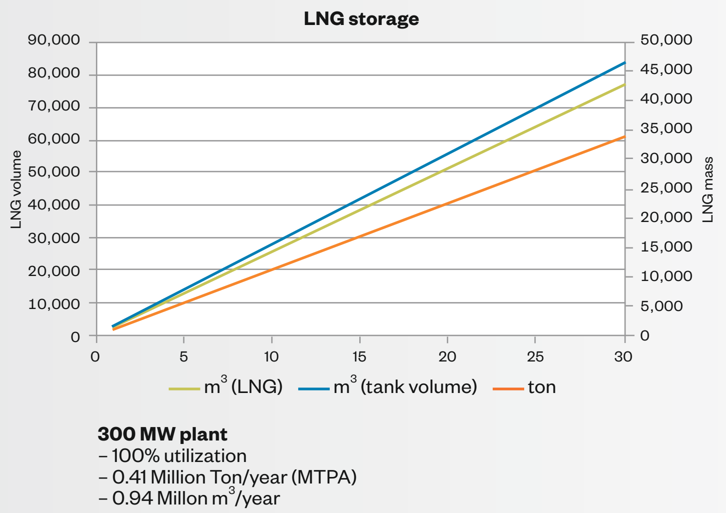
| LNG volume | LNG mass | Gas volume |
|---|---|---|
| 2.25 m³ LNG | 1 ton | 1,370 Nm³ Gas |
| | | |
| LHV | 49.0 MJ/kg | 35.9 MJ/m³ |
| | | 10.0 kWh/m³ |
| HHV | 54.4 MJ/kg | 39.8 MJ/m³ |
| | | 11.1 kWh/m³ |

| 1 ton LNG | 13,700 kWh |
|---|---|
| Electrical energy (Engine electrical efficiency 45%) | 6,165 kWh |
| **1 m³ LNG** | **6,090 kWh** |
| Electrical enercy (Engine electrical efficiency 45%) | 2,740 kWh |
| **50MW Electrical power** | **El eff. 45%** |
| LNG mass flow | 8.2 ton/h |
| LNG volume flow | 18.4 m³ LNG/h |
| Gas volume flow | 11,230 m³ LNG/h |
| 10,000 m³ LNG | 22.6 days |

Fig. 10 – Rule of thumb.

Fig. 11 – Storage need versus power.




according to ship size, LNG availability, and the cost of constructing the LNG storage facilities – all depend on the required gas send-out/consumption.

**Storage:** When the ship is safely moored and ship-to-shore communications are established, the vapour return arm and the LNG unloading arms are connected. The ship's unloading pumps unload the LNG, which is then piped to the onshore LNG storage tank.

The LNG handling process creates a boil-off gas (BOG) that can be burned as part of the fuel for a power plant. There are three sources of BOG. There is BOG from the unloading ship, mainly due to heat ingress and ship movement, where the rate can range from 0.10% to 0.15% of total tank mass per day. Since the ship is stationary during the unloading, the BOG rate is based on 0.10% per day.

There is also BOG from the onshore tank, generated from heat ingress. This normally ranges from 0.05% to 0.10% of total tank mass per day. Finally, BOG from loading the LNG into the onshore tank is released due to large liquid movement and a high tank temperature if the tank is not cooled properly. The BOG rate can vary between 100% and 1,000% of the normal BOG rate.

Wärtsilä 's onshore tanks are well cooled and designed to a 300% BOG rate. The rate of BOG is determined by the amount of →

Fig. 12 – A typical onshore power plant layout.

insulation in the tank. As the amount of insulation has an impact on cost, it is important to calculate the value of the BOG before determining the investment in insulation to limit BOG.

This requires two BOG systems; one that handles the normal operation of the terminal where the BOG comes solely from the storage tank, and another that handles the BOG produced during the loading and unloading of the tank. The combined BOG systems compress and handle the flow of BOG fed to the power plant. A BOG re-liquefaction system can be installed according to the operating mode of the terminal.

Having a power plant at the LNG receiving terminal can be a big advantage to customers. A power plant can be the main off-taker of the LNG, burning it along with the BOG to supply electricity to the grid. An integrated power plant can also provide the electricity and heat requirements of the LNG terminal. Wärtsilä power plants can be easily integrated with LNG receiving terminals with no modifications needed to the engines.

These power plants can utilise LNG directly without an external evaporation system, as the fuel is heated before the engine. They can also use the low-pressure gas coming from the send-out system without the need for any additional compressors.

### Low (LP) pressure send-out system:

If the consumer's needs are less than 10 bar, then liquid is sent out from the LNG storage tank, pumped by the LP LNG pumps and sent to a LNG vaporiser. In this unit, the low pressure LNG is vaporised and heated to ambient condition before being sent as fuel to the Wärtsilä power plant. Vaporised LNG is mixed with compressed BOG upstream of the power plant.

### High pressure (HP) send-out system:

The same equipment used for the regas unit can also be used to increase the gas pressure to the level needed for injection into a natural gas pipeline. If a pressure higher than 10 bar is required, liquid is sent out from the LNG storage tank. It is pumped by the LP LNG pumps and sent to a regasifier. The regasifier can be a module of the type supplied by Wärtsilä Oil & Gas, Norway, comprising HP LNG pumps and a LNG vaporiser. In this unit, the low pressure LNG is vaporised and heated to ambient temperature before it is fed to a standard natural gas high-pressure pipeline system. If fuel is needed for the Wärtsilä power plant it can be taken from the HP line via a reduction valve. Vaporised LNG will be mixed with compressed BOG upstream of the power plant.

Whether the LNG comes from the low-pressure or high-pressure send-out system, it has to be heated. This presents another opportunity for power plant integration. The ethylene glycol (glycol water) used to provide engine cooling can be used to help vaporise the LNG into natural gas.

This vaporisation takes place in a stainless steel shell and tube heat exchangers. The glycol water has a fixed flow rate, where it enters the heat exchangers at 80°C and returns at 30-65°C, depending on the LNG regasification capacity.

### Project evaluation

Before offering an EPC contract for an integrated plant, Wärtsilä makes an in-depth evaluation, looking at criteria such as the size of the project and its location, whether there is sufficient in-house experience, and a network of local sub-suppliers and sub-contractors.

One of the first tasks is to look at the LNG import terminal in terms of sizing. Wärtsilä assesses the gas demand – for both the power plant and direct sales to either the pipeline network, the LNG truck filling station, or the ship bunkering service at the terminal. This will give the total gas demand.

The next step is to look at the seasonal variations to work out the peak demand and average demand. It is also important to investigate the supply of the LNG – i.e. the travel distance and time needed for a round trip, together with the ship size and

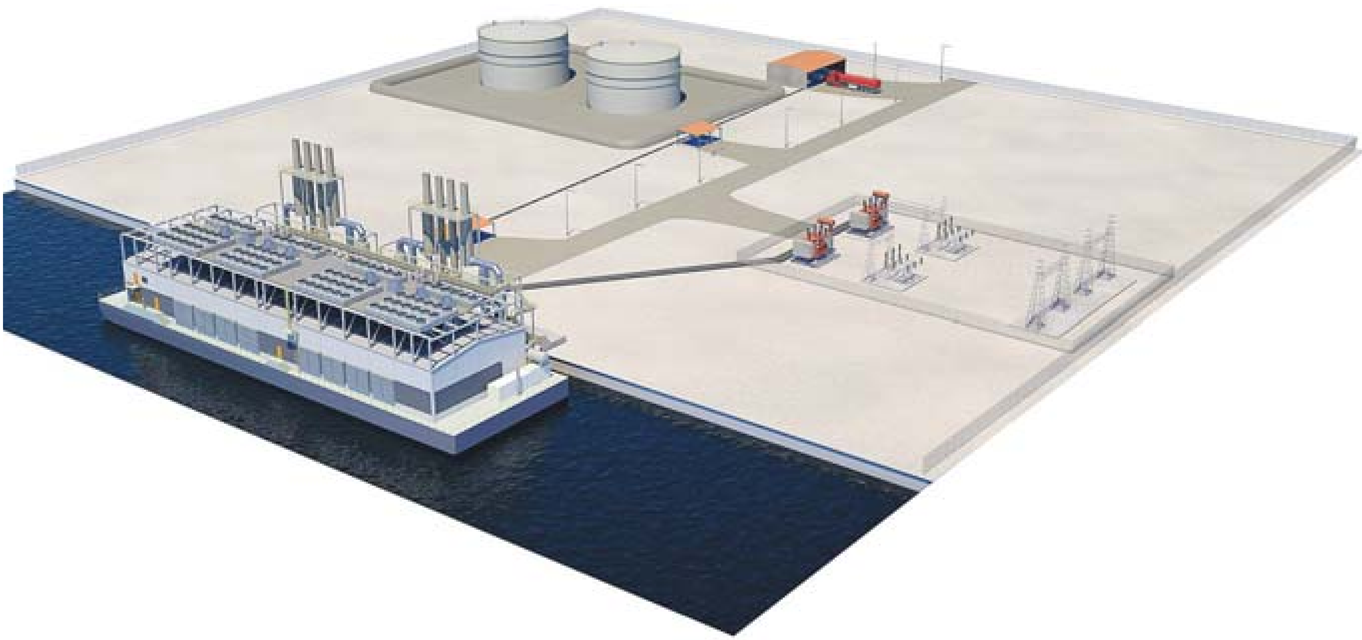


Fig. 13 – A typical power barge layout.

availability, LNG consumption, and the amount of required storage capacity.

All of this data is entered into a model to determine the optimum for each of these considerations, and for the receiving terminal in terms of capital expenditure and operational expenditure. It is important to size items, such as storage, correctly as costs increase with storage capacity and it may not make economic sense to store a commodity such as gas.

Wärtsilä bases its project evaluation on the price of LNG at the source, the shipping costs, and the terminal import regasification costs. This gives a total cost of gas output from the terminal, which serves as an input for the price of gas delivered to the power plant or other consumers.

### Project execution

The ability to deliver the equipment for both the LNG terminal and power plant provides customers with assurance as to the quality and function of the equipment throughout the installation.

Being able to execute these integrated projects on an EPC basis can also bring added benefits for customers. While there are cost advantages, the main benefits result from having just a single company with which to interface. This makes the assignment of responsibilities much easier and reduces the risks relating to project execution and schedules. →

Fig. 14 – A moored power barge.


Fig. 15 – The 'Viking Grace' – the world's largest LNG fuelled passenger ferry.

**Strong market**

The continued expansion of global gas markets, along with steady growth in power demand, will see the market for FSRUs continue to be lucrative over the coming 3-5 years. In addition to those currently being built, there are perhaps 30 FSRUs in existence with prospects for another 30.

The use of FSRUs is increasingly becoming the favoured option for bringing gas to energy hungry countries with high demand for energy, such as Indonesia, India and China, as well as countries in Africa and South America, which will continue to drive demand. It is a trend that is likely to continue, especially in those countries that foresee a continued dependence on fossil fuels for power generation but are looking to cut emissions at the same time.

Indeed the entire LNG chain is expanding. Its attraction as a cleaner energy source compared to coal and oil for power generation, and its growing use for land and sea transport continues to drive more exploration.

From an energy-to-price point of view compared to oil, gas is perhaps three to four times cheaper. If it can be traded and distributed more easily, it will become even more attractive.

Wärtsilä, through its activities right across the LNG chain, from transport and distribution, to processing and utilisation, is in a good position to help customers take advantage of this energy source by offering complete systems with improved interfaces.

# MODULAR FABRICATION

To allow the modular fabrication of its regasification systems, Wärtsilä entered into a strategic partnership with a China-based oil and gas engineering and construction company in September 2010. The first contract secured by the partnership was for the supply of the seawater/propane-based regasification system for the Khannur FSRU conversion.

The 125,000m$^3$ spherical tank Khannur, built in Norway in the mid-1970s, has operated reliably for several decades. The transformation of the vessel into an FSRU was carried out at a yard in Singapore.

Wärtsilä handled the system's conceptual design, basic specification, and the provision of key equipment for the regas unit. The layout for all the equipment, structure and pipes was carried out at a yard in China. Wärtsilä's joint venture partner was also responsible for the procurement, construction, assembly and final testing of the module.

The complete regasification unit, based on an assembly of skid-mounted units, weighs around 700 tonnes and measures 21m x 27m x 15m.

The modular approach enabled Wärtsilä to complete the unit on a fast-track basis, and to have the regasification system almost complete before lifting onboard the vessel. The limited number of interfaces between the ship and the equipment were easily connected, and delivery of the regas unit took place in November 2011.

The Khannur, with the SOE-built regas unit mounted on its bow, is now on station in Jakarta Bay as the receiving facility for the West Java LNG project. The vessel, renamed the FSRU Regas Satu, is Indonesia's first LNG regasification terminal and represents the first FSRU project in Asia.

The vessel has the capacity to regasify up to 3 million tonnes per annum (mta) of LNG, and the project operator plans to increase the facility's throughput up to this maximum level in the coming years.

The Khannur project marked SOE's first foray into the LNG market and the good relationship with Wärtsilä is continuing. The Nantong yard completed the JRU for Petronas and delivered it to the new Malacca LNG receiving terminal on the east coast of the Malaysian peninsular last year. Weighing 945 tonnes, the jetty-mounted regas unit has three trains, each with a capacity of 220 tonnes per hour, and is built to accommodate a 70 bar send-out pressure.

Following completion of the JRU for Malacca, regas units are also being fabricated for the three 170,000 m$^3$ FSRU new builds under construction for Höegh LNG. Each of these units, which are also based on Wärtsilä's propane/seawater LNG regasification technology, will weigh about 600 tonnes.

Fig. 16 – The PETRONAS Melaka Jetty regasification unit.