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Introduction

Towards the gas age

Natural gas has been a part of the global energy landscape for a long time already, utilised in residential heating and cooking, energy production and transport. Additionally, natural gas is important for the production of, for example, hydrogen, ammonia, fertilisers, methanol and refinery products. As the world is searching for energy sources and chemical feedstocks that are low in emissions yet affordable, gas has become increasingly attractive.

Methane, natural gas in its purest form, is the cleanest of all the fossil fuels. It produces lower emissions of CO$_2$, NO$_x$, SO$_x$ and particulate matter than competing fuels. Many industrial processes can be improved considerably by using natural gas instead of dirtier alternatives, whereby it is possible to achieve lower operational and maintenance costs. Natural gas is well suited to complement wind and other renewable energy sources in the power generation mix. By adding a share of biogas to the natural gas, environmental benefits can be further increased.

More and more reserves have been discovered, which ensures that natural gas will be available for a long time. Today, natural gas is mainly distributed to demand centres by pipeline, but increasingly also in the form of liquefied natural gas (LNG). This allows gas to be shipped in large quantities on a worldwide scale.

LNG has traditionally only been available in large amounts to be regasified and injected into national gas grids. Thus it has been out of reach for smaller, remotely located demand centres. However, with the increased interest in monetising new gas sources as well as introducing gas to the energy mix in previously stranded markets, small-scale LNG infrastructure is spreading steadily. Increased awareness of LNG, lower costs and technological development have challenged the traditional way of thinking, making LNG available in new places.

As a forerunner in gas and multi-fuel engines, fuel systems, technology and services, Wärtsilä wants to participate in the global shift to gas also with LNG infrastructure projects in new and decentralised locations. We focus especially on developing the small-scale LNG value chain together with our customers, offering technology both for liquefaction and regasification.
Introduction

Our value proposition

Small-scale LNG can be described as an industry in transition from niche business to mainstream. The technical solutions for LNG infrastructure are proven and available, but the understanding of the small-scale LNG value chain is still often lacking. Those that can create a bankable project that benefits all stakeholders quicker than competitors are the winners in the market. Wärtsilä offers unique capabilities that bring value to your project.

- Combined power plant and LNG infrastructure
  - Wärtsilä offers full wrap EPC (engineering, procurement and construction) package including power plant and LNG infrastructure.
  - Existing Wärtsilä power plants can be converted from liquid to gas fuel, including the required LNG infrastructure.
  - Wärtsilä’s dual-fuel engine technology helps to reduce LNG supply risk for power plants.
- Reduce risk by guaranteed price, delivery & performance
  - EPC contracts guarantee performance, on-time delivery and fixed price.
  - Operations & Maintenance solutions ensure reliable operations and predictable costs.
- We turn project ideas into reality!
  - We not only help customers with all-in LNG solutions but can also assist with project structuring and financing arrangements.
- Increase revenues by shortening lead time of project development and EPC
  - A collaborative approach to the project definition phase shortens time to Final Investment Decision, allowing you to act on business opportunities first and make money sooner.
- Reduce costs by adequate & standardised solutions
  - Solutions fit for the purpose of small-scale LNG lower capital and operating expenditures (CAPEX & OPEX) without compromising functionality and safety.
  - Modularisation and standardisation lower design and installation costs.

About Wärtsilä

Wärtsilä was established in 1834. For over 180 years we have been at the frontier of engineering innovation. This vision and ingenuity mean that we deliver ever smarter solutions that keep our customers one step ahead. Today, Wärtsilä is a global leader in complete lifecycle power solutions for the marine and energy markets, with almost 19,000 employees. By emphasising technological innovation and total efficiency, Wärtsilä maximises the environmental and economic performance of the vessels, power plants and LNG infrastructure of its customers.

Wärtsilä is organised in three businesses

Wärtsilä Energy Solutions
We are a leading supplier of power plants for the decentralised power generation market. Wärtsilä offers engine-based power plants for baseload, peaking and industrial self-generation purposes as well as for the oil and gas industry. Wärtsilä Energy Solutions also provides utility-scale solar PV power plants, as well as small- and mid-scale liquefaction plants and terminals for LNG.

Wärtsilä Marine Solutions
We are the leading provider of ship machinery, propulsion and manoeuvring solutions. Wärtsilä supplies engines and generating sets, reduction gears, propulsion equipment, control systems and sealing solutions for all types of vessels and offshore applications. Wärtsilä has for several decades pioneered the development of gas technology for marine and oil & gas markets.

Wärtsilä Services
We support our customers throughout the lifecycle of their installations by optimising efficiency and performance. Wärtsilä provides the most comprehensive portfolio of services and the broadest service network in the industry, for both the energy and marine markets. We can also convert existing Wärtsilä liquid fuel power plants so that they can run on gas or even switch between fuels.
An additional piece of the LNG puzzle had been added in 2006 with Wärtsilä’s acquisition of the Total Automation group which brought the Whessoe Tank Control Systems into the solutions portfolio. More than 250 LNG tanks have been equipped with Whessoe branded instruments.

Wärtsilä’s accomplishments in the LNG industry include:

- Powering most of the world’s LNG carriers and Floating Storage and Regasification Units (FSRUs) with our dual-fuel engines.
- Providing complete LNG solutions to the latest gas-driven ships – the world’s first LNG-fuelled passenger vessel Viking Grace being the most famous one.
- Supplying regasification system modules for more than one-third of the FSRUs in active operation.
- Market leader for boil-off gas (BOG) reliquefaction systems for liquid gas carriers.
- Delivering one of the first biogas liquefaction plants in the world.
- Building the largest LNG receiving terminal in the Nordic countries, with a storage capacity of 50,000 m³.
LNG basics

The changing LNG landscape

The first commercial LNG operations commenced in 1940 in the form of an LNG peak shaving plant in the United States. It took until the mid-1960s for the technology to mature so that construction of liquefaction plants and terminals could take off on a global scale. According to today’s standards, early facilities could be characterised as small-scale. Over time, economies of scale led to the construction of much larger facilities and carriers. Now, the world is re-discovering small-scale LNG as a means of providing a cleaner, more affordable fuel to new areas and applications.

Even though LNG has been around for a long time, it is still quite unknown to people in general. This chapter aims to provide you with a summary of what you need to know about LNG and, in particular, small-scale LNG.

Conventional LNG value chain (pages 12-13)
The conventional setup of the LNG industry is based on the assumption of economies of scale. Traditionally, there have been large liquefaction plants in gas producing countries that have supplied large terminals serving large demand centres in countries that do not have sufficient own energy resources. Terminals could be built onshore or in the form of Floating Storage and Regasification Units (FSRU). Contracts were generally long-term (20-30 years) and indexed to the oil products that LNG was intended to replace.

In areas with considerable seasonal variation in demand and unsatisfactory pipeline capacity, LNG peak shaving plants exist. The idea is to liquify and store gas in the form of LNG for the majority of the year and regasify it during peak demand for additional, easily accessible capacity.

In the age of conventional LNG, markets without sufficient demand to justify gas pipelines or large-scale LNG infrastructure had to settle for other fuels. Especially smaller islands did not have the possibility of choosing LNG for their energy mix. Similarly, small gas sources could not be put to use if the distance to market prohibited construction of pipelines. However, the time has come for small-scale LNG.

Conventional + small-scale LNG value chain (pages 14-15)
The picture combining conventional and small-scale LNG looks very different. The large-scale infrastructure is still there but complemented by new, smaller facilities. Supply contracts are more often hub based and shorter in duration. Some countries may have gas reserves or pipeline access, but still choose to invest in LNG infrastructure for other reasons, such as security of supply.

With mini and small-scale liquefaction plants, it is now possible to monetize gas sources that previously were not commercially feasible to develop or where the gas was an unwanted by-product that would have been flared or re-injected into the ground. This includes the possibility to liquefy biogas (LBG) and landfill gas (LFG) to produce renewable energy while at the same time reducing the emissions of greenhouse gases. Satellite terminals can be set up in smaller demand centres to which LNG can be distributed by tanker trucks. For high-horsepower vehicles and equipment, the coverage of LNG/LBG filling stations near major roads and at mines and oilfields is expanding each year.

Implementation of Emission Control Areas for the maritime industry makes LNG a very interesting fuel option for shipping companies. Increasingly, ports invest in bunkering terminals, bunkering vessels and bunker barges to maintain their competitiveness and ability to serve a growing fleet of LNG fuelled ships.

LNG producers and shipping companies are increasingly interested in serving the small-scale market. Innovative developments such as LNG storage and regasification barges in combination with dual-fuel power plants reduce the project and fuel risks. Smaller islands and other areas stifled by the cost of electricity or pollution now have the opportunity to access LNG and improve the competitiveness and attractiveness of business and the living conditions of their citizens.
Conventional + small-scale LNG value chain
The reason of existence for liquefied natural gas is that it is the only viable option for transporting natural gas over long distances where it is not technically or economically feasible to build gas pipelines. The LNG value chain comprises five basic steps:

- Gas production
- Liquefaction
- Transport
- Regasification
- Consumption

1. Gas production
Natural gas was once seen as an unwanted by-product of oil production. Nowadays this cleanest fossil fuel available is a valuable energy source that is often worth monetising even in relatively small amounts. In addition to conventional gas from oil fields or natural gas fields, other sources are increasingly being developed. These include shale gas, tight gas, coal seam gas, biogas and landfill gas. As an alternative to fossil fuel, biogas, a renewable energy source, can be produced from agricultural waste, manure, municipal waste, plant material, sewage or food waste.

Natural gas is defined as a hydrocarbon gas mixture that consists primarily of methane but is very rarely discovered in a 100% methane form. Typically 70% to 90% of the extracted gas is methane. Of the rest, the majority is made up of the longer chain hydrocarbons (ethane, propane and butane) as well as carbon dioxide, oxygen, nitrogen, water vapour and other impurities.

Generally, raw natural gas is converted into gas that fulfils pipeline specifications in a natural gas processing plant, extracting other valuable fractions in the process. Liquefaction plants also treat the gas to a varying extent depending on input/output specifications.

2. Liquefaction
LNG is natural gas that has been cooled below its boiling point and thus converted to liquid state. This process takes place in a liquefaction plant. Methane was first liquefied in 1886 and the key patents that enabled development of the LNG industry were filed in 1915 and the mid-1930s.

In liquid state, the volume is just 1:600 compared to natural gas which considerably facilitates storage and transport. However, as the temperature of LNG at atmospheric pressure is -162°C (-260°F), special, cryogenic materials are required for the construction of the liquefaction plant. Also, boil-off gas generated due to the unavoidable heat leaks and mechanical energy from pumps etc. must be managed.
3. Transport
Generally, specially designed cryogenic sea vessels (LNG carriers), but also cryogenic tanker trucks and rail tank cars are used for transporting LNG. The first successful shipment of LNG took place from the US to the UK in 1959. Following the discovery of large gas fields in Algeria, sea transport of LNG started to take place on a regular basis.

LNG shipping is a global business with an excellent safety record. The largest LNG carriers available today are the Q-Max that have a capacity of 266,000 m³, corresponding to almost 160 million m³ of natural gas. Increasingly, also smaller carriers for regional trade of LNG are being built for the needs of the emerging small-scale LNG infrastructure.

4. Regasification
LNG is used for transporting natural gas to markets, but because it has a temperature of -162°C, it cannot be used as such in engines or other applications. It always has to be heated and return to its gaseous state before it can be used. This regasification process generally takes place in an LNG terminal from where the natural gas is distributed in pipelines. In vessels and vehicles, LNG passes through a regasification system on its way from the storage tank to the engine.

Most LNG terminals have been built on land, but also Floating Storage and Regasification Units (FSRU) are increasingly common. There are also hybrid terminals that have a Floating Storage Unit (FSU) in combination with a Jetty Regasification Unit (JRU). For small-scale LNG, there is the additional alternative of storage & regasification barges, performing the same duties as FSRUs, but in smaller quantities and with fewer requirements for marine infrastructure.

5. Consumption
The traditional mode of operation has been to inject the natural gas after regasification into the national gas grid for domestic consumption – heating and cooking – as well as for power generation. Increasingly also in areas without access to gas pipelines, LNG is being considered in energy intensive industries as the fuel of the future. Mines, drilling rig operations, metal processing plants, petrochemical plants and different types of manufacturing plants have all benefitted from LNG as a clean and affordable energy source.
LNG basics

Access to LNG can dramatically improve both the competitiveness and the environmental profile of industries that use hydrogen gas in their production processes. Natural gas is intrinsically the most hydrogen-rich of hydrocarbon feedstocks and therefore contributes more hydrogen compared to other feedstocks on a unit weight basis. Through improved production processes possible with the use of natural gas as a cleaner fuel, lower operational and maintenance costs can be achieved. All this, in combination with expectations for LNG to be competitively priced in the long term, makes an LNG terminal an investment worth to consider.

With the implementation of Emission Control Areas, sea areas with stricter control for airborne emissions, a large amount of LNG-fuelled vessels are forecast to be built during the next decades, Europe currently being the leading market. On the other hand, while LNG in on-land transport has been slowly implemented in Europe and North America so far, Asia, and in particular China, has shown what a tremendous potential LNG possesses as a truck fuel. There, an estimated 170,000 LNG-fuelled vehicles are in use compared to some 5000 in Europe and North America combined. Other high-horsepower applications, such as locomotives are also prospective consumers of LNG.

LNG facts

| Boiling temperature at atmospheric pressure | -162°C | -260°F |
| Volume reduction compared to gaseous state | 1:600 |
| Typical density | 450 kg / m³ | 28lb / ft³ |
| | | 1 tonne LNG = 2.2 m³ |
| Maximum transport pressure | 25 kPa | 4 psi |
| Typical Higher Heating Value | 50 MJ / kg | 21,500 Btu / lb |
| Typical Lower Heating Value | 45 MJ / kg | 19,350 Btu / lb |
| Typical Energy Density Value (based on higher heating value) | 22.5 MJ / litre |
| (based on lower heating value) | 20.3 MJ / litre |
| Relative Energy Density of LNG compared to: | Diesel: 60% | Gasoline: 65% | LPG propane: 90% | Compressed Natural Gas (CNG): 250% |
LNG basics

LNG

- Is a colourless and odourless fluid with about half the density of water.
- Is non-toxic and non-corrosive.
- Is non-flammable and non-explosive in its liquid state.
  - LNG is only flammable if it evaporates and comes in contact with an ignition source when the amount of gas in the air is between 5 and 15 percent.
  - If a vapour cloud does ignite, the flame speed is fairly slow (3-4 m/s). This means that in open spaces, it does not explode.
- Does not pollute soil or groundwater.
  - Most other gaseous and liquid fuels descend or pool if leaked, but methane is lighter than air when warmer than -100°C (-148°F). In open spaces, LNG evaporates fairly quickly without leaving any residue on water or soil.
- Is a cleaner fuel compared to
  - Traditional heavy fuel oils…
    ...25% reduction in carbon dioxide (CO₂) emissions,
    ...90% reduction in nitrogen oxide (NOₓ) emissions,
    ...100% reduction in sulphur (SO₂) and fine particle emissions.
  - Coal…
    ...81% reduction in carbon dioxide (CO₂),
    ...8% reduction in nitrogen oxide (NOₓ),
    ...100% reduction in sulphur (SO₂) and fine particle emissions.

<table>
<thead>
<tr>
<th></th>
<th>LNG</th>
<th>LPG (propane)</th>
<th>Gasoline (petrol)</th>
<th>Fuel oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toxic</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Carcinogenic</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Flammable</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Flammable limits in air (%)</td>
<td>5-15</td>
<td>2.1-9.5</td>
<td>1.4-6</td>
<td>N/A</td>
</tr>
<tr>
<td>Asphyxiant</td>
<td>Yes, in confined spaces</td>
<td>Yes, in confined spaces. Descends to low-lying areas.</td>
<td>Unlikely</td>
<td>Unlikely</td>
</tr>
<tr>
<td>Other human health hazards</td>
<td>Low temperature that causes severe frostbite</td>
<td>No</td>
<td>Eye irritant, narcosis, nausea, others</td>
<td>Eye irritant, narcosis, nausea, others</td>
</tr>
<tr>
<td>Stored pressure</td>
<td>Ambient or low pressure</td>
<td>Pressurised</td>
<td>Ambient</td>
<td>Ambient</td>
</tr>
<tr>
<td>Behaviour if spilled</td>
<td>Evaporates forming flammable visible vapour cloud that disperses fairly quickly</td>
<td>Evaporates forming explosive vapour cloud that descends to low lying areas</td>
<td>Forms flammable pool that requires environmental clean-up</td>
<td>Depends on specific oil type. Potentially requires difficult long-term environmental clean-up.</td>
</tr>
</tbody>
</table>
### Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid gas</td>
<td>Natural gas that contains a certain quantity of gases, e.g. carbon dioxide (CO₂) or hydrogen sulphide (H₂S) that are acidic and corrosive in the presence of water. The gas therefore often needs drying or removal of these acidic gases to conserve the pipeline and equipment.</td>
</tr>
<tr>
<td>Availability</td>
<td>The ratio of the total time that an LNG facility is capable of performing its services.</td>
</tr>
<tr>
<td>Biogas</td>
<td>A mixture of gases produced by the breakdown of organic matter in the absence of oxygen. Has a methane content of approximately 50-75%. Biogas is a renewable energy source that can be produced from agricultural waste, manure, municipal waste, plant material, sewage or food waste.</td>
</tr>
<tr>
<td>Boil-off gas (BOG)</td>
<td>Light components of LNG that have naturally converted to gaseous phase in a storage tank when LNG has warmed to its boiling temperature due mainly to heat ingress. There are several options for BOG handling, such as using it as fuel, gas send-out to the grid, flaring, reliquefaction and recondensation.</td>
</tr>
<tr>
<td>British thermal unit (Btu)</td>
<td>A Btu is the amount of heat required to raise the temperature of one pound (0.454 kg) of liquid water by 1°F (0.556°C) at a constant pressure of one atmosphere.</td>
</tr>
<tr>
<td>Brownfield</td>
<td>A planned development built on a site with existing infrastructure.</td>
</tr>
<tr>
<td>Bunker fuel</td>
<td>Any fuel oil, diesel fuel or LNG taken into the bunkers of ships for use as fuel.</td>
</tr>
<tr>
<td>Bunkering</td>
<td>The process of filling the bunker of a ship with fuel. See Ship-to-ship bunkering, Shore-ship bunkering and Truck-to-ship bunkering.</td>
</tr>
<tr>
<td>Cargo-by-Cargo</td>
<td>Contract structure where the buyer’s failure to take a delivery of LNG is determined on an individual cargo-by-cargo basis, as opposed to an annual basis as in Take-or-Pay. Normally, the matter is settled in the following way: The buyer is obligated to compensate the seller. The seller is entitled to resell the cargo and will reimburse the buyer the net proceeds received from such resale.</td>
</tr>
<tr>
<td>Calorific Value (CV)</td>
<td>The amount of heat produced in a complete combustion of a fuel. This can be measured either dry or saturated with water vapour, and net or gross.</td>
</tr>
<tr>
<td>Coal seam gas</td>
<td>Coal seam gas is methane that exists in coal seams, also known as coal bed methane (CBM). The methane is adsorbed into the coal. Gas is recovered by drilling wells into suitable coal seams and reducing the pressure in the rock, usually by pumping out water, which subsequently frees the gas.</td>
</tr>
<tr>
<td>Compressed Natural Gas (CNG)</td>
<td>Natural gas stored in gas form at high pressure (20-25 MPa or 2,900-3,600 psi). CNG is mainly used as an alternative to liquid fuels in road vehicles.</td>
</tr>
<tr>
<td>Custody transfer</td>
<td>The process of handing over the LNG from its seller to the final buyer. At this point, both the final value of the cargo is determined and all liability is passed.</td>
</tr>
<tr>
<td>Energy Density</td>
<td>The heating value per unit volume. It is measured as MJ per cubic metre. See Higher Heating Value.</td>
</tr>
<tr>
<td>Floating LNG (FLNG)</td>
<td>Floating LNG is the use of a vessel equipped with a liquefaction plant to enable liquefaction of LNG to be carried out offshore. FLNG can start more quickly than could happen onshore, where lead times are often lengthened by the local approval process, and also makes it possible to switch location when gas reserves are depleted. Construction of the first FLNG vessel was completed in 2016.</td>
</tr>
<tr>
<td><strong>Floating Storage and Regasification Unit (FSRU)</strong></td>
<td>An FSRU is a purpose-built or converted ship that stores LNG in its tanks and regasifies it on board. Thereafter gas is sent out into pipelines onshore.</td>
</tr>
<tr>
<td>-----------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Fuel oil</strong></td>
<td>Fuel oil defines oils that make up distillation residue. It comprises all residue fuel oils, including those obtained by blending.</td>
</tr>
<tr>
<td><strong>Gas processing</strong></td>
<td>The separation of oil and gas as well as the removal of impurities and natural gas liquids from natural gas to meet the delivery specification.</td>
</tr>
<tr>
<td><strong>Greenfield</strong></td>
<td>A planned development which must be built from scratch on a new site without existing infrastructure.</td>
</tr>
<tr>
<td><strong>Heel</strong></td>
<td>The amount of LNG left in storage tanks to maintain their cryogenic temperatures.</td>
</tr>
<tr>
<td><strong>Henry Hub</strong></td>
<td>Henry Hub is the largest centralised point for natural gas spot and futures trading in the United States and an increasingly important reference for market-based pricing of LNG worldwide. The New York Mercantile Exchange (NYMEX) uses Henry Hub as the virtual point of delivery for its natural gas futures contract. Henry Hub is owned and operated by Sabine Pipe Line, LLC, which is a wholly owned subsidiary of ChevronTexaco. It is physically located at the interconnection of nine interstate and four intrastate pipelines in Louisiana.</td>
</tr>
<tr>
<td><strong>Higher Heating Value (HHV)</strong></td>
<td>Also called Gross Heating Value (GHV). The amount of heat which would be released by the complete combustion in air of 1 kg, 1 Mol or 1 standard cubic metre (mass-, molar- or volume-based) of gas at conditions of t1, p1; in such a way that the pressure (p1) at which the reaction takes place remains constant, and all the products of the combustion are returned to the same specified temperature (t1) as that of the reactants, all of these components being in the gaseous state except for water formed by combustion, which is condensed to the liquid state. The Higher Heating Value mass based is expressed in MJ/kg, Molar based in KJ/Mol and volume based in MJ/m(^3). This under standard conditions of 15ºC and 101,325 Pa. (ISO 6976:1995). See Energy Density.</td>
</tr>
<tr>
<td><strong>Hub</strong></td>
<td>1. A point for natural gas spot and futures trading. The most important in the US is Henry Hub (HH) and in Europe, the largest hubs are the National Balancing Point (NBP) in the UK and Title Transfer Facility (TTF) in the Netherlands. 2. A central LNG terminal from which LNG is distributed in smaller volumes to satellite terminals, also called spokes.</td>
</tr>
<tr>
<td><strong>Impurities</strong></td>
<td>Unwanted components that could be present in the gas that might cause damage to the manufacturing or processing facility. These can typically be solids, chemicals, carbon dioxide (CO(_2)), sulphur (S), mercaptans and mercury (Hg).</td>
</tr>
<tr>
<td><strong>Japan Customs-cleared Crude (JCC)</strong></td>
<td>Also nicknamed Japanese Crude Cocktail. Crude oil price based on the average Japan importing price of a basket of crude oil. Historically used as an index for Asian LNG pricing, although its influence is diminishing with the trend towards market-based pricing.</td>
</tr>
<tr>
<td><strong>Landfill gas</strong></td>
<td>A mixture of gases created by the action of microorganisms within a landfill, with approximately 40-60% methane content.</td>
</tr>
<tr>
<td><strong>LBG</strong></td>
<td>LNG produced from biogas.</td>
</tr>
<tr>
<td><strong>Lean gas</strong></td>
<td>Gas high in methane content typically 95% or more and with few higher fractions and thus of relatively low calorific value. Also known as dry gas.</td>
</tr>
<tr>
<td><strong>LFG</strong></td>
<td>LNG produced from landfill gas.</td>
</tr>
<tr>
<td><strong>Liquefaction</strong></td>
<td>The conversion of natural gas into LNG.</td>
</tr>
<tr>
<td><strong>Liquefaction plant</strong></td>
<td>Facility where gas is converted to LNG. Liquefaction plants consist of one or more LNG trains, each of which is an independent gas liquefaction unit.</td>
</tr>
<tr>
<td><strong>Marine facility</strong></td>
<td>Infrastructure, e.g. jetty and breakwater, that connects a ship to the terminal or liquefaction plant and enables loading/unloading of LNG, and gas send-out in the case of FSRUs.</td>
</tr>
<tr>
<td><strong>Methane number</strong></td>
<td>Rating indicating the knocking characteristics of a fuel gas (ISO 14532)</td>
</tr>
<tr>
<td><strong>National Balancing Point (NBP)</strong></td>
<td>The NBP is a virtual point at which all gas that has paid the entry charge to enter the UK National Transmission System is deemed to be located. This is where most UK gas trading takes place and is also the largest gas hub in Europe.</td>
</tr>
<tr>
<td><strong>Lower Heating Value (LHV)</strong></td>
<td>Also called Net Calorific Value (NCV). The heat generated by the complete combustion of a unit volume of gas in oxygen, excluding the heat which would be recovered by condensing the water vapour formed. It is usually seen as a measure of the effective heat produced rather than the total heat in the gas.</td>
</tr>
<tr>
<td><strong>Odorants</strong></td>
<td>Strong smelling chemicals injected into natural gas, which otherwise is odourless, in order to make its presence more easily detectable.</td>
</tr>
<tr>
<td><strong>Odorisation</strong></td>
<td>The process of giving odourless natural gas a smell for safety reasons by injecting small quantities of organic sulphur compounds, such as mercaptans, typically at the rate of 30 ppm. Usually carried out at the city gate or at the exit from the high-pressure transmission system.</td>
</tr>
<tr>
<td><strong>Peak shaving</strong></td>
<td>Peak shaving is a means of reducing the peak load on the gas transportation and supply system by injecting gas from a conveniently located temporary gas/LNG storage. Peak shaving may be daily or seasonal and will be handled in a variety of ways e.g. through LNG terminals, LNG peak shaving plants, underground storage, line pack, gas holders and propane-air plants.</td>
</tr>
<tr>
<td><strong>Regasification</strong></td>
<td>The heating and subsequent vaporisation of LNG into gas suitable for pipeline transportation.</td>
</tr>
<tr>
<td><strong>Rich gas</strong></td>
<td>Rich gas is gas with relatively large quantities of heavier fractions in its composition (typically up to about 15%) and thus of high calorific value. Also known as wet gas.</td>
</tr>
<tr>
<td><strong>Rollover</strong></td>
<td>Phenomenon that occurs inside LNG tanks when two layers of LNG, the lower level being warmer and lighter than the upper level, mix. Rollover generates large volumes of BOG in a short period of time.</td>
</tr>
<tr>
<td><strong>Shale gas</strong></td>
<td>Natural gas that is found trapped within shale formations. It is extracted through a process called hydraulic fracturing, or fracking.</td>
</tr>
<tr>
<td><strong>Ship-to-Ship (STS) bunkering</strong></td>
<td>The method of bunkering LNG from a bunkering vessel. Flexible with respect to capacity and location, but high investment costs compared to currently low utilisation rates.</td>
</tr>
<tr>
<td>LNG basics</td>
<td></td>
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<tr>
<td>------------</td>
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</tr>
<tr>
<td><strong>Shore-ship bunkering</strong></td>
<td>The method of bunkering LNG directly from a bunkering terminal, liquefaction plant or terminal. A good option for ports with stable, long-term bunkering demand, but the main disadvantage is that the location for bunkering is fixed.</td>
</tr>
<tr>
<td><strong>Shrinkage</strong></td>
<td>Shrinkage is the difference between energy imported into a terminal as LNG and exported from the terminal as gas. It consists of lost and unaccounted for gas and energy used by the terminal during operations.</td>
</tr>
<tr>
<td><strong>Sour gas</strong></td>
<td>Gas containing a high level of hydrogen sulphide (H₂S). Natural gas is usually considered sour if there are more than 5.7 milligrammes of H₂S per cubic meter of natural gas. In addition to being toxic, hydrogen sulphide in the presence of water also damages piping and other equipment. The process of removing H₂S is called gas sweetening.</td>
</tr>
<tr>
<td><strong>Specification</strong></td>
<td>The technical description of the allowable limits of the chemical composition of gas which may be admitted into a pipeline or process.</td>
</tr>
<tr>
<td><strong>Spokes</strong></td>
<td>Satellite terminals to which LNG is distributed from a hub.</td>
</tr>
<tr>
<td><strong>Spot trading</strong></td>
<td>A term that in the LNG industry lacks a definition regarding its duration. Loosely it can be described as the buying and selling of LNG for “immediate delivery”. However, this can mean anything between &lt; 6 months to four years.</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
<td>Depending on volumes, safety requirements and cost, there are several options for onshore storage of LNG:</td>
</tr>
<tr>
<td></td>
<td>• In-ground tanks</td>
</tr>
<tr>
<td></td>
<td>• Flat-bottom tanks: single, double or full containment</td>
</tr>
<tr>
<td></td>
<td>• Bullet tanks: horizontal or vertical</td>
</tr>
<tr>
<td></td>
<td>• Spherical tanks</td>
</tr>
<tr>
<td><strong>Sweet gas</strong></td>
<td>Gas containing little or no hydrogen sulphide (H₂S)</td>
</tr>
<tr>
<td><strong>Take or Pay (TOP)</strong></td>
<td>A contractual structure where if the buyer’s annual purchased volume is less than the Annual Contract Quantity (ACQ) minus any shortfall in the seller’s deliveries, minus any Downward Quantity Tolerance, the buyer pays for such a shortfall as if the gas had been received. The buyer may have the right in subsequent years to take the gas paid for but not received, either free or for an amount to reflect changes in indexed prices. Also, see Cargo-by-Cargo.</td>
</tr>
<tr>
<td><strong>Tight gas</strong></td>
<td>Natural gas that is found trapped mainly within sandstone formations, but sometimes also in limestone. It is extracted through a process called hydraulic fracturing, or fracking.</td>
</tr>
<tr>
<td><strong>Title Transfer Facility (TTF)</strong></td>
<td>A virtual trading point for natural gas in the Netherlands created in 2003 by Gasunie in order to facilitate trading in the Dutch market. Similar to NBP.</td>
</tr>
<tr>
<td><strong>Tolling fee</strong></td>
<td>A fee for providing liquefaction plant or terminal services often quoted as USD/mmBtu.</td>
</tr>
<tr>
<td><strong>Train</strong></td>
<td>An LNG production unit.</td>
</tr>
</tbody>
</table>
Treatment or pre-treatment is a gas purification process to bring the gas to adequate specifications for the intended market as well as stripping out components that would interfere with the liquefaction process.

The method of bunkering LNG from a tanker truck. Today the most widely used bunkering method thanks to low investment costs and flexibility, but quite slow and not suitable for large amounts of LNG.

Collective term for natural gas, such as coal seam gas, shale gas and tight gas.

Natural gas containing condensable hydrocarbons. A synonym for rich gas.

Occasionally referred to as the Wobbe number. A measure of the rate at which gas will deliver heat on combustion and hence of the compatibility of a gas with gas burning equipment.

Incomplete combustion whereby excess hydrocarbons can possibly result in unacceptable levels of carbon monoxide (CO) being produced (ISO 14532).

---

### LNG conversion tool

**Conversion factors for a typical LNG composition**

<table>
<thead>
<tr>
<th></th>
<th>Tonnes LNG</th>
<th>m³ LNG</th>
<th>Nm³ gas</th>
<th>ft³ gas</th>
<th>mmBtu</th>
<th>boe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tonnes LNG</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>m³ LNG</strong></td>
<td>2.22</td>
<td>1300</td>
<td>45,900</td>
<td>53.4</td>
<td>9.20</td>
<td></td>
</tr>
<tr>
<td><strong>Nm³ gas</strong></td>
<td>0.450</td>
<td>585</td>
<td>20,700</td>
<td>24.0</td>
<td>4140</td>
<td></td>
</tr>
<tr>
<td><strong>ft³ gas</strong></td>
<td>7.69 x 10⁻⁴</td>
<td>0.0017</td>
<td>35.3</td>
<td>0.041</td>
<td>0.0071</td>
<td></td>
</tr>
<tr>
<td><strong>mmBtu</strong></td>
<td>2.18 x 10⁻⁵</td>
<td>4.80 x 10⁻⁵</td>
<td>0.0283</td>
<td>0.0012</td>
<td>2.01 x 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td><strong>boe</strong></td>
<td>0.0187</td>
<td>0.0416</td>
<td>24.4</td>
<td>860</td>
<td>0.172</td>
<td></td>
</tr>
</tbody>
</table>

Example: You need to know how much $10 \text{ m}³ \text{ LNG}$ is in $\text{ft}³ \text{ gas}$. $10 \times 20,700 = 207,000 \text{ ft}³ \text{ gas}$
### LNG quantity converter

<table>
<thead>
<tr>
<th>TPH</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ib/h</td>
<td>1000</td>
<td>2000</td>
<td>3000</td>
<td>4000</td>
<td>5000</td>
<td>6000</td>
<td>7000</td>
<td>8000</td>
<td>9000</td>
<td>10,000</td>
<td>11,000</td>
</tr>
<tr>
<td>Am³/h</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>GPH (US)</td>
<td>500</td>
<td>1000</td>
<td>1500</td>
<td>2000</td>
<td>2500</td>
<td>3000</td>
<td>3500</td>
<td>4000</td>
<td>4500</td>
<td>5000</td>
<td>5500</td>
</tr>
<tr>
<td>Sm³/h</td>
<td>0</td>
<td>1000</td>
<td>2000</td>
<td>3000</td>
<td>4000</td>
<td>5000</td>
<td>6000</td>
<td>7000</td>
<td>8000</td>
<td>9000</td>
<td>10,000</td>
</tr>
<tr>
<td>SCFH</td>
<td>0</td>
<td>50,000</td>
<td>100,000</td>
<td>150,000</td>
<td>200,000</td>
<td>250,000</td>
<td>300,000</td>
<td>350,000</td>
<td>400,000</td>
<td>450,000</td>
<td></td>
</tr>
<tr>
<td>TPD</td>
<td>0</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>100</td>
<td>120</td>
<td>140</td>
<td>160</td>
<td>180</td>
<td>200</td>
</tr>
<tr>
<td>lb/d</td>
<td>0</td>
<td>50,000</td>
<td>100,000</td>
<td>150,000</td>
<td>200,000</td>
<td>250,000</td>
<td>300,000</td>
<td>350,000</td>
<td>400,000</td>
<td>450,000</td>
<td>500,000</td>
</tr>
<tr>
<td>Am³/d</td>
<td>0</td>
<td>50</td>
<td>100</td>
<td>150</td>
<td>200</td>
<td>250</td>
<td>300</td>
<td>350</td>
<td>400</td>
<td>450</td>
<td>500</td>
</tr>
<tr>
<td>GPD (US)</td>
<td>0</td>
<td>10,000</td>
<td>20,000</td>
<td>30,000</td>
<td>40,000</td>
<td>50,000</td>
<td>60,000</td>
<td>70,000</td>
<td>80,000</td>
<td>90,000</td>
<td>100,000</td>
</tr>
<tr>
<td>Sm³/d</td>
<td>0</td>
<td>30,000</td>
<td>60,000</td>
<td>90,000</td>
<td>120,000</td>
<td>150,000</td>
<td>180,000</td>
<td>210,000</td>
<td>240,000</td>
<td>270,000</td>
<td>300,000</td>
</tr>
<tr>
<td>MMSCFD</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>TPA</td>
<td>0</td>
<td>10,000</td>
<td>20,000</td>
<td>30,000</td>
<td>40,000</td>
<td>50,000</td>
<td>60,000</td>
<td>70,000</td>
<td>80,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MMSm³/y</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>MMSCF/y</td>
<td>0</td>
<td>500</td>
<td>1000</td>
<td>1500</td>
<td>2000</td>
<td>2500</td>
<td>3000</td>
<td>3500</td>
<td>4000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Units and Definitions:**
- **TPH** = Tonnes per hour
- **Ib/h** = Pounds per hour
- **Am³/h** = Actual cubic metres per hour
- **GPH (US)** = US gallons per day
- **Sm³/h** = Standard cubic metres per hour
- **SCFH** = Standard cubic feet per hour
- **TPD** = Tonnes per day
- **lb/d** = Pounds per day
- **Am³/d** = Actual cubic metres per day
- **GPD (US)** = US gallons per day
- **Sm³/d** = Standard cubic metres per day
- **MMSCFD** = Million standard cubic feet per day
- **TPA** = Tonnes per annum
- **MMSm³/y** = Million standard cubic metres per year
- **MMSCF/y** = Million standard cubic feet per year

**Note:** Volumetric values are based on saturated LNG of approximately 96.2% C1, 3.7% C2, 0.4% C3, 0.15% C4 and 0.55% N2 (at -161.8 °C, 1.1 bara)
LNG projects

Overview

What sets Wärtsilä apart from competitors is the scope and quality of our services. In addition to the actual technology, we have unique capabilities to assist our customers on the path from idea to successful business.

- Our customers benefit from Wärtsilä’s global team of project developers and financing professionals that ensure the bankability of projects.
- The technology for our LNG infrastructure solutions is proven and supported by an LNG Solutions Design team of more than 250 inter-disciplinary engineers backed up by intellectual property rights.
- We are an experienced EPC contractor that has carried out energy projects all over the world. Our personnel uses professional project management methodology and best practices.
- Through Operations & Maintenance solutions, we can offer our customers guaranteed performance and predictability of maintenance costs.
- Wärtsilä can also offer an LNG terminal and power plant in one EPC package. Synergies between these facilities are often considerable.

By choosing Wärtsilä to supply a complete solution, you have a reliable and trustworthy partner for the whole lifecycle of the investment.

Considerations

As small-scale LNG is in a state of development, LNG project developers must look farther than the actual infrastructure. Decisions in different parts of the value chain are highly interdependent. To ensure the success of a project, the viability of the whole value chain should be investigated and all stakeholders aligned.

Wärtsilä is there to support our customers throughout this process. There are a number of questions that need to be answered:

- Where is LNG available and at which price?
- Who will do the shipping and with what type of ships?
- What is the right location for the terminal? Should it be onshore or floating? What is the optimal capacity?
- How much consumption can be secured? How can the LNG/gas be delivered to the offtakers?
- What is the best way to finance the project?
- How can we ensure compliance with the requirements of permitting authorities?
LNG projects

LNG supply
There are 20 LNG-exporting countries in the world and hundreds of LNG carriers. With the shale gas boom in the US, gas prices have fallen. Considering liquefaction projects currently under construction, the production of LNG will increase by almost 50% in the near future. Still, this does not guarantee that LNG becomes a freely traded commodity available to any small-scale LNG project. Wärtsilä can help you evaluate your LNG supply options to overcome this challenge.

Another factor that needs to be considered is that natural gas has different specifications depending on its origin. Some LNG is produced on rich gas and some on lean gas. A terminal needs to adhere to its customers’ requirements and will, therefore, specify an allowable range of components and heating values. For large-scale terminals, gas conditioning solutions may be installed, but this is seldom feasible for small-scale terminals. This may further limit the supply options.

Most large-scale liquefaction plants operate according to a business model where financially strong entities commit to long-term contracts for large volumes of LNG. For these giants, a small-scale project is seldom an attractive customer. Moreover, they are often not equipped for the berthing and loading of small LNG carriers. Hence, in most parts of the world, there are not many options for small-scale terminals to contract LNG. However, the trend is that large-scale liquefaction plants and terminals are modifying their marine facilities to allow loading on small LNG carriers as well. For small liquefaction projects, the tight supply situation presents an interesting business opportunity.

Shipping
Shipping of small amounts of LNG is still in its infancy, but there are a lot of shipping companies looking to enter this promising market. Still, transportation may be a bottleneck for a small-scale project. Especially considering that most of the vessels in this size range are multigas carriers that in addition to LNG also are able to transport LPG and/or ethylene, which means that they will be deployed where earnings are highest. In many cases, the choice of LNG carrier is dictated by the facility where the LNG will be loaded and not by what is optimal for the regasification terminal.

LNG infrastructure
Small-scale LNG infrastructure is very much dependent on a good location. While large-scale facilities often can be feasible despite requiring considerable investment in marine facilities, a small-scale
LNG projects

from idea to successful operation

terminal usually needs to be built where some type of port or harbour already exists. Also, floating solutions, such as FSRUs or storage and regasification barges, have their limitations related to location-specific conditions.

Making smart decisions regarding the storage and regasification capacities of the terminal improves project economics, but demands a good understanding of the whole value chain. For example, choosing bullet tanks instead of flat-bottom tanks is quicker and allows for a stepwise increase of storage capacity as demand grows. However, availability of LNG carriers and requirements from LNG suppliers might force you to already from the start commit to larger shipments, which requires a larger storage capacity that can only be economically built as a flat-bottom tank.

**Distribution**
Normally, regasification terminals have sent out gas at high pressure to the national grid. However, with increasing LNG demand from decentralised power generation, ship bunkering and high horsepower vehicles and equipment, your business model might benefit from offering multiple options. This requires you to consider whether to handle these activities yourself or to find a suitable partner for distribution of LNG.

**Offtake / consumers**
A confirmed demand for gas/LNG is the basis for any project, which makes it a good idea to already in an early stage engage an anchor customer that can provide a considerable demand and, in some cases, contribute with equity. Such potential anchor customers could be found within the power generation industry, energy-intensive manufacturing industries or petrochemical industry, while for small-scale projects gas-driven transportation and domestic gas consumption may contribute with additional consumption that can help you to reach a targeted capacity.

**Financing**
As many projects can only materialise with the help of external financing from banks or equity partners, limited recourse or non-recourse financing is a common financing arrangement for LNG projects. Lenders and investors will want to carry out an extensive due diligence on the potential viability of the project and a detailed review of whether the project risk allocation protects the project company sufficiently. Therefore, experience in setting up so-called Special Purpose Vehicles is necessary. It also requires close consideration of which project delivery method offers the best guarantees for a successful project.

**Authorities and permitting**
There are stringent standards and regulations that cover the construction and operation of LNG facilities. High environmental standards are demanded by local, national and supranational authorities who require extensive environmental assessments of design and operation before granting their approval to construct and operate.
Also, the relevant permits require rigorous safety studies and risk assessments. The main objective is a safe, reliable and operable LNG facility based on a simple and effective design that meets the latest international safety and environmental codes and standards.

Risk to both personnel and property must be closely examined through:

- Study basis – documentation of site conditions
- Risk assessments
  - QRA – Quantitative Risk Analysis – simulation of worst case scenarios based on design data and scenarios from other safety studies
  - FERA – Fire and Explosion Risk Assessment
  - HAZID – Hazard Identification
  - HAZOP – Hazard and Operability study
  - SIL – Safety Integrity Level study.
  - LOPA (layers of protection analysis) is the most common method.
  - AEA – Action Error Analysis (one type of human error analysis) based on procedures.
  - RAM – Reliability, Availability, Maintenance analysis
- Siting – establishing safety distances for the operation
- Verification – confirmation that design is in accordance with requirements & recognised standards and that agreed safeguards are implemented

Wärtsilä produces documentation and training for the project stakeholders to support the maintainability and safe operation of the infrastructure. Wärtsilä can also provide operation and maintenance services.

Project development & financial services

Our customers benefit from Wärtsilä’s global team of project developers and financing professionals that ensures the bankability of projects. Wärtsilä Development & Financial Services (WDFS) actively works with both LNG infrastructure projects and power plant projects for Independent Power Producers (IPP).

Project development
WDFS develops LNG infrastructure projects by taking a holistic approach to the LNG value chain and ensuring a sound business case for all stakeholders – all the way from liquefaction through logistics and regasification to consumption. Thanks to its wealth of experience and extensive network in power generation and shipping, Wärtsilä is well positioned to develop both offtake (e.g. through fuel conversions of existing power plants) and logistics for LNG projects.

With a proven track record since 1991, WDFS has 25 years of experience developing large energy infrastructure projects around the world. WDFS structures and negotiates project financing on a limited recourse or non-recourse basis. WDFS has over the years proven its ability to mobilise capital from multilateral and bilateral institutions, local and international commercial banks, and equity investors.

Financial services
WDFS supports clients with advice and assistance in deal structuring and financing, including financial modelling and feasibility studies. Through its strong relationships with both local and international financing institutions, including export credit agencies (ECA), commercial banks and development banks, WDFS is well positioned to structure financing to suit each customer’s requirements. Wärtsilä may also participate in projects with an equity stake.
Front-end work services

Wärtsilä can take either a supporting or a leading role in the customer’s LNG project development process. In a supporting role, we provide technical and commercial input to our customers or the customer’s design consultant for their traditional conceptual and feasibility study. However, with Wärtsilä in a leading role, we carry out the studies on behalf of the customer based on their requirements.

Choosing Wärtsilä’s collaborative front-end work services over a traditional Conceptual – Feasibility – Pre-FEED – FEED – Tendering process offers valuable benefits:

- A collaborative approach to the project definition phase shortens time to Final Investment Decision (FID), allowing the customer to act on business opportunities first and make money sooner.
- A collaborative approach leads to fewer uncertainties regarding the scope of work and therefore lowers both the project risk and cost.
- A good project definition that takes Wärtsilä’s technological and organisational strengths into account ensures constructability and solutions fit for the purpose of small-scale LNG at lower CAPEX and OPEX without compromising sustainability, functionality and safety.

The outcomes of the pre-study, conceptual study and FEED study will support the customer’s feasibility study.

Pre-study
The pre-study defines the project frame and gives a basic understanding of the project.

The result of the pre-study is a cost estimate and project requirement overview that the customer can utilise for the decision to make a conceptual study of such a project.
LNG projects

Capabilities

- Inter-disciplinary team of more than 200 Project Managers and Project Engineers with 100+ PMI certified professionals
- Project control and planning team
- Certified HSE Management System OHSAS 18001 & ISO 14001. Lost Time Injury Frequency (LTIF) ≈ 1.0 (EPC construction sites)
- Quality Management System ISO9001
- Efficient sourcing process and well-managed supplier base
- Experienced construction management team of 400+ engineers
- Established network of partners, engineering, manpower etc.
- Sustainable construction strategy utilising qualified subcontractors with positive local socioeconomic impact

Information systems

- Project Portfolio Management (Clarity)
- Schedule Management (built on MS Project)
- Document Control Management (DCM365) to manage collaboration, submittals and interfaces between project stakeholders
- Digital Document Repository (IDM) for document management
- Project Quality Management Plan (PQMP) Configurator
- HSSE Incident Investigation and Reporting tool (WeCare)
- Management of Construction Site Information (Site 365)
- Commissioning Management (SQAD) to generate and configure projects’ Quality Assurance / Control Documentation
- Project Logistics and Material Management (LOGWIS)

Delivery methods

Wärtsilä believes that complete Engineering, Procurement, Construction (EPC) is the delivery method that provides the best value to customers. However, in certain cases such as for large-scale LNG projects, Wärtsilä may also limit its scope to the delivery of a process solution, for example, reliquefication or regasification units.

With EPC, the customer does not need to commit as much time and resources to administration, legal consultations and contractual setup. More importantly, it also significantly reduces the customer’s risk by offering a guaranteed price, delivery date and performance. Having eliminated these risks is often a pre-requisite for the bankability of the project.

The following variations are offered:

- EPC turnkey (Wärtsilä-developed project)
- EPC including front-end work done by Wärtsilä on a reimbursable basis
- EPC based on front-end work done by the customer’s design consultant
- EPC / EPCIC excluding civil works, based on front-end work done by the customer’s design consultant
LNG projects from idea to successful operation

**Project management value proposition**

**Speed**
- Pre-fabricated product minimising site work
- Global network of proven partners and suppliers
- Earlier access to market

**Collaboration**
- Early involvement enables proactive and collaborative project approach
- Listening to customer needs
- Open communication
- Customer Relation On-Line process CROL®

**Predictability**
- 25 years of EPC construction experience in 90 countries
- Quality assured, professional project management
- Experienced personnel and partners
- Access to all Wärtsilä experts and resources
- Risk mitigation

**Scope flexibility**
- Clear and managed contractual interfaces
- Reduced project complexity
- Optimal scope of supply through several scope packages
LNG projects

Operations & Maintenance

Optimising your operations and preventing the unexpected is our shared passion – we serve you whenever, wherever. Wärtsilä serves and supports customers in improving and optimising their operational efficiency throughout the whole lifecycle of the installation. Our Services organisation currently features more than 11,000 dedicated professionals in almost 70 countries. Our Services solutions cover everything from comprehensive customised long-term Lifecycle solutions to product support with parts, field service and technical support, training and online support.

Benefits of Wärtsilä’s lifecycle services:
• Ensured productivity throughout the asset lifecycle
• High availability with minimised unplanned downtime
• Predictability of maintenance costs over medium to long term
• Attention to safety and environmental aspects

Maximise the productivity through a maintenance solution

With a maintenance solution you can ensure the certainty of operations by transferring responsibility for maintenance of your LNG facility to Wärtsilä. This is a proven way of keeping your LNG facility productive and profitable throughout the asset lifecycle. With this Lifecycle solution you can maximise the lifetime for your LNG facility and optimise maintenance costs in a safe, reliable, and environmentally sustainable way.

Scope of supply
• Online remote operations support
• Maintenance management & planning
• Technical evaluation
• Operational data analysis
• Technical support
• Spare parts for planned maintenance
• Manpower for planned maintenance
• Inventory management
• Safety stock & onsite tools
• Capital spare parts
LNG projects

Online remote operations support
With online connection, we can remotely log into the plant control system and review operations. The operational data is retrieved for trend analysis which enables us to provide recommendations for fine-tuning of operation as well as maintaining and upgrading your equipment.

Maintenance management
This service covers maintenance planning, parts logistics, manpower coordination and maintenance reporting. In order to perform maintenance efficiently and reliably, we ensure that required manpower and spare parts are available for planned maintenance.

Technical support
Technical support to resolve your operational problems is available by telephone and email, within agreed response times.

Further, we visit your installation twice a year to perform technical evaluations. By reviewing trends, we can recommend improvements which can be implemented separately, as agreed.

Safety & capital spare parts
We recommend that you maintain a stock of critical spare parts, especially for parts with long lead times for delivery. If you require, we can manage these stocks for you.
Overview of Wärtsilä’s solutions portfolio

Small-scale LNG is generally defined to comprise liquefaction plants and terminals with a capacity of less than 1 MTPA. Wärtsilä divides the solutions we offer in the following way:

<table>
<thead>
<tr>
<th>Liquefaction plants</th>
<th>Liquefaction capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini liquefaction plants</td>
<td>2000-30,000 TPA 3400-51,000 GPD</td>
</tr>
<tr>
<td>Small-scale liquefaction plants</td>
<td>20,000-300,000 TPA 34,000-510,000 GPD</td>
</tr>
<tr>
<td>LNG peak shaving plants</td>
<td>10,000-100,000 TPA 17,000-170,000 GPD</td>
</tr>
<tr>
<td>Mid-/large-scale liquefaction plants</td>
<td>&gt; 300,000 TPA &gt; 510,000 GPD</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Terminals</th>
<th>Storage capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG satellite terminals for gas power plants</td>
<td>100-20,000 m³ tank 26,400-5.3 million gallons</td>
</tr>
<tr>
<td>Small satellite terminals</td>
<td>100-20,000 m³ tank 26,400-5.3 million gallons</td>
</tr>
<tr>
<td>Storage &amp; regasification barges</td>
<td>1000-30,000 m³ tank 264,000-7.9 million gallons</td>
</tr>
<tr>
<td>Medium-scale terminals</td>
<td>20,000-160,000 m³ tank 5.3-42.3 million gallons</td>
</tr>
<tr>
<td>Large-scale terminal</td>
<td>&gt;150,000 m³ tank &gt; 39.6 million gallons</td>
</tr>
</tbody>
</table>

TPA = Tonnes per annum  
GPD = Gallons per day

LNG storage tanks

Onshore storage for small-scale LNG can either be arranged using a flat bottom tank with a storage capacity of ≈15,000-160,000 m³, spherical tanks of ≈1000-8000 m³ or, for small LNG storage volumes, bullet tanks. Bullet tanks are available up to 1200 m³, meaning that larger storage capacities (up to 20,000 m³) are arranged with multiple bullet tanks.

**Flat bottom tanks** can be divided into single containment, double containment or full containment tanks. Above-ground full containment tank technology is the preferred solution when it comes to storing large quantities of LNG with maximum safety in a limited site area. But depending on safety requirements and free space available around the tank, also the single and double containment tanks can be considered. Flat bottom tanks are produced at the site, which prolongs construction time.

Full containment tank

1. Concrete  
2. Insulation  
3. Steel lining  
4. Inner tank  
5. Thermal protection system  
6. Suspended roof  
7. Main operating platform  
8. Pump columns  
9. Instrumentation casing pipes
LNG infrastructure solutions

A single containment tank is composed of an inner, self-supporting cylindrical container made of cryogenic steel (9% nickel steel). Insulation surrounds the inner tank to control heat leak into the tank. An outer tank made of carbon steel, in turn, holds the insulation. The outer tank is non-cryogenic (carbon steel), meaning that only the inner tank provides the containment for the LNG. However, single containment tanks are always surrounded by a bund external to the tank. The bund is designed to contain the full volume of LNG plus some safety margin in the event of a complete failure of the tank.

The double containment tank is similar to a single containment tank, but instead of a containment bund, the tank is surrounded by a close-in, reinforced open top concrete outer container. If the inner tank fails, the secondary container is capable of containing all of the cryogenic liquid. The outer concrete wall increases the cost of the tank, but less space is required because there is no need for a containment bund.

Full containment is essentially a double containment tank in which the secondary container completely encases the primary container and is designed to be liquid and vapour tight in case of rupture. It, therefore, offers the highest inherent safety of the tank alternatives whereby limiting the required safety area. The majority of LNG flat-bottom storage tanks built in the last 10 years worldwide have been designed as full containment tanks.

Spherical tanks are rarely used for LNG, but can in some cases be the best option. The spherical shape creates a strong structure because of the even distribution of stresses on the sphere’s surfaces. Their main advantage is that they have a smaller surface area per unit volume than any other shape of the tank, meaning less heat ingress and thus less BOG.

Bullet tanks are of interest when it comes to storing smaller volumes of LNG. They are vacuum and perlite or vacuum and multilayer insulated stainless steel pressure vessels, operating
LNG infrastructure solutions

above 0.5 barg. These tanks are modular, flexible, available in vertical or horizontal formats, and may be arranged in tank farms of any number of manifold rows of tanks to provide the desired amount of storage. Bullet tanks are pre-fabricated in factories, which reduces site costs. Pressurised tanks are designed and operated so that no boil-off gas compressor is needed.

Vertical tanks
• Small footprint compared to horizontal tank
• Heavy foundations
• Sizes up to approximately 300 m³ per tank

Horizontal tanks
• Large footprint compared to vertical tank
• Sizes up to approximately 1200 m³ per tank

The safety requirements are an important input for selecting the type of bullet tank system. Bullet tanks have an inner shell made of cryogenic steel and an outer shell of cryogenic or non-cryogenic steel. The tanks can have a bund around the whole tank farm area or only under the process area.

Double shell bullet tank

<table>
<thead>
<tr>
<th>Tank type</th>
<th>Bullet tank (Double shell steel tanks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>Single tank 100-1200 m³</td>
</tr>
<tr>
<td></td>
<td>Multiple tanks 100-20,000 m³</td>
</tr>
<tr>
<td>Boil-off gas (holding mode)</td>
<td>0.05-0.15% per day, but the tank is capable of handling the increased pressure for up to one month</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>0.5-8 barg</td>
</tr>
<tr>
<td>Rollover monitoring needed</td>
<td>No</td>
</tr>
<tr>
<td>Manufacturing method</td>
<td>Pre-fabricated in factory</td>
</tr>
<tr>
<td>Installation time on site</td>
<td>Days to weeks</td>
</tr>
</tbody>
</table>

LNG storage alternatives offered by Wärtsilä

<table>
<thead>
<tr>
<th>Tank type</th>
<th>Flat bottom tank (Single, double or full containment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>15,000-160,000 m³</td>
</tr>
<tr>
<td>Boil-off gas (holding mode)</td>
<td>0.05% per day</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>Atmospheric</td>
</tr>
<tr>
<td>Rollover monitoring needed</td>
<td>Yes</td>
</tr>
<tr>
<td>Manufacturing method</td>
<td>On site</td>
</tr>
<tr>
<td>Installation time on site</td>
<td>24-36 months</td>
</tr>
</tbody>
</table>

1. Inner vessel (cryogenic steel)
2. Insulation (vacuum and perlite)
3. Outer vessel (cryogenic steel and non-cryogenic steel)
4. Inner vessel over pressure line
5. LNG spray line
6. LNG inlet/outlet line
Boil-off gas (BOG) handling

One of the main challenges of LNG storage is handling the BOG. BOG is produced because LNG is stored at cryogenic conditions in a much warmer ambient environment. It is the result of several factors:

- Heat leak into the LNG carrier, storage tanks, process equipment and process piping
- Mechanical energy input by process equipment [e.g. low-pressure (LP) in-tank and high-pressure (HP) send-out pumps]
- Displaced vapours from the LNG carrier and LNG storage tank due to unloading, loading and send-out flowrates
- Atmospheric pressure changes
- Elevation difference between the LNG carrier and the storage tanks

BOG forms in the top of the LNG tank and creates pressure that has to be managed or released in order to maintain the pressure within the limits of the tank design. For flat bottom tanks, during normal operation and storage BOG is only about 0.05% of tank mass per day, while it can be eight to ten times higher during ship unloading. When excess BOG is generated during ship unloading it is common to return the BOG to the LNG carrier through a vapour return line, compensating for the reduction of the liquid volume in the vessel. However, in small-scale LNG it is sometimes possible to eliminate the vapour return line if the LNG carrier is equipped with vaporisation systems for equalising the pressure.

BOG consists of lighter hydrocarbons that boil off more quickly, mainly methane and nitrogen. It is not allowed to be purged into the atmosphere due to its greenhouse gas effect, so the simplest way to get rid of BOG is to burn or flare it. This is of course not desirable, wasting valuable gas, therefore this option is only considered when no other options are available. The normal way to handle BOG in terminals with a constant send-out is to use a BOG compressor pumping the BOG out together with the gas send-out to a local offtaker, such as a power plant, or into the gas pipeline. Depending on the gas piping pressure level there is either a low-
pressure or high-pressure BOG compressor. A temporary solution to get rid of the BOG forming at the top of the tank is to recirculate or top spray the tank with cold LNG from the bottom. Another alternative that also requires LNG send-out is to use a BOG re-condenser. In the BOG re-condenser, the BOG is mixed with subcooled LNG for re-condensation of the BOG. When there is no gas send-out, the LNG terminal is in a so-called zero send-out mode. If you have excess BOG during zero send-out mode the only other alternative to flaring is to re-liquefy the BOG and pump it back into the tank. Wärtsilä has developed modularised packages for the various BOG handling systems with the BOG compressor as the main component.

Wärtsilä’s recommendation is to build the terminal in conjunction with gas consumers that can utilise the BOG in their processes or power production. This way we can guarantee BOG consumption at any time. In addition, no gas is wasted and energy use for reliquefying the gas is avoided. Combining a Wärtsilä gas power plant with a terminal is a perfect solution as the BOG can be directly converted into electric power. The electricity can be used in the LNG terminal itself or exported to other consumers.

**Options for handling BOG**

- Venting (only allowed in emergency situations)
- Flaring
- Returning the BOG to the LNG carrier during unloading (only an add-on solution during unloading)
- BOG re-condensation and pumping back to LNG tank (requires a constant send-out of LNG)
- Utilising BOG in a nearby power plant converting into electric power and heat
- LNG recirculation / top spraying
- Pumping it to the LP gas pipeline (< 10 bar)
- Pumping it to the HP gas pipeline (10-50 bar)
- Reliquefation of BOG into LNG

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Import and export options

Large-scale LNG infrastructure has traditionally been very straightforward with liquefaction plants loading their products onto LNG carriers, and terminals unloading from LNG carriers to tanks and sending out high-pressure gas. Small-scale LNG, on the other hand, must offer more flexibility in loading and unloading the LNG. A transformation in the same direction can now also be seen in the large-scale landscape, where more and more facilities offer at least truck loading.

**Loading/unloading**

**LNG carriers** are often the best option for facilities located by the sea when there are large quantities of LNG to be transported. To accommodate LNG carriers, marine facilities must be designed to ensure safe navigation, berthing/unberthing and loading/unloading. Small-scale LNG terminals should also the bi-directional flow of LNG to allow for re-loading onto smaller LNG carriers.

**Tanker trucks** are commonly used for distribution of LNG from in-land liquefaction plants, but it makes sense for all types of LNG facilities to include one or multiple loading/unloading bays. Loading/unloading can be done using either arms or flexible hoses. Containerised tanks are vacuum insulated tanks installed inside
a container shaped frame. These can be used to transport LNG by road on flatbed trucks, railroad or enable shipping to ports that don’t have LNG unloading infrastructure.

**Rail tank cars** are a less common form of transportation but could be an option if railroad infrastructure is available nearby.

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**Gas send-out**

Gas send-out is the main function of a terminal or LNG peak shaving plant and the regasification/vaporisation unit is the core system. BOG compressors are normally integrated into this system, releasing the excess BOG together with the send-out as described earlier.

Depending on the requirement, there can be an LP send-out system (< 10 bar), or an HP send-out (10-50 bar). The low-pressure send-out is a fairly simple system where the tank low-pressure LNG pumps are pushing the LNG via the regasification/vaporisation module to the pipeline. In case of a high-pressure send-out system there will be additional HP pumps that can be supplied as part of the vaporiser/regasification module. Typically gas transmission pipelines require a pressure above 10 bar while more local gas distribution pipelines can have a design pressure of less than 10 bar. Gas turbine power plants require 15-40 bar of gas pressure, while a Wärtsilä gas or dual-fuel power plant runs at pressures as low as 6 bar.

In order to convert the LNG back to gaseous form for the final consumers, all the energy that was extracted from the gas to make it liquid in the first place has to be returned to it through the vaporiser. The vaporiser is essentially a large heat exchanger that heats the LNG.

Typical types of vaporisers that have been used worldwide for LNG regasification are:

- Open rack vaporisers (ORV) based on seawater heating
- Submerged combustion vaporisers (SCV) based on fuel heating
- Ambient air vaporisers (AAV) based on ambient air heating
- Intermediate fluid vaporisers (IFV) using for example propane or intermediate fluid to prevent freezing

Wärtsilä offers all of these options and combinations of them.

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**Fuelling**

**Ship bunkering** can be carried out using tanker trucks or bunker vessels, but in some cases also at, or close to, a liquefaction plant or terminal. A shore-ship configuration offers large capacity and high bunkering rates.

**LNG filling stations** for LNG-fuelled trucks can conveniently be located next to a liquefaction plant or terminal if there is a sufficient amount of consumers in the vicinity. In such cases, the filling station is located outside of the facility’s fences.
LNG infrastructure solutions

Liquefaction plants

**INPUT**

- **Gas sources**
  - Pipeline gas
  - Biogas
  - Landfill gas
  - Associated gas
  - Coal seam gas
  - Tight gas
  - Shale gas

**PLANT**

- **2000-300,000 TPA**
  - **Mini liquefaction plants**
    - Mixed Refrigerant:
      - 2000-30,000 TPA (3400-51,000 GPD)
    - Reverse Brayton:
      - 20,000-300,000 TPA (34,000-510,000 GPD)
  - **Small-scale liquefaction plants**
  - **Peak shaving plants**

**OUTPUT**

- **LNG transport**
  - Carriers
  - Tanker trucks
  - Containers
  - Rail cars

- **Peak shaving gas send-out**

- **Ship bunkering**

Wärtsilä’s portfolio includes mini and small-scale liquefaction plants in the range from 2000 to 300,000 TPA (5 to 822 TPD) trains. The same proven technology that has successfully been used for reliquefaction on board LNG carriers is used here as well.

- Modular skids based on proven design are quality-checked in the factory, easy to transport and quick to install, thereby reducing risk and cost.
- Load variation is easy to handle, which gives flexibility of operations while maintaining efficiency.
- State-of-the-art control system automates the plant and makes it easy to operate. Even unmanned remote operation is possible.
- Easy maintenance ensures high availability throughout the years of operation, maximising profit.

When discussing the efficiency of different liquefaction technologies, one should keep in mind that the choice depends on the requirements of the specific project. Plants can be designed for maximum efficiency with tailor-made processes at additional cost, but in many cases it is more important to simplify the plant and make it easy to operate. The target is to have an optimal balance between energy efficiency, operational flexibility and cost efficiency that yields the best return on investment.

### Mixed refrigerant

- **Production capacity**: 2000 to 30,000 TPA
- **Refrigerant system**: Proprietary mix of hydrocarbons in a closed loop
- **Energy consumption**: As low as 0.7 kWh/kg depending on project specific conditions
- **Technology features**: Off-the-shelf components that enable a less expensive solution, quick delivery and simplified maintenance
- **Installation**: Plug-and-play design with standard capacities 10, 17 and 25 TPD delivered within 12 months

### Reverse Brayton

- **Production capacity**: 20,000 to 300,000 TPA
- **Refrigerant system**: Nitrogen produced from air on-site
- **Energy consumption**: As low as 0.32 kWh/kg depending on project specific conditions
- **Technology features**: Robust technology that allows for quick and simple start-up & ramp up/ramp down compared to competing technologies
- **Installation**: Reduced installation time and small footprint through a modularised design
Mini liquefaction plants

These are liquefaction plants that have a capacity of 2000-30,000 TPA (= 5-80 TPD) and the LNG is primarily intended for local consumption. They can be built anywhere near a gas source for the following purposes:

- Virtual pipeline (end-of-pipeline gas liquefaction)
- Stranded gas liquefaction (associated gas, coal seam gas, tight gas, etc.)
- Biogas and landfill gas liquefaction

Wärtsilä provides the complete process package of mini liquefaction plants as a minimum. Also, civil engineering and construction can be included, as well as delivery of the complete plant as an EPC. Furthermore, Wärtsilä can offer an Operations & Maintenance (O&M) package tailored to the customer’s requirements.

For mini liquefaction plants, Wärtsilä mainly uses bullet tanks combined with the MR (Mixed Refrigerant) liquefaction technology due to their small size.

Wärtsilä has developed a simplified version of the MR process based on a simple screw compressor and a special mix of refrigerants. Thanks to a buffering system it is a fully closed loop system that does not need refilling after a start and stop procedure. The system is delivered as three prefabricated modules. It is based on standard components with a level of standardisation that allows for low investment cost and fast manufacturing of the module. The repetitive design gives consistent high quality in a compact module.

With a slightly different refrigerant mixture, an intelligent automation system and standardised components, Wärtsilä has been able to combine the high efficiency of the MR process, with the simplicity needed for smaller plants. For small capacities below 50 TPD, Wärtsilä’s MR process is the ideal solution.

Wärtsilä’s MR solution is perfect for biogas and landfill gas liquefaction plants that are usually built in smaller sizes. The first plant built with this technology is the biogas liquefaction plant for the City of Oslo, Norway, which has been operational since 2013.
LNG infrastructure solutions

Advantages of Wärtsilä’s MR technology for mini liquefaction plants:

- Easy and quick start-up and shut down of all systems.
- Can be started in 30 min, but typically < 3h due to heat exchanger cool down limitations.
- The lowest specific power consumption in the small size plants.
- All components based on conventional parts and proven technology, spares can be delivered quickly.
- Short delivery time (< 12 months) where the cold box and compressor are the only long lead items.
- Reliable main rotating machinery with high efficiency (Oil flooded screw compressor).
- Compact design & easy shipment as all in one module and a separate compressor skid.
- Designed for unmanned operation.
- Local control of LNG export, truck driver handles loading.
- Simple energy supply, only electrical power needed.
- Standard capabilities: 10, 17 and 20 TPD.
- Plug and play philosophy, skid based – relocation possible.
- A broad range of applications, biogas, pipeline, CBM and associated gas.

<table>
<thead>
<tr>
<th>Customer</th>
<th>Cambi AS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Mini liquefaction plant</td>
</tr>
<tr>
<td>Tank capacity</td>
<td>180 m³</td>
</tr>
<tr>
<td>Capacity</td>
<td>11 TPD / 4000 TPA</td>
</tr>
<tr>
<td>Size of liquefaction unit</td>
<td>8 m x 14 m</td>
</tr>
<tr>
<td>Gas source</td>
<td>Biogas from 50,000 TPA of food waste</td>
</tr>
<tr>
<td>Details</td>
<td>Fuel production for 135 buses in the city of Oslo</td>
</tr>
<tr>
<td>Scope of supply</td>
<td>Complete plant, including</td>
</tr>
<tr>
<td></td>
<td>• Gas pre-treatment</td>
</tr>
<tr>
<td></td>
<td>• Cooling system (ambient air)</td>
</tr>
<tr>
<td></td>
<td>• MR liquefaction process</td>
</tr>
<tr>
<td></td>
<td>• Storage tank</td>
</tr>
<tr>
<td></td>
<td>• Electrical and control system</td>
</tr>
<tr>
<td></td>
<td>• Service agreement</td>
</tr>
<tr>
<td></td>
<td>Excluding civil works and installation</td>
</tr>
<tr>
<td>Delivery method</td>
<td>EPC</td>
</tr>
<tr>
<td>Delivery</td>
<td>2013</td>
</tr>
</tbody>
</table>
Small-scale liquefaction plants

These are liquefaction plants that have a capacity of 20,000-300,000 TPA (= 60-800 TPD). They are either built inland next to a smaller gas field or by the shore at the end of a gas pipeline for easy access by LNG carriers. For these applications, dependent on storage capacity, we use either bullet tanks or flat bottom tanks. The preferred liquefaction technology is the Reverse Brayton cycle, but the MR process can also be an alternative in certain cases.

Wärtsilä provides the complete process package as a minimum. Also, civil engineering and construction can be included, as well as delivery of the complete plant as an EPC. Furthermore, Wärtsilä can offer an Operations & Maintenance (O&M) package tailored to the customer’s requirements.

Generally, for the larger sizes (> 60 TPD) Wärtsilä recommends a liquefaction system with double expanders based on the Reverse Brayton Cycle process. The advantage of this system compared to other systems is that it is very adaptive to capacity changes and very easy to operate. Furthermore, the nitrogen used as refrigerant is produced directly from the air at the site. Wärtsilä has improved and fine-tuned the Reverse Brayton process to reduce electricity consumption. Wärtsilä’s Reverse Brayton system is used in more than 40 LNG carriers for their reliquefaction systems, many thanks to its ease of operation, reliability and robustness.

Advantages of Wärtsilä’s Reserve Brayton Cycle for small-scale liquefaction plants:

- Robust, reliable and simple to operate technology.
- Designed for unmanned operation.
- Capacity control is very easy and quick.
- Easy start-up and shut down of all systems.
- Simple energy supply, only electrical power needed.
- Refrigerant will be produced directly from air to site – No logistics connected to the refrigerant.
- There is no required handling of chemicals.
- ZERO FLARE solution during normal operations, hydrocarbon losses will be zero.

![Process overview of Wärtsilä Reverse Brayton technology](image-url)
These are plants with a capacity of 10,000-100,000 TPA (= 27-274 TPD). They are normally built along gas pipelines and act as temporary storages in locations where the gas consumption varies and a buffer needs to be available for peak demand.

LNG peak shaving plants have both liquefaction trains and regasification systems. For part of the year, the plant liquefies natural gas and transfers the LNG to a storage tank, but is ready to offer a large regasification capacity when needed. In this application, Wärtsilä mostly uses flat bottom tanks due to the large sizes normally required. The liquefaction technology used is normally Reverse Brayton Cycle.

Wärtsilä provides the complete process package as a minimum. Also, civil engineering and construction can be included, as well as delivery of the complete plant as an EPC. Furthermore, Wärtsilä can offer an Operations & Maintenance (O&M) package tailored to the customer's requirements.
LNG infrastructure solutions

LNG storage as affordable energy security

- Fraction of the cost of battery storage
  - Additionally, batteries have a limited lifetime resulting in recycling/waste problems
- Superior to underground gas storage
  - Less location specific as it can be built anywhere next to the pipeline
  - Gas can be more quickly inserted to the grid
  - Less risk of gas leakage
- LNG has considerably less volume than compressed natural gas
- Less environmental impact and a fraction of the cost of pumped hydro

Mid- and large-scale liquefaction plants

These are plants that have a capacity of >300,000 TPA (>800 TPD). They are always located on the sea shore for easy access by large LNG carriers.

These are mega projects normally done in consortiums or as EPCMs. Therefore Wärtsilä is currently not offering these type of plants as EPC, but rather as a supplier of selected processes and modules. In these applications Wärtsilä can provide for example:

- Gas/LNG driven power plant for the terminal (typically 20-100 MW)
- BOG reliquefaction systems
- Modularised liquefaction trains of up to 300,000 TPA, ideal for step-wise increase of capacity
- LNG tank control systems

BOG reliquefaction system with 150,000 TPA capacity for a mid-/large-scale liquefaction plant

1. Compressor building
2. Cold box
3. Air coolers
4. Nitrogen tank
5. Electrical and control system
An LNG terminal is a liquid gas processing plant whose main purpose is to receive, store and further distribute natural gas. The storage tank is usually the most expensive part of a terminal unless marine facilities are part of the scope, and the terminals are usually defined according to the size of the tanks. Wärtsilä’s portfolio consists of terminals with various functions combined with a storage capacity in the range of 100 to 160,000 m³.

- Specifically adapted for the requirements of small-scale LNG through elimination of complexity and increase of flexibility
- Single use (e.g. providing fuel for a power plant) or multi-use (e.g. gas send-out, ship bunkering, truck loading)
- Available for both hub and spoke operations
- Onshore and near shore (barge) concepts
- Stringent safety regulations during both construction and operation

These are single-use satellite terminals dedicated to supplying a gas or dual-fuel power plant and include fuel storage and LNG processing systems in the size range of 100-20,000 m³. The storage is mainly built as bullet tanks and capacity depends on the size and operational profile of the power plant and the frequency of filling. For example, a 50 MW baseload plant with an average of 12 days between fillings would need a storage of about 5000 m³.

For this concept, Wärtsilä provides a complete EPC delivery for both the power plant and the LNG satellite terminal. The services and maintenance agreement provided can also include both facilities. For more information about the benefits of a combined EPC delivery, please refer to page 106.
These terminals are smaller local terminals with a size of 100-20,000 m³ and located by the sea shore or rivers. They are often placed in harbours where there is easy access for supply vessels to fill the tanks. The storage is mainly built as bullet tanks. These terminals are often built primarily as bunkering facilities for ships, but they can also include additional services such as truck and container loading to facilitate distribution of LNG in liquid form. In larger sizes, a regasification unit supplying a local gas pipeline can also be added.

Wärtsilä’s preference is to deliver these projects as EPC with full delivery and performance guarantees. The terminal can be supported with full Lifecycle solutions.
LNG infrastructure solutions

Storage and regasification barges

The smallest FSRUs today are around 120,000 m³. There are no small LNG carriers available that can be converted to FSRUs. Wärtsilä has created a solution for this problem by designing a barge containing storage tanks (1000-30,000 m³) and regasification systems. These can be an attractive alternative to onshore satellite and bunkering terminals. The LNG barge can be equipped with the similar processes as the land-based solution. The process can also be split between the barge and land. This can be done, for example, by locating the LNG storage on the barge and process equipment and support facilities onshore.

Wärtsilä prefers to deliver the barge and necessary infrastructure onshore as a complete EPC. Wärtsilä can also provide services and maintenance solutions for the total solution.

- Ideal for providing fast and flexible access to gas in new areas.
- For land unsuitable for onshore LNG tanks or difficult to permit.
- Where there is a lack of skilled labour and local construction material.
- A mobile asset, possible to relocate or trade – ideal for temporary demand and uncertain market conditions.

Medium-scale terminals

These are LNG terminals in the size of 20,000-160,000 m³ located at sea shores, working as hubs for whole regions or larger cities. Due to the major investment and volumes, a group of industries and consumers are needed to make these projects possible. They are always multi-use terminals with flat bottom tanks and can include regasification, pipeline distribution, ship bunkering, re-loading, truck and container loading to facilitate re-distribution of LNG in liquid form.

Wärtsilä’s preference is to deliver these projects as EPC with full delivery and performance guarantees. The terminal can be supported with full Lifecycle solutions.
Tornio Manga LNG
Tornio, Finland

LNG infrastructure solutions

Customer
Manga LNG Oy

Type
Small-/medium-scale terminal

Tank capacity
50,000 m³

Send-out
Max 40 tonnes per hour at 6.0 barg

Scope of supply
- Civil works and infrastructure
- Full containment storage tank
- Regasification & gas metering
- BOG system
- Electrical and control system
- Unloading system
- Bunkering and truck loading

Delivery method
EPC

Delivery
2018

Large-scale terminals

These terminals are built only in countries with large imports of LNG. They are terminals with >150,000 m³ tank capacities and a throughput of >3 MTPA and located at the sea shore for easy access by large LNG carriers.

In these mega projects, Wärtsilä does not assume EPC responsibility but rather supplies selected modules and design packages. Wärtsilä can for example supply:
- Gas-driven power plant for the terminal (typically 10-50 MW)
- BOG reliquefaction systems
- Regasification system
- LNG tank control systems

BOG reliquefaction system with 150,000 TPA capacity for a large-scale terminal

1. Compressor building
2. Cold box
3. Air coolers
4. Nitrogen tank
5. Electrical and control system
LNG infrastructure solutions

Regasification system with 750 MMSCFD capacity for a large-scale terminal

Customer: Dragon LNG
Type: Boil-off gas reliquefaction unit for large-scale terminal
Capacity: 340 TPD / 120,000 TPA
Scope of supply:
- Reverse Brayton liquefaction process
- Cooling system (ambient air)
- LNG buffer tank
- LNG transfer pump
- Instrument air compressor/dryer
- Instruments
- Valves
- Control system
- Supervision/commissioning of site installation
Delivery method: Engineering & Procurement
Delivery: 2017
Regasification units for FSRUs

Our portfolio of LNG regasification technologies represents an industry benchmark in terms of energy efficiency, robustness, and operational flexibility.

Wärtsilä has delivered and commissioned numerous floating LNG regasification plants based on either closed-loop regasification technology, using steam with water/glycol as the intermediate heating medium, or open loop regasification technology using sea water with propane or glycol as the intermediate heating medium.

We have also delivered modularised regasification plants for jetty installations. These facilitate a much shorter construction time compared to conventional land-based LNG regasification terminal projects.

Reliquefaction units for LNG carriers

Wärtsilä is a leading designer, developer and supplier of energy efficient LNG boil-off gas (BOG) reliquefaction plants. These systems are designed to be efficient, reliable, safe, robust and flexible.

With more than 35 systems in operation, Wärtsilä has the highest number of BOG reliquefaction plants installed in the global LNG carrier fleet. Similar solutions can also be installed with onshore LNG terminals.

We work closely with our customers to develop technological solutions that meet their needs for increased fuel flexibility, energy efficiency, and environmental performance in today’s fast changing LNG market.
Additional LNG solutions

Cargo handling system for semi-refrigerated gas carriers
The semi-refrigerated segment covers the range from 4000 m³ to 30,000 m³. Wärtsilä offers a cargo handling system including the design and delivery of C-type cargo tanks designed in either cylindrical or bilobe format.

Recent cargo handling design developments include the capability of handling propane cargo with high ethane content.

Cargo handling system for ethylene / multi-gas carrier
The ethylene carrier segment has grown during the last years, from small size vessels to handy size, and now also includes a large-scale carrier purpose built for ethane trading.

Wärtsilä has become the largest supplier of complete cargo handling systems for vessels in this segment, covering the whole range of sizes requested in the market today. These vessels are known for their flexibility and can trade multiple types of cargoes from gas to chemicals. Deliveries also include carriers with LNG capacity and dual-fuel propulsion.

An increasing supply of ethane has created a new segment of shipping, namely the trade of ethane as feedstock to the petrochemical industry on a large-scale. Wärtsilä is also delivering complete cargo handling system to these very large ethane carriers.

Cargo handling system for fully pressurised gas carrier
The largest fleet of gas carriers in the world is in the fully pressurised segment. For fully pressurised vessels the cargo tank volumes are typically in the range 1000 m³ to 11,000 m³.

Wärtsilä Gas Solutions offer modern solutions and advanced solutions for such vessels.

Fully pressurised vessels carry LPG at ambient temperatures, with the corresponding gas pressure this gives. Cargo tanks are usually able to handle a tank pressure of 18 barg.

Wärtsilä has developed the new QiCool Chiller unit suitable for fully pressurised LPG ships.

Gas cargo handling systems

Cargo handling for small LNG carriers
There is a growing demand for the small-scale transport of LNG to end users that are located in areas where pipelines are not feasible or economically viable. Typically, such end users are power generation plants, land-based industries, and suppliers of LNG as fuel for vehicles or ships. Wärtsilä has developed a cargo handling system that is designed from the extensive experience that Wärtsilä has accumulated in delivering such systems for LPG, LEG and LNG carriers.

The scope available includes:
- Cargo handling system
- Boil-off gas handling
- Cargo tank design and complete tank delivery
- Ship design
- LNG fuel supply system

We provide designs for small size LNG carriers carrying LNG only, or multi gas carriers able to carry all types of gas cargo, including LNG. Typically these ships are between 4000 and 40,000 m³.
Additional LNG solutions

QiCool allows increased loading of the cargo tanks and a possibility to lower the design pressure for the cargo tanks thereby enabling weight and cost savings to be achieved.

Cargo handling system for fully refrigerated vessels
For many years already, Wärtsilä has been the preferred cargo handling equipment supplier for many of the leading owners of fully and semi-refrigerated vessels. When transported in these ships the LPG is normally kept at its coldest temperature (atmospheric pressure) and the required equipment has, therefore, to be extremely reliable. Our innovative and energy efficient solutions, together with the broadest portfolio of reliquefaction configurations, have given us a leading position in this market.

Ship & cargo tank design
Wärtsilä Ship Design offers a ship design portfolio that is among the most extensive in the industry. This portfolio includes the design of gas carriers, for which we have focused on small to handy size vessels with the possibility to tailor the appropriate final design in cooperation with the owner and shipyard. Our services cover the spectrum from conceptual studies to class approved designs and yard workshop drawings.

Having the in-house resources to design C-type cargo tanks allows us to be a complete partner for the building of gas carriers. Our IMO C-type cargo tank designs include the cylindrical tanks, bilobe tanks, and tanks for LPG FP (-10°C), ethylene (-104°C) and LNG (-163°C).
Additional LNG solutions for marine and energy

Wärtsilä Ship Design offers innovative designs with the emphasis on cost efficiency. Our designs are initiated from detailed discussions with the ship owner to attain a deep understanding of the company’s business model, and from this basis, we develop the specific type of vessel needed. In this attention to detail, we differentiate from the majority of our competitors. All of our designs are optimised to achieve higher energy efficiency, lower operating costs, and enhanced environmental performance. They also ensure optimal construction at the shipyard.

Our unique expertise, knowledge, and global footprint allow us to turn our customers’ vision into reality and maximise their profits and asset values. With more than 4000 vessels built to our designs, including the most advanced LNG fuelled ships, the competitive edge we bring our customers is a well-established fact.

We cover the full range of ship design disciplines, including naval architecture, hull optimisation, stability calculations, hull and structural engineering, machinery- and piping engineering, and outfitting. We offer a broad range of options, from basic designs including classification drawings, to detail designs and optimised 3D production drawings. We also offer a comprehensive range of marine consultancy services for shipyards, or owners undertaking newbuilding, conversion, and retrofit projects.
Additional LNG solutions for marine and energy

LNG carriers and bunkering vessels

Wärtsilä’s small-scale LNG carrier series comprises five ship designs, the WSD59 3K, WSD59 6.5K, WSD59 10K, WSD55 12K, and WSD50 20K, all of which have been developed in close cooperation with customers to produce vessels that are appropriate for the global LNG infrastructure and applicable for both ocean-going and inland water operations. In each case, fuel economy, performance guarantees, optional versions to meet specific needs, and the flexibility to choose particular features and solutions have been emphasised.

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<tr>
<th>Name</th>
<th>WSD50 20K</th>
<th>WSD55 12K</th>
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</table>

Please see the corresponding catalogue. Available on Wärtsilä’s website.
Additional LNG solutions

Fuel gas handling system

Wärtsilä LNGPac™ is a complete fuel gas handling system for LNG fuelled ships and includes the bunkering station, LNG tank and related process equipment as well as the control and monitoring system. The LNG fuel system can be offered as a standalone product, as well as a part of a complete propulsion system. Wärtsilä can deliver LNG systems for propulsion and power generation for any applicable types of ship or engine.

Complete solution

The Wärtsilä LNGPac™ system is based on IMO type C LNG storage tank with either double walled vacuum or single walled polyurethane insulation. Bunkering takes place from the bunkering station to the LNG tank via an insulated pipe. All necessary process equipment is installed in a separate unit which can be either mounted directly to the LNG tank or placed remotely from the LNG tank. The main process equipment ensures correct gas temperature and pressure for the engines and other gas consumers. The LNGPac system can be customised to the needs of each project on a case by case basis. Dedicated engineering is conducted from the beginning of the project to match the specific operational requirements, safety and classification society requirements.

Features

Our innovative features have made the LNGPac™ a simple plug and play solution with the following benefits:

Integrated Airlock

The Airlock can be integrated with the LNGPac™. This reduces the floor footprint, increases safety aspects and makes the installation for the yard much easier.

Integrated Control Cabinet

The Control Cabinet can be integrated with the LNGPac™. This innovation results in a dramatic reduction of interfaces since the electrical cabling from the LNGPac™ to the external switchboards can be reduced to only a few cables. LNGPac automation can be connected to the Wärtsilä engine digital ecosystem for global maintenance support during complete vessel life cycle. One supplier for automation design, project execution, commissioning work and services – reducing project risk and minimising delays in communication.

Integrated Gas Valve Unit (GVU)

The functional components of the GVU can be integrated as part of the LNGPac™. By combining the LNGPac™ and the GVU into a single system, considerable space can be saved. The solution will also save installation time and costs for the yard.
Additional LNG solutions

Removal of the heating media skid
New evaporator type allows the engine LT-water to be directly connected to LNGPac without the need of an intermediated heating media circuit. This leads to fewer interfaces and installation work is required.

Maintenance-oriented design
LNGPac™ design focuses on enabling safe service and maintenance of all core equipment related to the operational functionality of LNG bunkering and gas consumption without emptying the tank.

Deepwell gas pumps

When absolute confidence in offloading safety and efficiency are critical, Wärtsilä Svanehøj is the natural choice among gas carriers worldwide for deepwell and cargo booster pumps. Our dedicated project teams deliver solutions for vessels from the smallest fully pressurised push barges and dedicated CO₂ carriers to the largest fully refrigerated VLGCs.

Our pumps handle all types of cargo at all temperatures and gravities without any component changes, offering potentially huge cost savings. Our range spans:

- Fully pressurised tankers, cargo at ambient temperature, tank pressure up to 18 bar.
- Fully refrigerated atmospheric tankers, cargo cooled to saturation temperature (typically -48°C).
- Semi-refrigerated tankers, cargo liquefied by cooling/pressure process down to -104°C.
- We lead in long-shafted pumps for LNG at -163°C.
Additional LNG solutions for marine and energy

Svanehøj ECA Fuel Pump

Wärtsilä Svanehøj deepwell cargo pumps have proven their reliability for more than 50 years at sea. All the benefits of the existing larger Wärtsilä Svanehøj deepwell cargo pumps have now been attributed to the Wärtsilä Svanehøj ECA fuel pump.

The Wärtsilä Svanehøj ECA Fuel Pump (EFP) offers the advantages of no tank connections below the liquid level, no electrical components inside the tank and hardly any contribution to boil-off gas generation. It is independent of weather, sloshing and thermal conditions and ensures a steady, reliable fuel gas supply with a fast response time.

The EFP model was developed in close cooperation with designers of LNG fuel gas systems to support highly efficient, environment-friendly LNG fuelled engines driven by the implementation of Emission Controlled Areas (ECAs). It is also prepared for other fuel types such as ethane and methanol.

Main design criteria:
- Safety & reliability
- 5-year service intervals or 25,000 operating hours
- Contingency: safe handling in emergencies

Tank control systems

If your product is LNG, LPG or ammonia, Wärtsilä Tank Control Systems can provide an application-specific solution for your business needs. Today, the liquid gas industry is driven by the economics of operational scale. In order to apply efficient business management, while adhering to stringent safety regulations, operations personnel must have access to correct information.

Throughout the production cycle, from storage to distribution, the availability of precise data is essential, and it needs to be relayed to the control room in real time.

Whether your operation is large or small, our solutions are custom designed to suit your requirements. They can operate independently, or be interconnected within a plant-wide system. Our vast experience, research, instrumentation technology, and service support will add value to your business.

Marine gauging

LNG secondary tank gauging systems
- World leaders in LNG marine gauging, more than 320 vessels supplied worldwide
- FLIV isolation valves

Product and chemical carriers
- LPG level gauging
- Alarm systems
- Supervisory control and data acquisition system
**Liquefied natural gas (LNG)**

**Total LNG tank gauging system**
Our total LNG storage tank instrumentation solution comprises the following, fully integrated system components:

- SIL-3 certified servo level gauges
- High/high-level alarm gauges
- Product temperature probes
- Fully automatic LTD gauges
- Leak detection and cooling temperature transmitter system
- PC based SCADA package
- Roll-over predictive alarm software

The entire system communicates via a redundant communication link.

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**CNG and CBG refuelling stations**
We offer solutions for compressed natural gas (CNG) and compressed biogas (CBG) refuelling stations to serve buses, trucks and other vehicles.

CNG/CBG is a more environmentally acceptable alternative than petrol, diesel, or propane/LPG, and is significantly lower in price. Our offering covers a range of options, from a basic compressor block to a fully installed and commissioned CNG/CBG refuelling station that includes the compression module(s), cascade storage, priority panels and fuel dispensers. The units are designed to comply with European and International standards.

We provide systems for either ‘fast fill’ (temperature compensated) or ‘timed fill’ with 200 or 250 barg filling pressures. The gas composition may be required to ensure correct compressor and material selection.
Power plants

There are many benefits of having a Wärtsilä Smart Power Generation power plant next to the terminal. Wärtsilä can help to find a suitable partner.

**LNG terminal and power plant in one EPC package**

- A power plant as an additional offtaker increases the LNG throughput volumes and thereby the feasibility of the LNG project.
- Heat from the nearby power plant can be used in the regasification process.
- Boil-off gas to power plant in a low pressure pipeline is a cost-efficient way of handling BOG.
- For areas with limited infrastructure and/or siting challenges, storage & regasification and/or power plant can be barge mounted near shore.
- Combined construction schedule for PP & terminal to optimise delivery time & costs.
- Combined O&M solution for PP & terminal for lowest possible lifecycle cost.
- Integrated control and automation systems for both assets.

For more information about Wärtsilä Smart Power Generation, please see the corresponding catalogue for power plants, available on the Wärtsilä website.

**Fuel conversion of power plants**

Our service project team offers EPC solutions for fuel conversions of power plants, including:

- HFO/DO to spark-ignited conversion
- HFO/DO to dual/tri-fuel conversion
- HFO/DO to gas-diesel conversion

We can manage your projects in all aspects of feasibility studies, financing solutions, solution proposals, execution planning and implementation to full EPC solution.

**Gas conversion**

As part of Wärtsilä’s lifecycle services, a gas conversion can help reduce operating costs and extend asset lifetime. We offer several conversion concepts for power plants, depending on your needs and specific requirements. To ensure maximised return on the gas conversion and smooth transition to operation, we recommend the inclusion of a long term service agreement as part of your gas conversion project.
**Additional LNG solutions**

**A clean new start for your asset**

A gas conversion done by Wärtsilä is an effective way to reduce operating costs, as well as extend the lifetime of your asset while increasing its value.

A Wärtsilä gas conversion not only offers the benefits of a new fuel, it also means a fresh start for your asset. Converting the existing engines gives the same benefits as installing new ones. All aspects from safety to reliability of operation are considered, so that the conversion concept follows the same principles as a new build made by Wärtsilä according to the latest design and engineering.

After converting to a new fuel or fuels, a tailored Lifecycle solution can help secure a smooth restart and maximise the return on the fuel conversion investment.

Benefits of a gas conversion in combination with a long-term Lifecycle solution:
- Guaranteed reduction of operating costs.
- Extended asset lifetime and increased asset value.
- Smoother transition to operation.
- Higher availability due to prolonged maintenance intervals.
- Guaranteed availability and fuel efficiency.
- Reduced environmental footprint.

**Guaranteed availability and fuel efficiency**

The decision to invest in a gas conversion is based on the economic and operational benefits attainable through improved efficiency and fuel flexibility. Operating on cleaner fuel like gas also leads to higher availability due to longer maintenance intervals. To ensure that these benefits are achieved, a Lifecycle solution can include guarantees for reaching the desired level of performance and availability over a long term, with the added advantage of predictable maintenance costs ensured by fixed prices.

**Reduced environmental footprint**

The challenges of complying with environmental legislation and addressing the global need for energy conservation have made the efficiency of the generating sets used to deliver electrical power increasingly important. Fuel type is also a key factor here. Converting to natural gas is an effective way to reduce the environmental footprint of a power plant.
Worldwide contacts

Our LNG contact persons:

Area business development managers

Europe & Africa

Tord Johnsson
Götvärgsgatan 10, Box 8006, SE-402 77 Gothenburg, Sweden
E-mail: tord.johnsson@wartsila.com
Tel: +46 709 517 108

Americas

Jens Norrgård
Puotikuja 1, Powergate, 65380 Vaasa, Finland
E-mail: jens.norrgard@wartsila.com
Tel: +358 40 7485586

Middle East, Asia & Australia

Kari Punnonen
Puotikuja 1, Powergate, 65380 Vaasa, Finland
E-mail: kari.punnonen@wartsila.com
Tel: +358 50 5986470

Director, sales and marketing LNG infrastructure

Kenneth Engblom
Puotikuja 1, Powergate, 65380 Vaasa, Finland
E-mail: kenneth.engblom@wartsila.com
Tel: +358 40 7566686

Heading

Headquarters

Wärtsilä Corporation
John Stenbergin ranta 2, 00530 Helsinki (Finland)
Tel: +358 10 709 0000

Argentina

Wärtsilä Argentina S.A.
Tresnord 963, C1427CRS Buenos Aires.
Tel: +54 11 4555 1331

Australia

Wärtsilä Australia Pty Ltd. (Sydney)
48 Huntingwood Drive Huntingwood, NSW 2148
Tel: +61 2 9672 8200
Wärtsilä Australia Pty Ltd. (Perth)
Sa Sparks Road, Henderson, WA 6166
Tel: +61 9410 1300

Azerbaijan

Wärtsilä Azerbaijan LLC (Baku)
Nobel ave. 108 E, Baku, A21023
Tel: +99412 372 06 80
24hrs phone: +994 50 255 6124

Bangladesh

Wärtsilä Bangladesh Ltd. (Dhaka)
SMC Tower (3rd Floor) 33 Banani C/A, Dhaka-1213
Tel: +880 2 9821070

Brazil

Wärtsilä Brasil Ltda. (Rio de Janeiro)
Rua da Alfandega, 33 – 7 o andar – Centro, Rio de Janeiro - RJ 20070-000
Tel: +55 21 2206 2500
Wärtsilä Brasil Ltda. (Manaus)
Rua Acrã, 12 - Distrito Industrial, 69075-030 Manaus - AM - Brazil
Tel: +55 92 32373579
24hrs phone: +55 92 88025525

Canada

Wärtsilä Canada Inc. (Vancouver, BC)
1771 Savage Road, Richmond, BC V6V 1R1
Tel: +1 604 244 8181
Wärtsilä Canada Inc. (Victoria, BC)
118-1759 Sean Heights, Saanichton Victoria, BC V8M 0A5
Tel: +1 250 360 1557
Wärtsilä Canada Inc. (Halifax, NS)
Unit 3, 90 Cutler Avenue, Dartmouth
Halifax, NS B3B 0J6
Tel: +1 902 4681 264
Wärtsilä Canada Inc. (St. John’s, NL)
27 Sagona Ave., Mount Pearl, NL A1N 4P8
Tel: +1 709 747 4600

Chile

Wärtsilä Chile Ltd. (Valparaíso)
Avenida Brasil 2060, Valparaíso
Tel: +56 32 2570600
Wärtsilä Chile Ltd. (Santiago)
Orinoco 90, Oficina 2121, Las Condes.
Santiago de Chile, Chile
Tel: +56 2 2573 7766

China

Wärtsilä China Ltd. (Hong Kong)
TYTL 1089P, Sai Tso Wan Road, Tsing Yi Island, NT
Tel: +852 2953 2901
Wärtsilä China Ltd. (Beijing)
Room 2601 Full Tower No. 9 DongSanHuan Middle Road, Chaoyang District, Beijing 100020 China
Tel: +86 10 6409 6211
Wärtsilä China Ltd. (Shanghai)
Building 11, 170 Jin Feng Road
Pudong New District, Shanghai 201201
Tel: +86 21 5858 5500
24hrs phone: +86 400 111 0056

Colombia

Wärtsilä Colombia S.A. (Bogotá)
Cra 196 # 83-63 Edificio Calle 83 Torre II Piso 5°, Bogotá
Tel: +57 16358168
Cellular: +57 3152420655
Wärtsilä Colombia S.A. (Ibagué)
Km. 3 via Buenos Aires - Payandé, Planta Caracolito, Ibagué
Tel: +57 8 2709170

Denmark

Wärtsilä Danmark A/S (Aalborg)
Kystvejen 100, DK-9400 Nørresundby
Tel: +45 99 56 99 56
Wärtsilä Danmark A/S (Copenhagen)
H.C. Andersens Boulevard 11, 3rd floor, DK-1553 Copenhagen V.
Tel: +45 99 56 99 56

Dominican Republic

Wärtsilä Dominicana, SRL
C/E Recodo #4, Bella Vista, Santo Domingo
Tel: +1 809 564 4440

Ecuador

Wärtsilä Ecuador S.A.
Los Floripondios N57–120 y Leonardo Murielado (esquina), Edificio Wartsila, Quito
Tel: +5932 2811 215
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<td>EGYPT</td>
<td>Wärtsilä Egypt</td>
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<td>FRANCE</td>
<td>Wärtsilä France S.A.S. (Paris)</td>
<td>Les Collines de l’Arche, Imm. Opera E, 76, Route de la Deme-Lune, FR-92057 Paris</td>
<td>+33 141 74 89 20</td>
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<tr>
<td>GERMANY</td>
<td>Wärtsilä Deutschland GmbH (Hamburg)</td>
<td>Schlegenztraße 6, 21107 Hamburg</td>
<td>+49 40 75 190 0</td>
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<tr>
<td>GRECE</td>
<td>Wärtsilä Greece S.A.</td>
<td>17, Posidonos Av., 183 44 Moschato, Grease</td>
<td>+30 210 413 5450</td>
<td>+30 69 44594562</td>
</tr>
<tr>
<td>HUNGARY</td>
<td>Wärtsilä Hungary Kft. (Budaörs)</td>
<td>Gyar utca 2, HU-2040, Budaföv. Pf. 43 Budaföv.</td>
<td>+36 23 532 127</td>
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<tr>
<td>INDIA</td>
<td>Wärtsilä India Ltd (Navi Mumbai)</td>
<td>Kesar Solitaire, 21st Floor, Plot No. 5, Sector No. 19, Palm Beach Road, Sanpada, Navi Mumbai 400 705</td>
<td>+91 22 2781 8300 / 8550</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wärtsilä India Ltd. (Secunderabad)</td>
<td>D.No.1-8-271, Flat No.109, 1st Floor, Ashoka Bhoopali Chambers, Sardar Patel Road, 500 003 Secunderabad</td>
<td>+91 40 2771 5383</td>
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<tr>
<td></td>
<td>Wärtsilä India Ltd. (Noida)</td>
<td>B - 37, 1st Floor, Sector - 1, Dist. Goutam Budh Nagar 301 301 Noida</td>
<td>+91 120 419 2000</td>
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<tr>
<td></td>
<td>Wärtsilä India Ltd. (Chennai)</td>
<td>Sheyare Vridhhi 123, Velachery Main Road, Guindy, Chennai-600 032</td>
<td>+91 44 2220 1080</td>
<td></td>
</tr>
<tr>
<td>INDONESIA</td>
<td>PT. Wärtsilä Indonesia (Jakarta)</td>
<td>Tempo Scan Tower, 19th Floor Jl H.R. Rasuna Said Kav. 3-4, Jakarta 12950</td>
<td></td>
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<tr>
<td>ITALY</td>
<td>Wärtsilä Italia S.p.A. (Milano)</td>
<td>Piazza Duca d’Aosta, 8, 20124 Milano</td>
<td>+39 02 669 7648</td>
<td></td>
</tr>
<tr>
<td>JAPAN</td>
<td>Wärtsilä Japan Ltd. (Tokyo)</td>
<td>Yaeusu Mid Bldg, 5F, 1-11-2, Kyobashi, Chuo-ku, Tokyo 104-0031</td>
<td>+81 3 5159 8700</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wärtsilä Japan Ltd. (Kobe)</td>
<td>6-7-2, Minatojima, Chuo-ku, Kobe 650-0045</td>
<td>+81 78 304 7501</td>
<td>+81 90 1913 0474</td>
</tr>
<tr>
<td>JORDAN</td>
<td>Wärtsilä Jordan Ltd.</td>
<td>4 Dobryninsky per., bl., 8, Office E02-300, Moscow, 116040</td>
<td></td>
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</tr>
<tr>
<td>NETHERLANDS</td>
<td>Wärtsilä Netherlands B.V. (Drunen)</td>
<td>Hanzelaan 95, 90017, Zwolle, Netherlands</td>
<td>+31 88 980 4000</td>
<td></td>
</tr>
<tr>
<td>NETHERLANDS</td>
<td>Wärtsilä Netherlands B.V. (Schiedam)</td>
<td>Havenstraat 21, 3115 HD, Schiedam</td>
<td>+31 88 980 2000</td>
<td></td>
</tr>
<tr>
<td>NORWAY</td>
<td>Wärtsilä Norway AS (Rubbestadnesset)</td>
<td>N-5420 Rubbestadnesset</td>
<td>+47 53 42 25 00</td>
<td>+47 53 42 25 00</td>
</tr>
<tr>
<td>NORWAY</td>
<td>Wärtsilä Pakistan Pvt Ltd. (Karachi)</td>
<td>Plot No F-8, KDA Scheme #1, Tipu Sultan Road, Karachi</td>
<td>+92 021 3437 5830</td>
<td></td>
</tr>
<tr>
<td>NORWAY</td>
<td>Wärtsilä Pakistan Pvt Ltd. (Lahore)</td>
<td>16 km Rawind Road, Lahore</td>
<td>+92 42 3541 8846</td>
<td></td>
</tr>
<tr>
<td>NORWAY</td>
<td>Wärtsilä Oil &amp; Gas Systems AS</td>
<td>Selbrowe 10, P.O. Box 144, N-1383 Aker</td>
<td>+47 815 48 500</td>
<td></td>
</tr>
<tr>
<td>PAKISTAN</td>
<td>Wärtsilä Pakistan Ltd.</td>
<td>17, Posidonos Av., 183 44 Moschato, Grease</td>
<td>+30 210 413 5450</td>
<td>+30 69 44594562</td>
</tr>
<tr>
<td>PHILIPPINES</td>
<td>Wärtsilä Philippines, Inc. (Laguna)</td>
<td>No. 6 Diode St., Light Industry and Science Park, B. Diezmo, Cabuyo, Laguna</td>
<td>+63 49 543 0382 /+63 2 843 7301</td>
<td></td>
</tr>
<tr>
<td>POLAND</td>
<td>Wärtsilä Polska Sp. z.o.o. (Warsaw)</td>
<td>Ul. Chmielu 134, 00-805 Warsaw</td>
<td>+48 22 206 0201</td>
<td>+48 22 206 0200</td>
</tr>
<tr>
<td>PORTUGAL</td>
<td>Wärtsilä Portugal, Lda. (Maia)</td>
<td>Rua de Joaquim Dias Rocha 361, PT-4470-211 Maia</td>
<td>+351 93 733 1644</td>
<td></td>
</tr>
<tr>
<td>PUERTO RICO</td>
<td>Wärtsilä Caribbean Inc. (Carolina)</td>
<td>Road 687 Km 0.6, Street A Lot 5, Industrial Park Julio N. Matos, PR 09067 Carolina, P.O. Box 7039</td>
<td>+1 787 701 2288</td>
<td></td>
</tr>
<tr>
<td>RUSSIA</td>
<td>Wärtsilä Vostok LLC, (St. Petersburg)</td>
<td>Business centre Link, 36 A Petrogradskaya Naberezhnaya, St. Petersburg, 197101</td>
<td>+7 812 448 32 48</td>
<td></td>
</tr>
<tr>
<td>SAUDI ARABIA</td>
<td>Wärtsilä Power Contracting Co. (Jeddah)</td>
<td>Office No: 8058, 8th floor Tower B, Bin Homran Commercial Centre, Prince Mohammed Bin Abdulaziz Street, Ar Rawdah, Dist, P.O. Box 2132, 21451 Jeddah</td>
<td>+966 92000 1898</td>
<td></td>
</tr>
<tr>
<td>SENEGAL</td>
<td>Wärtsilä West Africa (Dakar)</td>
<td>Immeuble Le Thiargane, 7ème étage, Mermoz, Place OMVS, B.P. 21861 Dakar-Ponty, Dakar</td>
<td>+221 33 865 41 20</td>
<td></td>
</tr>
<tr>
<td>SINGAPORE</td>
<td>Wärtsilä Singapore Pte. Ltd.</td>
<td>11 Pandan Crescent, Singapore 128467</td>
<td>+65 62659122</td>
<td></td>
</tr>
<tr>
<td>SOUTH AFRICA</td>
<td>Wärtsilä South Africa Pty Ltd.</td>
<td>20 Dorsetshire Street, Paarden Eiland, 7405 Cape Town</td>
<td>+27 21 511 1230</td>
<td></td>
</tr>
<tr>
<td>SUDAN</td>
<td>Wärtsilä South Africa Pty Ltd.</td>
<td>2nd Floor, West Tower, Nelson Mandela Sq., Maude St., Sandton, 2196 Johannesburg</td>
<td>+27 11 881 5953</td>
<td></td>
</tr>
</tbody>
</table>
**Worldwide contacts**

**SOUTH KOREA**  
Wärtsilä Korea Ltd. (Busan)  
15-36, Gangbyeon-daero 456 beon-gil, Sasang-gu, Busan, 47033  
Tel: ..................................................+82 51 329 0500

**SPAIN**  
Wärtsilä Ibérica S.A. (Bermeo)  
Polígono Industrial Landabaso, s/n  
48370 Bermeo, Vizcaya  
Tel: ..................................................+34 946 170100  
Email: wartsilab@iafrica.com

Wärtsilä Ibérica S.A. (Las Palmas)  
Avda. de las petroleras, s/n (Astican)  
35008 Las Palmas de G. Canaria, Las Palmas  
Tel: ..................................................+34 946 170100

**SWEDEN**  
Wärtsilä Sweden AB, (Gothenburg)  
Götaverksgatan 10, Box 8006  
SE-402 77 Gothenburg, Sweden  
Tel: ..................................................+46 0 317 444 600

**SWITZERLAND**  
Wärtsilä Switzerland Ltd.  
P.O. Box 414, Zürcherstr. 12, CH-8401 Winterthur  
Tel:..................................................+41 52 262 49 00  
Email: mail-ch@wartsila.com  
Power Sales for Switzerland are handled from Wärtsilä France s.a.s., Paris

**TAIWAN**  
Wärtsilä Taiwan  
台北市中山區中山北路2段68號4樓 4F, No.68, Sec.2, Zhongshan N. Road, Zhongshan District  
Taipei city  
Tel: ..................................................+886 2 25222239

**THAILAND**  
Wärtsilä Singapore Pte Ltd (Thailand)  
571 RSU Tower, Unit 4-5, 10th floor, Sukhumvit 31  
Sukhumvit Rd., Klongton-Nua. Wattana, Bangkok 10110  
Tel: ..................................................+66 0 2259 6921

**TURKEY**  
Wärtsilä Enpa Dis Tic.A.S. (Istanbul)  
Aydıntepe Mah. D-100 Karayolu (E-5) Cad. No: 14/E  
Bahar İş Merkezi 34947 Tuzla Istanbul  
Tel: .................................................+90 216 494 50 50

**UKRAINE**  
Wärtsilä Ukraine LLC (Odessa)  
20/1, Transportnaya Str., Illyichevsk  
Odessa region 68000  
Tel: ..................................................+380 48 796 5646

**UNITED ARAB EMIRATES**  
Wärtsilä Gulf FZE (Dubai)  
DIP Plot 597-572, Dubai Investment Park 2, Dubai  
Tel: ..................................................+9714 8857222

**UNITED KINGDOM**  
Wärtsilä UK Ltd. (Glasgow)  
Inchinnan Business Park, Cartside Avenue  
Paisley, Renfrewshire, PA4 9RX  
Tel: ..................................................+44 141 812 2888

Wärtsilä UK Ltd. (Segensworth)  
30 Brunel Way, Segensworth  
 Fareham, Hampshire, PO15 5SD  
Tel: ..................................................+44 1489 550050

**U.S.A**  
Wärtsilä North America, Inc. (USA Headquarters, Houston)  
11710 N. Gessner Rd, Suite A, Houston, TX 77064  
Tel: ..................................................+1 281 233 6200  
24hrs phone: ..................................................+1 877 927 8745

Wärtsilä North America, Inc. (Ft Lauderdale)  
2900 SW 42nd Street, Fort Lauderdale, FL 33312  
Tel: ..................................................+1 954 327 4700  
24hrs phone: ..................................................+1 877 927 8745

Wärtsilä North America, Inc. (NOLA)  
3131 Mac Arthur Ave, Harvey, LA 70056  
Tel: ..................................................+1 504 733 2500  
24hrs phone: ..................................................+1 877 927 8745

Wärtsilä Defense, Inc. (Chesapeake)  
3617 Koppens Way, Chesapeake, VA 23323  
Tel: ..................................................+1 757 558 3625

Wärtsilä Defense, Inc. (Poulsbo)  
26264 Twelve Trees Lane, Poulsbo, WA 98370  
Tel: ..................................................+1 360 779 1444

Wärtsilä North America, Inc. (San Diego)  
1313 Bay Marina Dr., National City, CA 91950  
Tel: ..................................................+1 619 350 6300  
24hrs phone: ..................................................+1 877 927 8745

Wärtsilä North America, Inc. (Annapolis)  
100 Bestgate Road, Suite 400, Annapolis, MD 21401  
Tel: ..................................................+1 410 573 2100

Wärtsilä North America, Inc. (Seattle)  
3000 17th Avenue West #3, Seattle, WA 98119  
Tel: ..................................................+1 206 746 8280

**VENEZUELA**  
Wärtsilä Venezuela C.A. (Valencia)  
Av Cabriales, entre calle 131 and 132, Centro Comercial y Profesional La Trigaleña Plaza, (CCP La Trigaleña Plaza) Piso 2, Oficina 2-10  
Tel: ..................................................+58 241 774 7033

**VIETNAM**  
Wärtsilä Vietnam Co. Ltd.  
Saigon Trade Center, Unit 1901, 19th Floor  
37 Ton Duc Thang Street, Ben Nghe Ward, District 1, Ho Chi Minh City  
Tel: ..................................................+84 8 222 00718

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