StarLNG™
Leading standardized small- to mid-scale LNG plants.
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Growing importance of natural gas

In the bid to find cleaner, more environmentally sound sources of energy, the spotlight is increasingly shining on natural gas. Burning methane, the principle component of natural gas, produces around 30% less carbon dioxide (CO₂) than crude oil, and almost 45% less CO₂ than coal. When combusted, it also releases around 90% less sulfur oxide and 80% less nitrogen oxide than fossil fuels, and it emits no heavy metals or soot particles. It is thus the ideal choice to meet stricter environmental regulations for pollutant emissions, especially in transport and shipping. Natural gas reserves are set to last for the foreseeable future, and advanced extraction technologies are unlocking new deposits all the time, especially in shale reserves.

Changing LNG landscape

Today, natural gas meets approximately 30% of the world’s energy demand and this share is set to rise. Consequently, natural gas is moving beyond a niche market to serve a much broader application spectrum at local level. The trucking and marine transport industries are two good examples. This growing merchant market relies on state-of-the-art liquefaction and transport technologies, especially tankers, to deliver gas economically from remote deposits to the point of use. Reflecting this shift, Liquefied Petroleum Gas (LPG), Natural Gas Liquids (NGL) and Liquefied Natural Gas (LNG) have become much more important in the world’s energy mix over the past two decades.
Full-line supplier offering value along the complete LNG value chain

At Linde, we have over 40 years of experience in the natural gas business. Linde Engineering is the only company in the LNG business capable of offering its customers Linde-developed plant modules in conjunction with a broad portfolio of liquefaction technologies, distribution infrastructures and services. In fact, we are the only equipment manufacturer to offer both coil-wound and plate-fin heat exchangers – equipment at the heart of most natural gas processing steps. Complementing this strong engineering portfolio, Linde Gas also has extensive process and operating expertise in the LNG business. This know-how covers the entire LNG value chain – from extraction through purification and liquefaction to distribution and regasification. Building on this synergised expertise and our strong track record in the successful execution of natural gas EPC (engineering, procurement, construction) projects on a lump-sum, turnkey basis, we have developed a flexible and modularized plant concept specifically for the emerging mid-scale LNG market. Mid-scale StarLNG™ plants leverage our standardization and modularization experience in air separation to bring a variety of benefits to our customers.
Benefits of Linde’s StarLNG™ standardized LNG concept.

Road-transportable from 100 tpd liquefaction capacity

1 coldbox including up to 2 PFHEs, each with 400 tpd max. capacity

Linde Engineering has supplied custom-designed LNG plants for many years. These plants are recognized worldwide as excellent LNG reference projects. To deliver the same quality at lower cost and in shorter time frames, we have ferreled the standardization and modularization experience in air separation to the LNG business.

StarLNG™ was developed especially for the small- to mid-scale LNG market and is designed as a process toolbox with configurations supporting about 90% of LNG projects. The generic LNG plant design can be adapted to meet most pipeline gas specifications as it covers a wide feed gas envelope and includes options for heavy hydrocarbon or nitrogen removal, for instance. It comes with modularized pre-treatment and process units, as well as main pipe racks. The StarLNG™ plant concept is adjustable within a wide liquefaction capacity range. Our engineers can guide you through the available choices to find the plant concept best suited to your requirements.

StarLNG™ offers a number of benefits. It leverages our safety and operational experience building world-scale LNG plants and is designed to the same rigorous safety and reliability standards. This reduces execution risk and capital investment over a wide capacity range. Our excellent track record in safety is reflected in our construction permits for plants located close to urban developments in some of the world’s most highly regulated geographies.

Safe, simple, robust and highly efficient process design (lowest OPEX)

- Strong focus on health and safety makes StarLNG™ plants as safe as our world-scale plants
- Process design validated in dynamic simulations
- High reliability, robust design and ease of operation due to high degree of automation; remote control possible

Fast-track EPC time schedule

- Pre-engineered toolkit for process and plant design, standard documentation and modularized layout for shortest delivery time with minimum on-site construction effort

Lowest CAPEX

- Toolkit approach supports customization, while benefiting from standardization and production cost efficiencies of best-cost countries

Pre-engineered standard documents

Set of generic standard documents prepared and validated for base case and selected alternatives:

- Equipment specifications
- Plant CAD model
- Plot plan
- Start-up concept
- Automation philosophy
- Operation manual

Stick-built/customized large modules for liquefaction capacities

1 x CWHE mounted into a steel structure for capacities above 600 tpd or 2 or more coldboxes incl. up to 2 PFHEs for each road-transportable CB module

Bergen, Norway, 120 tpd. Kwinana, Australia, 175 tpd. Mid-scale LNG plant with 813 tpd liquefaction capacity located in Shan Shan, China, on stream since 2013. Mid-scale LNG plant with 900 tpd liquefaction capacity located in Stavanger, Norway.
• Process simulation models (OPTISIM)
• Process sketches and descriptions
• PFD template
• 100% piping and instrumentation diagrams (PID) prepared
• Set of design concepts for all disciplines
• HAZOP report template
• Conceptual HAZAN for CWHE
• Value engineering for critical equipment
• 100% process data sheets completed
• Winterisation concept
• Execution strategy for LNG storage

Pre-engineered deliverables are optimized through extensive value engineering, e.g. plot plan, PID and modularization/transport concepts.

StarLNG™ plant capacity range

The StarLNG™ concept was originally developed for the typical small-scale capacity range of 100 to 600 tonnes per day (tpd) and was based on Linde’s proprietary single mixed refrigerant liquefaction process (LIMUM®1) using plate-fin heat exchangers (PFHE). During the concept development, the engineers recognized that many of the standardized design solutions and features can also be applied to LNG plants using other liquefaction technologies. Therefore the concept was extended to larger-scale plants up to 1 million tonnes per year (mtpa) using the LIMUM®3 process based on Linde’s proprietary coil-wound heat exchangers (CWHE).

Overview of the members of the StarLNG™ family

The figure gives an overview of the different members of the StarLNG™ family together with the applied liquefaction processes.
Benefits of Linde’s StarLNG™ standardized LNG concept

**StarLNG™ feed gas design envelope**

In order to cover a wide range of real-life LNG projects and cope with most pipeline gas specifications, a wide feed gas envelope was created forming the design basis for the concept. The feed gas compositions were selected to cover almost all known pipeline gas compositions. Pipeline gas was used (i.e. dew point controlled, limited heavy hydrocarbon content (HHC), etc.) because the high technical effort required to pretreat well gases (as is done in world-scale LNG plants) is not deemed economically viable for small-scale LNG projects.

- Feed gas variations between 0.8 and 20 vol% N₂
- Feed gas pressure varied between 30 and 60 bar (abs)
- Feed gas compression for lower pressures, let-down station for higher pressures
- Feed gas temperature varied between 0 and 50°C

Generic feed gas conditions are selected to cover almost all known pipeline gas compositions.

**Toolbox matrix for different feed gas qualities**

Having extensively screened all relevant feed gas conditions, Linde engineers developed a versatile but simple standard to support a wide envelope of operating parameters.

**Toolbox approach for different feed gas qualities**

If a feed gas contains heavier hydrocarbons (pentanes and heavier) and aromatic material (BTX), the gas will freeze unless the concentration of these components has been lowered sufficiently. The simplest method is a separator (HHC KO drum) in the feed path of the main cryogenic heat exchanger. Alternatively, a separation column (demethanizer) can be installed to remove heavy hydrocarbons.

Both alternatives are part of the StarLNG™ toolbox and are readily available for deployment. StarLNG™ plant components and toolbox options also include nitrogen rejection for high N₂ content depending on availability/capability of a flash gas sink (e.g. gas turbine).

**StarLNG™ design envelope with generic feed gas compositions**

<table>
<thead>
<tr>
<th></th>
<th>Base case</th>
<th>N₂ rich</th>
<th>HHC rich</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vol%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N₂</td>
<td>0.85</td>
<td>5.00</td>
<td>0.80</td>
</tr>
<tr>
<td>CO₂</td>
<td>4.80</td>
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<td>2.00</td>
</tr>
<tr>
<td>CH₄</td>
<td>88.71</td>
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<td>89.13</td>
</tr>
<tr>
<td>C₂H₆</td>
<td>5.25</td>
<td>1.86</td>
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<td>C₃H₈</td>
<td>0.36</td>
<td>0.23</td>
<td>1.94</td>
</tr>
<tr>
<td>C₄H₁₀</td>
<td>0.02</td>
<td>0.04</td>
<td>0.78</td>
</tr>
<tr>
<td>C₅H₁₂</td>
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<td>0.00</td>
<td>0.31</td>
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<tr>
<td>C₆⁺</td>
<td>0.01</td>
<td>0.00</td>
<td>0.18</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>
Applied codes and standards

StarLNG™ plants are designed to cope with the typical codes and standards which apply to market regions like North America, Europe and Asia:

- Installation and equipment for liquefied natural gas: EN 1473
- Standard for the production, storage and handling of LNG: NFPA 59A
- Design codes for pressure-bearing parts and piping: ASME, EN, GB
- Electrical and Instrumentation (E&I) design codes: IEC, ANSI, NEC, NEMA
- Structural materials: EN, ASTM
- Process safety: API, NFPA

A range of standards is supported for USA, EU and China.

Process plant units

The above block diagram shows the plant units involved in the StarLNG™ concept based on the toolbox approach.

All process units have been selected and designed with a strong focus on simplicity, reliability and cost effectiveness. The design builds on Linde’s unique combination of experience as technology provider, EPC contractor and plant operator and therefore ensures easy automation and remote control.
The following pre-treatment units have been implemented for the StarLNG™ concept following the design rules described above:

- Inlet facilities (KO drum, feed gas metering)
- Mercury removal (single guard bed with zeolitic adsorbent)
- Sour gas removal (amine wash column with BASF-licensed activated methyl diethanolamine as absorbent)
- Dehydration (single guard bed with zeolitic adsorbent; regeneration with dry feed gas)
Liquefaction.

StarLNG™ plants for capacities up to 0.3 mtpa per train

Small-scale StarLNG™ using single mixed refrigerant process
The small-scale StarLNG™ concept was originally developed based on Linde’s single mixed refrigerant liquefaction process LIMUM®1 (Linde Multistage Mixed Refrigerant) using PFHEs manufactured at Linde’s workshop in Schalchen, Germany. The refrigerant cycle provides cold temperatures by Joule-Thomson expansion and liquid vaporization of the mixed refrigerant. An integrally geared turbo compressor is typically used as the main refrigerant compressor, driven by an electric motor. The refrigerant cycle contains methane (sourced from dry feed gas), nitrogen (available as plant utility), as well as commercial-grade ethylene or ethane (depending on availability at site) and butane.

StarLNG™ using nitrogen expander cycle process
As an alternative to the single mixed refrigerant process, we can also offer a double nitrogen expander process technology.

Key features
- N₂ refrigerant
- Vapor phase operation
- Brazed aluminium PFHE
- Electric motor drive
- Water cooling

In summary, the small-scale StarLNG™ concept offers the following main advantages to our customers:
- Lower complexity and equipment count compared with multiple refrigerant cycle based technology, but still with high efficiency
- Most economical type of main cryogenic heat exchanger
- Part load capability of 50% or even less
- Minimized on-site installation works due to installation in road-transportable, workshop-assembled coldbox

Small-scale StarLNG™ process with nitrogen expansion cycle

![Diagram of small-scale StarLNG™ process with nitrogen expansion cycle](diagram.png)
**StarLNG™ plants for capacities up to 1 mtpa per train**

The StarLNG™ concept has now been extended to mid-scale LNG plants with capacities up to 1 mtpa per train (corresponding to approx. 3000 tpd).

To avoid multiple parallel blocks of PFHEs, which results in complex piping arrangements, higher plot space requirements and potential flow distribution issues, Linde offers its LIMUM®3 liquefaction process using its proprietary CWHEs for this capacity range.

This type of heat exchanger is extremely robust and easy to operate, which is why it is deployed in most world-scale plants.

**Key features of StarLNG™ with CWHE (LIMUM®3 process)**
- Typical for mid-scale LNG plants for liquefaction capacities up to 1 mtpa
- Suitable for very high feed gas pressures
- Robust design allows easy start-up

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**Mid-scale StarLNG™ process with LIMUM®3 liquefaction process**
StarLNG™ plant with 813 tpd liquefaction capacity in Beiniuchuan, China
Liquefaction and storage pressure.

Unlike the large-scale LNG business with its downstream LNG distribution chain at atmospheric pressure using LNG carriers, the small-scale LNG business may require pressurized storage facilities for a number of reasons:

- Economical pressurized storage tanks can be designed for low storage capacity needs
- Downstream LNG distribution (by ship/truck) to end consumers is typically based on pressurized gas

Pressurized storage can translate into liquefaction energy savings of 20%.

Drive concept for main refrigerant compressors.

Small-scale StarLNG™ concept plants generally use electric motor drives for the main refrigerant compressor(s). However, gas turbine drives can also be offered.

As gas turbines are only available in a limited number of discrete sizes, electric motors offer higher design flexibility with regard to liquefaction capacity. Other advantages of an electrical motor drive include:

- Electric motor drive systems boost plant efficiency
- Electric motor delivery times are shorter than those of gas turbine drives
- LNG production capacity is not impacted as much by ambient temperature swings as it is with gas turbine drives
- An electric motor-driven LNG facility requires less maintenance compared with a gas turbine-driven compressor solution. Frequent turnarounds are not required for electric motor-driven LNG plants
- LNG plant operation can be more profitable and environmentally friendly if low-cost, reliable electricity is available – for instance from a nearby hydroelectric facility
LNG storage concepts.

Linde is one of the very few companies in the world that can offer all LNG storage tank technologies typically applicable for small- and mid-scale LNG plants. Our engineers are happy to advise customers on the best fit for their needs depending on their requirements for:

- Storage volume
- Storage pressure
- Safety

Depending on storage volume and operation of the LNG plant as well as the downstream distribution chain:

- Flat-bottom tank (larger capacities are feasible) 2,000 – 40,000 m³
- Spherical tank 1,000 – 8,000 m³
- Bullet tank 100 – 1,000 m³

The safety of LNG storage tanks has become a top priority worldwide. Double integrity or – as is more common nowadays – even full integrity LNG storage tanks have become the global standard. Depending on the safety features of an LNG tank, the following scenarios are conceivable in the unlikely event of a tank rupture:

- Single integrity tanks → uncontrolled LNG spill to ambient air
- Double integrity tanks → LNG spill into secondary containment (dike, pit), but uncontrolled vapor release to ambient air
- Full integrity (containment) tanks → no LNG spill to ambient air, only controlled gas release (recommended for plants located in densely populated areas)
Truck loading.

The small-scale StarLNG™ concept comprises truck loading facilities for delivering LNG to the merchant market by specialized trucks. The concept is based on the following:

- Simultaneous and independent loading of two trucks at two loading bays
- 50 m³/h loading flow rate per bay
- 50 m³ typical LNG truck working volume
- 6–10 kPa(g) typical LNG truck mechanical design pressure
- Expandable for more loading bays, if needed
- Alternatives for LNG ship loading and regasification for export by pipeline (peak shaver)
At Linde, occupational health, safety and the environment (HSE) has always been a top priority when planning and building our plants all over the world. HSE is 100% of our behaviour, 100% of the time.

Safety standards

- Same rigorous safety standards as world-scale LNG plants (codes, standards, safety practices)
- Generic piping and instrumentation diagrams validated in HAZOP (Hazard and Operability Study)
- Generic plant layout validated in QRA (Quantitative Risk Assessment)
- Various LNG storage alternatives validated in generic QRA
- Hazardous area classification
- Depressurization concept
- Fire protection concept

StarLNG™ delivers small- to mid-scale LNG plants that are designed to the same “zero-compromises” safety standards as world-scale LNG plants.
Construction strategy.

Standard versus alternative construction approach

Especially in remote areas or environments with high construction costs, our strategy is to reduce on-site construction work by supplying largely pre-fabricated assemblies to the site.

The larger and more complete the module, the lower the on-site hook-up cost. However, transport costs rise with module sizes and – at a certain point and depending on local limitations – transportation becomes simply impractical.

Unlike some of our competitors, we assume responsibility for the entire EPC scope and thus not only optimize module fabrication cost, but also overall EPC cost. Our modularized construction approach is adaptable to support project-specific conditions such as:

- Cost and availability of on-site labour
- Geographically suitable and best-cost workshop alternatives

Kwinana LNG plant in Western Australia.
StarLNG™ includes a fully modular design of the base case plant. The module size has been chosen to enable road transportation (possibly involving escorts or extra permits) in many places, while also aiming for minimum hook-up work on site and moderate crane capacity requirements. To enable road transportation, the following transportation limitations have been considered for the design of the StarLNG™ modules:

<table>
<thead>
<tr>
<th>Limitation</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Maximum width</td>
<td>6 m</td>
</tr>
<tr>
<td>Maximum height* (incl. 0.8 m trailer height):</td>
<td>5.9/10 m</td>
</tr>
<tr>
<td>Maximum overall length (e.g. coldbox):</td>
<td>36 m</td>
</tr>
<tr>
<td>Maximum overall weight*:</td>
<td>50/100 t</td>
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</table>

* disassembled/assembled

Fully modularized design – 80% of piping work has already been completed in the module assembly yard, with all equipment and modules designed for installation by truck, ship or mobile crane.

Transport of coldbox on public road.
Transport of pre-fabricated modules

Off-site module pre-fabrication in best-cost countries reduces the project budget in a high-cost labour environment.

The design builds on extensive modularization experience in cryogenic natural gas plants at Linde-owned and partner module workshops in Germany, USA, China, etc.
Long-standing experience in cryogenic plant design.

Linde is recognized by the financial world as a reliable technology provider and EPC contractor that cooperates with local EPC partners and construction companies during all phases of a project. We have gained vast experience with modularization concepts during the many EPC turnkey, lump-sum contracts we have successfully executed, e.g. Snøhvit, Kwinana, etc.

Manufacturing and operating experience

Linde Engineering is not only a technology provider and EPC contractor, but also a manufacturer of cryogenic key equipment such as heat exchangers and coldboxes. Here is a selection of LNG-related references:

- CWHEs for third-party world-scale LNG projects, i.e. North West Shelf Australia LNG T4 & T5, Snøhvit, Sakhalin, Pluto and Brunei
- LNG coldboxes including PFHE for Idku (Egyptian LNG), Darwin LNG, Gladstone LNG, Arzew replacements, Bergen, Kwinana, etc.
- Vacuum-insulated pressure vessels for LNG storage for various applications, e.g. semi-trailers, rail cars, local storage in satellite stations, etc. and for a multitude of customers worldwide

Furthermore, Linde Engineering can draw on the many years of operational experience gained by Linde Group member BOC at an LNG plant in Dandenong, Australia and brand-new plants in Tasmania and California. In addition, we also operate a mid-scale LNG import terminal in Nynäshamn, Sweden.

Competence in and ownership of core cryogenic equipment, complemented by long-standing operational experience.
How to get your Star.
Please contact our Linde Engineering head office or your local representative office for more information about StarLNG™ or to get a quote for your individual small-scale LNG project. To achieve maximum benefit from our pre-engineered StarLNG™ toolbox, we recommend completing a final Basis of Design (BoD) document at an early stage during the bidding phase. This document is required to develop a Process Design Package (PDP), including a Process Flow Diagram (PFD), heat and material balance and process datasheets, before the contract award phase. This enables us to order long-lead equipment like compressors and cryogenic heat exchangers as soon as you place your order.

Building on our long-standing experience in constructing and operating cryogenic plants to protect your investment.
Collaborate. Innovate. Deliver.

Linde’s Engineering Division is a leading player in the international plant engineering business. Across the globe, we have delivered more than 4,000 plants and cover every step in the design, project management and construction of turnkey industrial facilities. Our proven process and technology know-how plays an indispensable role in the success of our customers across multiple industries – from crude oil, natural gas extraction and refining to chemical and metal processing.

At Linde, we value trusted, lasting business relationships with our customers. We listen carefully and collaborate closely with you to meet your needs. This connection inspires us to develop innovative process technologies and equipment at our high-tech R&D centres, labs and pilot plants – designed in close collaboration with our strategic partners and delivered with passion by our employees working in more than 100 countries worldwide.

From the desert to the Arctic, from small- to world-scale, from standardized to customized builds, our specialists develop plant solutions that operate reliably and cost-effectively under all conditions. You can always rely on us to deliver the solutions and services that best fit your needs – anywhere in the world.

Discover how we can contribute to your success at www.leamericas.com

Get in touch with our natural gas plant team:
Phone: +281.717-9090, e-mail: sales@leamericas.com

Core competencies at a glance

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<th>Plant engineering</th>
<th>Component manufacturing</th>
<th>Services</th>
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<tbody>
<tr>
<td>Air separation plants</td>
<td>Coldboxes and modules</td>
<td>Revamps and plant modifications</td>
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<td>LNG and natural gas processing plants</td>
<td>Coil-wound heat exchangers</td>
<td>Plant relocations</td>
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<td>Petrochemical plants</td>
<td>Plate-fin heat exchangers</td>
<td>Spare parts</td>
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<td>Hydrogen and synthesis gas plants</td>
<td>Cryogenic columns</td>
<td>Operational support, troubleshooting and immediate repairs</td>
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<td>Cryogenic storage tanks</td>
<td>Long-term service contracts</td>
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<td>Cryogenic plants</td>
<td>Liquefied helium tanks and containers</td>
<td>Expert reviews for plants, operations and spare part inventory</td>
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<td>Carbon capture and utilization plants</td>
<td>Air-heated vaporizers</td>
<td>Operator training</td>
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<td>Furnaces, fired heaters, incinerators</td>
<td>Water bath vaporizers</td>
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