

New market potentials with new technologies.  
Liquefied natural gas.





# Liquefied natural gas (LNG). Secure and eco-friendly energy source.

The world's growing energy demand and the need for a low-carbon economy are key challenges of our time. The global energy mix is still heavily based on depleting oil reserves. Therefore, attractive alternatives are needed to reduce energy consumption from scarce resources and emissions from transport, industry, utility and other sectors. Natural gas offers such an alternative: it is readily available across the globe, significantly cleaner-burning than oil and coal, and can also be produced from various biomass sources.

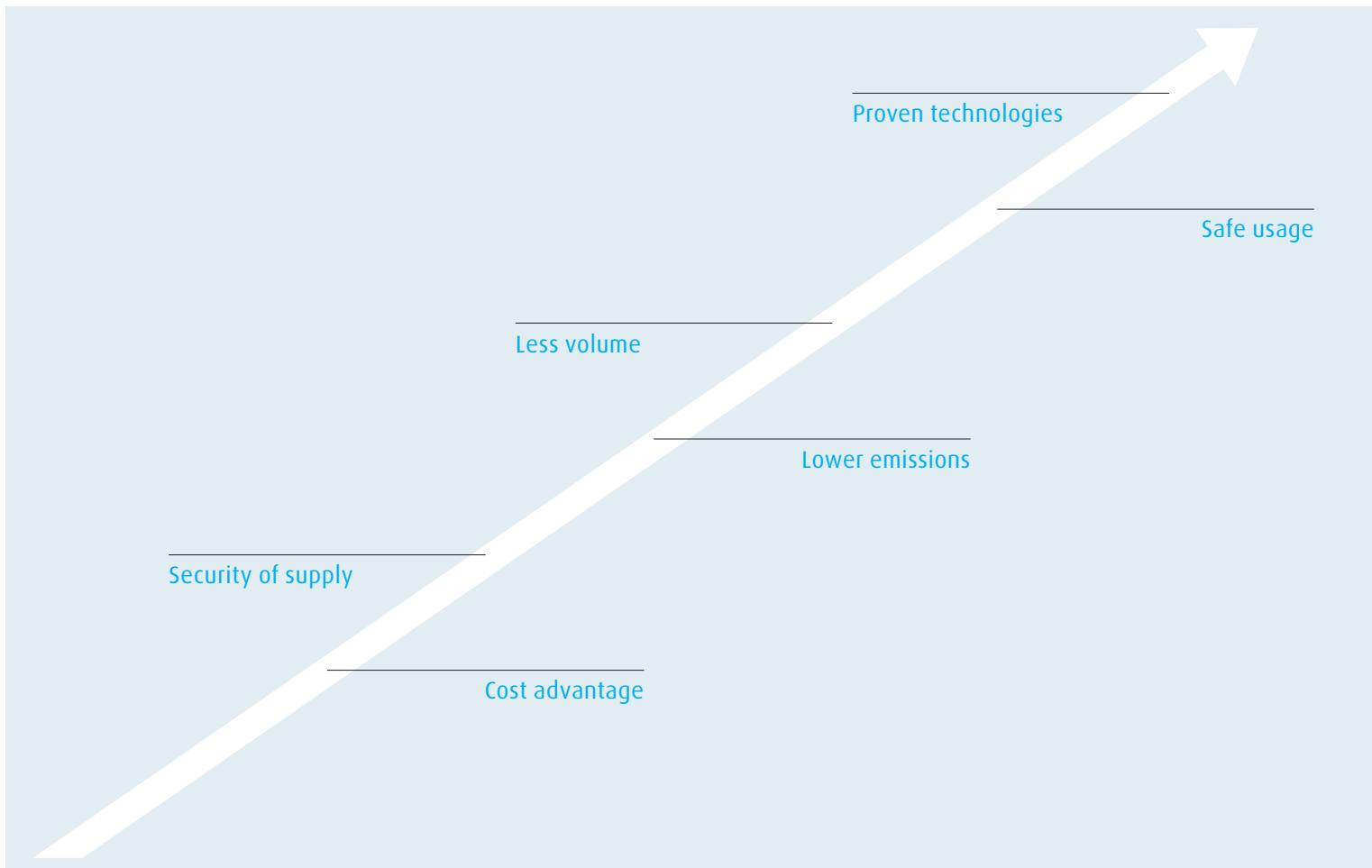
Natural gas is distributed either in its compressed gaseous (CNG) or cooled liquefied state (LNG). The share of LNG in total natural gas consumption has increased continuously in many markets, thus drawing more and more attention from both suppliers and customers.

A major driver for this shift is the competitive price of natural gas compared to oil and other energy sources. Additionally, in many markets, traditional gas resources previously used to feed local gas networks have been depleted and are being replaced with imported LNG. As such, LNG can also easily be used beyond traditional grid injection – for example as fuel for transport vehicles or ships, taking advantage of the higher energy density of LNG and therefore reaching an acceptable distance between refuellings.

LNG production and handling is well known and based on established technologies, its use is simple and safe. This makes it a perfect energy source for a wide range of applications – as transportation fuel, but also as energy for various industrial applications and gas-fired power generation.

## What is LNG exactly?

LNG is natural gas in its purified and liquefied form. The clear, colourless and odourless liquid basically consists of methane ( $\text{CH}_4$ ) with low concentrations of other hydrocarbons (e.g. ethane, propane and butane) and inert components such as nitrogen. As such, it is a clean and controllable fuel, offering high performance in every application.



## Economical and ideal for any use. LNG offers many benefits.

### General benefits of natural gas

#### Cost advantage

Due to the large amount of natural gas reserves, natural gas prices have decoupled from oil prices. While, in the last 20 years, natural gas has sold at about two-thirds of the price of oil (per unit energy), it is now selling at around one quarter of the price of oil in some markets. In most other markets, its price is still significantly lower than that of alternative oil products. Even if the spread between natural gas and oil prices fluctuates, the more abundant supply of natural gas will continue to maintain low and stable natural gas prices for years to come.

#### Security of supply

Global resources of natural gas are enormous and widely distributed around the globe. In recent years, innovations in extraction techniques have led to the development of many new natural gas reserves. Today's estimated U.S. gas reserves, for example, are 40% higher than they were a few years ago. Moreover, a significant amount of natural gas still remains to be discovered, which makes it difficult to estimate the actual size of all reserves. One thing, however, is certain: when the world's oil supply will run low, there will still be enough natural gas left, as this energy source is expected to last at least another 100 to 150 years.

#### Lower emissions

Natural gas is widely considered as a more environmentally friendly energy carrier with a promising future. For example, it generates almost 20% less CO<sub>2</sub> than crude oil and nearly 45% less CO<sub>2</sub> than coal (when combusted). It also produces virtually no SO<sub>2</sub> emissions, less NO<sub>x</sub> emissions and less solid particle emissions than other fuels. Furthermore, natural gas can also be obtained from renewable sources such as biomass and biogenic raw materials. More and more research and development efforts are being focused on the improvement of this sustainable production method.



## Additional benefits of LNG

### Less volume

The higher energy density of LNG is the crucial advantage over its gaseous counterpart CNG and many other refined products. When natural gas is liquefied by cooling it down to approximately -161 °C, it contracts to 1/600th of its original volume. As a result, LNG can be stored, transported and used as a fuel in a convenient and cost-efficient way. Moreover, it also offers the opportunity to produce in remote regions with no access to pipelines, thus allowing the development of local natural gas resources.

### Safe usage

Natural gas is non-toxic as well as non-corrosive and can be safely used. Its high ignition temperature of 649 °C (gasoline: 315 °C) and limited flammability range (5 % to 15 % in air) make its unintentional combustion unlikely. LNG vapour is also lighter than air, i.e. less likely to cause a fire hazard and unable to pollute soil and water compared to other fuels that are heavier than air. In case of leakage, LNG evaporates, rises into the atmosphere and dissipates.

### Proven technologies

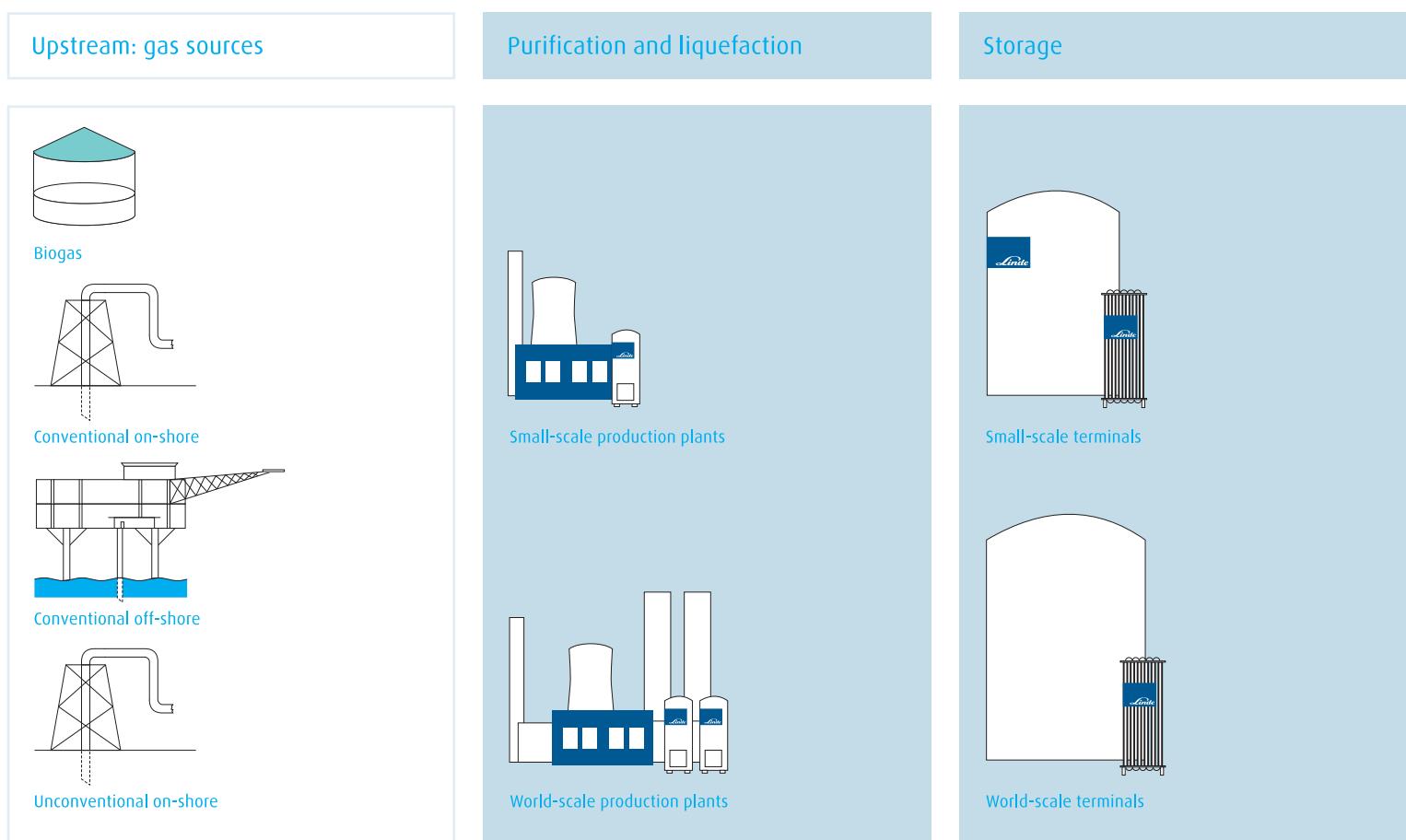
LNG has been well known since the first half of the 20th century. LNG technologies have also been established for many years and have proven that LNG is ready for everyday use. At the same time, improved technical solutions are now needed for small-scale applications, e.g. in the transportation sector. Based on its extensive engineering and operational experience, Linde is driving the development of such solutions, covering a range of efficient small-scale production and storage units as well as LNG and LCNG fuelling stations.

# The one-stop shop for LNG. Linde covers the entire LNG value chain.

Linde has been a specialist in cryogenic technology for many years and is therefore the perfect full-service partner for any LNG project. As a true one-stop shop, we are offering our customers everything from investing in and operating the complete supply chain needed for the widespread use of LNG to Linde-developed solutions, such as small-scale LNG liquefaction plants, storage units, distribution equipment and fuelling stations.

## Typical LNG value chain

■ Linde competence



## Upstream: gas sources

Generally, natural gas is extracted from on-shore or off-shore gas reserves or taken from renewable methane sources, e.g. landfills. The development of unconventional natural gas sources, such as shale gas, tight gas, Coal Bed Methane (CBM) and Coal Mine Methane (CMM), has already started in several markets, driven by the advancement of drilling and extraction technologies. After extraction, there are two main possibilities: either the natural gas is brought to purification and then to pipelines or it is purified and liquefied directly on site.

## Purification and liquefaction

Prior to liquefaction and transport, natural gas has to be purified: unwanted components must be removed and the heavier hydrocarbons may need to be separated from the methane. These treatment steps involve a combination of adsorptive, absorptive and cryogenic processes – all of which are part of Linde's core competencies. Depending on geological and customer-specific requirements, Linde develops tailor-made solutions for the production of LNG – from micro-scale to world-scale plants. We build, own and operate small to mid-scale liquefaction plants with annual capacities of 5,000 to 500,000 metric tons of LNG and build world-scale LNG export plants with capacities of more than four million metric tons of LNG per year. Our heat exchangers, which are at the heart of a liquefaction plant, have defined the state of the art in LNG technology and are also used by many world-renowned oil and gas companies.

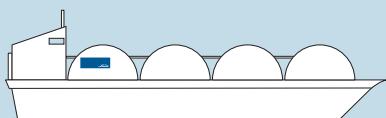
## Storage and distribution

Because of its very low temperatures, LNG has to be stored in special cryogenic tanks. Linde offers storage tanks of various sizes for both distribution and on-site storage as well as small to large-scale vaporisers. Thanks to these solutions, LNG can be stored along the entire value chain: in trailers, on ships, at the production site, at the point of use as well as in small-scale terminals for intermediate storage. In addition, Linde can also support customers if compressed natural gas is needed. Our CNG portfolio comprises compression technologies as well as specific storage and distribution systems.

## Point-of-use solutions and applications

LNG can be applied in many different ways. A new and growing market is the use of LNG as a fuel for trucks, ships and even locomotives. For fuelling, Linde provides complete fuelling stations and on-board storage solutions for ships. Linde also has the know-how for fuelling solutions that combine LNG and CNG technologies, so-called LCNG stations. For industrial applications and power plants, Linde offers LNG supply, logistics, on-site storage tanks as well as regasification processes – as part of its comprehensive portfolio, which provides a complete chain of products and services "from well to wheel" and thus allows the end customer to use LNG as an efficient replacement for more expensive oil-based products.

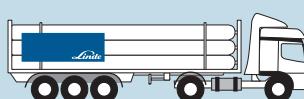
### Distribution



**Ships with tanks**



**LNG trailers**



**CNG trailers**

### Point-of-use solutions



**LNG and LCNG fuelling stations**



**On-board storage tanks**

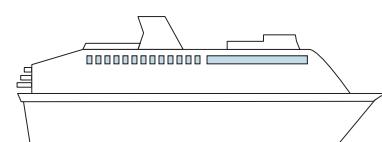


**On-site storage tanks and vaporisers**

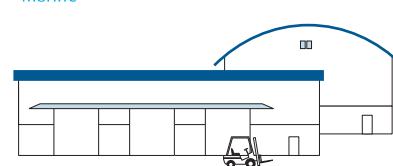
### Applications



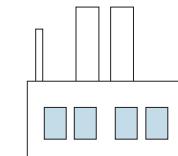
**Road transport**



**Marine**



**Industrial**



**Utility**

# Micro, small, medium, large or renewable. You name it and we make it happen.



## Micro plants: Australia

Australia's large natural gas resources make LNG a viable alternative to diesel as a fuel for trucks. In order to establish a widespread LNG fuelling infrastructure, Linde's local business BOC has developed dedicated micro LNG plants with a daily capacity of 50 metric tons of LNG (corresponding to around 70,000 litres of diesel). Due to the vast distances in Australia, multiple smaller LNG plants located close to customers make more economic sense than fewer plants with larger capacities.

On Tasmania, BOC has already built a micro LNG plant to supply a consortium of transport operators. It also designed, invested in and is now operating the entire supply chain infrastructure, including LNG road tankers and the servicing of six fuelling stations. On the Australian mainland, BOC is currently building an "LNG highway" between Victoria and Queensland – with a planned total of eight fuelling stations supplied by two LNG plants.

## Mid-scale LNG terminal: Stockholm, Sweden

Linde provides LNG solutions for every region. In Nynäshamn near Stockholm, Sweden, Linde's local subsidiary AGA has invested in a mid-scale LNG terminal, selling and distributing LNG to various customers in the Eastern part of Sweden, where there is no natural gas grid. In addition to supplying the city grid of Stockholm and some industrial facilities, the terminal also allows for the safe and reliable distribution of LNG to the rapidly growing number of natural gas vehicles in the region. The supply of the fuelling stations is mainly based on biomethane, but since its production varies and total biomethane sourcing is still limited, the LNG from the terminal is indispensable to ensure the uninterrupted supply of the fuelling stations.

The terminal can currently store up to 20,000 m<sup>3</sup> of LNG, most of which is sourced from the Linde-built natural gas liquefaction plant in Stavanger, Norway, and shipped to Sweden by specially equipped tankers.





### World-scale plant: Hammerfest, Norway

With the design and construction of the world's northernmost LNG plant on the island of Melkøya near Hammerfest, Linde's engineers have proven that they are able to adapt liquefaction systems to even the most challenging environmental settings. Located 600 kilometres north of the Arctic Circle, Melkøya has six months of snow and ice each year.

The world-scale production plant was opened by the Norwegian petroleum company Statoil at the end of September 2007 and has a capacity of more than four million metric tons of LNG per year, making it the first and largest LNG plant in Europe. In addition to the plant's complete engineering and assembly, Linde's experts also trained Statoil's staff to operate the plant and continue to provide operational and optimisation support.

### Renewable LNG: Livermore, USA

A significant advantage of LNG is the fact that it can also be produced from renewable sources. Linde is a leader in this field of production. At the Altamont Landfill near Livermore, California, Linde North America and Waste Management, North America's leading waste services company, have formed a joint venture to build and operate the world's largest plant for converting landfill gas into LNG.

At the facility, which was commissioned in 2009, LNG is produced from the gases created by the natural decomposition of municipal waste. For this process, Linde provided the entire gas compression, purification, liquefaction and cryogenic storage technology, and is now responsible for the operation of the plant.

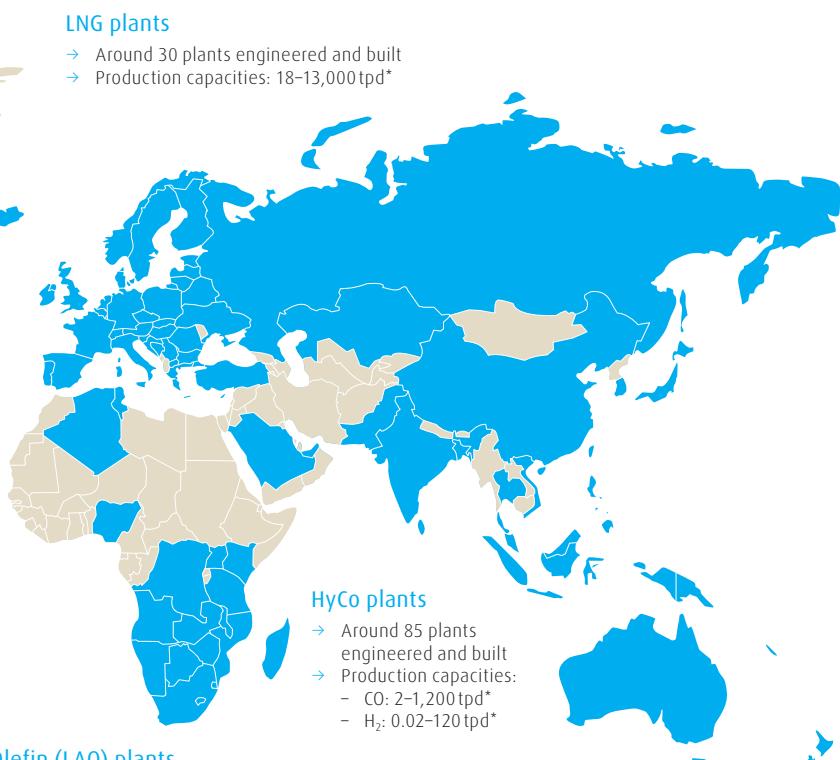
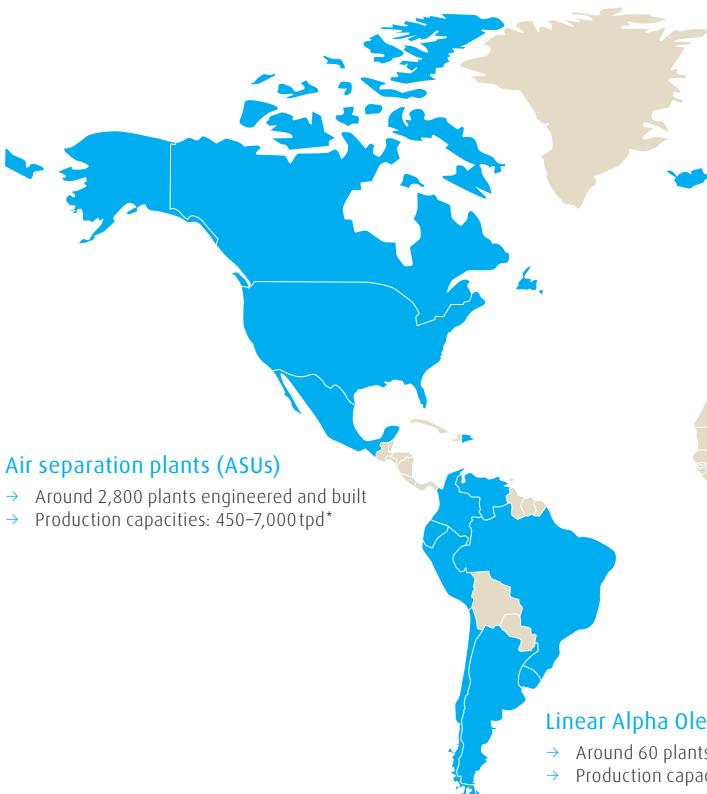


# More than 100 years of cryogenic expertise. Your key to the LNG business.

Linde's expertise in cryogenic applications goes back as far as 1895, when the founder of the company, Carl von Linde, successfully liquefied air for the first time. The following start-up of the world's first air separation plant in 1902 initiated the development of the cryogenic industry. Today, Linde is a leading global industrial and medical gases, cryogenic liquids and engineering company, which owns, operates and maintains over 1,000 cryogenic and non-cryogenic plants around the world. In the cryogenic sector alone, Linde supplies tens of thousands of customers, making over 25,000 cryogenic deliveries per day.

## Overview of Linde's global presence and its cryogenic expertise

■ Company presence



\* Metric tons per day and unit (specification of lowest and highest plant capacity)



Into a cleaner energy future. Switch to LNG now.  
We are just a call away to assist you.

# Getting ahead through innovation.

With its innovative concepts, Linde is playing a pioneering role in the global market. As a technology leader, it is our task to constantly raise the bar. Traditionally driven by entrepreneurship, we are working steadily on new high-quality products and innovative processes.

Linde offers more. We create added value, clearly discernible competitive advantages, and greater profitability. Each concept is tailored specifically to meet our customers' requirements – offering standardised as well as customised solutions. This applies to all industries and all companies regardless of their size.

If you want to keep pace with tomorrow's competition, you need a partner by your side for whom top quality, process optimisation, and enhanced productivity are part of daily business. However, we define partnership not merely as being there for you but being with you. After all, joint activities form the core of commercial success.

**Linde – ideas become solutions.**

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