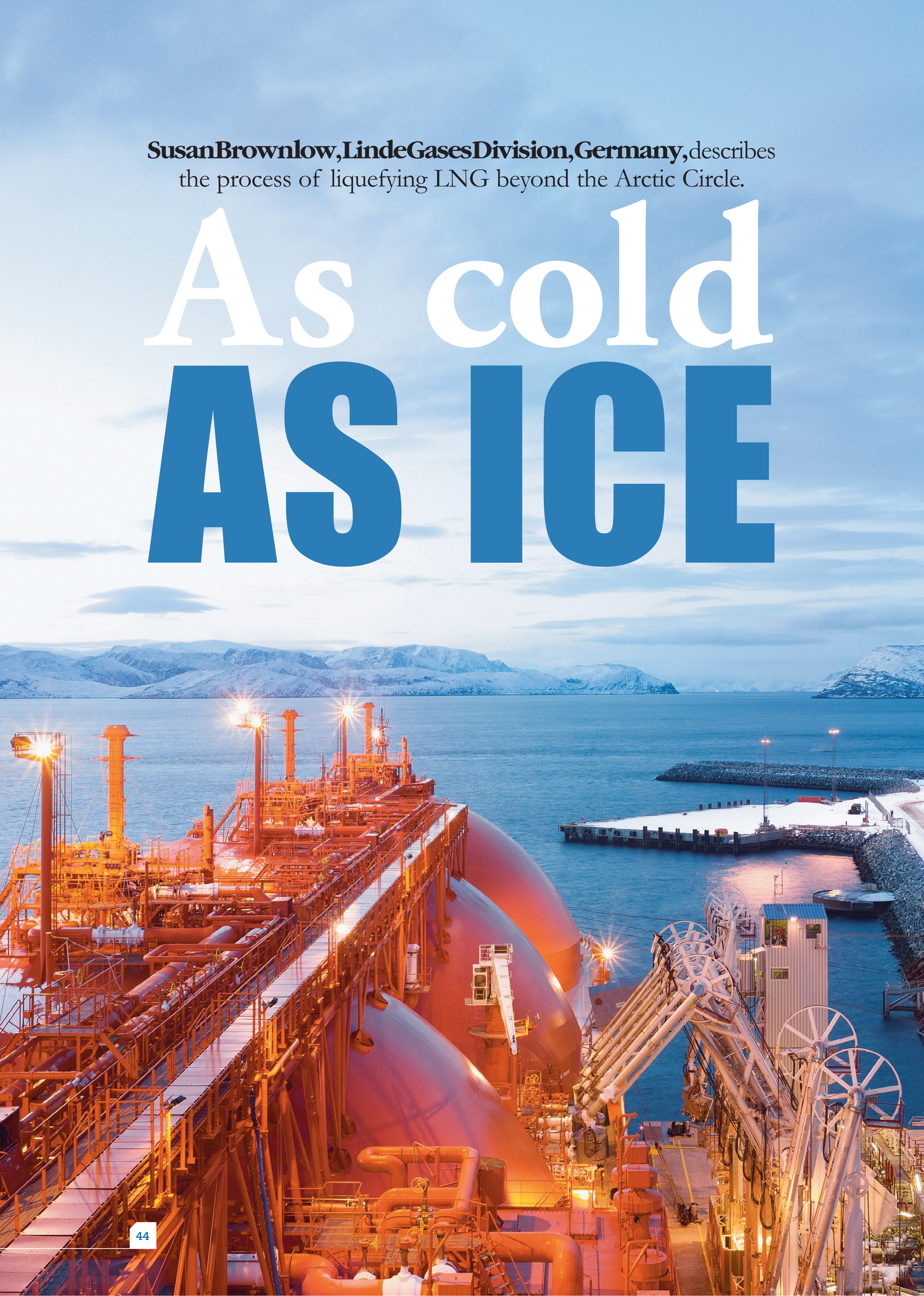
Susan Brownlow, Linde Gases Division, Germany, describes the process of liquefying LNG beyond the Arctic Circle.

As cold AS ICE



Building a low carbon economy is one of the great challenges of the modern era. In order to protect the climate, the world needs clean energy and natural gas is an important stepping stone on that journey, bringing the world power with a much lower carbon footprint.

Natural gas, a mixture of primarily hydrocarbon gases, is colourless and odourless in its purified form and is the cleanest fossil fuel with the lowest CO_2 emissions when burnt. As well as being an important fuel source, it is also a major feedstock for fertilisers and petrochemicals. As a raw material, it is almost as versatile as crude oil, yet is significantly kinder to the environment.

Burning methane, the principle component of natural gas, produces approximately 30% less CO_2 than crude oil, and almost 45% less CO_2 than coal. In addition, it emits significantly fewer pollutants: approximately 90% less sulfur, 80% fewer nitrogen oxides and no heavy metals or soot particles. Furthermore, natural gas reserves are forecasted to continue to yield for at least another 200 years.

Natural gas is already one of the most important sources of energy today, covering approximately 25% of global energy requirements and this figure is set to rise. Yet while it is evident that natural gas stands to play an important role in the energy mix of the future, innovative technologies for exploration, production, processing and transporting it are key factors in realising this.

As with oil, most natural gas deposits are located far from the actual point of use. Natural gas can be transported via pipeline or liquefied in order to allow its economic transportation over large distances by ship or truck, particularly to and from remote areas which are not serviced by a pipeline network or where it is uneconomical to use a pipeline.

Traditionally, the vast majority (90%) of natural gas is pipelined over long distances to power plants, industrial facilities and homes. However, after approximately 3000 km onshore pipeline, 1500 km offshore pipeline, or in case of distribution to diverse, small consumers in remote areas, pipelines become uneconomical, with costs for pipe laying, materials and compressor stations outweighing the benefits. LNG can be economically transported many thousands of kilometres and and distribution to customers is much more flexible. Approximately 250 million t of LNG (representing 10% of the natural gas market) is already transported around the globe each year.

Figure 1. Tanker loading of LNG at Melkøya.

Figure 2. LNG plant at Melkøya.

Figure 3. Aerial view of the LNG plant at Melkøya

After extraction in its natural form directly from the gas field, LNG production involves pretreatment of the incoming gas, fractionation into the diverse product fractions (e.g. natural gas, LPG, condensate) and liquefaction by cooling the natural gas down to a temperature of -163 ˚C. This process reduces its volume dramatically to only 1/600th of its normal volume, resulting in easily and cost efficiently transported fuel.

LNG plants are typically distinguished by their capacity into small scale, mid scale and world scale plants. For example, the journey of the LNG often begins at a world scale LNG plant, which have capacities of between 3 – 10 million tpy. From the large storage tanks, special LNG tankers then transport the LNG to receiving terminals in ports all over the world, where the LNG is typically converted back to gas, fed into national pipeline grids and delivered to consumers.

Linde has a strong and extensive history in the LNG industry, having designed, built and started up numerous LNG plants (from small scale to world scale) worldwide since 1967. The company is involved in many of the innovative, highly efficient processes in operation across the entire LNG value chain: from industrial scale liquefaction plants, over receiving terminals, and up to fuelling stations for LNG.

Liquefaction in a cold climate

In the inhospitable and icy cold of northern Norway stands the world's largest LNG production facilities in an Arctic climate. Just outside the town of Hammerfest lies the small barren island of Melkøya, where Linde has built one of the world's major natural gas processing plants.

In this stark Norwegian landscape, 600 km north of the Arctic Circle, the project presented a formidable challenge from the outset. No world scale plant of this size and capacity had been built before, especially not in such an inhospitable climate. The entire LNG operation is the world's northernmost world scale LNG plant, located below Norway's Barents Sea. The Snøhvit (translated as 'Snow White') LNG project was constructed to exploit the resources of three gas fields in the Barents Sea: Snøhvit, Albatross and Askeladd (250 – 345 m deep), which lie approximately 140 km northwest of Hammerfest. The fields, which were first discovered in the 1980s, have estimated reserves of 193 billion m^3 of LNG, 17.9 million m^3 of condensate and 5.1 million t of natural gas liquids. Snøhvit and Albatross have already been onstream since 2007 and Askeladd is due to come onstream by 2014 – 2015.

The project was led by Norwegian energy group Statoil as part of a consortium of several oil and gas companies including Petoro, Hess, RWE Dea, GDF Suez and Total. Engineers from Linde and Statoil started first discussions for an LNG plant on Melkøya in the late 1990s. Linde engineers responsible for developing the plant were required to plan for every eventuality, with design of the liquefaction module being the top priority. Storms were simulated; temperatures in which technicians would have to work considered; and even how snow drifted was tracked. Engineers also constructed a test rig, which was set up on Melkøya to see how the snow accumulated and whether it affected the rig. Even with today's sophisticated technology, a liquefaction plant of this scale in such an environment would still be an enormous challenge; this underlines the level of technical expertise

Figure 4. Coil wound heat exchangers.

which had to be channelled into the Melkøya development process.

Heat exchangers

A priority in the plant design was to create not only an extremely energy efficient liquefaction system for gas processing, but one that was highly compact given the space limitations on Melkøya. A further key requirement was low emissions output.

Due to the limited plot space available and difficult construction conditions, the plant was designed to be very compact and modular. The heart of the plant is the 35 000 t floating central process module. This LNG plant module, which is the largest ever built, was prefabricated in a Spanish yard and then transported 2700 nautical miles to the island Melkøya. Moreover, Hammerfest LNG uses a pioneering efficient, environment friendly direct sea water cooling system suitable for arctic whether conditions. Other features include the complete separation of CO_2 from the process gas and its reinjection into a reservoir under the seabed, as well as the realisation of flareless plant operation. With the objective of enhancing plant availability, all main compressors are electrically driven for the first time ever in a world scale LNG plant.

Statoil selected to partner with Linde due to its significant expertise in low temperature industrial processes such as LNG (both regarding process technology and EPC project execution), as well as its particular capabilities in heat exchanger technology. Linde proposed to jointly develop a new optimised liquefaction process called the Mixed Fluid Cascade (MFC) process to ensure that the most energy efficient process technology is applied. The MFC was selected due to its superior energy efficiency against competing processes for world scale plants, such Air Products' C3MR® process and the ConocoPhillips' Optimized Cascade® process (both of which are employed in many world scale liquefaction plants).

The MFC consists of three cooling stages with mixed refrigerant as cooling medium. Each cycle has its own composition of refrigerants (e.g. nitrogen, methane, ethane/ethylene, propane): precooling to -50 ˚C; liquefaction to -80 ˚C; and subcooling to approximately -165 ˚C. The core heat exchangers of the liquefaction unit are Linde's own manufactured heat exchangers: plate fin heat exchangers for precooling and coil wound exchangers for liquefaction and subcooling of the natural gas.

Careful tailoring of the composition and relative volumes of the mixed refrigerants to each cooling stage makes it possible to achieve an very close match to the idealised cooling curve using the minimal amount of energy. Importantly, the resultant cooling takes place smoothly and economically, rather than step wise, as is typical of the more classical processes.

Linde is the only manufacturer to produce the two types of cryogenic heat exchangers common in world scale LNG plants: coil wound and plate fin heat exchangers. They are employed not only within Linde's own engineered LNG plants, but also in plants built and operated by other LNG producers such as Shell, Woodside, ConocoPhillips and other oil and gas corporations.

The Hammerfest LNG plant went on stream in late 2007 with a design capacity of 4.3 million tpy of LNG. In 2010, Statoil celebrated the 100^{th} LNG tanker to set sail from the plant. During operation, a production record of 109% of Hammerfest's planned design capacity was reached. Energy efficiency of the liquefaction facility at Melkøya is the best yet achieved in any world scale LNG plant across the world, with approximately 230 kWh needed per ton of LNG for liquefaction. Benchmarking has shown that the MFC process is the most energy efficient liquefaction process for world scale LNG plants.

The successful realisation of the MFC process at Hammerfest LNG means there is now a proven European LNG technology for world scale LNG plants, representing an alternative to the two American technologies for large scale plants that have historically dominated the growing LNG market.