LINDE TECHNOLOGY

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FEATURED TOPIC: POWERING THE FUTURE

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Key contender in the energy mix of the future: Natural gas is one of our most climate-friendly energy carriers. In a liquefied state, it can be transported around the globe, moving efficiently from the source – here, for example, in Norway's Hammerfest – to the point of use.

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EDITORIAL

Dear Readers,

The need for a low-carbon energy chain is one of the greatest challenges facing society today. One thing is clear – emissions of greenhouse gases such as carbon dioxide cannot be stopped overnight. However, we can make a start by drastically reducing emissions today. One way of achieving this is by switching to natural gas – an attractive alternative to current energy sources. Natural gas is a key stepping stone on the pathway towards more climate-friendly energy choices for private households, industry and transport. Similar to oil, it is flexible but generates significantly lower levels of CO_2. In addition, global reserves of natural gas are set to last much longer than crude oil deposits. Innovative natural gas technologies are thus key enablers in the transition to a zero-carbon economy.

Across the globe, The Linde Group is playing a major role in unlocking the benefits of this primary energy source at all key steps in the value chain, from the source to the point of use. The feature article in this issue of Linde Technology shows the sheer range and depth of our natural gas know-how. Our technologies ensure that liquefied natural gas (LNG) can be efficiently transported from even remote locations to where it is needed. The cryogenic technology required to make this happen is one of Linde's core skills. Our engineers have been able to adapt liquefaction systems to even the most challenging environmental settings, as seen at the most northerly LNG plant in the world – Hammerfest in Norway. We also provide innovative LNG transport solutions and are actively contributing to the ever-expanding LNG infrastructure. Linde engineers have developed storage tanks for ports and ships, for instance. They also design, build and operate micro LNG plants to supply truck fuelling stations.

Hydrogen offers great potential as an environmentally friendly alternative to fossil fuels for regular road traffic. For many years now, Linde has been innovating H_2 technologies to bring hydrogen to the streets. The fruits of these efforts are best demonstrated by early success stories – such as a hydrogen-powered bus fleet in California and the sight of hydrogen fuel-cell cars driving around the globe.

The chemical industry is also becoming greener as it moves towards renewable raw materials. Experts from Linde-KCA-Dresden GmbH are at the forefront of biotech engineering developments.

Today, we already deliver the right technologies and processes to conserve natural resources and meet our energy needs from climate-friendly sources. With future generations in mind, we are firmly committed to sustainability.

I hope you enjoy reading more about these and other exciting topics in this edition of Linde Technology.

Belloni

Dr Aldo Belloni
Member of the Executive Board of Linde AG

LIQUEFIED NATURAL GAS: From Norway around the globe

MEDICAL TECHNOLOGY: Bone cells grow on porous surfaces

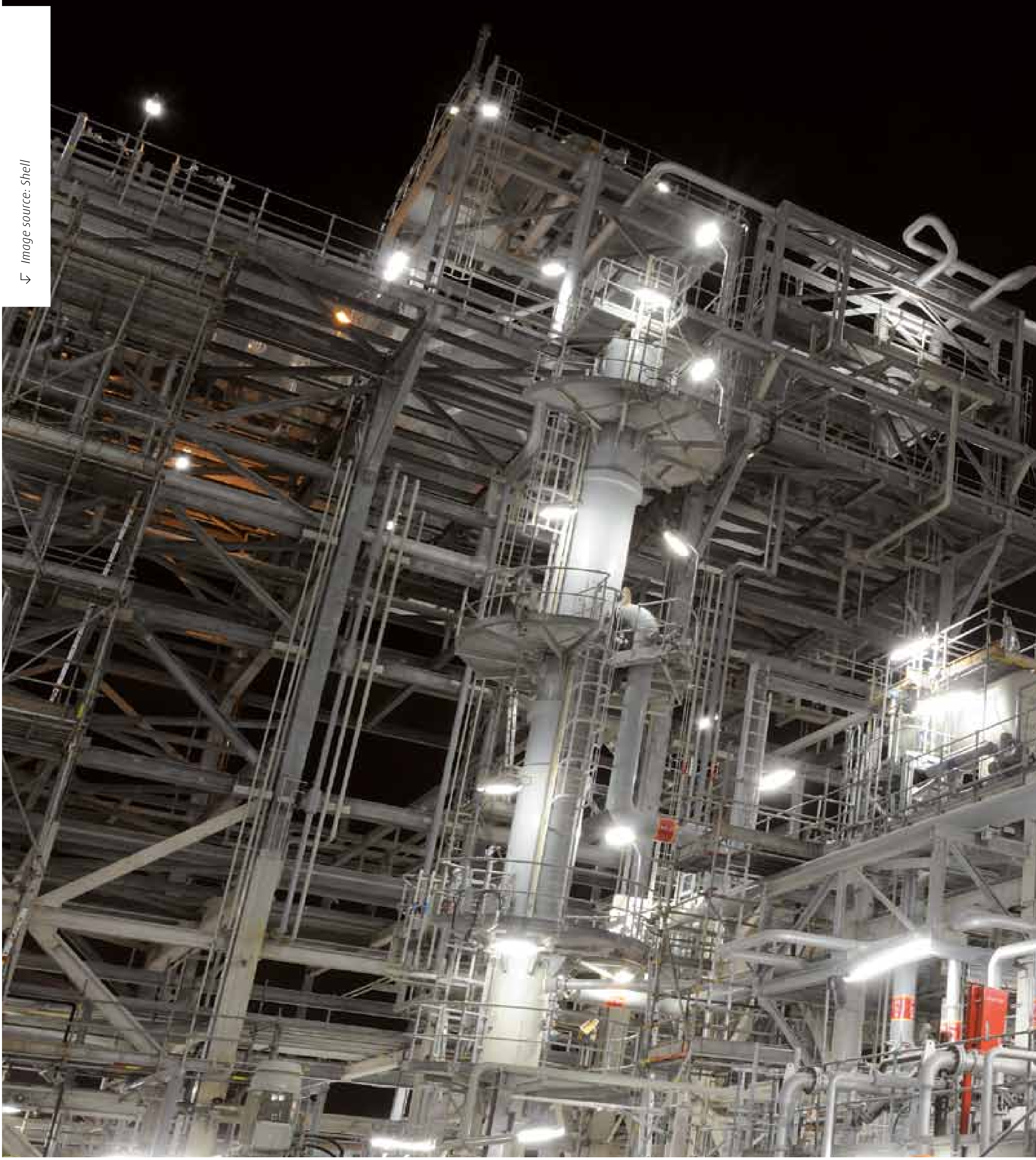
STEEL PRODUCTION: Using oxygen to save energy

HYDROGEN: Fuel cells increase mobility

FEATURED TOPIC

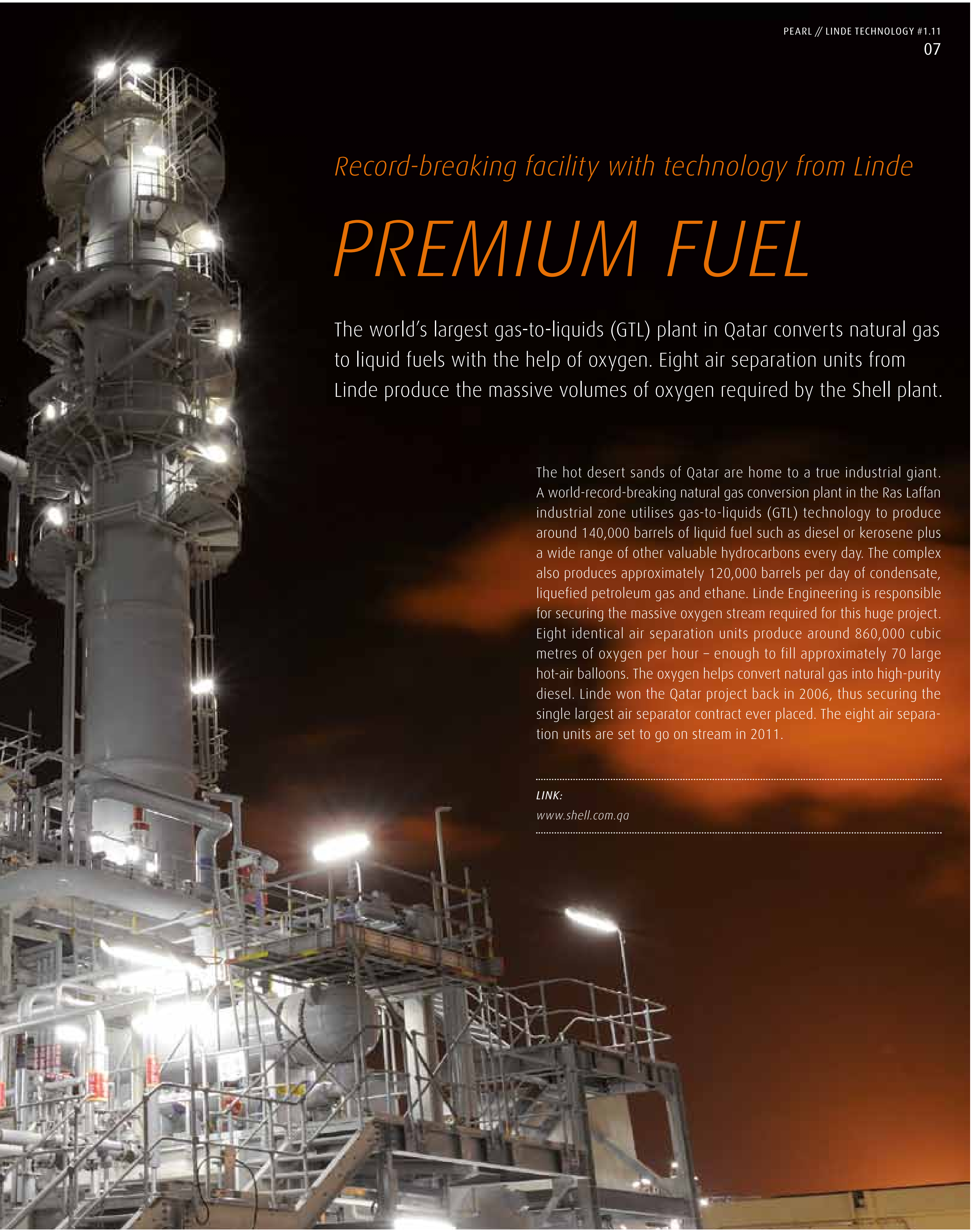
POWERING THE FUTURE

Linde liquefaction technologies enable natural gas to be safely transported around the globe. Natural gas is a key stepping stone on the pathway to a zero-carbon economy.



Liquid power: *The gas-to-liquids facility in Qatar enables Shell to produce valuable fuel from natural gas.*

→ *Image source: Shell*



Record-breaking facility with technology from Linde

PREMIUM FUEL

The world's largest gas-to-liquids (GTL) plant in Qatar converts natural gas to liquid fuels with the help of oxygen. Eight air separation units from Linde produce the massive volumes of oxygen required by the Shell plant.

The hot desert sands of Qatar are home to a true industrial giant. A world-record-breaking natural gas conversion plant in the Ras Laffan industrial zone utilises gas-to-liquids (GTL) technology to produce around 140,000 barrels of liquid fuel such as diesel or kerosene plus a wide range of other valuable hydrocarbons every day. The complex also produces approximately 120,000 barrels per day of condensate, liquefied petroleum gas and ethane. Linde Engineering is responsible for securing the massive oxygen stream required for this huge project. Eight identical air separation units produce around 860,000 cubic metres of oxygen per hour – enough to fill approximately 70 large hot-air balloons. The oxygen helps convert natural gas into high-purity diesel. Linde won the Qatar project back in 2006, thus securing the single largest air separator contract ever placed. The eight air separation units are set to go on stream in 2011.

LINK:
www.shell.com.qa

NEWS

CO_2 CAPTURE STARTS LONG-TERM TEST:

CLIMATE PROTECTION AT THE SOURCE

Since 2009, RWE, Linde and BASF have been working together to test an innovative solvent-based technology that can cut the energy required to capture carbon from flue gases by 20 percent. The partners have been demonstrating the process at RWE's power plant in Niederaussem, near Cologne. The pilot facility has passed the test with flying colours. "The increase in energy efficiency and resulting cost savings will help drive the success of carbon capture and storage (CCS) technology, which we see as a key enabler on the journey towards a climate-friendly, coal-based energy value chain," explains Dr Johannes Heithoff, Head of Research and Development at RWE Power.

The pilot plant is part of RWE Power's Coal Innovation Centre. The partners have now decided to start the next project phase. Starting in March, the pilot plant will undergo a long-term test until the end of 2013. Linde is responsible for engineering and construction and BASF for process optimisation. This new technology could be used to capture over 90 percent of carbon dioxide contained in power plant emissions in the future. This CO_2 could then be stored underground or used to produce other materials such as fertilisers.

CO_2 capture in coal-fired power plants is expected to reach commercial maturity by 2020. RWE Power is investing around nine million euros in the current development project. Germany's Federal Ministry of Economics and Technology also contributed around four million euros to the pilot plant.

SOUTH KOREA:

SYNTHETIC NATURAL GAS – AN ALTERNATIVE FOR COAL-RICH REGIONS

South Korean steel group POSCO is building a plant that will produce synthetic natural gas (SNG) from coal and petroleum coke in the city of Gwangyang. The facility will have a nominal annual capacity of 500,000 tonnes of transportable synthetic natural gas and is scheduled to start production at the end of 2013. Linde's Engineering Division is supplying the entire technology chain to process and condition the synthetic gas along with its Rectisol® wash process to remove sulphur. Haldor Topsøe, a leading provider of integrated catalyst solutions, is also a technology partner in the project. SNG technology is an extremely useful way for coal-rich regions to convert their coal deposits into more convenient gas and liquid fuels.

STEEL PRODUCTION:

AIR SEPARATION UNITS FOR ASIA

Steel production is booming worldwide, driving demand for air separation units, which are crucial to produce high-grade steel. In the northern Chinese province of Shanxi, Linde is building two major new air separation units for Taiyuan Iron & Steel Company Limited (TISCO). Each unit has a daily capacity of around 2,000 cubic metres. The company is also building a new air separation unit for the world's leading steel company, ArcelorMittal, at its Temirtau site in Kazakhstan, with the same capacity. Around 95 million euros will be invested in the new plant. The project also includes a long-term supply contract that will see Linde deliver gaseous oxygen and nitrogen to the ArcelorMittal steelworks in this fast-growing region.

SOUTH AFRICA:

COAL GASIFICATION KNOW-HOW

South African company Sasol Technology Ltd. has selected Linde as its preferred engineering partner for key coal gasification technologies for the next ten years. The agreement covers raw gas cooling, raw gas shift and by-product processing as well as the overall integration of process units. Drawing on its expertise in hydrogen and synthesis gas production and gas treatment, Linde will provide consulting and engineering services to Sasol. To date, Linde has been awarded over 70 contracts from Sasol, ranging from design projects to complete turnkey installations.

MEDICAL GASES:

HEALTHCARE FUND

Linde is dedicated to promoting therapeutic gases in medicine. The Linde Healthcare REALfund, founded by the Linde Healthcare Global Business Unit, underscores this commitment. The fund supports innovative ideas and research projects exploring the therapeutic benefits of medical gases, including solutions aimed at raising patient safety, comfort and mobility levels. Each successful project application will receive funding of up to 75,000 euros.

H_2 REFUELLING STATION:

GREEN HYDROGEN

Under the umbrella of the Clean Energy Partnership (CEP), TOTAL Deutschland and Linde are building another hydrogen fuelling station in the heart of Berlin. The hydrogen will be generated from fully renewable sources. Some of it will be sourced from a Linde pilot plant that uses liquid biomass as feedstock. The rest will be generated through wind-electrolysis, a technology that TOTAL is developing in collaboration with ENERTRAG.

Innovative surface finish for implants

STEEL SPONGE FOR STRONG JOINTS

Artificial hip and knee joints have to form a permanent bond with human bones. The surface of implants plays a key role here. Now, Linde researchers have developed a process to create a wafer-thin, porous surface on steel. This gives special properties to the metal surface and opens up new possibilities in the medical field.

↲ Author: Ute Kehse
↳ Image source: Miriam Maslo/SPL/Agentur Focus

Bones tire with age. And as demographics shift, more and more otherwise healthy people are finding that their knee or hip joints can no longer deal with the stresses of everyday life. Implants can restore mobility to people whose bones have become less dense, for example through osteoporosis, or so worn down that every movement causes pain. The number of operations worldwide is increasing dramatically each year. Cases of much-dreaded arthritis are also increasing among young people, subsequently fuelling the number of artificial implants in this segment of the population.

Biocompatible, lightweight and strong

Doctors, however, have not yet found the ideal material for these implants, and hundreds of different models and compounds are available. "The lifetime expectation for artificial joints is constantly growing, as are the quality expectations for the implant material," explains Prof. Fritz-Uwe Niethard from the Schwertbad Therapy Centre in the German city of Aachen. An artificial joint has to be resistant to corrosion and biocompatible to ensure it does not trigger any rejection responses. It also has to withstand the extreme pressures and bending forces within the body, which in some cases can be up to six times the actual body weight. Natural bone, a composite of fibrous collagen proteins and the mineral hydroxyapatite, is – when healthy – able to take on all of these challenges. This is because bone tissue forms a structure that is both light and strong and through which nutrients, cells and metabolites can easily pass.

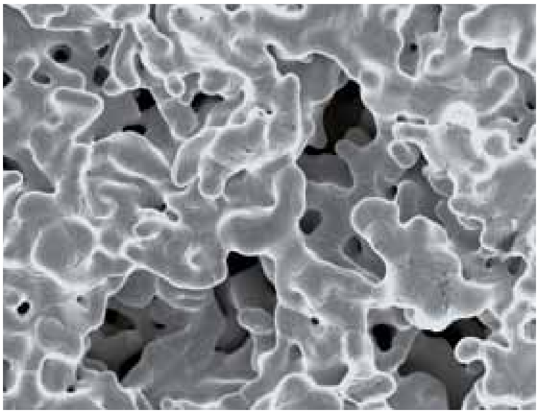
TISSUE CELLS FUSE WITH POROUS SURFACES.

It is because of these extreme mechanical loads that biomedical scientists often use special stainless steel alloys for hip and knee implants, in particular cobalt chrome steel alloys or the highly corrosion-resistant chrome nickel molybdenum alloy 316L. Steel has excellent mechanical properties and these alloys are biocompatible. "However, steel does not bond well with bone tissue," explains Pierre Forêt from the heat treatment team in Linde's Gases Division. Material specialists are therefore trying to create metal implants with a porous structure to improve the osseointegration of the material.

Joint implants are an important part of Forêt's "porous structures" project. In Munich, the Linde expert and his colleagues have developed a new process to apply a porous metal mesh to the surface of any stainless steel material. The major benefit here is that instead of a weak layer that can easily flake off, the finish is an integral part of the solid steel structure. A microscope throws some light on these special surface properties. Magnified 500 times, the

X-ray check: *Artificial implants are custom-fit to allow the surrounding bone tissue to fuse with the prosthesis.*

High-tech theatres: Surgeons ensure that hip and knee implants fit perfectly into the human musculoskeletal system. Steel implants have to fuse with bone tissue to form stable joints. Linde experts have developed a process for creating sponge-like metal surfaces (see photo below). This porous finish provides a perfect surface with which the cells can bond.



seemingly solid steel turns out to be a complex structure of round, irregular moulded grains. The elegant metal structure is full of serpentine cavities.

This fine layer is only a fraction of a millimetre thick, and with the porous structure of a household sponge, it opens the door to new possibilities in the medical field. "The fine surface structure could make implants, stents and medical instruments more compatible with the human body," continues Forêt. Surface structure plays a key role in determining whether the human immune system accepts or rejects foreign matter. This is because bone cells grow better on implants with a rough surface than those with a smooth finish. The tiny cavities could also be used to store active components that suppress rejection responses. This is important with stents used to widen narrow blood vessels, for example. Syringes, medical instruments and the electrodes of artificial pacemakers could all be made with variants of this new material impregnated with antibiotics to prevent bacterial infection.

HOT STEAM BORES MICRO PORES INTO THE STEEL MANTLE.

This new development stems from a chance effect observed in 2006 by a team of scientists working under Christoph Laumen, Head of Process Industries Metallurgy & Glass at Linde's Gases Division, and Sören Wiberg from the Swedish company AGA Gas, a member of The Linde Group. While conducting material tests, Linde's researchers subjected stainless steel to temperatures of over 1,000 degrees Celsius in an argon/water vapour atmosphere. The water reacted with the nickel, chrome, molybdenum, cobalt and silicon in the alloy. As a result, grains of different metal oxides formed on the surface. The researchers then subjected the steel to a dry hydrogen-based atmosphere to remove the oxides. Under certain conditions, however, they were surprised to find that a metal structure remained, full of pores and cavities with diameters between one and twenty micrometres. The chemical composition of this porous layer, approximately as thick as a human hair, had also changed from its original solid state. "During oxidation, elements such as chrome move to the surface, making the porous layer even more resistant to corrosion," reports Forêt.

In the following months, the material experts worked intensively with the material and the chemical processes in order to control the way the pores were created. “We discovered the factors that control pore size and learnt how to create uniform pore sizes,” explains project manager Forêt. A large number of parameters determine the type of oxides created and the size of the new metal grains, including temperature, the composition of the steel, the gases used and the duration of oxidation and reduction. The reduction timeframe is particularly important. “If the reduction period is too long, the structure collapses. If it is too short, the oxide does not completely disappear,” elaborates Forêt. Yet even these effects can be turned to the scientists’ advantage under certain conditions and harnessed, for instance, to adapt the chemical makeup of a surface. This process technology can also be applied to treat large amounts of material or individual finished works very quickly.

Automotive and photovoltaic applications

The benefits of this new process technology extend way beyond the medical field. Linde experts believe that porous stainless steel surfaces could play a useful role in heat exchanger or solar panels. Superior heat transfer capabilities also make the extremely thin porous layer an interesting option for industrial processes. During heat treatment, the surface increases by between twenty and one hundred times its original size, thus enabling the component in question to dissipate heat much faster. “In lab tests, we’ve seen heat transfer capacity increase by up to 40 percent,” reports Forêt. He and his colleagues are currently collaborating with a partner company to test their prototypes in exhaust gas recirculation (EGR) coolers. These coolers are installed in millions of cars and help reduce harmful emissions – primarily nitrogen oxide – by cooling exhaust gases after combustion before they are recirculated back into the engine. “If we can make these heat exchangers more efficient, they can be made to smaller specifications. This of course saves material, which is a real plus for the environment,” explains Forêt.

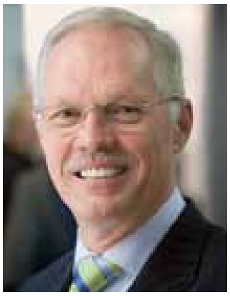
Linde experts are currently investigating the sponge-like steel’s potential as a biomaterial and are already partnering with a leading implant manufacturer. In the coming months, Forêt and his colleagues want to test how well bone cells fuse with the porous steel. “The concept is already resonating strongly among industry experts,” adds Forêt. Which is no big surprise. Other processes for creating porous surfaces already exist, for example, using lasers or ion beams. However, Linde’s heat treatment process is a considerably less expensive alternative.

LINK:

www.nlm.nih.gov/medlineplus/hipreplacement.html

A BRIEF CHAT

“ONE OF THE MOST SUCCESSFUL SURGICAL PROCEDURES”



Linde Technology talked to Prof. Fritz-Uwe Niethard, an orthopaedic and trauma surgeon. Prof. Niethard is head of the Schwertbad outpatient rehabilitation centre in the German city of Aachen.

THE NUMBER OF ARTIFICIAL HIP AND KNEE JOINT REPLACEMENTS IS INCREASING ENORMOUSLY. WHY?

Demographics are one factor here. Deterioration of hip and knee joints as well as femoral neck fractures are primarily problems that occur in old age. Treatment preferences have also changed. Patients who previously would have undergone corrective surgery (corrective osteotomy) for joint problems are now more likely to receive an artificial implant. Excess body weight is also a key factor for many patients, especially in the case of knee joints.

HOW IMPORTANT IS THE SURFACE TEXTURE OF AN IMPLANT WHEN IT COMES TO COMPATIBILITY?

The surface plays an important role for a number of reasons. Firstly, the surfaces of a joint have to be as smooth as possible to prevent friction. This is no problem when ceramic meets ceramic, or when metal or ceramic meet plastic. Secondly, surfaces that come into contact with bone must have the most compatible surface possible to ensure the bone and the prosthesis fuse. A somewhat rough texture is the best option here. Thirdly, the surface should not release any substances that may harm the body.

HOW LONG – AT BEST – DO TODAY’S HIP REPLACEMENTS LAST?

The lifetime of prostheses is documented in some countries. According to the Swedish Total Hip Replacement Registry, only ten percent of the most modern prosthesis components loosen or need to be replaced after fifteen years – making modern endoprosthetics one of the most successful surgical procedures ever.

Sophisticated process chain: Linde's liquefaction technology cools natural gas to minus 160 degrees Celsius. The gas liquefies at this temperature and contracts to 1/600th of its original volume, making it easier to transport.

FEATURED TOPIC: POWERING THE FUTURE

Technologies for efficient liquefaction of natural gas

NATURAL GAS – SECURE POWER SOURCE

Building a low-carbon economy is one of the great challenges of our time. Natural gas is an important stepping stone on that journey, bringing us power with a much lower carbon footprint. When it comes to transporting this environmentally sound energy carrier from the source to the point of use, suppliers are increasingly turning to liquefaction. Engineers at The Linde Group are working on innovative processes across the entire liquefaction value chain, from industrial-scale liquefaction plants to fuelling stations for LNG (liquefied natural gas).

↲ *Image source: Linde AG*
↳ *Author: Caroline Zörlein*

In order to protect the climate, the world needs clean energy. Natural gas is a step in the right direction. 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 around 30 percent less carbon dioxide (CO_2) than crude oil, and almost 45 percent less CO_2 than coal. Furthermore, natural gas deposits are set to last at least another 200 years. Natural gas is already one of the most important sources of energy today, covering around 25 percent of global energy requirements. And this figure is set to rise.

> *200 BILLION CUBIC METRES OF LNG ARE TRANSPORTED ACROSS THE GLOBE EACH YEAR.*

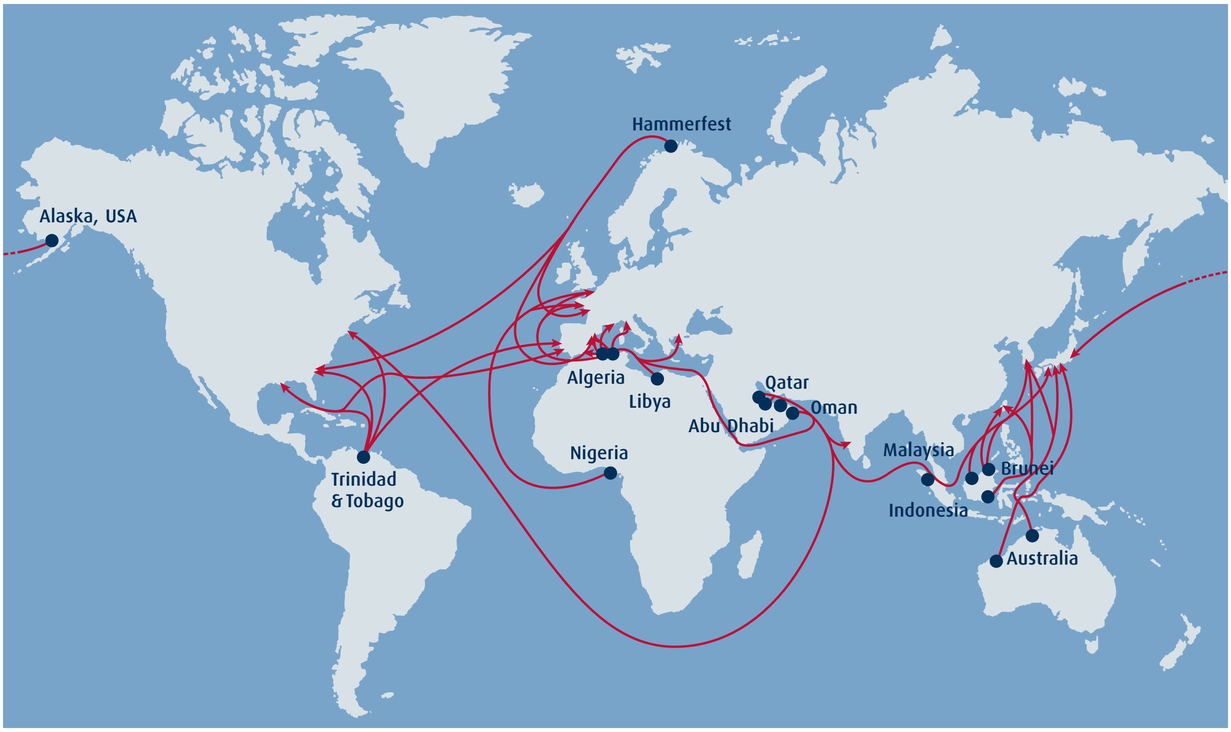
As with oil, most natural gas deposits are located far away from the actual point of use. Traditionally, the vast majority – around 90 percent – of natural gas is pipelined over long distances to power plants, industrial facilities and homes. However, after 3,000 kilometres or so, pipelines become uneconomical. The costs for pipelaying, materials and compressor stations are just too high.

New strategies have been developed to overcome the distance challenge. Natural gas can now be transported many thousands of kilometres in liquid state. Already today, around 200 billion cubic metres of LNG are transported around the globe each year – around ten percent of the natural gas market. One of the major benefits of this strategy is that natural gas takes up less space in liquid state. When cooled to minus 160 degrees Celsius, natural gas contracts to 1/600th of its original volume. As a result, LNG can be easily and cost-effectively transported to consumers from remote regions. In fact, LNG is already travelling the world in the holds of over 200 special ships known as LNG tankers. Just one of these ocean-going giants carries enough gas to supply 34,000 households in Germany for a year.

The journey starts at large LNG plants, known as world-scale facilities. There are currently 70 of these in operation. With capacities of around 10 million tonnes per year across several production lines, these plants liquefy enormous amounts of natural gas for export. The tankers then transport the LNG to special docking stations in ports the world over, where it is converted back to gas, fed into national pipeline grids and delivered to consumers.

ACROSS THE GLOBE BY TANKER

Liquefied natural gas trade routes: *Shipping is the only economically viable way of transporting natural gas once the journey runs into thousands of kilometres. Before it can start its journey, however, the gas has to be liquefied. In this state, it can then be loaded onto special LNG tankers. Around 200 of these vessels are currently in service, transporting LNG around the globe. Once the tankers reach shore, the LNG can be transferred to trucks at coastline stations and transported to the point of use or it can be re-evaporated and continue its journey by pipeline.*



Japan and Korea have long been major LNG importers. Both countries established supporting infrastructures early on and are regarded as pioneers in the field.

Natural gas – a climate-friendly energy carrier

In cooler climate zones, 60 percent of natural gas is used for heating. However, this energy carrier has many uses – it can generate electricity and fuel trucks, for instance. Ships are also set to be powered by clean LNG, as Hermann J. Klein, Executive Board Member of the Germanischer Lloyd Group, outlined at the maritime industry's first global maritime environmental congress (gmec): "LNG contains less sulphur and carbon and is thus much kinder to the environment." In Klein's opinion, the majority of ships will be powered by natural gas by 2035.

Natural gas's share of the global energy mix is increasing thanks to liquefaction technology and cutting-edge tankers. "LNG has become synonymous with clean energy," states Marcus Lang, Executive Vice President LNG and Natural Gas Processing at Linde. "Our broad portfolio of energy-efficient, tailored plant solutions meets the needs of a wide market spectrum, from world-scale plants to smaller LNG terminals for regional markets," continues the Linde engineer. And to ensure that more remote natural gas reserves can also be efficiently tapped in the future, Linde is continuously evolving its liquefaction technology. Many natural gas deposits are located off-shore and can only be accessed via floating platforms or processing ships known as floating production, storage and offloading (FPSO) units. "We decided to collaborate with companies that develop FPSO units in order to adapt our liquefaction technology for this kind of extraction and transport," reports Lang. Linde engineers are also developing special plant modules that can boost yields from natural gas deposits. These units inject nitrogen into the deposits, enabling developers to increase recovery rates of this valuable raw material in an environmentally sound way.

Linde's LNG innovations are key enablers in the transition to a renewable energy value chain.

SHORT INTERVIEW

"ONE-STOP SHOP FOR LIQUEFIED NATURAL GAS"

Natural gas stands to play an important role in the energy mix of the future. Innovative technologies for liquefying and transporting natural gas are key factors here, and Linde has a broad portfolio of solutions. Marcus Lang, Executive Vice President LNG and Natural Gas Processing at Linde, explains.

↳ WHAT NATURAL GAS LIQUEFACTION TECHNOLOGIES DOES LINDE OFFER?

Converting natural gas to LNG requires the latest cryotechnology. We are specialists in this field. Many elements such as heavy hydrocarbons, CO_2, nitrogen, sulphur compounds and water have to be separated from methane before LNG can be transported. Our cryogenic heat exchangers are at the heart of liquefaction plants. Most world-scale LNG plants use coil-wound heat exchangers up to 70 metres high. Linde is one of just two companies in the world with this technological know-how. Our heat exchangers are not only used in our own LNG plants, but also by companies such as Shell, Woodside, ConocoPhillips and other oil and gas corporations.

↳ IS IT TRUE THAT LINDE ALSO BUILDS SMALLER LNG PLANTS AND COMPONENTS FOR DISTRIBUTION?

Yes. Our small- and mid-scale terminals serve regional markets. At Linde, we refer to liquefied natural gas that is traded as merchant LNG. These kinds of plants produce around 10,000 to 1.5 million tonnes per year. We have also delivered this technology for the first time to a larger LNG plant in China, to the west of the Gobi Desert. Our customer Guanghui is China's LNG pioneer. The company is replacing petrol, diesel and kerosene in its transport and industrial activities with LNG. In some cases, the liquefied gas will be transported several thousand kilometres across China. We are currently finalising a further deal with this customer for a liquefaction plant with a capacity in excess of 400,000 tonnes per year. Linde also offers a range of LNG distribution solutions via Group members Cryostar and Cryo AB. Our portfolio here includes on-board storage solutions, truck and ship fuelling technology as well as small- and mid-scale LNG terminals.

↳ HOW IS LINDE POSITIONED IN THE MERCHANT LNG MARKET?

We are already a global leader in the merchant LNG sector. We intend to strengthen our position here by leveraging the synergies between our Linde Engineering and Linde Gases divisions. This approach consolidates our strategy of covering the entire LNG value chain. 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. Linde even operates smaller LNG facilities. All of which makes us a true one-stop shop for liquefied natural gas.

↳ WHAT LNG PROJECTS HAS LINDE GOT LINED UP FOR THE FUTURE?

We want to follow on from the success of our first major showcase plant in Hammerfest, Norway, and position ourselves as a strong partner for world-scale plants. We are also currently negotiating a contract to supply the technology for a major LNG plant in Venezuela. At the same time, we are continuing to enhance our engineering portfolio. In collaboration with the company Single Buoy Moorings, we are working on the first off-shore liquefaction solution, to be built on a floating production, storage and offloading (FPSO) unit.

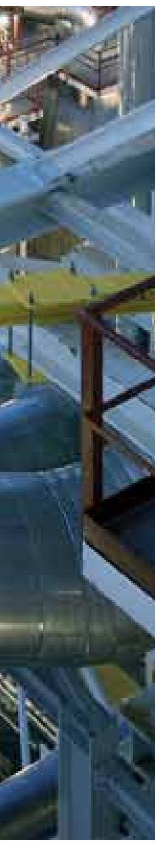
High-tech plant inside the Arctic Circle: *Valuable natural gas reserves from the Barents Sea are liquefied with cutting-edge technologies from Linde.*

Hammerfest: Liquefied natural gas for the global market

SOURCING LNG FROM THE ARCTIC

In the icy cold of northern Norway stands one of the world's largest liquefied natural gas (LNG) production facilities. The project was a huge challenge right from the word go. Linde's innovative technologies played a key role in making it happen. Not only is the plant a secure source of LNG, it has given a huge boost to liquefaction technology in general. It also serves as a unique example of what can be achieved on land and sea in the future – and is of course a great showcase project for the globally expanding LNG market.

↰ *Image source: Linde AG*
↳ *Author: Tim Schröder*



When blizzards rage in Hammerfest, almost everything freezes. In this stark Norwegian landscape, 600 kilometres north of the Arctic Circle, there's no hiding from the biting winds. Snowdrifts pile up between houses and the damp iciness chills to the bone. Just off the coast of Hammerfest lies the small barren island of Melkøya, where, if anything, the wind is even wilder. This of course only adds to Melkøya's fame. After all, it's hard to think of a more inhospitable location for a high-tech industrial complex – let alone one of the largest natural gas liquefaction plants in the world. Yet on Melkøya, natural gas sourced from below the Barents seabed is cooled to minus 160 degrees Celsius, liquefied and loaded onto tankers. There are around 70 of these world-scale LNG terminals across the globe. Most are located in warmer regions such as Algeria or the Arabian Peninsula. And none of them have to brave six long months of snow and ice each year.

The island has a long history. Engineers from Linde and Norwegian energy group Statoil first started discussing plans for a terminal on Melkøya back in the late 1990s. Everyone involved knew it would be a very unusual undertaking involving a number of challenges. Some ten years later, Statoil described the project as a model of success. The terminal went on stream at the start of 2008 and has produced almost four million tonnes of liquefied natural gas (LNG) each year ever since – enough to supply three million private households for an entire year. Last year, Statoil celebrated the 100th LNG tanker to set sail from Hammerfest. Today, the terminal even exceeds original expectations, working at 104 percent of its planned capacity.

4 MILLION TONNES OF LNG PER YEAR – ENOUGH FOR 2 MILLION HOUSEHOLDS.

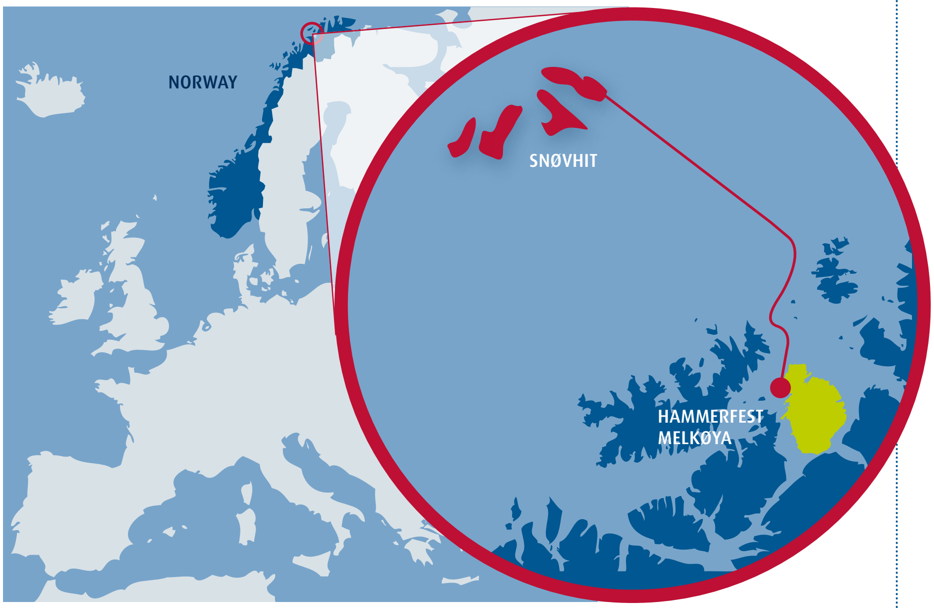
Engineering innovations for the harshest of climates

"No-one had ever designed a plant on this scale for this kind of climate. So it was a real engineering challenge," explains Peter Hortig, Linde's project manager on Melkøya for many years. The developers had to plan for every eventuality. The design of the liquefaction module was of course top priority. But the engineers also simu-

A global journey that starts in Norway: Cryogenically frozen LNG from Hammerfest travels the globe in the spherical tanks of the Arctic Princess (top left). 12,000 cubic metres of natural gas are pumped into the carrier's hold each hour. The LNG is stored in massive storage tanks (opposite).

SNOW WHITE'S BURIED TREASURE

Snøvhit (which means Snow White) is the name of one of the world's largest natural gas fields, located below Norway's Barents Sea. Once extracted, the natural gas is transported 140 kilometres by pipeline to the island of Melkøya, near Hammerfest, Norway. Melkøya is home to a state-of-the-art Linde-engineered plant that converts the energy-rich gas to liquid. The liquefied natural gas (LNG) is then transported across the globe in special tankers.



lated storms, calculated the temperatures in which technicians would have to work, and even tracked which way the snow drifted. To do this, the engineers constructed a test rig of steel girders, ducts and valves, which they set up on Melkøya. "We used a webcam to see where the snow accumulated and whether it affected the rig," recalls Hortig. The enormous engineering effort paid off. "Our preparations were spot on – allowing us to design what is, in effect, a perfect fit," explains Hortig proudly. Even with today's sophisticated technology, a liquefaction process on this scale is still an enormous challenge, which underlines just how much technical expertise had to be channelled into the Hammerfest development process. Every natural gas field is different – the pressure, composition and temperature can vary significantly. The process chain, above all cooling and liquefaction, therefore has to be tailored exactly to these variables.

On Melkøya, liquefaction takes place in a cold box around 40 metres high and as large as a narrow office block. It functions along the same lines as a fridge. A compressed coolant condenses and expands as it is fed past natural gas in huge heat exchangers, where the gas gradually cools until it liquefies. In this state, the gas shrinks to a fraction of its original volume, making it perfect for transport by sea. In the Melkøya cold box, there is enough space for the pre-cooling, intercooling, liquefaction and subcooling heat exchangers. "The heat exchangers were a key design priority. Here we channelled our entire expertise and experience into optimising them for the conditions on site," continues Hortig.

However, this ground-breaking project did experience some teething problems, such as small leaks in some of the components that were newly designed. "We were able to resolve these issues quickly and replace the defective components with more robust parts," reports Markus Vogt, Hortig's successor and the current project manager for Hammerfest. The actual process chain was a success from the word go. An LNG terminal, however, cannot be switched on and off like an electric motor. The process has to be started slowly and gradually optimised until the plant reaches full capacity. All of which takes quite some time. Linde's experts also trained

NATURAL GAS PORT – GIANT CONCRETE TANKS HOUSE 125,000 CUBIC METRES OF LNG.

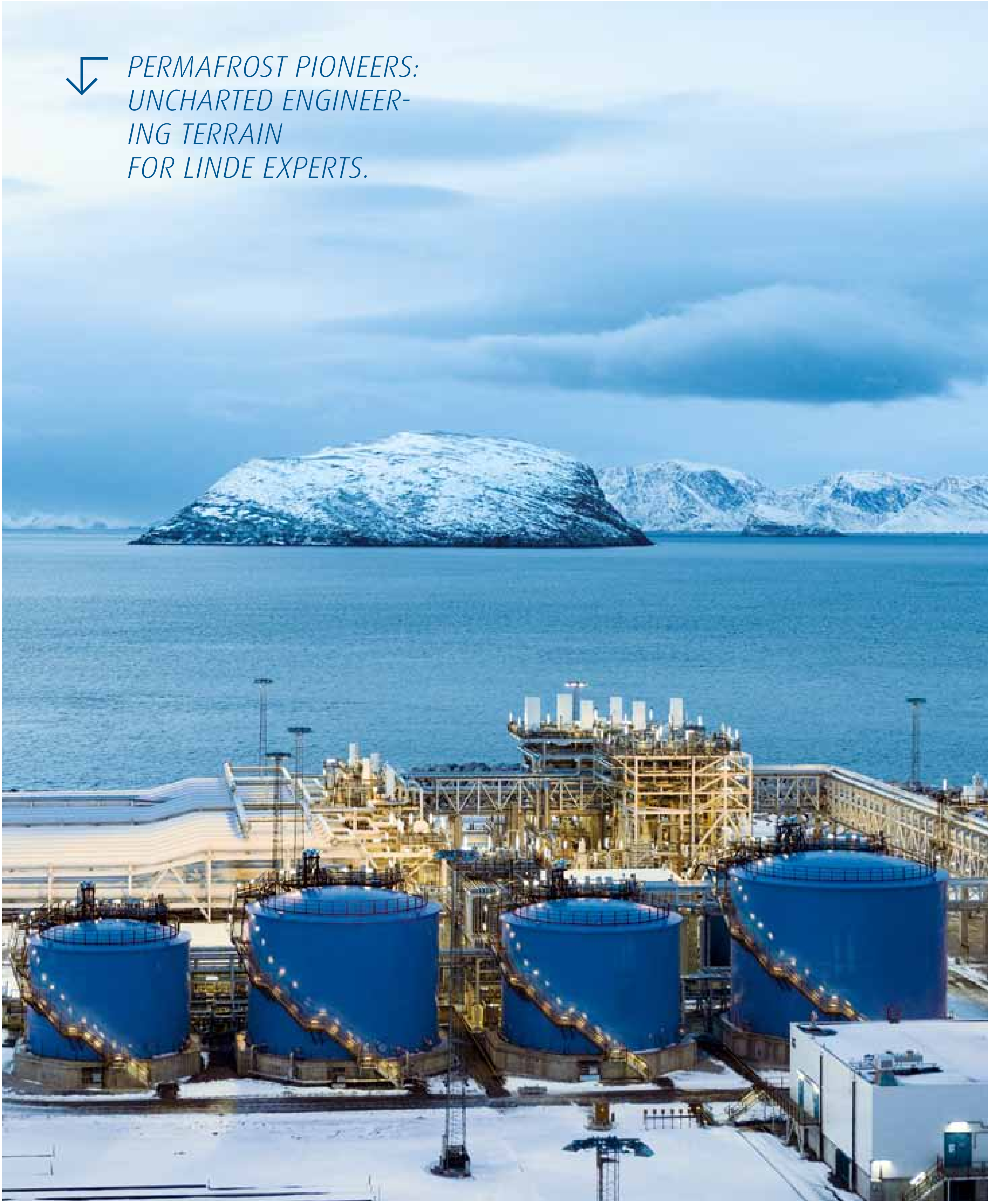
Statoil staff to operate the facility and they can still be seen every day at the site, which spreads out over one square kilometre. “A project like Hammerfest doesn’t just come to an end when construction is complete and the keys are handed over. We give ongoing operational and optimisation support,” states Vogt.

Harsh conditions for man and machine

Although Linde already had experience with LNG plants when it took on the Hammerfest project, existing references were for smaller liquefaction capacities located in warmer climates, for example in South Africa. It was a huge step for Linde engineers to ramp up from smaller capacities to four million tonnes per year in arctic conditions. “Hammerfest was definitely the right move. We learnt a great deal and are now thoroughly familiar with the processes and challenges involved in designing world-scale LNG plants,” adds Vogt. In addition, such a complex process chain always offers scope for optimisation. So Linde has already installed new components to boost LNG yields, enabling the facility to operate at 104 percent of its capacity.

The Melkøya project changed the global market for world-scale LNG plants. Ten years ago, two technologies dominated the international market for plants capable of producing millions of tonnes of LNG per year. Linde engineers raised the game by developing their own highly efficient liquefaction process specially for the Melkøya project, thus sending out a clear message to the industry. “We’ve proven our expertise across the entire spectrum – from small terminals to world-scale plants operating under the harshest conditions,” explains Vogt. The company is already planning its next world-scale plant in Venezuela. Further formidable LNG facilities with annual capacities running into millions of tonnes will also be required for the world’s largest gas reserves in the Arabian Peninsula, the Per-

Giant jigsaw: The individual plant modules for Hammerfest were preassembled at different locations across Europe. These giant steel components were then transported thousands of kilometres on huge ships to the north of Norway. Linde engineers supervised local assembly, ensuring the gas turbines, pumps, compressors and heat exchangers dovetailed to perfection.



PERMAFROST PIONEERS: UNCHARTED ENGINEERING TERRAIN FOR LINDE EXPERTS.

Control tower on the gas island:
Natural gas occurs naturally. So pressure, composition and temperature can vary. To ensure the gas is liquefied efficiently, the processes chain must be aligned with local conditions.

ENGINEERING INNOVATIONS BOOSTED CAPACITY TO 104 PERCENT.

sian Gulf as well as in Russia and Australia. Linde will continue to supply the engineering know-how for projects at this extreme end of the scale together with custom-engineered components such as cold boxes and heat exchangers – individual modules that can easily cost up to 50 million euros.

LNG production of the future – far out at sea

The Hammerfest terminal has also ideally positioned Linde for another market that is looking extremely promising. In the future, liquefaction facilities will be installed on floating platforms or production vessels at sea. These LNG floating production storage and offloading (FPSO) islands will help open up natural gas fields far out to sea. Connecting these kinds of deposits to the coast by pipeline over hundreds of sea miles and at great depths would be too costly. An LNG FPSO, however, could extract the gas, reduce its volume considerably through liquefaction and transfer it directly to tankers at sea. Although the terminal on Melkøya is on dry land, core components such as the 35,000 tonne process unit with pumps, gas turbines and heat exchangers plus the large cold box were transported to the island by sea on special ships. "On land there's plenty of room. For the journey by sea, however, we had to pack all components very tightly onto a floating platform," outlines Dr Marc Schier, project manager for LNG-FPSO at Linde. This experience gave Linde a fundamental understanding of the processes and technologies involved in floating plants. Obviously, transporting components by sea is not the same as producing LNG on board a ship. Here, the cold box and heat exchangers have to keep working even in rough seas. Cargo pumps and loading arms have to keep functioning reliably and safely in high waves when the tanker has drawn up alongside. "The world is waiting for the first LNG FPSO," states Schier. With years of experience on Melkøya, Linde feels ideally placed to take on the task. An opinion that is obviously shared by its customers. There is already interest in a liquefaction ship destined for the waters off Australia. So there is every possibility that the first LNG FPSO will be in action off the coast of Australia in just a few years – basking in glorious sunshine rather than icy winds and snow.

HEAT EXCHANGERS AT THE HEART OF IT ALL

The bundle of tubes that makes up a coil-wound heat exchanger is the core technology in a cold box. It is here that the liquefaction process takes place, making the cold box a key component of the Hammerfest LNG plant. These boxes comprise numerous heat exchangers, separation columns and separators together with connecting pipes and instruments. The gas cools gradually as it passes through the heat exchangers, its temperature falling from around 40 degrees Celsius to minus 163 degrees, at which point it liquefies. Linde is the only manufacturer to produce the two types of cryogenic heat exchangers common in industrial-scale LNG plants – coil-wound and plate heat exchangers.

LINKS:

www.lngfacts.org
www.gl-group.com/pdf/nonstop_2007-02_D.pdf
www.statoil.com
www.linde-engineering.com/en

Baltic Sea's first liquefied natural gas terminal

COLD AS ICE

In liquid form, natural gas can be transported by ship or truck to remote areas that are not on a pipeline network. Near Stockholm, The Linde Group has now built the Baltic region's first LNG terminal. The company also provided the building blocks along the entire LNG value chain – from the liquefaction plants through the transport ship tanks to the actual terminal.

Author: Andrea Hoferichter
Image source: HO/Reuters/Corbis

In May 2011, a small peninsula around 60 km south of Stockholm will host the official opening of Sweden's first ever liquefied natural gas (LNG) terminal. Built and operated by AGA, a member of The Linde Group, the facility is set to supply Sweden and the entire Baltic region with LNG. Linde was the one-stop provider for the entire LNG terminal in Nynäshamn, supplying "everything from the LNG production plant in Stavanger to the storage tanks for trucks and ships, and from the on-site storage units to the on-board reliquefaction units, not forgetting the liquid-to-gas converters," explains Trond Jerve, LNG Manager at AGA. The terminal is owned by the Swedish company AGA Gas AB and staffed by the company's own employees. Gothenburg-based cryogenic and storage specialists Cryo AB, also a member of The Linde Group, provided the technology for the storage tanks.

TEN PERCENT OF NATURAL GAS IS ALREADY TRANSPORTED AS LNG.

A round, gleaming concrete storage tank with a diameter and height of almost 36 metres is the heart of the plant in Nynäshamn. "We can store up to 20,000 cubic metres of LNG here," adds Jerve. And since each cubic metre of LNG expands to around 600 times its volume when it converts back to gas, this actually corresponds to around twelve million cubic metres of gas. Cryogenically frozen to minus 162 degrees Celsius, the liquefied gas is pumped into storage tanks on trucks and transported directly to the customer or a network feed point. The LNG is then carefully heated in Linde regasification units and distributed as natural gas. "In the region around Stockholm, transporting natural gas in liquid form is the most cost-effective option. More to the point, it's the only option as there simply aren't any distribution pipelines here," reports Jerve.

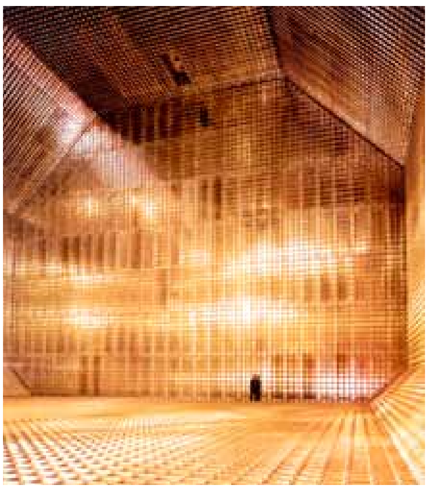
Transporting natural gas in liquid form is growing in popularity as it frees carriers from the restrictions of a pipeline infrastructure. Today, more than 10 percent of natural gas traffic worldwide is in liquid form. And the figure is rising. AGA already has firm plans to build a second storage unit at the terminal. "Even with this addition, Nynäshamn terminal will still be a small-scale facility," he explains. Although these smaller plants are still the exception among the approximately 70 LNG terminals worldwide, they do have one major benefit. Their size makes them ideal for sites near industrial parks and cities, keeping them close to the customer. The AGA terminal in Nynäshamn, for example, will also be supplying the neighbouring crude oil refinery run by the company Nynas. The refinery needs hydrogen gas to process crude oil. In the past it used naphtha for this but now wants to use natural gas. The switch to natural gas will cut the refinery's carbon dioxide emissions by up to 58,000 tonnes. Energy company Stockholm Gas was also involved in constructing the new terminal and is adopting the same strategy to reduce greenhouse emissions of carbon dioxide by some 50,000 tonnes.

At Nynäshamn, Linde keeps the LNG flowing. Most of it is sourced from a state-of-the-art, extremely energy-efficient natural gas liquefaction plant in Stavanger, Norway. Built by Linde's Engineering Division for Skangass AS, the Stavanger facility went on stream at the end of 2010. "With an annual capacity of 300,000 tonnes, this plant again underscores our leading position in the mid-scale LNG market," explains Dr Erich Ettlinger, Project Manager at Linde. LNG is shipped from Stavanger to Sweden in dedicated LNG carriers such as the Coral Methane

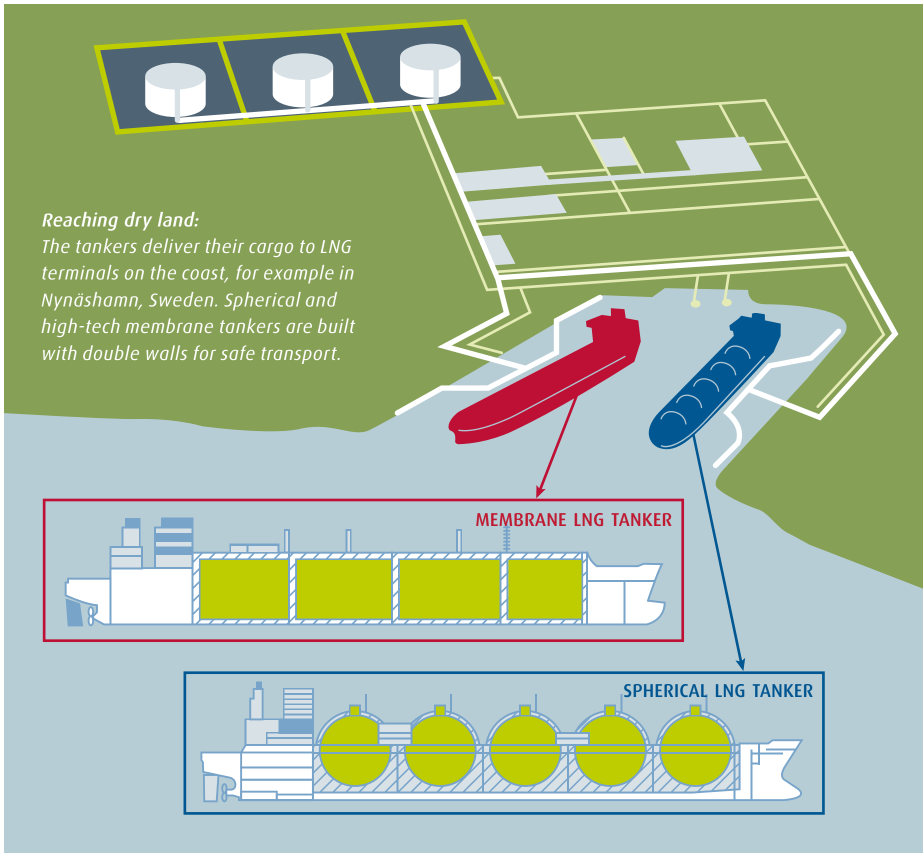
Energy-rich cargo:
Modern membrane tank LNG carriers transport liquefied natural gas across the oceans of the world, creating a global LNG infrastructure.

Full of energy: In Nynäshamn, liquefied natural gas is stored in special tanks built by Linde Group member AGA, from where it is transported to various customers.

Everything under control: Engineers from Linde's Swedish company AGA Gas AB at the construction site of the Baltic Sea's first LNG terminal.



Insulated hold: Membrane tankers are built with high-grade steel and layers of insulating material for efficient, safe storage of LNG.



from the Dutch shipping company Anthony Veder. These currently hold 7,500 cubic metres and this figure is set to rise to 15,000 cubic metres in 2013.

Fuelling eco-friendly mobility

When LNG evaporates, it forms methane vapour, which can create an explosive mixture if it comes in contact with air. So safety is a top priority at all times. Linde stores LNG in reinforced, double-walled tanks and containers. The inner wall is made of steel, the outer wall of concrete. "If a leak occurs in one of the walls, it will be contained by the other," explains Jerve. The gas is transferred via a cryogenic system of pumps, pipes and tubes. Any evaporated gas is captured by custom-built reliquefaction units.

Compared with fossil fuels such as diesel, petrol and oil, natural gas reduces carbon dioxide emissions by 30 percent. In addition, it emits significantly less pollutants. The figures speak for themselves: around 90 percent less sulphur, approximately 80 percent fewer nitrogen oxides and no heavy metals or soot particles. Jerve therefore believes that the new LNG terminal will play an increasingly important role in shaping personal mobility in Sweden. "Environmental regulations are already strict here," he explains. Airport taxis, for example, must be powered by gas, hybrid or electric engines in order to be able to pick up passengers at Arlanda airport. In addition, Swedish

EXTRACTION, LIQUEFACTION AND TRANSPORT

RESCUING GAS ON THE HIGH SEAS

The world's largest natural gas tankers plough their way through the waves between Qatar and the US. Modern membrane type Q-Max tankers from Samsung Heavy Industries are longer than three football fields and as high as a twelve-storey high-rise. They are also equipped with a very special technology – EcoRel reliquefaction units developed by French company Cryostar, a member of The Linde Group. "This technology can reliquefy the liquid natural gas that evaporates, or boils off, during transport," explains Cryostar engineer David de Nardis. As liquefied natural gas is stored only just below its boiling point at minus 162 degrees Celsius, even slight temperature fluctuations can trigger unwanted evaporation.
Vast amounts of LNG are lost in this way. During a transport period of twenty days, around three percent of LNG in tanks evaporates. With ships the size of a Q-Max tanker, this can quickly add up to the equivalent of one million litres of natural gas. "The benefits of our process increase with the size of the tank," reports de Nardis. Without reliquefaction technology, the boil-off gas (BOG) is removed from the tank to prevent excess pressure building up and is either used to power the ship's engine or simply released into the air. The technology that recaptures this valuable liquid natural gas is based on the Brayton cycle. This thermodynamic cycle is a standard process in the world of cryogenics and uses nitrogen gas as a coolant. The nitrogen is cooled to a very low temperature over a number of stages. The process harnesses two inherent properties of gases to do this. Firstly, gases cool rapidly as they do work, in this case driving a turbine. Secondly, gases also cool if they are released through a valve and can expand to a much larger volume – as is the case when air is let out of a balloon.
A heat exchanger then transfers the cold from the nitrogen to the boil-off gas, which then reverts back to a liquid. "This cooling process does not run continually. It is only activated when a sufficient amount of boil-off gas has accumulated," adds de Nardis. A certain amount of cooled gas is always held in reserve to ensure the process can be started quickly where necessary.
Cryostar engineers started work on the first EcoRel units three years ago. Today, more than 14 tankers are equipped with this LNG-saving technology. And, according to de Nardis, the trend is upward.

truck manufacturer Volvo Trucks recently started a public field test with diesel trucks that can run on LNG (with a 25 diesel to 75 LNG ratio) and intends to launch a small fleet of these trucks next year.

"But the biggest market will most likely be marine transport as we move forward," the natural gas expert continues. For example, in Norway car ferries are required to run on natural gas. By 2013, more than 40 ships will be powered by LNG, and the majority of these will be equipped with cryogenic equipment from Cryo AB according to Jerve. At international level, industry experts also agree that natural gas is the fuel of the future for marine fleets across the globe as environmental shipping regulations set down by the International Maritime Organization (IMO) become increasingly stringent. Thresholds for sulphur levels in fuel have been subject to particularly strict regulation, with limits for shipping in the North Sea and Baltic Sea set to drop from the current 1.5 percent to 0.1 percent by 2015. Ships docking in European ports today must already comply with a 0.1 percent limit. "Natural gas is an attractive option in the move towards these goals," confirms Jerve.

Switching to a more environmentally friendly marine fuel could bring big benefits to the Baltic Sea region and its residents. Some 40,000 square kilometres or close to 28 percent of the Baltic Sea is classified as a dead zone, so pollution levels here are already high. This is compounded by the dense population. For example, Oslo-based Det Norske Veritas (DNV), one of the world's leading classification societies, has estimated that if the Mediterranean region had the same number of people per water volume as the Baltic, some 17 billion inhabitants would be living on its shores.

In addition to improving the environmental balance in the immediate vicinity and ensuring a secure supply of natural gas for the Baltic region, the new LNG terminal is also paving the way for a renewable energy era. Long term, the aim is to source liquid biogas (LBG). The chemical makeup of gas sourced from plants, slurry, waste water or landfill is very similar to that of its fossil relatives. It too comprises over 90 percent methane and can be just as easily liquefied. Biogas and natural gas can also be easily mixed, regardless of their physical state. "Natural gas is a good backup solution for the interim period as it can be mixed with biogas reserves when supplies run low," explains Jerve. This combination is an ideal strategy to secure future year-round supplies through an energy value chain that is as kind to the environment as possible.

LINKS:
www.aga.com
www.cryostar.com
www.energy.ca.gov/lng/faq.html

Road giants: *In Australia, over 72 percent of all goods are transported in huge trucks known as roadtrains, which can be up to 50 metres long.*

Australian trucks switch from diesel to natural gas

FULL SPEED AHEAD DOWN UNDER

In Australia, most goods are transported across the country in huge trucks. However, extreme fluctuations in diesel prices are a logistical headache for the transport industry. As a result, many operators are keen to convert their trucks to liquefied natural gas (LNG) – which means they need a refuelling infrastructure stretching along the country's endless highways. To resolve this challenge, Linde has developed dedicated micro LNG plants and is building a supporting network of LNG refuelling stations. These plants are also making a valuable contribution to reducing emissions down under.

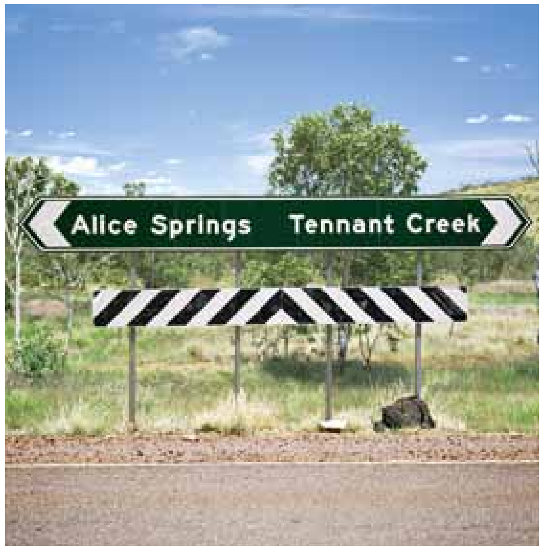
↲ Image source: Hemis/laif
↳ Author: Julica Jungehülsing

There's no real need for a fast lane on the Stuart Highway. This 2700-kilometre asphalt strip connects Australia's North with the South. Yet parts of it seem often deserted. The deafening silence is broken only by the odd thundering roadtrain – an Australian truck up to 50 metres long and weighing 150 tonnes fully loaded. Then the dust settles again to reveal a ghost-like strip stretching as far as the eye can see. Australia holds the record for the smallest number of people per kilometre of road in the developed world. Yet it transports more goods per capita by road than any other country. And this figure is rising. Transport by heavy goods vehicles (HGVs) is booming down under. People, goods and production sites are often separated by vast distances. Although most Australians live on the coast, much of the country's raw materials are located far inland. Alternatives to road transport are few and far between. There are no navigable rivers or canals and even the rail network is no real contender.

When it comes to getting fruit, vegetables, meat, computers, TVs and beverages to the inhabitants of the world's sixth largest country by area, road transport is the only option. Industrial companies also rely on trucks to transport raw materials and machinery. However, the booming transport sector is facing a problem. The price of diesel is rising and subject to huge fluctuations. "It is extremely difficult to plan for the future when such a key cost factor is so unstable. The price sky-rockets as soon as someone sneezes in the Middle East or an oil platform is threatened by a storm," comments Ken Padgett, one of the largest timber transporters in Tasmania.

FLUCTUATING DIESEL PRICES MAKE LNG AN ATTRACTIVE ALTERNATIVE.

Many freight carriers in Australia's forested south tell a similar tale. Tired of being dependent on volatile diesel prices, transport companies began looking for alternatives – and hit upon liquefied natural gas, or LNG for short. After all, Australia is the third largest LNG producer in the Asia Pacific region. Such are its natural gas reserves that it exports almost half of what it produces as LNG. In 2008, this was 15.2 million tonnes, worth 5.9 billion Australian dollars (4.4 billion euros). The abundance of natural gas in Australia makes it a cost-effective alternative to crude oil.



A milestone on the LNG highway: Natural gas can be extracted from coalbed gas and liquefied. The LNG is then stored in pressurised tanks at special filling stations, giving Australia's trucks a cost-effective source of fuel.

Interest in LNG as a fuel has long been dampened by the typical chicken-and-egg dilemma. No carrier is willing to convert to a new source of fuel without a network of fuelling stations. Without customers, even the most cutting-edge gas fuelling station is doomed to fail. Determined to solve this dilemma, Australian carriers teamed up with Linde's local business, BOC. The transport companies in Tasmania launched an LNG pilot project. Together, the seven member operators send more than 160 heavy goods vehicles across the state's roads every day. This represented a solid starting point for BOC, a gases pioneer with thirty years' experience in the LNG business. In the early years, BOC built Australia's first LNG plant in Dandenong, north of Melbourne, Victoria. This plant is currently being expanded and modernised for the new road transport project. In January 2011, a second facility was formally opened in Westbury, Tasmania. Professor Dr Wolfgang Reitzle, Chief Executive Officer of Linde AG, formally opened the plant with Senior Australian Government Ministers and the Premier of Tasmania. Natural gas is fed to the Tasmanian plant by pipeline.

FILLING UP ON LNG: 20 PERCENT LESS TRAFFIC-RELATED CO_2 EMISSIONS.

The commitment from Tasmania's carriers enabled BOC to invest and expand in east coast Australia. Thus far, the company has primarily focused on the densely populated southeastern region between Queensland and Victoria. Over two thirds of Australia's heavy goods vehicles travel the inland and coastal highways between Melbourne, Sydney and Brisbane. And a third facility is now being constructed near the town of Chinchilla in Queensland's resource-rich Surat Basin. This micro LNG plant will convert methane from coalbed methane reserves into liquefied natural gas. Here, a purifier filters impurities from the coalbed gas. The process also removes CO_2, sulphur and moisture. A refrigeration unit fitted with special heat exchangers then cools and liquefies the gas. For this process, BOC engineers used a patent from the Gas Technology Institute (GTI), developed it further and now owns the global license for this technological innovation. "We already have a large share of Australia's industrial gases market. The energy sector is opening up interesting new possibilities for LNG and further growth opportunities for BOC," explains Mike Karbanowicz, General Manager, Strategy & Planning at BOC in Sydney.

Linde has long been aware that the stable price of liquid natural gas gives it a major advantage over diesel in Australia. So BOC developed a special concept to bring LNG to the transport industry. It may sound straightforward, but the "LNG substitution of diesel" project entailed a lot of uncharted territory for the Group. The challenge for Linde's LNG experts was to develop dedicated micro plants that could produce small volumes economically. Karbanowicz explains the reasoning behind this scaled-down concept: "Considering the vast distances in Australia, it makes more economic sense to build multiple smaller plants close to customers and keep transport costs low." The micro plants have a daily capacity of 50 tonnes of LNG, which corresponds to around 70,000 litres of diesel.

The engineers used existing standard plant modules to keep costs as low as possible. "We took the largest commercial refrigeration unit we could find and built the micro plant more or less around the coolant compressor," adds Karbanowicz. The development phase lasted two years. "The time-consuming bit was not so much the build phase. The bigger challenge was reaching the target market – after all, this was a totally new concept," continues Alex Dronoff, LNG Business Manager at BOC in Sydney.

Switching to LNG pays off

To make LNG a financially attractive alternative for as many operators as possible, BOC has already built a refuelling network in Tasmania with the added bonus of a stable price guarantee – relative in particular to diesel with its unpredictable pricing. And BOC is now building an "LNG highway" on the Australian mainland between Queensland and Victoria. A total of eight stations are planned. Linde's gases experts are currently talking to operators to work out the best mainland fuelling locations.

Refuelling with LNG is not only cost-effective, it is also very easy. The new stations, which were designed by Cryostar, a member of The Linde Group, do not even require an attendant to operate them. Drivers fill up the trucks themselves. It's not just the transport carriers who benefit from the new system, the environment also stands to gain. LNG-powered trucks are quieter and emit over 20 percent less CO_2.

Converting a truck to LNG costs between 50,000 and 95,000 euros, depending on the technology. The most expensive option up front, however, saves the most money in the long term. Although all trucks are equipped with diesel and gas tanks, the volume for both systems differs significantly. With some manufacturers, diesel only accounts for around five percent of the entire tank volume as it is only needed to ignite the engine. The vehicles then use LNG, which makes up around 95 percent of the tank. This is the most cost-effective system in the long term, as Karbanowicz explains: "LNG is not only cheaper than diesel, it also extends engine life and reduces the need for maintenance work." Depending on driving patterns and mileage, the conversion to LNG can pay for itself within three years.

Karbanowicz goes on to list the main target groups for this technology: "Liquid natural gas is an attractive option for any heavy haulage operator, such as timber carriers, and for any carrier with trucks transporting raw materials or foodstuffs over distances up to 250,000 kilometres a year." BOC may also be included in this list in the future. "We are currently assessing which of our vehicles are best suited to conversion." Within three years, BOC aims to be supplying LNG to around 500 roadtrains as well as articulated trucks and tankers every day. This target is also good news for the Australian government, which provided financial support for the pilot project in Tasmania. "LNG is the first real alternative to diesel for heavy goods vehicles," confirms Martin Ferguson, Australia's Minister of Resources and Energy.

ROAD TRANSPORT IS BOOMING

Heavy goods traffic is on the rise in Australia. By 2030, the amount of goods transported by truck is set to be 180 percent higher than the 2008 figure. Traffic between states is expected to more than double. Even now, the figures are impressive. Over 81,000 multi-trailer articulated trucks plied Australia's roads in 2009. 72 percent of all freight is transported by road and highway. In 2008, this was 191.5 billion tonnes per kilometre. In twenty years, this figure is expected to rise to 342 billion.

LINKS:
https://boc.com.au
www.abare.gov.au/interactive/09_auEnergy/htm/chapter_6.htm

Efficient processes for enhanced gas and oil recovery

UNLOCKING RAW MATERIAL DEPOSITS

Although global natural gas reserves are set to last significantly longer than oil, they must be used as effectively as possible. Nitrogen can play a key role in raising efficiency levels. When pressure in deposits falls, nitrogen can be pumped into the gas pockets to push pressure back up again. Linde engineers develop modules that help draw more of this raw material to the surface without damaging the environment.

Sometimes, buried treasure can be difficult to reach. For example, complex drills and sophisticated technology are often needed to extract valuable raw materials such as natural gas from underground reserves. Yet even with this equipment, geology can still prevent companies from getting maximum yields from gas deposits. In some cases, the natural pressure in gas pockets can leave up to 25 percent of reserves untapped below ground. In the case of oil, this can be as much as 50 percent.

Yet there are processes that can continue to flush out natural gas from layers of rock even in partially depleted reservoirs. Nitrogen (N_2), for example, plays an important role here. In a process known as enhanced gas recovery (EGR), nitrogen is injected into natural gas reservoirs in order to artificially raise pressure and consequently increase yield. Other inert gases can also be used for this purpose. In the US, for example, carbon dioxide (CO_2) sourced from underground wells is a cost-effective alternative. Equally, recycled CO_2 captured

Separating nitrogen: *Cryogenic scrubbing is expanding the possibilities of reserves such as the Pluto natural gas field in Western Australia, where it is being used to separate nitrogen from the gas stream.*

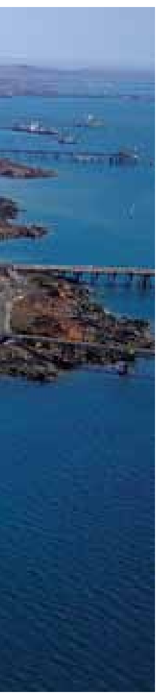
from power plant emissions can also be put to good use in enhanced recovery. The great benefit of nitrogen, however, is that it can be generated almost anywhere – all you need is atmospheric air and an air separation plant. There are also differences in its physical properties. CO_2 requires more compression than N_2. As a result, significantly more CO_2 is needed to raise pressure in natural gas reservoirs, making nitrogen the more energy-efficient EGR option.

Another widespread method of maintaining pressure in reservoirs involves feeding part of the recovered natural gas back below the surface. Abu Dhabi National Oil Company (ADNOC), for example, uses this process at its Habshan gas field. "It has to be said, however, that natural gas can be put to much better and more economical use as a much-needed source of electricity," explains Dr Gerhard Beysel from Linde Engineering. Which is why ADNOC and Linde formed the joint venture Elixier. Under the umbrella of this collaboration, two major air separation plants are being built in Mirfa, on the coast of Abu Dhabi (United Arab Emirates). The plants are scheduled to be completed at the end of 2011. The total cost of the project comes to USD 800 million.

NITROGEN BOOSTS RECOVERY RATES.

The nitrogen will then be transported via pipeline around 50 kilometres inland to Habshan, where it will be used for the enhanced recovery of gas and oil reserves. "For the two facilities in Mirfa, which will be capable of producing 670,000 cubic metres of nitrogen an hour, we are using the same air separation technology that has proven so successful for enhanced oil recovery at Cantarell in Mexico," states Beysel, Business Development Manager Air Separation Plants. This is also a strategic project. ADNOC has access to around 90 percent of Abu Dhabi's oil and gas reserves, which are estimated to be the fourth largest in the world.

Author: Frank Frick
Image source: Woodside, Linde AG



AIR SEPARATORS IN THE DESERT

Abu Dhabi National Oil Company (ADNOC) plans to inject nitrogen into its Habshan natural gas field to maintain pressure and increase recovery rates. Linde is building two major air separation units for the company in Mirfa, 50 kilometres away from the field. The gas will be pipelined from Mirfa.

Under certain geological conditions, part of the nitrogen mixes over time with the natural gas during recovery. This in itself is not a problem. Nitrogen does not react with the compounds in natural gas, nor does it corrode steel or other materials in the recovery chain. In fact, natural gas itself contains a certain amount of N_2. However, if the amount of nitrogen exceeds a certain level, the natural gas is no longer viable for industrial use. This is because nitrogen reduces the calorific value of natural gas, thus making it uneconomical for the chemical industry. "In order to store or transport natural gas in liquid form, the nitrogen content should ideally be below one percent", explains Beysel. If the nitrogen levels in the deposits are too high for liquefied natural gas (LNG), a nitrogen-rich stream of natural gas is separated during production. This stream can then be used, for example, as a fuel for the turbines that power the liquefaction process. "However, if the nitrogen content is too high, the turbines cannot handle the fuel," continues Dr Georg Schopfer, Project Manager Sales for LNG and Gas Processing Facilities at Linde Engineering. "The typical threshold here is around six percent – as is the case in the Pluto and Xena natural gas fields, near Karratha off the coast of Western Australia," reports Schopfer.

Separating nitrogen – the efficient way

The Australian oil and gas company Woodside opted for a different solution in order to get the most out of the captured gas stream. While planning the liquefaction plants in 2006, the company decided to integrate a nitrogen rejection unit (NRU) into the liquefaction facility. This module cools the nitrogen-rich stream until part of the gas liquefies. Fractionating columns separate almost all of the nitrogen from the natural gas at temperatures between minus 140 and minus 180 degrees Celsius. Linde is supplying the NRU for Karratha. "The components for the facility have already arrived in Australia and are currently being assembled," said Schopfer. Woodside plans to go on stream with the liquefaction facility in 2011. "The NRU in Western Australia is another important showcase project for us in the natural gas arena," explains Schopfer. Linde's gas separation technology will grow in importance as more and more companies start developing natural gas reservoirs with a high nitrogen content.

Schopfer also sees interesting growth prospects for enhanced oil recovery (EOR). Linde's efficient process technology has already helped boost yields at the Cantarell oil field in the Gulf of Mexico. The amount of oil recovered leapt 60 percent just one year after deployment of Linde's injection technology. The gas used here was taken from the air and produced at five air separation plants built by Linde. Splitting the air certainly helps maximise the value of raw material reserves.

LINKS:

www.elixier.ae/elixier/profile.html

www.woodside.com.au/Our+Business/Pluto/

CO_2 extinguishes smouldering fires in biomass silos and waste bunkers

FIGHTING FIRE WITH GAS

Organic materials are a great source of energy and so biomass is in big demand. But wherever large amounts of wood, waste and straw are stored in huge silos, there is also a risk of smouldering fires and even explosions. Conventional methods are relatively ineffective at extinguishing fires such as these. But a new extinguishing system from Linde uses CO_2 to effectively fight smouldering fires at the source.

In biogas combustion chambers, flames have to burn intensely to keep the power turbines moving and district heating flowing. To make sure the flames never die down, organic fuels such as grass, straw, rubbish and scrap wood are stored in huge bunkers or heaps. Yet these stores are a continuous source of worry for power plant operators. As in every compost or hay stack, there is always a risk of materials igniting. This is usually caused by bacteria's love of the carbon and moisture abundant in fresh grass or household waste. As the bacteria feed on the carbon, they create new microorganisms and release heat in the process, which can ignite the biomass. Reports of fires in woodchip stockpiles appear time and again in the media. "These kinds of fires can quickly cause damage that runs into hundreds of thousands or even millions of euros," explains Dr Michael Heisel from the Linde Gases Division.

Risk of explosion in grain silos

Power plant bunkers are not the only places at risk from fire. Grain for mills, rapeseed for biodiesel production and wood chips for manufacturing chipboard are also stored in silos or halls. Regardless of whether the organic material is destined for energy production or further processing, smouldering fires or even explosions are an ever-present threat in these huge bunkers. In 2005, for example, dozens of fire fighters used water, foam and a mixture of water and surfactants in a vain attempt to extinguish a waste bunker fire at an incineration plant in the German city of Bielefeld. The fire started in a huge hall measuring 75 metres long, 25 metres wide and 15 metres high and could not be controlled. After three days, the power plant operator called Linde and asked for support. Linde Gas Bielefeld delivered liquid CO_2 which was fed into the fire as a gas, extin-

Fire hazard: *The combustion chambers of biomass and waste power plants are supposed to get pretty hot. Yet wood, waste and straw can even get hot when they are just being stored in huge silos. Oxidation and microbiological processes can generate enough heat to start smouldering fires deep below the surface.*

guishing it within one and a half days. Linde delivered approximately 130 tonnes of liquid CO_2 at the time, which corresponds to around six tankers worth.

The fire in Bielefeld got Heisel thinking. He asked himself what the actual cause of the fire in the hall was and how the CO_2 behaved when extinguishing the fire. Fired up himself at this stage, the gases expert started looking for answers. “Smouldering fires usually start in the bottom third of a silo,” explains Heisel. “Material here has been in storage for a long time and is well isolated from the surrounding environment.” Experiments at the SP Technical Research Institute of Sweden have revealed that smouldering fires are actually caused by slow oxidation. Microbiological processes in biomass – in other words fermentation of organic matter – can at times intensify oxidation.

A smouldering fire in a biomass bunker is a big problem for fire fighters – not only because of the fumes, which can be harmful to humans and the environment. Wood chip piles are huge and some silos can be as high as 100 metres. Fire crews often can’t get close to the source of the fire. “Even if you poured a whole lake onto a pile, the water just wouldn’t penetrate far enough down,” adds Heisel. “Conventional extinguishing methods using water or foam are only really effective for surface fires. They usually do not make much of an impact on deeper fires.” Water damage also turns the remaining waste, paper or wood pellet silos into a sticky mass that is unusable and difficult to clear out.

CARBON DIOXIDE PERMEATES THE ENTIRE BIO-MASS BUNKER.

Nitrogen can fan the flames

“Feeding inert gas into a silo from below is currently regarded as the most effective method for extinguishing low-lying fires. The most commonly used gas here is nitrogen,” explains Heisel. Nitrogen (N_2) is lighter than air and therefore rises in the silo, creating an inert atmosphere, which sooner or later smothers the fire by cutting off its oxygen supply. However, tests have shown that injecting N_2 during the early stages of a fire can accelerate combustion and even lead to explosions. “It pushes the remaining air in the silo upwards past the source of the fire, thus feeding sparks and fumes. Combined with air and sparks, these fumes are explosive, and can create a pretty big bang,” continues Heisel. When combustion takes place with residual air, carbon dioxide (CO_2) and water (H_2O), neither of which burn, are generated. If there is insufficient air, however, large amounts of the flammable gases carbon monoxide (CO) and hydrogen (H_2) are produced in addition to CO_2 and H_2O. When gaseous hydrogen and oxygen come into contact with embers or sparks, the result is an explosive oxyhydrogen reaction. The threat of an explosion can only be controlled by inerting the entire silo with nitrogen. In other words, making sure there is hardly any oxygen left.

A blanket of CO_2 smothers the fire

During lab tests, Linde experts observed that CO_2 was more effective at extinguishing smouldering fires than nitrogen. “Covering the material with a layer of CO_2 is more efficient,” adds Heisel. “It is heavier than air and fumes and therefore filters down through the material from above.” The carbon dioxide cuts off the supply of air. “And without oxygen there is no fire,” concludes Heisel, neatly summing up the simple yet effective solution. The carbon dioxide blanket also takes the heat out of sparks as CO_2 has a higher thermal capacity than nitrogen. There are further benefits to using CO_2 as an extinguishing gas – it has a low toxicity, does not oxidise and is available in large quantities at any number of places.

The carbon dioxide layer has to be evenly distributed above the silo for it to effectively extinguish the fire. To ensure this is the case, Linde experts use venturi nozzles that completely sublimate the carbon dioxide. The nozzles are built into the silo from above or inserted in the event of a fire so they can slowly and evenly distribute the gas without disturbing any dust, which – like fumes – can pose a further risk of explosion. Linde has filed a patent for this innovative extinguishing system under the tradename ADURIS®. The fire-fighting gas system is already installed in ten major incineration plants, creating a new safety standard for the protection of silos and bunkers against fire.

Heisel played a major role in the development of this process and is a firm believer in its benefits: “ADURIS® extinguishes smouldering fires effectively. It also prevents damage to the material and silos, and significantly reduces risk for fire fighters as they can work from a safe distance.” Not to mention the financial gains – operators with ADURIS® extinguishing systems have been able to lower their insurance premiums. We will never be able to totally avoid smouldering fires in biomass silos and waste bunkers – chemical reactions will see to that. But Linde’s extinguishing system can get them quickly under control and put an end to persistent fires such as the one that blazed in the biogas-fired heating plant in Taufkirchen near Munich, Germany. There an entire stockpile burnt for two and a half months before it could be fully extinguished – using water.

LINKS:

www.carmen-ev.de

www.erneuerbare-energien.de

www.eubia.org

↵ Author: Heidi Wahl

↱ Image source: BMU/Bernd Müller, R. Kreuels/laif

REMEO® care programme for long-term ventilated patients

FOR A BETTER QUALITY OF LIFE

People who require ventilation assistance often spend a long time in intensive care. Yet an intensive care environment full of state-of-the-art medical equipment can be a source of stress for patients. Linde's REMEO® programme helps long-term ventilated patients return home as quickly as possible. In dedicated REMEO® centres, specialised healthcare professionals prepare ventilated patients for the return to everyday life, with or without ventilation equipment. REMEO® not only boosts patient morale, it also helps cut healthcare costs.

↵ *Author: Clara Steffens*
↳ *Image source: Linde AG*

For people on assisted ventilation, the tube that connects them to their breathing apparatus is their lifeline. A ventilation device then feeds oxygen directly into the lower airways. In some cases, the treatment can run for extended periods of time. Otherwise an insufficient amount of oxygen enters the blood and carbon dioxide is not exhaled. Chronic ventilated patients often need extensive, complex therapy in addition to basic care. Most nursing homes, however, are not geared towards the needs of chronic ventilated patients. Which is why Linde has developed REMEO® – a programme that goes much further than the delivery of medicinal oxygen, combining clinical expertise with state-of-the-art ventilatory technology. "REMEO® represents a new dimension in medical care," explains Dr Peter Kalin, Marketing Manager of Linde Healthcare in Germany. It offers ventilated patients optimal care outside of a hospital environment. "In the event of respiratory failure, this vital function has to be fully controlled outside the body," adds REMEO® Care Manager Antje Kassin. Pressurised gas equipment does this job, taking over from the body's respiratory muscles. If a patient is mechanically ventilated over several weeks, however, muscle tissue starts to waste, in much the same way as muscles in a broken leg that has been in a cast for several weeks. "Patients have to start training at this point," explains Kassin. Although they no longer need to be in intensive care for this, patients and their families are often not yet ready for the new care challenge at home.

BRIDGING THE GAP BETWEEN INTENSIVE CARE AND THE HOME.

REMEO® bridges this gap between intensive care and the patient's home. Derived from the Latin for "I return home" (remeo), the programme's name reflects the ultimate goal for patients. It also underscores a clear medical objective. "In the best-case scenario, patients will eventually be able to live without any ventilation assistance," emphasises Kalin. If this is not possible, dependency on assisted ventilation can often be reduced to specific periods such as at night. In some cases, however, continuous ventilation is the only option and these chronic ventilated patients can either stay at a REMEO® centre or return home. "In these situations, we focus on preparing patients and their families for a new life at home with assisted ventilation," explains Kalin.

The new care programme is designed above all to reduce the number of "revolving door" hospitalisations. These are typical cases

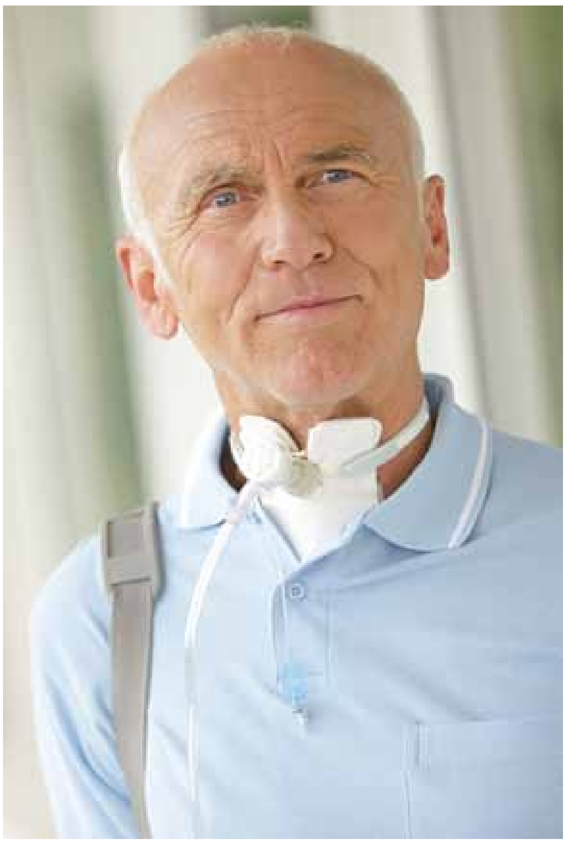
Getting ready to go back home:
In REMEO® centres, trained care specialists prepare long-term ventilated patients for life outside a hospital environment.

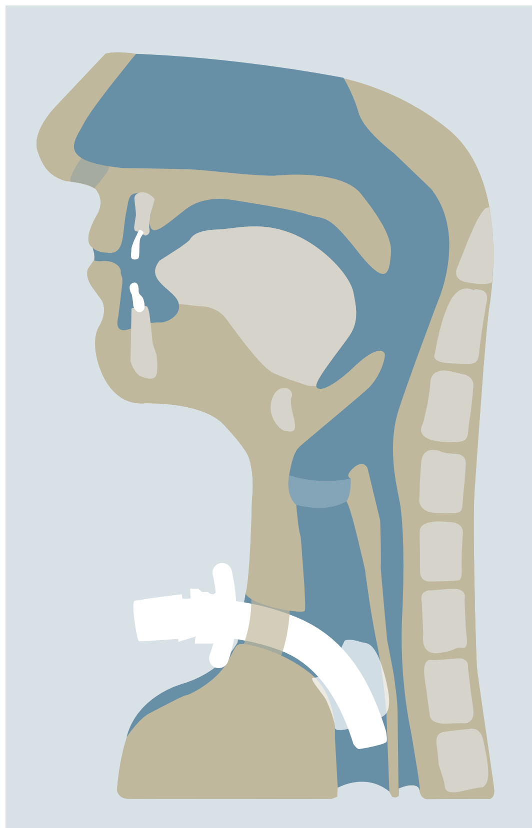
where patients have to be readmitted from care homes or their own homes after being discharged too early from intensive care. "Our staff is specially trained to care for chronic ventilated patients," continues Kalin. The therapies are also tailored to the patient's complex care needs. Swallowing, speech and breathing therapies are just as important as regular movement and physiotherapy. Success rates at individual centres show that the REMEO® programme works. "Thirty-eight of our patients have shown signs of being able to live without ventilation at some point in the future," reports Kassin from the Mahlow centre near Berlin, the first REMEO® centre worldwide. After two years, fifteen former chronic ventilated patients are now living entirely without oxygen equipment. Four others only require breathing assistance.

REMEO® is not just there for the patients, it also provides valuable support to spouses, children and siblings to help them prepare for the new care situation at home. "We talk to relatives and are happy to include them in daily care routines, showing them how to correctly operate the ventilator or what to do in an emergency," adds Care Manager Kassin. Support is also available once the patient has returned home. In addition to care centres, the REMEO® programme also provides individual assistance for ventilated patients at home. Homecare services range from regular visits to multi-hour care – all using the very latest technologies. An emergency service is also available night and day for all medical or technical queries. "Modern medical technologies enable us to provide professional, high-quality care outside the hospital environment," explains Konrad Bengler, Global Business Manager REMEO®.

SPECIALISED IN THE CARE OF PATIENTS REQUIRING LONG-TERM VENTILATION.

Linde's care professionals attach great importance to close collaboration with pulmonary specialists. These medical specialists regularly visit the centre to discuss ongoing care plans and the progress patients are making towards a life without assisted ventilation. "In some cases, the doctors already know the patients from their stay in hospital," explains Kassin. According to Kalin, this combination of specialist therapy and clinical expertise in intensive care is exactly what makes the REMEO® programme so exceptional. "We've created a care programme that previously did not exist, for example, in the German healthcare system," he adds. The REMEO® centres are gradually being certified. Every step is defined and validated. Regular visits from external specialists ensure that the centres comply with the standard and retain their certification. Patient care is financed through contracts with health insurance companies. Kalin explains that a bed at a REMEO® centre costs around 12,000 euros per month. The same bed in an intensive care unit can cost up to 40,000 euros.





Even home-based nursing care would amount to 18,000 euros or more. "So it's not just a question of medical ethics, it is also an economic problem that needs to be solved," he continues.

International service network

REMEO® homecare is also available in Italy, Portugal and Argentina. More REMEO® centres are being set up in Columbia and the US. New centres are in the pipeline but a great deal of planning is still required here. "When we establish a new centre, our services need to be tailored to the exact requirements of each country," explains Bengler. This strategy has proved successful in the US state of Tennessee, where the Knoxville and Nashville centres have a strong reputation for weaning chronic ventilated patients. "We are currently developing strategic plans for further REMEO® sites and are focusing in particular on areas that did not previously have facilities for chronic ventilated patients," states Gene Gantt from REMEO® USA. Patients here often have to be cared for in unfamiliar surroundings a long way from their families.

REMEO® has also tailored its services to local requirements in South America. In Columbia, for example, there are significantly fewer hospital beds than in Europe or North America, so a doctor is on site round the clock at the Bogotá, Medellín and Cartagena centres. "We are reaching out to more and more patients – and this is reflected in our strong financial figures," explains Javier Ramirez at REMEO® South America. The respiratory therapist has been working for Linde since 2005. The company's successful track record is changing the way it is perceived by the public. "Our name is no longer associated exclusively with industry. We have also established a strong presence in the healthcare sector," adds Ramirez.

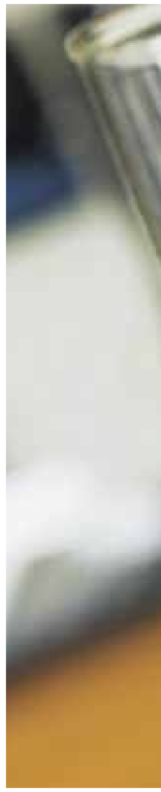
CHRONIC DISEASE COPD

Patients may need assisted ventilation for any number of reasons. Serious conditions such as chronic obstructive pulmonary disease (COPD) are common causes. As they progress, the diseases damage lung tissue and inhibit the body's respiratory capacity. The tiny air sacs (alveoli) inside the lungs become enlarged and lose their elasticity, leaving them unable to expel air from the lungs and ensure vital gases are exchanged. As a result, an insufficient amount of oxygen enters the blood and carbon dioxide is not exhaled. If enough tissue is damaged, the bronchi become unstable and collapse at the slightest pressure, exacerbating exhalation even further. People with poorly ventilated lungs are also at a higher risk of developing pneumonia – perpetuating a vicious circle that leads to further lung tissue damage. An estimated 600 million people worldwide suffer from COPD. The World Health Organisation (WHO) ranks it as the fourth leading cause of death after heart attacks, strokes and pneumonia. Experts predict that the number of deaths resulting from lung failure is set to rise even further over the coming years. Conditions such as paraplegia brought about by accidents can also inhibit respiration so severely that an individual is no longer able to breathe independently.

ASSISTED VENTILATION

When gases are no longer exchanged in the lung's air sacs (alveoli) or if the body's respiratory functions are inhibited, immediate assisted ventilation is a patient's only chance of survival. In such cases, a ventilation device provides the body with the vital supply of oxygen and assists with the exhalation of carbon dioxide. During natural respiration, the diaphragm creates slight negative pressure. In contrast, assisted ventilation works by creating positive pressure. There are two modes of assisted ventilation. The first is a form of respiratory support where the patient can still breathe independently and only requires additional oxygen, for example, at night. The second mode involves complete ventilation via a tube inserted in an opening, or tracheostoma, cut into the patient's trachea. Oxygen is then fed directly into the lower airways through the tube. This invasive procedure is necessary for coma patients, for example, who have suffered a stroke or had an accident and therefore require long-term assistance. Weaning intensive care patients from long-term assisted ventilation is a difficult process that can take weeks. Some patients never recover the ability to breathe independently and therefore require continuous ventilation at home.

LINKS:
www.remeo.com
www.nhlbi.nih.gov/health/dci/Diseases/Copd/Copd_WhatIs.html
www.nhlbi.nih.gov/health/dci/Diseases/hlw/hlw_respsys.html



Producing a sustainable source of water from industrial wastewater

BACTERIA AT THE OXYGEN BAR

For many industrial manufacturing and processing plants worldwide, wastewater treatment is a sizeable operating cost factor. Engineers at Linde have now developed a highly efficient bioreactor that significantly reduces the costs for water treatment and excess sludge disposal.

How about a glass of recycled industrial wastewater, totally purified and safe to drink? “That is no joke and technically absolutely possible,” says Darren Gurney, an expert in industrial wastewater treatment at Linde. To convert wastewater back into purified water suitable for return back to rivers or even reuse is becoming a reality for industries. This is being driven in part by the annual rise in costs for once-through disposal and purchase of clean water. Each year in Germany alone, enough industrial wastewater is generated to fill approximately 150 billion bathtubs. Water recycling works remarkably efficiently in Linde’s new AXENIS™ plant, combining traditional biotreatment and cross-flow ultra filtration (UF) separation technology. “AXENIS™ plants have a compact, containerised, modular design, require less electricity to operate and produce less surplus biomass sludge than conventional systems,” Gurney cites as their most important advantages. Thus they are not only eco-friendly, but also affordable for smaller companies who until now could not invest in their own on-site wastewater treatment plant.

PURE OXYGEN REDUCES TREATMENT SLUDGE BY 70 PERCENT.

Bioreactors with trillions of bacteria

A core element of the new plant is the membrane bioreactor, which contains an activated sludge population comprising trillions of bacteria and other specialist aerobic microorganisms. The microorganisms, only visible with a microscope, are capable of breaking down soluble organic pollutants into carbon dioxide and water. These pollutants are released during chemical, pharmaceutical, food and beverage manufacturing processes, for example.

The microorganisms not only need the wastewater’s substrate (food) to survive, but also sufficient volumes of dissolved oxygen at all times. To this end, conventional systems deliver vast quantities of air into the bioreactor. AXENIS™, on the other hand, works with pure oxygen. “Pure oxygen dissolves more effectively in wastewater effluent,” Gurney explains. The Linde plants therefore achieve higher oxygen concentrations and can potentially work with up to two or three times the biomass concentration of conventional plants.

This improves the degradation of pollutants, with yet another benefit. When a highly concentrated population of biomass receives a limited amount of pollutants, it tends to produce less surplus biomass. “This is a considerable benefit, because exploiting this natural process can produce up to 70 percent less surplus sludge, which must be continually removed from the plant and is increasingly costly to dispose of,” says Gurney.

Furthermore, the microorganisms in the AXENIS™ bioreactor operate at a higher average temperature than most air-based treatment plants, which increases reaction rates. “In the plant we have average temperatures above 25 degrees Celsius,” Gurney cites as the main reason. This heat generation is created largely by the microorganisms’ metabolism. While this also happens in conventional reactors, there the heat escapes in air bubbles, creating lower average temperatures – typically around 15 degrees Celsius.

It’s not only the use of pure oxygen that makes the patented application unique. In addition, the bioreactor is coupled to a cross-flow UF membrane separation stage, where the mixture of biochemically purified water (permeate) and activated sludge (retentate) is separated. The membrane filters are comprised of tubular membrane structures with “sieve-like” polymer walls. The pores of these membranes are so small (0.03 to 0.05 microns) that they retain virtually all the suspended and colloidal material. Solids and biomass remain behind and are returned back into the bioreactor via the activated sludge membrane return line. The UF membranes have two key advantages: “They can produce

Pure water: Lab analyses show that industrial wastewater treated in Linde's plant can be transformed into clean water that meets drinking quality standards.

high-quality treated effluent virtually free of suspended solids and low in residual dissolved pollutants, and they require less space than conventional separation plants," Gurney reports. A conventional separation clarifier relies on gravity for efficient separation of biomass and treated effluent, meaning that large surface areas are required and these take up valuable space.

Recycling up to 75 percent of industrial wastewater

Enriched with oxygen, the pressurised activated sludge is returned to the bulk flow of the bioreactor. There it doesn't just maintain the dissolved oxygen levels essential for the microorganisms, as Gurney explains, "it also ensures that the microorganisms and wastewater are well mixed." The mixing velocity generated is determined by means of an engineered sidestream and sub-surface injection nozzle arrangement. This eliminates the need for the secondary aeration device in the bioreactor typically required in conventional plants. Hence the AXENIS™ process has the added benefit of significantly lower lifecycle costs – enabled by the reuse of separation energy. Gurney emphasises: "AXENIS™ plants expect to use between 20 and 30 percent less electrical power."

After the conditioning steps in the bioreactor and UF membrane, the permeate water is ready for reuse or further processing. Between 70 and 75 percent of the wastewater can be reused after treatment. "The UF permeate can be clean enough to return it directly to a river course," Gurney points out. Attach an auxiliary reverse osmosis (RO) plant to remove residual salts, and the former industrial wastewater even becomes drinkable. "Technically and practically, it's not a problem at all," remarks the engineer.

Since wastewater is never the same, and because the type and amount of contaminants can vary immensely, Linde engineers always recommend pilot trials on new wastewater streams. The AXENIS™ pilot plant is containerised and includes the bioreactor and UF membrane, as well as a wealth of measuring equipment. "So we can perfectly calibrate the plant to the wastewater of a particular company," says Gurney. It can take around four months to stabilise the treatment and to determine optimal operating parameters.

The first AXENIS™ plant is already in operation, treating approximately 140 cubic metres per day. More than a dozen other companies have already expressed interest. "Our next goal is to develop a modular system that is expandable as the need arises and can manage any given amount of wastewater," says Gurney's colleague Stefan Dullstein." In the medium term we'd like to be able to offer AXENIS™ to big industrial enterprises and deliver Greenfield Site solutions producing a sustainable source of high-quality water from their wastewater streams."

Dullstein and Gurney predict a strong interest for water reuse technology in the near future. "The pressure on industry to become more sustainable in its use of water resources is constantly increasing, not least because of climate change and increasing demand from private households," they say.

Especially in countries with limited water supplies, the environmental standards governing wastewater quality, the cost of wastewater disposal and the cost of fresh water are all constantly increasing.

Thus AXENIS™ plants could soon be deployed in regions where clean drinking water – regardless of the source – was something people could previously only dream about.

← Author: Andrea Hoferichter
→ Image source: Getty Images, Linde AG

LINK:
www.un.org/waterforlifedecade

INTERVIEW

"BIOREFINERIES GET THE MOST OUT OF RENEWABLE RAW MATERIALS"

With the chemical industry moving ever closer to a green future, Uwe Welteroth and Dr Markus Wolperdinger, biotechnology experts at Linde-KCA-Dresden GmbH, a member of The Linde Group, explain how cutting-edge engineering systems and innovative biotechnology are changing the face of the chemical industry.

↵ Interview: Caroline Zörlein
↳ Image source: Linde AG/E. Rodtmann

↳ WHAT MAKES BIOTECHNOLOGICAL PROCESSES SO SPECIAL?

Uwe Welteroth: Biotech processes enable us to efficiently harness renewable raw materials from a wide variety of sources. Microorganisms or enzymes cultivated in modern bioreactors are used in industrial biotechnology to produce basic and speciality chemicals as well as biofuels and intermediate chemical products. The biotech and physicochemical processes in individual biorefinery plant systems are tailored exactly to these raw materials or products.

↳ INDUSTRIAL BIOTECHNOLOGY IS AN IMPORTANT GROWTH FIELD. HOW IS LINDE-KCA POSITIONED HERE?

Welteroth: At quite an early stage, we correctly predicted that the fossil-based manufacture of chemicals would increasingly give way to bio-based production processes in the future. In 2005, Linde-KCA-Dresden GmbH initiated a long-term programme to fully focus its Biotechnology Plants department on industrial biotechnology. And today, we are able to provide green production processes. We are working closely with our customers to further develop biotech procedures and plant modules and tailor them to specific applications.

↳ WHAT'S THE NEXT STEP?

Dr Markus Wolperdinger: The next milestone in our biorefinery journey involves ramping up biotech processes to industrialscale production. Pilot and demonstration plants play a pivotal role at present. They are the only sure-fire way to develop integrated biological processes. In other words, where the full energy and material potential is derived from renewable materials through intelligent, cascading process chains.

↳ WHAT ARE THE CHALLENGES OF THIS APPROACH?

Welteroth: Renewable raw materials need to be available in sufficient quantities and at the right price. Integrating bio-based material flows into existing – primarily petrochemical – production environments in the chemical industry and ensuring that these kinds of plants are economically viable are further challenges. At Linde-KCA, we bundle the know-how required to take biorefineries to the next level, effectively dovetailing our global expertise in industrial-scale plant engineering with our core competence in industrial biotechnology.

↳ WHAT PROJECTS IS LINDE-KCA CURRENTLY INVOLVED IN?

Wolperdinger: We are currently involved in an important project at the chemical hub in Leuna, Germany. Linde-KCA has been appointed by the Fraunhofer Institute as general contractor to plan, supply and construct the Fraunhofer Chemical Biotechnological Process Centre (CBP). With the support of site operator InfraLeuna and Linde's Gases Division, this project will integrate biotechnological processes into existing plants and material flows at Leuna. The biorefinery research centre is a flagship project. Under its umbrella, the Fraunhofer Institute and over 25 partners from industry and research will be advancing renewable-based biotech and chemical processes to industrial scale. Over 50 million euros

***Biotech experts:** Uwe Welteroth, Director Biotechnology Plants (left) and Dr Markus Wolperdinger, Head of Business Development Biotechnology Plants (right)*

INDUSTRIAL BIOTECHNOLOGY

Industrial biotechnology, also known as white biotechnology, harnesses natural resources such as bacteria, fungi and enzymes on an industrial scale. It is already capable of efficiently manufacturing key basic and speciality chemicals. Linde-KCA is involved in the construction of a chemical biotechnological research centre at Leuna and supplies the expertise and plant technology required for tomorrow's biorefineries.

have been earmarked for investment in the CBP. Linde-KCA is also actively involved in several research projects at the CBP to establish its own processes. Research at the CBP will focus on a broad range of raw materials such as lignocellulosic biomass (wood and agricultural by-products, for example) as well as vegetable oils and fats, all of which can be used as feedstock for the production of lubricants, surfactants or basic chemicals.
Welteroth: Linde is also involved in many other biotech projects such as the production of green hydrogen, biogas or bioethanol (using algae). At Linde-KCA, we are also working on a raft of innovative processes such as the thermal conversion of biomass to chemical products.

WHAT EXACTLY HAPPENS INSIDE BIOREFINERIES?

Welteroth: With biorefineries, we are not only focusing on harnessing carbon synthesis in nature, but also looking to develop energy- and resource-efficient processes, minimise waste streams and cut CO_2 emissions. Leuna is proof-of-concept for the integration of biotech/chemical processes into existing chemical or refinery landscapes. The infrastructure and existing material streams provide a number of openings for incorporating green technology and will enable us to gradually supplement petrochemical processes with bio-based alternatives. Biotechnology will not be able to fully replace existing methods in the medium term.
Wolperdinger: Ethylene is a prime example of these material streams. It is a key component of Linde's portfolio and plays an important role at the Leuna site. It can be produced with a zero carbon footprint using biomass – ideally bioethanol produced from plant-based raw materials that have not had an impact on the production of food or animal feed. We are working with selected technology partners to optimise bioethylene production and reduce manufacturing costs.

WHAT DOES THE FUTURE HOLD FOR INDUSTRIAL BIOTECHNOLOGY?

Wolperdinger: Integrated bioproduction is a technological trend that is rapidly gaining momentum. So it is not just down to technology players such as Linde to drive developments here. Policy-makers also have a key role to play by ensuring the right frameworks and initiatives are in place for rapid transition to economic viability. The US was an early mover here. The European Union followed suit in March 2010 with its initiative "EUROPE 2020 – A Strategy for Smart, Sustainable and Inclusive Growth". Establishing a bio-economy is a cornerstone of the German Government's bio-economic strategy for the future and is actively supported with funding.
Welteroth: We strongly believe that industrial biotechnology will play an increasingly important role in the future. Demand for plants that efficiently use biomass to create chemical products is rising worldwide. At Linde-KCA, we are committed to advancing industrial biotechnology and are involved in numerous projects aimed at developing and implementing innovative processes on an industrial scale. We intend to help increase sustainability in the chemical industry by incorporating "green" intermediate products into the value chain.

LINK:
www.linde-kca.com

Clean city: *In the San Francisco Bay Area, zero-emission hydrogen buses are set to help drastically cut CO_2 emissions.*

Turning the hydrogen vision into reality

H_2 HITS THE ROAD

Electromobility is set to play a key role in the mobility landscape of the future. Fuel cells are an important technology here and are moving ever closer to series production. According to experts, this drive technology could be cheaper than batteries in just a few short years, which would mark a major breakthrough for hydrogen. What was once a vision of H_2-powered mobility is now well on the way to becoming a reality. Hydrogen buses have already been integrated into public transport services, fuel-cell forklifts hum silently through factory halls and hydrogen cars are whizzing around the globe.

Image source: Anthony Pidgeon/Lonely Planet Images/picture alliance

Author: Michael Kömpf

Hydrogen has arrived on the streets of the San Francisco Bay Area. Since autumn 2010, the latest generation of fuel-cell buses has been humming silently along California’s roads. Bus operator AC Transit is using hydrogen-powered fuel-cell buses to transport customers on several routes in Bay Area cities. From its central depot in Emeryville, adjacent to the studios of the animation company Pixar, and from three other operating divisions, AC Transit’s fleet of 600 buses serves 13 cities and more than 1.5 million people. AC Transit’s fleet also includes a dozen third-generation fuel-cell vehicles from Belgian manufacturer Van Hool. For Jaimie Levin, AC Transit’s Director of Alternative Fuels, these fuel-cell buses are a key milestone on the pathway to sustainable and environmentally sound transport. The company plans to reduce its annual diesel consumption, currently around 22.7 million litres (6.0 million gallons). The hydrogen fuelling technology is supplied by Linde and can also be used to fuel cars. “We are confident that Linde’s fuelling technology will enable us to establish and operate a commercial fleet of buses powered by hydrogen fuel cells,” explains Levin.

HYDROGEN IS PARTICULARLY SUITED TO LONG-DISTANCE TRAVEL.

The two new bus fuelling stations are located in Emeryville and Oakland. Already some of the H_2 is produced using regenerative sources of energy. The roofs of the filling station in Emeryville and other AC Transit buildings are fitted with more than 700 kW of solar panels that supply an electrolyser with the power it needs to produce hydrogen. The unit is capable of producing 60 kilograms of H_2 per day, enough for two of the buses. The remaining ten are fuelled from an on-site tank that can hold up to 34,000 litres of liquefied hydrogen. An ionic compressor converts this to gas for refuelling. In addition to supplying the fleet of buses, the tank has sufficient capacity to power up to twenty fuel-cell cars every day. “The aim of this project is to demonstrate that H_2 fuel-cell buses perform better than diesel buses, providing the benefits of non-toxic emissions, while reducing CO_2 emissions by at least 40 percent using methane as a source of fuel, and 100 percent when using renewable sources,” continues Levin.

AC Transit is building on what experts see as the most important benefits of fuel-cell technology for future mobility. “Fuel-cell powertrain technology holds great potential for larger vehicles typically

H_2 at home in the city and on the production line: *Each day the environmentally friendly hydrogen buses deployed by Californian operator AC Transit carry over 200,000 passengers around the San Francisco Bay Area. At BMW's Spartanburg plant in South Carolina (US), 85 zero-emission fuel-cell forklifts hum silently through the production halls.*

WHERE DO WE GET OUR HYDROGEN?

Hydrogen can be generated from any source of primary energy, whether renewable or conventional. The greatest amount, however – around 75 percent of the world's hydrogen – is generated by steam-reforming natural gas. This process is extremely efficient and mature, bolstered by the fact that natural gas is widely available around the world. Linde has built over 200 plants for producing hydrogen worldwide. Moving forward, Linde plans to increase the regenerative share in the hydrogen mobility mix.

covering longer distances and emitting significantly higher levels of CO_2," explains Andreas Tschiesner from management consulting firm McKinsey. At the start of the year, the company presented the results of an extensive study on powertrain technology at the North American International Auto Show in Detroit. "The analyses show that fuel cells have much greater CO_2-reducing potential in larger vehicles than batteries or range extender technology (a combination of electric motor and combustion engine)," continues Tschiesner. Fuel-cell powertrain technology also fared better on the cost front as it accounts for a lower share of total vehicle costs. In Tschiesner's opinion, CO_2 regulations will have the strongest impact on the development of the powertrain market. "Future CO_2 limits will play a major role in defining the dominant powertrain technology of tomorrow."

Key enabler of low-emission mobility

Among experts, the initial euphoria surrounding battery-only electric vehicles is increasingly giving way to harsh reality. Representatives from the auto industry also showed a united front at the World Future Energy Summit (WFES) in Abu Dhabi at the start of 2011. The industry increasingly believes that future transport strategies will require a mix of battery electric and fuel-cell cars rather than one dominant

FAST REFUELLING WITH CRYO PUMPS

Linde has developed a modern cryogenic pump to compress liquid hydrogen into high-pressure hydrogen. This pump allows H_2 vehicles to refuel quickly and efficiently from a liquid hydrogen tank. The cryo pump leverages the advantages of direct, single-step liquid compression to reduce energy consumption to a minimum at the fuelling station. No additional cooling power is needed for compression given the cryogenic temperature of the liquid hydrogen. A specially designed system of air heat exchangers and a temperature control unit raise the temperature of the hydrogen to minus 40 degrees. The cryo pump generates a maximum pressure of up to 900 bar and reaches a fuelling capacity of up to 100 kilos of hydrogen an hour. Ideally suited to high volumes, cryo pumps are also very quiet and require little maintenance.

drivetrain. And this future could come as early as 2020, according to Prof. Dr Herbert Kohler, Head of e-drive & Future Mobility and Chief Environmental Officer at Daimler AG. In an interview with German automobile magazine Auto Motor und Sport during WFES, Kohler stated that fuel-cell cars could be commercially viable by 2020 at a similar price to a four-cylinder diesel hybrid capable of meeting the EU 6 emissions standard.

Europe's most extensive study to date on the future viability of different powertrain concepts for road transport also confirms that hydrogen-powered fuel-cell cars will play a key role in tomorrow's low-emission mobility choices. Linde joined over thirty other companies and organisations from the automotive, oil and gas, industrial gases, utility and energy industries in supporting the study with their latest findings and figures. The study was prompted by the target set by the EU Commission and G8 nations to reduce overall CO_2 emissions by 80 percent and road emissions by as much as 95 percent by 2050. The study explored and compared the economics and performance of four different car types – namely internal combustion engines, battery electric vehicles, fuel-cell electric vehicles and plug-in hybrids. "This latest study provides convincing substantiation of the key conclusion we drew in a study back in 2005," explains Dr Andreas Opfermann, Head of Clean Energy and Innovation Management at Linde. "Namely, the cost involved in building up a hydrogen infrastructure is of reasonable proportions."

FUEL CELLS: BEST POWERTRAIN TECHNOLOGY FOR MID- AND LONG-RANGE DRIVING

In its mid-range scenario, the study assumes that fuel-cell vehicles will account for 25 percent of all cars on the road by 2050. This would require investment of around 3 billion euros to establish a Europe-wide infrastructure of hydrogen fuelling stations – a small amount compared to the cost of expanding Europe's electricity network, which the EU puts at around 200 billion euros. The study also reveals that fuel-cell, battery and plug-in hybrid vehicles will have to gain significant market share if CO_2 reduction limits are to be met. The study found that whereas battery electric vehicles are ideal for short trips, in urban locations for example, fuel-cell electric vehicles offer the added advantage of longer ranges and shorter refuelling windows. "This makes fuel cells the ideal powertrain technology for reducing CO_2 emissions in the mid and upper driving ranges," reports Markus Bachmeier, Head of Hydrogen Solutions at Linde. Although these classes account for around 50 percent of all vehicles, they currently cause around 75 percent of total CO_2 emissions in road traffic.

Even with today's conventional method of producing hydrogen by steam reforming natural gas, fuel-cell cars produce up to 30 percent less CO_2 emissions per driven kilometre than petrol or diesel-powered vehicles." And we are working hard to increase the amount of hydrogen produced from regenerative energy sources," explains Bachmeier.

Looking at total cost of ownership, the EU study also shows that the playing field will be more or less level for all drive concepts by 2025 at the latest. Tax breaks and incentives could speed this development along.

These findings are of course good news for the majority of drivers. Electric vehicles have thus far been presented as a second car option for better-off consumers with their own parking space and ideally a second car for longer trips. Now, fuel-cell cars could be the answer to an entire family's mobility needs – at an affordable price. McKinsey consultant Tschiesner is certainly sure of one thing: "We need to ignite drivers' passion for electric cars in order to create demand and inject early-adopter momentum into the market for hydrogen and battery vehicles. This is the only way of ensuring dynamic growth." For H_2 expert Bachmeier, what this means in concrete terms is "getting more cars on the roads to demonstrate just how well hydrogen technology can master the challenges of everyday driving."

This is an opinion shared by car manufacturer Mercedes-Benz. At the end of January, the company launched a world first with its endurance F-CELL World Drive. Over 125 days, three Mercedes-Benz B-Class F-CELL cars – the first fuel-cell car to go into series production – will be driving 30,000 kilometres across 14 countries in a bid to circumnavigate the globe. The cars will be crossing a range of different climate zones on asphalt and dirt roads. "This unique world trip will demonstrate the technical maturity of fuel-cell technology in electric cars. We would not be able to do this with cars powered solely by batteries," elaborates Dr Thomas Weber, Member of the Board of Management of Daimler AG, Group Research & Mercedes-Benz Cars Development. Linde is an exclusive partner on the Mercedes-Benz project. The company's hydrogen experts are responsible for the H_2 fuelling stations along the route. To keep the hydrogen flowing in even remote locations, Linde engineer Robert Adler, inventor of the ionic compressor, and his team collaborated with Daimler to develop a new mobile 700-bar fuelling unit built around a Mercedes-Benz Sprinter. The transporter contains all the technology for compressing H_2 and refuelling the cars.

"Even today, the technology in our B-Class F-CELL cars gives them a range of 400 kilometres. And refuelling only takes a couple of minutes," explains Peter Fröschle, Head of Strategic Energy Projects & Market Development Fuel Cell/EV at Daimler AG. All of which makes the B-Class F-CELL ideal for both day-to-day use in urban settings and long-distance travel.

IONIC TECHNOLOGY FOR FAST COMPRESSION

Hydrogen can be compressed extremely efficiently with Linde's ionic compressor. With this compressor, conventional metal pistons are replaced by a specially designed, nearly incompressible ionic liquid. These organic salts remain liquid within a specified temperature range. During compression, the ionic liquid behaves like a solid. Ionic compressors are considerably more efficient than conventional compressors. Ionic liquids are anti-corrosive – keeping maintenance outlay to a minimum. Plus the ionic compressor uses up to 20 percent less energy than traditional compression methods.

H_2 forklifts – cleaner air on the factory floor

But it's not just in the latest automotive innovations where fuel cells are seriously vying with battery electric vehicles. Car manufacturers' production facilities also use hydrogen for zero-emission mobility – with H_2 forklifts looking after daily logistics. At the end of 2010, almost 1,000 hydrogen forklifts were in operation across various facilities. Linde experts are one of the main providers of the technology and hydrogen infrastructure needed to operate such vehicles. One of the more recent examples is the BMW Manufacturing Co. facility in Spartanburg, South Carolina (US). Here, Linde supplies hydrogen for a forklift fleet of more than 85 vehicles used in the assembly line. These hydrogen-powered vehicles have paved the way for zero-emission intralogistics at BMW.

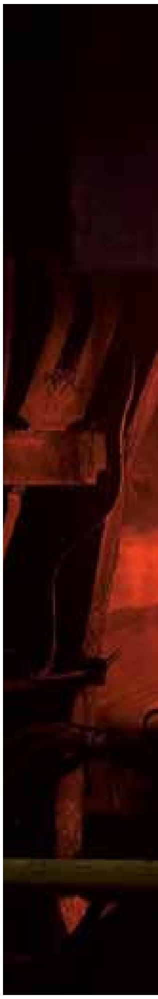
The six fuel pumps that supply hydrogen in the BMW factory use ionic compressors developed by Linde. The hydrogen is a by-product

Around the world with hydrogen: *As part of the F-CELL World Drive challenge, three fuel-cell cars are all travelling around 30,000 kilometres across 125 countries. A specially designed vehicle equipped with an ionic compressor keeps the cars supplied with hydrogen even in remote areas.*

at a nearby chemical factory and Linde liquefies the gas using power from a hydroelectric plant to create carbon-free hydrogen. "We have a clear vision – to use renewable energy at every opportunity in our factories," says Josef Kerscher, President of BMW Manufacturing. "This hydrogen and fuel-cell project is another key milestone on our journey towards this ambitious goal." Switching to hydrogen has many benefits for BMW. For example, fuel-cell forklifts can be fuelled with hydrogen in just three minutes – much quicker than changing a battery, which takes around 20 minutes. And a full two-kilo hydrogen tank can power a vehicle for eight to ten hours, without losing power during service – unlike battery-operated vehicles. Removing battery charging stations reduces the factory's energy consumption and eliminates the need to dispose of batteries containing lead or acid.

Engineers across the globe have thus taken a step closer to the vision of hydrogen as the energy carrier of the future. It remains to be seen as to whether a single drivetrain will prevail. But one thing is clear, as Andreas Tschiesner explains: "Both battery electric and fuel-cell vehicles involve high costs and risks, both for industry and infrastructure providers. Early-mover incentives are imperative to advance new drivetrains. Due to the huge up-front investment for consumers and for industry, both industry and policy-makers must jointly put a suitable framework in place to incentivise demand and ensure an appropriate infrastructure is in place." Jaimie Levin was able to turn his vision of a hydrogen-powered bus service into reality with support from the regional agencies, the state of California and the U.S. Federal Transit Administration. And it's not just the buses' environmental credentials that made a big impression on him. Levin is equally enthusiastic about the low vibration levels and how quiet they are. He even went as far as testing his buses using Tibetan bells welded to the chassis to alert waiting passengers to their arrival. Because the buses are so smooth, Levin found the bells didn't ring loud enough, and he is now exploring the use of a wind chime.

LINKS:
www.actransit.org
www.zeroemissionvehicles.eu



Using oxygen to reduce energy consumption in steel production

THE EFFICIENT WAY TO HEAT STEEL

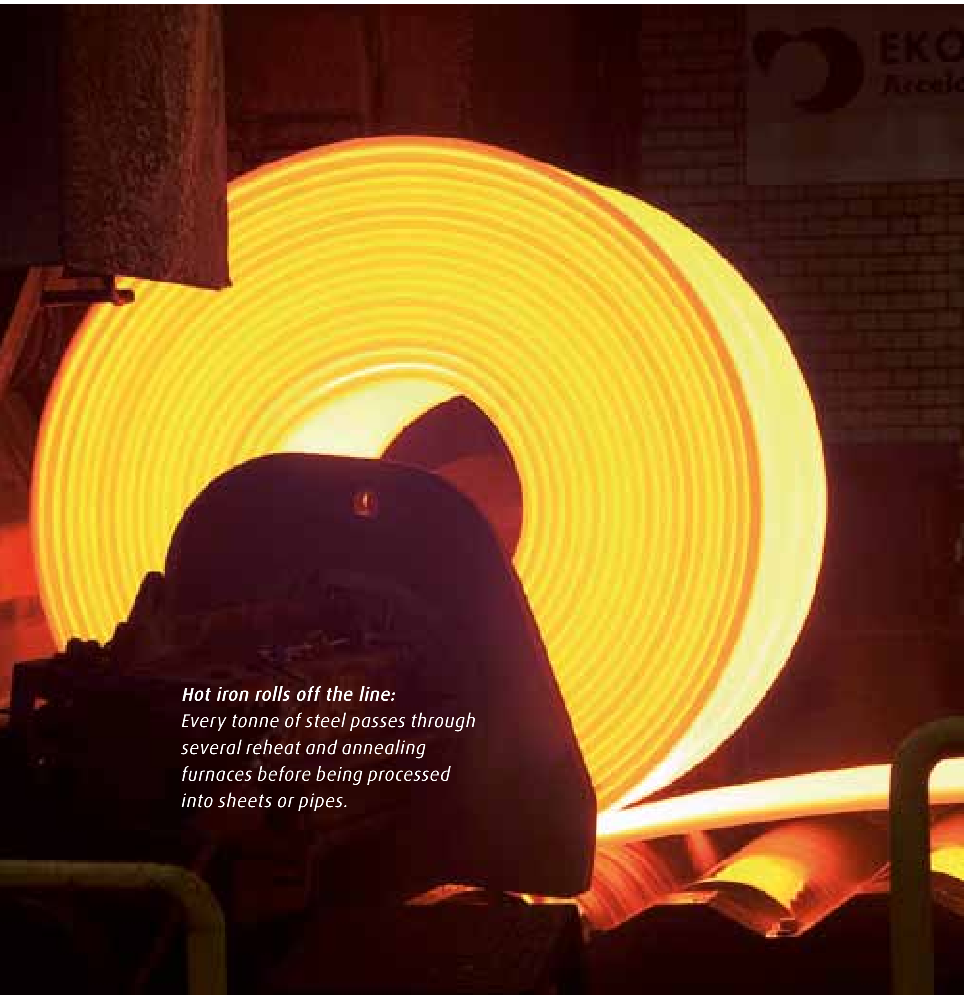
Steel, once it has been cast, has to be reheated twice on average before it can be rolled or forged. All of which uses a lot of energy. Linde has developed a technology that makes steel production more cost effective and climate friendly. By using oxygen, manufacturers can save energy, reduce emissions and increase throughput.

Steel is at the very heart of our modern world. Found in everything from buildings through cars to machines, this metal alloy is one of the most important materials in industrial engineering. And 2010 was a record year for manufacturers, with global steel production reaching a new high of 1.4 billion tonnes. And demand keeps rising. As do the astronomical energy costs. Once steel has been cast, it has to be reheated to around 1,200 degrees Celsius in rolling mills or forge shops before it can be further processed. This consumes a huge amount of energy, between 1.3 and 2.0 gigajoules per tonne – similar to the amount of energy carried by a bolt of lightning. In some countries, energy accounts for up to 40 percent of total steel production costs.

FURNACES WITH EFFICIENCY RATES OF UP TO 80 PERCENT.

Linde's REBOX® oxyfuel portfolio is a very effective way of controlling costs here. Instead of using air in reheat and annealing furnaces, this feature-rich technology uses pure oxygen, which cuts fuel consumption by more than 50 percent. Dr Joachim von Schéele, Marketing Manager of Metals and Glass at Linde, explains the benefits of the REBOX® oxyfuel technology: "Every tonne of cast steel has to go through reheat and annealing furnaces twice on average before it can be processed into sheets, pipes or bars." The standard combustion process uses air from the surrounding atmosphere, which comprises 78 percent nitrogen. A large part of the energy is used to heat this "ballast" nitrogen. Feeding pure oxygen to the liquid or gas fuel, however, makes combustion much more effective, as the compounds can bond without any restrictions. And this is exactly what happens in the oxyfuel process. "Using oxygen means that more energy is transferred to the melt," continues qualified metallurgist and steel expert von Schéele. "Whereas most plants only achieve a thermal efficiency rate of around 50 percent, we can deliver 75 to 80 percent with REBOX®." This also reduces the amount of time needed for heating, and significantly raises productivity levels. "It's better than enlarging a furnace, and the investment often pays for itself in less than a year," adds von Schéele. Work on oxyfuel combustion started back in 1990. Since then, Linde has retrofitted around 120 reheat and annealing furnaces, saving around 1,000 gigawatt hours of electricity each year. According to figures from Germany's National Research Centre for Aeronautics and Space (DLR), this is enough electricity to keep 200,000 average households running for a year.

With energy prices on the rise, fuel savings are a big success factor for steel producers. But that is not the only appeal of REBOX®. "Many of our customers want to increase productivity without having to enlarge their furnaces," explains von Schéele. Statutory regulations governing expansions are becoming increasingly stringent. "And that is when our REBOX® technology comes into its own. It enables manufacturers to increase productivity and reduce emissions," adds von Schéele. Replacing air with pure oxygen significantly cuts harmful nitrogen oxide (NO_X) emissions. An installation at the world's largest steel company, ArcelorMittal, is a case in point. Following a



Hot iron rolls off the line:
Every tonne of steel passes through several reheat and annealing furnaces before being processed into sheets or pipes.

INVISIBLE FLAME – VISIBLE RESULTS

Two innovations within the REBOX® portfolio raise efficiency levels even further in the steel business. In the case of flameless combustion, or to use its correct scientific term volume combustion, the flame is diluted with flue gas, making it practically invisible. The resulting flame is cooler yet spreads out further so that the heat is more evenly distributed. The lower temperature also reduces NO_x emissions.
The other innovation, direct flame impingement (DFI), has proven successful in improving heat transfer by ensuring that the flame comes into direct contact with the metal. This is the same principle as in welding, where metal is heated by the torch flame before being welded. This technology is successfully deployed by many companies, including ThyssenKrupp Steel, Germany, which installed it in several of its plants. DFI enabled ThyssenKrupp Steel to increase capacity by 30 percent without having to extend the furnace.

← Author: Katharina Becker
→ Image source: Boening/Zenit/laif

retrofit in 2007 at the company's US plant in Shelby, Ohio, production levels here increased 25 percent while NO_x emissions sank by 92 percent. Fuel consumption and carbon dioxide emissions also fell by 60 percent.

Cutting steel throughput times in half

Ascometal is another success story. At its site in the French commune of Fos-sur-Mer, the company manufactures long products and wire rods for bearings, springs, automotive applications as well as oil and gas drilling equipment. After switching from air to oxygen, the company was able to produce the same volumes with just nine furnaces, instead of the previous thirteen. Another leading stainless steel maker, Finnish company Outokumpu, has been using REBOX® for quite a while now at a total of 15 installations. After installing Linde technology at its plant in Nyby, Sweden, the capacity of the first catenary furnace rose from 42 to 65 tonnes an hour. The technology also boosted the second catenary furnace's capacity from 11 to 23 tonnes an hour while at the same time enabling the company to meet strict emissions regulations. The surface quality of the heated steel also improved. This eliminated the need for several post-processing steps, which further lowered production costs.

Linde's most recent installation is also the world's largest. In the Swedish town of Borlänge, steel manufacturer SSAB has the capacity to roll around 600 tonnes of steel per hour, most of which is sold to the car industry. "A facility of this size is a real milestone for us," explains von Schéele proudly. Following the positive results here, SSAB now wants to convert both of its furnaces to REBOX® technology in order to raise future productivity levels by ten percent and cut fuel consumption by 15 percent. The move will also reduce nitrogen oxide and carbon dioxide emissions by 25 and 15 percent respectively.

Joachim von Schéele is certain that CO_2 will become an increasingly important issue in the future, especially in Europe. After all, 1.9 tonnes of CO_2 are emitted on average for every tonne of steel produced according to the World Steel Association. According to the International Energy Agency, this means that the iron and steel industry is responsible for four to five percent of global CO_2 emissions. "Following the introduction of the European Union Emissions Trading Scheme, companies that increase their carbon dioxide emissions must purchase allowances on the exchange, while those that reduce their emissions are free to sell their excess credit," says von Schéele. Reducing CO_2 therefore plays a key role in cutting steel production costs.

LINKS:
www.worldsteel.org
www.stahl-online.de

↵ Author: Katharina Becker
↳ Image source: Linde AG

Effective freezing with liquid nitrogen

SHOCK FREEZING BERRIES

Sensitive foods such as fruit do not freeze well at regular sub-zero temperatures. Quick freezing at extremely low temperatures is the only way of ensuring that high-value foodstuffs retain their shape and taste. Linde supplies cryogenic gases for deep freezing and also a broad portfolio of dedicated freezers.

The moment fruit and vegetables are harvested, the pressure is on. Freezing is often the best way to prevent the harvest from spoiling rapidly. However, freezing at regular sub-zero temperatures is not suitable for delicate foods such as fruit. “You can start out with a beautiful raspberry,” explains Tobias Rapp, Head of Sales and Market Development for Foodstuffs at Linde Gas Germany, “but after freezing and thawing, you are often just left with a mushy pulp.” And no matter how good the fruit may still taste, appearance is everything. Delicate foods do not freeze well at slow temperatures. Raspberries, for example, are largely made up of water – encapsulated by a thin cell membrane. “In a home freezer, the water in a raspberry slowly develops long, sharp ice crystals as it freezes. These crystals eventually penetrate and puncture the cell membranes,” continues Linde’s food expert. When the fruit is defrosted, the juice in the membrane seeps out – often leaving behind little more than unappetising pulp.

It’s a very different story if the fruit is shock frozen with liquid nitrogen. Speed is the key success factor in retaining a frozen product’s original appearance. If fruit is cooled quickly, the water in its cells freezes in a flash. This produces very small crystals which cannot damage the cell membrane. As a result, the cells in fruits such as raspberries and blackberries retain their juice, which not only keeps them firm but also looking and tasting great when they have been defrosted.

Consumers are increasingly discerning when it comes to food. As Rapp explains: “Products have to look as fresh and natural as possible, be easy to portion and have a long shelf life.” Under its CRYOLINE® brand, Linde has developed numerous cryogenic freezers for the widest range of freezing challenges. Sensitive products, for example, are immersed in an odourless, tasteless liquid nitrogen bath at minus 196 degrees Celsius. The nitrogen first hardens the surface of, say, a raspberry to ensure that it retains its form. Once its exterior has been made stable, it is moved to a conveyor belt to freeze it through. “This is the only viable solution for very sensitive foods,” continues Rapp.

Rapid freezing also meets rising consumer demands for portionable vegetables and ready-serve meals. Less sensitive foodstuffs such as shrimps and mushrooms are frozen on vibrating conveyor belts that use gentle waves to quickly toss the products in the air. This movement keeps the individual ingredients from sticking together as they freeze. This cryogenic innovation from Linde quickly proved extremely popular with the German market.

A NITROGEN BATH PROTECTS THE PLUMP CELL MEMBRANE.

Germany’s largest manufacturer of ready-made meals uses a similar gentle freezing process. The company needed a solution that not only keeps the individual ingredients in dishes such as bami goreng, risotto and paella separate, it also wanted to quick-freeze and evenly distribute the accompanying sauces. This can only be done using a process known as coating, as Rapp explains: “The entire mixture is frozen loosely in a rotating drum. While this is happening, the sauce is sprayed onto the product, where it freezes immediately.” Although it is a complex process, the results are definitely worth it. The sauce is distributed evenly and consumers can reheat any size portion they require – making it the ideal choice for quick, flexible dining.

LINK:
www.linde-gas.com/en/products_and_supply/foodfreezing

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