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REGENERATIVE RAW MATERIALS FOR INDUSTRY

GREEN AT THE SOURCE

THE LINDE GROUP

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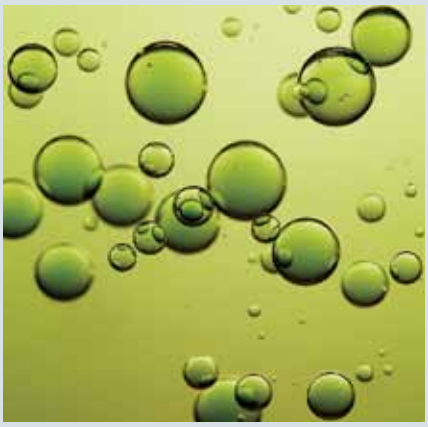

The green alternative: In the future, energy supplies and industrial production processes will have to increasingly rely on regenerative raw materials, replacing crude-based material flows with green chains.

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EDITORIAL

Dear Reader,

The world still beats to the tune of crude oil. Utilities, transport and countless other industries rely heavily on "black gold". But the growing scarcity of raw materials and the rising threat of climate change are forcing society to rethink its energy policy. We need to use the earth's limited natural riches more economically and supplement fossil reserves with alternative and regenerative sources such as wood, straw and plant residue.

Industries such as biotechnology have already developed the application processes to turn green resources into valuable commodities for manufacturing, transport and energy. However, the journey from lab to industrial-scale production is a long one – and one that calls for advanced plant engineering and gas management skills. Linde has assumed a leading role in both of these areas through its far-reaching, end-to-end concepts. Concrete examples of our engagement here include support in constructing the Chemical-Biotechnological Process Centre (CBP) in Leuna, Germany. The CBP aims to gradually replace crude-based material flows with biomass chains across industry. We are also driving the development of hydrogen as a climate-friendly mobility choice. Our pilot plant in Leuna is already producing green hydrogen from glycerine, which occurs as a by-product of a biodiesel manufacturing process. Another example of how we are applying our CO_2 management experience and know-how is the use of algae to generate green oils and biofuels. These microorganisms require huge volumes of carbon dioxide to produce green crude.

Our work doesn't stop with new applications. Existing industrial processes can also be made more efficient and sustainable. Take aluminium recycling, for instance. Our gas technologies can enhance the melting process to cut energy consumption and emissions. We were also involved in developing a process technology that makes it more economical to produce the building blocks required for widely used plastics such as polyethylene.

Natural gas is set to gain in importance in the fossil fuel mix. Compared with oil, it is a more climate-friendly source of energy. We are working with various technology partners to advance the offshore production and liquefaction of natural gas with state-of-the-art, custom-designed ships.

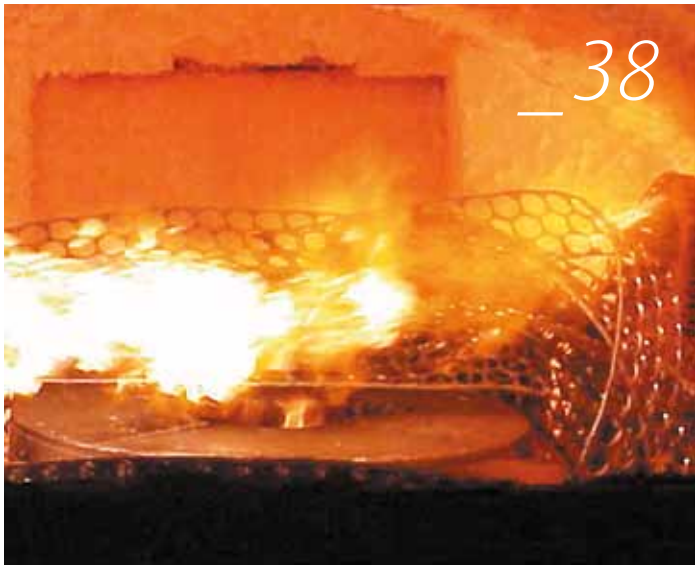
In this edition of Linde Technology, you will find numerous examples illustrating how we are making industrial processes, mobility and energy in general more compatible with the need to protect our environment.

We think they make for extremely interesting reading – enjoy!

Dr Aldo Belloni
Member of the Executive Board of Linde AG

BIOFUEL: *Cultures of algae produce green crude*

MEDICINE: *Cryotechnology supports research*



ALUMINIUM RECYCLING: *Efficiency up, emissions down*

PROCESS TECHNOLOGY: *Plastics made to measure*

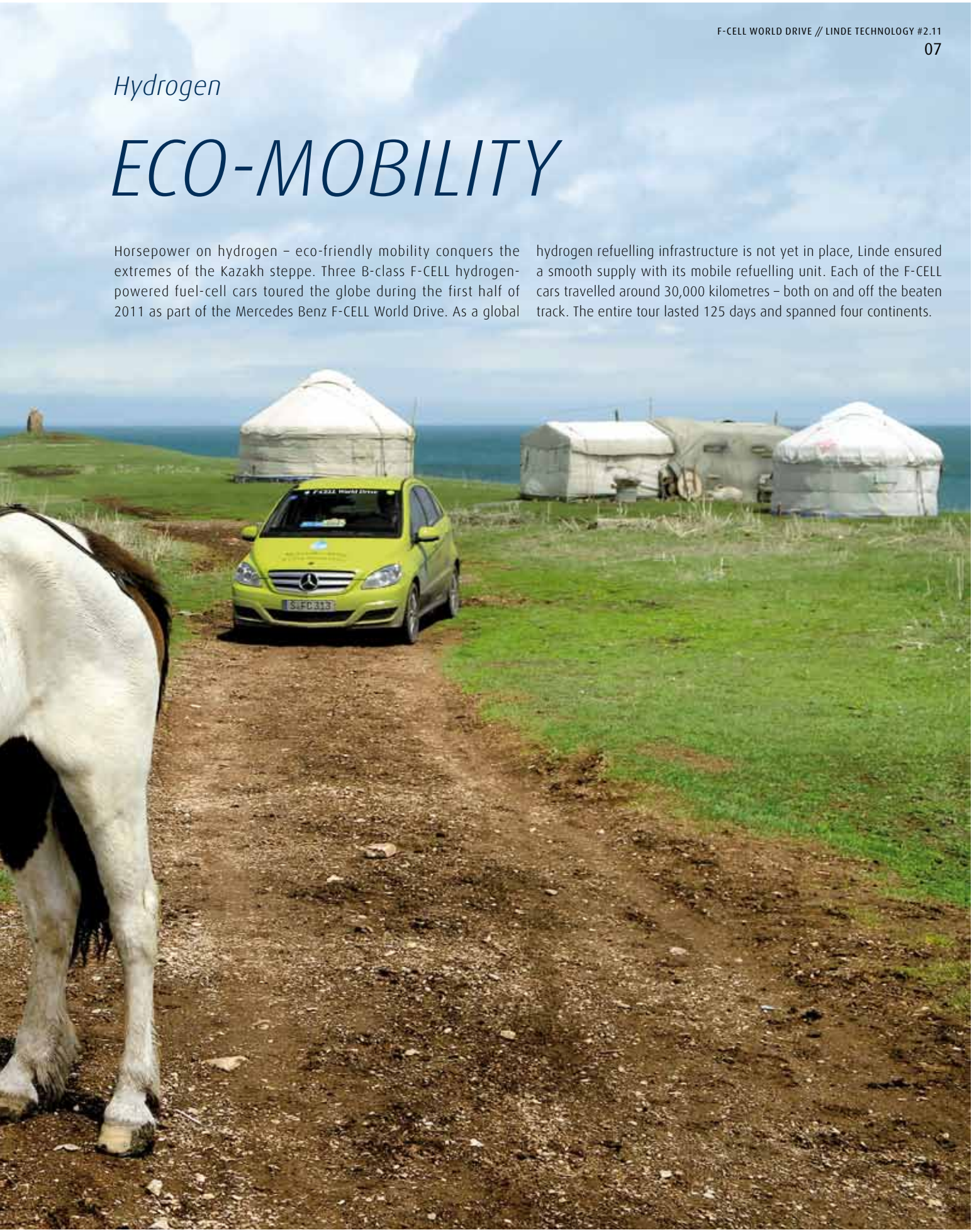
FEATURED TOPIC

↳ *Image source: Daimler AG*

Hydrogen

ECO-MOBILITY

Horsepower on hydrogen – eco-friendly mobility conquers the extremes of the Kazakh steppe. Three B-class F-CELL hydrogen-powered fuel-cell cars toured the globe during the first half of 2011 as part of the Mercedes Benz F-CELL World Drive. As a global hydrogen refuelling infrastructure is not yet in place, Linde ensured a smooth supply with its mobile refuelling unit. Each of the F-CELL cars travelled around 30,000 kilometres – both on and off the beaten track. The entire tour lasted 125 days and spanned four continents.



NEWS

ASIA:
GROWTH PARTNERS

Linde is investing in the strategic, fast-growing Asian market. In autumn 2011, for example, the Group's second air separation plant went on stream in the South Korean district of Giheung. The new facility produces high-purity nitrogen, oxygen and argon. Demand for gas products is continually rising, fuelled primarily by South Korea's steel, electronics and semiconductor industries, as well as by the automotive and petrochemical sectors. Semiconductor specialist Samsung is just one of the customers Linde supplies with high-purity nitrogen. The EUR 130 million investment strengthens Linde's position in South Korea and the region as a whole. "Asia is a key market for Linde and we plan to expand our business here in the long term," explains Sanjiv Lamba, Member of the Executive Board of Linde AG responsible for Asia.

Linde also has its sights firmly set on growth in China. The Group is planning to build two on-site air separation facilities in the East Chinese region of Shandong to supply the Chinese polyurethane manufacturer Yantai Wanhua. The two units will produce 55,000 standard cubic metres of oxygen per hour. They are scheduled to go on stream at the end of 2013/start of 2014. In addition to producing nitrogen for Yantai Wanhua, Linde will also manufacture liquid gases for the regional market.

In Indonesia, the Group has entered a long-term agreement with PT. KRAKATAU POSCO to supply gases to its new steelworks in Cilegon, 100 kilometres west of Jakarta. Linde is investing around EUR 88 million in a new air separation plant that will go on stream at the end of 2013. With a capacity of 2,000 tonnes of oxygen per day, the plant will be the largest of its kind in Indonesia.

Thailand is another growth market with huge potential, and Linde is already the leading gas provider here. The Group is consolidating this position by investing EUR 78 million in a new air separation unit at the Eastern Industrial Estate in Map Ta Phut. Industrial gases are crucial to many industries in Thailand, from the chemical sector through food and beverages to the electronics and pharmaceutical business. The air separation plant is set to start production in 2013, when it will manufacture 800 tonnes of liquefied gases per day. In addition to building the new air separation plant, Linde is also improving the gas supply infrastructure at Map Ta Phut. The Group is constructing a nitrogen compressor and a new pipeline network to improve gas supplies to customers.

UK AND ITALY:

HYDROGEN REFUELLING STATIONS FOR EUROPE

Europe's H_2 infrastructure is expanding. Now, drivers in the UK can also fill up on hydrogen. The first public H_2 fuelling station opened in autumn 2011 in the town of Swindon, to the west of London. The H_2 project was executed by Linde Group member BOC in collaboration with car maker Honda and local economic development company Forward Swindon. The station is located on the M4 motorway between London and Bristol. The hydrogen fuelling pump is specially designed for commercial use. The station can also be used as a blueprint for further projects. "The facility demonstrates our ability to provide the right infrastructure for hydrogen mobility," says Mike Huggon, Managing Director of BOC for Great Britain and Ireland.

Hydrogen is also the perfect clean fuel solution for public transport in urban environments. The Italian city of Milan is the latest conurbation to see hydrogen buses hit the road. Linde Gas Italia built the H_2 fuelling station for the new buses and is now responsible for running it. Milan joins other European cities, such as London, Oslo and Hamburg, where hydrogen buses have already proved a success. The station in Milan is part of the EU's "Clean Hydrogen in European Cities" project.

NORTH AMERICA:

ENGINEERING INITIATIVES

CO_2 capture in coal-fired power plants is being promoted in the US. The United States Department of Energy (DoE) is helping Linde advance technology in this area by providing USD 15 million in funding for the construction of a pilot plant in Wilsonville, Alabama. Linde aims to separate at least 90 percent of the carbon dioxide from flue gases at the plant, while keeping any rise in electricity costs to just 35 percent. By comparison, previous CO_2 capture processes have led to an 80 percent rise in electricity costs. During the project, Linde will apply the extensive know-how in carbon capture and storage (CCS) technology that it has gained from the coal-fired power plant in Niederaussem, near Cologne, Germany. The Group has been working with RWE and BASF at the site since 2009, successfully operating a pilot plant for scrubbing flue gases.

Linde is starting another project in North America with US plant manufacturer Bechtel. In future, the two companies intend to again join forces on ethylene engineering projects. Ethylene is crucial for many industrial processes. Ethylene producers are also planning new projects and expanding their business in light of the growing shale gas market in North America. "By collaborating with Bechtel, we will be able to offer the best ethylene technology solutions for the North American petro industry," explains Dr Aldo Belloni, Member of the Executive Board of Linde AG.

GERMANY:

PROMOTING MEDICAL RESEARCH

Linde has awarded the first grants under its REALfund initiative. At an event held in July 2011 in Munich, the Group awarded a total of EUR 300,000 in research grants to four recipients, who were chosen from over 30 applications. Linde's Healthcare business created the REALfund initiative to support innovative research projects and promote research into the use of gases in respiratory therapy, acute pain management and gas-enabled wound treatment. Every day, medical gases play a crucial role in the treatment of diseases – this was confirmed by all of the experts at the REALfund presentation.

Using cryotechnology to advance personalised medicine

SUB-ZERO ARCHIVES

The future of medical research rests in the icy repositories of biobanks. Tissue, tumour and stem cells hold information that could lead to more exact diagnoses of diseases and the development of individual therapies. To ensure this valuable biomaterial can be referenced in future, it must be kept frozen. Linde offers cryotechnologies for the entire cold chain, enabling samples to remain cryogenically preserved without damage for decades.

← *Author: Hubertus Breuer*
→ Image source: Colin Cuthbert/SPL/Agentur Focus

Imagine an ice-cold library – that's exactly where many scientists work. Medical biobanks are home to millions of human cells. Blood samples, stem cells and tumour tissue are all kept in a cryogenic deep sleep at a temperature of minus 196 degrees Celsius, waiting for the day when they can be used. At such low temperatures, organic material can be stored for decades and kept as a vital bioresource for future generations. This is because cryogenically frozen cells are still alive. And once they have been thawed, the important information that they store can be used to study diseases or solve crimes. Scientists can, for example, use tissue samples to track the different stages of a disease, clarify the results of examinations and develop therapies.

All this is only possible because of cryostorage – a term derived from "cryos", the Greek word for cold. Researchers have been focusing on how organic materials react at extremely low temperatures since the middle of the last century. When cells are cryogenically preserved, all of their internal metabolic processes come to a halt. While frozen, they do not age, grow or separate. Cell activity stops completely. Yet this can only be achieved if the cryogenic temperature is maintained during the entire time the cells are preserved. "Cryopreservation is only possible with reliable and precise cooling," explains Peter Mawle, Global Business Manager for Cryostorage at Linde. Liquid nitrogen provides the low temperatures, as low as minus 196 degrees Celsius, that scientists need. "Linde has a wealth of expertise in this area," states Mawle. This know-how could play a key role in personalised therapies. The icy bio-databases are an important part of the equation here. Based on a patient's genetic profile, cryogenic tissue samples and analyses of those samples and the biodata stored for that patient, medics can create a clear clinical picture of the individual's medical condition and develop a personalised therapy. There are huge differences between different types of cancer, for example. Every tumour develops in its own particular way.

FREEZING CANCER CELLS TO DEVELOP INDIVIDUAL THERAPIES.

Thanks to cryo research, doctors across the globe can now use patient tissue samples to diagnose illnesses and develop therapies. Frozen bone marrow stem cells, for example, are used to fight leukaemia, while heart valves can be used to save lives years after they were donated. Frozen sperm banks have already been around for a long time. Fertility doctors are now also able to freeze ova and ovarian tissue. One of the greatest cryotechnology success stories in the field of reproductive medicine took place back in 2004 in Louvain, Belgium, with the birth of a baby conceived using frozen ovarian tissue. This process gives hope to women whose ova have been damaged by chemotherapy, for example, and who would otherwise be unable to have children. Universities and research institutes are at the forefront of these and other medical advances.

Deep freeze treasure trove: *Tissue samples are archived in biobanks. Decades later, the frozen cells can play a key role in medical research.*

However, it is not all plain sailing. "Handling biological samples is not easy. The material is extremely sensitive. Cryotechnology enables it to be transported without damage or quality impairment," states Shivan Ahamparam, Market Segment Manager Chemicals and Energy at Linde. Linde supplies cryobanks around the world with liquid nitrogen and also offers a full range of vessels, from large sample storage volumes to small transport containers. On request, Linde's "cryo" experts also deliver turnkey facilities with specially designed freezers connected to automatic liquid nitrogen re-filling units. Building on its biobank in the Dutch town of Hedel, Linde offers the full range of cryoservices to university hospitals, blood banks and biomedical and pharmaceutical companies in Belgium and the Netherlands. "Our service portfolio ranges from secure transport through material-specific storage solutions to 24-hour monitoring," explains Will Kremers Commercial Manager Hospital-/Cryocare at Linde Healthcare Benelux.

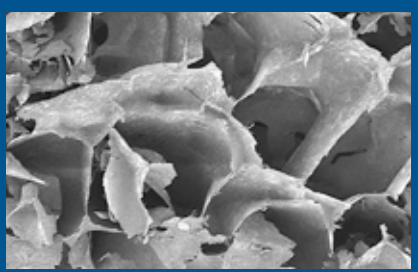
PRECISION FREEZING FOR SENSITIVE TISSUE SAMPLES.

"We transport tissue samples and biomaterial, for example, in special low-temperature containers," continues Mawle. The frozen material is then safely stored in the continuously monitored repositories of cryobanks. Cutting-edge technology and trained personnel ensure that these valuable biological resources are kept at the requisite temperature with a continuous, automatic supply of nitrogen, and that the entire process from freezing to sample removal can be accurately traced at all times. Biobanks have become increasingly important, and are now internationally networked. Which makes it more crucial than ever that they comply with the same high quality standards the world over. This is the only way of ensuring that research, science, industry and hospitals can collaborate seamlessly. "It therefore makes sense for biobank operators to have 'cryo' specialists on site to manage storage," explains Linde expert Ahamparam. Professional management is essential to ensure that the valuable samples are not prematurely awakened from their cryogenic slumber.

Linde also provides biological storage vessels that use liquid nitrogen in the gas phase. The samples are evenly cooled in the cold vapour atmosphere and are also easier to handle while minimising any risks of cross contamination. "DryStore®" is another storage vessel used, for example, by Linde Group member BOC in its cryobank in the UK. These containers feature a double wall that contains the ice-cold liquid nitrogen. This liquid nitrogen "jacket" keeps the samples in the container cool, and reduces the risk of coolant contamination. "Linde may not be a biotech company," explains Mawle. "But our innovative technologies and in-depth know-how on cryostorage make us the ideal port of call for biotech players,

FREEZING MIST ENHANCES PHARMACEUTICAL APPLICATIONS

Drug products, which are often protein based, must remain effective not only through the production process, but more importantly when administered into a patient's body. These substances are expensive, fragile, and can lose their efficacy during storage. Lyophilisation (freeze-drying) is a dehydration process for stabilising these valuable medical substances and prolonging their shelf life. It is a relatively expensive, complex, yet gentle procedure that involves freezing many vials at the same time and then removing this frozen water via sublimation. The temperature at which a vial freezes (ice nucleation temperature) is a critical parameter that impacts not only operating times but also the quality of the final product. However, there is as yet no commercially feasible way of achieving uniform ice nucleation across all vials within a batch, leading to long operating cycles, reduced yield and non-uniformity within a batch. "This is where Linde's cryogenic expertise and process knowledge provides the solution, resulting in more robust lyophilisation cycles and improved product quality," explains Beatrice Chinh, Head of the Pharmaceutical Industry Segment at Linde. The company has now developed a solution in collaboration with freeze drying equipment manufacturer IMA Life, formerly BOC Edwards. The new approach uses a sterile freezing mist (ice fog) that rapidly spreads throughout the lyophilising chamber and causes all vials to freeze at the same time, and at the desired temperature. The vial-to-vial uniformity in ice nucleation promotes product homogeneity and prevents wastage. The control of the ice nucleation temperature produces the preferred ice structure within the product, leading to shorter drying times during sublimation. The approach is feasible for both small-scale development and large-scale aseptic manufacturing. Prerona Chakravarty, Project Manager Pharmaceuticals, Fine and Specialty Chemicals, maintains that through this improvement in lyophilisation, a crucial downstream operation, Linde's proprietary induced nucleation technology will help scientists and pharmaceutical manufacturers set higher standards for quality control in drug manufacturing.



Frozen structures under the microscope: *Linde's technology enables shorter process cycles by enabling larger pores to form in sugar alcohol.*

Cryogenic freezing with nitrogen: *Biomaterial can be stored without damage in cryogenic storage banks and tanks until it is needed (above). All cell activity stops when samples are submerged in liquid nitrogen at minus 196 degrees Celsius (right). Scientists can thaw the biomaterial decades later and use it for medical research (left).*

universities and research institutes looking for advice and support in their search for cryogenic solutions."

Cryo-Save, one of Europe's leading stem cell banks, is a major customer for Linde's "cryo" specialists. Stem cells, however, need to be frozen in a special way. Linde can also supply computer controlled freezing equipment to ensure this is achieved in a precise manner. For many medical professionals, these cells represent a great opportunity in the development of specific medical answers to diseases.

Controlled cooling for stem cells

The pharmaceutical industry also uses frozen biomaterial, for example, in the search for new medicines and in high-throughput screening (HTS). HTS involves running thousands of experiments in parallel to determine, for example, whether a medical compound reacts with specific cells. "Demand for high-quality tissue samples is rising," explains Stephen Thibodeau, Professor of Laboratory Medicine at the prestigious Mayo Clinic in Rochester, Minnesota. Most sub-zero archives are often just small freezers in a basement. However, scientists are increasingly cooperating with external cryobanks that specialise in widespread diseases such as cancer or Alzheimer's. The world's largest brain bank, the Harvard Brain Tissue Resource Center is located in the US at the McLean Hospital near Boston. Working with biobanks can help doctors adopt a highly systematic approach to determining the causes and biological roadmap of diseases in the future. This will then give them the insights to develop more tailored, individual therapies.

Despite massive advances in cryotechnology, there are still major challenges to preserving life at extremely low temperatures. "Entire bodies or even organs cannot be frozen for extended periods of time. Transplant hearts are only cooled during transportation," explains Mawle. This is because organs and larger cell structures take much longer to freeze and also freeze at a more uneven rate than red blood cells or stem cells. In addition, cryopreserved material cannot be used for regular blood transfusions as not enough studies have been carried out in this area. But that could change. One thing is sure: Future medical progress hinges on controlled freezing and cryogenic storage as much as it does on advances in biotechnology. And we are only just beginning to realise the potential of cryobiology.

LINK:
www.cryo-save.com

REGENERATIVE MATERIALS FOR MOBILITY, ENERGY AND MANUFACTURING

GREEN AT THE SOURCE

The growing scarcity of fossil fuels and the rising threat of climate change are forcing society the world over to rethink its energy policy. In the foreseeable future, energy supplies and industrial production processes will have to increasingly rely on regenerative raw materials, replacing crude-based material flows with green chains. We have already reached the biotech watershed – thanks in part to innovative plants and gas technologies from Linde.

Fuel-cell cars are kind to the environment – water is the only thing that comes out of their exhaust pipes. To make the *hydrogen* for fuel-cell cars even *greener,* Linde's pilot plant in Leuna is researching hydrogen sourced from glycerine, which occurs as a by-product of biodiesel made from rapeseed oil. Algae also have huge potential for industrial applications. Modified strains can convert CO_2 into *green crude oil,* for instance. Refineries can process this bio-oil in much the same way as regular crude. Meanwhile, Linde Engineering in Dresden has teamed up with Fraunhofer-Gesellschaft to advance the economic viability of biotechnology at the *Chemical-Biotechnological Process Centre (CBP) in Leuna*. The aim of CBP is to bring biomass processes to industrial maturity at an even faster pace.

Green H_2 production: *The pilot plant in Leuna (building below right) feeds hydrogen from renewable sources into an industrial-scale H_2 production chain. The facility generates 50 cubic metres of green hydrogen per hour.*

Sustainable mobility: Linde pilot plant produces green hydrogen

CLEAN WITH GLYCERINE

In future, society needs to find better ways of uniting the goals of personal mobility and environmental protection. Hydrogen is one of the more promising answers. But to create truly sustainable mobility choices, hydrogen must be generated with a zero or almost-zero carbon footprint. Linde engineers have developed and are now trialling a method of manufacturing green hydrogen from biomass at the company's pilot plant in Leuna, Germany. Meanwhile, on the streets, the automotive industry is proving that hydrogen-fuelled vehicles are already fit for everyday use.

↑ *Image source: Linde AG*
↓ *Author: Henning Hochrinner*

One of the keys to green hydrogen is pyroreforming. In the small town of Leuna, around 30 kilometres east of Leipzig, Linde engineers are harnessing this technology to establish a key milestone in the move to secure future energy supplies. They have developed a new method of producing green hydrogen from renewable resources, which they are trialling at a pilot plant. The process is based on glycerine. "This substance belongs to the alcohol family. Alongside carbon and oxygen, it contains several hydrogen atoms, making it ideal for hydrogen production," explains Gerrit Spremberg. A process engineer in Linde's Gases Division, Spremberg supervises the pilot plant at the Leuna site. "Glycerine is also non-toxic, easy to handle and available all year round," he adds. For a zero carbon balance, the glycerine must be obtained from renewable resources. It occurs in particularly large quantities as a by-product of biodiesel manufacturing, where both diesel and glycerine are obtained from plant oils. "We are trying to develop cost-effective alternatives to conventional hydrogen production and ensure the process is as climate-neutral as possible," explains Dr Mathias Mostertz from Linde Innovation Management.

H_2 FROM RAPESEED FIELDS: USING BY-PRODUCTS FROM THE BIODIESEL INDUSTRY AS FEEDSTOCK.

The Leuna pilot plant is bringing the engineers increasingly close to this aim. It is set to commence regular operations from autumn 2011, generating 50 cubic metres of green hydrogen per hour. The production process begins with purification of raw glycerine. It still contains approximately 17 percent water and salts at this stage, which an initial distillation step removes. Pyroreforming can then begin. This involves cracking the desalinated glycerine molecules under high pressure and at temperatures of several hundred degrees Celsius. Like natural gas, the resultant pyrolysis gas primarily consists of methane. "Converting natural gas into hydrogen is a long-standing core competence at Linde, so we can draw on established processes and development know-how here," says Mostertz.

Following pyrolysis, the gas is fed into a steam reformer, where it is heated to generate synthesis gas. Alongside hydrogen, this still contains large amounts of carbon monoxide. So in a final process

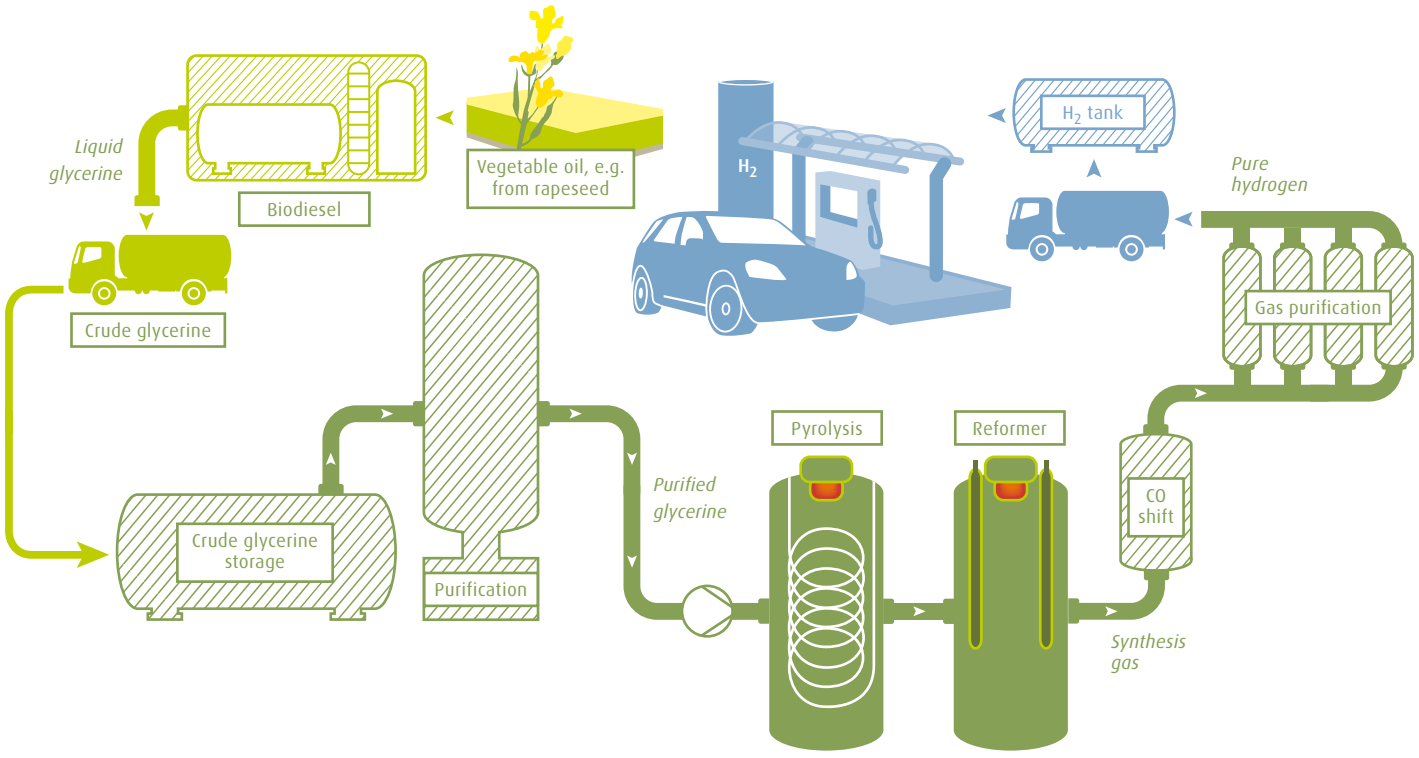
HYDROGEN DIVERSITY

Flanking research into H_2 from plant-based glycerine, Linde is also working on ways of generating H_2 from biogenic substances. In future, organic waste could also be used as a feedstock. Gasifying biomass generates a methane-rich gas, which is then converted into hydrogen. This process is particularly efficient, since the gasification residues then serve as fuel, providing the heat required for the reaction. Solar power can also be harnessed to produce hydrogen. As part of the Hydrosol research project, specialists at Germany's National Research Centre for Aeronautics and Space (DLR) are working on thermochemical cycles, which generate H_2 from solar energy. The researchers are using a field of solar collectors to focus sunlight onto a reactor. Inside it, water reacts with a special ceramic catalyst, binding oxygen and releasing hydrogen.

step, the H_2 constituent of the gas mixture is further increased. To save costs, the synthesis gas from the pilot plant is fed into the existing purification stage of the conventional H_2 production process. "But only the flow we pipe in from the pilot plant can be termed green hydrogen," Spremberg confirms, as only this gas is derived from biogenic raw materials.

Meanwhile, H_2-powered cars are already making a contribution to climate protection as they motor along our roads. The only thing coming out of the exhaust pipe is steam. "Of course, these vehicles are only as eco-friendly as the fuel that powers them," points out Mostertz. While hydrogen is the most abundant element in the universe, this sought-after substance only occurs naturally within chemical bonds, for instance in hydrocarbons such as methane or in water. And it takes a great deal of energy to split these highly stable compounds. If the electricity required to electrolyse water is generated by coal-fired power plants, the overall hydrogen production process still releases significant amounts of CO_2. Natural gas reforming – currently the most common method of producing hydrogen – also emits greenhouse gases. But if the H_2 is obtained from renewable raw materials, fuel-cell vehicles running on this eco-friendly gas have a carbon footprint 70 percent lower than conventional diesel cars. So the development of this new technology is laying the foundations for sustainable mobility. As such, it is subsi-

FROM FIELD TO FUEL



dised by the German National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP) run by the Federal Ministry of Economics and Technology (BMWi).

TÜV-certified sustainability

To ensure that the new technology really does prove an asset to the environment, Linde called in TÜV SÜD to analyse the carbon footprint for the entire production process. The calculations include all sources of emissions, from delivery of the glycerine to Leuna to the electricity consumed to light the pilot plant. "In commercial production, making better use of waste heat will save even more energy in future," notes Mostertz. In the best case scenario, the engineers will be able to reduce the total CO_2 emissions of hydrogen manufacturing by 80 percent.

H_2 IN BERLIN: FIRST REFUELLING STATION FOR GREEN HYDROGEN.

In Berlin, car drivers will soon be able to fill up on green hydrogen – Shell opened its first H_2 refuelling station in Germany, constructed by Linde, in June 2011. These will be the first pumps to offer certified green fuel. The facility has sufficient capacity to refuel around 250 hydrogen vehicles a day. "We are proud to be playing an active part in researching and developing hydrogen technologies to enable personal mobility. As a fuel, hydrogen can contribute to a lasting reduction in road traffic emissions," declares Dr Peter Blauwhoff, CEO of Deutsche Shell Holding, speaking at the opening in Berlin. More refuelling stations are set to follow in the near future. As Blauwhoff went on to point out: "In order for hydrogen to assume a greater role, we need to ensure there are enough H_2 vehicles on our roads. Industry has already made major advances in this area." Fuel suppliers, car manufacturers, equipment providers and policy-makers must all work closely together to cut costs and realise the economic potential of hydrogen. The French group Total already operates three public hydrogen fuelling stations in Germany and is working on several projects for further locations. "But the benefits of hydrogen extend far beyond fuel. It is also an ideal buffer to store peaks in electrical energy generated from renewable sources such as wind and solar, and feed this power back into the grid on demand," explains Total's fuel expert Dr Ralf Stöckel, Head of Sustainable Development – New Energies.

Hydrogen streams in his sights: *Linde specialist Gerrit Spremberg checks the pipeline network at the pilot plant. The glycerine purification plant is in the background to the left.*

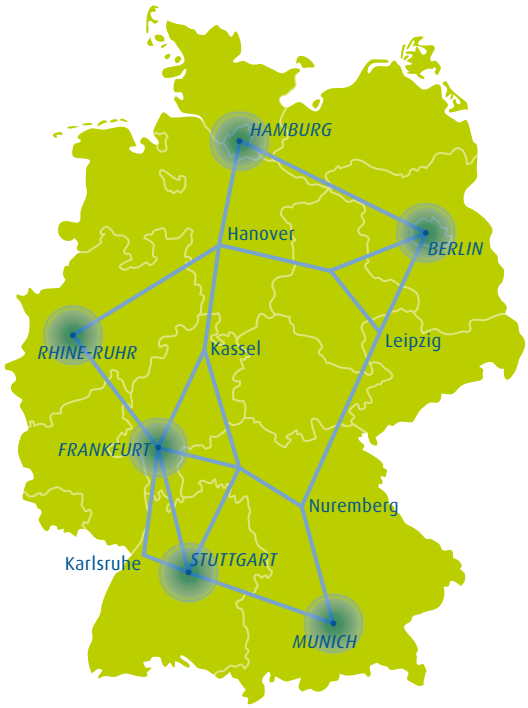
Green hydrogen is made using crude glycerine, a by-product of rapeseed-based biodiesel production. Once it has been purified, the glycerine is converted to a hydrogen-rich synthesis gas in a pyrolysis reactor and steam reformer. The subsequent CO shift reaction increases the percentage of H_2 in the gas mixture. The hydrogen is processed in further purification steps until it reaches the level of quality needed for fuel-cell cars and buses.

EXPANDING THE H_2 REFUELLING NETWORK

ON THE MOVE WITH HYDROGEN

Linde is working with industrial and political partners to put a comprehensive H_2 infrastructure in place and lay the foundation for the success of this sustainable fuel. H_2-powered fuel cells have a key role to play in advancing electromobility. In addition to developing innovative hydrogen production and storage technologies, industry leaders are also focusing on expanding the infrastructure for hydrogen-powered fuel-cell vehicles. Together with Daimler, Linde intends to set up a further 20 hydrogen refuelling stations in Germany over the next three years, ensuring that the steadily growing number of fuel-cell vehicles can be supplied with H_2 generated solely from renewable resources. This project forms a bridge between the established H_2 Mobility and CEP infrastructure projects, which are sponsored by the German National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP). The Linde and Daimler initiative, involving an investment in the double-digit million euro range, will more than triple the number of public hydrogen refuelling stations in Germany. The new facilities are planned for the existing hydrogen hubs of Stuttgart, Berlin and Hamburg, as well as along new, end-to-end north-south and east-west corridors (see below). The aim is to make use of existing, easily accessible locations belonging to various petroleum companies. These corridors will then make it possible to travel anywhere in Germany with a fuel-cell vehicle. "In combination with our green hydrogen from Leuna, this is a pioneering refuelling concept for sustainable mobility," states Olaf Reckenhofer, Managing Director of the Linde Gases Division in Germany, Austria and Switzerland.

GROWING H_2 INFRASTRUCTURE



To expedite the supporting H_2 infrastructure, Linde, Shell, Total and other companies are collaborating within the Clean Energy Partnership (CEP). Together, these players are demonstrating the viability of hydrogen as an everyday fuel and establishing a network of H_2 fuelling stations. The city of Hamburg is also making an active contribution to hydrogen-powered eco-friendly road traffic. Since summer 2011, four fuel-cell hybrid buses have been in regular service there, with three more set to follow in 2012. The benefits of hydrogen are especially evident with large vehicles that clock up many miles each day. Buses in particular emit large amounts of CO_2 in stop-and-go traffic around town.

H_2 series cars on the market from 2014 onwards

"Hydrogen is the new oil," Dieter Zetsche, CEO of Daimler AG, was pleased to announce at the 2011 International Motor Show (IAA). The German car-maker is set to launch its first series-production vehicle with fuel cell drive as soon as 2014 – a year earlier than originally planned. Although numerous manufacturers showcased battery electric vehicles (BEVs) at this leading automotive trade fair, industry insiders are not yet certain which drive technology will ultimately prevail. Many car-makers are thus adopting a two-pronged approach, developing both BEVs and H_2/fuel-cell vehicles. Small, battery-powered cars are ideal for short inner-city trips, while the fuel-cell versions are well suited to longer journeys. In contrast to BEVs, hydrogen fuel-cell vehicles have no distance limitations and can be refuelled almost as quickly as petrol or diesel cars, i.e. in around three minutes. Hydrogen cars can currently travel over 400 kilometres on a single tank. Indeed, the Mercedes F125 concept vehicle, presented at the IAA, is equipped with a lithium-ion battery pack as well as a

H_2 pump in Berlin's Sachsendamm: Refuelling with hydrogen now only takes a few minutes and is almost as easy as filling up with other liquid fuels.

fuel cell, and should be able to manage up to 1,000 kilometres. The series production of this concept is expected to start by 2025. However, efficient, large-scale supply of green hydrogen for motor vehicles will require a radical increase in the availability of this energy carrier. "Our method is very close to reaching economic viability," reports Mostertz. The Linde expert goes on to explain that further progress will require larger facilities than the Leuna pilot plant: "For economically sustainable production, the plant's hydrogen output needs to increase by at least a factor of 60." The next step, then, is to refine the technology further, making it even more cost-effective to deploy.

For a greener tomorrow

Efforts are also underway to widen feedstock choices for eco-friendly H_2 production beyond glycerine. Linde developers are already researching gasification of biomass and electrolysis of water with surplus electricity from renewable energy sources. "Crude oil currently dominates our transportation and economy. In future, however, we won't be looking at one single source of energy. Hydrogen will play a major role, and there will be several ways to produce it," explains innovation manager Mostertz. Furthermore, these new technologies will no longer operate on the large scale of today's crude oil refineries. Hydrogen will be generated locally, wherever the raw materials are available. "It would simply be a waste of energy to transport glycerine hundreds of kilometres from different biodiesel refineries for H_2 production," Mostertz declares.

Linde's engineers are steadily advancing towards an eco-friendly future, currently planning industrial-scale production of green hydrogen at a capacity of 500 cubic metres per hour. Gases specialist Spremberg is convinced that the new technology will play an enabling role in climate-neutral H_2: "We now have the opportunity to help shape our future energy landscape – and to make the world a bit greener in the process."

NATURAL FUEL CELLS

Humans are not the only creatures to obtain energy from hydrogen. Researchers from the Max Planck Institute for Marine Microbiology and the University of Bremen have now discovered deep-sea bacteria that oxidise H_2 to gain energy and nutrition – similar to fuel cells. The hydrogen enters the sea via deep-ocean hydrothermal vents known as black smokers. These hot springs occur in areas where tectonic plates meet. Seawater comes into contact with hot magma, heats up and washes nutrients into the sea. Since no sunlight penetrates these depths, organisms have to rely on other sources of energy and these bacterial fuel cells form the basis of an ecosystem located near the black smokers.

LINK:
www.cleanenergypartnership.de

Algal oil – CO_2 technology feeds sustainable energy chain

GREEN GOLD FROM THE DESERT

Algae may help us resolve the challenges presented by dwindling oil reserves and rising greenhouse gas emissions. They can turn carbon dioxide into valuable green crude. Refineries can process this bio-oil in the same way as regular crude oil. Working with Sapphire Energy experts, Linde is developing CO_2 delivery technologies for tomorrow's algae farms.

← Author: Ute Kehse
→ Image source: Sapphire Energy

The desert of New Mexico is home to amazingly prolific pools of algae. These veritable turbo chemists only need a few weeks to do something that normally takes Mother Nature millions of years. The end result is algal oil – which the experts are calling "green crude". This hydrocarbon mixture can easily replace petroleum oil, as it contains the same type of molecules. With regular crude oil, dead cells are deposited on the seabed, slowly compressed by kilometre-thick layers of mud under extreme pressure and ultimately converted into a heavy liquid hydrocarbon mixture through the high temperatures prevailing in the depths of the deposits. To fast-track this process, researchers from Sapphire Energy are using algae to turbo-produce green crude. The Sapphire pilot facility near Las Cruces in New Mexico only needs 14 days until the algae living in the open salt-water ponds produce the purest crude oil. "And refineries can purify this algal oil in exactly the same way as regular crude," says Cynthia Warner, President, Sapphire Energy. The biomass can even be refined into high-density jet fuel – something that was not feasible with conventional clean technologies available until now.

"The green crude production chain fits neatly into the current energy infrastructure and is therefore an exceptionally promising, environmentally friendly raw material for industry," explains Dr Mathias Mostertz, Head of the Clean Energy Technology Biomass Programme at Linde Innovation Management. Fossil-based crude oil is not just refined into fuels such as diesel, petrol and jet fuel. It is also used to make important base chemicals required across a variety of industries to manufacture plastics, for example, such as polyethylene, polyester and polyurethane. Countless petroleum-based products have become indispensable parts of our everyday lives. Linde engineers and the Sapphire Energy experts share a vision – to produce green crude. "We have signed a cooperation agreement and have been working together since May 2011 to bring this algae-based technology to market maturity," adds Mostertz.

Linde is responsible for supplying the tiny algae with powerfood – carbon dioxide in this case. The inhabitants of the open, 20cm-deep salt-water ponds in the Chihuahua desert of New Mexico are microscopic, single-cell organisms. These green and blue algae use the energy from the sun to photosynthesise the carbon dioxide into hydrocarbons. They need 600 kilos of CO_2 to make 1 barrel of green

NEW MARKETS FOR CARBON DIOXIDE

Many experts have flagged algae-sourced biofuels as the most promising replacement for fossil fuels as we move forward. These algae can grow in relatively compact water ponds and yield massive volumes of green crude. Supplying commercial algae farms with carbon dioxide is a promising business opportunity. Linde is working closely with leading algae companies to advance the enabling technologies. CO_2 experts at Linde are optimising the entire CO_2 supply infrastructure. Linde is collaborating with Sapphire Energy and Algenol Biofuels in this area. Algenol produces bioethanol in closed photosynthesis-based bioreactors (see article in Linde Technology 1/2010).

Where the journey to green crude begins: *Different algae strains are grown under artificial sunlight, their cells producing high-quality crude oil for biofuel.*

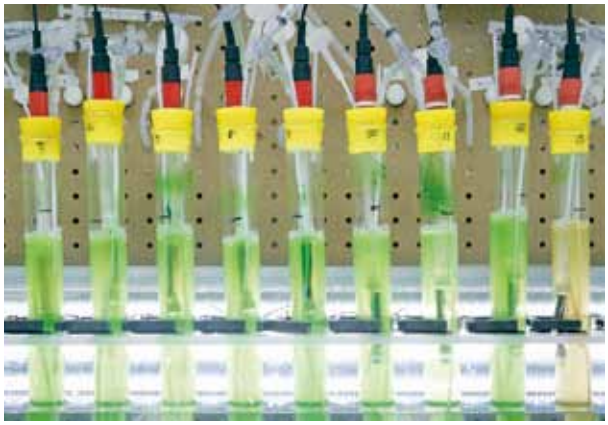
crude (1 barrel = 159 litres). "Algae are particularly effective at photosynthesis, so they can grow extremely quickly," comments Michael Mendez, one of the founders of Sapphire Energy. That is why these single-cell organisms yield around 100 times more biomass for a given surface area than other fuel crops such as soya beans or maize. The added bonus of algae is that they do not conflict with the human food chain as they are not dependent on valuable farmland or fresh water.

Biologists are still working to optimise the process chain. The microorganisms should reproduce as quickly as possible, while storing large quantities of oil reserves in their cells. At present, around half of the harvested algae biomass consists of oil. Sapphire Energy wants to increase this figure. The company is aiming for commercial maturity by 2018, and plans to produce up to 10,000 barrels of green crude a day by then. One of the big challenges, however, lies in managing CO_2 delivery for commercial-scale production. Until now, the CO_2 used in the existing merchant beverage and refrigerant market came from natural, underground sources. It was liquefied and transported by truck to customers. However, the planned yield of an algae farm would require up to 10,000 tonnes of CO_2 every day – in other words, one third of the total merchant volume per day in the US. As Mostertz explains, "That simply isn't feasible with the current infrastructure – we need new supply solutions."

Carbon dioxide from industrial flue gases

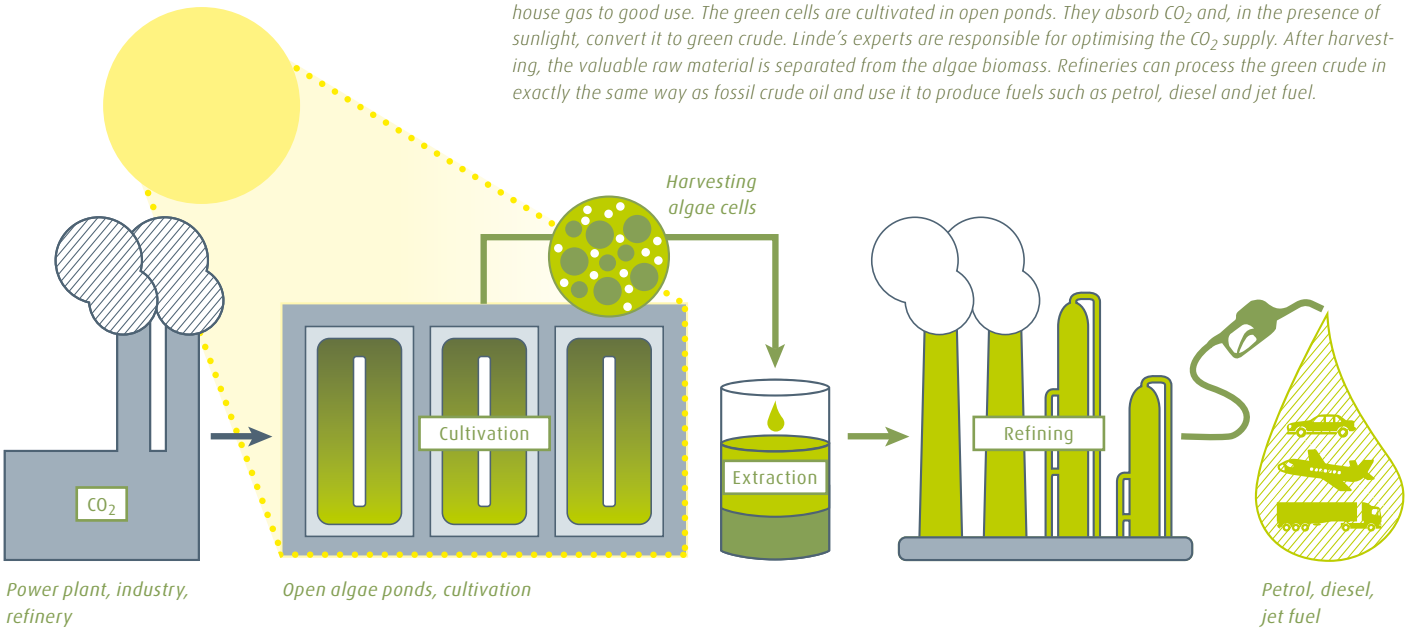
At the end of the day, the green crude must not be more expensive than regular crude oil. And the CO_2 supply is one of the biggest cost factors. "Carbon dioxide currently accounts for almost one third of the total price," explains Mostertz. Compared with other gases such as oxygen or nitrogen, the merchant market for CO_2 has remained relatively small to date. But that could soon change. Mostertz and a team of experienced CO_2 managers from Linde are looking at the development of cost-effective and environment-friendly solutions – solutions that also help to protect the climate. Ultimately, CO_2 is released everywhere coal, natural gas and crude oil are combusted, and is generally regarded as the biggest threat to our climate. If algae could be used to convert this greenhouse gas back to oil, they have the potential to cut CO_2 emissions by as much as 80 percent compared to fossil fuel.

Green diversity in the laboratory: *Researchers at Sapphire Energy develop new algae strains every day (left). Following a series of lab tests (top, right), promising candidates are cultivated in special plastic bags in greenhouses (bottom, right).*



TURNING CO_2 INTO ALGAL OIL

Carbon dioxide is a by-product of many industrial processes. Sapphire Energy's algae farms can put this greenhouse gas to good use. The green cells are cultivated in open ponds. They absorb CO_2 and, in the presence of sunlight, convert it to green crude. Linde's experts are responsible for optimising the CO_2 supply. After harvesting, the valuable raw material is separated from the algae biomass. Refineries can process the green crude in exactly the same way as fossil crude oil and use it to produce fuels such as petrol, diesel and jet fuel.



Linde engineers have already gained extensive experience in recycling industrial CO_2 emissions. In the Netherlands, for instance, the company supplies hundreds of greenhouses near Amsterdam with CO_2 captured from a local refinery. The gas acts like a fertiliser, encouraging plant growth in the greenhouses. It has a similar effect on grass. Carbon emissions from power plants, refineries and industrial plants could theoretically be fed to algae farms. "Carbon capture technologies, which separate the CO_2 stream from industrial emissions, are still in their infancy," adds Mostertz. So he and his colleagues are looking for other ways to capture the gaseous power-food as cost-effectively as possible. The CO_2 experts from Linde also have to find ways of cost-effectively transporting the CO_2 from the emitter to the algae farm. This covers everything from picking the most appropriate materials for the pipelines to pre-transport compression, so the gas can bubble vigorously through the salt-water ponds at a pressure of only a few bars.

CLIMATE HELPERS: ALGAE FARMS CONSUME 10,000 TONNES OF CO_2 EACH DAY.

In addition to optimising these typical links in the supply chain, Linde engineers also have to develop totally new solutions for the algae farm. For instance, the CO_2 flow must adapt to the natural rhythm of the algae. They can only consume CO_2 during the day – when the sun is shining. Regular power plants and refineries work around the clock, however. "So either we need storage solutions or we need to buffer the culture with chemical additives so that we do not rely on the diurnal variations," continues Mostertz.

If this algae farm proves a true success, it could convert the harsh Chihuahua desert into a green reference project. "We need to produce a million barrels a day if we want to have a significant impact on the current energy mix," says Jason Pyle, CEO, Sapphire Energy. It seems like an ambitious plan, but it could work. Simply because the more difficult it gets to extract dwindling fossil oil reserves from the earth, the more attractive green crude will become as an alternative to "black gold". And like petroleum, it can also be used as a raw material for "green" car seats, shoes, plastic packaging or home insulation. Green crude could go one step further and revolutionise air travel. In 2008, Sapphire successfully produced 91-octane petrol from algae. One year later, the biofuel experts from New Mexico took part in a test flight in which a dual-engine Boeing 737-800 was powered by algae-sourced jet fuel. Sapphire's vision is to use technology to achieve a green energy mix and reduce greenhouse gas emissions. And CO_2 managers at Linde are playing an enabling role in achieving that vision.

LINK:
www.sapphireenergy.com

Buried treasure: *The straw in these tubes contains valuable sugar compounds that can be converted to beneficial chemical building blocks in biorefineries.*

Linde and Fraunhofer-Gesellschaft advance bioeconomy at Leuna

WHERE CHEMISTRY MEETS BIOLOGY

Crude oil is not only used to power cars and heating systems, it is also indispensable in the chemical industry. Regenerative raw materials have the potential to replace fossil resources. To transition biomass-based processes more quickly from the laboratory to industrial production, researchers at Fraunhofer-Gesellschaft are building the Chemical-Biotechnological Process Centre (CBP) in Leuna. Linde Engineering Dresden is the main contractor for the new centre.

↑ *Image source: Fraunhofer-Gesellschaft*
↓ *Author: Caroline Zörlein*

Crude oil makes the world go round. It is the most important raw material for the global economy and is synonymous with prosperity and progress. It powers cars, planes and ships, and is the feedstock for the production of base chemicals, plastics, paints and many other products in our everyday lives. The secret to crude oil's success is its high carbon content. Carbon, a chemical element with the symbol C, can be used to create almost all chemical compounds, making it the most important building block for the chemical industry. No other chemical compound can be used to produce such an extensive variety of molecular architectures, including infinitely long chains, rings and 3D networks. Carbon is therefore crucial to industrial production. And with 85 to 90 percent carbon content, crude oil has a lot to offer. "However, carbon is also present in natural raw materials," explains Prof. Thomas Hirth, Head of the Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB) in Stuttgart. Vegetable oils and fats comprise around 76 percent carbon. And lignocellulose – the main component of wood – also boasts 50 percent carbon content. "Industry must now learn to capitalise on nature's carbon potential," continues the chemist. Especially now that the era of black gold is coming to an end.

BIOTECHNOLOGY: PUTTING NATURE'S CARBON RESERVES TO USE IN INDUSTRY.

Plant-based raw materials already contain the right substances and structures for many products. Fibres, for example, can be used as a basis for textiles or as a basic component for insulation and packaging. Vegetable oils can be processed to create surfactants for detergents. Maize and potato starch can be found not only in biodegradable materials such as yoghurt pots, but also in adhesives and pharmaceutical products. Currently only around 13 percent of feedstock for the chemical industry is sourced from regenerative raw materials. "This share of the sourcing mix has to rise. Today, almost all companies are looking to base more of their production processes on regenerative raw materials," explains Uwe Welteroth, Director Biotechnology Plants at Linde Engineering Dresden GmbH. "Biotechnological processes play a crucial role in processing and converting biomass to chemical products," continues Welteroth.

Industrial biotechnology, also known as white biotechnology, uses microorganisms such as bacteria, fungi and special enzymes to efficiently break down plant raw materials, turning cellulose, starch, oil and sugar, for instance, into smaller components or new, more complex molecules. These tiny, natural chemical factories and molecular vehicles produce substances such as lactic acid, amino acids and alcohols. These platform chemicals can then be used by the chemical industry to produce plastics and other chemical products. Biotechnological processes are increasingly being merged with physical,

chemical and thermal processes. Ethylene, for example, is a base chemical used for a wide range of applications, including the large-scale manufacture of plastics around the world. One innovative method for producing this compound involves a number of different steps, including thermal conversion of regenerative raw materials to gas, biotechnological processes for converting this gas to liquid alcohol and subsequent physical-catalytic steps.

SUPPORTING A SUSTAINABLE BIOECONOMY.

Talent hub in chemical park

"Yet many processes based on renewable raw materials often get stuck in the laboratory and pilot stage and never make it to industrial development," says Hirth. The experts at Fraunhofer want to change this. Following a Europe-wide tender, Fraunhofer commissioned Linde Engineering Dresden to design and construct the Chemical-Biotechnological Process Centre (CBP) in Leuna. The centre is designed to help small and medium-size businesses transfer biotech processes from the laboratory to industrial-scale production. Larger companies will also benefit from the facilities at the CBP. "Many companies do not have the financial or technical means to scale up their processes," explains Dr Markus Wolperdinger, Head of Business Development Biotechnology Plants at Linde Engineering Dresden. The CBP's main aims are therefore to help businesses scale up technologies and develop processes. "Chemical-biotechnological processes and plant modules that harness and convert regenerative raw materials can be developed and optimised at the centre. They can then be integrated directly into existing crude oil refineries as green production units," explains Hirth.

The objective is to gradually replace fossil-based material flows with biogenic flows. According to Wolperdinger, the centre's location gives it a great advantage: "The CBP Leuna is located in the heart of an established chemical cluster, giving it direct access to industry and a diverse range of products," he says. It is therefore ideally placed to pioneer the transition to an integrated hub, capable of processing both fossil and regenerative raw materials. "This is a key step towards a bioeconomy and sustainable production," confirms Hirth. "The CBP is like a microcosm of a bioeconomy." The centre is also part of the German Research and Science Network, giving it strong cross-regional pull.

The project is coordinated by the Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB) and the Fraunhofer Institute for Chemical Technology (ICT). As the main contractor, Linde Engineering Dresden is responsible for the various process units. "To harness the full energy and material potential of plant-based biomass, we will use cascading process chains – similar to those used by a biorefinery," explains Welteroth. To create an optimum infrastructure comprising pilot and mini plants, Linde Engineering is thus building five process plants for the development and up-scaling of industrial biotechnology methods. "For the entire system to work efficiently and economically, the individual units must be fully interoperable so they can maximise the material and energy flows," adds Wolperdinger. Experts from Linde Engineering Dresden are also collaborating as research partners at the CBP, investigating individual projects such as the use of industrial gases (such as hydrogen) in refineries and the development of plants to generate bioethylene from innovative biomass conversion processes.

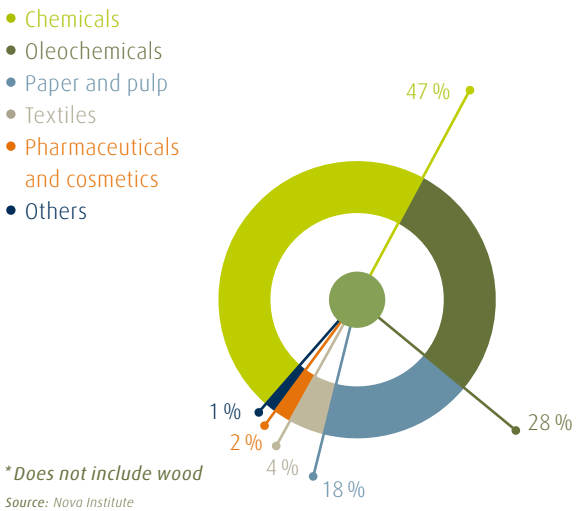
Smart algae: Cultivated microalgae produce chemical components for pharmaceuticals, fuel and food.

Making the most of straw, wood and waste

Construction on the CBP Leuna officially got underway at the end of 2010. However, the first projects with major companies, small and medium-sized partners, universities and non-academic research institutions started back in 2009. Over 20 industrial companies and 15 universities and research organisations have thus far agreed to collaborate on projects or are already actively involved. Together with his project partners, Hirth and his team started to lay the foundations for the CBP almost four years ago. "We involved all relevant players from industry, business and politics right from the word go so that we could start our research activities before the building had been constructed," recalls Hirth.

One of the key projects at the CBP involves lignocellulose, the primary component of wood. For some years now, scientists at the Fraunhofer IGB laboratories have been working on the thermal conversion of this highly prized feedstock, and developing tailored decomposition and separation methods to harness all of the materials in lignocellulose. To date, there is neither a technical process nor an integrated plant concept for lignocellulose. Once the CBP is finished

BIOMASS* IN INDUSTRY



*Does not include wood

Source: Nova Institute

in the summer of 2012, the biotech experts intend to establish a sustainable, demonstration-scale process at the centre and thus lay the foundations for future industrial-scale production of synthesis compounds and polymers from wood. They will be focusing in particular on ramping up processes that harness biogenic waste streams – in other words raw materials that are suitable as food sources – to industrial-scale production. With plants, technologies, laboratories, offices and storage space spread over an area in excess of 2,000 square metres, the CBP will provide the perfect all-round platform for the development of industrial biotechnology processes. The CBP receives funding from several German ministries, including the Federal Ministry of Education and Research (BMBF) and the Federal Ministry of Food, Agriculture and Consumer Protection (BMELV), and is also supported by the State of Saxony-Anhalt. "This is truly something special and a testament to our commitment to a bioeconomy," maintains Fraunhofer expert Hirth, who, together with other partners, has accompanied the Chemical Biotechnological Process Centre project every step of the way, from financing to realisation. Centres such as the CBP are crucial to intensify research into the kinds of renewable raw materials that have the potential to power a forward-thinking, sustainable future.

LINK:

www.cbp.fraunhofer.de/en.html

A BRIEF CHAT

SUSTAINABLE FEEDSTOCK FOR THE CHEMICAL INDUSTRY

Linde Technology spoke with Dr Gesa Behnken, Innovation Manager in the New Business department (regenerative raw materials) at Bayer Material Science, about green plastics and bio trends in the chemical industry.

↳ WHY USE REGENERATIVE RAW MATERIALS AS INDUSTRIAL FEEDSTOCK?

Renewable raw materials make sense if they enable energy savings across the entire product lifecycle and make production processes more sustainable. The technical criteria governing the choice of raw material depend on the actual purpose of the final product.

↳ HOW DO REGENERATIVE RAW MATERIALS COMPARE WITH CONVENTIONAL PETROCHEMICAL SOURCES FROM A COST PERSPECTIVE?

A lot of development work still has to be done to create regeneratively sourced products that can match the characteristics of conventional petrochemical-based products. We're talking long term here. If industrial-scale production is possible and demand exists, then bio-based materials will be economically viable.

↳ WHAT ARE THE BIGGEST CHALLENGES INVOLVED IN CONVERTING BIOMASS TO GREEN COMMODITIES?

We feel that the availability of biomass and an enabling logistics chain are two key issues. A successful market built on bio-based products would also require a completely new value chain extending from the agricultural landholder to the end manufacturer, for example, a sports shoe manufacturer. New production processes also have to be developed and scaled up from the lab to industrial maturity – this can be a critical step. This is sometimes the hurdle where researchers realise that the transition to industrial-scale production is not feasible for technical or financial reasons.

Prof. Dr Hans-Jörg Bullinger,
President of Fraunhofer-Gesellschaft

Essay

THE POTENTIAL OF INDUSTRIAL BIOTECHNOLOGY

From climate change through water and raw material shortages to soil degradation and dwindling oil reserves – the planet is facing several major challenges. Biotechnological processes that harness regenerative raw materials are becoming increasingly important for industry. They are key enablers in helping us move from petrochemistry to biorefineries.

Sustainability is now a top priority. Yet sustainability means taking a radical step away from conventional business practices based on spiralling resource consumption. Step by step, we need to start replacing fossil fuels such as crude oil with renewable raw materials. Crude oil has been our most important energy carrier for the past 100 years, and is the most common chemicals feedstock. Dwindling resources and rising prices, however, are forcing industries to rethink their dependency on crude oil. And although there may be many alternative sources of energy, the same cannot be said for the chemicals industry, which relies on carbon-based feedstock for its production processes. In fact, the only alternative to petrochemistry is to source carbon from plants.

NATURE'S OWN CHEMICAL FACTORIES ARE CHANGING THE FACE OF INDUSTRY.

In theory, regenerative raw materials are available in sufficient quantities and distributed evenly across the globe. Increased demand for this type of feedstock, however, is fuelling intense competition for land between raw material producers, food manufacturers and companies in the bioenergy industry. In light of the rising global population, only those technologies that avoid any conflict with food production will prove to be sustainable options for the future. Biogenic surplus products such as wood and straw from agriculture and forestry, as well as efficient biomass plants such as Chinese silver grass, prairie grass and algae offer a way out of the food versus fuel dilemma.

In recent years, white biotechnology has completely redefined the application spectrum of renewable raw materials. Modern biotechnology is set to pave the way for new production processes and products such as fine and base chemicals, bioplastics and food additives as well as agricultural and pharmaceutical materials. All leading chemical companies across the globe have identified white biotechnology as a key technology for the 21st Century and positioned it accordingly on their agendas. It is an area that holds great promise and potential for further research. Eight Fraunhofer institutes anticipated this potential many years ago,

leading them to team up and consolidate their expertise under the umbrella of an initiative called "Industrial biotechnology – nature's own chemical factory."

In Germany, the prospects for renewable raw materials are extremely favourable compared with the rest of Europe and the US. Biomass already accounts for over ten percent of all raw materials used by the chemical industry. Vegetable oils and carbohydrates such as sugar, starch and cellulose are the main feedstock here. Renewable supplies are not just being used for their material properties, they are also increasingly being converted into biofuels and bioenergy carriers in Europe and the US. By 2020, around 20 percent of all fuels are to be produced using biogenic raw materials in Europe. The US has set itself the national goal of producing around 10 percent of oils and fuels and 25 percent of chemical products from biological feedstock by 2030.

IMPROVED STARCH THANKS TO TARGETED POTATO CULTIVATION.

Harnessing valuable raw materials

Nature provides a huge spectrum of chemical compounds that we have only just begun to explore – each one offering great potential for the chemical, pharmaceutical, paper and textile industries. Products such as polymers, surfactants, solvents, dyes, odorants, active pharmaceutical ingredients, cosmetics, fuels, lubricants and fibres are already being produced from regenerative raw materials. In the future, we must learn to fully utilise nature's synthesis capabilities in order to harness all of these valuable materials. The ligneous parts of plants, for example, are also composed of valuable sugar molecules and polymers. Lignocellulose is the main structural component of plant cells, and is the most commonly occurring renewable raw material. Lignocellulose accounts for two thirds of biomass and mainly comprises cellulose and hemicellulose sugars as well as the biopolymer lignin. This makes it the ideal feedstock for the production of platform chemicals such as ethanol, lactic acid or succinic acid, substances that can be used to develop entire families of key industrial chemicals.

Our ability to obtain basic chemical elements is crucial for the future of industrial biotechnology. Which is why Fraunhofer institutes have been focusing on ways of unlocking these valuable substances. Lignocellulose has an extremely robust structure, and can only be broken down into the building blocks needed to create secondary chemical products using new methods. In order to transition these methods from the laboratory to industrial-scale production, the Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB) and the Fraunhofer Institute for Chemical Technology (ICT) constructed the Chemical-Biotechnological Process Centre (CBP) in Leuna. The institutes aim to convert and use various raw materials containing lignocellulose in full on an industrial scale, and have even built their own lignocellulose biorefinery for this purpose. The unique research centre enables cooperation partners from research and industry to develop and scale up biotechnological and chemical processes aimed at harnessing renewable raw materials.

Intensive research is also being carried out into optimising plant properties and preparing them so the raw materials can be used more effectively. The Fraunhofer Institute for Molecular Biology and Applied Ecology (IME), for example, has cultivated a potato that produces pure amylopectin, a starch required by the paper, textile and food industries. Another project focuses on obtaining rubber from dandelions. The IGB breeds microalgae in a flat-panel airlift reactor to produce fatty acids and carotenoids. Both institutes are systematically looking for new microorganisms and enzymes that are suitable for industrial use, and are optimising them for highly specific applications.

The next generation of biotechnological processes is already under development. Known as cell-free biotechnology, these processes use biochemical and molecular biological processes independently of cells or microorganisms. They can be used to create high-purity proteins, thus eliminating the costly protein purification steps required with conventional production procedures.

These new biotechnological processes open up extremely promising opportunities for the development of more efficient, environmentally sound and resource-friendly production processes in the chemical, pharmaceutical, food and cosmetic industries.

↱ *Image source: Fraunhofer-Gesellschaft*

Greenhouse dandelions: *Researchers at the Fraunhofer Institute (IME) use the plant's sap to create rubber.*

LINK:
www.fraunhofer.de

Recharging the body's batteries: *Proper rest at night is essential to stay healthy. Sleep laboratories help explain why some people still feel tired after a full night's sleep.*

Global, all-round LISA™ service provides relief for sleep apnoea

REST ASSURED

People who do not rest well at night often feel exhausted the following day. Sufferers of obstructive sleep apnoea (OSA) experience regular pauses in breathing while sleeping, and this can have a serious impact on their health. The LISA™ (Leading Independent Sleep Aide) therapy programme from Linde Healthcare provides all-round support for sufferers, from screening to follow-up checks – patient training, medical equipment and therapy included. The all-embracing nature of this service reduces the risk of patients abandoning therapy.

Image source: Corbis, AJ Photo/SPL/Agentur Focus
Author: Clara Steffens

Sometimes the brain sends an emergency signal in the middle of the night. This can happen, for example, to people who snore if they stop breathing for a dangerous length of time. The level of oxygen in the sleeper's blood falls quickly, causing the body's respiratory centre to send a wake-up call. The brain's control centre reacts immediately, quickening the pulse and increasing blood pressure. If these measures are successful, the sleeper gasps for air, usually with a loud snoring sound, and oxygen enters the body. The sleeper's airways are free again, enabling them to return to a rhythmic snoring pattern until the next disruptive pause in breathing. In some cases, this can happen up to 60 times an hour.

"These repeated pauses in breathing are also known as apnoea episodes. And they put the body under extreme stress," explains Prof. Christian Krüger, sleep disorder physician at the University Sleep Research Centre in Hamburg. He regularly treats patients suffering from this sleep disorder, known in medical circles as obstructive sleep apnoea (OSA) syndrome. Experts in the US estimate that four percent of men and two percent of women in middle age are affected. Sufferers are usually not aware of what is happening to them at night. The next morning, however, they wake up feeling tired with a dry mouth and complaining of headaches. They also experience difficulty concentrating. OSA patients do not have breathing difficulties during the day, and they sleep for sufficient periods of time at night. "By triggering the body's wake-up reflex, however, apnoea episodes stop sufferers from falling into the deep sleep that is so vital for the body to renew itself," explains Krüger.

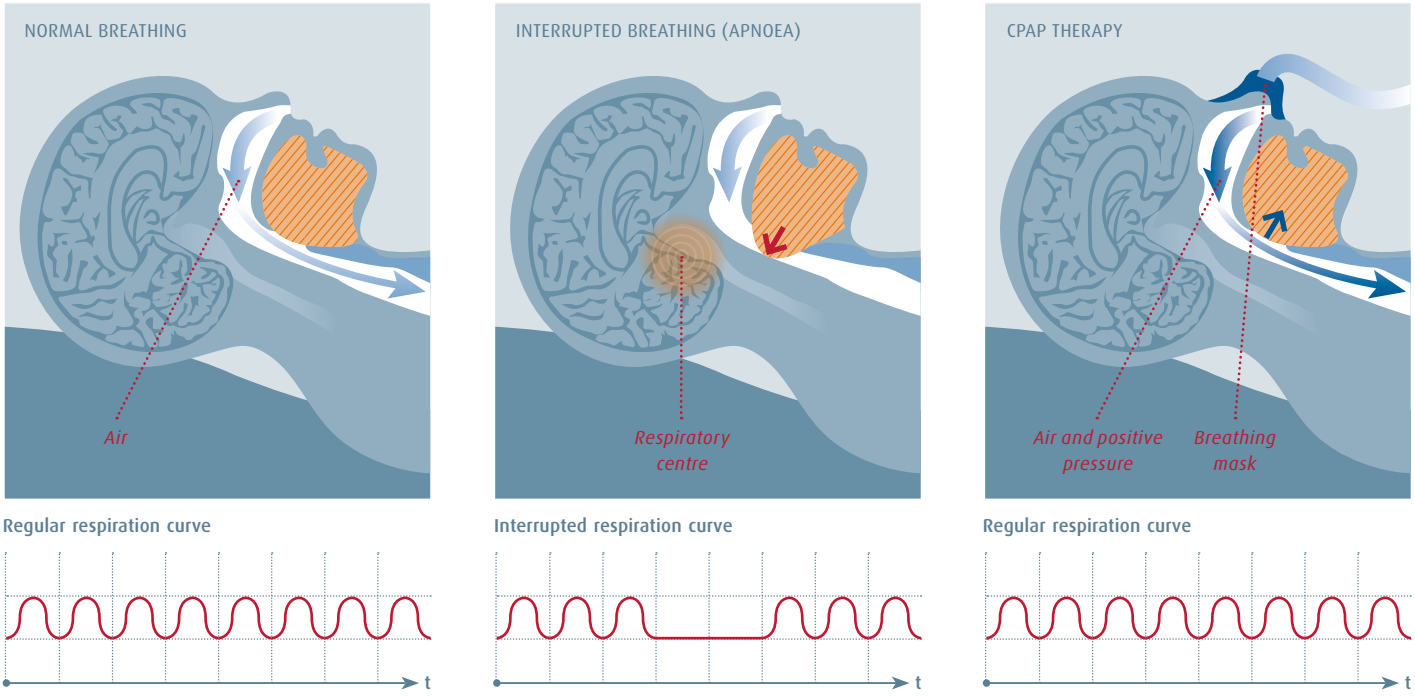
Linde Healthcare has been actively supporting people with sleep apnoea since the end of the 1980s. "Our Leading Independent Sleep Aide (LISA™) programme provides optimum support for each patient, at every step of the process from diagnosis through treatment to follow-up checks," explains Gildas Bonduelle, Business Manager Sleep at Linde Healthcare. In the long-term, apnoea episodes are dangerous and are detrimental to patients' health and wellbeing. "We now know that obstructive sleep apnoea is associated with high blood pressure and other cardiovascular diseases such as heart attacks, strokes and cardiac arrhythmias," says Krüger. Patients also often suffer from mild depression without knowing why. In addition, OSA puts a strain on relationships. According to Bonduelle, "Most patients are sent to their doctors by their wives, who find their partner's loud snoring irritating and are worried by irregular breathing patterns." The episodes occur when sufferers sleep on their back and the muscles and tissue

SLEEP LAB DIAGNOSIS

In suspected cases of obstructive sleep apnoea (OSA), the patient is given a portable machine by his or her physician. The machine measures the patient's breathing, heart rate and blood oxygen levels at home while he or she is sleeping. It also records snoring patterns and the sleeping position. If OSA is diagnosed, the patient is referred to a sleep laboratory, where specialists use recording devices and video cameras to monitor sleep patterns. The results provide information on the different stages of sleep. The experts can also determine how often people with OSA stop breathing and how long these interruptions last. To determine the right therapy, experts must also find at what stage the apnoea episodes occur and how they impact the cardiovascular system and oxygen levels in the blood.

"ALL CLEAR" FOR THE AIRWAYS

Healthy people inhale air into their bodies without any restrictions (left). If, however, the muscles in the palate and throat relax, they can block the airway and interrupt breathing. These dangerous pauses are known as apnoea episodes (middle). The body no longer receives sufficient oxygen, which causes the respiratory centre to send a wake-up call. During CPAP therapy (right), a continual supply of air is pumped into a patient's throat via a mask. This creates positive pressure that keeps the airways free.



in the palate and throat relax. These muscles flutter like a flag in the breeze when the sleeper breathes through the mouth, causing them to snore. If the palate tissue or tongue falls further back down the throat, the airway could become totally blocked, making it impossible to breathe. It usually takes a long time for sufferers to seek medical help, accept their disease and start therapy.

"It's a particularly good sign if both the sufferer and his or her partner want to learn how to deal with sleep disruption," says Bonduelle. Tens of thousands of patients in 20 countries (above all in Europe, South America and Australia) are already feeling the benefits of Linde's LISA™ programme. The company intends to roll out the service to further markets such as Asia.

Support is tailored to each patient's requirements. Carers, therapists and doctors can visit patients at home or provide support in hospitals or sleep laboratories. The LISA™ offering is split into four categories – enable, motivate, assess and progress. During the "enable" phase, LISA™ therapists provide information on the illness and treatment options. "Information is the key to success for us. Today, many doctors simply do not have the time to provide in-depth information," explains the Linde sleep expert. In group sessions, patients learn that the risk of developing OSA increases with age and that excess weight and excessive alcohol consumption can aggravate the condition. The soft tissue of many sufferers' palates is often particularly slack or thicker than normal. However, a small lower jaw, small soft palate and obstructed nasal passages are all factors that can contribute to snoring and breathing difficulties.

"Positive airway pressure is a standard therapy," continues Krüger. The patient receives a continuous positive airway pressure (CPAP) device, which is roughly the size of a shoe box, and includes a tube attached to a mask. The CPAP machine continually pumps ambient air into the patient's throat via the mask. This steady stream keeps the airways free. "Seeing the machine on your bedside table can be dis-

A reliable partner: LISA™ experts help patients choose and fit a CPAP mask. They also provide support throughout the therapy.

concerting and put people off," explains Bonduelle. But studies show that CPAP therapy can reduce blood pressure in the long term as well as significantly increase quality of life and therefore life expectancy.

Intensive support keeps patients committed to therapy

Choosing from a wide portfolio sourced from a number of different manufacturers, LISA™ experts help patients choose the right device and adapt the mask for a perfect fit. Before a new device can be added to the Linde Healthcare portfolio, a risk assessment is performed and quality and safety tests are conducted at Linde's application technology centre in Vienna. At the CPAP training centre, LISA™ participants learn how to operate their new devices correctly. "We want to empower patients and enable them to take responsibility for their therapy," states Bonduelle. In collaboration with a psychologist, Bonduelle and his team have created a video that patients can also view at home. "Clinical studies have proven that clearly structured video messages help patients remain committed to the therapy," outlines Bonduelle.

Getting patients to understand the benefits of therapy is the first important step. "CPAP is a long-term therapy. Regular motivation and check-ups are therefore crucial," explains Bonduelle. Which is why LISA™ "motivate" and "progress" action items focus on continued interaction with patients. Carers ask patients if they are experiencing any problems at regular intervals – and not just after the first night. Annual therapy check-ups provide a further opportunity for Linde experts to collaborate closely with physicians. LISA™ services go beyond ongoing patient support. The programme also promotes OSA screening under the umbrella of its "assess" action item. "We want to raise awareness among patients who have not yet been diagnosed and help them choose the right therapy to improve their health and quality of life," continues Bonduelle. Interest in these programmes is now growing among companies, as they recognise the results of numerous studies showing that a good night's sleep is crucial for a happy and efficient workforce. A pilot project at a Portuguese company made numerous shift workers and drivers aware of their sleeping problems, successfully diagnosing 32 workers from a 165-strong focus group with OSA. Linde is also planning a similar screening for drivers in South America.

Another project in Portugal was equally successful. In this case, however, it was specifically targeted at diabetes patients. Suspected cases were investigated in further detail. "We deliberately tailored the screening to diabetes patients as, statistically, over half of diabetes patients suffer from disrupted sleep patterns and 23 percent of these from obstructive sleep apnoea," explains Bonduelle. In addition to providing advice on CPAP therapy, the Linde Healthcare team also provided information on weight loss. The experiences LISA™ experts have gained over the years confirm the company's strategy: If OSA patients are given full support from the very beginning, they use their devices for longer at night and are less likely to abort their therapy. And for a relaxed, invigorating night's sleep, the effort is definitely worth it.

LINK:
www.sleepapnea.org

A BRIEF CHAT

"DISRUPTIVE SLEEP IS EXTREMELY STRESSFUL"

Linde Technology spoke with sleep disorder expert Prof. Christian Krüger, internist and head of the sleep laboratory at the University Sleep Research Centre in Hamburg.

↳ LOTS OF PEOPLE SNORE AT NIGHT. SHOULD THEY REALLY HAVE TO VISIT THEIR DOCTOR FOR THIS?

Snoring is unhealthy. Anyone who snores should find out why because it can also trigger the sleep apnoea syndrome. Continuous vibration damages the muscles in the throat. In some cases, snoring can be a direct symptom of sleep apnoea.

↳ BUT MANY SLEEP APNOEA PATIENTS FEEL FINE AND DO NOT REALISE THAT THEIR BREATHING IS INTERRUPTED...

That's true. Patients are not actively aware that they are waking up. But if they are not breathing, they are not taking in air: the level of oxygen in the sleeper's blood falls quickly. This causes the body to send a wake-up signal, which raises the sleeper's pulse and blood pressure. In the long term, this puts the entire body under a great deal of stress during the night, increasing the risk of a stroke, heart attack and circulatory disorders.

↳ WHAT THERAPIES ARE AVAILABLE TO COMBAT THIS?

Patients with a mild form of sleep apnoea which only occurs, for example, when they sleep on their back, can learn to sleep in different positions in special training sessions. A special brace is also available that pushes the lower jaw forward and keeps airways free. CPAP therapy remains the most effective approach, however. We have seen excellent results with it. Despite initial misgivings, an average 90 percent of our patients respond very well to the therapy.

High-tech gases for the multimedia industry

SHARPER, THINNER, FASTER

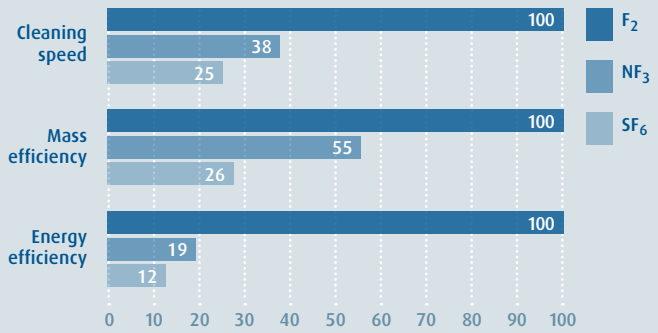
From smartphones to cash points – nowadays just about every computing device needs a display. High-performance transistors are essential for vibrant colour displays capable of responding to a finger swipe. And high-tech gases play a key role in producing electronic components.

The shelves of electronics stores are overflowing with flat panel displays, share prices flit across banks of screens, and posters are giving way to animated adverts in stations. From notebooks, smartphones and iPads through satnavs and cameras to cash points and supermarket check-outs, it's a rare device that gets by without a high-performance display these days. When it comes to high-tech screens, the motto is: bigger, better, flatter – a trend particularly in evidence in the television sector. Especially in Europe and the US, 2003 heralded the biggest sea-change in this market since the launch of colour TV. Cathode ray tube (CRT) devices have long since fallen by the wayside. And now that flatscreen TVs are affordable for private households and digital reception has unplugged them from aerial sockets, the traditional sitting room set-up is also a thing of the past.

"People are surrounding themselves with more and more devices," observes Jürgen Boyny, responsible for global consumer electronics at GfK, one of the world's largest market research companies. He estimates that electronics manufacturers will ship around 212 million LCD (liquid crystal display) flatscreen TVs worldwide in 2011. "In CRT times, it was 180 million devices per year at a pinch." While consumers once had to save up around three monthly salaries, a fraction of that will now bring the world of multimedia into your living room.

Behind this drop in prices lies cheap production in the Far East. Right from the start, the display business has been synonymous with the Asian market, beginning with Japanese giants like Sony, Sharp and Toshiba. In time, companies such as AUO in Taiwan and LG and Samsung in South Korea moved into pole position. But new players in China have long been gearing up for global leadership. Linde was quick to spot the potential of the burgeoning Chinese market and invested early on in a supply infrastructure for flatscreen producers, who need various specialty and electronic gases. Andreas Weisheit, Head of Market Development at Linde Electronics in Shanghai, explains: "No matter whether you're looking at sensitive touchscreens for iPhones, high-contrast, organic LED notebook displays or 3D TVs, you always need a high-performance transistor." The transistor effectively switches the liquid crystals covering it on and off. In simplified terms, it consists of a glass plate that is coated with alternate layers of silicon and silicon nitride in a reactor (by vapour deposition). For this process, Linde delivers ultra-pure gases such as silane, which is used to generate silicon. Today, over half of Chinese manufacturers rely on process gases from Linde. The use of high-tech gases in transistor products is essential to ensure high-performance

REACTOR CLEANING: INCREASED EFFICIENCY THANKS TO FLUORINE



100% corresponds to F_2 (fluorine); NF_3 = nitrogen trifluoride, SF_6 = sulphur hexafluoride

Image overload: *High-purity specialty gases from Linde are used for high-performance displays and environmentally sound production processes.*

High-tech series production: *Most displays are produced in Asia – such as here at the production facilities of Chinese manufacturer BOE.*

displays, combining faster-moving electrons with precise pixel control. This improves screen resolution, generates more vibrant images and enables new effects such as 3D television.

Climate-neutral fluorine for flatscreen displays

Increasingly, however, customers are looking for more than just crisp images. "The discerning consumer is attaching more and more importance to energy efficiency. Today's buyer wants electronic goods and devices built on production chains that are as green as possible," reports Weisheit. Yet conventional LCD manufacturing methods are problematic from an environmental point of view. They usually release large amounts of substances that contribute to climate change. The cleaning processes in display production are a case in point: since the silicon and silicon nitride cling to the reactor's walls during vaporisation, manufacturers have been using nitrogen trifluoride gas to remove the deposits and clean the process chambers for the last 15 years. But this is the ultimate greenhouse gas – "17,200 times more harmful than carbon dioxide," according to Weisheit. That is why Linde is increasingly relying on climate-neutral fluorine for reactor cleaning. Thanks to years of experience and proven, patented technology, Linde can draw on in-depth knowledge of this halogen element. Alongside environmental benefits, its use also makes good economic sense. Instead of having it delivered in high-pressure containers, as with nitrogen trifluoride, fluorine can be produced in generators at the customer's site – and the costs are around a fifth lower. Furthermore, while inactive components in nitrogen trifluoride slow down the cleaning process, the active fluorine gas works up to 50 percent faster.

The more eco-friendly solutions from Linde are already in everyday use. "A major Korean customer was the first to switch to fluorine," reports Weisheit – and significantly increased the plant's production capacity by doing so. That may well set the tone for the entire sector: "We can manage the conversion from start to finish. And the customer usually starts seeing returns from the changeover within less than half a year," Weisheit concludes.

LINK:
www.gfkrt.com

↱ Image source: Getty Images, BOE Technology Group
↳ Author: Katharina Becker

Aluminium recycling with flameless combustion

MAKING OLD METAL SHINE LIKE NEW

For many years now, aluminium has been successfully recycled on an industrial scale. The scrap metal is simply melted and used to make new products such as car bodies. Although recycling conserves natural resources, standard combustion processes offer room for improvement. Special burners and gas technologies from Linde raise energy efficiency levels and cut costs. They also significantly reduce harmful emissions.

← Author: Tim Schröder
→ Image source: International Aluminium Institute

Aluminium is a key part of everyday life, as common as the food we eat. We live in houses with aluminium window frames, for example, and drive cars with lighter aluminium bodies. We even wrap our sandwiches in it. Yet aluminium is a precious commodity, complex and expensive to manufacture. It is obtained from bauxite, an ore that is extracted from the earth in large mines, primarily in South America, Australia and Africa. Huge bulk carriers then transport it across the sea to industrialised countries, where it is heated to temperatures of up to 1,300 degrees Celsius in aluminium smelters. Once melted, it is processed to aluminium oxide using special chemicals. This process consumes an enormous amount of energy. Around five tonnes of bauxite are required to produce one tonne of aluminium.

Recycling has therefore been a valuable option for aluminium manufacturers for a long time. Unlike plastics, recycling aluminium does not impact on quality. The recycled material is just as good as new aluminium. It can be remelted and used for new products any number of times, turning cans, for example, into engine blocks. In 2009, 37 million tonnes of new, or primary, aluminium were manufactured worldwide. Almost 13 million tonnes were recycled. "There is room to raise the recycling quota significantly," says Thomas Niehoff, Head of Industry Segment Non-Ferrous Metals and Mining in Linde's Gases Division. Recycling is not just about saving resources. It also saves huge amounts of energy. It takes almost 13,000 kilowatt hours to produce one tonne of primary aluminium. This falls to just 1,500 kilowatt hours for one tonne of recycled aluminium – a drop of almost ninety percent. Yet even this figure can be significantly improved. Which could have a positive impact on price since up to 40 percent of the price of this much sought-after metal is attributable to energy costs.

Experts expect annual demand for aluminium to rise to 53 million tonnes by 2015. Recycling is the best way to meet this demand without overly depleting natural resources. Technical solutions for enhanced aluminium recycling have therefore been one of Linde's core competencies for some time now. The Group's engineers have a wealth of experience in making combustion and melting processes more efficient and environmentally friendly. "Even in the most established facilities, it is still possible to tease out more efficiency," explains Niehoff. "And not just in terms of energy consumption. Emission levels can also be brought down."

Scrap aluminium is heated and remelted in large smelting furnaces, powered by natural gas. Earlier methods used air from the surrounding atmosphere for combustion. This was inefficient, however. Air comprises over 70 percent nitrogen, which means that a

95 % less energy is required to produce secondary aluminium than that needed for primary aluminium.

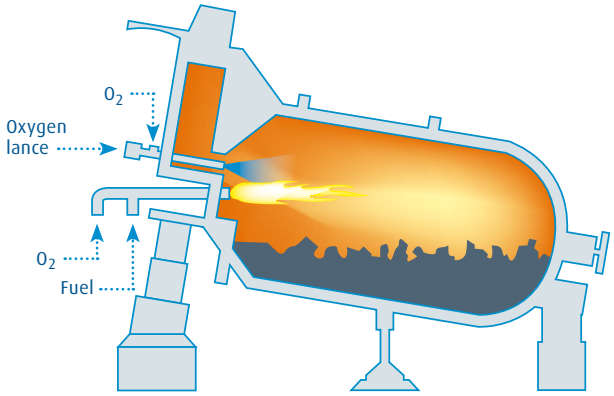
75 % of all aluminium ever made is still in use today and has been recycled numerous times.

1 kg of aluminium in a car creates a more lightweight design, thus reducing CO_2 emissions by 20 kg during the car's lifecycle.

New lease of life for scrap aluminium: *Scrap lightweight metal can be recycled into a premium product.*

SMART BURNER TECHNOLOGY

Raising furnace efficiency: *WASTOX® combustion process lances feed additional oxygen into the furnace to turn contaminants into valuable fuel – saving energy and reducing flue gases.*



Recycling machine: *The universal rotary tiltable furnace (URTF) processes contaminated scrap aluminium in particularly fast throughput cycles. Equipping URTF furnaces with WASTOX® technology optimises energy efficiency.*

large amount of energy is wasted on heating the nitrogen ballast, only for it to be discharged into the air as flue gas. As a result, this method was replaced with oxy-fuel combustion some years ago. Linde engineers were at the forefront of this new technology, which uses pure oxygen instead of air in smelting furnaces. It reduces flue gas volumes drastically and thus also the amount of wasted energy. Oxy-fuel enables manufacturers to produce one tonne of recycled aluminium with just 500 kilowatt hours.

"However, the shift to our oxy-fuel process brought its own challenges," continues Niehoff. This is because aluminium is very reactive with oxygen. During combustion, the aluminium and oxygen react to create aluminium oxide. This white powder, known as dross, is an unwanted and unused by-product that accumulates in furnaces, reducing the aluminium melt. Oxygen and aluminium react particularly strongly in hotter parts of a furnace. "Many manufacturers were appalled at the prospect of using oxygen in aluminium smelting," recalls Niehoff. This is because conventional oxy-fuel furnaces use a light, hot, glaring oxygen flame, which, like a flamethrower, heats the furnace unevenly. This creates hot spots, where dross concentrates. It was a problem that Niehoff and his team were best placed to solve. Their idea was to distribute heat more evenly by enlarging the flame. To achieve this, the fuels have to be fed rapidly into the furnace, causing the furnace gases to circulate so strongly that the flame expands. "Increasing the size of the flame prevents hot spots from forming," explains Niehoff. In contrast to the original hot glowing jet, the enlarged flame is hardly visible, which is why the process is also known as flameless combustion.

ALUMINIUM DEMAND IS SET TO RISE TO 53 MILLION TONNES PER YEAR BY 2015.

The new flame technology is now being successfully deployed in several aluminium smelters. One facility in Sweden has seen melting performance increase by ten percent compared with the conventional oxy-fuel process as a result of homogeneous heat distribution. Energy consumption also fell by ten percent. And dross formation dropped dramatically. The flame can be controlled more easily thanks to the flue gas stream. "Every aluminium plant and every furnace is different. Which is why we offer individual solutions and fine-tune the combustion process to exact customer requirements," reports Niehoff. "Our service doesn't stop on delivery."

One of the main reasons for this heterogeneous process landscape is that different aluminium producers handle very different kinds of secondary aluminium. A medium-sized smelting furnace can melt around 30 tonnes of aluminium. The furnace is gradually filled in several batches and the scrap aluminium is added to the melt. Some manufacturers use old engine blocks; others use empty beer cans together with the plastic wrap and labels. Products with short lifespans soon return to

the smelter, whereas an aluminium car body will be on the road for at least ten years. Niehoff recalls a plant that feeds tonnes of shredded drinking cartons into its furnaces. "The cartons are made of a mixture of cardboard, plastic and wafer-thin aluminium foil," explains Niehoff. "Recovering aluminium is still a viable option, even with this small ratio of metal in the feedstock."

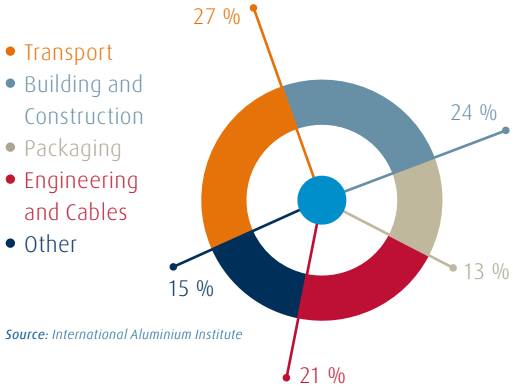
Exact oxygen dosing for aluminium furnaces

However, Niehoff was also concerned about the plastic, paint and engine oil residues released during secondary melting. Recent changes to emissions regulations reinforced the need for tighter control. Hydrocarbons are the main substances released when residue vaporises in molten aluminium baths at temperatures of 750 degrees Celsius and higher. Niehoff and his colleagues therefore developed a technology that burns off rising substances while they are still in the furnace. The engineers designed a lance that extends into the furnace from above and feeds in oxygen for additional combustion. Loading fresh scrap into a furnace triggers particularly intensive reactions, with large amounts of hydrocarbons released in just a few minutes. The lance can be ignited at this point to burn off these unwanted substances. "This process turns hydrocarbons into fuel, helping to heat the furnace and reduce natural gas consumption," says Niehoff. When the lance ignites and destroys the hydrocarbons, it can relieve the burner – accounting for up to 15 percent of combustion performance. This intelligent secondary combustion technology is called WASTOX®. It kills two birds with one stone by using emissions to heat the furnace while at the same time reducing the amount of hydrocarbons in the flue gas, according to Niehoff. "Compared with conventional oxy-fuel processes, WASTOX® results in 10 to 50 times lower volumes of hydrocarbons," says Niehoff.

To ensure that the WASTOX® lance can be activated and deactivated at the right time, Linde engineers install sensors that continually measure hydrocarbon levels in the furnace. As always, every solution has to be tailored to individual plant requirements. In some plants, technicians install laser scanners; in others, they use optical sensors. The gases are usually measured by a light beam which changes when it encounters different gases, as these absorb different wavelengths. The pattern of light absorption delivers a detailed profile of the various gases in the furnace. In addition, the light signal's strength can be used to determine the concentration of each gas, thus enabling the lance to be controlled with a high degree of precision. One Linde customer uses optoacoustic sensors, which also monitor the sound of the gas flame to detect whether hydrocarbons are rising from the melt. "These kinds of sensors are particularly challenging," explains Niehoff, "as the aluminium recycling environment is extremely dirty and extremely hot." Sensors therefore have to withstand steam, heat and sprays of molten metal. The combustion process is still primarily controlled by hand and so the Linde engineer and his colleagues are currently focusing on further automating the WASTOX® technology. In the near future, the sensor, burner and lance will be working on auto-pilot.

Linde engineers have matured the processes sufficiently, however, to enable resource-friendly aluminium recycling. But this doesn't mean that Niehoff's work is over. "Oxy-fuel is an established process. However, there is still need for further optimisation in many regions, above all in Asia, but also in Eastern Europe and the US," continues the metal expert. "Many of the plants in these areas can be retrofitted with flameless combustion and WASTOX® technologies." Niehoff is in no doubt that aluminium recycling is growing in importance. After all, as demand for primary aluminium rises, so too will the amount of secondary aluminium. "And recycling is the key to sustainability," he concludes.

GLOBAL MARKETS FOR ALUMINIUM PRODUCTS



Source: International Aluminium Institute

A bright future: *Recycling aluminium does not impact on quality. The reused metal can be used across a wide range of industries.*

LINK:
www.world-aluminium.org

Energy-efficient gas management for aquaculture

FIT FISH

Fish farming is increasingly taking place on shore, using large inland tanks and pools. This conserves natural fish stocks and protects marine ecosystems. Linde engineers have developed a new, highly energy-efficient oxygenation system to ensure that salmon and other popular fish can thrive in the tank.

Fish is good for the heart – Eskimos suffer from significantly fewer heart attacks than those of us with less salmon or cod in our diets. The flesh of these sea-dwellers is rich in 'good' fats or omega-3 fatty acids, which also support the brain and immune system. So demand for saltwater fish is higher than ever before. Whether as sushi, fried or in a salad or pie, global fish consumption has almost doubled over the last fifty years – and is still on the rise. Since natural reserves are no longer sufficient to meet this huge demand, aquaculture is also booming. Over the last decade, the proportion of farmed fish has shot up from around 30 percent to around half of total consumption, while catch figures have remained almost unchanged.

Linde engineers have now developed a powerful yet energy-saving solution for inland aquaculture: the SOLVOX® OxyStream system, which mixes pure oxygen with water in the breeding tanks. A continuous stream ensures particularly even distribution of this life-sustaining gas – even in tanks the size of swimming pools. "Many customers are already enjoying the benefits of our system in Norway," reports Stefan Dullstein, aquaculture expert at Linde. And global market leader Marine Harvest is among them. Since the new technology uses significantly less energy than conventional systems, it also places a previously elusive goal within reach – full-lifecycle on-shore breeding of fish intended for consumption. Up until now, this was deemed unaffordable.

AROUND 50 PERCENT OF FISH FOR CONSUMPTION COMES FROM FISH FARMS.

At present, however, fish still need to see the sea. Salmon, for instance, are cultivated on land for a matter of months, until their weight reaches between 80 and 100 grams. At this point, they are moved to netted marine enclosures. The long-term goal is to banish all fish farming from our oceans. "In the short term, major fish farmers are aiming to rear their stock to body weights of up to a kilo on land and only then introduce them to marine aquacultures," explains Dullstein. "The move towards on-shore fish farming is progressing by leaps and bounds." And there are good reasons for this. Aquaculture using concrete or steel tanks protects marine ecosystems, since wastewater contaminated with excrement and leftover food can simply be reconditioned. "It also prevents diseases being brought in from outside," adds the Linde expert, "and even if, say, a virus does break out, it is much easier to treat the fish properly within a closed environment." Inland aquaculture also avoids farmed fish escaping from the enclosures and mixing with natural stock – a risk when hungry seals damage the netting, for instance.

Linde's SOLVOX® OxyStream process is helping to reduce the environmental impact of on-shore breeding. The oxgyen delivery system resembles a submarine periscope – a curved tube with a diameter of between 20 and 60 centimetres. This is made of black plastic with a line of neat holes extending down into the tank. Water flows into the tank through these holes, enriched with a microstream of oxygen, even finer than champagne bubbles. This patent-pending technology uses a Venturi injector – a pipe with a constricted section in the middle, thus restricting the flow space. This speeds up the water and mixes it more effectively with the oxygen, injected at precisely this point. Without going into detail, Linde engineers reveal that there are further technical innovations inside the tube to ensure a perfect mix. "The really innovative feature of this system is the combined design. SOLVOX® OxyStream not only injects the oxygen into the tank, it also distributes it evenly," highlights Kenneth Glomset from Linde's Gases Division, responsible for developing the technology. "And this standalone unit can be easily installed in a fish tank." Previously, fish farmers needed two separate systems and an external pipe system for oxygenation. "Thanks to its compact design and effective mixing of gas and water, SOLVOX® OxyStream can work at very low pressures in the 50 to 200 millibar range," adds Glomset. That is approximately one order of magnitude smaller than the operating pressure of common systems.

The blue revolution: *The oceans can no longer meet human demand for fish. High-tech tanks with optimised oxygen delivery systems (right) can be used to rear fish for consumption on shore.*

A new home for schools of fish: *Moving aquaculture to land takes the strain off marine ecology. It also prevents cross-breeding between farmed and natural stocks.*

← Author: Andrea Hoferichter
↱ Image source: Linde AG

The ideal oxygen concentration for fish is around 85 percent. This value is based on the oxygen content of water saturated with air. "As a rule of thumb, this 85 percent translates into around 8.5 milligrams of oxygen per litre of water. The exact amount depends on various factors, including the temperature," explains Glomset. At values below 85 percent, the fish farm stock lose their appetite and become more susceptible to disease. Oxygen concentrations lower than 60 percent are indeed life-threatening for fish such as salmon and cod. Linde's new technology ensures optimum breeding conditions in the tanks. The strong stream also helps build muscle, helping to keep the fish fit: "They have to swim against the current, which keeps them in good condition," Glomset explains. In addition, the oxygen bubbles drive other gases such as argon, carbon dioxide and – most importantly – nitrogen out of the water. Even slight oversaturation with nitrogen can impede the growth of the fish and – in the worst case scenario – increase mortality. Several methods, ranging from vacuum technology through to sprinkler systems, have previously been deployed to keep the oxygen concentration at natural levels. Linde's SOLVOX® OxyStream technology now reduces the need for these systems with their energy-intensive pumps.

Salmon breeders, in particular, stand to benefit from SOLVOX® OxyStream on another count: "This new system enables an uninterrupted transition from fresh water to salt water – and also makes it affordable," explains Glomset. Wild salmon spend their first years of life in rivers – i.e. in fresh water conditions – before migrating to the sea. Previously, separate tanks have been used for the two water types, each requiring its own oxygen supply. "The problem with oxygenating fresh water is that the small gas bubbles rapidly merge into bigger ones, hindering absorption," explains the Linde specialist. This effect can be prevented by increasing the gas pressure. This ensures that the oxygen is completely dissolved as soon as it is injected, so bubbles don't even get a chance to form. "Other technologies can also be used to manage the formation of bubbles," acknowledges Glomset, "but the energy-saving SOLVOX® OxyStream system is the only one that also manages costs." This is a key benefit of the new solution, since alongside feed, energy consumption is the biggest cost factor in running on-shore fish farms.

This new delivery system is adapted to meet individual needs. As the Linde engineer emphasises: "No two facilities are the same. The technology always needs to be adapted to conditions at the individual farm." The stream speeds are optimised according to tank size, fish type and stocking density. Around 200 systems are currently in the planning stages – the lion's share for Norway. As Glomset is pleased to report: "The demand is definitely there." But the Linde experts have their sights set firmly on other markets too, especially in Chile, Great Britain and Northern Ireland, Canada and the US. After all, as fish consumption continues to rise around the world, so too will the need for on-shore farming. And this – in turn – will drive demand for effective oxygen delivery systems to sustain the fish.

LINK:
www.feap.info

High-tech chemicals plant:
Linear alpha olefins are produced at the United Olefins Complex in Al-Jubail, Saudi Arabia. Linde and SABIC jointly developed the enabling process technology, alpha-SABLIN®.

Innovative technology for polymer components

PLASTIC BUILDING BLOCKS TO MEASURE

Modern life would not be possible without plastics. They create robust yet lightweight cars, hygienic food packaging and a giant cable network that connects the world. To tailor the material properties of polyethylene to individual applications, industrial producers need special molecule components called linear alpha olefins (LAO). In collaboration with chemical company SABIC, Linde engineers have developed and brought to market a new, highly efficient technology for manufacturing LAOs in what has turned out to be an exemplary development reference project.

Image source: Linde AG
Author: Caroline Zörlein

We live in a plastic world. Bright and colourful plastics are all around us – in our shoe soles, computers, shopping bags and toothbrushes. In the space of just one hundred years, artificial polymers have conquered the world, and are now the most used material of our time. And global production continues to increase at an enormous rate. In the last ten years alone, manufacturers have produced almost as much plastic as in the entire last century. The plastics industry may be relatively young, but it has already produced a huge variety of products. Polyethylene (PE) is a real all-rounder. It is used across a huge range of applications, from flexible film for carrier bags, food packaging and coatings through drinks bottles, interior and exterior automobile fittings, household appliances and children's toys to water pipes and cable insulation.

PRECISION CONTROL OVER POLYETHYLENE PROPERTIES.

From a chemical standpoint, this type of plastic has a very simple structure, comprising extremely long hydrocarbon chains which can be interconnected. The material's properties are directly linked to the strength and characteristics of these PE networks. Polyethylene manufacturers have to use small chemical components known as co-monomers to create the bonds. "The industry uses linear alpha olefins, or LAOs, for this," explains Heinz Bölt, Manager Commercialisation & Licensing at Linde Engineering Division's R & D department. "Adding LAO molecules enables scientists to individually adapt the physical properties of polyethylene and create completely different product characteristics," continues the engineer. Linde teamed up with experts from chemical company SABIC (Saudi Arabian Basic Industries Corporation) to develop a new technology known as the alpha-SABLIN® process for producing co-monomers, and together they built the first commercial-scale LAO plant. This facility now produces around 150,000 tonnes of LAO per year for SABIC subsidiary Jubail United Petrochemical Company (UNITED) in Saudi Arabia.

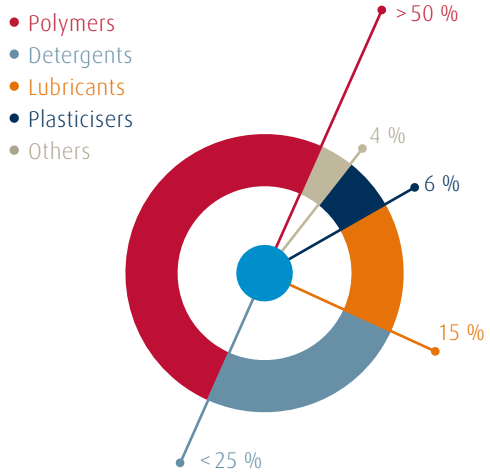
But it was a long process from the initial idea to commercial maturity. The first challenge was the lack of licensable technology in the market for manufacturing these chemical components. Linde therefore focused on developing its own technology for LAO production. The team, headed by Heinz Bölt and chemist Dr Peter M. Fritz, hit upon the basic idea behind the process during a visit to the Institute of Chemical Physics (ICP) in the Russian town of Chernogolovka. "Scientists at the institute had a lot of experience in the oligomerisation of ethylene, which is the key chemical process in LAO production," explains Bölt. "There had also been a pilot plant in Russia, but this was no longer available," recalls the Linde expert. However, to properly assess product quality, major plastics manufacturers need to run tonne-scale tests. "A new pilot plant on this scale costs several million euros. It also makes most sense to operate a facility like this at a petrochemical site," adds Bölt.

The company therefore needed a strategic partner – and found one in the chemical company SABIC, which also had one big advantage in its favour – optimum access to the process feedstock, gaseous ethylene. "Companies in the Middle East have established a stable, leading global platform for basic petrochemistry," explains Dr Wolfgang Falter, chemical industry expert at AlixPartners. "They are now building on this foundation to move into the refining stages. The chemical industry has strong roots in the Middle East, and we can expect to see many more dynamic offshoots in this region in the future," he continues. As a result, industrial production can now take place directly above the oil well. "Finding that first customer for a commercial plant is extremely difficult if you do not have any technical references for the new technology," explains Bölt. "At SABIC, we were able to locate the pilot plant within the SABIC Group and test product quality on site."

Once Linde had acquired the patents and rights for the basics of their LAO process from the ICP in Russia, the engineers and SABIC experts continued to fine-tune the technology concept and plant design. The greatest challenge facing engineers and chemists was ensuring that ethylene molecules did not spontaneously form extremely long chains – an unwanted side reaction known as polymer formation. The aim of an LAO reaction is to produce bonds between just a few carbon atoms, resulting in short hydrocarbon chains of between 4 and 30 or so carbon atoms. The catalyst that triggers the chemical reaction is therefore one of the core components of the alpha-SABLIN® technology. "Two catalyst components are involved in the process: one zirconium compound and one aluminium compound," explains Bölt. This is a very selective system that produces only very few unwanted long alpha olefin chains (over 30 carbon atoms). In addition, the product distribution can be easily varied by changing the ratio of the two catalyst components. A high aluminium/zirconium compound ratio, for example, results in a product mix comprising over 80 percent 1-butene, 1-hexene and 1-octene – in other words, alpha olefins with four, six or eight carbon atoms.

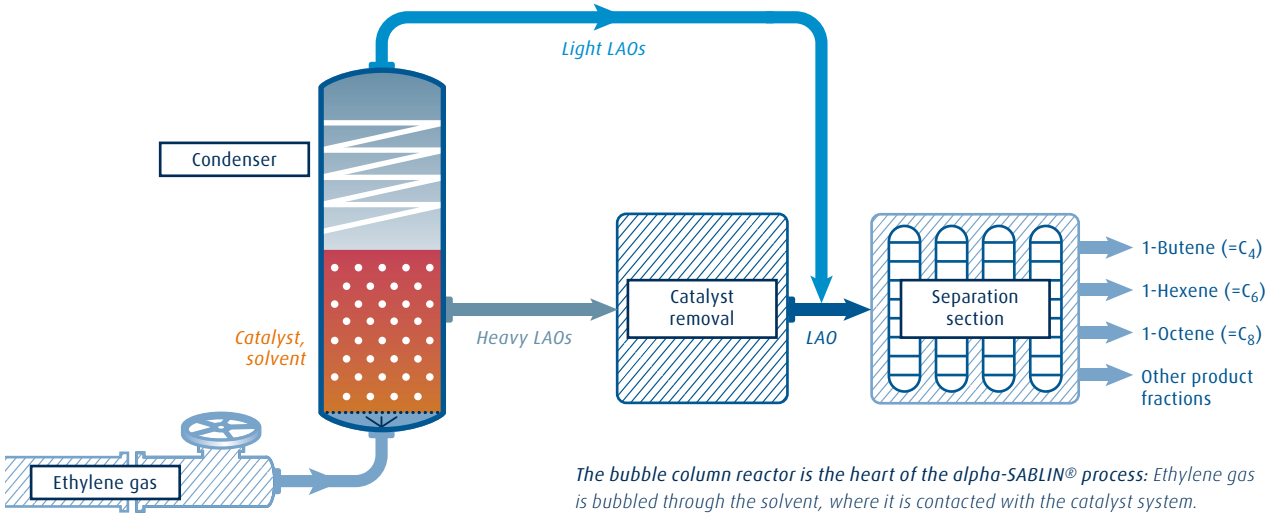
However, a sophisticated reactor concept is equally important. "Reaction heat is a particularly important issue," says Bölt. The LAOs are now produced commercially in a bubble column reactor that is

MARKET SHARES OF LINEAR ALPHA OLEFINS



CONTROLLED LINKING OF HYDROCARBONS

Small ethylene gas bubbles pass through the reaction solution, where ethylene is catalysed into linear alpha olefins (LAO). The heavy, long-chain fractions are recovered with the dissolved catalyst, which is deactivated and removed. The light and heavy LAO compounds are then separated into the desired products in downstream separation steps.



The bubble column reactor is the heart of the alpha-SABLIN® process: *Ethylene gas is bubbled through the solvent, where it is contacted with the catalyst system.*

Polymer pipelines: *Ethylene gas is converted into the widely used PE plastic at the polyethylene plant in Al Jubail, Saudi Arabia (right). This is then used to make plastic bottles (left) as well as a wide range of films, fibres, cables and moulded parts.*

over ten metres high and has a diameter of several metres. A special distribution system feeds millimetre-sized ethylene gas bubbles into the reaction-liquid in the columns. The catalyst system enables the growth of the small chemical components into longer molecule chains. This creates a lot of heat, which has to be removed from the reactor. Conventional concepts such as cooling loops or heat exchangers within the reaction mass were not viable options. "These cooling systems create cold surfaces where unwanted polymers could precipitate, and this was something we wanted to prevent," continues Bölt.

Innovative reactor concept saves energy

And so the Linde and SABIC experts had to dig deep into their process engineering expertise. By allowing excess volumes of cold ethylene gas to bubble through the column reactor, they were able to simultaneously use the gas stream as an internal cooling system. "The ethylene is fed in at ambient temperature. Inside the reactor it is heated – for example, to 80 degrees Celsius – and thus removes sufficient heat from the reaction mass. Finely dispersed gas bubbles also ensure that the temperature is evenly distributed within the reactor," explains the Linde engineer. This elegant solution is an effective way of preventing polymers or long-chain LAOs precipitating on cold surfaces in the reaction area. It also eliminates hot spots, which reduce the quality of the LAOs. However, this process does require relatively large amounts of gas as the majority of the ethylene bubbles are used for cooling the reactor.

Process recycles play a key role when lab-tested technology is scaled up to industrial production. "Processing and recirculating the ethylene gas and solvent for the reaction are just two areas where our process engineering expertise is crucial. The entire system can only operate reliably and cost-effectively if all plant components dovetail to perfection," says Bölt. The alpha-SABLIN® process has the added benefit of only requiring "mild" reaction conditions – in other words, a pressure between 20 and 30 bar and temperatures between 60 and 100 degrees Celsius. All of which saves energy and investment costs. By comparison, other LAO production processes, in addition to not being licensable, require a pressure of around 200 bar and temperatures of up to 300 degrees Celsius.

The LAO mixture is continuously withdrawn from the reactor, split into different fractions and purified, starting with the shorter hydrocarbon chains such as 1-butene and 1-hexene and progressing on to the heavy alpha olefins. The short-chain molecule components are of particular interest to polyethylene manufacturers. And these are also channelled directly into SABIC's polyethylene plants. The alpha-SABLIN® process is an outstanding example of a successful development reference project. It has seen a technology development starting from laboratory trials through pilot plant testing to successful marketing and deployment of a commercial, industrial-scale technology and plant.

"In recent years, focus has shifted to processes that enable the selective production of just one type of short-chain LAO, for example, only chains with six or eight carbon atoms," explains Bölt. The engineers have therefore teamed up with SABIC again and are already working on the next generation of LAO production processes, known as LAO on-purpose technology. Together with the Leibniz Institute for Catalysis at the University of Rostock, Linde and SABIC experts want to develop a new catalyst system to be utilised in the proven reactor concept and thus an even more effective way of providing the plastics industry with high-quality chemical components.

LINK:
www.plasticseurope.org

Creating antibacterial surfaces with cold spray technology

SUPERSONIC FIGHT AGAINST BACTERIA

Each year, thousands of patients pick up dangerous infections in hospitals. Door handles and light switches are particularly common sources of bacterial contamination. A new method called cold spraying can now be used to coat these surfaces with a protective layer of titanium dioxide ceramic – a robust substance with effective antibacterial properties. Linde engineers are working with materials researchers at the Helmut-Schmidt University in Hamburg to advance these technologies.

↑ *Author: Tim Schröder*
↓ Image source: Danny Gys/Reporters/SPL/Agentur Focus

Bacteria are everywhere. Around ten billion of these single-celled organisms can be found in our bodies and on the surface of our skin alone. Many microbes such as intestinal bacteria are vital to our health and boost our immune system. Yet these microscopic organisms can also be a threat to our health, particularly if the body is already in a weak state – as is usually the case with patients in hospitals. Experts estimate that around 500,000 people in Germany alone are infected each year with bacteria found in hospitals. Most patients recover, albeit after a longer hospital stay than initially planned. However, infections caused by multi-resistant bacteria are extremely dangerous. "These pathogens are resistant to many conventional antibiotics. The resulting infections can therefore be fatal," explains Peter Heinrich from Linde's Gases Division.

HOSPITALS: DOOR HANDLES ARE A BACTERIA HOTSPOT.

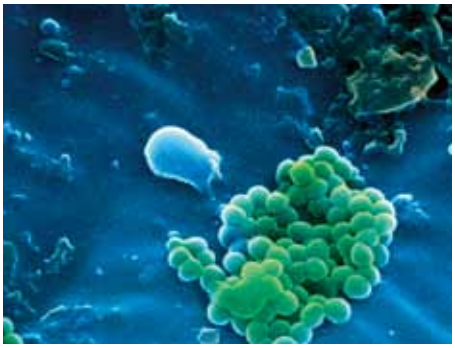
Heinrich is working with scientists to develop ways of fighting these bacteria in hospitals. "The most effective approach is to target microbe hotspots such as light switches, door handles and taps," he continues. These bacteria breeding grounds are of course regularly disinfected by cleaning staff. Between cleaning rounds, however, they are recontaminated by medical staff, patients and visitors, quickly cancelling out the protective effect of disinfectants.

Heinrich and his colleague Werner Krömmer have been working with materials researchers at the Helmut-Schmidt University (HSU) in Hamburg to develop a new self-disinfecting coating. This new ceramic surface "is completely harmless for humans but almost entirely lethal for bacteria," explains Jan-Oliver Kliemann, a physicist in the HSU task force. The new protective coating comprises titanium dioxide, a substance that has long been used in industry, for example, as a white pigment in toothpaste and paint. However, titanium dioxide is capable of much more than adding pigment thanks to a process known as photocatalysis. This chemical reaction is triggered by light and activates electrons that attack molecules in the thin bacteria membrane, puncturing the pathogens' vital outer layer.

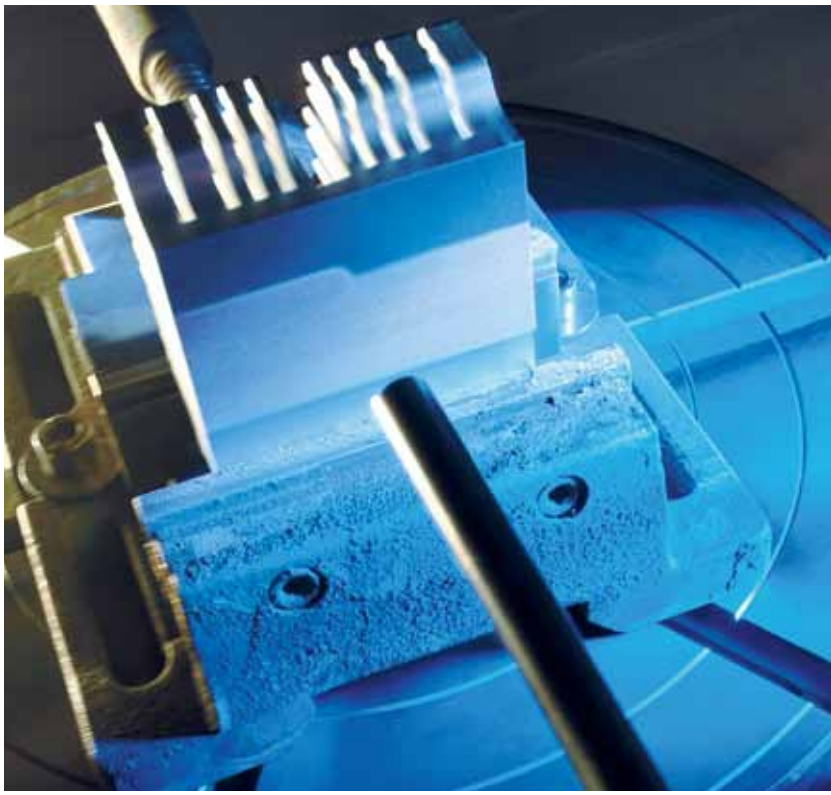
The surfaces experts were faced with the challenge of creating a hard, durable and antibacterial titanium dioxide coating for completely different metals such as aluminium, copper and steel. The researchers turned to a recently established industrial process known

Germ-free zones: *Hygienic conditions in hospitals are crucial to patient health.*

Door handle check: *Werner Krömmer, Peter Heinrich and Prof. Thomas Klassen (from left) check the coating.*



Dangerous bacteria: *Staphylococcus aureus is particularly dangerous for patients in a weak state of health.*



Particles travelling at supersonic speed: *Ceramic particles are blasted onto the material at extremely high speed and fuse with its surface.*

as cold spraying to achieve this. Cold spraying involves shooting a fine metal powder through a nozzle onto a surface at supersonic speeds. When the individual particles hit the surface at such high velocity, they fuse onto it in just a fraction of a second. Researchers at the Helmut-Schmidt University have now found a way of using this technology with ceramic titanium dioxide.

"Over the years, researchers across the globe have tried time and again to apply antibacterial titanium dioxide coatings to different surfaces," says Kliemann. "However, either the end results were not durable enough or their antibacterial properties were not strong enough." This is because previous methods always used conventional thermal spray processes that heat materials to temperatures in excess of 2,000 degrees Celsius. These conditions are too harsh for titanium dioxide. They change the compound, causing it to lose its photocatalytic properties, and therefore its antibacterial effect. By contrast, cold spraying only heats ceramic particles to temperatures of less than 100 degrees Celsius due to the high velocity at which they hit the surface. And titanium dioxide is more than capable of dealing with this heat. "It is of course hot if you compare it with ambient temperatures. But compared to thermal spray procedures, cold spraying is really very moderate," adds Kliemann's colleague Henning Gutzmann.

The Hamburg scientists are keen to point out that Linde's input was instrumental in overcoming the huge technical challenges involved in developing the titanium dioxide coating process. To accelerate ceramic particles to supersonic speeds, large volumes of carrier gas (in this case nitrogen) have to be pumped through conduits in an extremely short space of time. The particles are carried along in the gas stream and blasted against the metal surfaces. The nitrogen is fed through the nozzle at a pressure of 40 bar, 20 times greater than a car's tyre pressure. It reaches speeds of up to 800 metres per second – one and a half times faster than the fastest jet fighter aircraft. In one hour, almost 200 cubic metres of nitrogen – roughly the volume of a swimming pool – race through a nozzle opening of just a few millimetres. "The challenge for us was to develop a pipe and valve system that could handle a gas flow of this intensity," explains Heinrich, a cold spray specialist at Linde.

Teamwork: Light and titanium dioxide destroy germs

Although the nitrogen flows through the pipes at a high pressure of 200 bar, this has to be reduced to an operating pressure of 40 bar. "However, we still wanted to maintain a high flow rate," continues the Linde expert. Reducing pressure while maintaining a high flow rate initially seemed as feasible as squaring the circle. Yet Heinrich and his team designed a pipe system with a special pressure reducer in the shape of a steel pot. It throttles the gas pressure while at the same time allowing the gas to travel at 200 cubic metres per hour. In order to test the process independently, the engineers in Hamburg and at Linde's application centre in Unterschleißheim near Munich built two identical systems. Once the system has been powered up, the noise of the gas pow-

BASIS FOR GROWING BONE CELLS

From tooth to toe: Medical technology has developed implants for the most diverse human functions. These parts need a rough, open-pored surface to enable bone tissue to fuse with the implant. Thermal spraying can be used to coat knee (above) and shoulder (below) joints with suitable surfaces.

der mixture hitting the metal is immense. Which is why the test bed is located in an isolated part of Hamburg's university campus. The small lab houses a network of pipes, valves and apparatus. A heating coil heats the carrier gas to the correct temperature before it is blasted through the nozzle. Ceramic powder from two thermos flask-sized containers is added to the nitrogen as it rushes past. Researchers have to calculate the optimum mix of gas and powder to ensure the coating adheres to surfaces. All parameters have to be perfectly aligned, from pressure through flow rate and temperature down to the shape of the nozzle, which is just a few centimetres long. "The nozzle geometry determines whether the particles follow the ideal trajectory and reach requisite velocity," explains Heinrich. The shape of the nozzle has to be adapted precisely to the carrier gas and the particles. To ensure this is the case, Linde and the university in Hamburg called in the help of aerodynamics expert Horst Richter from Dartmouth College in Hanover, New Hampshire, USA.

The cooperation partners have since optimised the cold spray process for titanium dioxide coating. They have also compared their results with antibacterial surfaces that have been on the market and in use for several years now. Copper surfaces are extremely effective when new. Over time, however, they start to oxidise and lose their antibacterial properties. Silver compounds, which are also used for coating refrigerators, are adversely affected in the long term by aggressive cleaning agents. "Our cold sprayed titanium dioxide surface proved much more durable," summarises Gutzmann. The Hamburg scientists' new process has already been benchmarked against a number of different surfaces in a microbiological lab, including a titanium dioxide coating created using thermal spraying. The photocatalytic reaction was found to be much stronger on the cold spray surface.

The highly effective ceramic coating method developed by HSU and Linde opens up new opportunities for this technology, as cold spraying was previously used almost exclusively for metallic coatings. "This process has been around for almost ten years," explains Thomas Klassen, Professor of Materials Technology at HSU. Coating heat exchangers that cool computers is just one of the many applications. Expensive copper components are usually used to dissipate heat from processors. Now, a copper coating can be sprayed onto aluminium structures, which can then be used as heat sinks. "The copper particles penetrate the otherwise unavoidable oxide layer on the aluminium component, thus enabling heat to be transferred more effectively," says Klassen. Coating aluminium pots and pans with ferrous metal is another common application. With a thin layer of steel, these pots and pans can be used on modern induction cookers.

Today there are around 75 cold spraying facilities worldwide. Linde's expertise has been channelled into almost all of these. Yet it was only by chance that Heinrich and Klassen's predecessor Prof. Heinrich Kreye discovered the process in the 1990s. The principle was inadvertently uncovered by Russian materials scientists, who found that they had unintentionally created an adhesive metal coating on their measuring instruments in a wind tunnel. "The Russian scientists presented their findings at a conference," recalls Heinrich. "It was an extremely interesting concept for us." However, no one could have foreseen just how successful the technology would go on to be – or its potential for antibacterial ceramic coatings. The scientists in Hamburg are currently holding talks with two hospitals. "We soon realised the huge market potential of this technology," explains Kliemann. "And it has certainly generated a great amount of interest, particularly among hospitals and local authorities." The first titanium dioxide-coated door handles and switches are set to be tested in the coming year. Gutzmann and Kliemann have been testing their innovative finish for some time now. They have been using a titanium dioxide-coated handle on their office door for two years. "And it still looks great," concludes Kliemann.

FIGHT AGAINST BACTERIA GOES TO TRIAL IN 2012.

LINK:
www.coldspraying.info

Extracting natural gas from the seabed

FLOATING LNG FACTORY

Huge amounts of natural gas are locked away below the ocean floor. High-tech floating factories are being used to efficiently tap this valuable source of energy. Linde engineers and experts from SBM Offshore are developing ships capable of extracting and liquefying natural gas. This technology has the potential to make even remote off-shore reserves economically viable.

Deep beneath the ocean floor, around 680 kilometres west of the Australian coastal city of Darwin, lies a very special kind of treasure: several natural gas fields in close proximity to each other. In future, these reserves should make a climate-friendly contribution to solving the world's rising energy needs. This is because natural gas mainly comprises methane, and when methane is burnt, it emits 30 percent less CO_2 than crude oil, for instance. For energy experts, this makes natural gas an indispensable ingredient in the energy mix of the future.

Until now, however, remote off-shore gas reserves below the ocean floor have been mostly off limits due to the high cost of extraction. "Laying hundreds of kilometres of pipelines along the ocean bed is extremely expensive," explains Dr Marc Schier, Project Manager at Linde Engineering Division. He and his colleagues are therefore focusing on other technologies. A computer drawing on the wall behind his desk shows exactly what they are working on. It is a poster of a new type of ship or – to be more exact – a floating factory. The special vessel combines a huge tanker with a refinery. LNG-FPSO (Liquefied Natural Gas – Floating Production Storage Offloading) is written along its hull. The ship is designed to extract and liquefy natural gas far out at sea, thus enabling it to be easily transported across the globe. "We want this new technology to open up natural gas reserves in even the most remote ocean regions," says Schier.

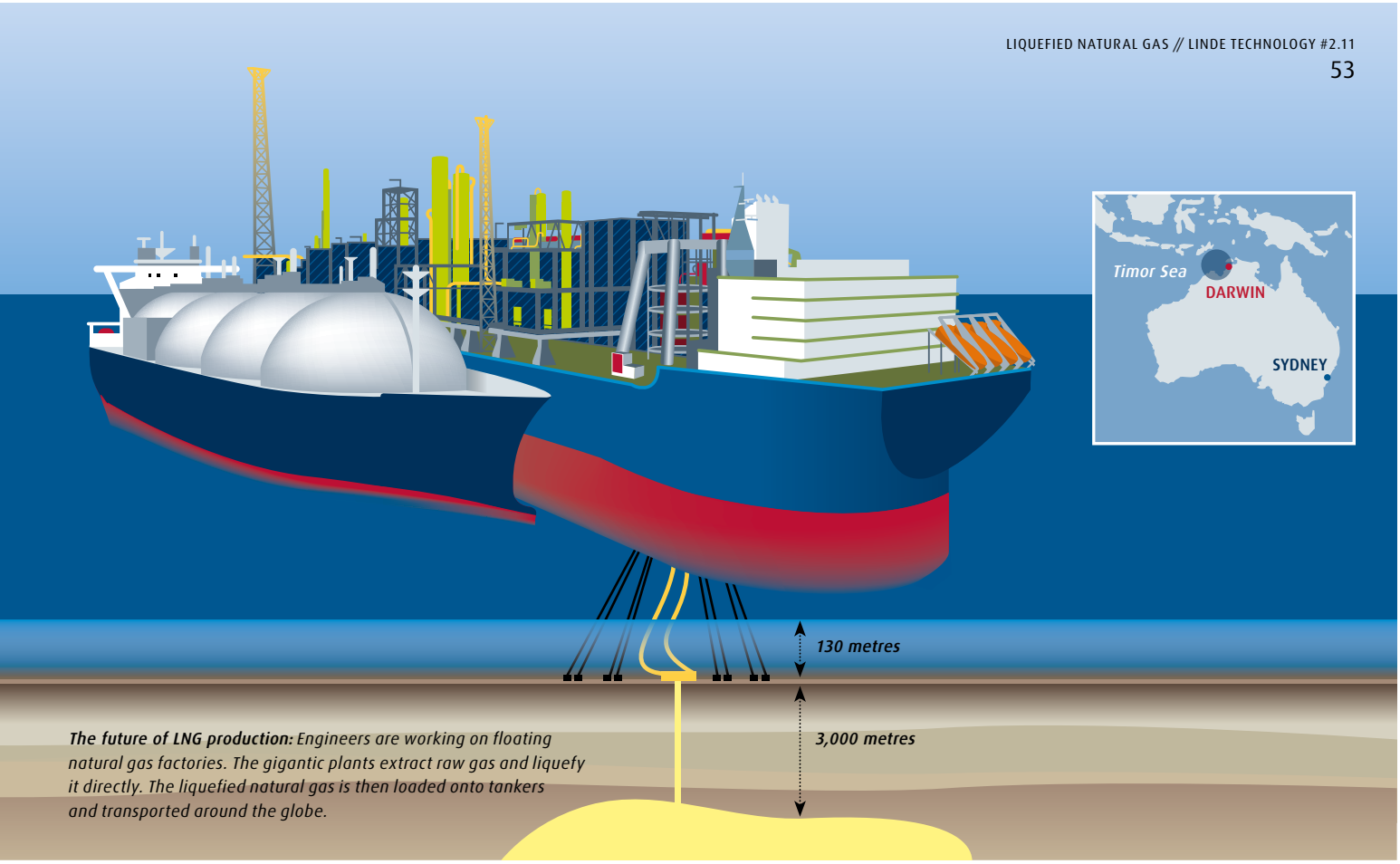
Liquid energy: *LNG carriers transport liquefied natural gas around the globe.*

Linde's engineers are working with off-shore technology experts at the Dutch company SBM Offshore to turn the computer drawing into reality. The high-tech ship will be equipped with all the facilities needed to purify the gas, cool it to the liquefaction temperature of minus 163 degrees Celsius and store it for several days. As you might expect, it is a floating giant. 400 metres long and 65 metres wide, the ship is as large as four football fields laid end to end. "The ship's hull is 36 metres high. The pipe systems and towers extend a further 40 metres above deck. The integrated flare boom is over 100 metres high," concludes Schier.

The ship must also provide accommodation for the crew and control rooms. At standard production capacity, up to 120 people will be living and working on board. Despite its gigantic dimensions, the floating LNG factory is much more compact than land-based liquefaction facilities. "On shore, a plant with comparable capacity would be ten times larger," explains Taco Terpstra, Project Manager at SBM Offshore.

Linde has been collaborating with SBM on off-shore liquefaction facilities since 2007. Linde's experts develop the plants for treatment

Image source: Ria Novosti/SPL/Agentur Focus
Author: Henning Hochrinner



The future of LNG production: *Engineers are working on floating natural gas factories. The gigantic plants extract raw gas and liquefy it directly. The liquefied natural gas is then loaded onto tankers and transported around the globe.*

and liquefaction of the gas while SBM delivers the expertise in ship building, off-shore power generation and LNG offloading. The engineers have already invested over 180,000 hours in the concept. And that effort is paying off. Linde and SBM have signed a cooperation agreement with the companies PTT FLNG Limited and PTTEP Australasia to develop the floating natural gas liquefaction factory. The companies intend to tap three gas fields (Cash/Maple, Oliver and Southern) located in the Timor Sea between Australia and Indonesia. If everything goes to plan, extraction could begin in 2017.

FPSO technology is already being successfully deployed under similar off-shore conditions to extract petroleum gas and crude oil. Petroleum gas, however, only has to be cooled to minus 40 degrees Celsius before it liquefies (LPG). The cooling process for natural gas is much more complex and requires larger facilities. "The superstructures of floating LNG factories weigh up to five times more than those of off-shore oil extraction ships," explains Terpstra. The cooling process also has a decisive impact on the ship design. The engineers chose Linde's LIMUM® process, which is built around coil-wound heat exchangers, and utilises a single mixed refrigerant. "The process is up to 40 percent more efficient than technologies based on nitrogen expander cycles," explains Linde expert Schier. "And this solution requires less space for the capacity we are looking for."

The production facilities and pipelines also have to function safely and reliably at sea. "The ship is constantly moving due to the waves," explains Schier. He and his colleagues adapted the heat exchangers to ensure that they remain fully functional and safe even on the high sea. Lab-based wave simulations have shown that the floating LNG factory could withstand a cyclone of a magnitude expected only once every 10,000 years.

Once it has been cryogenically frozen, the liquefied natural gas is ready to be transported by LNG tanker. "A tanker would then dock at the FPSO unit every eight to ten days and collect up to 140,000 cubic metres of LNG per load," explains Schier. Back on land, the cryogenic cargo will be re-vaporised, fed into an existing natural gas pipeline network and transported to the point of use.

OCEAN-GOING GIANT: FPSO SHIPS ARE 400 METRES LONG.

The floating LNG factory is expected to extract around 2.3 million tonnes of liquefied natural gas per year. This is enough energy to cover the heating, electricity and fuel needs of a city with two million inhabitants. This innovative liquefaction technology therefore has huge potential. Experts estimate that 85 trillion cubic metres of natural gas is locked away under the ocean floor. A huge – as yet untapped – underground treasure that will make a massive contribution to securing our future energy supplies.

LINK:
www.sbmoffshore.com

← Image source: H.-B. Huber/laif
→ Author: Clara Steffens

Ultralight emergency cylinder

SAVING LIVES WITH OXYGEN

Every second counts after a serious accident. First responders need light, portable oxygen cylinders as instant access to this gas is often essential in the fight to save lives. Now, Linde has developed the world's lightest gas cylinder to support emergency medics on the move.

Mountains can be dangerous places – sudden storms, extreme temperatures, avalanches, rockslides, not to mention climbing accidents and the risk of sheer exhaustion. Emergency response teams often rescue mountaineers and skiers by helicopter. Sometimes, paramedics need to be lowered from a helicopter to help the injured – and they are obviously limited in the medical supplies they can carry. A compact, lightweight emergency kit is essential. And oxygen is a must-have in that kit. Medical oxygen – inhaled with a breathing mask – can save the lives of patients who have trouble breathing or who are suffering from low oxygen saturation levels in the blood.

LIGHTWEIGHT O_2 CYLINDER FOR EMERGENCY SERVICES.

Linde Group member BOC Healthcare in Great Britain has developed an oxygen cylinder specially for rescue workers and paramedics. Weighing only 1.55 kg when full, this compact, handy cylinder is the lightest in its class worldwide. It is suited to all kinds of rescue operations – and not just mountain missions. "Emergency medics in cities also prefer a more lightweight solution," says Melike Palalioglu, Project Manager at BOC Healthcare. "Emergency services increasingly rely on fast, agile motorbikes, as they get the medics to the scene of the accident more quickly, especially in areas with limited accessibility. But that means that the emergency kit has to be ultra compact." Portability is just one of the advantages of these new lightweight cylinders. "When we designed these cylinders, ease-of-use was a big priority to ensure the safety of both patients and ambulance crews," continues Palalioglu. BOC Healthcare experts and cylinder specialist Luxfer Gas Cylinders worked closely with medical professionals to fine-tune the cylinder and valve design until they were satisfied that it met all of their performance and handling requirements. The ultralight 101-ZA cylinder has an inner aluminium alloy shell. The innermost wall has a carbon fibre layer. An additional gel-coated finish makes the carbon fibre composite material extremely robust. "This sturdy design lowers the risk of cylinder damage at the scene of an accident," adds Palalioglu. The gas valve features a simple regulator so the first responder can quickly and precisely set the flow rate to individual needs, with a full range of flow settings for both paediatric and adult use. A permanently live contents gauge also shows how much gas is left. "Reduced handling effort leaves the emergency team freer to concentrate on patient care."

BOC Healthcare's inhalable analgesic ENTONOX® – a mixture of nitrous oxide and oxygen – is now also available in the new ultralight cylinders. The inhalation of ENTONOX® offers rapid, effective pain relief without requiring an injection. A major benefit of ENTONOX® is its rapid onset and offset, allowing the patient to recover generally within 30 minutes of ceasing inhalation.

Looking beyond the benefits for emergency and ambulance services, compact gas cylinders are also ideal for homecare patients. "Easier handling is a big plus, particularly for young and elderly patients," explains Mark Habgood, Planning Manager. Robust, reliable and safe – these cylinders for medical gases may be small in size, but they are big on performance across a wide range of applications – and not just for emergency services.

LINK:
www.boclifeline.co.uk

As a world-leading gases and engineering company, Linde offers groundbreaking, sustainable energy solutions for the future. Hydrogen is ideally suited to meet the clean energy needs of tomorrow's world. At the Linde Hydrogen Center near Munich and at other Linde installations around the world, low-emission hydrogen technology is already in daily use. In addition to the practical application of hydrogen energy today, this facility also serves as a development and testing hub for the next generation of hydrogen-related technologies and applications. For further information, visit www.linde.com/hydrogen

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