LINDE TECHNOLOGY

Issue
#1.
12

FEATURED TOPIC: ENERGY UNDERGROUND

CO_2 CAPTURE
Climate-friendly coal power

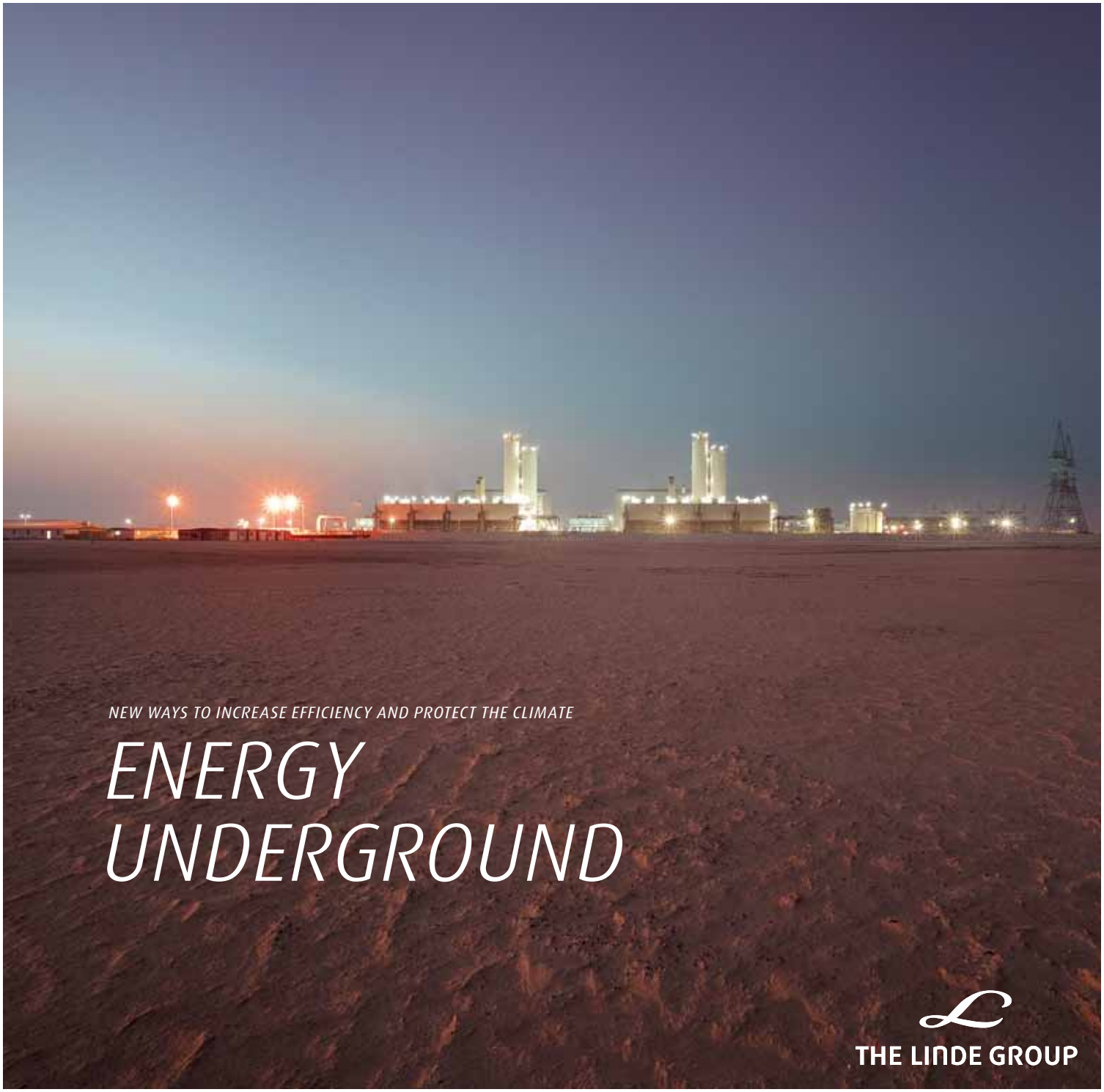
HARNESSING SHALE GAS
Extracting natural resources efficiently

CONVERTING COAL
Production of synthetic natural gas

FORENSIC SCIENCE
Hot on the trail with gas technology

METAL FABRICATION
Distortion-free welding

WATER TREATMENT
Turning salt water into drinking water



NEW WAYS TO INCREASE EFFICIENCY AND PROTECT THE CLIMATE

ENERGY UNDERGROUND

THE LINDE GROUP

#1.
12

Imprint

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Increasing natural gas yield: The Linde-ADNOC joint venture, Elixier, produces 670,000 cubic metres of nitrogen every hour at its two air separators. N_2 is used to increase extraction efficiency at Abu Dhabi.

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EDITORIAL

Dear Readers,

Global demand for energy is spiralling, raw material prices are rising and our climate is suffering the effects of global warming. We need to find a solution that will bring three seemingly conflicting elements – referred to by experts as the energy trilemma – into balance. But how? There is no easy answer to this. What we do know, however, is that innovative, environmentally sound technologies are key to ensuring sustainable, secure and affordable energy supplies.

Yet we must also face the fact that the majority of our energy carriers are currently being sourced from below the earth's surface. And that fossil fuels are set to remain our most important energy source for the foreseeable future – with coal leading the way here. Coal is available in large amounts and used the world over. It is therefore crucial that we focus on further reducing CO_2 emissions from coal-fired power plants.

Linde has the skills and technology needed to capture and store the vast majority of CO_2 emissions from power plant flue gases. By combining this with our flue gas scrubbing processes, we can help significantly lower the climate impact of coal-fired power plants. Converting coal into synthetic natural gas is another promising technology capable of turning black gold into a more environmentally friendly energy source. We are currently collaborating with a number of partners on a gasification reference project in South Korea. In Qatar, the world's largest gas-to-liquids plant converts natural gas to a liquid fuel for more eco-friendly mobility choices.

Projects in the biotech industry show how gases can increase process efficiency. Using pure oxygen in bioreactors, for example, makes them significantly more cost-effective to run. In fact, gases are used across an extremely wide range of industrial applications – including the treatment of desalinated water. Here, CO_2 can be used to adjust the pH value and chemical balance of the water to the exact levels required for drinking water quality.

In this edition of Linde Technology, we again show how our innovative engineering technologies and sophisticated gas management solutions are enhancing a wide range of industrial processes and – just as importantly – making them more sustainable.

I hope you enjoy this edition.

Professor Dr Aldo Belloni
Member of the Executive Board of Linde AG

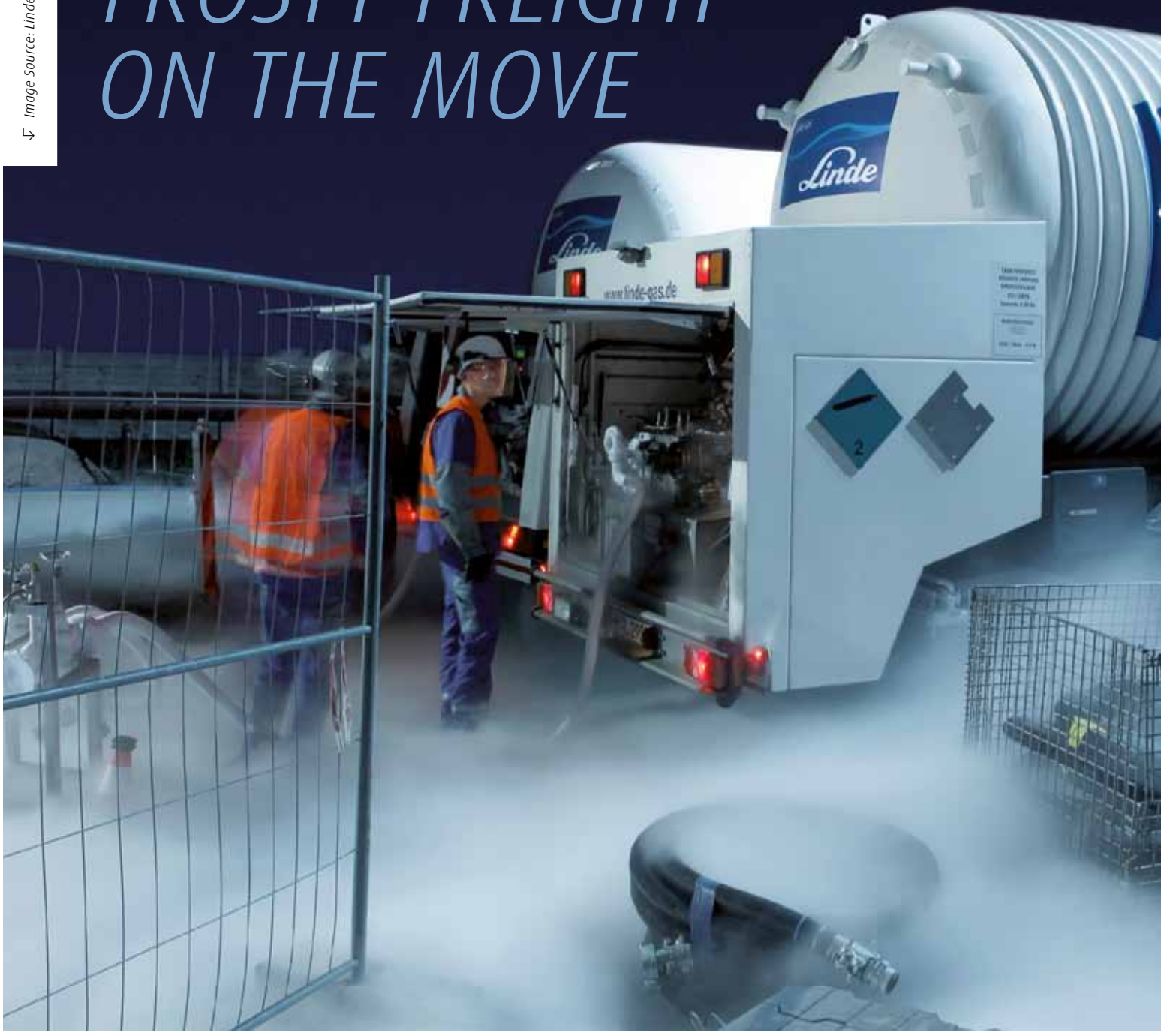
FEATURED TOPIC

Industry will remain dependent on fossil fuels such as coal and natural gas for the foreseeable future. Linde's innovative processes are bringing efficiency and environmental gains to the ways we use the earth's treasures.

Image Source: Linde AG / P. Ohligschläger

Nitrogen for the Nord Stream pipeline

FROSTY FREIGHT ON THE MOVE



Around 100 metres below the Baltic Sea, 1,224 kilometres of steel piping snake along the seabed: the Nord Stream pipeline links the Russian city of Vyborg with the town of Lubmin, near Greifswald, Germany. From the end of 2012, 55 billion cubic metres of natural gas are set to flow through the twin pipeline system each year, securing Europe's long-term energy supplies. But before this can get underway, the pipeline has to be free of any substances that could react with natural gas. Following initial cleaning with water and subsequent drying, one of the final steps is inertisation or nitrogen (N_2) purging. This removes hazardous, reactive substances by flushing the pipelines with gaseous

Temperature extremes: The liquid nitrogen in the tankers is maintained at minus 196 degrees Celsius (left). Damp air condenses to form frost on the ice-cold pipes in August 2011 (bottom). Following delivery (top), the cryogenic cargo is vaporised for the inerting step. Heat exchangers warm the N_2 up to 40 degrees Celsius.

nitrogen. Linde was selected to supply the vast amounts of N_2 required for the project, which will see 14,000 cubic metres of N_2 pumped through the system per hour, non-stop for an entire week. Linde rose to this logistical challenge with over a hundred road tankers, transporting the liquid nitrogen to Lubmin from several air separation plants.

NEWS

GERMANY:

LIQUEFIED NATURAL GAS FOR HAMBURG'S PORT

Linde and the Hamburg Port Authority (HPA) are advancing the possibilities of liquefied natural gas (LNG). The two companies are currently collaborating on an extensive feasibility study into the economic viability of LNG at Hamburg's port. The results could pave the way for the creation of an LNG infrastructure in the port that would enable ships and other vehicles such as trucks to fill up on this environmentally sound fuel. Natural gas generates significantly less emissions than diesel or crude oil. Gas-powered engines, for example, emit almost 90 percent fewer nitrogen oxides and up to 20 percent less carbon dioxide than diesel engines. They produce almost no sulphur dioxide or particulate matter. "Environmental standards are becoming increasingly stringent, and this is fuelling an ongoing rise in demand for LNG solutions in the transport sector," explains Dr Andreas Opfermann, Head of Clean Energy and Innovation Management at Linde. As an engineering and gases specialist, the company has a wealth of experience in using liquefied natural gas as a fuel. Swedish Linde Group member Cryo AB has already equipped 40 ships with LNG technology in Scandinavia. And it is Linde liquefiers and LNG terminals that keep these ocean-going vessels supplied with this extremely promising energy carrier.

GERMANY:

LOOKING TO THE FUTURE WITH ALGAE

At the end of March 2012, over 150 professionals from industry, universities and research institutes came together for the fifth German algae congress (Bundesalgenstammtisch). This year it was held at Linde AG in Pullach for the first time. Core topics included the engineering and design of photo bioreactors used to cultivate algae. Microalgae are seen as a promising source of regenerative raw materials. They produce much higher yields per surface area than land-based plants and are much easier to process. Linde is working with a number of partners, including Sapphire Energy, to develop industrial algae cultivation solutions. Algae not only offer promising opportunities for fuel production, they also have huge potential for the food and animal feed industries.

EUROPE:

STRENGTHENING THE HOMECARE SECTOR

Providing medical care for patients in their own homes is one of the more promising markets of the future. In order to further strengthen its homecare business, Linde has now acquired the Continental-European homecare business from US competitor Air Products. The move brings 250,000 new patients to Linde Healthcare from Belgium, Germany, France, Portugal and Spain. The European Commission approved the acquisition in April 2012 without any restrictions. The transaction was completed at the end of April. Linde has acquired the homecare activities at an enterprise value of around EUR 590 million. The move enables the Group to strengthen its position as one of the leading homecare providers.

"Healthcare is one of our three strategic fields. It is a stable business that benefits from demographic change. This acquisition enables us to strengthen our product portfolio and enhance our skill-sets," states Professor Dr Wolfgang Reitzle, Chief Executive Officer of Linde AG. "It gives us an ideal platform to develop new therapies and care concepts. The acquisition also makes us one of the leading providers in the European respiratory homecare business," continues Reitzle. The term homecare refers to medical services for patients outside of clinical settings. These include ventilation and sleep therapies.

SAUDI ARABIA:

INVESTING IN THE MIDDLE EAST

Linde has been awarded a long-term gases supply contract by Saudi chemical firm Sadara Petrochemical Company. The agreement will see the Group channel USD 380 million into the construction of carbon monoxide, hydrogen and ammonia production facilities at the Jubail site. "This contract is our largest on-site petrochemical project in the region and also our first in Jubail. It sees us strengthen our position as a global leader in the production and supply of carbon monoxide as a chemical component for the manufacture of polyurethane plastics," outlines Professor Dr Aldo Belloni, Member of the Executive Board of Linde AG. Sadara is building a major, integrated chemicals complex at the Jubail Industrial City II site. Linde's Engineering Division will be planning, supplying and constructing the new turnkey units. Production is set to start in 2015. The plants will then be run by Linde's Gases Division.

CHINA:

JOINT VENTURE FOR GAS SUPPLY

Linde is continuing its market development activities China. The company is investing EUR 70 million into the Dalian site in the north east of the country as part of an agreement to supply Chinese chemical company the Dahua Group with gases. The on-site agreement will see the engineering and gases specialist acquire and operate two existing air separation plants that previously belonged to the chemicals group. Linde's Engineering Division is also building a new air separation plant at the site, which will replace the two older facilities. The new plant is set to go on stream in 2014. It has a production capacity of 38,000 normal cubic meters of oxygen per hour – which is enough to accommodate rising needs at Dahua. The project is a key milestone in securing supplies to China's largest manufacturer of base chemicals and fertilisers. The new air separator will also provide liquefied gases for the regional gases market. The joint venture Linde-Dahua (Dalian) Gases Company, Ltd was founded to manage local supply.

Gas technology improves crime scene investigation

HOT ON THE TRAIL

Fingerprints are a key source of evidence when it comes to investigating crime. However, rendering them visible often takes a great deal of finesse on the part of crime scene technicians – as well as a special cocktail of chemicals. Linde engineers have now developed a method to make this work more efficient and environmentally friendly, using innovative gas technology to capture and store these individual traces with the utmost accuracy.

↵ *Author: Henning Hochrinner*
↳ *Image source: Linde AG*

Investigators are quick to arrive at the scene of a suspicious death. In fact, crime scenes are often teeming with technicians dressed in white body suits, carefully collecting hair samples and fibres, photographing evidence and searching for hidden traces of blood. The classic fingerprint remains one of the most important finds. Without these vital clues, special agent Leroy Jethro Gibbs would spend the TV series NCIS groping in the dark, as would Peter Falk a.k.a. Columbo. Even Sherlock Holmes caught numerous criminals by painstakingly comparing fingerprints.

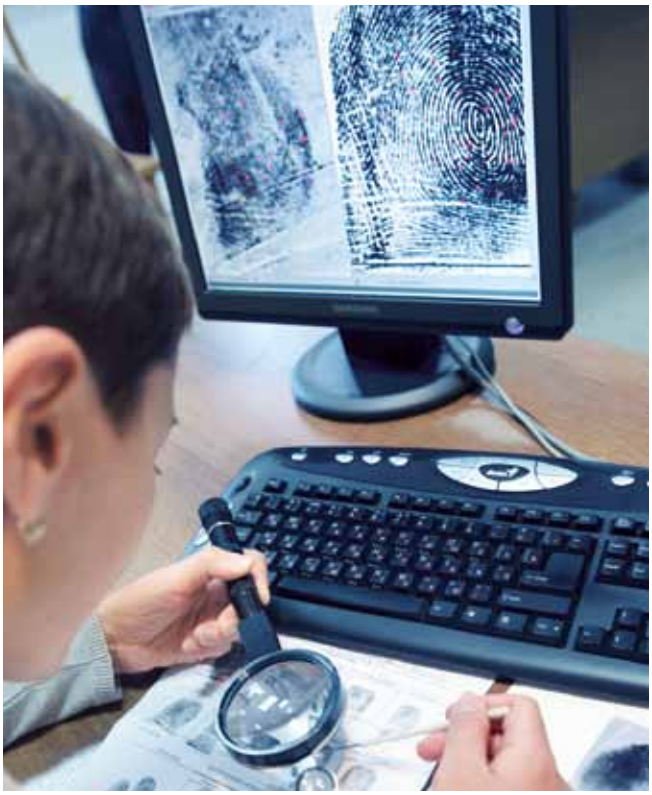
For over 150 years, fingerprints have been helping to ensure unambiguous identification. Each person's prints are unique, with no two patterns exactly the same. Even monozygotic ("identical") twins have different epidermal or friction ridges, as the fine lines on our fingertips are known. "If a perpetrator seizes a weapon with bare hands, these unique ridges leave a pattern like a stamp on the implement," describes Calvin Knaggs, Marketing Manager for speciality markets equipment at Linde in Canada. Tiny residues of sweat and sebum, constantly secreted by the cutaneous glands, make up the biological "ink". To assign these latent prints reliably to an individual, several features must match: fine bifurcations (forking), notable loops and whorls and abrupt ridge endings are all important indicators. This personal fingertip pattern develops while a foetus is still in the womb.

"However, a clear image of the fingerprint is crucial to reliable identification," specifies Knaggs – which of course means ensuring the prints are properly visible. Depending on the finish of the underlying surface in question, this can be a real challenge. Criminologists usually move in with an arsenal of brushes and carefully spread fine carbon powder over the evidence. However, that is by no means all they have at their disposal, since this method is only suitable for smooth surfaces such as glass or plastic. Porous, absorbent materials such as paper or wood present a far greater challenge, to which the investigators respond with chemicals such as ninhydrin, or iodine. "These substances react with amino acids in the fingerprint residue, making the print clearly visible," explains Knaggs. To apply the chemicals to the prints, the technicians first need to mix them with a solvent such as methanol, petrol ether or hydrofluoroether. The major disadvantage is that these can be toxic and pose a hazard to health and the environment.

70 MILLION

fingerprints are stored in the world's largest database: The FBI Integrated Automated Fingerprint Identification System.

New light on the case: *Fingerprints are unique. This sensitive evidence can now be exposed more easily with an innovative technology from Linde.*



Precise profile: Evidence placed in the ADROIT™ FC 300 (above) quickly reveals a detailed fingerprint profile – helping detectives narrow down their search (left).

Inventive spirit: Calvin Knaggs, Marketing Manager at Linde Canada, developed the innovative technology to uncover invisible fingerprints.

Calvin Knaggs set out to solve this issue. Together with his team, he worked to develop an innovative method that revolutionises the collection of fingerprints.

The resulting system is called ADROIT™ FC 300 – with the adjective "adroit" conveying the "skilful" or "dexterous" nature of the new technology. "The equipment uses a safe, eco-friendly carrier gas and makes developing invisible fingerprints a great deal easier," declares Knaggs. His years of experience in diverse areas at Linde stood him in good stead, as he could draw on his expertise in vacuum and thin-film technology as well as in specialty gases. His work brought him into contact with forensic science as he explored methods of developing latent fingerprint evidence. He was particularly interested in established procedures for collecting fingerprints: "I just thought there must be an easier and, above all, safer way than using easily inflammable and toxic solvents." And that is exactly what Knaggs has achieved with the ADROIT™ system. The device itself may look fairly unremarkable – a grey steel box with a viewing window, switches, tubes and a display – but it houses a sophisticated combination of vacuum, thin-film and gas technologies.

AN END TO LABORIOUS DABBING, SPRAYING AND BRUSHING.

At the core of the development lies the vacuum chamber, into which the forensic scientists place the evidence to be examined. There is even space for an entire rifle. An upstream vacuum sublimation system contains the substances that will develop the fingerprints. Heat is applied to evaporate these detection agents, which then bond with a carrier gas and are injected into the vacuum chamber via a special nozzle. There, they coat the evidence, depositing a thin, even film over the latent fingerprints to make them visible. According to Knaggs: "A wide range of detection agents can be fed into the system, including fluorescent substances." These then begin to glow under laser or UV light, ensuring the marks are clearly visible. Thanks to the ADROIT™ system, investigators can work much more efficiently without the need for manual laborious dabbing, spraying and brushing with chemical agents. "This is a major advantage, since these techniques also often damage the prints," explains Knaggs. The inventor first developed an initial prototype of the system in his garage at home – until his wife protested.

Yet Knaggs was convinced of his innovation, so continued developing the system with his team at the Linde laboratory. The engineers also worked closely with experts from the US Army Criminal Investigation Laboratory (USACIL) to align the technology as closely as possible with the requirements of investigators. Crime scene technicians tested the solution, comparing the new method with established alternatives. The tests showed that ADROIT™ delivers the same or superior clarity to conventional approaches and has the added bonus of eliminating the need for toxic solvents.

Even surfaces that are usually difficult to examine become workable with the new technology – thermal paper being a case in point. This special paper is used for airline tickets, receipts and faxes, for instance. It features a heat-sensitive coating that turns black when

heat is applied. While obviously very practical for its intended purpose, this poses quite a challenge for criminal investigators – the paper also changes colour on contact with solvents used in laboratories, destroying any evidence or notes it might have held. By contrast, Linde's innovation can be used to develop fingerprints at room temperature, leaving the heat-sensitive layer intact to reveal any important signs. Traces of DNA or drugs on a piece of evidence remain equally unscathed for subsequent examination.

Storing and sharing analysis results worldwide

Linde engineers used test results from USACIL to optimise their technology. "We were then able to improve the solution in terms of ergonomics, dimensions and process speed," confirms Knaggs. The system was presented to the industry for the first time at the Annual Meeting of the American Academy of Forensic Sciences (AAFS) in early 2012. "We received very positive feedback from the experts, who described our innovation as a technical breakthrough," reports the Linde specialist. The FBI, US Army and German federal police force have already shown strong interest.

The computer system integrated in the ADROIT™ solution makes life even easier for technicians, allowing them to program standard processing regimens, for instance. Recurring inspections can then be run according to a predefined routine, enabling reproducibility and consistent quality. To maximise ease of use, the system also features a network interface, which allows remote monitoring via Internet and a way of recording the process applied for each case file. Agencies with multiple systems can update process recipes in satellite systems – at any location worldwide. All in all, ADROIT™ is an invaluable addition to the toolkit of investigators. Criminals will find it even harder to cover their tracks at crime scenes.

TELL-TALE RIDGES

The ridge pattern of every fingerprint is unique. 150 different major features (minutiae) of a fingerprint pattern have been identified. The friction ridges that form fingerprints grow while a baby is in the womb.

LINK:
www.interpol.int/INTERPOL-expertise/Forensics/Fingerprints

SHORT INTERVIEW

"EVEN TWINS HAVE UNIQUE FINGERPRINTS"

Linde Technology speaks to Alexandra Herrmann-Tamm, Detective Chief Superintendent at the German Federal Office of Criminal Investigation (BKA) in Wiesbaden, about securing evidence at crime scenes.

↳ HOW IMPORTANT ARE FINGERPRINTS TO CRIMINAL CASES NOW THAT WE HAVE DNA TESTING?

Both are important. All the available information – which could include fibres, microscopic particles or traces left by tools – and of course people's statements must be examined by investigators, public prosecutors and courts. DNA traces do not necessarily mean that the identified person is the offender or was even at the crime scene, since such material can easily be moved from one place to another – unlike fingerprints. Another advantage of dactyloscopy, as we call methods of collecting and analysing fingerprints, is that even monozygotic or "identical" twins can be told apart even though they have the same DNA profile.

↳ HOW LONG DOES IT TAKE TO RECOVER FINGERPRINTS?

That depends on the collection method, the underlying surface and subsequent examinations. Say you are working with carbon powder and lifting tape on a non-absorbent surface such as glass or metal and you are not constrained by the possibility of other evidence, you could take prints within minutes. But absorbent surfaces such as paper would take longer – especially if you also had to consider possible DNA material or other traces on those surfaces.

↳ AND WHAT ARE THE BIGGEST CHALLENGES?

Rendering the prints visible in the first place. You don't usually know beforehand whether fingerprints are actually present on an object or surface, and technicians must avoid damaging any other evidence that might be relevant. Materials such as polystyrene and certain metals are particularly challenging, as are prints combined with blood. Damp surfaces and banknotes are another hurdle. So constant efforts are being made to refine recovery methods and improve analysis. The latest tests have even successfully recovered prints from skin.

NEW WAYS TO INCREASE EFFICIENCY AND PROTECT THE CLIMATE

ENERGY UNDERGROUND

For some time to come, industry will remain dependent on coal and natural gas. Modern plants and gas technologies from Linde are helping manufacturers across the globe to use fossil fuels in more efficient, climate-friendly ways.

USA

Shale gas

More and more trucks are being powered by natural gas. Thanks to Linde's gas technologies, natural gas from unconventional reserves can be extracted and processed more efficiently. **Page 20**

United Kingdom

CCS technology

Coal-fired power plants have to become more climate friendly. Linde's oxyfuel process separates CO_2 from flue gases so it can be stored. **Page 16**

GERMANY

Flue gas scrubbing

CO_2 must meet stringent purity standards for underground storage. Linde's LICONOX® process makes the grade. **Page 24**

SOUTH KOREA

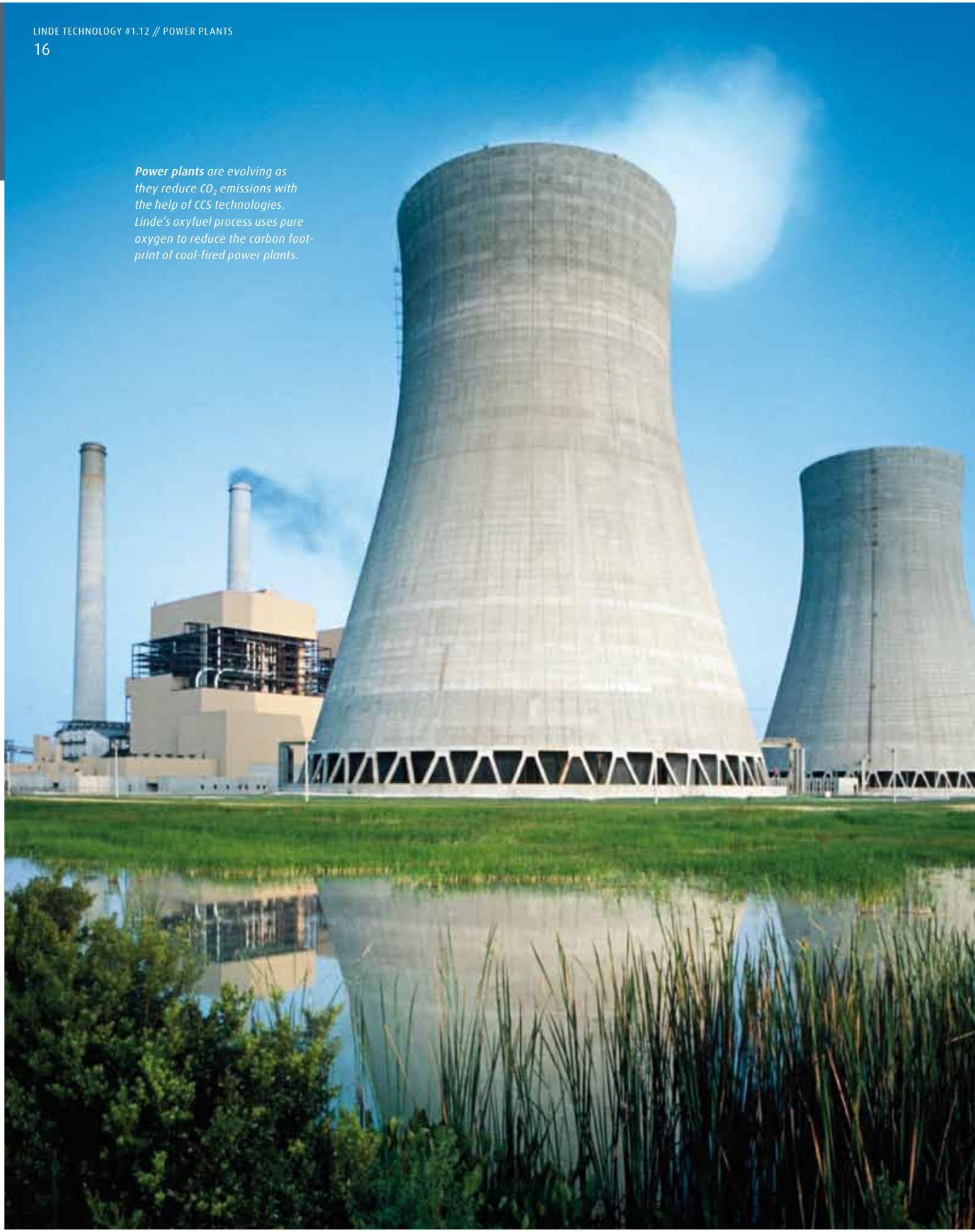
Coal gasification

Coal can be converted to synthetic natural gas, making it a more environmentally friendly natural resource. **Page 26**

QATAR

Gas-to-liquids

Turning natural gas into liquid fuel requires large amounts of oxygen. Eight Linde air separators keep the O_2 flowing.
Page 30



***Power plants** are evolving as they reduce CO_2 emissions with the help of CCS technologies. Linde's oxyfuel process uses pure oxygen to reduce the carbon footprint of coal-fired power plants.*

Taking CCS to commercial scale

THE GREEN SIDE OF COAL

The world needs climate-friendly coal power. One way of doing this is to store carbon dioxide (CO_2) from power plant flue gases below ground. Linde's oxyfuel technology plays an important role here. Linde engineers have teamed up with a number of industry partners to plan the world's most powerful oxyfuel power plant in the UK. It is the first time that this technology will be tested on a commercial scale.

↑ Image source: John Zoiner/Getty Images
↓ Author: Henning Hochrinner

The need for climate-friendly coal has never been greater. And it's obvious why – energy consumption is rising sharply the world over. According to the International Energy Agency (IEA), global energy demand is set to double by 2050. Yet this rise in demand cannot be met by renewables alone. Which is why fossil fuels – in particular coal – will most likely continue to be part of the energy landscape for decades to come. To keep climate change in check, however, we urgently need to reduce CO_2 emissions from power plants. In industrialised Western economies, coal still forms the backbone of power production. As statistics from the U.S. Energy Information Administration show, in 2011 around 42 percent of electricity in the United States was generated by coal-fired power plants. In Germany – a leading light in renewable energies – a similar figure applies. Yet coal is also an importance resource in Asia. "The easiest way for countries such as China and India to produce electricity quickly and cost-effectively is to build new coal-fired power plants," explains Philip Beer, Director Clean Energy Europe at Linde. "Coal is cheap and usually available locally. Plus these countries have the know-how to build coal plants."

UNITED KINGDOM

The planned oxyfuel plant should reduce CO_2 emissions by two million tonnes every year.

Carbon capture and storage (CCS) is an effective way of squeezing CO_2 emissions despite spiralling energy production. It involves capturing CO_2 released when coal is combusted in power plants, purifying it, and storing it underground. By 2050, this process could be used to achieve around 20 percent of the CO_2 savings needed to limit global warming to two degrees Celsius.

Linde is firmly committed to advancing and testing CCS technologies. CO_2 managers at Linde are collaborating with power plant specialists at the French company Alstom and British power plant operator Drax to plan and build an innovative oxyfuel plant in the English county of North Yorkshire. With a net power output of 304 megawatts, it will be the most powerful oxyfuel power plant in the world, providing climate-friendly electricity for over 900,000 households. "Compared with a conventional power plant, the new facility will emit around two million tonnes less CO_2 per year," continues Beer. "These two million tonnes will be captured and stored in saline aquifers under the North Sea." Linde's engineering specialists are building the air separators for the new plant. These will supply around 6,300 tonnes of oxygen per day, which will

be fed to the coal combustion chamber. Replacing air with pure oxygen in the oxyfuel process means that the resulting flue gas primarily comprises steam and CO_2, which can be easily separated by cooling.

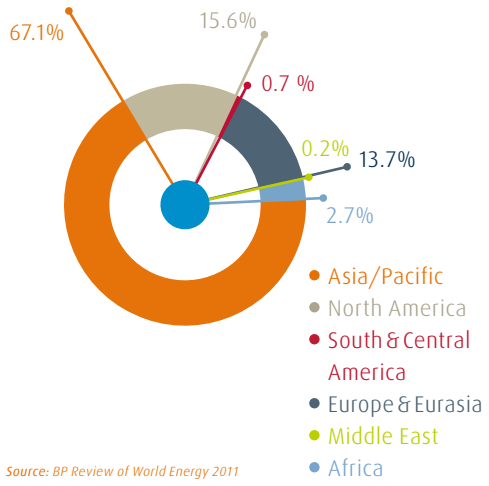
The power plant in North Yorkshire will be an important demo project for both CCS technology and the oxyfuel process. Until now, oxyfuel has only been implemented in smaller pilot projects such as Vattenfall's 30-megawatt plant in Germany's Schwarze Pumpe industrial park. Linde supplied many of the components for this project and developed the concept for the overall process. "Moving forward, it is important that we gradually scale up the technology in order to improve overall performance," states Beer. The power plant in North Yorkshire is the next step in the journey. "It is the first commercial-scale CCS demo plant," continues Beer. If the project proves a success, the team plans to take the technology to a massive, gigawatt-scale plant.

"To choose the best CCS option from all available technologies, we have to test all processes in a medium-scale plant in the power class up to 300 megawatts," explains Dr Bernd Holling, Director Business Development Clean Energy and CCS at Linde. The only way to effectively benchmark oxyfuel, pre-combustion and post-combustion processes is to test them in the field. Although these technologies all aim to reduce CO_2 emissions, each one approaches this challenge from a completely different angle. In pre-combustion, the coal is gasified and the CO_2 is removed prior to combustion in a process known as the Integrated Gasification Combined Cycle (IGCC). What is left and subsequently burnt is pure hydrogen. In contrast, post-combustion technology removes carbon dioxide after combustion, using different processes to wash the flue gas and remove contaminants. Once this is done, the CO_2 can be separated. This scrubbing process is more complex than oxyfuel technology as the flue gases contain more contaminants.

The site in North Yorkshire is an ideal test ground for CCS technology. The carbon dioxide from the plant can simply be piped to the coast of the North Sea and from there to the open sea where it is stored below sea bed. "In contrast to other countries, the geography of the UK makes it an ideal location. No matter where you are, you

COAL-HUNGRY NATIONS

Regional share of global coal consumption



Source: BP Review of World Energy 2011

Feedstock: *The Drax coal-fired power plant in the UK (above) is considered one of the most efficient worldwide. There are plans to construct an innovative oxyfuel plant with CO_2 separation (right) in North Yorkshire, England. On completion, it will be one of the world's most important CCS demo projects.*

are never far from the coast," confirms Beer. The UK's clear political standpoint on coal-based power generation is a further plus, as all new coal-fired power plants must be equipped with CCS technology.

More demo projects

However, CO_2 storage can be a controversial topic – for instance in countries without direct access to the sea. There is often resistance to mainland storage sites, which – in turn – prevents key CCS demonstration projects from being realised. Opponents fear that the underground storage sites will not be able to safely hold the carbon dioxide or that injecting CO_2 into saline aquifers will cause salt water to contaminate groundwater. None of these reservations, however, have been confirmed by research. The GFZ German Research Centre for Geosciences has been testing this technology since June 2008 as part of CO_2MAN project (former CO_2SINK). At the chosen site in Ketzin, it has been pumping 1.5 tonnes of CO_2 per hour through arm-width pipes into deep layers of rock that are completely capped by impenetrable layers of plaster and clay. For this test project Linde provides the necessary carbon dioxide and also the techniques for intermediate storage and compression. Critics, however, claim that the volumes stored in Ketzin are too small to draw conclusions about large-scale sites. The technology therefore needs to be tested on an industrial scale in projects such as the one in the UK.

There are, however, further obstacles facing climate-friendly power plant technology. "CO_2 capture and storage requires major investments in technology. It also lowers power plant efficiency levels," explains Beer. All CCS processes require additional plant modules that consume energy in order to capture CO_2. This lowers power plant efficiency by around ten percent at the current state of technology and makes plant operators cautious about the technology. Programmes such as the European Union's NER300 support initiative are therefore crucial to the future development of CCS processes. Linde and its partners Alstom and Drax have applied to NER300 for funding to help finance the oxyfuel project in England. The application has already passed the first stages and is now being thoroughly assessed by the EU. If the industry partners receive the subsidy, they will be committing to environmentally friendly energy production in the long-term as recipients of the funding are obliged to continue with CO_2 capture and storage for at least ten years. If all goes according to plan, the power plant could be connected to the grid by 2017.

So although developing CCS technology is a big undertaking, the rewards are more than worth it. "Coal-fired power stations and large-scale industrial consumers emit significant quantities of CO_2 at the point of production. This makes it more effectively to equip them with climate-friendly technologies compared with other emitters," says Beer. Reducing emissions caused by private households or road traffic to the same extent would involve a disproportionately high effort. With CCS, rising energy needs do not necessarily go hand in hand with higher CO_2 emissions – which is good news for the climate.

LINK:
www.draxgroup.plc.uk

SHORT INTERVIEW

"WE HAVE TO LIMIT CO_2 OUTPUT"

Linde Technology talked to Dr Bernd Holling, expert for carbon capture and storage (CCS) at Linde, about the benefits and the future of this technology and Linde's projects in this area.

↳ WHY DO YOU SUPPORT CCS TECHNOLOGY?

Anyone who takes the link between global warming and greenhouse gas emissions seriously knows that we have to limit CO_2 output. CCS does consume extra energy, but the benefits outweigh the risks of doing nothing at all. Industrialised countries have an important role to play in establishing this technology and must take the lead here. Without their efforts, the technology will not advance to industrial scale – and that would be a serious blow for the climate.

↳ WHICH PROCESS IS THE MOST EFFECTIVE?

Unfortunately, it is impossible to say at the moment. Oxyfuel power plants work at a higher temperature and are therefore slightly more efficient at combustion – that is one benefit. The post-combustion process, however, is the only technology that can be retrofitted to existing power plants. What we can say at this stage is that all three technologies – oxyfuel, post-combustion and pre-combustion – reduce power plant efficiency levels. Demonstration plants like the one in the UK are key to helping us reach a final decision. We can only assess these technologies by testing them in the field.

↳ IS LINDE WORKING ON OTHER TEST PROJECTS FOR CO_2 CAPTURE AND STORAGE?

In addition to the planned oxyfuel power plant in the UK, we are working with Italian energy group ENEL SpA to develop CO_2 scrubbing, liquefaction and storage processes at a pilot plant currently being built by the group near the Italian city of Brindisi in the region of Apulia. We are also constructing a CCS pilot plant in Wilsonville (Alabama) with funding from the US Department of Energy. From 2014 on, we will be testing innovative CO_2 scrubbing processes for post-combustion technology here. We expect to be able to remove at least 90 percent of carbon dioxide from flue gases, while capping the rise in electricity costs at 30 percent.

Shale gas – LNG goes mobile

FUEL FROM THE DEEP

Our mobile society needs energy to keep moving. Thus far, most types of fuel were derived from crude oil. As resources dwindle, however, the search is on for replacements. Natural gas is a strong contender. North America is home to huge reserves of shale gas. And so more and more trucks and cars are being powered by liquefied natural gas (LNG). Technologies developed by Linde are helping operators efficiently extract and refine this raw material. And Linde itself is using LNG to power an increasing number of its own trucks.

↙ Author: Caroline Zörlein
↘ Image source: Shuli Hallak/Corbis

In the US, trucks are the kings of the road. They rule the interstates – endless stretches of highway that criss-cross the entire country. These giants of the road transport all manner of goods, for example, wood from the east to the west coast, and fruit and vegetables on the return trip. Interstate 80 alone covers almost 5,000 kilometres from New York to San Francisco. En route, these heavy-duty trucks guzzle huge amounts of diesel. Natural gas vehicles (NGVs) are a viable alternative to these diesel-thirsty giants. Natural gas reserves are a lot more abundant than crude oil supplies and consequently, now also cheaper. There is also another benefit: "Natural gas burns more cleanly than diesel, lowering carbon dioxide and NO_X emissions by 20 percent and up to 70 percent respectively, eliminating sulphur emissions, and reducing particle emissions," explains Earl Lawson, Vice President Energy Solutions at Linde North America. The vehicles help lower emissions while cutting costs for operators.

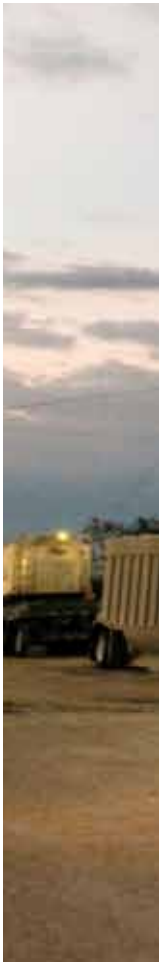
USA

Today, shale gas accounts for 23 percent of the US energy market. The IEA expects this figure to grow to 49 percent by 2035.

Linde is also using liquefied natural gas (LNG) to power a growing number of trucks in its own fleet. In southern California, the company has already completed a pilot project testing the efficiency of three LNG trucks that transport liquid CO_2 in and around Los Angeles. The project has revealed that natural gas cuts fuel costs by 30 percent – an important factor in the overall equation as the Linde LNG trucks travel around 50,000 miles (80,000 kilometres) each year. The Group has now purchased 20 more LNG-fuelled trucks, a move that deepens the Group's commitment to this emerging alternative fuel. The new vehicles are scheduled to hit the road in the US during the third quarter of 2012. They will be integrated into Linde's fleet of 700-plus trucks that deliver cryogenic gases to consumers throughout North America.

"The current series of LNG trucks is over 500 kilograms lighter than their diesel-powered counterparts, which is an added plus as it enables us to increase the cargo weight," outlines Ed Windsor, Fleet Maintenance Manager at Linde North America. The new LNG trucks also operate considerably more smoothly and quietly than their diesel counterparts, which is a major benefit for drivers who spend around ten hours on the road each day. It is hard to spot the difference between a diesel and an LNG truck. "The only visible difference is the fuel tanks," states Windsor. "Diesel trucks have an aluminium saddle tank whereas LNG vehicles are equipped with a cryotank made of high-grade stainless steel," he explains.

The new fleet means that Linde is now also an LNG customer. "It's a testament to our belief in the benefits of LNG and its ability to support the move towards greater sustainability," explains Lawson. A belief that is also shared by politicians. In his State of the Union speech at the end of January 2012, US president Barack Obama expressed his support for natural gas as a fuel for trucks. He also announced that the US would be relying more heavily on domestic natural gas reserves. This announcement comes on the back of discoveries of huge shale gas deposits in the US and Canada. These reserves have triggered a gold rush among energy companies, positioning the US as the largest natural gas producer in the world,



Raw material boom:
Shale gas reserves have turned the US into the world's largest natural gas producer.

ahead of even Russia. Shale gas now accounts for around 23 percent of the US natural gas market. The International Energy Agency (IEA) expects this figure to rise to 49 percent by 2035.

Extracting natural gas deposits more efficiently

The gas deposits, however, have to be extracted from layers of rock kilometres below the earth's surface. Mining companies use a sophisticated technology known as hydraulic fracturing to open up these unconventional reserves. It involves drilling a well thousands of metres into rock, first vertically and then horizontally in several directions. A mixture of water, sand and chemicals is then injected into the well at high pressure. This creates cracks in the rocks through which the natural gas can escape and be pumped to the surface. "Drilling costs have shrunk dramatically and shale gas extraction has increased sharply in the US," explains Steve Bertone, President of Linde Process Plants, USA. "The number of drilled wells in the Marcellus Shale, for example, in the US state of Pennsylvania, rose from almost zero in 2007 to around 1,400 in 2010," confirms Bertone.

LESS WATER, HIGHER YIELDS – GAS/WATER MIXTURE OPTIMISES EXTRACTION.

Linde covers the entire shale gas value chain from extraction to purification. Natural gas specialists at Linde were particularly keen to reduce the high volume of water required for hydraulic fracturing. "A lot of water is needed to create a sufficient number of cracks. The bigger the fractured surface, the higher the volume of gas that can be extracted, and the more cost-effective the process," explains Robin Weir, Oil and Gas Technology Manager for Linde's energy solutions group at Linde North America.

Linde provides an innovative technology to achieve these goals. Experts add nitrogen or carbon dioxide to the mix, which reduces the amount of water needed and increases gas yields. "The nitrogen is delivered to the site as a liquid. It is then vaporised on site and pumped down as a pure gas. Alternatively, the gas is added to the water-based fluid to create an emulsion or foam," says Weir. Liquid carbon dioxide can also be pumped below the surface or mixed with an aqueous solution on site to create an emulsion or foam. "The amount of gas extracted depends on the viscosity of the liquid and the pressure at which it is injected below ground," explains Weir. These properties can be carefully controlled by adapting the CO_2 and N_2 ratios. The gas/water mix also reduces the amount of waste water produced. Although some of the liquid remains in the rock, large amounts flow back to the surface where it has to be stored in special basins for disposal. Linde provides operators with an all-in service package that includes the gases, professional on-site storage solutions, booster pumps and operators.

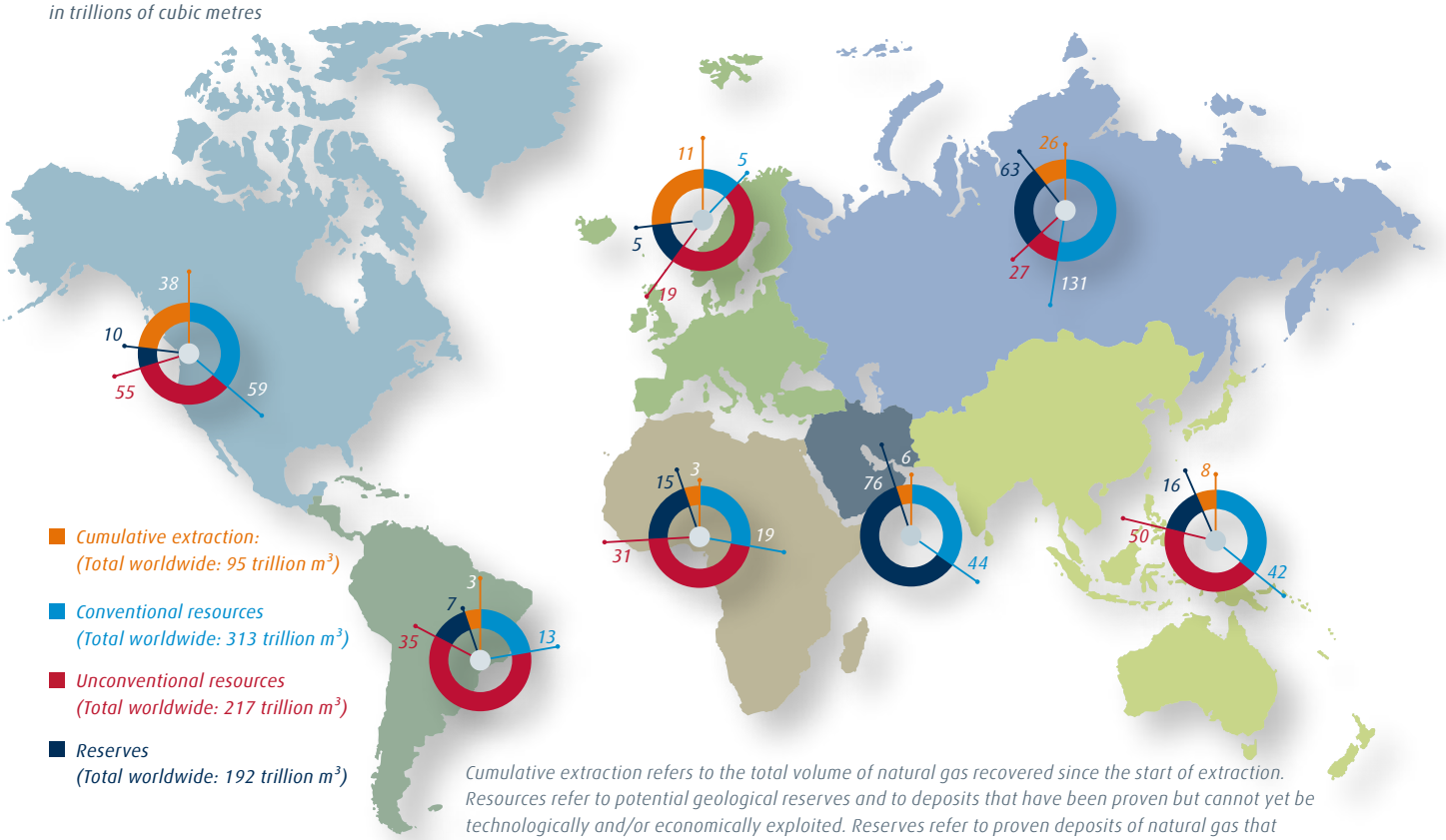
A study of shale gas reserves confirms the benefits of this procedure. Experts estimate that over 1,400 trillion cubic metres of natural gas reserves are locked away underground close to Montney, in the western Canadian province of British Columbia. The wells in this area that used nitrogen and carbon dioxide extracted significantly more gas and consumed fewer additives such as sand and chemicals. "The water savings alone make this process an attractive option," explains one of the co-authors of the study, Lyle H. Burke, from the consultancy RPS Energy in Calgary, Canada. The technology does involve additional costs, but they are more than offset by the increase in yield.

Once it has been extracted, the gas has to be treated to make it suitable for private and industrial use. "The extracted shale gas contains various components including carbon dioxide, methane, ethane, propane and butane, as well as heavier hydrocarbon compounds," explains Bertone. "The crude gas is conditioned then refined in a number of proven Linde process steps, including compression and cryogenic cooling so that it can be further broken down into its constituent parts." Products, such as methane, are delivered to private and industrial users while the heavier components (ethane, propane, and butane) are further processed by chemical and petrochemical industries.

Natural gas liquids (NGLs) are a sought-after by-product of shale gas extraction. NGLs comprise ethane and heavy hydrocarbons and serve as an optimal feedstock for steam cracking in the petrochemical industry to produce olefins. The liquid gas also has a significantly higher market value. Linde's Engineering Division offers a proven process, CRYOPLUS™, to recover this valuable raw material

POTENTIAL NATURAL GAS MARKET*

in trillions of cubic metres



*Source: DERA Rohstoffinformationen 2011

Cumulative extraction refers to the total volume of natural gas recovered since the start of extraction. Resources refer to potential geological reserves and to deposits that have been proven but cannot yet be technologically and/or economically exploited. Reserves refer to proven deposits of natural gas that can be economically extracted at today's prices and using today's technology.

from shale gas at efficiency levels of up to 98 percent. The boom in shale gas exploration is fuelling the market for NGLs. In less than one year, Linde Process Plants was commissioned to build three liquid gas recovery units in the Williston basin and one in the Anadarko basin. "Shale gas reserves have lessened US dependency on foreign oil," outlines Lawson. "And they create domestic jobs, boosting local economies." Natural gas is also the cleanest of all fossil fuels and can therefore play a key role in the journey towards a low-carbon energy economy. Before the heavy-duty US trucks can roam the highways across all American states, however, the network of LNG production facilities and fuelling stations has to be expanded. "We are now seeing a lot of impetus in the move to improve the supply infrastructure," explains Lawson. LNG is not only a viable fuel option for heavy duty trucks, it can also be used as an alternative to diesel in the marine industry as well as in the locomotive, power generation and industrial heating sectors. Natural gas has huge potential. And the reserves are there – they just need to be efficiently captured and made readily available.

Natural gas for the road: To extract shale gas (left), artificial cracks have to be created in layers of rock deep below the surface. Once processed, the natural gas is transported by large tankers for use as an environmentally friendly fuel (middle and right).

LINK:
www.eia.gov

Efficient separation of power plant off-gases

CLEANING UP FLUE GASES

CO_2 from coal power plants can be stored underground or used in chemical processes – as long as it has been purified first. Linde has developed an efficient purification method that filters out harmful sulphur and nitrogen components – making coal-based power more eco-friendly.

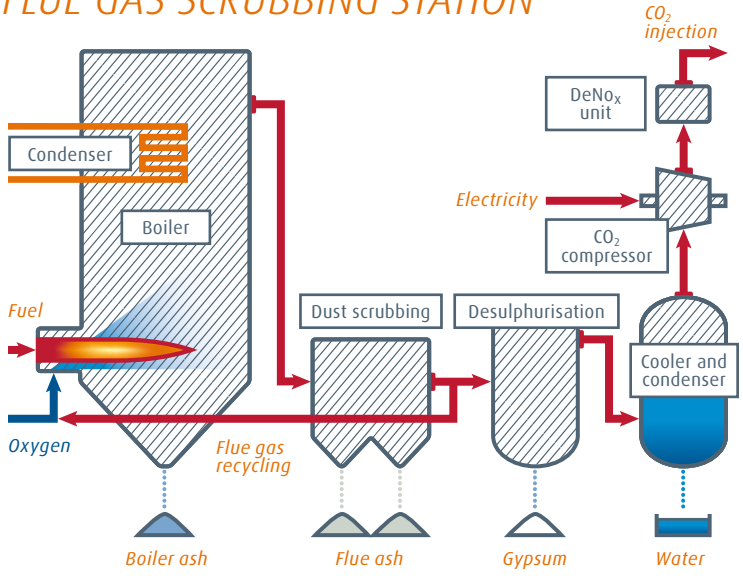
Making energy produced from coal more climate-neutral means resolving a major challenge: fossil-based power plants need a method of separating carbon dioxide (CO_2) in the purest possible form from the flue gas stream. Only then can it be stored in suitable underground reservoirs or used in industrial processes. Carbon capture and storage (CCS) concepts for power stations have already evolved to market maturity, and the purity of the separated CO_2 is one of the biggest success factors. The established oxyfuel process offers a promising solution here, since it uses pure oxygen for combustion rather than air, which is used in conventional coal-fired plants. This significantly reduces the flue gas stream, since it eliminates the nitrogen ballast present in normal air. The Vattenfall energy group has been trialling this method at its Schwarze Pumpe power station in the German state of Brandenburg for several years now.

Three in one

However, the oxyfuel off-gas still needs treating, as combustion produces small amounts of pollutants – especially sulphur dioxide and nitrogen oxides. Cleaning the gas is essential, as injecting CO_2 into geological formations is governed by strict purity regulations. The maximum contamination level permitted is 100 parts per million (ppm), meaning that for every million molecules, only 100 may be foreign to carbon dioxide.

"Coal-fired power plants have been filtering nitrogen oxides and sulphur dioxide out of flue gases for around thirty years now, as these are the chemicals that cause acid rain. Carbon dioxide, however, is non-toxic and has therefore been released into the atmosphere despite being harmful to the climate," explains Dr Roland Ritter, process engineer at Linde Engineering Dresden GmbH. So isolating all three of these off-gas components – sulphur dioxide, nitrogen oxides and carbon dioxide – is relatively new. Various research groups worldwide have already demonstrated that such three-fold purification is possible. Linde's engineers have gone a step further at Vattenfall's Schwarze Pumpe plant. Since 2008, the oxyfuel pilot facility there has been separating all three components and producing plaster, plant fertiliser and pure carbon dioxide as by-products. The pioneering

FLUE GAS SCRUBBING STATION



Pre-injection stage: The oxyfuel pilot plant with integrated flue gas scrubbing at the Schwarze Pumpe power plant supplies high-purity CO_2.

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

process behind this is called LICONOX®, an amalgamation of "Linde cold denitrification" and NO_x, the chemical symbol for nitrogen oxides.

"Our concept offers a host of advantages over conventional and alternative approaches to flue gas purification," emphasises Ritter, who was involved in developing the process at Linde. Traditional denitrification $DeNO_x$ at standard coal-fired plants involves separating the nitrogen oxides from the flue gas as soon as it leaves the combustion chamber and some of the heat has dissipated (at a temperature of around 350 degrees Celsius). The gas flows into a large tower through a type of bulk solid, which functions like a catalytic converter in a car. At the same time, an ammonia solution is injected into the tower through nozzles. "The ammonia reacts with the nitrogen oxides in the presence of the catalyst to form harmless nitrogen," the Linde specialist explains. The downside is that, since the exhaust gas from the combustion chamber contains a great deal of dust, the catalysts keep clogging up and have to be changed – a costly undertaking.

Denitrification presents a particular challenge when the flue gas is at a low temperature and not under pressure. In this case, nitrogen monoxide (NO) can only be removed by using ozone to oxidise it to nitrogen dioxide (NO_2). This compound can then be isolated from the flue gas by scrubbing with water. However, the disadvantage here is that ozone is expensive. Ritter and his colleagues developed a more efficient strategy that works without expensive catalysts or ozone. Their solution was partly enabled by the pressure conditions required for the CCS process chain. For the carbon storage step, the CO_2 is injected below ground at a pressure of around 100 bar. Chemical reactions are often much more effective at high pressures – and nitrogen oxides are no exception.

GERMANY

The CO_2 capture rate at Vattenfall's oxyfuel facility is higher than 90 percent.

Even at 10 bar, NO converts to NO_2 of its own accord in the presence of oxygen. As Ritter explains: "You have to compress the power plant off-gases anyway for CO_2 injection, so it definitely makes sense to remove the nitrogen oxides at high pressure." Lab tests confirmed the Linde experts' idea: as expected, a pressure of 10 bar saw NO change into the more reactive NO_2. If the researchers then added the ammonia solution, they obtained ammonium nitrate and ammonium nitrite – "the basis for liquid fertilisers," confirms Ritter. So this method turns power plant off-gases into a usable product. Going a step further, the researchers then found a controlled way of producing ammonium nitrite – which has the benefit of turning into harmless nitrogen when moderate heat is applied. The tests clearly showed that the cold $DeNO_x$ principle is viable in practice. Today, a large-scale test system is up and running in Schwarze Pumpe. The oxyfuel pilot facility here features integrated gas scrubbing and has been operating without a hitch since 2010.

But the Linde experts had a second issue to tackle: sulphur oxides, which also have to be removed from the off-gas. The new oxyfuel pilot plant harnesses a proven method here. Conventional coal-powered plants filter out the sulphur by spraying lime milk into the gas. The resultant reaction produces high-purity plaster, which the construction industry has been using for many years now. This type of flue gas desulphurisation system is also installed at Schwarze Pumpe. However, in contrast to conventional power plants, the desulphurisation stage occurs upstream of the $DeNO_x$ module that separates the nitrogen oxides. This means that the flue gas has already cooled down by the time it flows into the $DeNO_x$ compressor – "which explains the presence of 'cold' in LICONOX®," clarifies Ritter.

There are now alternative purification modules on the market that simultaneously remove both nitrogen oxides and sulphur dioxide. But, as Ritter explains: "These methods scrub the gases with water, which produces sulphuric and nitric acid." The wastewater is so acidic that it corrodes pipelines and containers, and it obviously requires careful disposal. By contrast, the plant fertilisers and ammonium salts produced by Linde's method are useful products in their own right. So the engineers are convinced that their flue gas purification system, which has now reached market maturity, is the solution of choice. High-pressure denitrification also carries a further benefit: "Because the gas is highly compressed, at a pressure of 20 bar, the overall facility can be designed with a much smaller footprint – which in turn reduces the investment outlay," explains the Linde specialist.

"Our LICONOX® solution allows us to effortlessly achieve the strict purity standards that must be met before carbon dioxide can be injected into underground reservoirs," continues Ritter. The technology also easily exceeds legal requirements for emissions, remaining around 50 percent below the maximum limit: With the LICONOX® system, Linde's engineers are clearly undercutting these levels, ensuring compliance with more stringent limits on flue gases in the future.

LINK:
www.vattenfall.de/de/klimaschutz-ccs.htm

Alternative energy sources: Coal gasification in South Korea

SYNTHETIC NATURAL GAS FROM COAL

Asia's emerging economies are growing rapidly. Yet the cost of importing energy sources such as natural gas is also on the rise. South Korea is now increasingly turning to a less expensive alternative – coal, which can be converted to synthetic natural gas (SNG) using a process known as coal gasification. Linde is collaborating with Danish company Haldor Topsøe to develop one of the first plants to support this process. From 2013 on, the facility will supply a number of plants with synthetic natural gas, including one of the largest steelworks in South Korea.

↑ Author: Tim Schröder
↓ Image source: Cameron Davidson/Corbis

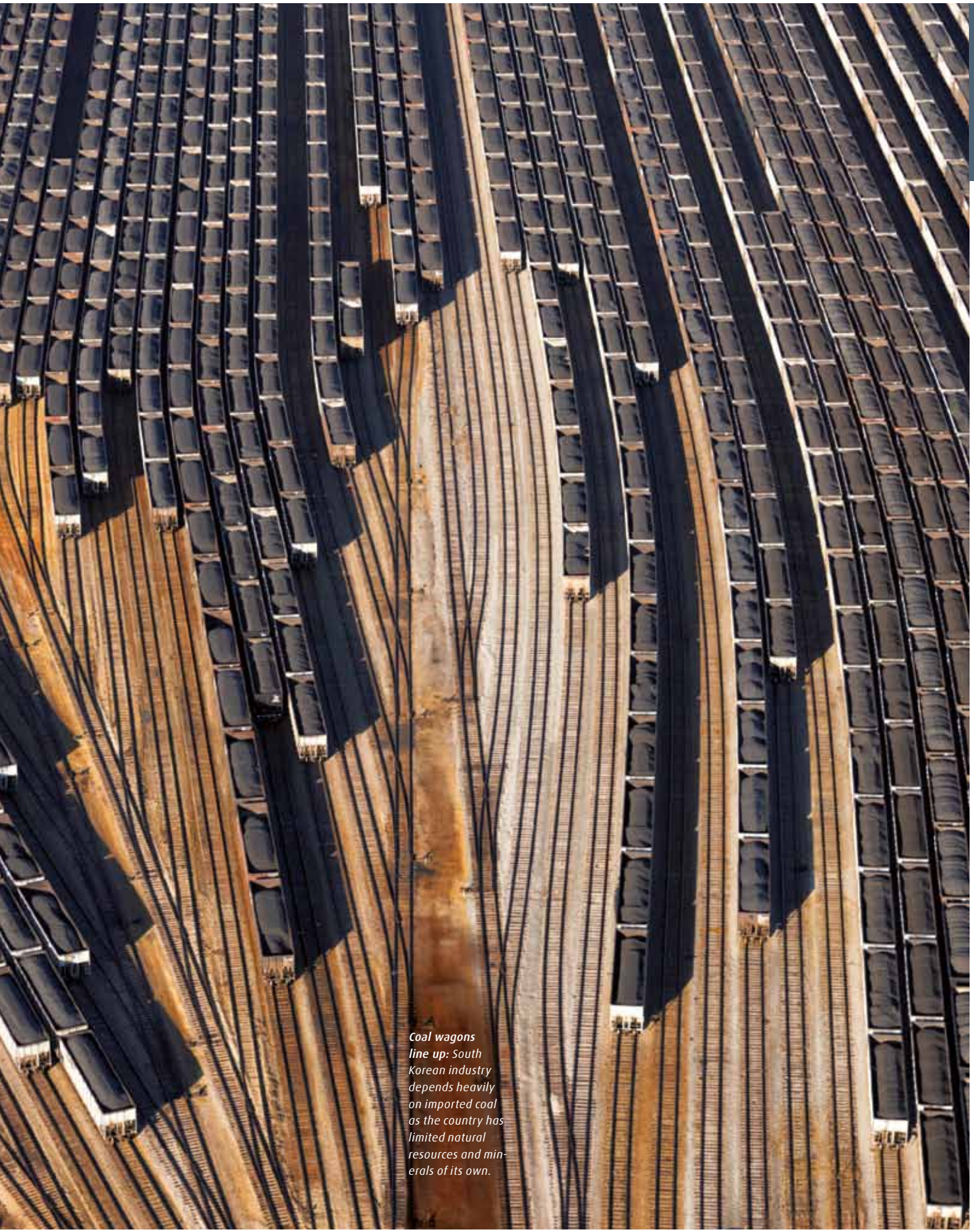
Steel is indispensable for any industrialised nation. It forms the skeleton around which skyscrapers are built. Cars, too, are made from sheet steel and each year, a billion tonnes of goods are transported across the globe by giant ocean tankers made of steel. Yet steel production requires enormous amounts of energy. Leading ship-building nation South Korea, for example, has to import many natural gas each year to power its domestic steelworks. To reduce the cost of energy supplies, industry players in South Korea are turning to a fossil fuel available much more cheaply from China or Australia – coal.

For a long time, this black fuel was hugely underestimated as a potential source of natural gas. Previously, only one gasification plant existed worldwide. Today, however, modern technology provides environmentally friendly ways of converting coal into high-purity synthetic natural gas (SNG). Yet standards are high in the South Korean market. The gas produced from coal must be pipeline-ready so that it can be fed directly into the supply grid. It must therefore be free of contaminants and have the same high energy density as natural gas. Linde process specialists and Danish company Haldor Topsøe have stepped up to this challenge. In the South Korean seaport of Gwangyang, a first SNG plant is being constructed to convert coal into natural gas. The plant is being built by steel manufacturer POSCO. From the end of 2013 on, it will serve as an alternative source of natural gas and primarily supply neighbouring steelworks with 500,000 tonnes of natural gas per year. The core process of synthesis gas treatment is based on technology developed by Linde and the Danish company Haldor Topsøe. For Claude Keller, project manager at Linde's Engineering Division, it is a unique project. "We have to deliver particularly high gas purity levels," he explains. The extremely complex nature of the project also requires that Linde collaborates very closely with the Danish partner. "In this technology alliance, we started planning together right from the word go. This has enabled us to develop an efficient, reliable production process," explains Keller.

SOUTH KOREA

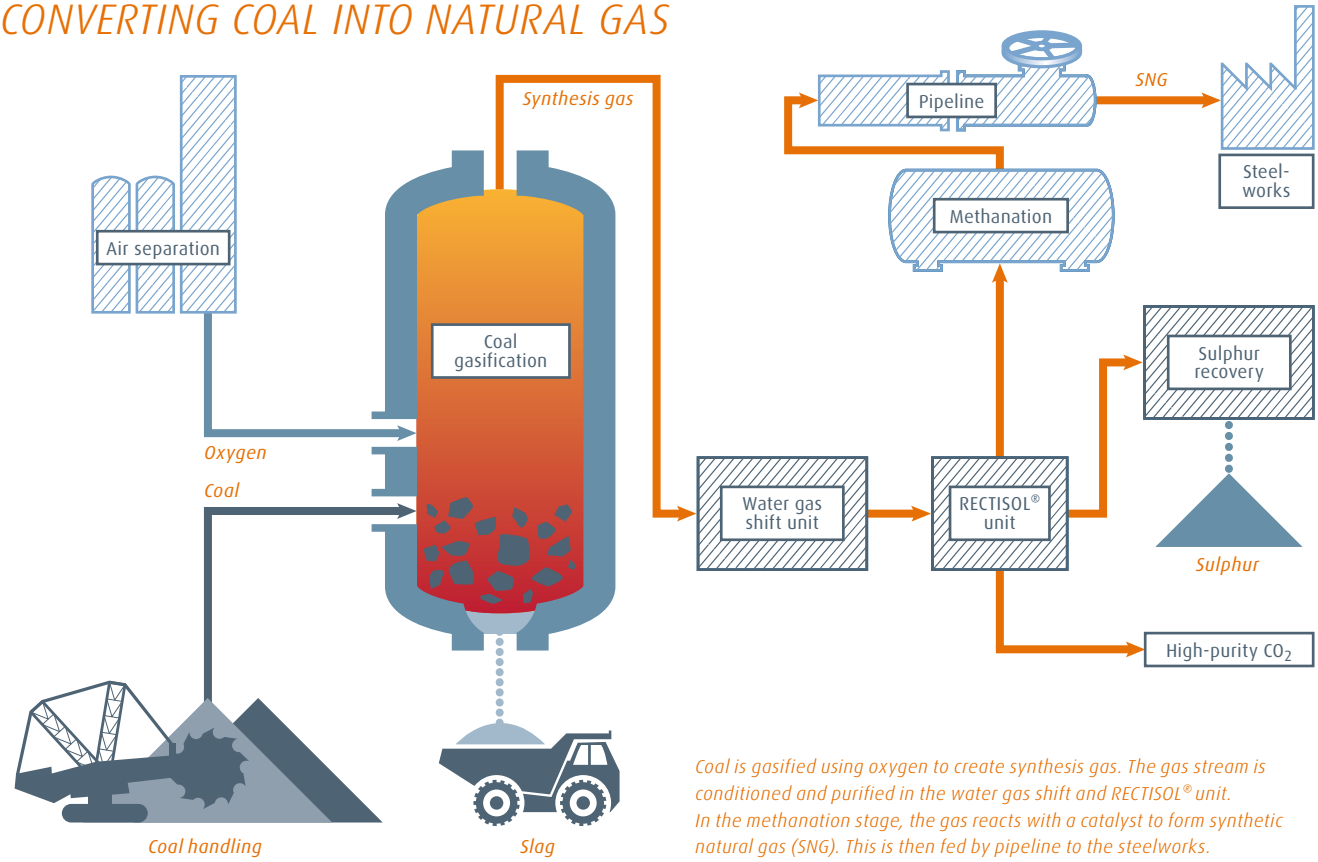
The coal gasification plant will produce 500,000 tonnes of natural gas in the future.

Haldor Topsøe is responsible for the methanation step. It uses a process known as TREMP™ (Topsøe Recycle Methanation Process), where the gas (syngas) previously obtained from the coal reacts in a catalyst to create methane, the main component of natural gas. Linde supplies the technology for processing and cleaning the impure gasified mixture in the SNG plant. This mainly comprises the water gas shift, RECTISOL® and sulphur recovery process steps. The gas mixture is generated in the first stage – coal gasification. At this point, it contains water vapour as well as a mixture of hydrogen, carbon monoxide, carbon dioxide and numerous other impurities such as sulphur and carbon components. "Our job is to obtain a clean synthesis gas and feed this to the methanation stage with the right concentration ratio," elaborates Keller.



Coal wagons line up: *South Korean industry depends heavily on imported coal as the country has limited natural resources and minerals of its own.*

CONVERTING COAL INTO NATURAL GAS



Coal is gasified using oxygen to create synthesis gas. The gas stream is conditioned and purified in the water gas shift and RECTISOL® unit. In the methanation stage, the gas reacts with a catalyst to form synthetic natural gas (SNG). This is then fed by pipeline to the steelworks.

This is no easy task. "The ratio can only deviate by a minimum in order to meet the required heating value of the SNG. This is a huge challenge in light of the natural fluctuations inherent in coal," continues Keller.

As with natural gas, SNG should also primarily contain methane, which forms when carbon monoxide (CO) and carbon dioxide (CO_2) react with hydrogen (H_2) at the catalyst, which is part of the methanation stage. The gases for this process are generated directly during coal gasification. However, they are not produced in the right ratio. The percentage mix of these three components can be tailored to application requirements using the water gas shift reaction with downstream acid gas removal (RECTISOL®). And this is exactly what Linde technicians have done in Gwangyang. Downstream gasification, they separate the gases into two streams. In the first stream, surplus carbon monoxide from the gasification process is converted in a process known as the water gas shift reaction. Here, the CO reacts with water vapour to create hydrogen and carbon dioxide.

The second stream is initially untreated (unshifted stream). It contains the raw synthesis gas in the component ratios resulting from gasification. "By implementing a smart control system for both streams, we can meet and guarantee the strict requirements for methanation," explains Keller. Linde has the technical expertise and years of experience in handling effectively requirements of this kind on an industrial scale. "We can assess how quickly changes during coal gasification at the start of the process chain will affect subsequent methanation," continues Keller. Therefore it is very important that the composition of the coal used in SNG plants is kept constant. Besides setting the correct ratio in the synthesis gas and convert it in the methanation stage, another key step involves purifying the gas. Impurities such as sulphur components and surplus carbon dioxide must be removed. These impurities influence the catalytic process of methanation and subsequently impact product quality. In South Korea, Linde is using the RECTISOL® process, a long-established method that uses the scrubbing agent methanol to separately remove the sulphur compounds and the CO_2 from the two different streams. Methanol contaminated with CO_2 and sulphur components are regenerated in one combined regeneration unit, resulting in a compact and highly efficient solution.

MANAGING GASES: GETTING THE METHANE MIX RIGHT.

A further highlight of the RECTISOL® process is the fact that the two components dissolved in the methanol can be regenerated separately and used for other processes. In the first regeneration stage, the pressure is decreased to produce sulphur-free CO_2, which can be used as a product itself or for further processes such as enhanced oil recovery or for CO_2 sequestration. In the second step, the methanol is heated, releasing highly concentrated sulphur components ideally suited for downstream processes to generate valuable sulphur products. The RECTISOL® unit is very flexible and can be easily adapted to individual customer needs during process design. For project manager Claude Keller, an SNG facility therefore extends far beyond SNG production. "We consider SNG plants as polygeneration plants for producing a range of different products." The sulphur components removed in the RECTISOL® process are also used in this plant. Linde technicians implemented an established process known as Claus process to produce high-purity elemental sulphur for other industrial applications.

High-purity carbon dioxide for industrial applications

It is the combination of all these steps that makes this SNG facility unique. "We are combining a two-stream synthesis gas treatment in addition to a combined RECTISOL® unit and sulphur recovery with methanation using the TREMP™ process. This has all been made possible through close collaboration between experts from two different companies," continues Keller. This includes the challenge of optimizing numerous and complex interfaces of heat and mass transfers to ensure efficient and economic operation. The result is a highly integrated, efficient and unique clean coal technology that sets standards for future projects. For POSCO chairman Joon-yang Chung, the SNG project is a prime example of how clean coal can be used to secure future energy supplies.

Energy for steel production: Imported coal (above) is converted to methane and used as a source of energy in steelworks (left).

LINK:
www.topsoe.com

SHORT INTERVIEW

"STEEL PRODUCTS ALSO SAVE ENERGY AND CO_2"

Linde Technology speaks to Hans Jürgen Kerkhoff, President of the German Steel Trade Association and Chairman of the Steel Institute (VDEh), about the importance of coal in the steel industry.

↳ HOW CAN THE STEEL INDUSTRY BALANCE THE NEED FOR ENERGY SECURITY WITH CLIMATE PROTECTION?

For energy-intensive steel production, security of supply and affordability are key factors in the face of international competition. In the EU, for example, fossil fuel prices have risen sharply. And emissions trading has dramatically increased energy costs for steel manufacturers over the past few years. But the transition to a new energy landscape should also accommodate economic criteria. We need a technically sound solution that is geared towards real-world industrial production, factors in the energy and CO_2 savings realised with steel products and acknowledges the unlimited recycling capabilities of this material. Because steel also contributes to climate protection: windmills, high-efficiency turbines and lightweight automotive materials save six times as much CO_2 as their production generates.

↳ TO WHAT EXTENT IS STEEL PRODUCTION DEPENDENT ON COAL?

For technical reasons, blast furnaces cannot be operated without coal or coke. The blast furnace/converter route accounts for around 70 percent of global crude steel production, or 1,060 million tonnes. This process route is also highly efficient, so it is unlikely that steel manufacturers will be able to do without coal in the foreseeable future.

↳ WHAT CLEAN COAL SOLUTIONS ARE VIABLE?

The use of coal in iron ore reduction inevitably results in carbon dioxide. These CO_2 emissions can be significantly reduced through carbon capture and storage (CCS). However, complex technical issues must be resolved and public acceptance must be won before this technology can be rolled out on an industrial scale. It is also associated with substantial additional costs, which, as things stand, steel manufacturers would not be able to finance in the face of current global competition.

Linde air separators for gas-to-liquids (GTL) plant

THE FUEL MACHINE

A petrochemical plant par excellence – operated by Shell, Pearl GTL is the world's largest facility for converting natural gas into liquid fuel. Eight Linde air separation units produce the enormous quantities of oxygen required for this process.

The desert is blooming. But it is natural gas, not water, that has brought the dry Arabian peninsula of Qatar to life. Where sandstorms previously swept across the parched land and debris, a huge industrial complex now hums – Shell's Pearl GTL (gas-to-liquids) plant. Here, natural gas is transformed into liquid fuel. The gigantic dimensions of Ras Laffan Industrial City are particularly impressive from the air: the Persian Gulf's engineering masterpiece comprises kilometres of pipelines, reactors, distillation columns and storage tanks, as well as eight of the world's largest air separation cold boxes, jutting out of the desert.

The natural gas comes from one of the world's largest reserves just off the coast of Qatar, which is home to 260 billion cubic metres of this volatile energy feedstock. Pipelines transport it around 30 kilometres to the GTL plant – "the largest construction site in the oil and gas industry," according to Andy Brown, Executive Vice President for Shell in Qatar and Managing Director of Pearl GTL. Towering behind him as he speaks is the immense industrial complex. 600,000 square metres of concrete were laid – enough to build Wembley Stadium seven times over. "And we could have built 15 Eiffel Towers with the 120,000 tonnes of steel that we used," adds Brown. A total of 48,000 people helped to build the plant. The first products were shipped from the GTL facility in June 2011: kerosene for aircraft, diesel fuel for vehicles and naphtha for the petrochemical industry.

Several process steps are required to convert the raw gas into these valuable products. First, other gas components – condensates – must be separated from the methane-rich stream through cooling. Every day, the plant in Qatar produces 120,000 barrels (1 barrel = 159 litres) of useful by-products such as propane, butane and ethane. These are used as base chemicals in a number of industries. Hydrogen sulphide, which occurs naturally in raw gas, must also be removed prior to the GTL process. The resulting sulphur is another important feedstock for the chemical industry. After these pre-purification stages, the resultant high-purity methane is piped to the GTL facility for the next process step. Oxygen is a key component here,

provided by eight air separation units (ASUs) from Linde. "The Pearl GTL project was the largest ever order in the history of ASUs," recalls chemist Dr Gerhard Beysel, responsible for development and sales of air separation plants at Linde's Engineering Division. But it was a long journey to secure such a strategic win – and a credit to the technical and economic viability of the impressive concept developed by Linde Engineering. The initial deliberations began over a decade ago, when the oil price was still at 12 dollars a barrel. By 2006, the year the contract was signed with Shell, the price of oil had already increased fivefold.

The contract was also Linde's most challenging ever in terms of oxygen production capabilities. "Part of the reason we got the go-ahead from Shell was that we offered a one-stop, turnkey solution as general contractor," Beysel explains. Linde also offers the benefits of global networking, which extends to both purchasing and manufacturing. According to Beysel: "This enables us to flank the highest quality with the best possible price."

140,000 barrels of liquid energy every day

The market logic behind this giant project in Qatar is clear: dwindling crude oil reserves and soaring prices make finding an alternative raw material for fuel increasingly urgent. Natural gas reserves are set to last significantly longer than oil. And, as Beysel puts it: "We can obtain cleaner, lower-emissions diesel from natural gas, as the harmful sulphur is much easier to separate than it is from crude oil." Another benefit is that, once converted into liquid products, natural gas is efficient to transport. "The maximum air separation capacity that can be built into a single strand is limited by the air compression step upstream of the liquefaction and separation processes," explains Beysel. That is why eight ASUs were required altogether to cover the huge oxygen demand at the Pearl plant.

"Carl von Linde began this story in 1902, producing five kilograms of oxygen per hour. Today, the Qatar plant has an hourly output of up to 1.25 million kilograms of oxygen," describes Beysel. That is around fifty times as much oxygen as the entire population of the emirate of Qatar needs to breathe in the same timeframe. Such quantities are rendered possible by powerful machinery, including compressors driven by steam turbines. "The GTL process releases a large amount of thermal energy, so there is enough steam available to power the eight air compressors – and it would be difficult to put it to good use otherwise," Beysel adds.

The oxygen from the Linde ASUs is combined with the methane to produce synthesis gas or syngas. This mixture of hydrogen and carbon monoxide is then piped into the actual GTL reactor, where Shell's specially developed catalysts are poised for action at a temperature of 1,350 degrees Celsius. "The reactor contains 5,000 tonnes of these catalysts," says Shell Director Brown. These fine particles have an extremely large surface area: "18 times the size of Qatar in total," he adds. The catalysts facilitate conversion of the syngas into long-chained waxy hydrocarbons.

These waxes are then sent to a refinery for further processing. Here, hydrocrackers split the long-chained hydrocarbons into shorter molecules, which are then distilled. In this way, the Shell plant produces 140,000 barrels of liquid fuel per day. Another product of the GTL reaction is water: "We actually obtain more water than waxes," clarifies Brown, "so the plant does not need to source additional water."

Installing the ASUs in Qatar was already a giant undertaking. The cold boxes at the heart of the units are 60 metres high and weigh 470 tonnes, containing the aluminium plate-fin heat exchangers and rectification columns. These key components originate from Linde sites in Germany and China, where the cold boxes for Qatar were assembled as packaged units. This pre-assembly reduces laborious on-site construction – a definite plus in Qatar, where scorching heat, dust and frequent sandstorms make this kind of work much harder. Needless to say, these conditions are an endurance test not only for people but also for materials and equipment. The temperature inside the cold boxes, for instance, must remain at minus 190 degrees Celsius – even at ambient temperatures of 50 degrees in the shade.

The steam turbines and compressors were produced by MAN in Oberhausen, Germany. There, all process strands were subjected to performance tests over several weeks to ensure they fulfilled the appropriate specifications. Only once this was successfully accomplished could the journey to Qatar begin. After the entire complex was put into operation step by step, the ASUs were officially handed over to Shell in March 2012. And Linde's experts are already working on the next, even higher-performance generation of ASUs. "GTL plants are also suitable for processing shale gas, which is currently taking the US market by storm," concludes Beysel. So the natural gas boom has only just begun.

QATAR

The natural gas field off the coast of Qatar is one of the world's largest, with reserves of 260 billion m^3.

Taking the O_2 out of desert air: 60-metre coldboxes are at the heart of the air separators (left). Heat and sand challenge both man and machine in Qatar (right).

LINK:
www.shell.com

↖ *Author: Caroline Zörlein*
↙ *Image source: Linde AG (2)*

A patchwork of peel:
Potatoes vary in both colour and taste – from fruity through strong and spicy to nutty and sweet. But whatever the type, they must be sprout-free to hit the market.

Keeping vegetables fresh with ethylene gas

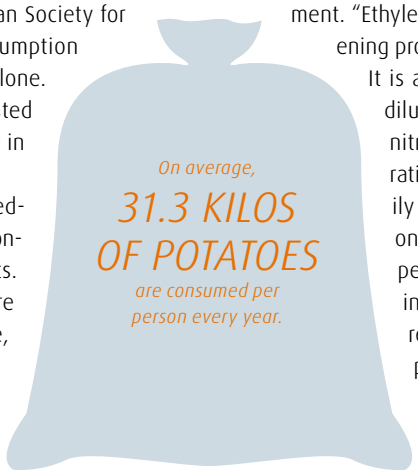
SPROUT-FREE TUBERS

When potatoes sprout, they can no longer be sold. A new technology from Linde uses a gas mixture modelled on nature to prevent unwanted germination and keep one of the world's most popular tubers fresh. The method is particularly kind to the environment and can even be used with organic potatoes.

↑ *Image source: Jonelle Weaver/Getty Images*
↓ *Author: Andrea Hoferichter*

The potato has conquered the world, growing even in the chilly climes of Greenland, on the earth's most northerly field. This humble member of the Solanaceae or nightshade family is now a global star. And regardless of variety or form, its popularity shows no signs of waning. According to figures from the German Society for International Collaboration (GIZ), potato consumption has risen 20 percent in the last twenty years alone. In total, around 320 million tonnes are harvested each year. And this figure is set to rise, above all in Asia and in many emerging countries.

The tuber could even play a key role in feeding the world's growing population. "Potatoes contain a lot of protein, nutrients and trace elements. They are just as nutritious as wheat but require only half the crop area," explains Silvia Henke, Market Development Food at Linde. In recent years, Henke has become a true potato expert. She has also developed a new technology that prevents potatoes from sprouting. In a retail environment, the appearance of shoots can condemn an entire delivery. It is not just a question of aesthetics or the fact that sprouting potatoes do not sell. The sprouts also contain the poisonous alkaloid solanine, which is why they have to be removed before consumption. "If a retail inspector finds just one sprouting potato, the whole delivery is destroyed," outlines Henke.



Linde experts have turned to the gas mixture BANARG® to combat this problem. Its active ingredient is the natural plant hormone ethylene, a simple molecule comprising two carbon and four hydrogen atoms. This compound sends the potatoes to sleep, arresting their development. "Ethylene is a slightly sweet-smelling gas used for ripening processes and leaf abscission on trees and bushes. It is also released by apples," continues Henke. To dilute the ethylene concentration, it is mixed with nitrogen, one of the main components of air, at a ratio of roughly 1:25. The mixture can then be easily handled without any risk to users, as ethylene only becomes flammable at concentrations of five percent or higher. The gas mixture is not itself an innovation. It has been used to ripen bananas in record time for many years, and its sprout-suppressing properties have also been common knowledge for decades. What has been missing is the right technology to enable its widespread use in the food industry.

Ethylene offers significant benefits over conventional sprout inhibitors, as it does not present any health risks to users or harm the environment and is even approved for organic potatoes. Most conventional agents use the synthetic chemical ingredient chlorpropham. "BANARG®, on the other hand, eliminates the need for extensive occupational safety measures and cost-intensive

residue checks that are required with conventional agents," emphasises Henke. By contrast, chlorpropham can irritate eyes if handled incorrectly and cause digestive and neurological problems. It is also suspected of being carcinogenic and takes a very long time to degrade. In Germany, potatoes that have been sprayed with chlorpropham must feature a label to say they have been treated. The undesirable side effects raise questions over whether chlorpropham will even be reapproved for use when it is up for renewal at the end of 2018.

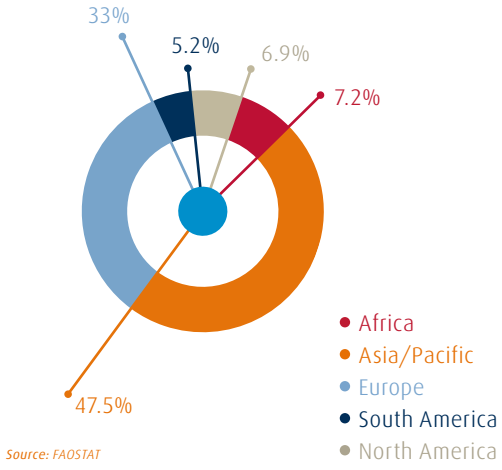
Technology proved the biggest practical hurdle to the use of environmentally friendly ethylene. "For the treatment to be a success, ethylene must be applied as effectively and consistently as possible across the entire warehouse," explains the potato expert. If there is not enough ethylene, it will not have the desired effect. Applying too much, however, causes potatoes to shrivel faster and even start sprouting again. "This can be an advantage for seed potato growers, as they can use the shoots faster," remarks Henke. Unsurprisingly, then, accurate dosage seems to be the weak point of an alternative procedure using the alcohol ethanol. In this rival method, the active ingredient ethylene is produced by a chemical reaction in the potato storage facility. "According to our measurements, however, this method is less exact and the concentration of ethylene in the air fluctuates greatly," reports Henke.

Sensors detect ethylene molecules

The gas mixture from Linde can be carefully controlled. To ensure precise dosage, Henke partnered with the company HTK Hamburg GmbH to develop a control unit with up to eight sensors that continually measure the ethylene concentration in the air at different positions in a potato warehouse. These sensors can even detect individual ethylene molecules among millions of air particles. "The control mechanism itself is actually very simple," explains Henke. "If there is too little ethylene in the air, the system opens a solenoid valve and feeds in gas. The valve closes once the ethylene content reaches a threshold value." The system also comes with an oxygen sensor as standard. "This ensures that the warehouse can be safely entered," reports Henke. Customers can then choose additional sensors that detect further key storage parameters such as humidity, carbon dioxide concentration and temperature. "The system can also be connected to the standard ventilation systems found in today's modern warehouses," concludes Henke.

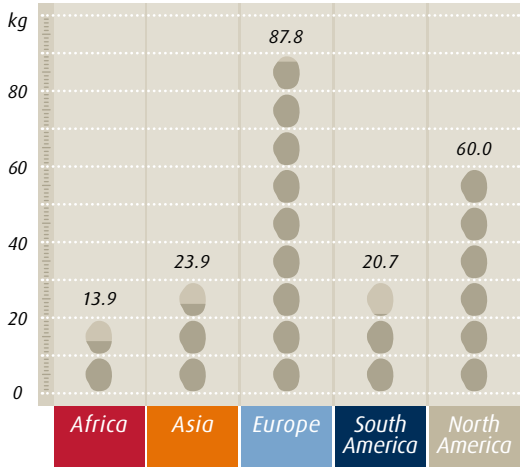
POTATOES AROUND THE GLOBE

Total production in 2010: 324 million tonnes



Source: FAOSTAT

Annual per-capita consumption in kilos



Ranked by size: *Sorting facilities separate large tubers from small. Damaged or sprouting potatoes are then removed by trained workers.*

RIPENING TOMATOES IN RECORD TIME

At the end of the growing season, sunshine is a rarity – and hundreds of green tomatoes wait in vain for harvesting. In greenhouses, up to four kilos per square metre might be waiting to ripen. Depending on the variety, this can affect the annual yield by up to ten percent. However, all is not lost for the unripe fruit. To change green to red, hot house operators harness one of nature's tricks: the plant hormone ethylene. Even small amounts of this gas ensure the fruit ripens within days – no sun required. Up to now, ethylene has been obtained indirectly, using etephon as the active agent. "However, this can easily lead to overdosage, leaving unwanted residues on the fruit," says Christoph Andreas from the Straelen horticultural centre, run by the Chamber of Agriculture in the German state of North Rhine-Westphalia. "Indeed, it is questionable as to whether this agent will even be permitted in future," adds Andreas. Linde's BANARG® gas mixture offers a safe alternative. Comprising nitrogen and four percent ethylene, it is already approved for bananas and onions in Germany; authorisation for tomatoes is still pending. Tests conducted in the Straelen centre's tomato greenhouses in November 2011 showed promising results: after a week at most, all the tomatoes were red. "The test series showed that just ten parts per million (ppm) ethylene is sufficient to produce positive results and yield tomatoes that are ripe for the market and full of flavour," reports Andreas.

Maturing fast: *The plant hormone ethylene reddens greenhouse tomatoes faster.*

From wooden barns to high-tech warehouses

The easyHTK MAPAX® control software, developed by HTK, records the measurements and displays them on a computer monitor for tight control over all storage variables. However, maintaining a consistent ethylene concentration was not the only challenge facing the engineers. They also had to adapt the system to the individual conditions and requirements at customer sites. "Potatoes can be stored in a wide variety of buildings," explains Henke, with structures ranging from simple wooden barns to high-tech warehouses. While some operators still use windows and hatches to ventilate, others work with modern ventilation systems. In addition, some potato varieties are more prone to sprouting than others – another factor to take into consideration when setting ethylene doses. Furthermore, every retail chain and processing company has its own expectations and requirements regarding appearance. "If the potatoes are being shipped whole to supermarkets, they have to look particularly appealing," says Henke. However, if they are going to be processed after storage, aesthetics do not play such an important role.

The new technology has proven its value in several pilot projects. One major German company that processes potatoes into convenience products such as dumplings and powdered mashed potato has confirmed that the Linde method delivers the same great results as conventional treatment with chlorpropham – but without the undesirable side effects. In November 2011, Silvia Henke was awarded first place in the "Young Engineers in Industry" category by the Association of German Engineers (VDI) for her success in applying BANARG® to potatoes. The new technology is currently only available in Germany. However, the Linde expert is sure that it will go on to be a global success – just like the potato itself.

LINK:
www.potato2008.org
www.cipotato.org

CO_2 cooling ensures high-quality welded joints

REDUCING STRESS IN SHEETS OF METAL

Sparks are flying in the steel sector. Metal sheets are now joined within seconds in both the shipbuilding and the automotive industries. However, the sheets sometimes become distorted after welding, requiring expensive reworking. Engineers at British Linde Group member BOC are part of a consortium of companies that have developed an innovative method to prevent this. It involves cooling the welding joint with CO_2. This has the potential to enhance production efficiency.

↙ Author: Bernd Müller
↘ Image source: Thomas Ernsting/laif

Every car starts out as metre-long steel sheets. These are punched, moulded and pressed in steel fabs, and gradually converted into various automotive body parts. Dozens of robotic welders with high-precision arms then set to work, producing a stable metal skeleton for the car. In their unprocessed state, as they leave the metal press, the steel panels are completely flat – placed on a level surface, they don't even wobble. This changes abruptly after welding, however. The welding head instantly heats the metal to 1,500 degrees Celsius, releasing energy that has built up in the sheet during rolling. When the welding joint cools down, significant tension often remains, with the material even contracting by around half a percent along the seam. As a result, the panel sometimes buckles to such an extent that it could be used as a seesaw.

SMOOTH WELDS THANKS TO TARGETED COOLING.

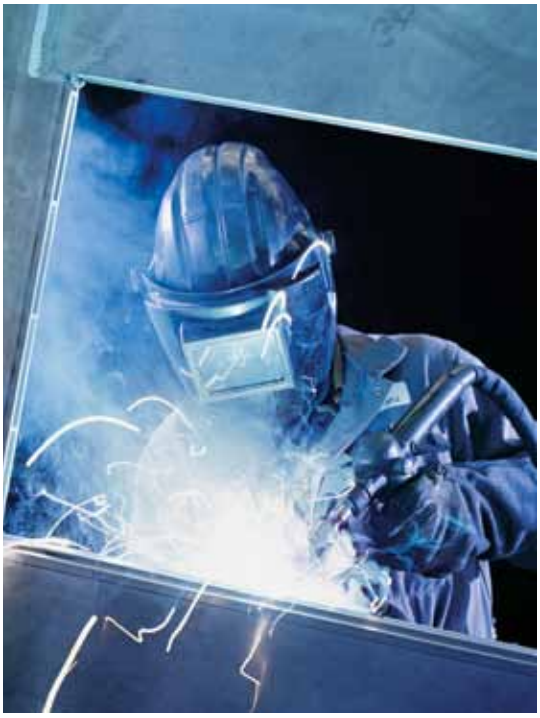
Cold companion for hot welding head

Car manufacturers are particularly affected by this issue, waging a never-ending war on welding stress. Some try to resist or counteract the distortion with additional material. However, this makes the part heavier, ultimately increasing fuel consumption of the car. Other alternatives may include laborious reworking of the component: optimised heat management or fixturing and clamping to remain within the stipulated tolerance band, but both options are expensive. Given the limitations of current approaches, the industry would warmly welcome workable solutions to this challenge.

"Local cooling is an option that shows definite promise," reveals Walter Veldsman, Senior Technology Specialist for production technologies at Linde Group member BOC. He explains that distortion is significantly reduced by intensively cooling the seam directly behind the welding head. This is borne out by mathematical models, computer simulations and practical tests – some of which were conducted by the Linde Gases Division's application technology centre in Unterschleissheim, Germany. However, in many real components, this positive effect only arises when cooling is applied to the same side of the sheet as the welding head – and as close to it as possible. Attempts to cool the welding joint from the underside of the panel, for instance, may be impractical on real automotive components.

In 2006, several companies and research institutes joined forces to prove the potential of this promising concept. The MALCO (Manufacture of Lightweight Components) project was coordinated by The Welding Institute in Cambridge, UK. BOC was largely responsible for developing the enabling technology. Steel users such as

Superior bodywork: *Steel parts make cars safe and robust. Combined with lightweight aluminium components, today's cars become fuel-savers.*



Flying sparks: Whether skyscraper facades, ship hulls or vehicle skeletons (right) – steel frames provide the necessary stability. Steel sheets are permanently welded together by hand (left) or using high-precision robotic arms.

Gestamp affiliate Tallent Automotive, Bentley Motors and Komatsu were also involved. Around one million pounds were channelled into the project, with half the funding contributed by the Technology Strategy Board – the UK government's innovation agency. "The MALCO project ran for four years. During that time, we learnt a huge amount and overcame all sorts of hurdles," Veldsman confirms.

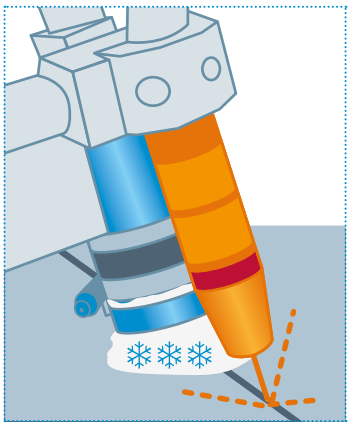
The biggest challenge was to apply the cooling gas as close as possible to the welding head, as its relaxing effect can only be obtained while the seam is still at a temperature of at least 500 degrees Celsius. At this heat, the metal is as pliable as warm plastic and the forces producing tension can simply be ironed out. "On the other hand, the cooling can't come too close to the head, or the arc is extinguished – like a candle caught in a draught," describes Veldsman. The Linde experts use carbon dioxide as the coolant. Drawing on long-standing experience, BOC covers the full competence chain to supply CO_2 and to pump the used gas out of the robotic cell.

To dispense the coolant precisely, BOC engineers have developed a special nozzle that releases around 370 grams of CO_2 per minute at high pressure. The interior of the nozzle is designed to accommodate an abrupt pressure drop. "Most of the liquid carbon dioxide stream solidifies instantly, so the nozzle shoots out tiny CO_2 pellets," outlines the Linde expert. These hit the hot welding joint and immediately sublimate. "The transition from a solid state directly to a gas produces an extremely effective cooling effect, even trumping that of colder liquid nitrogen," continues Veldsman. But this posed another challenge for the engineers: left to evaporate unchecked, the CO_2 risked disrupting the welding process near the head.

To prevent this, the MALCO-Team specialists developed a type of shield to enclose the cooling nozzle. However, the search for a suitable material proved harder than anticipated, since this "curtain" is positioned just 35 millimetres behind the welding head. Attempts with metal fibres backfired, as the material soon began to burn. This resulted in holes in the curtain where it moved along the red-hot welding seam, allowing CO_2 to escape and

HOT AND COLD COLLIDE

The engineers designed a special coolant nozzle, positioned behind the welding head. This enables precise application of liquid carbon dioxide to the hot joint. The pressure drop inside the nozzle shoots tiny CO_2 pellets onto the surface.



disturb the arc. "It was only when we hit on the idea of using glass and ceramic fibres instead of metal that we were able to overcome this hurdle," Veldsman explains.

Tests have shown that the new technology reduces distortion and buckling of certain components in the region of 40 percent. On this basis, the method is now ready for trials in factory conditions. The first port of call here is the car industry, starting with project partner Tallent Automotive, which supplies axles, subframes, chassis components and body parts to many European vehicle manufacturers. Together with The Welding Institute, Tallent Automotive and BOC jointly developed and patented the curtain technology for the cooling head.

Post-weld cooling prevents corrosion

However, the automotive business is not the only industry that stands to benefit from the new solution. "This new technology is beneficial wherever metal is welded – so also in shipbuilding, for instance," adds Veldsman. A report from the US Navy concludes that the direct or indirect reworking of metal parts distorted as a result of welding defects increases the cost of building a frigate by around three million dollars.

Weld cooling has the added bonus of solving another process challenge. It inhibits a hazardous process known as intercrystalline corrosion that can occur in steel. Students at the University of Birmingham conducted a project to investigate further. Also known as intergranular attack or weld decay, this phenomenon arises in otherwise corrosion-resistant steels when chromium bonds with carbon during welding. The reaction renders the chromium unable to protect the iron atoms prone to corrosion, so the metal gradually rusts – which poses a safety risk for load-bearing components in ships or vehicles. The students were able to demonstrate that CO_2 cooling reduces the reaction between carbon and chromium, and thus the likelihood of corrosion.

This discovery throws the spotlight on many more potential applications for CO_2 cooling. Deep-sea pipeline operators, for instance, also have to contend with rust along welding seams. And nuclear power plant operators must prevent stress corrosion cracks in the welds of reactor vessels, where the metal is subject to high internal tension. BOC has registered a patent for the prevention of these corrosion cracks through weld cooling. According to Veldsman, "The initial research stage is complete," and it is now a question of maturing the process technology for various industry applications. "The technology is 95 percent ready," the Linde specialist clarifies, "and the final five percent takes place on site." BOC already registered four patents in 2011, and more are set to follow.

LINK:
www.twi.co.uk

SHORT INTERVIEW

"THE WHEELS OF DEVELOPMENT HAVE TO KEEP TURNING"

Linde Technology speaks to Roger O'Brien, Research and Development Manager at Gestamp affiliate Tallent Automotive, about the MALCO project and the potential of weld cooling.

↳ WHAT PROMPTED TALLENT AUTOMOTIVE TO PARTICIPATE IN THE MALCO PROJECT?

When manufacturing a car, distortion due to welding can occur in all sorts of different places. Just welding a threaded nut into a pipe, for instance, can easily cause cracking. Parts then have to be reworked or even redesigned – and since so much is now done by computer and fewer prototypes are built, this kind of problem often only emerges near to or during series production. MALCO technology may allow us to prevent such disruptions in the future. And the wheels of development have to keep turning.

↳ IS THIS TECHNOLOGY READY FOR INDUSTRIAL DEPLOYMENT?

We are currently testing a robotic welder fitted with the cooling technology in real factory conditions, within our prototyping facility, but we have not yet transitioned it to series production. However, there are niche applications in which this method is already yielding benefits – for instance when centring and roundness are critical, so when welding a thin plate to the outer end of a pipe, for instance.

↳ IS WELD COOLING COST-EFFECTIVE?

When customers stipulate smaller tolerances for components, our costs rise – and at higher volumes, this becomes a significant factor. The price of reworking parts has previously driven costs up, but if we can stay within the required tolerances at the welding stage, this will no longer be necessary. So the process will automatically become more effective for us – and thus benefit our customers too.

Hydrogen innovation replaces diesel generators

PORTABLE POWER – CLEAN AND QUIET

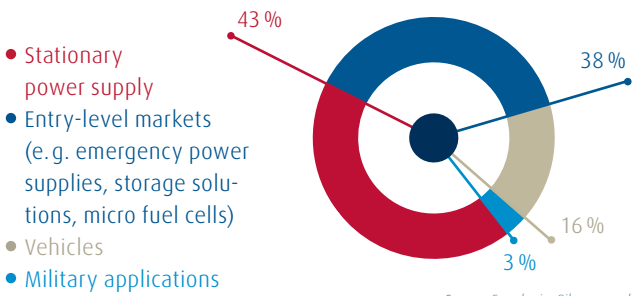
When electricity is needed off-grid, people usually turn to diesel generators. Now, though, Linde has developed an eco-friendly alternative: Hymera. This portable fuel cell significantly increases efficiency, runs at a whisper and produces zero emissions – all thanks to innovative hydrogen technology.

Electricity sometimes announces itself loud and clear – a dull hum and distinctive petrol-station odour are immediate telltale signs that power is coming from a generator rather than the grid. After all, most portable electricity supplies rely on diesel or petrol combustion engines. But that may now be set to change. In just three years, engineers at British Linde Group member BOC have developed the Hymera fuel cell generator in collaboration with Horizon Fuel Cells in Shanghai. This portable solution produces electricity from the reaction between hydrogen and oxygen; the only by-product being water. And it barely makes a sound – at around 45 decibels, you could practically take it to the library. Together, the generator and hydrogen cylinder (the oxygen is obtained from the surrounding air) weigh only 17 kilos – which is about the same as a holiday suitcase.

This peaceful and portable power source is gradually making a breakthrough across a wide range of applications. "We have just delivered a significant number to a water supplier," reports Stewart Dow, energy expert at BOC UK. The supplier is using Hymera to power its alarm systems and water-level monitors. Construction company Morgan Sindall, currently building new railway lines and tunnels in the London area, is also making use of the portable power source. "We need to measure noise levels, so a loud conventional generator is simply not an option," explains Casey Fleming, the company's

Power you can rely on: When it comes to measuring noise in underground tunnels (right), a quiet fuel cell is the solution of choice. These cells can also be used to power LED lighting at sports venues (top).

OUTLOOK FOR THE GLOBAL FUEL CELL MARKET IN 2017



Source: Freedonia, Pike research

Bundle of energy: A single H_2 cylinder can provide 40 hours of LED light.

Model of efficiency: The Hymera fuel cell delivers impressive power efficiency levels of 50 percent.

environmental protection officer. Linde's portable fuel cells also provide electricity for overnight track maintenance and ensure sufficient lighting. There are various other possible applications for Hymera in the construction industry too. The fuel cell is ideal for supplying electricity to portable offices, for instance, that are not yet connected to the grid.

Security services are emerging as the third sector to benefit from this technology. Here, Hymera is already providing electricity for isolated surveillance cameras that previously ran on batteries. Although popular, batteries have a major disadvantage – they have to be changed regularly, which is not only inconvenient but also liable to draw attention to the monitoring equipment. "We had to replace the batteries every four to five days, whereas the fuel cell allows us to keep a camera running around the clock for three full weeks," confirms Tom Ryan, responsible for business development at surveillance equipment specialist Advanced Monitoring in Dublin, Ireland. Last but not least, Linde's hydrogen innovation is also a plus for fans of festivals and other open-air events, where they are an attractive alternative to noisy, smelly diesel generators. For White Light, a leading British supplier to event organisers, Hymera cells and matching lightweight hydrogen cylinders from Linde have become an indispensable part of their event portfolio.

The Hymera fuel cell provides up to 200 watts of power. "That might not sound like much at first, but thanks to today's advances in energy efficiency, it is perfect for a wide range of applications," explains Dow. A few years ago, 100 watts and a conventional bulb might have provided sufficient lighting for your desk at home. Now, however, the same wattage can illuminate an entire tennis court in combination with modern LED lights. With a single cylinder of hydrogen, Hymera can generate up to three kilowatt-hours of electricity – enough to power LED lights for up to 40 hours or a modern laptop for an entire week.

Reliable, efficient and eco-friendly

Diesel and petrol generators usually supply electricity in the kilowatt range. There simply are no standard models available for lower wattages. "So a portable fuel cell offers a huge competitive advantage in the lower performance class," observes Dow. It is cheaper to purchase and to run thanks to Hymera's energy-efficient design. Conventional generators have efficiency levels of just a few percent at lower wattages, whereas Hymera achieves an impressive 50 percent. So not only does the new fuel cell go easy on our ears, health and wallets, it is easier on the climate too.

Batteries are the only power source that outperform fuel cells in terms of energy efficiency, but they lag behind in other areas – and not only when it comes to video surveillance. Lead-acid batteries are several times heavier, which affects portability. And while lithium batteries hold their own on the weight front, they are significantly more expensive. The photovoltaic sector represents another competitor for portable fuel cells, but is unable to match reliability and footprint. "Solar panels can't generate any electricity whatsoever at night – and only to a limited extent in areas subject to fog or shaded by trees," explains Dow. Even in optimum conditions, the amount of electricity produced still depends on the weather, so solar collectors have to cover a particularly large surface area to ensure a reliable power supply. "To run a 100-watt application, you need a three-kilowatt panel. In other words, a surface area of over 20 square metres, which in many cases just isn't feasible," summarises the BOC expert.

As the 200-watt fuel cell climbs the sales charts, the engineers already have their sights set on new models for other power classes, ranging from just a few watts to a few hundred. According to Dow, "Fuel cell technologies have already achieved a high level of maturity," so he does not anticipate any technical challenges in realising the new models. "As long as the manufacturers we are working with have all the necessary components available, we could be presenting market-ready models within the next year." Positioning these solutions on the market is a slightly bigger challenge, however, as the variety of potential applications is huge with no single "killer application". So far, though, after a long period of development fuel cell manufacturers are finally making in-roads into real markets. "It's a bit like the beginnings of the computer industry," reports Dow. "There are already between 50 and 100 applications that are efficient enough to run on a portable fuel cell – and the trend is clearly upward."

SO QUIET YOU CAN USE IT IN A LIBRARY.

LINK:
www.horizonfuelcell.com

Author: Andrea Hoferichter
Image source: Andreas Hub/laif, Bally/Keystone Schweiz/laif

Markus Bachmeier, Head of Hydrogen Solutions at Linde AG

H_2 mobility: An interview on the state of the art

"HYDROGEN THROUGH TO THE SEMI-FINAL"

Between advances in fuel-cell cars, new storage technologies and an expanding infrastructure, hydrogen mobility is taking shape. Markus Bachmeier, Head of Hydrogen Solutions at Linde, talks to Linde Technology about the latest technical breakthroughs and gives his views on the future of H_2.

↳ MR. BACHMEIER, LINDE HAS CARVED OUT A UNIQUE POSITION IN THE HYDROGEN SPACE. COULD YOU GIVE US A BRIEF OVERVIEW OF YOUR CURRENT ACTIVITIES?

Well, we are now at an intensive, fine-tuning stage. We have already demonstrated that hydrogen mobility is viable in numerous pilot projects. And the last few years have seen major advances towards market-ready systems and products in terms of both vehicles and infrastructure. 215 H_2 refuelling stations are currently in operation around the world – and there are concrete plans for over 100 more. It's now a question of taking all this to the next level. Our colleagues in Vienna are setting up batch production for ionic compressors, for instance, while our team in Munich is busy enhancing our cryopump technology. At the same time, we are holding in-depth discussions with all market players – from the car manufacturers through to energy providers – about further developments and projects. Hydrogen technology is steadily gaining in importance as a way of storing wind power, for example, and there are a number of promising approaches here ...

↳ ... ALTHOUGH THEY'RE ALL STILL A LONG WAY FROM MARKET MATURITY?

That may well be true. Establishing an infrastructure for new energy carriers requires a great deal of ground work – and that takes time. But in contrast with the shift from wood to coal and then to crude oil, we don't have half a century here.

↳ VARIOUS TRENDS – SUCH AS THE NEED FOR CLIMATE PROTECTION, THE TRANSITION TO RENEWABLE ENERGIES AND THE PACE OF DEVELOPMENT IN EMERGING ECONOMIES – ARE ALL

UPPING THE STAKES. MANY MOBILITY STUDIES AND PROGRAMMES HAVE EARMARKED 2015 AS A SIGNIFICANT MILESTONE. WHERE WILL HYDROGEN MOBILITY BE BY THEN?

We will continue to press ahead with efforts to expand the H_2 infrastructure – that much is clear. Our project with Daimler to build 20 new H_2 fuelling stations will most likely be an important driver, for instance. I expect to see a significantly higher number of hydrogen refuelling stations by 2015. New initiatives have also sprung up in the UK, Scandinavia, France and Benelux, while existing projects are being expanded in Japan and the US. And in South America, the Brazilian city of São Paulo is now planning a fleet of 25 hydrogen buses. We've already reached the stage where "just" opening a new hydrogen refuelling station is no longer big news for the general public – or even the media. Other companies are also now showing a growing commitment to hydrogen infrastructure and hydrogen-powered cars. The Mercedes B-Class F-CELL went into small-series production in 2010 with almost 200 vehicles for Europe and the US, and larger batches are set to follow from 2014. Toyota, Hyundai and GM/Opel are also aiming for series production of fuel-cell cars in 2015, and the Chinese manufacturers are heading along the same path. Linde is one of the key pacemakers here – and we intend to keep it that way beyond 2015.

↳ AN OUT-AND-OUT RACE HAS EMERGED BETWEEN BATTERY-POWERED AND FUEL-CELL VEHICLES. WHICH WOULD YOU PICK AS THE WINNER?

I don't have a crystal ball, so can only look at the facts and market data. As I see it, we've now come back down to earth after the massive hype that initially surrounded electromobility – as was also the case with hydrogen, in fact. Everyone involved has recognised that several crucial issues still need to be worked out. Linde holds proven expertise in hydrogen technology, which it will steadily continue to build on. And the prospects for H_2 technology have been greatly enhanced through the growing engagement of completely new market players. The market is now highly dynamic, even bringing back players who had already left the pitch – or at least retired to the bench. Staying with the football analogy, I'd say that in the league of alternative fuels, hydrogen has already reached the semi-final.

↳ AND GIVEN THE CURRENT FUEL PRICES, WE MUST BE GETTING CLOSE TO THE FINAL?

Well, first and foremost, the non-stop rise in petrol and diesel prices shows us how important it is to establish alternatives in good time – not only from an environmental perspective, but also from an economic and social standpoint. After all, we still want to enjoy personal mobility twenty years down the line – and be able to finance it. Hydrogen offers an eco-friendly and sustainable option here. And that's why I think it is crucial that we continue this journey in close collaboration with industry partners and government bodies. Petrol prices could increase a lot faster than we can set up infrastructures for alternative fuels, and that's what we must avoid.

↳ LINDE HAS ALSO REACHED ANOTHER IMPORTANT MILESTONE WITH GREEN HYDROGEN CERTIFICATION, HASN'T IT?

That's right. For the first time, green hydrogen from Leuna gives us a certified fuel to power zero-emissions fuel-cell vehicles all over Germany.

↳ WOULD YOU VENTURE A PREDICTION ABOUT THE STATE OF PLAY IN 2025?

Predictions age quickly these days. But what is certain is that we will continue working with our research and industry partners to test more materials and advance technologies aimed at sustainable generation and usage scenarios for H_2. Our aim for 2025 is to be a good deal closer to a global, green hydrogen mobility landscape – and to enjoy an attractive share of that market.

LINK:
www.cleanenergypartnership.de

CERTIFIED GREEN HYDROGEN

In Leuna, Linde produces green hydrogen from by-products of the biodiesel manufacturing process – and this has now been certified by TÜV SÜD, Germany's leading inspection and certification body. As demonstrated at the pilot facility, the pyroreforming process developed by Linde to convert raw glycerine already has the potential to reduce greenhouse gas by over 50 percent in comparison with conventional hydrogen production from natural gas. A mature, commercial production plant could deliver savings of up to 80 percent. Linde also supplied green hydrogen for fuel-cell vehicles from GM/Opel, Volkswagen, Honda and Toyota at Germany's Hannover Messe trade fair in 2012, using its trailH_2-gas mobile refuelling unit.

↵ Interview: Michael Kömpf
↵ Image source: Linde AG

Thirsty fields: *Agriculture guzzles 70 percent of the total water consumed worldwide. In dry regions, rainfall is insufficient, so seawater desalination is growing in importance.*

Carbon dioxide for the right water chemistry

QUENCHING THIRST WITH SEAWATER

Water is in short supply, and not only in the desert – rivers are running dry and groundwater levels are sinking the world over. Desalination systems tackle this global problem by making seawater drinkable, but it has to be specially treated before it is fit for human consumption. This is where Linde's CO_2 technology comes in, helping to make the most of our precious H_2O.

↑ Image source: Janet Forster/Getty Images
↓ Author: Caroline Zörlein

The earth's water resources are becoming increasingly scarce. Many regions are already suffering from acute shortages and the situation is escalating. The factors causing this vital resource to dwindle are widely recognised: the mounting impact of climate change, rising water consumption as the world's population continues to expand and changing lifestyles. Above all, agriculture and the growing consumption of meat are swallowing up a great deal of this valuable liquid. Industry, too, requires water for the production of everything from cars and plastics to drugs.

Looking at our blue planet, you wouldn't know that it is short of water. After all, it covers almost two thirds of the earth's surface. But of these 1.4 billion cubic kilometres of H_2O, directly usable freshwater accounts for just 2.5 percent – of which almost 70 percent is trapped in glaciers. In addition, the distribution of this freshwater is extremely uneven. "Booming metropolitan areas of Asia, in particular, are housing more and more people and becoming steadily thirstier," reports Dr Stefan Dullstein, Head of Aquaculture & Water Treatment in Linde's Gases Division. "And what's more, these densely populated areas are often located in regions that see little rainfall in the first place."

3 LITRES
of water go into producing one beverage can.

11,000 LITRES
of water are needed to make one pair of jeans, enough to fill an entire swimming pool.

380,000 LITRES
of water are consumed in manufacturing a car.

The importance of groundwater, then, is increasing. According to the United Nations World Water Development Report (WWDR), it now accounts for almost half of the world's total drinking water. However, groundwater levels are rapidly dropping around the globe – in some cases by as much as a metre each year.

At the World Water Forum held in March 2012 in Marseille, France, environmental protection organisations warned that global water problems are set to grow more acute. "The situation in Western Europe may be largely relaxed at present but that does not alter the fact that we are already in the midst of a global water crisis," states Martin Geiger, Head of Freshwater at WWF Germany. An analysis by the environmental group reveals that since the millennium, there have been over fifty violent conflicts worldwide related to water usage.

While clean water is a matter of course in industrialised nations, the UN reports that around 900 million people across the globe have insufficient access to safe drinking water. Its estimates indicate that two thirds of the world's population will be affected by water shortages in 2025. And a current study warns that, from 2070,

Central Europe could also be hit. According to the United Nations Educational, Scientific and Cultural Organization (UNESCO), another fact is often overlooked: many developed countries meet their growing water requirements with the help of poorer nations. The UK, for instance, imports 62 percent of its total consumption as 'virtual' or 'embedded' water in the form of rice and meat – the production of which entails large quantities of H_2O.

Balanced water chemistry thanks to CO_2

Many regions of North Africa, the Middle East, Australia, Mexico and the US rely on seawater desalination to provide water for both drinking and agricultural use. According to the German Desalination Society (DME), there are now around 12,000 sizeable desalination plants around the world, producing a total of 36 million cubic metres of drinking water each day – and that figure is on the rise. Seawater desalination has thus become a global growth market.

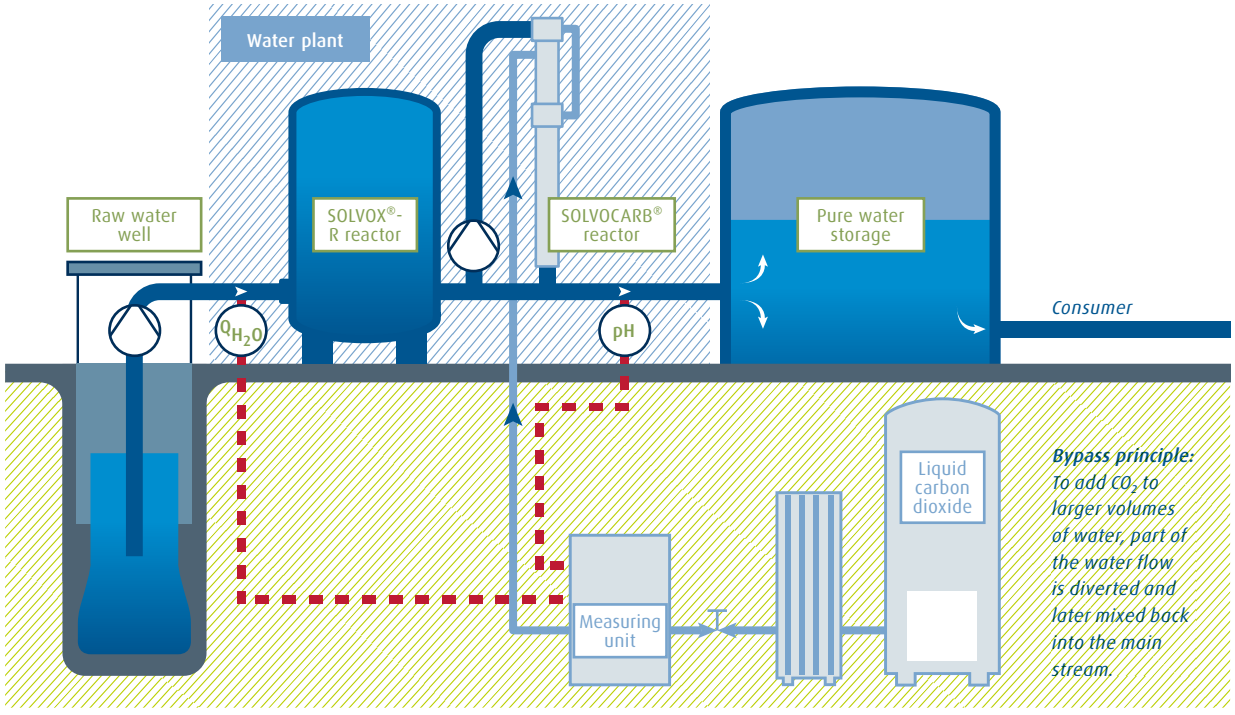
"However, desalination initially produces pure H_2O – in other words, water without minerals. And that can't be used for drinking or watering fields," explains Linde engineer Dullstein. Drinking water normally contains many different minerals, including calcium and magnesium compounds. To add these important elements, the pH value of the water must first be lowered. One way to achieve this is by acidification with hydrochloric or sulphuric acid. A more natural and environmentally friendly alternative comes in the form of carbon dioxide, avoiding unnaturally high concentrations of chloride and sulphate compounds in the water.

The benefit of carbon dioxide is that "It also occurs naturally in freshwater," as Dullstein elaborates. A small part of the gaseous CO_2 reacts with water to form carbonic acid, a "weak" acid characterised by its high buffer capacity. This means that the pH value of the water barely changes, even when acids or bases are added. "That is vital to balance the water chemistry," the Linde engineer continues. "If you then run the slightly acidic water through a limestone filter or add lime milk, the calcium both contains dissolves into the water as calcium bicarbonate." If the carbonic acid content and calcite (calcium carbonate or lime) concentration is in equilibrium, calcite will neither be dissolved nor precipitated. Excess CO_2, however, attacks pipelines and causes corrosion damage to concrete and metal pipes. If, however, the water contains too little dissolved carbon dioxide, unwanted limescale deposits in pipes and taps are the result.

To get this balance right and ensure the correct CO_2 dosage, Linde engineers have developed the SOLVOCARB® solution. This offering covers everything from the gas supply to installation of the entire control system, including pressure regulators, valves and injection systems. Whether the carbon dioxide is injected into the water through perforated hoses, reactors or nozzles depends on the plant

DRINKING WATER – GETTING THE BALANCE RIGHT

First, the raw water undergoes a quality check (Q_{H_2O}). If it contains high metal concentrations, these are removed using oxygen in the SOLVOX® unit. Next, the SOLVOCARB® reactor adds carbon dioxide, stabilising the water's pH value.



Water on standby: A technician checks the reverse osmosis equipment required for seawater desalination (top). Before the raw water (left) can be used, it must pass through Linde's CO_2 enrichment system, SOLVOCARB® (right, front).

dimensions and specific site requirements. The SOLVOCARB®-D process, for instance, was developed for CO_2 injection into pressure pipelines. Here, the gas is fed directly into the raw water stream through a stainless steel nozzle. However, this method takes time, which means that a reaction section is necessary for the carbon dioxide to dissolve. This prompted the Linde specialists to develop a different solution for larger volumes of water: "In that case, we divert part of the water flow and set up a bypass. This secondary stream is heavily enriched with CO_2 delivered through special nozzles or reactors before rejoining the main stream," describes Dullstein.

H_2O FOR MEGACITIES – CHALLENGE OF THE FUTURE.

Simulations for optimum CO_2 supply

The Linde team has installed a SOLVOCARB® pressure saturator at an Algerian seawater desalination plant near the Moroccan border. Here, 2,000 tonnes of carbon dioxide bubble into the valuable liquid each year, making it fit for human consumption and use in local agriculture. This entails tank systems complete with liquid CO_2, vaporisers, plus pressure and flow regulators – all in duplicate to guard against any possible malfunction. Without the CO_2 technology from Linde, not a single drop of water would leave the treatment facility.

In Australia, too, the Sydney Desalination Plant relies on carbon dioxide. This drinking water facility uses CO_2 generated by industrial processes to convert the blue gold into a usable resource. Each year, up to 6,000 tonnes of the gas flow into the plant, which then produces up to 250 million litres of water per day – around 15 percent of Sydney's water requirements.

But the efforts of Linde's engineers extend beyond achieving the right balance at desalination plants. "Water from lime-poor regions or dams usually also has insufficient buffer capacity, so needs extra CO_2. The requirements depend heavily on local geological conditions," explains Dullstein. The greatest challenge at drinking water plants is ensuring the gas is dispersed evenly throughout the huge volumes of water. To develop an efficient solution for each set of requirements, the gas specialists rely on fluid dynamics simulations.

"The operator of a drinking water plant in Australia had some concerns about whether the carbon dioxide would be evenly distributed, since the water there flows through an artificial, open channel," recalls the engineer. Using the simulations, the Linde experts were able to dispel all concerns. They found that, having enriched the bypass water with CO_2, injecting it back into the main stream with several nozzles produced the necessary level of agitation to ensure an optimum mix. Varying the injection depth and nozzle direction allowed Dullstein's team to find the best constellation. "Our recipe for success here is to develop tailored solutions together with our customers. Thanks to our expertise, they can always be certain that sufficient quantities of CO_2 will be available in the right place at the right time," confirms the Linde specialist.

Looking to the future, the know-how of Linde's water experts is set to remain in high demand. Booming megacities, in particular, face major challenges in providing sufficient drinking water for their inhabitants. Improving and sustaining the world's drinking water supplies is a mammoth task – and one to which Linde's gas specialists are proud to contribute.

LINK:
www.waterfootprint.org

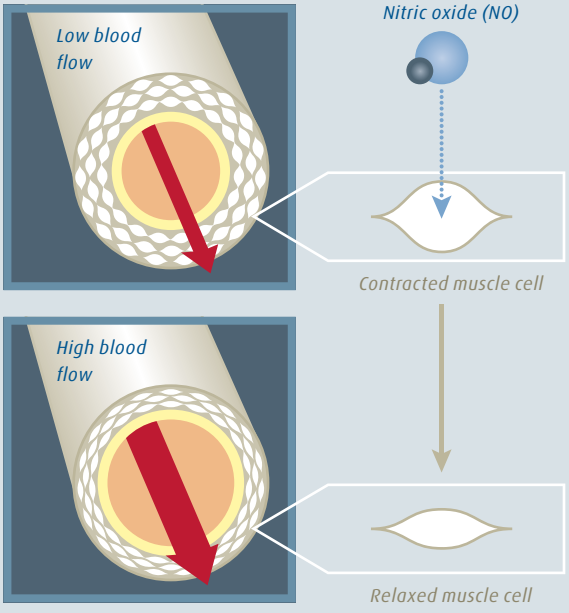
Heart surgery: nitric oxide relaxes constricted pulmonary arteries

RELIEVING THE PRESSURE

Acute oxygen deficiency places the entire body under stress. This can happen in association with pulmonary hypertension, a condition that can occur, for instance, before, during or after heart surgery. Linde's INOmax® therapy can provide fast relief. It contains the medical gas nitric oxide, which relaxes the constricted arteries and subsequently improves heart function and oxygenation.

Heart surgery is a serious procedure. The patient's life – whether child or adult – often hangs by a thread during an operation. Although many procedures such as bypasses, heart valve replacements and organ transplants are now routine, they still require a full medical team and complete concentration. "During an operation, a patient's condition can change dramatically at any time," explains Berit Lindh at Linde Healthcare in Lidingö, Sweden.

In some patients, the arteries that carry blood from the heart to the lungs constrict during surgery – with dangerous consequences. Known as vasoconstriction, this process gradually increases blood pressure in the pulmonary arteries causing pulmonary hypertension and subsequently right heart failure. As a result, less oxygen from inhaled air is transferred from the lungs to the bloodstream. This puts extra strain on the cardiovascular system and could result in severe oxygen deficiency throughout the entire body. In intensive care, there are several ways of preventing this process and stabilising a patient's condition. INOmax® therapy, which uses nitric oxide (NO), is one of these. "Clinical studies have shown that treating patients with NO reduces the increase in pulmonary artery pressure," says Lindh. "This, in turn, improves right heart function, blood circulation and improves oxygenation and oxygen delivery."



Improving blood flow through relaxation: *When muscle cells contract, vessels narrow and restrict blood flow. NO relaxes muscles, increases blood flow and improves oxygen supply.*

Inhaled NO works specifically on pulmonary circulation

Around 420,000 heart operations are performed in Europe each year. When a patient inhales the medically approved NO gas along with air, it is absorbed by the pulmonary alveoli, and from there by the pulmonary arteries, where it triggers a biochemical reaction. This process was demonstrated by US researchers Ferid Murad, Robert Furchgott and Louis J. Ignarro – all of whom received the 1998 Nobel Prize in Physiology or Medicine for their work in this area (see breakout box). INOmax® acts like NO produced naturally by the body, signalling the arteries to relax and expand. If nitric oxide (nitroglycerine) is administered intravenously, it relaxes all arteries and increases blood flow and the supply of oxygen to all organs and tissue in the body, which may lead to a drop in blood pressure. Inhaled nitric oxide

NO – SMALL MOLECULE, BIG IMPACT

The 1998 Nobel Prize in Physiology or Medicine was awarded to the scientists who demonstrated the properties of the two-atom molecule nitric oxide (NO). NO is created in endothelial cells, in other words, the layer of cells that lines the interior surface of arteries. It is a signalling molecule that quickly diffuses to the deeper smooth muscle cells, where it activates guanylate cyclase (GC). This is the enzyme that then produces the messenger cyclic guanosine monophosphate (cGMP), the actual signalling molecule that relaxes the smooth muscle cells. As cGMP levels in muscle cells in the pulmonary arteries increase, the vessels become more flexible, and this, in turn, reduces blood pressure from the heart to the lungs.

↑ Author: Clara Steffens
↳ Image source: Linde AG

has the major benefit of being transported via the airways directly to the point where it is needed. "Inhaled NO works specifically on pulmonary circulation," emphasises Lindh. It selectively reduces the pulmonary artery hypertension, eases the strain on the right heart and improves oxygenation.

Linde Healthcare has been supplying the INOmax® inhalation gas for almost 12 years. This gaseous drug has already helped around 300,000 patients in intensive care. INOmax® has been approved for treating pulmonary hypertension in newborns since 2001 and has become the standard treatment for hypoxic respiratory failure. The European Commission recently approved INOmax® for a new indication, which allows it to be used during cardiac surgery as a treatment for peri- and post-operative pulmonary hypertension in adults and children of all ages. In future, around 10,000 patients will benefit from INOmax® therapy each year across Europe. Treatment normally lasts between 24 and 48 hours. If necessary, however, NO can also be inhaled over several days. "Regardless of how long a patient has been inhaling NO, it is crucial that the treatment is withdrawn gradually," warns Lindh. Weaning patients off the treatment too quickly can lead to a rebound effect, where pressure in pulmonary arteries increases again and circulation destabilises.

Linde Healthcare offers training courses for critical care medics, anaesthetists and nursing staff. In the courses, they learn about the best ways of weaning patients off treatment as well as how to determine optimum NO concentrations for individual patients and how to best start treatment. "With INOmax®, we offer much more than just a drug. We provide hospitals with an all-round therapy package that includes equipment as well as clinical support and training, covering everything from service provision to technical assistance," explains Lindh. "Our INOvent® administration system can be attached to all conventional ventilator supply modes and ensures that the correct concentration is fed into the oxygen/air mixture," continues Lindh. To ensure reliable, accurate NO concentrations over time, Linde Healthcare also regularly services and maintains the equipment, thus ensuring that patient safety is never compromised. "Approval from the European Medicines Agency gives doctors and nursing staff the reassurance of knowing that they can treat patients presenting symptoms matching the new indication with an approved drug product," explains Roel Kellenaers, Head of Global Marketing, Sales and Business Development, Linde Healthcare.

"Overall, INOmax® is a very safe therapy," states Lindh. As with all medicines, however, side effects cannot be excluded, but no major signs of safety concerns have emerged and these are normally dependent on the dose applied. Some patients, for example, have shown a lower number of platelets and therefore longer bleeding times. Nitric oxide is not just used to relax arteries in the event of pulmonary hypertension during heart surgery. Oral nitric oxide administered as nitroglycerine has long been used to treat angina pectoris. NO also plays a key role in relaying signals between nerve cells in the brain and is crucial for the body's sense of smell and immune defence. Research into the different underlying reactions is being carried out across the globe, unlocking a wealth of medical potential for this unassuming colourless gas.

LINK:
www.nhlbi.nih.gov/health/health-topics/topics/hlw/system.html

Oxygen ups efficiency of biotech processes

TURBO BOOST FOR CELL FACTORIES

Dwindling supplies of crude oil are forcing industry to step up the search for new, regenerative raw materials. Mother Nature may well hold the answer. And biotechnology has the key to unlock this potential, with microorganisms that have been custom-developed for specific applications. Experts from Linde Gas Germany and Linde Engineering Dresden aim to get even more out of these tiny cell factories by using oxygen.

↵ Author: Caroline Zörlein
↳ Image source: Science Photo Library/Agentur Focus

Living cells have neither a degree in biology nor a PhD in chemistry, yet they still master a complex biochemical process chain. Humans have been harnessing the talents of single-cell organisms such as bacteria, yeast or fungi for a long time now. Cheese, wine, yoghurt and penicillin are just some of the most well-known examples of what microorganisms can achieve. The metabolic processes in the cells dovetail to perfection – no chemical engineer could have come up with a better design blueprint.

Industry has long recognised the potential of these cell factories. Today, manufacturers harness nature's innovative powers to manufacture pharmaceutical ingredients, base chemicals and biofuels. "Microorganisms are particularly efficient at converting biomass into useful compounds," explains Johann Kaltenegger, application engineer in the chemicals market development team at Linde Gases Division. "Which means that biotechnology has the potential to completely transform the chemicals industry by transitioning it to a green value chain."

Tailored bacterial strains and specially cultivated animal cell cultures are a much more cost-efficient, sophisticated way to produce complex active agent molecules, enzymes and bulk chemicals such as citric acid or animal feed additives such as the amino acid lysine. "Fermentation is one of the key processes in biotechnology. It involves the industrial-scale cultivation of microorganisms that convert substances such as glucose or starch into chemical products," continues Kaltenegger. These tiny chemical factories live in huge containers made of stainless steel known as fermentation reactors. The reactors are filled with a liquid nutrient solution that can be heated, cooled, aerated and stirred. The majority of commercial cells thrive and multiply rapidly at temperatures between 30 and 40 degrees Celsius.

"In addition to sugar-rich food, microorganisms also need oxygen in order to manufacture many of the by-products," states Dr Michael Buchmann, discipline manager for industrial biotechnology at

BUILT ON SUGAR

Sugar is crucial for industrial biotech processes. Most of the sweet raw material for the industry stems from sugar cane or sugar beet as well as from corn, wheat and manioc. Worldwide, microorganisms convert 160 million tonnes of carbohydrate each year. Since the start of the new millennium, however, global demand for sugar has regularly outstripped production. The US and Brazil lead the field here, using more than three quarters of global sugar supplies for fermentation – primarily for the production of bioethanol. The twenty seven member states of the EU use around 5.5 million tonnes of carbohydrates for industrial biotechnology. Researchers the world over are working hard to convert residual agricultural materials and wood into sugar in order to ease growing conflicts with food supplies.

Figures: ECO SYS

Breath of fresh air: *Microorganisms in a fermenter grow faster with oxygen. The right oxygen concentration can often increase product yield of biotech processes.*

Chemicals go bio:
The perfect growth conditions for organic cells are created in giant stainless steel fermenters (left and bottom right). Getting the oxygen supply right is a key step in the cultivation of bacteria (below) and in the fermentation of animal cells, used for instance to produce mono-clonal antibodies (bottom left).

Linde Engineering Dresden GmbH. This is because many fermentation processes in the pharmaceutical and specialty chemicals industries are aerobic – in other words, they require oxygen. O_2 is crucial for cell life. It is essential for respiration, also stimulating and intensifying many metabolic processes. And in the case of many biotech processes, the more biomass the cells produce, the higher the exploitable yield. So optimum growing conditions inside a fermenter translate directly into higher productivity. A stirring unit ensures that the cultivation solution is mixed properly. "If more oxygen is required, the stirring speed has to be increased to accommodate cell growth. This improves the dispersion of air bubbles fed into the container and increases the oxygen supply due to the larger surface area," says Dr Karl-Heinz Schneider, Global Drug Discovery at Bayer AG.

More oxygen, less mixing

"At 21 percent, natural oxygen content in the air is usually too low to ensure optimum oxygen levels, particularly if manufacturers want high growth rates," explains Buchmann. This can lead to oxygen deficiency and slower cell growth – especially if the mixture is very viscous. "To ensure that sufficient amounts of O_2 are dissolved in water under these difficult conditions, the solution must be vigorously mixed or the gas pressure increased," adds Kaltenegger. There are downsides to both of these options, however. Vigorous mixing can damage or even destroy sensitive cells. "The biotechnological production of mono-clonal antibodies almost exclusively uses animal cells that are extremely sensitive to shear stress," explains Johanna Leisling, application engineer in the chemicals market development team at Linde Gases Division. These cultures must be stirred gently.

BIOTECH TAKES IT UP A GEAR – O_2 INCREASES EFFICIENCY.

"To meet the rising O_2 needs of these cells, they are fed a mixture of air and oxygen," continues Schneider. "A pure source of oxygen is a must for the fermentation of animal cells," explains the expert from Bayer. Especially as the alternative – increasing the pressure of the O_2 supply – also has its drawbacks. Although this enables the cells to absorb oxygen more easily, it also makes it more difficult for them to release carbon dioxide into the surrounding solution. This reduces the cells' ability to breathe and makes them less productive.

The experts at Linde's Gases Division have teamed up with colleagues at Linde Engineering in Dresden to solve the O_2 deficiency challenge. They are working on a solution to enrich fermentation atmospheres with pure oxygen. "Some customers in the pharmaceutical sector, for example, have already expressed interest in a more O_2-rich gas. These customers often use a particularly pure synthetic gas mixture comprising 20 percent oxygen and 80 percent nitrogen due to the sensitivity of their cell cultures," confirms Buchmann. Lab tests have already shown that aerobic fermentation processes benefit greatly from increased oxygen levels. Linde engineers have

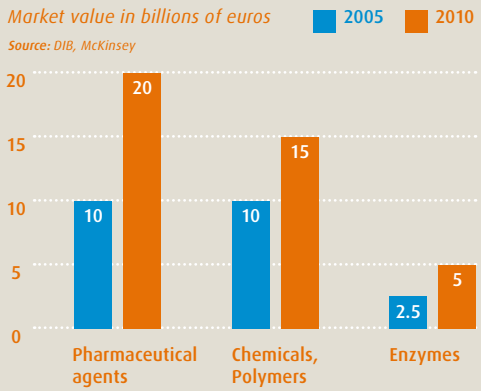
carried out profitability analyses and computer simulations to underscore the benefits for industrial-scale biotech processes. "We based our work here on the bacterium Escherichia coli, which we cultivated in a 50 cubic metre fermenter. This is a conventional biotechnology system used, for example, to manufacture insulin. The simulation models enabled us to accurately investigate the amount of biomass that forms over time with natural air and the amount that forms with an enriched oxygen atmosphere," outlines Buchmann.

Cell cultures in oxygen bath

The results speak for themselves: increasing O_2 content to 30 percent pushes up growth rates, resulting in 50 grams of biomass per litre after just 15 hours. By contrast, using air from the surrounding atmosphere in the fermenter means that just 30 grams of biomass is produced per litre after a period of 60 hours. Increased oxygen levels in the reactor also raise cell density, thus enabling a larger number of microorganisms to be cultivated in the same space. In other words, adding oxygen turns fermenters into high-performance factories. "Oxygen improves biotech process efficiency," explains Buchmann. "This leads to higher growth rates over shorter periods of time and subsequently greater yields." The additional oxygen also reduces the amount of gas that bubbles through the solution. In many cases, this reduces the amount of foam in bioreactors, eliminating the need for chemical anti-foaming agents that can disrupt the biotech process.

Rapid microorganism growth, however, also comes with its own risks. "When cells metabolise at a high rate, they produce significantly more heat, which in turn requires more powerful cooling systems," states Leisling. This extra equipment, however, soon pays for itself. The profitability analyses carried out by Linde experts show that process acceleration, energy and nutrient savings and lower waste water levels more than compensate for this initial outlay. "In addition, installing an O_2 system is a simple step. This is because bioreactors are already equipped with an air inlet," outlines Leisling. Linde's OXIMIX® oxygen supply system and FLOWTRAIN® measurement and control system can thus be easily integrated.

BIOTECH MARKET GROWING RAPIDLY



THE COLOURFUL WORLD OF BIOTECHNOLOGY

The different fields of application in biotechnology are colour coded. **White biotechnology** harnesses natural resources such as bacteria, yeast cells and enzymes for industrial production. These agents have been enriching people's diet for thousands of years. Wine, bread, beer, cheese and yoghurt are just some of the everyday products generated with the help of these microorganisms. Today, these cell factories are also used to manufacture base and specialty chemicals.

Red biotechnology gets its name from the colour of human blood. It is the largest field in biotechnology and focuses on the development of new therapeutic and diagnostic processes, for example medicines such as antibodies and hormones. It builds on the scientific foundations of modern gene research.

Green biotechnology gets its name from the green leaf dye chlorophyll. It involves the cultivation of new types of plants and also uses molecular methods to improve the properties of commercial plants, for example, and to develop new agricultural crops that produce higher yields.

Blue biotechnology focuses on ocean-going organisms. Heat-resistant enzymes from deep-sea bacteria that live close to hot, undersea volcanoes are of particular interest to researchers.

The oxygen-fuelled turbo growth process is set to be investigated further by a research group at the Chemical-Biotechnological Process Centre in Leuna (see article in LT #2/2011). Researchers from the Fraunhofer-Gesellschaft have teamed up with Linde engineers and other industry players and research bodies to develop new biotech processes, for instance. "Despite all of these benefits, the biotech scene is still somewhat sceptical," explains Kaltenegger. "Most manufacturers are happy enough if a bacterial strain produces the right product in reasonable quantities." However, the Linde expert is convinced that the "never change a running system" philosophy will change in the coming years as the substantial gains afforded by O_2 enrichment are exposed in full.

LINK:
www.europabio.org

Eco-friendly mosquito battle

CO_2 GNAT TRAP

Summertime is mosquito time. Previously, insecticides and UV light traps were the only ways to deter these bloodsuckers – unfortunately also harming helpful bees. Now, though, Biogents AG has developed an eco-friendly gnat trap, partnering with Linde for the gas supply solution.

↑ Author: Ulrike Feigl
↓ Image source: M. Barraud/Getty Images, Bayer AG

Another summer, another swarm of mosquitoes. No sooner is it warm enough to spend balmy summer evenings on the balcony or in the garden than the first bloodthirsty bugs begin to whine and circle. And that soon leads to itchy bites on arms and legs. So far, the standard protection against this onslaught has been chemical. But mosquito sprays contain insecticides that can also do damage to useful creatures.

A new method in use in Germany takes an entirely different tactic, using carbon dioxide to trick and trap these painful pests. In comparison with insecticides, this alternative is also easier on the environment. Carbon dioxide is one of the most important magnets for almost all Central European mosquitoes – and humans exhale around a kilo of it per day. The gas acts as an invisible scent trail, leading the biters straight to their next meal. However, with this new trap, their weakness for carbon dioxide becomes their downfall. Biogents AG has collaborated with researchers at the University of Regensburg, Germany, to develop a simple but effective CO_2-based solution: Mosquitaire™ Plus.

GETTING THE BETTER OF GNATS – 85 PERCENT FEWER BITES!

The gas comes from Linde subsidiary Unterbichler Gase GmbH and is marketed under the name BIOGON® C. Dr Stephan Schmitz, Head of Product Management at Linde Gas Germany, has already put the trap to the test in his own garden and is delighted: "The trap is easy to install – you connect BIOGON® C, turn on the power and it's up and running."

Mosquitaire™ Plus comes in a sturdy plastic housing. The connected CO_2 supply flows out through a nozzle, imitating human breath. The system can "exhale" 200 or 500 grams per day depending on the setting. In the middle is a hole into which the mosquitoes, once attracted, are pulled with suction power. They then end up in a special bag, from which they cannot escape. The trap only attracts female mosquitoes, since they are the blood-feeding variety, while the males feed on plant nectar. According to the developers, this new solution should lower the occurrence of bites by up to 85 percent. "What's more, longer-term usage of the trap can significantly reduce the mosquito population. After all, each female can lay around 200 eggs over its lifespan – from which yet more mosquitoes emerge," explains Schmitz.

The trap not only imitates human respiration but also body scent. This is accomplished by a simple circulation system, sucking the artificial breath back into the device along with the insects. The CO_2-rich air is then diverted and a scent dispenser adds small amounts of substances present in human perspiration. This heady aroma is released from a large area on the upper surface of the trap, enriching the carbon dioxide magnet and making it even more enticing to the insects. This mixture has the power to attract mosquitoes that are up to 20 metres away.

In contrast to insecticides or UV light traps, which attract all types of insects including pollinators and other useful creatures, this CO_2 trap only targets biting mosquitoes. "The Mosquitaire™ Plus simulates the odour of humans, so it only draws blood-feeding insects and leaves bees, butterflies and ladybirds in peace," Schmitz concludes.

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