H2 Fuelling the Future

BOC
A Member of The Linde Group

Hydrogen offers the perfect balance between low carbon mobility and climate protection

As an energy carrier, hydrogen (H_2) has the potential to fundamentally change the way we source energy for a whole range of stationary, mobile and transportation applications. It is also set to play a key role in securing future energy supplies as it can be used to directly store energy captured from fluctuating renewable sources. This energy can then be efficiently converted back to electricity, for example, via fuel cells. Furthermore, hydrogen does not generate harmful emissions when used to power vehicles. Hydrogen technologies also have the capacity to significantly reduce dependency on single energy sources and imports. BOC, a member of The Linde Group, is a pioneer in the development of forward-looking hydrogen technologies. The company's expertise covers the entire value chain, from generation and liquefaction through transportation solutions to fuelling of hydrogen-powered vehicles.

Crude oil's reign as the dominant source of energy for road transport is slowly coming to an end. Today's global, mobile society is facing major challenges in light of rising energy consumption, dwindling resources and increasing levels of harmful emissions. In order to meet the 80-percent CO_2 reduction target set by the G8 in September 2009, emissions from the transport sector alone must fall 95 percent by 2050. This cannot be done with conventional methods and technologies and so the focus must shift to new, zero-carbon energy sources and CO_2 friendly mobility.

Hydrogen is an energy carrier that can be used to store regenerative energy efficiently. Effective energy converters such as fuel cells can then be used to release the stored energy whenever it is needed, thus balancing out peaks and troughs in supply and demand. Water vapour is the only emission produced by hydrogen-powered cars – just one of the numerous features that help position hydrogen as the most environmentally sound fuel to date.

Hydrogen has been deployed as an industrial gas for over one hundred years and large volumes are used across the widest range of applications every day. It is the most commonly occurring element in nature and – unlike fossil fuels such as crude oil or natural gas – it will never run out. Like electricity, hydrogen is an energy carrier – not a source of energy. It therefore has to be produced. Yet hydrogen offers several key benefits that raise its potential to replace fossil fuels, particularly in the transportation sector. Stored hydrogen, for example, can be used directly as a fuel or to generate electricity. Hydrogen is the only alternative fuel that can deliver sustainable low carbon mobility, long vehicle range and fast re-fuelling windows.

Decades of research, development and testing have shown that hydrogen technology is a workable, economically viable alternative suited to mass deployment. There is still a long way to go before broad scale commercialisation, however, even today's conventional method of using steam reforming to generate hydrogen from natural gas already reduces carbon dioxide emissions along the entire value chain, from well to wheel. Hydrogen-powered vehicles emit up to thirty percent less CO_2 than modern diesel cars.

In terms of environmental and climate protection, hydrogen-powered transportation makes most sense when hydrogen is produced using renewable energy sources. BOC has therefore set itself the long-term goal of producing green hydrogen from energy sources such as the sun and wind as well as from renewable raw materials and biological waste. The list of possible production chains is long and includes, for example, sourcing hydrogen from glycerine, a by-product of biodiesel production.

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Covering the entire H_2 value chain

As a pioneer in the development of hydrogen technology, BOC is working hard to commercialise this environmentally sound energy carrier. BOC is the only company worldwide that has the technology and expertise to cover the entire hydrogen chain – from the production of hydrogen using fossil and renewable energy sources through compression, liquefaction, storage and transport, to fuelling solutions for compressed (CGH_2) and liquid hydrogen (LH_2).

Hydrogen is the energy carrier of the future and a key enabler of low carbon, sustainable mobility in our everyday lives. Yet when it comes to assessing sustainability, it is crucial that we look at the entire value chain from well to wheel. This is because hydrogen production processes are extremely diverse. Today, for example, the majority of hydrogen is produced using fossil fuels. In the medium and long term, however, renewable primary sources such as the sun, wind, water and biomass will account for a larger share in the global hydrogen mix. The process of determining the best hydrogen production solutions for individual applications and locations will take place at local level. As the largest global provider of hydrogen plants and the world's leading supplier of equipment for hydrogen fuelling stations, BOC's hydrogen technology portfolio covers the entire hydrogen value chain, from production through liquefaction and storage to refuelling.

Steam reforming of natural gas, also known as steam methane reforming, is currently the most economically viable method of producing hydrogen. During this process, steam and natural gas are catalytically cracked in a steam reformer at around 800 degrees Celsius, generating hydrogen, carbon monoxide and carbon dioxide. In the following step, referred to as the CO shift reaction, carbon monoxide reacts with steam to create CO_2 and more hydrogen. This hydrogen-rich gas is then purified until it has reached the desired quality level. Steam reforming is a proven technology that is already deployed on an industrial scale. Steam reforming of natural gas accounts for over 75 percent of all hydrogen produced directly.

BOC's parent Company, The Linde Group, is already investing heavily in the development of alternative solutions for a sustainable flow of hydrogen. The Group's long-term aim is to significantly increase the sustainable share in the hydrogen mix using renewable energy sources such as wind, water and biomass. Electrolysis is one alternative that promises a zero-emission hydrogen energy cycle. For small-scale applications, as little as 1.5 volts are sufficient to produce hydrogen from water.

Electrolysis splits water into its constituent parts of oxygen and hydrogen, with oxygen forming on the positively charged electrode (anode) and hydrogen forming on the negatively charged electrode (cathode). A membrane between the anode and the cathode prevents the two gases from reacting with each other and reverting back to water. If this process is carried out under high pressure, less effort has to be expended on subsequent hydrogen compression, which cuts energy consumption and saves system space. BOC has extensive experience with hydrogen electrolysers and has the know-how to incorporate this technology into existing hydrogen value chains. Hydrogen produced in this way can be compressed as a gas or cryogenically liquefied for storage, transport and further use.

In Germany, The Linde Group is also developing other innovative biogenic ways of generating hydrogen from feedstocks such as glycerine. Raw glycerine is an ideal candidate for climate-neutral hydrogen as it is a by-product of biodiesel made from rapeseed. Converting the glycerine into hydrogen fuel increases the per-hectare return on land used to cultivate rapeseed as biomass. The Group has set up a demo plant for glycerine-based production at its Leuna site in Germany. This plant prepares, pyrolyses and reforms raw glycerine to produce a hydrogen-rich gas, which is then fed into an existing facility to be purified and liquefied. This truly "green" liquefied hydrogen will initially be used as fuel in Germany's pioneering hydrogen cities such as Berlin and Hamburg. Glycerine that has been biogenically produced in this way does not conflict with food supplies, is easy to transport, non-toxic and available all-year round. Chemists at The Linde Group are also experimenting with blue-green algae in an attempt to obtain hydrogen from photosynthesis.

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Hydrogen mobility

Hydrogen (H_2) is an environmentally friendly transport fuel with a high energy density. Heat and water are the only substances it emits when it burns. One kilogram of H_2 has three times as much energy as one kilogram of crude oil. Car manufacturers are therefore turning to hydrogen and fuel cells in the drive to advance automotive electrification.

There are already over 900 million vehicles on the world's roads today. Experts predict that this number will double in less than 30 years. However, dwindling oil reserves and rising energy prices are major hurdles to increased global mobility – which is why green mobility has become one of the key buzzwords of the century. Car makers are focusing on a variety of concepts here. In addition to battery-powered vehicles, hydrogen-fuelled cars will also play a key role on the low-emission mobility landscape. Both concepts complement each other well since a third of the components in battery-powered and fuel-cell cars are the same and both systems will appeal to a specific market segment and application spectrum. In contrast to battery-powered vehicles, fuel-cell cars are ideally suited to long distance travel as they use on-board hydrogen to create electricity, which gives them longer driving ranges and enables them to be refuelled quickly.

Fuel cells generate electricity through an electrochemical reaction between hydrogen and oxygen. The only by-products of this process are heat and water vapour.

The amount of CO_2 generated in the course of hydrogen production depends on the energy source and production process in question. Fuel cells are highly effective, which means that the overall CO_2 footprint of today's fuel-cell cars is already up to 30 percent smaller than for modern diesel cars. If a fuel-cell vehicle is powered by hydrogen from a regenerative energy source, its overall CO_2 footprint may be over 90 percent smaller than for a diesel car. Consequently, almost all car manufacturers are advancing this technology and investing heavily in cost-cutting research and their efforts are paying off. The first commercial fuel-cell cars with a similar price tag to plug-in hybrid vehicles are expected now to be available from 2015. The majority of car makers working in this field opt for hydrogen combined with polymer electrolyte membrane fuel cells (PEM), also known as proton exchange membrane fuel cells.

The automotive group Daimler has already put over 100 cars and buses on the road as part of an extensive test to determine how fuel-cell vehicles perform under real-life conditions. The vehicles have notched up a combined total of 4.5 million kilometres. In Germany, the Hamburg transit company Hochbahn AG has already carried over a million passengers across the Hanseatic city in its fuel-cell buses. Mercedes-Benz has also launched its first series-produced fuel-cell passenger car. Equipped with a 700-bar hydrogen tank located in its sandwich floor, the B-Class F-Cell has a range of around 400 kilometres. Its electric motor is on a par with a two-litre diesel engine and the fuel-cell drive train consumes the equivalent of around three litres of diesel per one hundred kilometres.

Honda has had its own hydrogen vehicles on the road for some time now and has been leasing its FCX Clarity model to customers in California since summer 2008. Equipped with a 100-kilowatt electric motor, the FCX Clarity has a range of around 460 kilometres on a full tank. Moving on to GM – around 100 of its HydroGen4 fuel-cell cars have been on the road since the end of 2007. And engineers at BMW working on a hydrogen combustion engine also regard hydrogen as the long-term answer to sustainable, personal mobility.

H_2 technology has strong backing in Japan and the US as well. Toyota, for example, will be launching a hybrid fuel-cell car in 2015. The company has launched a major programme in the US to support this. The company will initially place over 100 Toyota FCHV-adv cars with private companies, universities and government agencies in New York and California. During a field test requested by the US Department of Energy, the FCHV-adv achieved an astonishing range of 693 kilometres on a single tank.

Hydrogen is an extremely light gas, so storage plays a key role in the supply chain for H_2-fuelled electric vehicles. At normal air pressure, 3,000 litres of hydrogen gas contain the same energy as one litre of petrol. The gas must therefore be highly condensed before it can be effectively stored and transported. Hydrogen can be either compressed as a gas (CGH_2, compressed gaseous hydrogen) or cryogenically liquefied at minus 253 degrees Celsius (LH_2, liquid hydrogen).

BOC, as a member of The Linde Group, has access to a range of powerful, highly efficient vehicle fuelling technologies for both hydrogen formats. The Group's ionic compressor can be used to refuel cars directly with high-pressure hydrogen (350 bar or 700 bar). Alternatively, liquid hydrogen stored at fuelling stations can be converted to high-pressure gaseous hydrogen using innovative, new cryo pump technology. Both processes enable drivers to fill up H_2 cars with gaseous hydrogen in under three minutes. A third option enables cryogenic liquid hydrogen to be fed directly – and quickly – into a car's tank using a patented LH_2 Coupling system. Fuelling stations can be equipped with all of these systems to give drivers maximum flexibility.

Initial hydrogen infrastructures are already established, with around 200 hydrogen fuelling stations set up to date across the globe. There are currently almost thirty H_2 fuelling stations in Germany alone, six of which are integrated into public garages. This makes Germany the clear hydrogen pioneer in Europe. Around EUR 3 billion in investments would be required for a Europe-wide infrastructure of fuelling stations by 2020. That was one of the findings of Europe's most extensive study to date "The Role of Battery Electric Vehicles, Plug-in Hybrids and Fuel Cell Electric Vehicles - A portfolio of power-trains for Europe: a fact-based analysis" (Download: www.zeroemissionvehicles.eu).

Aligning infrastructure expansion with series production of hydrogen cars would resolve the "chicken or egg" dilemma currently hampering the advancement of hydrogen mobility worldwide.

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Market-ready solutions for H_2 fuelling

Over the past two decades, BOC, as a member of The Linde Group, has been concentrating on the development of fuelling technologies for liquid and gaseous hydrogen – and now many of the world's hydrogen fuelling stations are equipped with ground backing technology.

Depending on local needs, hydrogen fuelling stations can supply both liquid (LH_2) and gaseous (CGH_2) hydrogen. Choosing the right technology for a fuelling station depends on a large number of factors, including the number of vehicles to be refuelled each day, whether gaseous hydrogen, liquid hydrogen or both, hydrogen flow per hour, fuelling pressure and available space. Compression is the key success factor and a defining technology for hydrogen fuelling stations. Through The Linde Group, BOC has access to a range of turn key fuelling solutions for both forms of hydrogen allowing hydrogen-powered vehicles to be refuelled in around three minutes, the same time it takes to refuel a petrol or diesel car.

Hydrogen is stored at a fuelling station in a gaseous or liquid state. A newly deveoped cryo pump converts liquid hydrogen to high-pressure hydrogen. This technology can be used to quickly and efficiently fuel vehicles running on compressed gas from a tank storing liquid hydrogen. The cryo pump is particularly suited to high volumes since it leverages the advantages of direct liquid compression, thus reducing energy consumption to a minimum. The cryogenic temperature of the liquid hydrogen means that no additional cooling is required for direct compression. During the fuelling process, the cryo pump compresses the cryogenic liquid hydrogen stored in a tank. It uses a specially designed system of air heat exchangers and a temperature control unit to take the temperature of the hydrogen to minus 40 degrees. The hydrogen can then be pumped into the vehicle. The cryo pump generates a maximum pressure of up to 900 bar, giving it a fuelling capacity of up to 120 kilos an hour. It is quiet and requires very little maintenance. Due to its special design, the cryo pump is a particularly energy-efficient way of supplying vehicles with gaseous hydrogen – twenty four hours a day, at the touch of a button.

Hydrogen stored in a gaseous state at a fuelling station can be compressed very efficiently using an ionic compressor developed by The Linde Group. Instead of solid, metal pistons, this technology uses ionic liquids, which are organic salts that remain liquid within a specified temperature range. During the compression process, the ionic liquid acts like a solid but has the properties of a liquid. Unlike conventional molecular liquids, ionic liquids are made of salts, which, like table salt, are made up of positive (cations) and negative (anions) particles.

Ionic liquids are a crossover between organic and inorganic chemicals and therefore have unusual properties. These liquids do not have a vapour pressure for instance. This means that none of the liquid's molecules will evaporate or mix with a surrounding medium until the liquid reaches its decomposition temperature. Since there is an almost endless number of organic molecules, the physical and chemical properties of ionic liquids can be adjusted to meet almost any requirements – which is why they are often referred to as "designer" liquids.

Thanks to the ionic compressor's innovative design, hydrogen can be compressed at an almost isothermal temperature. It is considerably more efficient than a conventional compressor. Ionic liquids also help prevent corrosion. And since the compressor does not have any moving mechanical parts, it is not susceptible to wear and tear, which in turn reduces maintenance effort. Ionic compressors also consume up to twenty percent less energy than conventional processes and can also convert liquid hydrogen stored in a tank. Here, the liquid hydrogen first evaporates to reach a gaseous state. The compressor then compresses the gaseous hydrogen to the required fuelling pressure.

Flanking the re-fuelling technologies for stationary facilities are a range mobile solutions for gaseous hydrogen. Mobile units can be used to re-fuel small fleets of H_2 test and demo vehicles with gaseous hydrogen (CGH_2) on the move. They are particularly useful in areas where stationary fuelling points are not available. These can store gaseous hydrogen at 200, 300 and 450 bar in cylinder packs and an on-board compressor then takes the gas up to 700 bar. Two separate high-pressure couplings are then used to refuel CGH_2 vehicles at pressures of 350 and 700 bar. This flexible fuelling concept means that vehicles can be supplied with hydrogen at almost any location.

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