PANGEA
Strategic
Intelligence

Hydrogen Value Chain Overview

A Hydrogen 101

Contents

Development Of The Hydrogen Economy

Carbon dioxide emissions have resulted in global warming. To combat this threat to our natural environment and wellbeing, decarbonisation will be essential. Amongst other things, this will require a reduction in our reliance on burning hydrocarbon fossil fuels and emitting the carbon dioxide to the atmosphere. As a clean burning fuel, hydrogen will have a central role to play in securing the 2050 target of 'net-zero' carbon dioxide (CO_2) emissions which is written into the EU Green Deal and is the shared aspiration of many nations worldwide.

The increasing importance of hydrogen in our future means that a variety of production methods, including modern electrolysis and traditional thermal catalytic conversion of natural gas, for example on a steam methane reformer (SMR) will be required. Emerging hydrogen applications such as energy storage, mobility, heating and direct reduction of steel (DR) will also grow to become commonplace and hydrogen will substitute traditional fossil-fuels in these processes.

A molecule from our past holds the key to our future

Two hundred years after the industrialisation of Hydrogen, we are now seeing clearly that this gas can help us to navigate the next two hundred years.

Our sun creates energy through the fusion reaction of hydrogen to form helium: that's been going on for millions of years. On earth, the use of hydrogen as an energy source started more than 200 years ago when William Murdoch lit his house and office in Cornwall from town gas – a mixture of hydrogen, carbon monoxide and carbon dioxide produced in a small retort. Over the next century, gasworks and gas distribution pipelines were built across the UK to keep the country warm and well lit.

Early-town gas and hydrogen production

The commercialisation of natural gas from the North Sea led to a broad decline of town gas in the UK. Natural gas reserves in Russia have also been exploited in recent decades with pipelines transporting gas thousands of kilometres to markets in Europe.

The emergence of liquefied natural gas production, predominantly from sources in Australia, Qatar and the United States has enabled Asian consumers to benefit from natural gas and has led to a decline in the use of town gas worldwide.

Almost a century of hydrogen industrial applications

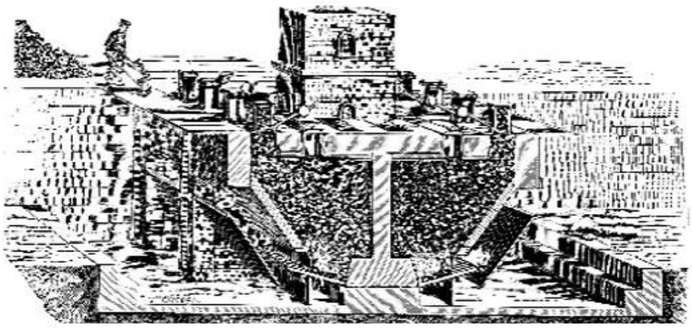
In the 1930s, hydrogen production for industrial applications commenced using steam methane reformers (SMRs). At this time, it was associated with the chemicals industry with ICI and BASF owning many early patents. The technology was closely linked to ammonia and urea production for fertilizers.

Modern ammonia plant

Since then, tonnage scale hydrogen production has become the norm. The most sophisticated hydrogen production network is in the United States, where Air Products operates the 960 km long Gulf Coast hydrogen pipeline which can supply a total of 1.5 million Nm3 per hour of hydrogen to refineries and chemicals companies along the Gulf Coast in Texas and Louisiana.

Hydrogen is used on refineries for desulphurisation of fossil fuels and hydrogenation of biofuels. Beyond the refinery, hydrogen is used in high temperature heat treatment processes to produce metals and glass. It guarantees a 'reducing' atmosphere (i.e. avoids the presence of oxygen) which is required to influence the material properties. It is also used to hydrogenate oils to fats in the food sector, for example the production of spreadable margarine from sunflower oil.

Over the next 30 years, it is likely that its use in fossil fuel processing will decline. However, its application to biofuels processing may grow. It will also be used in increasing amounts to produce e-fuels.



Early town-gas / hydrogen production process

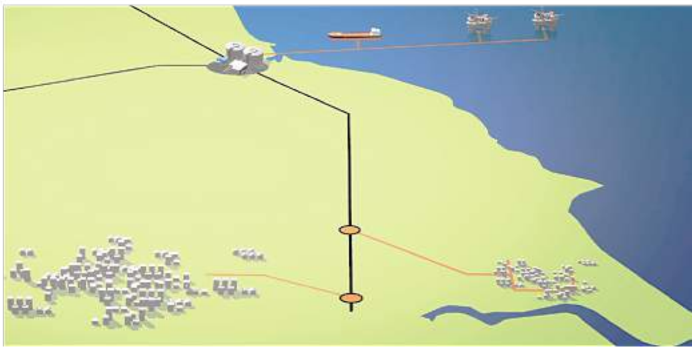
Turning To The Future - Hydrogen As The Heating Fuel

In the future the hydrogen to be injected into the gas distribution grid will be produced by renewable technologies, such as electrolysis of water using solar, wind or hydro-electric power – thus enabling a decarbonised heating fuel supply.

The UK invested heavily in natural gas distribution infrastructure to exploit the benefits of North Sea gas. This has resulted in the country having a high proportion of its heating requirements derived from natural gas. To meet the vision of a decarbonised future, an alternative heating source must be found. Whilst electricity from renewable sources is often spoken of as a green fuel, its application for power-hungry heating would be a stretch for the renewables sector in the short term.

Hydrogen electrolyser for gas grid admixing © TÜV SÜD

These are the drivers behind the H21 Leeds City Gate project in the north of England which aims to use hydrogen as a heating fuel in the future energy mix. The project plans to take natural gas from the North Sea and convert that to hydrogen using steam methane reformers (SMRs). Carbon dioxide produced in the process will be captured and stored in an underground carbon capture and storage (CCS) scheme to avoid its release to the atmosphere. The hydrogen can then be distributed in gas pipelines, like the current method of natural gas distribution.



H21 Leeds City Gate Concept © Northern Gas Networks

Sakhalin Island LNG, Russia

Combustion of natural gas is seen as a cleaner alternative to coal for electrical power generation. It is, however, a fossil fuel and creates CO_2 emissions which contribute to global warming. So, the next energy transition will be the search for decarbonisation, and this is rejuvenating interest to use hydrogen as a gaseous fuel.

In the future the hydrogen to be injected into the gas distribution grid will be produced by renewable technologies, such as electrolysis of water using solar, wind or hydro-electric power – thus enabling a decarbonised heating fuel supply. For this purpose, the use of electrolysers for industrial scale hydrogen production is becoming a realistic proposition.

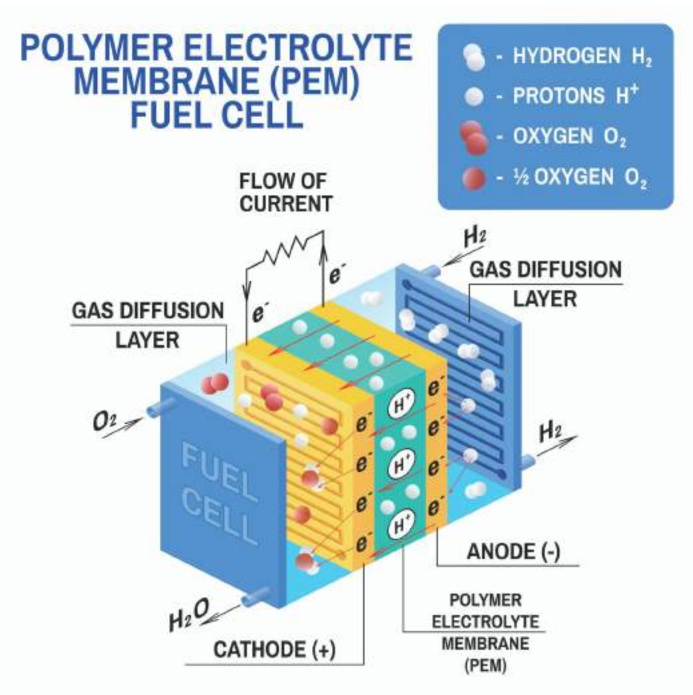
Comparing Hydrogen Electrolyser Technologies and Selection Guidance

One of the building block technologies for a decarbonised future is electrolysis of water to produce hydrogen. When considering which kind of electrolyser technology and manufacturer to use, a robust selection process is required. The key purchasing criteria such as: the need to have relevant reference installations; safety management processes; technical quality of the proposal; energy conversion efficiency for our specified operating profile and the initial capital outlay must all be considered. Often the goal is to find a solution with lowest total cost over an extended operating period, say 10 years.

The three main hydrogen electrolyser technologies in play are alkaline electrolyte, polymer electrolyte membrane - also known as proton exchange membrane (PEM) - and Solid Oxide Electrolysis (SOE), which is also referred to as High Temperature Electrolysis (HTE).

AE

Alkaline electrolyte systems have a lower capex than the other technologies and are the most mature technology which means they have a proven track record of reliability that the PEM and SOE processes have not yet had the chance to accumulate. The alkaline electrolyte equipment also avoids the need for water purification, which is a requirement of the PEM system.



An illustration of a PEM fuel cell

PEM Hydrogen Electrolyser © ITM Power

PEM

PEM systems offer a quick ramp-up and when operated at pressure (which other systems can also do) they offer a small footprint. A perceived disadvantage of the PEM system is that due to its recent emergence, there is no long-term operational data to validate the lifetime of the electrolyser. It is hoped that the membrane system will last many years in operation and avoid frequent replacement, but at present this is an unproven ‘hope’. Operating experience will soon give substantive data to this point. Furthermore, the membrane is a highly specialised and expensive polymer with very few production and sourcing options worldwide.

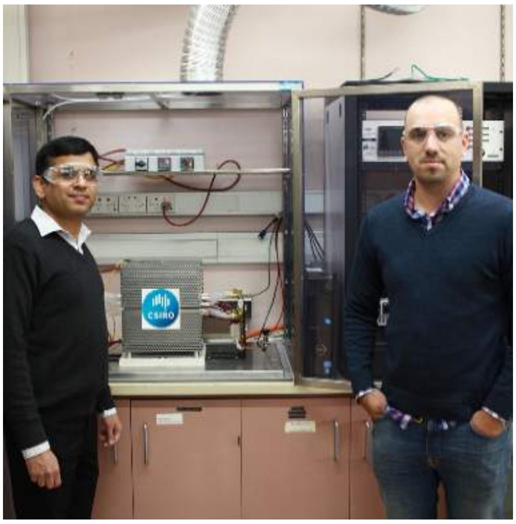
SOE/HTE

SOE has high potential in a diverse range of Power to X applications and it can integrate seamlessly into several chemical processes. SOE is a highly capable all-rounder has been known about for many decades, but its use at an industrial scale has been handicapped by some practical challenges related to the high temperature operation which makes robust design and manufacture of the electrodes challenging.

Solid Oxide Electrolysis (SOE) technology is ideally suited for combination with industrial applications because the electrolyser gets about 30% of its energy from steam, not electrical power. If this is excess heat from a nearby industrial process such as a steel works or refinery an SOE electrolyser can product 30% more hydrogen per MW of electrical power consumption than a PEM system or alkaline electrolyte process. That is a step change in performance that incremental evolutionary improvements in the alternative electrolyser technologies are unlikely ever to bridge.

Key Considerations for the Technology

Thermal Stress



Members of the SOE research team at CSIRO
© CSIRO

SOE operates at about 500 °C using solid electrodes. This differs from a PEM system which might operate at 80 °C with a flexible polymer electrolyte membrane. In state of the art SOE equipment,the solid electrodes are constructed from a stack of flat plates. Removing heat from the outer parts of the electrode stack is OK, but hot spots can form. This leads to thermal stress which can damage the electrodes over the long term through delamination. So, periodic replacement of the SOE electrode stack is required which puts a comparatively high maintenance cost into the system. In terms of technology maturity, SOE electrolysers are perhaps two years behind PEM, but they areinnovating fast and gaining ground quickly. Some researchers, for example a team at CSIRO in Australia are focusing on alternative shapes of the electrolyser plates to minimise the thermal stress issues.

Energy Efficiency and Power-to-Liquids Capability

The energy efficiency benefits and Power-to-Liquids capability of the SOE process will mean that itwill have a substantial role to play beyond hydrogen production. Also, the SOE process is reversible. That means that SOE systems can double up as fuel cells. These attributes give SOE plenty ofmarket potential and means that production is likely to benefit from economies of scale.

Elevated Pressure

Pressure is another consideration. Some technologies have the potential to operate at elevated pressures, up to 30 bar. The benefit of high pressure is electrical current density and process intensity. Compared to an atmospheric pressure system, the high-pressure electrolyser technology can deliver a lot more hydrogen from a much smaller footprint. As an example, an atmospheric pressure alkaline electrolyte system would need circa 3 to 5 times as much space as one that operates at 30 bar.

One or the other? Or both?

When it comes to electrolyser technology, the future will involve a mix of solutions. It is like the BEV or FCEV question in e-mobility: both will likely have a role to play, alongside the internal combustion engine, for some years to come also. The same goes for electrolysers – the future will employ all three relevant technologies.

Furthermore, there is a good case for combining different electrolysers. An SOE electrolyser may be ideal to perform the baseload hydrogen production and a PEM can cut in and out for peak shaving to meet a dynamic demand profile. That would exploit the primary strength of each technology in a hybrid system.

Hydrogen Electrolyser Scale-up for Capex Cost Reduction

A mid-sized modern alkaline electrolyte electrolyser unit consumes approximately 0.5 MW of electrical power to produce around 200 cubic metres per hour of hydrogen. The footprint of such a unit might be 2.5m by 6m and can fit neatly into a standard 20' cargo container for transportation or long-term installation. This is a good start, but to produce the volumes of hydrogen that will be required in 2030 and 2050, significant scale up will be required.

The commercial production of Hydrogen electrolysers is still at an early stage of industrialisation. It is acknowledged that the initial cost of electrolyser units must be reduced to ensure that hydrogen is a cost-competitive energy solution. Part of the key to reducing the capex cost will be to scale-up. Cost reductions will be achievable as the size of the electrolysers increase from the current 10MW order to magnitude to 100MW and 1GW scale. Many units today are based on a modular concept using electrolyser stacks in the 1-2MW range. When 1GW electrolysers are being built, manufacturing must change to use modular designs based on new larger stack sizes, for example at 5 to 10MW.

'Element Eins' in Germany is a relevant example of the next order of magnitude of hydrogen production from electrolysers. At the heart of the proposed project is a 100 MW electrolyser that generates green hydrogen from renewable power which is produced by wind turbines off the coast of northern Germany. The hydrogen is proposed to be used for natural gas grid admixing at 2% and to supply local chemicals industry applications.

Offshore wind turbines for renewable power production

Project and Pilot Insights

There are several other projects in the planning stage at large scale and 100 MW represents the next natural scale up step. The aforementioned Element Eins is not expected to deliver commercial returns, but it will help to prove that the electrolysis technology is scalable. Furthermore, this and other pilot projects collectively send a clear signal to regulators that policy development related to hydrogen energy must soon catch up with the physical reality.

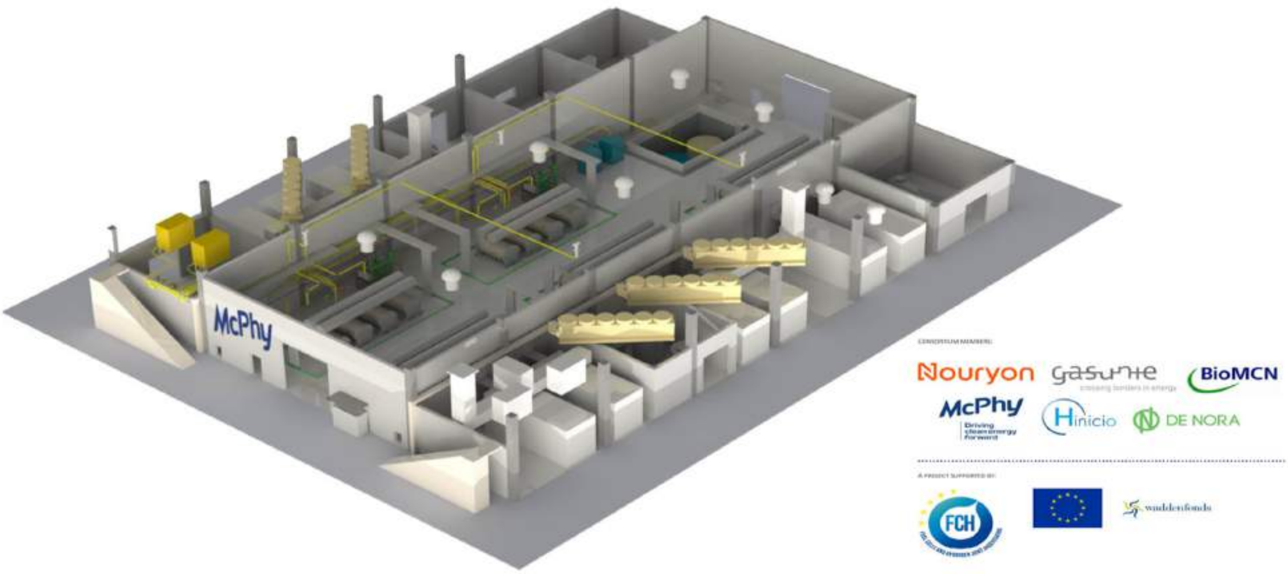
20 MW Electrolysis Factory

McPhy recently announced their participation in an EU backed consortium to build a 20 MW alkaline electrolyte electrolyser at the heart of a chemical park in Delfzijl, the NL. The funding will be from the EC Fuel Cells and Hydrogen Joint Undertaking and Waddenfonds. In addition to McPhy, the consortium involves five other partners with a diverse range of expertise and interests in hydrogen energy. That 20 MW electrolyser will produce 3000 Tonnes per year of hydrogen. The electricity will be from renewable sources, so this will be one of the largest zerocarbon hydrogen projects ever undertaken. Nouryon and Gasunie will jointly operate the plant and BioMCN will use the hydrogen to produce renewable methanol. There are discussions about increasing the capacity to 60 MW in the future, so this project will be a beacon to light the way to green hydrogen and Power to liquids and Power to gas project scale up.

McPhy Electrolyser © RAG & Karin Lohberger Photography

The REFHYNE Project

Turning to PEM electrolysers, the REFHYNE project at Shell's Rhineland Refinery at Wesseling in central Germany is a good case study. The project is supported by the EC Fuel Cells and Hydrogen Joint Undertaking (FCH JU). The electrolyser will be operated by Shell and manufactured by ITM Power. The PEM electrolyser has a maximum hydrogen production capacity of 1,300 Tonnes per year and at that flowrate would consume circa 10 MW of power. The hydrogen will be used to process clean burning hydrocarbon fuels and will augment current SMR hydrogen production.



3D simulation of the 20 MW electrolysis platform © McPhy Energy

Industry Applications

Heavy Industrial Applications

For industrial applications, the refining sector is by far the largest consumer of hydrogen. In the future, the steel sector will also become a major consumer as it seeks to decarbonise. A fundamental step in the production of steel is the reduction of iron oxide ore to iron. This is generally performed using coke which is produced from coal through pyrolysis – a process that releases thousands of Tonnes of CO_2 to the atmosphere each year. The coke reacts with the ore to yield the desired iron and CO_2. As an alternative, hydrogen can be used in a process referred to as 'direct reduction' or DR. In this case, the hydrogen reacts with the ore to produce iron and water vapour. The ArcelorMittal plant in Hamburg is conducting tests to establish the viability of this.

Steelmaking blast furnaces

Another pilot in the steel sector is taking place at Salzgitter in Germany. A 200 KW electrolyser from Sunfire, capable of producing up to 50 cubic metres per hour of hydrogen, is used in their annealing plant. Heat treatment requires either reducing, nitriding or other controlled atmospheres to influence the crystalline structure of the steel which feeds into its physical properties. That pilot has been a success and the idea is to ramp up to 1MW of electrolysis capacity which should cover about 70% of Salzgitter's annealing hydrogen requirements. Separately, Salzgitter are keen to implement hydrogen for direct reduction of steel. The electrolyser required to supply the hydrogen for a blast -furnace will be in the order of 300MW. That will be a major scale up from state-of-the-art technology.

Sunfire Electrolysis Module © Salzgitter Flachstahl GmbH

Hydrogen Production on SMRs and ATRs

Steam methane reformers (SMR) are the most common large-scale hydrogen production technique in use today. Much of the installed base of SMRs is linked to refinery operations, with the balance being associated with syngas, methanol and ammonia production in the chemicals and fertilizer sectors.

SMR on a chemicals plant producing resins

Hydrogen consumption on refneries has increased significantly in recent decades to treat heavy feedstocks, produce clean burning low sulphur fuels and for the hydrogenation of biofuels. The most recent uptick in demand has been driven by the IMO2020 changes which have increased the demand for low sulphur marine fuels. In this context, anything that could be done to squeeze a few percent more hydrogen out of an existing SMR has been desirable. Strategies that SMR operators have used to increase hydrogen output have been diverse, including maximising the catalyst performance; use of reformer and shift reactor catalysts with high conversion yields; minimising hydrogen losses through optimising the PSA hydrogen purification system bed sizing and operation; installation of additional reformer tubes within the SMR to increase the catalyst volume and consequently the plant capacity; adding a pre-reformer or post reformer; adjusting the steam to carbon ratio in the feed to the SMR and process control improvements or implementation of SMR operating best practices.

Hydrogen Purity Standard

The purity of Hydrogen for use in a wide range of applications is subject to an international standard: 'ISO14678:2019 Hydrogen fuel quality – product specification'. There are a range of application-specific purity specifications. For example, hydrogen that is to be used in fuel cell electric vehicles and other fuel cells. In that case, impurities such as carbon monoxide and hydrogen sulphide are capped at levels that will guarantee the hydrogen is compatible with standard modern fuel cells and does not poison the sensitive catalysts.

Further Industry Applications

Nitrogen is also deteriorate gradually over time. Many of the specifications are easy to achieve with hydrogen produced on an electrolyser, but they become more pertinent when hydrogen is produced on an SMR.

SMR on a Refinery

In recognition of the principle that focus adds value, industrial gases producers who have developed expertise in SMR operations over many decades and have taken on the operation of 'captive' refinery SMRs, converting them to 'over the fence' (OTF) or pipeline hydrogen supply schemes. Economies of scale have tremendous advantages for industrial gases hydrogen producers such as Air Products, Linde and Air Liquide. Sometimes clustering of several SMRs together is possible, which has significant advantages. It improves the overall reliability and ensures optimal performance of each SMR. Customers hooked up to clusters or pipelines have the security of a backup supply if one of the SMRs needs to be taken out of service for maintenance or catalyst replacement.

Despite ongoing incremental improvements in capacity and reliability, it is expected that many more SMRs will be built in the next 10 years to provide the high volumes of additional hydrogen that will be required for heating and industrial applications such as the direct reduction of steel, which will require hundreds of Tonnes per day to feed a single blast furnace.

Steel plants will require thousands of Tonnes of hydrogen per day

SMRs are ideally suited to methane-rich natural gas a feedstock and they can be adapted to use other light hydrocarbons such as butane or naphtha. They are also available in a range of sizes covering smaller and mid-scale supply requirements.

ATRs as an alternative to SMRs

However, the demand for hydrogen in major domestic heating applications in some projects will be very high flow rates at high pressure. These parameters are out of the scope that a typical SMR could yield. For larger scale methane-fed applications with high pressure hydrogen requirements, the related autothermal reforming (ATR) process can be suitable.

The interest in ATRs as an alternative to SMRs for large scale hydrogen production has been highlighted by the HyNet North West project, which the UK gas network company Cadent is planning. The original scheme involved SMRs to produce hydrogen for local energy and mobility applications. However, the most recent plans have evolved to replace the SMRs with two ATR units. One of the applications for the hydrogen is injection into the gas pipeline grid network where high pressures are required. This contributed to the motivation for switching technologies because the ATR option can reduce the hydrogen gas compression power consumption because ATRs are able to operate at higher pressures than SMRs.

SMR on a refinery

Power to Liquids – The Role of Hydrogen in E-fuels Production

SOE can be used to produce either hydrogen or syngas. Compared to alternative electrolyser technologies this not an incremental difference. It's a game changer which means SOE electrolysers can be the starting point of a synthetic fuels value chain. In the field of power to liquids, a decarbonised solution for aviation fuel must be the priority. Neither compressed gases nor batteries will be able to keep jets up in the air long enough to fly long- distance. To get the right energy density a light weight, fossil-free liquid fuel must be the answer.

Power-to-Liquids Electrolyser

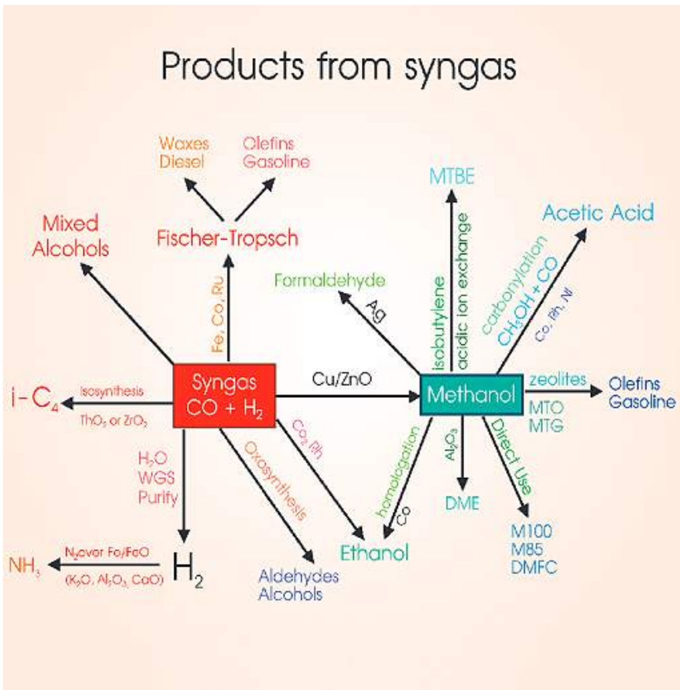
In Germany, Leuna, Sunfire is are working with Total to build a 1MW electrolyser which will feed a process for e-methanol production. Integration into the refinery means that the SOE process can use steam to maximise the efficiency and Total are keen to produce e- fuels. Sunfire are also working with Neste in Rotterdam, NL. Neste are a leader in biofuels production where hydrogenation reactions are important. So, the electrolyser for that project is optimised for hydrogen production. That means a material capex cost reduction and about 3% less power demand compared to an SOE electrolyser designed for syngas production.

Power-to-liquids Electrolyser © Sunfire GmbH

Power-to-liquids – Products

Beyond that, e-fuels such as methanol might have potential in land or sea transportation. As a liquid, it's like handling petrol, diesel or marine bunker fuel, so users could readily accept it as an alternative. These fuels are not emissions-free, but a combination of solutions will be required to hit the 2030 decarbonisation targets. Further developments can follow as we move closer to 2050 and the EU Green Deal net-zero goals.

Power-to-liquids – Products © Sunfire GmbH



An illustration of products from Syngas

Hydrogen Mobility

Mobility is a major application for hydrogen. Heavy- duty commercial vehicles and trains are very likely to utilise hydrogen powered fuel cells. Long-range or larger passenger cars are also high potential candidates for hydrogen mobility. Beyond that, shipping is also showing potential. The heavier end of the mobility sector is especially suited to using hydrogen because of the power to weight advantage that it offers over batteries. The Alstom Corodia iLint hydrogen powered regional train is a great case study here. Two of the trains now operate to connect various cities in Lower Saxony. The Alstom team at Salzgitter developed the train which is now fully operational after a period of testing.

Marine Applications

In marine applications, the premium cruise sector leads with their interest to adopt hydrogen as a propulsion system. One reason is that passengers do not want to get coated with dirty soot particles from the exhaust gases from the cruiser's funnel when sunbathing by the onboard pool. Furthermore, the type of people who book Arctic and Antarctic cruises could be interested in sustainable energy usage on board the ship. There are also discussions taking place in Norway that some fjords will only be open to non-polluting ships in the future. So, to offer access to these natural wonders, cruise operators will need to convert to a clean fuel such as hydrogen.

CORADIA iLINT Groningen NL

Fleets

When it comes to hydrogen in general and especially the topic of hydrogen mobility where hydrogen at 700 bar is stored in a car that may be travelling at 130km/h on the Autobahn, safety is the most important topic. This applies to high pressure gas storage on board the vehicle and is paramount for our filling stations as well. Knowledge is shared by operators through industry associations and committees such as the EIGA Working Group 11, which coordinates safety practices for hydrogen energy. It includes automotive OEMs and leading industrial gases companies.

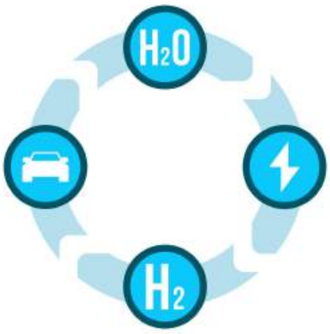
The vehicle filling protocols are broadly harmonised internationally according to standards laid down by the Society of Automotive Engineers (SAE). At a local level, regulatory authorities will want to examine aspects of a hydrogen fuelling installation such as noise levels, fencing, security, safe separation distances and the avoidance of enclosed spaces. The issues here differ from country to country and even within each country there are regional requirements. To navigate this process qualified consultants who can support the permitting process are often required.

Fuelling Stations

Lager fuelling stations are referred to as public fuelling stations. Smaller ones may be known as fleet owner fuelling stations (FOFS). That an easy entry point for operators to get into hydrogen mobility and an installed cost between a quarter and half a million Euro is realistic. A larger public station might cost somewhere between 1 and 2 million Euro.

H2 Filling Station Air Liquide © H2 MOBILITY

There are many applications where small fleets of hydrogen powered cars operate from a fixed location such as taxi fleets or company carpools. When the vehicle fleet operates close to the FOFS, they can be sure that a top up of hydrogen is always at hand. As the hydrogen mobility topic develops, there could also be good potential for hydrogen filling stations in other applications, for example, fork-lift trucks that operate inside warehouses are ideal to be converted to zero emission fuel cell vehicles because nobody wants toxic exhaust gas fumes polluting the enclosed workplace and causing a health hazard.



Cross-Sector Collaborations and Hydrogen Infrastructure Initiatives

The Hydrogen Council which is an international forum to promote hydrogen as a fuel. The big energy companies, industrial gases majors and some well-known auto brands all get together to share their enthusiasm with politicians and present a realistic vision of how hydrogen can shape a greener future for our planet. Also, there is a lot of interest in the H2 Mobility infrastructure development from some Asian countries and this international forum is a good way to cascade experiences.

H2 Mobility

Another cross-sector collaboration is H2 Mobility, which was founded in 2015. The goal of that joint venture is unconditionally to build 100 hydrogen fuelling stations in Germany which would represent a basic infrastructure and coverage. This should give OEMs, the public and commercial transport operators the confidence to invest in developing and purchasing hydrogen powered vehicles. The plan should break out of the chicken and egg problem of whether the cars or the infrastructure should move first.

H2 Mobility is a cross-sector industry body © H2M Max Jackwerth

Public Hydrogen Refuelling Stations

At 83 hydrogen filling stations in operation at the time of writing, the German hydrogen mobility infrastructure is a beacon showing the way to green energy and less transportation pollution. H2 Mobility is the organisation which operates all public hydrogen refuelling stations in Germany. It is supported by big names such as Daimler, Linde, OMV and Total. It is a collaboration of industrial gases suppliers, oil and gas majors as well as automotive OEMs. This multi-disciplinary model is currently being used as a template for the development of hydrogen mobility infrastructure in Japan and Korea.

Hydrogen filling stations compress hydrogen to 350 bar for heavy duty vehicles and 700 bar for cars to ensure a high energy density in the fuel tank inside the hydrogen powered car, bus truck or train. The compression systems may use ion pumps or hydraulically driven compressors.

Linde Hydrogen FuelTech Ion Compressor IC 90 © The Linde Group

Linde Hydrogen FuelTech

There are many passionate advocates of hydrogen mobility. And at the same time, it must be recognised that BEVs also have their strengths. It is most likely that both technologies will develop side by side. For example, fleets of app -controlled, battery powered autonomous taxis hooked up to power points in cities may be a vision for the future. On the other hand, in rural areas or for heavy vehicles where range and power are important hydrogen is in its element.

The pace of German hydrogen mobility infrastructure development is clearly world-class. However, when it comes to the production of fuel cell electric vehicles (FCEVs) – hydrogen powered cars, the story is very different. German car makers are famous for their top-tier luxury brands, but Toyota and Hyundai lead the international league table for sales of FCEVs with their Mirai and Nexo models. Their combined monthly sales of FCEVs regularly exceed 5,000 units. Whilst the Asians are ahead, parts of the German auto industry are beginning to follow.

Presentation of the Mercedes GLC F-Cell, world's first electric vehicle featuring fuel cell and plugin hybrid technology at the Frankfurt motor show in September of 2017 was a key milestone and two years later, BMW revealed their pre-production BMW i Hydrogen. Nevertheless, neither company yet has a production model in place.

H2 FCEV Hyundai Nexo

In November of 2019, VW re-confirmed their strategic focus towards battery electric vehicle (BEV) production for the masses, so no FCEVs rolling off their production lines soon either. Whilst the German hydrogen infrastructure races ahead the German auto sector is investing heavily in BEVs. And to add to the competitive intensity in the BEV space, in November of 2019, Elon Musk announced that Tesla will build batteries, powertrains and the Model Y in the new 'Gigafactory 4', close to Berlin. Another important move in the German electromobility scene.

Need More Guidance?

Visit: www.pangea-si.com

Phone: +44 (0)20 3907 1990

Email: info@pangea-si.com

Follow us

PANGEA
Strategic
Intelligence