PANGEA
Strategic
Intelligence

The Investment Case For Green Hydrogen

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The Growing Green Hydrogen Industry

Green hydrogen has a role to address 'the main challenge of our generation'

Carbon dioxide emissions have resulted in global warming. Decarbonisation to the point of carbon neutrality will be essential to avoid a climatic catastrophe. Amongst other things, this will require a switch from hydrocarbon fossil fuels to renewable forms of energy, such as green hydrogen.

As a clean burning renewable fuel, green hydrogen will have a central role to play in securing the 2050 target of 'net-zero' carbon dioxide (CO2) emissions which is the shared aspiration of many nations worldwide.

The value of the hydrogen sector in Europe today is estimated to be €2 billion. By 2030 this is expected to grow to become a staggering €140 billion. That is a compound annual growth rate in excess of 50%. It is speculated that 140,000 jobs will also be created along the way. The reason that hydrogen will substitute other fuels is its contribution to decarbonisation, so it is inevitable that much of that growth with will be related to green hydrogen.

Green hydrogen is perhaps 'the investment opportunity of our generation'

The EU Hydrogen Strategy, published on the 8th of July 2020, indicates a strong emphasis on green hydrogen with some tolerance for low-carbon hydrogen. Grey (AKA brown) hydrogen is not favoured in this policy. These colours of hydrogen are explained in this White Paper.

Project finance, equity investment, bolt-ons, IP acquisition & VC opportunities

The development of the hydrogen economy will provide project finance investment opportunities for infrastructure projects: fuel storage, filling stations, bunkering and pipeline distribution as examples.

Hydrogen producers will also pull for investment through debt or bonds to fund expansion of their hydrogen production capacity. Hydrogen technology start-ups will pull for VC funding – and many opportunities are likely to yield attractive returns.

Established players are actively seeking bolt-on acquisitions to build scale and improve their technology portfolio. IP investments can also accelerate their R&D pipelines. The industry is not yet in a phase of consolidation, but leading players are seeking to make the right moves to ensure that they have access to the technologies that will dominate in the sector 10 years from now.

The Linde group former HQ in Munich

Established green hydrogen companies may present good equity investment opportunities. As examples, publicly listed electrolyser manufacturers such as McPhy Energy, Nel or ITM Power may be considered. Stock prices in these companies have surged recently as a result of policy commitments in the EU to invest heavily in green hydrogen. Fuel cell producers also have a similar characteristic.

Investment in diversified industrial and chemicals companies will also provide some exposure to the green hydrogen sector. DAX majors Siemens and Linde have a strong presence. Catalyst manufacturers such as Haldor Topsøe and diversified chemicals players such as BASF and Clariant are also deepening their exposure to the green hydrogen scene through involvement in catalysts for hydrogen production and power to liquids catalysts.

The Growing Green Hydrogen Industry

EDF head office Paris, France

Further up and down the green hydrogen value chain, some car makers provide limited exposure and others such as Nikola trucks are strongly focused on hydrogen.

Automotive OEMS buy in technology such as fuel cells

Component makers such as Hexagon Purus (Hexagon Composites ASA) who make high pressure hydrogen cylinders for trucks and cars are also heavily exposed. Companies focused on renewable electricity through wind, solar or hydro-electric power will also stand to benefit in the regions of the world that are blessed with abundant natural resources in each of those directions.

Renewable electricity is required to make green hydrogen and major investment will be required to expand the renewable power generation

Don't miss the green hydrogen clean-tech opportunity

At a projected compound annual growth rate of more than 50%, the broad hydrogen sector is poised for phenomenal returns. The reason for getting in is clear, and with the recent confirmation of significant regional, national and local funding throughout the EU the timing is also good. With Amazon and others investing tens of billions in clean tech VC, there is a risk of getting caught in the rush. However, as with all investments, a considered selection of the right investment opportunity that fits your risk / reward profile, hurdle rates, fund rules or portfolio policy could be your next step.

Remember the VHS/Betamax question for video recording technologies 40 years ago? Or the number of search engines, such as Bing, Ask Jeeves and Yahoo that were competing for attention before the dominance of Google? Picking the long-term winners requires a robust analytical approach with expert input. That's where Pangea SI experts can support your decision-making process. They will help you to move with agility to capture the opportunity early and with clarity to make the right decisions that fit your investment strategy.

The Political Agenda and Funding For Green Hydrogen

Green hydrogen is at the top of the political agenda and due to receive massive public funding

Hydrogen strategies around the world have been emerging rapidly since Australia's National Hydrogen Strategy was published in November of 2019. Australia threw the stone in the pond, and the ripples are growing to become a tidal wave of change. Hydrogen is flying to the top of the political agenda.

Grey (AKA brown) hydrogen production from brown coal in the Latrobe valley, Australia

Whilst the Australian hydrogen strategy supports a range of hydrogen production technologies including coal gasification, many hydrogen strategies focus on green hydrogen. Much of the reason for the interest in hydrogen is related to environmental policy commitments to become carbon neutral, therefore green hydrogen, or low-carbon hydrogen are key.

In Europe, Norway (hydrogenstrategi) and Germany (Wasserstoffstrategie) both confirmed their hydrogen strategies in June. And within Germany, the Bavarian Federal State took a bold lead to announce their hydrogen strategy a fortnight before the national document was passed as law through the German parliament. Green hydrogen is at the heart of these three policy documents. Other German states, such as North Rhine Westfalia (NRW), are also drafting their local hydrogen strategies.

Norway published their hydrogen strategy in May 2020

In a speech that European Commission President, Ursula von der Leyen, gave on 27th of May 2020, she confirmed three European priorities: 'strengthening our digital single market, European Green Deal and resilience'. The Green Deal includes 2050 net-zero carbon emissions targets - where green hydrogen can play a leading role. She also alluded to a potential CO2 tax which could be implemented on goods imported into the EU to raise funds to support the energy transition. This would bring the costs of goods produced using cheap hydrocarbon energy closer to the cost of goods produced in the EU using green hydrogen and further incentivise investment in green hydrogen in the EU.

On the 26th of May 2020, the EU DG ENERGY also announced the roadmap that will lead to the production of A EU Hydrogen Strategy. Kadri Simson, the new Commissioner for energy will be able to use that hydrogen strategy as a component of the European Green Deal Investment Plan to catalyse, harmonise and scale up hydrogen's role in the energy transition across the Union.

We might also expect that Germany will use their upcoming tenure as Presidency of the Council of the EU (effective from 1st July 2020) to align the EU vision with some other aspects of the German Wasserstoffstrategie. For example, the New Mobility Approach initiative will be central to Germany's period of Presidency. One of its three pillars is sustainability, which will rely heavily on hydrogen as a transportation fuel and the long-term goal will surely be to increase the percentage of green hydrogen that is used for mobility.

27 May 2020

"The recovery plan turns the immense challenge we face into an opportunity, not only by supporting the recovery but also by investing in our future: the European Green Deal and digitalisation will boost jobs and growth, the resilience of our societies and the health of our environment. This is Europe's moment. Our willingness to act must live up to the challenges we are all facing. With Next Generation EU we are providing an ambitious answer"

Funding for green hydrogen through post-Coronavirus recovery packages

The hydrogen strategies that have been announced around the world have not been hollow. Significant funding has been promised to underpin hydrogen's place in the renewable energy transition. For example, the German Covid-19 economic recovery plan will also channel billions of Euro in this direction. The Next Generation EU post Covid-19 stimulus programme will also allocate billions of Euro to hydrogen investments.

Notably, green (and low carbon) hydrogen is likely to get a significant boost it as part of the €750 billion Next Generation EU recovery package. The instrument will create a 'green, digital and resilient Europe'. In the section related to 'Kick-starting the economy and helping private investment', there is an explicit reference to support for 'clean hydrogen'.

Hydrogen powered fuel electric vehicles © H2 MOBILITY, Max Jackwerth

€750 billion is approximately €1500 per EU citizen. Expressing that as an actionable programme, it is about €45,000 per new car registered in the EU in 2019 – approximately the amount that would be required to fund the total annual new vehicle purchases in the EU as FCEVs.

But it should be emphasised – the total will be spread across many areas, of which green hydrogen is one.

In the German media, it was recently reported that €22 billion could be earmarked to incentivise the purchase of new 'clean-cars'. The definition of 'clean' would almost certainly include BEVs and hydrogen powered FCEVs, both of which have with zero CO2 emissions from the vehicle. There are clear reminders of the impactful car scrapping incentive that was offered in the EU in 2009 to improve air quality and stimulate economic recovery after the financial crisis – that resulted in a massive stimulus to the European automotive industry.

Regional funding will focus on local needs

Through the Covid-19 recovery plans, and more broadly, it is becoming evident that investment in the hydrogen economy will not only lead to environmental benefits but will stimulate economic development and create high quality jobs in R&D, manufacturing and advanced energy technologies. Regional hydrogen strategies, such as that of Bavaria, will also support local companies and organisations which are active in the hydrogen economy and focus on the needs of the local economy.

In Bavaria, that might mean technology development aligned to fuel cells which may be of value to BMW and Audi, the two big Bavarian premium auto brands. Linde and Siemens, two major DAX concerns, are also grounded in Bavaria and both also have major stakes in the emerging hydrogen economy. For North Rhine-Westfalia (NRW), a heavily industrialised region with a history of mining, refining, steel making and chemicals production, the implications are more about how to generate green hydrogen at scale to fuel local economic activity. NRW is also developing its own regional hydrogen strategy.

Investing in a green, digital and resilient Europe

Supporting Member States to recover

- Recovery and Resilience Facility
- Recovery Assistance for Cohesion and Territories of Europe
- Reinforced rural development programmes
- Reinforced Just Transition Mechanism

- Supporting investments and reforms
- Supporting a just transition

Kick-starting the economy and helping private investment

- Solvency Support Instrument
- Strategic Investment Facility
- Strengthened InvestEU Programme

- Supporting key sectors & technologies
- Investing in key value chains

Learning the lessons from the crisis

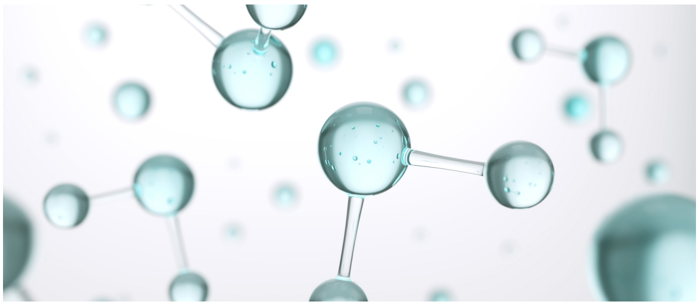
- New Health programme
- Reinforced rescEU
- Reinforced programmes for research, innovation and external action

- Key programmes for future crises
- Supporting global partners

How Green, Blue and Grey Hydrogen Differ

A definition of 'green hydrogen'

The use of hydrogen as a fuel is emission-free at in the fuel cell or heating boiler. But, the production of hydrogen can potentially produce significant carbon dioxide emissions. Most of the hydrogen produced in the world today is derived from a team methane reforming which is thermal catalytic conversion of natural gas. This process can yield what is sometimes known as 'blue' hydrogen. The gasification of coal produces syngas, which is rich in hydrogen. Hydrogen produced through this route is designated as 'brown' or ' rey'. Blue and grey hydrogen production methods are both sources of significant carbon dioxide (CO2).



In the EU, there is a scheme which can validate how 'green' hydrogen is. CertifHy Green Hydrogen refers to hydrogen generated by renewable energy with carbon emissions 60% below the benchmark emissions intensity threshold (based on the current hydrogen production default technology: an SMR fed with natural gas). CertifHy Low Carbon Hydrogen (AKA blue hydrogen) is hydrogen created by non-renewable energy with emissions below the same threshold, for example by capturing and sequestering a significant share of the carbon dioxide by-product on a CCS scheme.

The transition from blue hydrogen to green hydrogen will take time

Solar energy has the potential to produce vast quantities of green hydrogen. However, the conversion of solar energy to hydrogen is comparatively inefficient. Energy losses in the PV cell and electrolyser multiply to result in overall conversion rates less than 10%. Some people would say that in sun-drenched deserts, there is as excess of solar energy and these energy conversion concerns are irrelevant. However, improvements in the overall energy efficiency of the sun to hydrogen energy conversion pathway are regarded as desirable.

Despite the energy conversion inefficiencies, producing green hydrogen via electrolysis powered with renewable energy for fuelling stations must be the scenario for the future. However, most hydrogen fuelling stations today are supplied with so-called 'blue' hydrogen produced from natural gas in a steam methane reformer. As a transition step towards full decarbonisation, this may be acceptable. At least it will ensure that fuelling stations can be operated reliably at a reasonable cost which might incentivise automotive OEMs to invest in the development and commercialization of FCEVs. Blue is a good bridging option, but we must move to green later to meet the 2050 net-zero CO2 emissions targets.

Grey hydrogen as a bridge fuel for mobility – the view from Linde Hydrogen FuelTech GmbH

More and more customers demand 'green' hydrogen for their fueling stations. Linde Hydrogen FuelTech has already installed numerous systems that meet this requirement and always offer fueling stations with integrated electrolysis technology. However, most stations today are still supplied with hydrogen produced from natural gas in a steam methane reformer delivered in high pressure cylinder bundles. As a transition step towards full sustainability, Linde Hydrogen FuelTech regards this as is acceptable, especially considering that an FCEV fueled with so called 'grey' hydrogen emits 30% less CO2 well-to-wheel compared to a state-of-the-art internal combustion engine car.

For the time being, Linde Hydrogen FuelTech believes that reliable and plentiful availability of hydrogen it is of paramount importance. This will ensure that fueling stations can be operated reliably at a reasonable cost for drivers and means that automotive OEMs can invest in the development and commercialization of fuel cell vehicles in the knowledge that the fuel will be affordable and accessible. Simply put, the chicken must be built first, so that it can then lay the golden egg.

Hydrogen Electrolysers

The link between renewable power and green hydrogen

The three main hydrogen electrolyser technologies in play at scale today are alkaline electrolyte (sometimes called AEC), polymer electrolyte membrane (also known asproton exchange membrane or PEM) and Solid Oxide Electrolyte (SOE, or HTE).

Electrolysis of water, steam or an alkaline electrolyte are the most common large scale power to hydrogen routes as present

Alkaline electrolyte systems have a lower capex than the other technologies. It is also the most mature technology which means the equipment has a proven track record of reliability which the PEM and SOE processes have not yet had the chance to accumulate. The alkaline electrolyte equipment avoids the need for water purification (which is a requirement of the PEM system) and this helps to reduce cost and complexity.

PEM systems offer a quick ramp-up. When operated at pressures of up to 30 bar (which some other systems can also achieve) they offer a smaller physical footprint compared to atmospheric pressure electrolysis systems. A perceived disadvantage of the PEM system is that due to its recent emergence, there is no long-term (10 years+) operational data to validate the lifetime of large-scale PEM electrolyser units.

Solid Oxide Electrolysis (SOE) technology is sometimes referred to as High Temperature Electrolysis (HTE). It could equally well be called High Efficiency Electrolysis.

SOE also has high potential in a diverse range of Power to X applications because it can also produce syngas, a mixture of carbon monoxide and hydrogen.

It can therefore integrate seamlessly into several chemical processes. It consumes water in the form of steam and derives a significant percentage of its energy from the heat of the steam. This means that approximately one third less electrical power is required, compared to a PEM or alkaline electrolyte system, to produce hydrogen gas.

A fourth electrolysis technology called 'Plasma Electrolysis' is on the mid-term radar. It uses an electrolyte of ethanol mixed with water. Ethanol can be produced from the fermentation of crops, so when combined with renewable electricity this can become a source of green hydrogen. At present, this technology is still at an R&D / pilot project stage. It is likely that established players will wish to secure a foothold in this emerging technology, due to its comparatively high energy efficiency.

Green Hydrogen electrolyser case study from Germany

Hydrogen pipelines fed by SMRs are common in the refining and chemicals sectors. The Hypos initiative in Germany looks to feed such a pipeline with green hydrogen produced on an electrolyser. For the past three years stakeholders have been investing in R&D and building infrastructure in a vast region of Eastern Germany, centred around Leuna, to enable the use of green hydrogen in mobility, energy, refining and chemicals applications.

Gas pipelines are used to store and distribute hydrogen gas

In this concentrated geographic location, the hydrogen economy can be proven at scale and the full value chain from green hydrogen production through storage and to use can be stress-tested.The project has built up a lot of momentum and approximately 100 companies and organisations are now involved. Some of the major global industrial gas producers like Linde and Air Liquide are on the list of partners, as are some of leading Germany universities and several hydrogen electrolyser producers such as McPhy and Sunfire.

Green Hydrogen Case Studies

Green hydrogen production from Wind Energy – a case study from the UK

As an example of green hydrogen production for heating, a project at Levenmouth, Fife, will use green hydrogen to heat 300 homes. The idea is to produce renewable electrical power on a nearby offshore wind farm and convert that to hydrogen with an electrolysis unit. As a nation that embraced natural gas as a heating medium and invested heavily in a gas pipeline distribution infrastructure, it makes good sense for the UK to consider hydrogen as a domestic heating fuel. The same could be said of the Netherlands and other countries that have extensive reliance on a natural gas distribution infrastructure.

Wind turbine in Fife, Scotland

Hydroelectric power for green hydrogen – a case study from Switzerland

In addition to their equity investment in ITM power, Linde owns a 10% stake in Hydrospider, a producer of 'green' hydrogen from hydro-electric power in Switzerland. Hydrospider's flagship is the 2 MW electrolyser at Alpiq's Gösgen power station near the town of Olten on the river Aare. The electrolysis plant can produce up to 300 tons of hydrogen a year which is enough to keep approximately 50 trucks or 1700 cars on the road. On the topic of green hydrogen, Linde is committed to make emission free hydrogen widely available and easy to use. Producing hydrogen via electrolysis powered with renewable energy for fueling stations is regarded as the must-be-scenario for the future.

Integrated systems are essential to maximise energy efficiency

Cars and taxis delivering passengers to Germany's new Berlin-Brandenburg airport, and other airport vehicles, will be able to fill up with hydrogen at the Total Multi-Energy fuelling station there. The McPhy alkaline electrolyte hydrogen electrolyser for this project utilises as many green energy principles as possible. Wind and solar energy are used to produce electricity for the local power grid, which feeds the electrolyser with power to produce hydrogen. Since these natural energy sources fluctuate with the weather conditions and the demand profile for hydrogen over a 24-hour period is variable, there is a hydrogen buffer storage system between the electrolyser and the hydrogen car fuelling station. Excess hydrogen can also be ad-mixed into to the local natural gas pipeline network. Alternatively, hydrogen can be fed to a combined heat and power plant at the site. Excess hydrogen can also be collected by the industrial gas company Linde in road tankers and delivered to users nearby.

Waste heat recovery will be implemented at a large hydrogen electrolyser project in Laage, northern Germany where a 2MW alkaline electrolyte electrolyser manufactured by McPhy will be installed. In the first phase, the gas will be used as power to power energy storage in combination with stationary fuel cells and a combined heat and power plant. In a second phase, a road-side hydrogen fuelling station for private cars and buses is planned.

Electrolysers generate low-grade heat as a natural part of their operation. To make the overall hydrogen production, storage and power regeneration energy balance greener, it is advantageous to re-use this warmth. It also makes economic sense: local factories and properties need heating energy at moderate temperatures which is exactly what the electrolyser produces.

FCEVs vs BEVs For The Way Forward

Green hydrogen doing well in the emissions-free mobility race

There is a lot of debate about the relative merits of Battery Electric Vehicles (BEVs) and hydrogen-powered Fuel Cell Electric Vehicles (FCEVs). This debate often discusses the cars and it is commonly said that the BEV is twice as energy efficient as the FCEV. Drawing a neat box around the car, this may be true. However, the long-term macro system-wide issues go beyond the vehicle propulsion mechanism and include the energy storage, distribution and refuelling or charging infrastructure which would be required to support either technology.

The issue also play into the wider context of electricity transmission and gas distribution infrastructures. Ultimately, there are significant advantages of BEVs and FCEVs co-existing for individual mobility.

One of the issues that many developed nations face is that electrical power distribution infrastructure is heavily loaded with bottlenecks in many places. With the transition from coal and gas-fired stations to wind and other renewables the electricity grid will also need to change shape, and in some countries, this will put additional stress on heavily utilised parts of the grid.

In some countries, the electricity grid is fully loaded in many places

Electrical power is expensive to store. So, in the future, when renewables play a larger role in the total power production, the daily and seasonal cyclicality of hydro, wind and solar power generation will mean that energy storage at small and large scale becomes even more of an issue at both centralised and decentralised levels.

On the other hand, hydrogen gas could potentially be distributed in the extensive existing pipeline grid at comparatively low transport costs and it will be possible to convert parts of the natural gas grid to move hydrogen. This all means that a combination of molecule and electrical power movement could be an attractive solution.

Green hydrogen for FCEVs vs BEVs – a case study from Germany

With 84 hydrogen fuelling stations operational at the end of June 2020 and a near-term target of 100, Germany clearly leads the way with hydrogen mobility fuelling infrastructure in Europe. But, the tug of war between BEVs and FCEVs is not a binary issue. Both are likely to have a long-term role to play.

Shell hydrogen fuelling station Wiesbaden, Germany - © H2 MOBILITY, Felix Krumbholz

Investment in a hydrogen filling station network to replicate the current number of petrol stations (or probably with slightly fewer stations) would be a highly visible cost that would need 'up-front' investment. It looks like a lot of pain, but a recent total-system study in Germany concluded that when the BEV and FCEV options are compared over the long term, there comes a point when the slow incremental rise in the cost of the BEV infrastructure significantly increases above the cost of the hydrogen-powered FCEV infrastructure. That is a very important conclusion in favour of hydrogen mobility, or at least in favour of a mix of green hydrogen and green power.

A clear benefit of hydrogen is that both the refuelling stations and each vehicle has built-in energy storage in the form of a high-pressure hydrogen gas fuel tank. Each tank is small, but when there is significant penetration of FCEVs they would collectively add up to a huge energy storage buffer. The battery in a BEV also has power storage capacity, but it stores less energy than a typical automotive 700 bar high-pressure hydrogen cylinder.

In an extreme case that was modelled in the recent study in Germany mentioned above, if there was high penetration of BEVs in the future, there might be an additional 20% of load onto the electricity grid. In many rural areas, the electricity grid would struggle to serve this load. Especially in the evenings when commuters return home after work and plug in their BEVs to recharge.

Hydrogen Mobility

Another point that is often overlooked is that the costs of the BEV infrastructure investment would be incremental over a long period as more and more people convert to BEVs. The costs are also distributed to the consumer because the car-owner will often pay for a charging station in their home. It is not about a few 'big ticket' items such as the construction of new hydrogen fuelling stations - it is very diffuse.

Green hydrogen for maritime applications - case study from Germany

A recent study undertaken for the German Ministry of Transport compared the feasibility of implementing various alternative fuels for inland barge operations on German rivers. Millions of Tonnes of cargo are transported by barges up and down the Rhine, Elbe, Neckar and Danube Rivers each year. Commercial cruisers also use these waterways – floating hotels or restaurants. These barges and cruisers travel through the centres of major cities such as Berlin, Cologne, Frankfurt, Hamburg and Mannheim, so the idea would be to use fuel cell powered boats which would reduce noise levels and eliminate emissions of toxic air pollutant gases.

The river Spree in Berlin is used by industrial barges and commercial cruisers

The question that the German Ministry of Transport wanted to investigate was 'which fuels might replace diesel for inland shipping in future fuel-cell operated ships?'. The impact of adapting the existing bunkering terminals and potentially building out the infrastructure to enable storage of the new fuels was assessed. Also, the costs of converting the barges to store the alternative fuels were estimated.

Several clean burning renewable fuels were considered in the study. For example, hydrogen gas at 350 or 700 bar and liquid hydrogen. It also considered hydrocarbon e-fuels such as synthetic diesel, LNG and methanol, all of which can be synthesised using renewable electricity.

Fuels bunkering and fuelling stations for inland waterways would need to be adapted

The liquid hydrocarbon e-fuels could be used with an on-board catalytic converter (a miniature steam methane reformer) to generate hydrogen to operate the fuel cell drive system. Liquid hydrocarbons have the benefit of high energy density and low-cost storage, but that must be offset by the additional capital cost and energy losses of the onboard conversion to generate hydrogen. Alternatively, some liquid hydrocarbon fuels can be fed directly to a high temperature Solid Oxide Electrolysis fuel cell to produce power directly. The study concluded that the liquid hydrocarbon e-fuels could also be viable options.

Green hydrogen gas would also be a viable option if the infrastructure and on-board storage is at 700 bar. The lower pressure 350 bar hydrogen option was determined to be the least effective of all the fuels studied. Liquid hydrogen also came out as a feasible option.

700 bar high-pressure gas cylinder of composite construction

Whilst this study focused on inland shipping, it is reasonable to expect that some of the conclusions may extrapolate to offshore shipping. However, since the study focused on the use of fuel cell power systems for noise and emissions reduction, it is likely that ocean going vessels would operate with fewer constraints. Therefore, the renewable liquid fuels such as biodiesel or e-fuels could be fed directly to an internal combustion engine (like the current marine diesel engines) and this would put them at a significant advantage versus hydrogen due to the reduced cost of modification of the ships themselves.

Further Industry Applications

Green hydrogen to decarbonise flight

Hydrogen mobility has, up to now, largely focused on trucks, buses, cars, rail and shipping. As an alternative to e-bikes, hydrogen powered bicycles have also emerged. In the air, a few hydrogen drones and small-scale transporters have been proposed and piloted, but it is often said that aviation will be the hardest area to decarbonise. Perhaps the inclusion of e-fuels quotas in national and regional hydrogen strategies will further catalyse major advances in hydrogen fuelled aviation this decade.

Hydrogen fuelled drones are used for agricultural surveillance

The German hydrogen strategy will pull for renewable fuels in aviation with a 2% electricity-based fuel quota being discussed to be achieved by 2030. The policy document sets the direction. The market will determine the most economically viable options for production of these fuels. Possible renewable fuels include green hydrogen or e-fuels such as kerosene produced on an SOE combined with a Fischer-Tropsch reactor, a technology that Sunfire are marketing.

Airbus penned designs for the 'CRYOPLANE' 20 years ago. It was a modified A310 with four liquid hydrogen tanks straddled on top of the passenger area from the nose to the tail. Compared to traditional aviation kerosene, liquid hydrogen has a relatively poor energy to volume ratio, but it does have an excellent energy to weight ratio. In flight, it's the weight of the plane that matters most. Bulky planes tend to fly quite well, as various transporters have demonstrated over time. So, putting big cryogenic liquid hydrogen fuel tanks on the top of a jet liner is not a deal-breaker in terms of aerodynamics and overall fuel efficiency.

Fischer-Tropsch reaction process for Power-to-Liquids – © Sunfire GmbH

Further Industry Applications

Green hydrogen for industrial applications

For industrial sector applications, refining is taking the lead in adopting green hydrogen. For them it is a rather simple substitution of hydrogen produced from fossil fuels on Steam Methane Reformers to the use of green hydrogen from electrolysers. The Get H2 Nukleus project in north west Germany is a clear forerunner here. A 100 MW electrolyser will generate green hydrogen which will be connected by pipeline to two BP refineries in Lingen and Gelsenkirchen. In the chemicals sector, the same is sometimes possible and Evonik are also tapping into the Lingen hydrogen pipeline.

Refineries use hydrogen for desulphurisation and hydrogenation of liquid hydrocarbon fuels

Linde has formed a 50/50 joint venture with ITM Power which is focused on large scale (>10MW) electrolysers for industrial applications. Linde also took approximately 20% equity stake in ITM power in early 2020 with a €45million share purchase. The electrolysers can be fed with power from renewable or other sources. It is expected that in the long term this option will supplement Linde's current strong position in the production and distribution of non-green hydrogen.

Power to Gas - Molecular energy storage case study from Austria

In many countries, we must find a reliable way to smooth out the seasonal imbalance of renewable electricity generation, which peaks in the summer and the demand for energy, which peaks in the winter. Molecular energy storage as hydrogen is a potential solution.

Hydroelectric power on Austrian rivers is seasonal

In Austria, around 65% of the nation's electricity is derived from renewable sources. Much of that comes from hydro-electric power plants on the Danube River. The stream of the river is strong during the summer months when rain is falling but it is quieter in winter when the precipitation falls as snow, which accumulates on the land. That frozen water is then released to the river during the spring thaw. Solar power is also a major contributor to the Austrian grid in summer but is also not reliable in cloudy winter months. And with lots of snow and fewer sunlight hours in winter, it is naturally the peak demand season for domestic heating with natural gas.

Green hydrogen can be used as a molecular energy store achieving the first 65% of renewable electricity production in Austria has been relatively easy but getting from 65% closer to 100% will become progressively more difficult. Taking the peak in power production in the summer and storing that for use in the winter is therefore the critical challenge that the nation faces. And, they are not alone. Many other central European countries such as Germany, Switzerland and the Czech Republic have similar weather patterns and face similar challenges. The climatic conditions in Canada, northern parts of the United States and Southern parts of South America are the same.

During the summer months, solar power also suffers from over-production during daytime and under-production at night. However, batteries or pumped storage hydro-electricity schemes can effectively be used to smooth out these short-term demand imbalances. To provide long-term energy storage which can use the summer peak to fill the winter trough, we will probably need to store energy in molecules such as hydrogen and methane.

Pumped storage hydro-electric schemes act as an electrical power reservoir

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