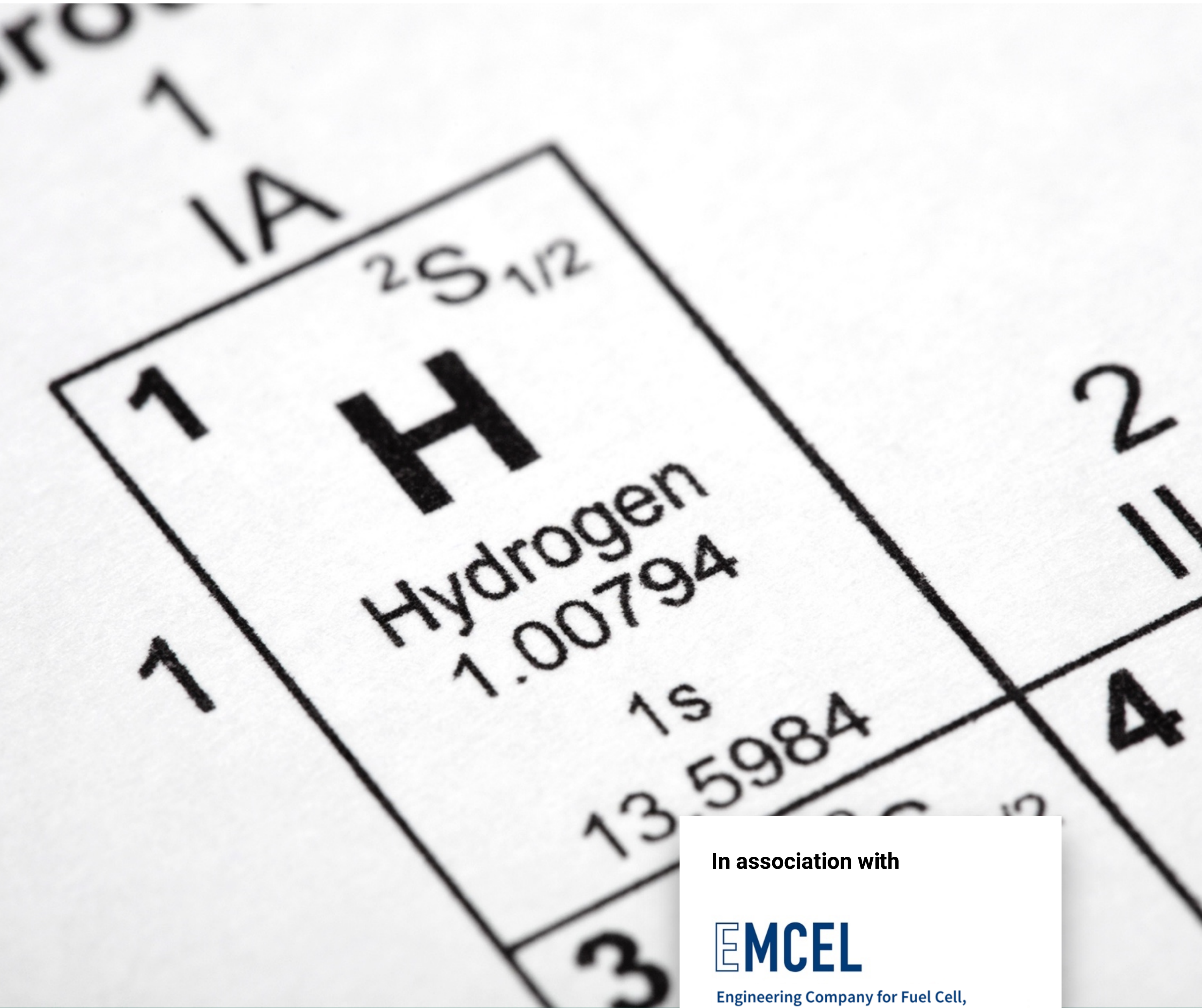
SENCO HYDROGEN CAPITAL®



In association with

EMCEL
Engineering Company for Fuel Cell, Hydrogen Technology and Electric Mobility

ZSW
Center for Solar Energy and Hydrogen Research

MARKET OPPORTUNITY PAPER

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SENCO'S OUTLOOK ON HYDROGEN

Germany and the EU aim to become carbon-neutral by 2050 – a target that demands a radical renunciation of fossil fuels. The significance of hydrogen in achieving these climate goals and creating a diversified, future-proof energy supply has increased dramatically in the last months. Carbon-neutral hydrogen and its derivatives are becoming game changers for a successful energy transition and SENCO's target and mission is to contribute its corporate efforts to achieving just that.

SENCO's corporate strategy is based on the central realisation that hydrogen – and in this context, green hydrogen produced using renewable energies in particular – plays a fundamental role in establishing a decarbonised energy system today and will become a key technology when it comes to substituting fossil commodities in key areas of the industry.

Green hydrogen will replace grey, fossil hydrogen as a commodity to decarbonise industrial products in a range of industries, including the petrochemical, chemical, fertiliser and metal industries. Green hydrogen and its derivatives, such as ammonia, synthetic fuels and synthetic gases, allow us to harness a steady supply of renewable energy at an industrial scale, no matter where, no matter when. Produced using wind, solar and hydropower, hydrogen and its derivatives can be stored in caverns, transported by ship or through pipelines, or reconverted into electricity via gas turbines, thus turning green energy which has been generated locally into a carbon-free, climate-neutral energy source for global and universal use.

The underlying technologies for producing hydrogen by means of electrolysis and using it in fuel cells and chemical processes have been around for more than a hundred years; essential structures, such as caverns for storage and gas pipelines for transport, are in place and can generally be used for hydrogen as well. Drive technologies with hydrogen-based fuel cells are being used in lorries, trains and ships today, while the industrial production and utilisation of synthetic, hydrogen-based fuels in aircrafts, for example, will be a significant step towards decarbonising aviation.

The above shows that hydrogen is becoming a central component of a carbon-free and energetically diversified economy today and is no longer a vision of the distant future. Now we need to focus on achieving the necessary industrial scale, coupling sectors smartly along each step of the value chain, from renewable energy generation to hydrogen production, from transport and storage to utilisation.

To do so, we need to ramp up the hydrogen economy, which in turn offers institutional investors attractive, risk-compatible investment opportunities today; these include opportunities in project development, in the production, storage and use of hydrogen as well as in companies that develop and manufacture the components it takes to do so.

The declared commitment of the stakeholders in the hydrogen economy plays a significant role in this:

- There is a growing tendency among investors and financiers to look for ESG-compliant investments for their own institutional investors who are geared towards sustainability.
- Many leading industrial countries are optimising their regulatory frameworks and making start-up funds available today.
- Industrial companies are gearing their process and production chains towards using hydrogen at an industrial scale today.

On the following pages, and in cooperation with our experts within the SENCO network, we have summarised the key theses on hydrogen, providing fact-based explanations.

Facts and theses on hydrogen:

1. Hydrogen is one of the most important feedstocks worldwide and is indispensable in a number of key industries. The hydrogen we use today is produced on the basis of natural gas and will need to be replaced by green hydrogen over the next 20 years to reach climate targets and ensure a future-proof supply.

2. Water electrolysis is the most viable technology for producing green hydrogen. The number and size of generation plants will increase massively in the next years, while the costs for producing hydrogen will decrease due to economies of scale. For plant operators, investing in production plants at an early stage is worthwhile, as this helps secure attractive and scalable locations with sustainable access to necessary input factors, such as green power. Plant operators will participate both in the degressive price development while scaling up their plants as well as in the expected long-term degression in costs for green power.

3. Without hydrogen, there can be no energy transition: hydrogen will become the green energy, the commodity and central energy storage system of the future in global trade, employed in numerous applications – from private households to large-scale industrial plants – through sector coupling.

4. Several technologies are currently being established, all of which facilitate the required regional transport and global import of hydrogen over long distances. These technologies will all require considerable investments in means of transport and infrastructures such as pipelines, ships, storage systems and shipping terminals.

5. Today, there is an overwhelming consensus among experts on the role green hydrogen will play in the relevant applications in industry, heavy goods traffic and electricity generation, as well as on the fact that these same applications will require more than 2,300 TWh by 2050.

6. The industrial market ramp-up will require investments of at least € 400 billion by 2030 in Europe alone and will offer tremendous investment opportunities at all levels of the value chain. Data on levies imposed on renewable energies in the past show that it will be possible to finance investments of this magnitude in the future.

7. The costs of producing and transporting green hydrogen will decrease considerably over the course of the next years: key drivers include the exemption from levies and the expected long-term degression in costs for green electricity; the decreasing cost of investing in and operating electrolysers; larger plants; and extended operating periods. All of the above will stimulate the demand, which will in turn provide additional support in ramping up the market.

8. The current market drivers reinforce one another and thus put the hydrogen economy on an irreversible developmental trajectory with tremendous potential for growth and investments.

I. THE MATERIAL AND ENERGETIC PROPERTIES OF HYDROGEN AS THE BASIS FOR THE ENERGY TRANSITION

What is hydrogen?

Hydrogen (chemical element; symbol: H; hydrogenium) is the most common chemical element within our solar system. Hydrogen makes up 75% of the entire mass, or 93% of all atoms, in the solar system, and is the basic element that represents the mass of the gas giants: Jupiter, Saturn, Uranus and Neptune.[1] Hydrogen is the lightest chemical element. Under normal conditions, unbound hydrogen cannot be found on earth; it usually bonds with oxygen to create water. Before we can use pure hydrogen, we therefore first need to obtain it by means of technical processes.

One tonne of hydrogen has an energy value of more than 30,000 kWh,[2] which is the equivalent of the average annual power consumption of eleven three-person households in an apartment building.

What are derivatives of hydrogen?

Hydrogen derivatives are hydrogen-based, gaseous or liquid chemicals and/or energy sources; these include hydrocarbon compounds methane and methanol. Ammonia, a chemical compound of hydrogen and nitrogen, is another common derivative. The following table provides an overview of energy values (heating values) of selected hydrogen derivatives. The "H" in the respective molecular formula shows that hydrogen is the common denominator.

Energy source	Molecular formula	Energy value/heating value (in kWh/kg)
Hydrogen	H_2	33.3
Methane (gas)	CH_4	13.9
Methanol	CH_4O	5.5
Ammonia	NH_3	5.1

Figure 1: Derivatives of hydrogen[3]

[1] chemie.de, the leading portal for the German chemical industry

[2] Related to the heating value

[3] ECH Elektrochemie Halle, The use of ammonia to generate energy ("Nutzung von Ammoniak zur Energieerzeugung"), Prof. Dr. Matschiner / Institute for Energy Technology, Eastern Switzerland University of Applied Sciences

In terms of quantity, ammonia is the most important hydrogen derivative and a chemical commodity primarily used in the manufacture of fertilisers; around 75% of the approx. 200 million tonnes of ammonia manufactured worldwide are used in this field. The energy expenditure for the manufacture of ammonia corresponds to about 2% of global energy generation.[4] Ammonia has also been used as a fuel and an energy storage system in the past; in 1872, trams in New Orleans were powered by ammonia, as were Belgian buses during World War II.

With a global annual production of more than 100 million tonnes, methanol is also a key base chemical.[5] Conventional manufacturing processes are based on fossil commodities such as natural gas, coal and crude oil and have been brought to a high level of technical maturity over the course of the past decades; however, these processes cause high carbon dioxide greenhouse gas emissions. In the course of the energy transition, conventional methanol is increasingly being replaced by green methanol. During the production of green methanol, renewable energies are used to generate green hydrogen, which is in turn converted into synthetic methanol using CO_2.

In the chemical industry, this is then used as a basis to produce formic acid and acetic acid; it is also used as a solvent in dyes, resins and paints. In many branches of the industry, methanol has great meaning as a softening agent, antifreeze compound, cleaning agent and thinner. Methanol is also used as a substitute fuel in heating and for certain fuel cell applications;[6] as early as 2018, Maersk, the world's largest shipping company, ordered eight ships with a capacity of around 16,000 standard containers each which can be operated with "green" methanol, for example.

Today, hydrogen derivatives form the basis for a range of industrial applications and are a main cause of carbon dioxide emissions when fossil energy sources are used in their production. However, derivatives can also be manufactured synthetically, via Power-to-X[7] solutions which use green hydrogen, for example, making this one of the most effective instruments against climate change.

[4] Bayern Innovativ/Energy Technology Cluster, Prof. Dr. Jochen Fricke, Ammonia – An ideal storage system for hydrogen ("Ammoniak – ein idealer Wasserstoff-Speicher"), Oct. 2018

[5] Fraunhofer ISE

[6] Methanol is either used as a supplier of hydrogen for hydrogen fuel cells (indirect methanol fuel cell) or directly, in direct methanol fuel cells.

[7] Power-to-X comprises any method that converts electricity into a chemical source of energy, such as hydrogen, ammonia and methanol.

What is hydrogen used for today?

Today, the current global output of 125 million tonnes of hydrogen[8] is primarily produced in refineries and chemical plants using natural gas and consumed directly on site, which explains why hydrogen's outstanding importance as a raw material is rarely recognised by the public. Without hydrogen, there would be no petrol or diesel[9], no artificial fertiliser[10] or end products such as plastics in the chemical industry; even medicines are frequently based on hydrogen. Of all the chemicals that are made out of hydrogen, the most important by far are ammonia for fertilisers and methanol, a simple alcohol which is used in the production of numerous chemicals as well as in other applications in the steel, cement and glass industries. This makes hydrogen one of the world's most important and widely used commodities today. In proportion to the population of the European Union, the annual global output corresponds to approx. 250 kg of hydrogen per capita – or a driving distance of 25,000 km in a fuel cell car.

How is hydrogen produced today?

In nature, hydrogen (H_2) is not found in its purest form; instead, it generally forms bonds with other elements, for example with oxygen (O_2) in water (H_2O). Methane (CH_4) – the main component of natural gas – and crude oil are also key hydrogenous compounds, known as hydrocarbons. A lot of known minerals also contain hydrogen as well as the steam in the earth's atmosphere.

Depending on the energetic raw material and/or energy source used in the production process, hydrogen is classified using a colour spectrum which ranges from grey to green. The following table shows the most common colour designations as well as the CO_2 emissions related to the respective method of hydrogen production. SENCO's activities focus on production methods that reduce CO_2 and are thus climate friendly.

[8] IRENA, Global Hydrogen Trade to Meet the 1.5° C Climate Goal, 2022
[9] During the refining process, crude oil is manufactured into petrol and diesel using hydrogen.
[10] Fertiliser is made out of ammonia; hydrogen is in turn an elementary component of ammonia (NH_3).

Hydrogen colour	Raw material	Energy	By-product	CO_2 emissions (per kg of H_2)
Grey	Natural gas, coal	Electricity mix, fossil fuels	CO_2 in the atmosphere	approx. 10-23 kg
Blue	Natural gas, coal (CCUS)	Electricity mix, fossil fuels	CO_2 underground	Approx. 5-7 kg
Pink (sometimes also red or violet)	Water	Nuclear power	O_2, radioactive waste	< 1 kg
Turquoise	Methane	Variable, including renewable energy	Solid carbon	Variable
Yellow	Water	Electricity mix	Depends on the electricity mix	Variable
Green	Water	Renewable energy	O_2	< 1 kg

Figure 2: The hydrogen colour spectrum

Today's methods of producing hydrogen on a large scale are robust and proven; production plants can be built in gigantic dimensions and reliably operated for decades. The method most commonly used today obtains "grey" hydrogen from natural gas, with comparatively high emissions of 10 kg of CO_2 per kilogram of hydrogen[11]; approx. 50% of hydrogen produced worldwide is obtained in this manner. In this process, known as steam reforming, natural gas is converted into hydrogen and CO_2 at high temperatures using steam. About 30% of all hydrogen is obtained from crude oil in a comparable process, which primarily uses crude oil residues from refineries. A further approx. 20% of hydrogen is produced by gasifying coal using steam. A prominent example of coal gasification is South African petrochemical company SASOL's plant in Secunda (South Africa), which emits approx. 55 million tonnes of CO_2 per year, making it the world's biggest emitter of greenhouse gases in the world.[12]

In another method, the CO_2 produced during these processes is not emitted into the atmosphere but gathered and pumped into the earth, for example into exhausted oil deposits. Formally, the "blue" hydrogen produced using this method is carbon-free and thus appealing

[11] Https://www.dihk.de/resource/blob/24872/fd2c89df9484cf912199041a9587a3d6/dihk-faktenpapier-wasserstoff-data.pdf (German only)
[12] Bloomberg, The World's Biggest Emitter of Greenhouse Gases, März 2020

from an environmental perspective. In Europe, depleted oil fields off the coast of Norway, for example, can be used to store CO_2; however, these storage sites are frequently far from the places where hydrogen is needed.

Other methods of producing hydrogen are based on the decomposition of natural gas into hydrogen and carbon or on water electrolysis using nuclear power (pink); further technologies, such as pyrolysis, are currently still in the early stages of development.

Water electrolysis is the most viable production method and has been employed for decades. In this method, electricity is used to decompose water (H_2O) into hydrogen (H_2) and oxygen (O_2); the energetic source employed today is usually electricity based on fossil energy carriers. Large water electrolysis plants have been in operation for more than 50 years. Compared to all other methods of production, electrolysis offers the option of using green power or renewable energy in manufacture and to thus obtain sustainable and carbon-free "green" hydrogen. Approx. 10-14 litres of fresh water are required to generate one kilogram of hydrogen; when using salt water, the water is desalinated beforehand. If all hydrogen produced in Germany in 2021 had been manufactured by means of electrolysis, it would have taken up around 5.5 million tonnes, or only about 0.04%, of Germany's annual operational water usage, equalling the amount of water that flows past Cologne in the Rhine in approx. 45 minutes.

The degree of efficiency of electrolysis depends on various aspects,[13] and is usually 60-70% – which means renewable energy is converted into green hydrogen in an extremely efficient manner. In comparison: the degree of efficiency of coal is 30-40%. As a tremendous amount of research is currently being done in the field of hydrogen production, we can expect the degree of efficiency to increase even further in the next years, when the heat created during electrolysis is also put to good use.[14]

As the above shows, green hydrogen produced using renewable energy is especially well suited for sustainable decarbonisation. While pink hydrogen produced using nuclear power is also virtually carbon-free, the fundamental challenges of nuclear power – such as disposing of and storing the fuel rods – will not lead to a significant production of pink hydrogen, at least in Germany. Countries that include France, the United Kingdom, Japan and the USA will be using nuclear power in hydrogen production, in addition to ramping up the generation of green hydrogen.

1. Hydrogen is one of the most important commodities world-wide and is indispensable in a number of key industries. The hydrogen we use today is produced on the basis of oil and gas and will need to be replaced by green hydrogen over the next 20 years to reach climate targets and ensure a future-proof supply.

[13] Influencing factors include the size of the plant and the mode of operation (full-load or partial-load operation)
[14] The Center for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW)

How is carbon-free hydrogen produced?

In future, water electrolysis will be the preferred method of hydrogen production. This method uses electric power to decompose water into hydrogen and oxygen, however, it can only be considered fully carbon-free if 100% of the required energy is from renewable energy sources. In general, energy generators and electrolysis plant operators conclude agreements on the long-term supply of green power, for example through Power Purchase Agreements, or PPAs for short.

If, on the other hand, the electrolysis plant is operated with “grey” power from the conventional German power grid, the share of green power is currently approx. 50%; this value will improve over the course of the next years, as the share of green power increases. From a technical perspective, it doesn’t really matter where the power for installed electrolysis plants comes from. Physically, green power provided via a PPA and power from the grid are identical, which is why it will be possible to operate any electrolysis plant with 100% green power in future, without the need for specific modifications or expansions.

In countries with a high share of renewable energy in the overall electricity mix (e.g. Sweden, Austria, Switzerland), water electrolysis that uses power from the grid has already become the most CO_2-efficient form of hydrogen production.

It is also likely that countries that have wind, sunshine and open areas in abundance will gain importance as global production hubs for hydrogen and its derivatives: these include Norway, Scotland, Ireland, Spain, North Africa, the Arabian Peninsula as well as Australia, Chile and the south-west of the USA. The low purchasing prices for green power prevalent in the countries of origin compensate for the additional costs of transport, despite the distances. Australia, for example, estimates that the costs of transporting green ammonia from Australia to Germany will ultimately only make up approx. 5-10% of the overall cost. The German and Australian governments are negotiating the supply of green hydrogen in the form of ammonia from Australia to Germany as part of the joint HySupply project. With projected costs of transport by sea of € 0.06-0.08 per kilogram of ammonia, no economic reasons preclude this supply; according to an expert opinion issued by the Institute for Climate Protection, Energy and Mobility (IKEM), no legal reasons do, either.[15]

[15] Die Welt, In need, Germany puts its hopes in the world’s longest hydrogen bridge (“In der Not hofft Deutschland auf die längste Wasserstoffbrücke der Welt” German only), July 2022

Figure 3: Distribution of overall costs of supplying Germany with green ammonia from Australia.[16]

From a technological perspective, the electrolysis of hydrogen is mature and can be realised through various methods. In general, an electrolyser cell consists of two electrodes (a cathode with a negative charge and an anode with a positive charge), which use electric energy to decompose water into its gaseous components: hydrogen on the cathode side and oxygen on the anode side. A membrane between the electrodes prevents the two gases from mixing.

Currently, two types of water electrolysis are primarily used at a large scale:

- alkaline water electrolysis (AWE) and
- polymer electrolyte membrane electrolysis (PEM)

[16] Author's diagram; see publication issued by the Australian Embassy, Berlin, homepage, accessed July 2022

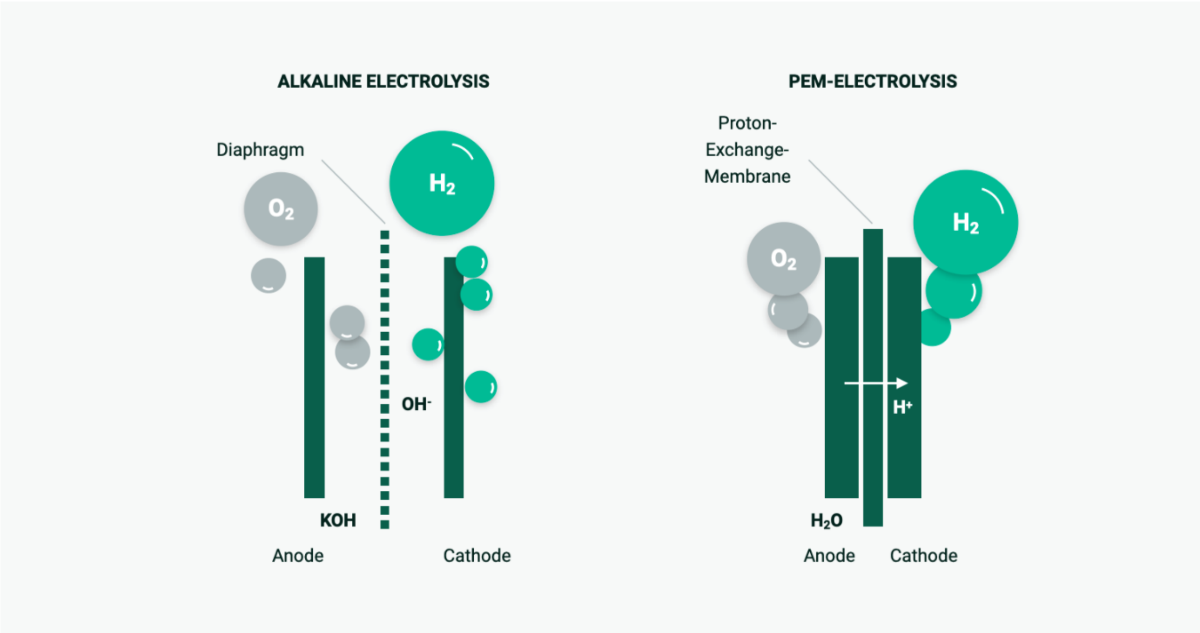

Figure 4: Schematic depiction of PEM and alkaline water electrolysis[17]

The method known as alkaline water electrolysis (AWE) uses a mixture of potassium hydroxide and water as a liquid operating medium, with which the membrane is fully saturated. In the "dry" polymer electrolyte membrane electrolysis method (PEM electrolysis), the electrolysis water is added on the anode side, while a polymer electrolyte membrane acts as an electrically conductive operating medium between the anode and the cathode. As the membrane is used without a liquid electrolyte, this method is known as dry cell electrolysis.[18] AWE and PEM are mature electrolysis methods that can be used at industrial scale.

There are other manufacturing methods, such as solid oxide electrolyser cells (SOEC), which have not yet reached technological maturity. Solid oxide electrolyser cells are based on solid oxide fuel cells (SOFC), which are operated in reverse mode to produce hydrogen and oxygen using solid oxide or ceramic electrolytes. As this requires operating temperatures of more than 650° C, this is known as high temperature electrolysis. Although SOECs can be used to achieve high degrees of operational efficiency in electrolysis itself, the required heat is associated with considerable inefficiencies. At the current time, however, we do not expect this method to play a particularly important role.

Plants today are produced and built at a scale of up to 25 MW. In the next years, we expect to see considerable increases, both in size (up to gigawatt dimensions) and in units produced.

[17] Author's diagram; see Siemens Energy data sheet
[18] The Center for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW), Electrolysis – Basics II ("Elektrolyse – Basics II", German only)

Leading manufacturers of electrolysis plants, including Siemens Energy, thyssenkrupp Nucera, MAN Energy Solutions (H-Tec), Cummins, Plug Power, Nel Asa, ITM and Sunfire, are all investing massively in the expansion of their manufacturing capacities. According to estimates, global capacities are expected to more than triple between 2021 and 2024. On 5 May 2022, the European Commission signed a joint declaration with 20 CEOs from the industry, in which the companies committed to increase their production capacities for electrolysers tenfold to 17.5 gigawatts per year by 2025.[19] This has a significant pull effect on the corresponding suppliers and component manufacturers. The associated economies of scale will reduce the production costs of green hydrogen considerably, resulting in market dynamics which offer numerous attractive opportunities for investors.

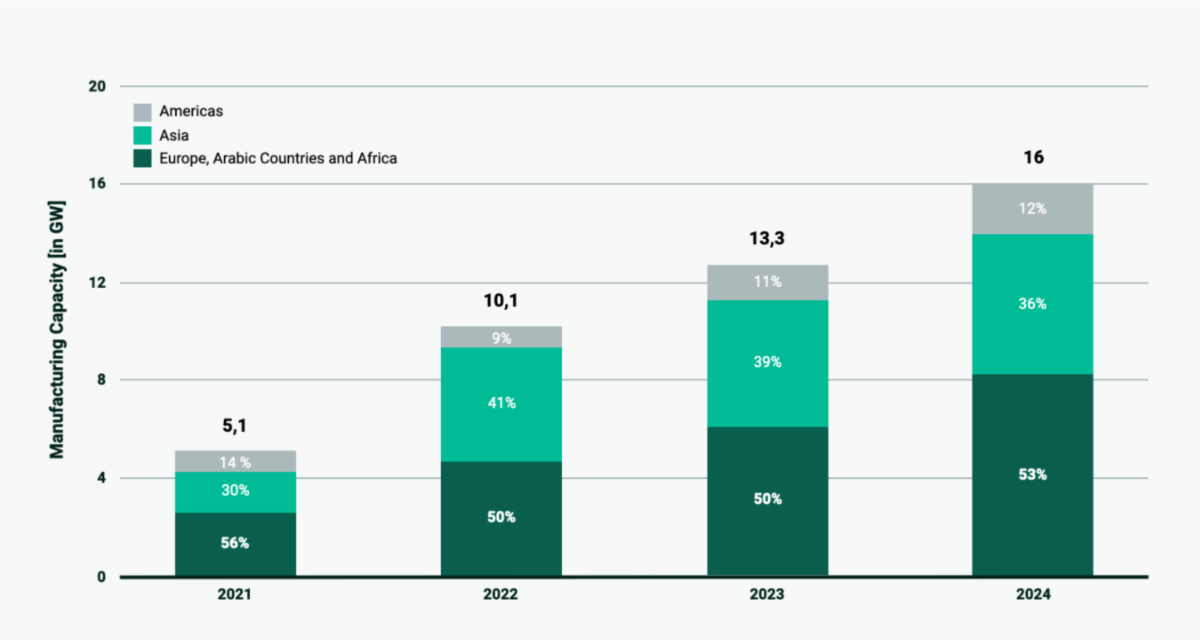

Figure 5: Projected global capacity of electrolysis plants[20]

2. Water electrolysis is the only technically available and viable technology for producing green hydrogen. The number and the size of production plants will increase massively in the next years, while the costs of hydrogen production will decrease due to economies of scale.

[19] European Commission, press release dated 5 May 2022

[20] Author’s diagram; see IRENA, Geopolitics Hydrogen 2022

II. THE HYDROGEN MARKET RAMP-UP: A DRIVING FACTOR IN THE ENERGY TRANSITION

Why will the hydrogen economy now change radically?

The conversion to the production of clean hydrogen is a key requirement for achieving the climate targets defined in the Paris Agreement. As industrial processes are decarbonised, the production of hydrogen using fossil energy sources will no longer be a viable option due to the associated CO_2 emissions. Based on a global production of approx. 125 million tonnes of hydrogen[21] per year, emissions amount to a calculated 1.2 billion tonnes of CO_2, which we will need to avoid in future in the context of the energy transition.

On top of this, we have the current geostrategic implications that arise from Russia's war against the Ukraine. For regions that lack raw materials, such as Western Europe, a high consumption of fossil energy sources automatically means a dependency on countries with large reserves of raw materials. Transformation and diversification that lead us away from fossil energy sources and towards renewable energies reduce this dependence. As a source of renewable energy, hydrogen has gained even more importance and is the most sensible alternative in the long term. Unlike green power, hydrogen can be used universally: as a medium of storage, a medium of transport, as a feedstock in the (petro-)chemical and plastics industries and as an energy provider in industrial processes that cannot be electrified, such as steel production.

Against this background, it seems clear that the 200-year development of coal, oil and natural gas as humanity's main sources of energy is coming to an end. The energy transition, and with it, hydrogen's triumph as a sustainable source of energy suitable for industrial use, cannot be stopped, as:

- politics and the majority of society support the energy transition;
- we have the necessary technologies, and they are competitive;
- sufficient funds from politics and institutional investors are available for impact investments;
- hydrogen is available as a universal solution, and can help utilize the fluctuating generation of renewable energy in industrial processes, regardless of time and space; and
- increasing gas prices paired with a long-term decrease in the costs of green electricity ensure that hydrogen will become competitive even more quickly and sustainably.

[21] IRENA, Global Hydrogen Trade to Meet the 1.5° C Climate Goal, 2022

What makes hydrogen more than a commodity and a driving factor in the energy transition?

Hydrogen's role will change fundamentally over the course of the next years: in addition to being a commodity for the (petro-)chemical industry, it will become a carbon-free source of energy that is traded globally, used universally and services various sectors of our daily lives. Green electricity generated using wind power and photovoltaics will become the central source of energy within our decarbonised energy system. Many applications in industry and private households have even been electrified today, or can be in the near future. As a flexible source of energy, hydrogen can compensate for the disadvantages of electric energy, such as insufficient power line capacities and limited storage abilities.

The large number of applications that cannot be electrified plays another key role here. In this context, green hydrogen will represent the climate-friendly solution of the future, for example in the chemical industry, in plastics production and direct reduction processes in steelmaking, in the manufacture of fertilisers and production of sustainable kerosene.

Thanks to its ability to function as a storage system, green hydrogen will also balance the generation of green electricity, which fluctuates depending on region and season, as well as the uneven global distribution of power generation and utilization. Logistics infrastructures form the basis of this and include pipelines, storage caverns and transport vessels, which already exist within the current energy system and will need to be converted or expanded accordingly. Green hydrogen can be used in every area of the industry, the energy economy and the traffic sector, and can help couple these – hitherto separate – sectors, which is in turn one of the key concepts of the energy transition.

This makes the global expansion of hydrogen as an energy source and sector coupler a key to the success of the energy transition. Hydrogen is the only way industrial sectors such as steel, chemicals or cement can become carbon-neutral, and hydrogen is the only way to store and distribute/transport enough green electricity globally.

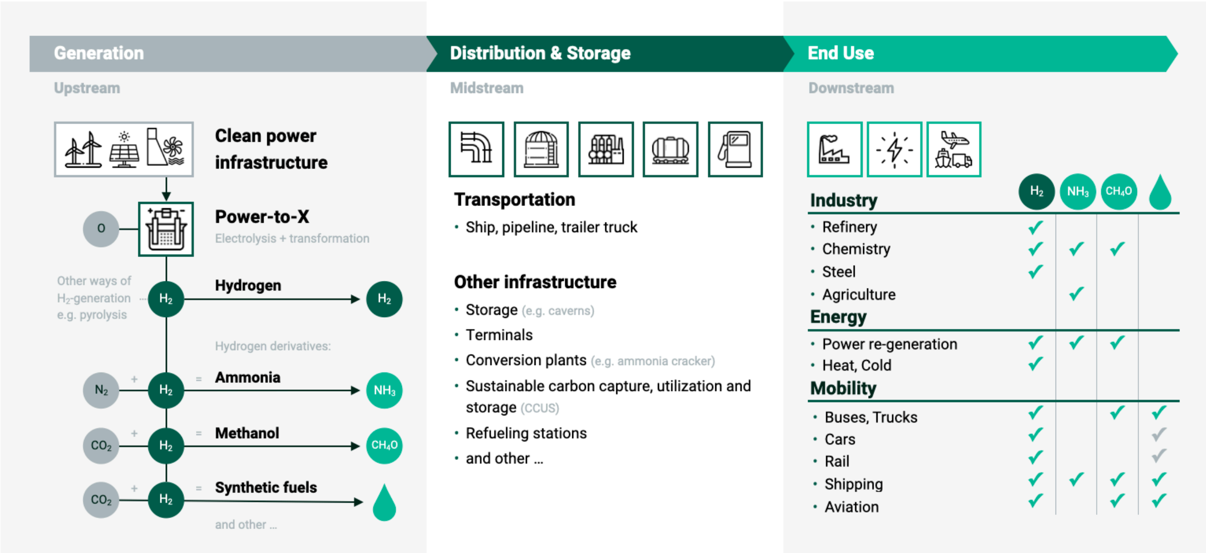

Figure 6: The hydrogen value chain[22]

New applications and business models are emerging along the entire value chain of generation, distribution / storage, and end use. In the next years, this will result in a number of attractive opportunities for investors. With the SENCO Hydrogen Equity Fund, SENCO aims to harness these opportunities for institutional investors to enable both attractive returns and a positive impact on the environment. To do so, we are investing in infrastructure projects as well as in the relevant suppliers and service providers in this field.

What is the significance of hydrogen in the context of sector coupling?

The decarbonisation of the industry by means of hydrogen will lead to new industrial value chains and will couple them across sectors via the hydrogen value chain. In the course of this, distributed energy supply systems will emerge that link the generation, distribution / storage, and end use of hydrogen across sectors.

[22] Author's diagram

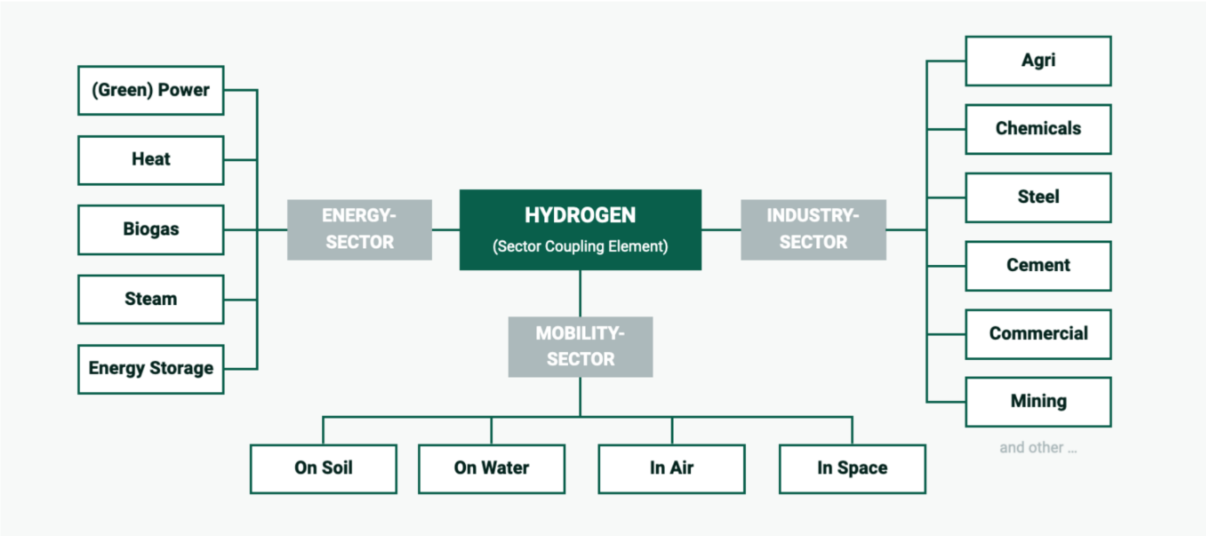

Figure 7: Simplified depiction of sector coupling[23]

Experts all believe that hydrogen will be used wherever, or whenever,

- there is not enough space available to generate wind or solar power locally, necessitating the purchase of additional energy which is, for example, transported from the North Sea to the south of Germany in the form of H_2 via the existing natural gas network;
- it is necessary to store large quantities of energy for longer periods of time, e.g. solar power generated in the summer for the winter;
- hydrogen is used as an energy source or industrial commodity, such as in the steel or cement industry;
- hydrogen offers a complete package of benefits, such as in truck traffic, where lorries need to be filled quickly, require large ranges and heavyweight batteries are out of the question.

These examples are by no means an exhaustive description of hydrogen's range of use, nor that of its derivatives, as these can also:

- be delivered to heating burners in houses via the natural gas network to generate heat;
- be used as liquid fuel, for example as sustainable kerosene or fuel in shipping;
- function as a sustainable fuel for fuel-cell cars; and,
- in connection with sustainably manufactured carbon compounds, be converted into chemicals to make end products (such as plastics, synthetic fibres, paints, and many more) that are currently almost exclusively manufactured on the basis of coal, oil and gas.

[23] Author's diagram

Hydrogen is a universal component which the energy transition urgently needs if it is to succeed; unlimited amounts of green hydrogen can be generated by means of water electrolysis using green solar and wind power.

What market activities and projects have been initiated in 2022?

The realignment of the energy system has already generated massive investment opportunities and activities, of which the press releases below provide some examples for 2022:

- **Deutz CEO Hiller:** "Hydrogen engines are [also] in our future [as an alternative to fuel cells]" | 08/02/2022, Redaktionsnetzwerk Deutschland[24]
- **RWE** invests € 4 billion in North Rhine-Westphalia | No other German state will consume as much hydrogen as industrial location North Rhine-Westphalia, an opportunity RWE has seized today. | 09/02/2022, Handelsblatt[25]
- **MAN Energy Solutions** invests € 500 million in hydrogen | MAN Energy Solutions was on the verge of being sold. Now, the VW subsidiary is investing massively in hydrogen systems and set on generating billions in turnover. | 25/02/2022, Handelsblatt[26]
- **Steag** plans to supply **thyssenkrupp Steel** with hydrogen | Green hydrogen from Duisburg-Walsum to contribute to the decarbonisation of Europe's largest steel location. | 21/03/2022, Solarserver[27]
- **Copenhagen Infrastructure Partners** and **Blue Earth Capital** invest in **Sunfire** | The Series D funding round has grown to a whopping €195 billion – and is related to a purchase agreement for 640 megawatt high-pressure alkaline electrolysers made by Sunfire. | 24/03/2022, Cleanthinking[28]
- **Siemens Energy** settles on Berlin as its production location for hydrogen electrolysers | Christian Bruch, CEO of Siemens Energy, says "With the new production plant for hydrogen electrolysers, we are emphasising our aim to actively help shape the energy transition. [...] To us, hydrogen is a key component of the energy world of tomorrow. [...]" | 31/03/2022, press release, Siemens Energy[29]

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[24] https://www.rnd.de/wirtschaft/deutz-chef-hiller-der-wasserstoffmotor-wird-kommen-XDCB5XFNBRBQBJJPBZ4RLA34DY.html (German only)
[25] https://www.handelsblatt.com/unternehmen/energie/energiewende-wasserstoffwirtschaft-rwe-investiert-vier-milliarden-euro-in-nrw/28051630.html (German only)
[26] https://www.handelsblatt.com/unternehmen/energie/energiewende-man-energy-solutions-investiert-500-millionen-euro-in-wasserstoff/28085230.html (German only)
[27] https://www.solarserver.de/2022/03/21/steag-will-thyssenkrupp-steel-mit-wasserstoff-beliefern/ (German only)
[28] https://www.cleanthinking.de/copenhagen-infrastructure-partners-und-blue-earth-capital-investieren-in-sunfire/ (German only)
[29] https://press.siemens-energy.com/global/en/pressrelease/siemens-energy-start-production-hydrogen-electrolyzers-berlin

- Shipping company **Maersk** enters into strategic partnership for green methanol | 06/04/2022, ECOreporter[30]
- **BP** plans to invest € 20 billion | Energy group BP has announced plans to invest the equivalent of more than € 20 billion in the UK energy system by the end of 2030. Investments focus on hydrogen, CCS and offshore wind projects, among others. | 02/05/2022, Chemietechnik[31]
- **German Rail ("Deutsche Bahn")** and **Siemens** present new hydrogen train in Krefeld | A range of 800 kilometres, with speeds of up to 160 kilometres per hour | 05/05/2022, WDR[32]
- **Bosch** aims to invest € 500 million in hydrogen technology | Stuttgart-based technology group Bosch aims to develop proprietary components to utilize hydrogen. The company has announced plans to invest € 500 million in the project until 2030. | 10/05/2022, Chemietechnik[33]
- **Covestro** joins the H2Global foundation, which fosters the production of hydrogen | By taking this step, the company aims to help ramp up the hydrogen market. | 17/05/2022, Chemietechnik[34]
- **Airbus** opens hydrogen centre in the UK | 30/05/2022, Electrive[35]
- **RWE** acquires 1.4 gigawatt plant from Vattenfall and develops the Eemshaven location in the Netherlands to the leading energy and hydrogen hub in Northwestern Europe | 02/06/2022, RWE corporate website[36]
- **Schaeffler** launches hydrogen joint venture with Faurecia and Michelin | 07/06/2022, Handelsblatt[37]
- British oil and gas group **BP** has taken over leadership of a project worth more than US$ 30 billion. The project aims to produce large quantities of hydrogen using renewable energy in the Pilbara region of the Australian Outback. According to the British group, BP will receive a 40.5% share in the Asian Renewable Energy Hub project and will become the operator. **Intercontinental Energy** will hold a share of around 26%, while **CWP Global** will hold an 18% share in the project. Divisions of the **Macquarie Group** are also on board, with a share of around 15%. | 15/06/2022, FinanzNachrichten.de[38]

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[30] Https://www.ecoreporter.de/artikel/maersk-geht-weltweit-strategische-partnerschaften-ein-um-die-produktion-von-grünem-methanol-bis-2025-zu-steigern/ (German only)
[31] https://www.chemietechnik.de/anlagenbau/bp-plant-investitionen-von-20-milliarden-euro-222.html (German only)
[32] https://www1.wdr.de/nachrichten/rheinland/wasserstoff-zug-krefeld-102.html (German only)
[33] https://www.chemietechnik.de/anlagenbau/bosch-will-500-mio-euro-in-wasserstoff-technologie-investieren-534.html (German only)
[34] https://www.chemietechnik.de/markt/covestro-wird-stiftungsmitglied-von-wasserstoff-foerderprojekt-h2global-840.html (German only)
[35] https://www.electrive.net/2022/05/30/airbus-eroeffnet-wasserstoff-zentrum-in-grossbritannien/ (German only)
[36] https://www.rwe.com/en/press/rwe-ag/2022-06-02-rwe-acquires-1-4-gigawatt-power-plant-from-vattenfall
[37] https://www.handelsblatt.com/unternehmen/industrie/zulieferer-schaeffler-gruendet-wasserstoff-joint-venture-mit-faurecia-und-michelin/28404818.html (German only)
[38] https://www.finanznachrichten.de/nachrichten-2022-06/56312396-bp-uebernimmt-fuehrung-bei-wasserstoff-megaprojekt-in-australien-015.htm (German only)

- French mineral oil group **TotalEnergies** has joined a large-scale project to produce climate-neutral hydrogen in India. | 20/06/2022, finanzen.net[39]
- **Volvo** presents fuel cell lorry with a range of 1,000 km | 21/06/2022, electrive.net[40]
- **Siemens Energy** forms hydrogen alliance with **Air Liquide** | The joint venture aims to produce electrolysers for renewable hydrogen. By 2025, the annual capacity could rise to 3 GW. | 23/06/2022, Handelsblatt
- **Shell** has made the final investment decision (FID) for the construction of Holland Hydrogen I, which will be the largest plant for renewable hydrogen in Europe once it is put into operation in 2025. | 06/07/2022, Shell corporate website[41]
- **BMW** starts serial manufacturing of fuel cells in in Garching | 31.08.2022, Automobil–Industrie Website[42]
- Cottbus lignite group **Leag** plans to convert its surface mining areas into green power factories with billion-size investments. Until 2030 a capacity of 7,000 MW in wind and solar farms is to be established.[43] | 30.09.2022, energate messenger
- **Schott** plans to become climate neutral | The Mainz special glass manufacturer plans to have all processes climate neutral and gas-free by 2030, also considering hydrogen as a means | FAZ 30.09.2022[44]
- The European Commission has granted aids of € 134 million to **BASF** for the generation of sustainable hydrogen | 03.10.2022, Website European Commission [45]

Why do we need hydrogen as a supplement to green electricity?

Green hydrogen has two decisive advantages over green electricity, as it can be:

- traded and transported globally and
- stored in large quantities.

This means the generation and use of electric energy can now be decoupled spatially and temporally on a large scale as well. Without hydrogen as a storage medium, the *temporal decoupling* of the generation and use of electric energy is impossible, or only possible within limits: pumped storage requires a topography that is not yet fully available; battery storage

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[39] Https://www.finanzen.net/nachricht/aktien/grossprojekt-totalenergies-aktie-legt-zu-totalenergies-steigt-bei-wasserstoff-projekt-in-indien-ein-11456847 (German only)
[40] https://www.electrive.net/2022/06/21/volvo-praesentiert-brennstoffzellen-lkw-mit-1-000-km-reichweite/ (German only)
[41] https://www.shell.com/media/news-and-media-releases/2022/shell-to-start-building-europes-largest-renewable-hydrogen-plant.html
[42] https://www.automobil-industrie.vogel.de/bmw-beginnt-brennstoffzellenproduktion-in-garching-a-ec1cf2cdf73863d2eb0eb641ae3b1fd1/
[43] energate, 29.09.2022: Braunkohlekonzern Leag will Grünstromriese werden
[44] https://www.faz.net/aktuell/rhein-main/region-und-hessen/schott-mainz-testet-wasserstoff-fuer-klimaneutrale-produktion-18352526.html
[45] https://ec.europa.eu/commission/presscorner/detail/de/ip_22_5943

systems require large quantities of scarce commodities such as lithium; and flywheel energy and high-temperature storage systems (HTS) are technically complex and limited in terms of capacity. In addition, none of these storage methods is able to overcome spatial separation to the same extent as hydrogen.

In electric energy, the *spatial separation* of energy generation and consumption is the norm; plants and consumers are traditionally connected via power lines. However, it is neither economic nor possible to use these lines to transport power across continents. Hydrogen, on the other hand, is not subject to such restrictions; green energy from Australia will not get to Europe via power lines, but will rather arrive here by ship, in the form of hydrogen or hydrogen derivatives.

Figure 8: Visualisation of the hydrogen ecosystem[46]

3. Without hydrogen, there can be no energy transition. Hydrogen will become the green energy of the future in global trade. Hydrogen will become a commodity and central energy storage system, found in numerous applications – from private households to large-scale industrial plants – through sector coupling.

Why does Europe offer outstanding investment opportunities?

Europe – particularly those countries with a strong focus on technology and industry, such as Germany, France and the UK – is home to the leading producers and manufacturers of key technologies for the hydrogen economy and has thus assumed a leading role. Medium-sized German companies and research institutes, such as the Fraunhofer Institute or the Center for

[46] Author's diagram

Solar Energy and Hydrogen Research Baden-Württemberg (ZSW), are global leaders in the development of technologies to produce, process and store green hydrogen, and the hydrogen industry of tomorrow will depend on them.[47] These technologies can be applied along the entire value chain, and range from measuring devices for determining levels of hydrogen purity to security and digital control systems, from components for electrolysis plants to modern carbon recovery technologies.

The hydrogen strategies of the EU and its Member States allow us to conclude that governments have anticipated the existential meaning of these technologies – also for the global market – and are promising considerable support to expand this competitive position; not least to prevent a similar exodus occurring in the hydrogen industry as it did in the solar industry, thus creating new geopolitical dependencies. The economic necessity for a strong hydrogen economy in Europe is flanked by an increase in public awareness. In addition, hydrogen technologies are extremely knowledge-based, offering long-term opportunities on the global market for countries with a high level of engineering expertise and well-trained specialists.

Within the hydrogen ecosystem, market participants from the private sector range from small businesses to traditional medium-sized enterprises to major groups. This creates an investment universe which offers attractive opportunities for investors who have recognised the tremendous trend toward hydrogen and want to participate in long-term market growth.

Where will hydrogen be produced in future?

In future, hydrogen will be produced especially in those regions in which the necessary primary wind and solar energy, access to water and vast expanses of land are available, favourable and affordable. Regions that lack the free space to construct wind parks or large-scale photovoltaic power parks are therefore more likely to be ruled out as locations for major plants. Areas with comparably low population densities, such as Northern Germany, Scotland and Norway (wind) as well as Spain and Southern Italy (solar), are particularly suitable for high-volume projects. Generally speaking, however, it is possible to produce hydrogen at a smaller, distributed scale for immediate, local use. Key factors for these locations are access to power sources and grids, gas networks and industrial consumers.

A core area is beginning to emerge: 75% of clean hydrogen projects currently announced in Europe focus on the areas around the North Sea, where projects for an annual production of approx. 3.7 million tonnes of hydrogen with a capacity of 40 GW are expected to be realised

[47] Fraunhofer Institute, German Hydrogen Strategy

by 2030.[48] Current studies even forecast a total European production of 8 million tonnes of hydrogen.[49]

The following diagram illustrates the high significance of this region of Northwestern Europe in the production of clean, European hydrogen.

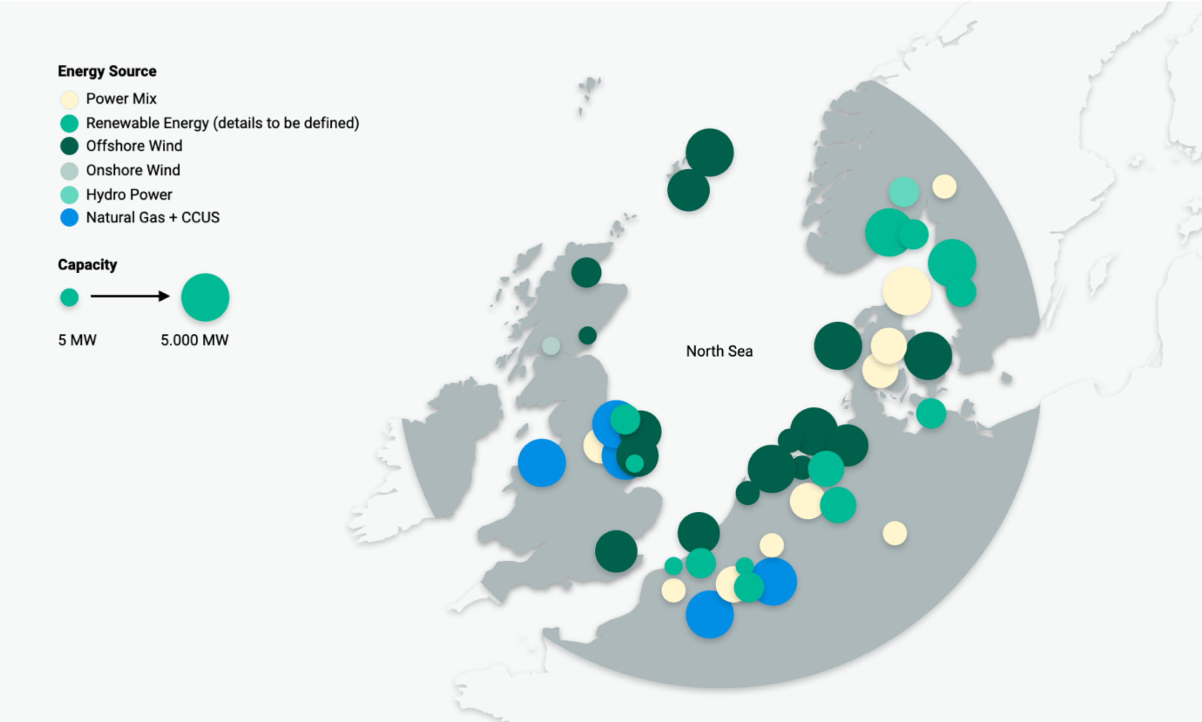

Figure 9: Hydrogen generation in Europe[50]

Despite the tremendous potential to produce hydrogen locally, we can assume that about 50% of Europe's future hydrogen demand will need to be met through imports. Expanding the possibilities for producing green hydrogen closer to home – especially in those parts of Germany and Europe that are particularly windy and sunny – will be critical to the success of the energy transition, not least in light of the target, derived from geostrategic aspects, of a broadly diversified energy supply. On the one hand, Power-to-X methods allow us to compensate the volatile generation of renewable energy and are a grid-friendly option to increase the flexibility of the energy system. On the other, expanding the hydrogen ecosystem in due time, with a correspondingly strong positioning on the global market, is the best way to secure a lead in know-how, and thus a competitive edge, in the field of hydrogen technologies.[51]

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[48] Monitor Deloitte, The European Hydrogen Economy – Outlook until 2030
[49] Hydrogen Council & McKinsey, Hydrogen Insights 2022, Sep 2022
[50] Author's diagram; see Deloitte, The European hydrogen economy – taking stock and looking ahead, May 2022
[51] EMCEL

Outside of Europe, windy and sunny countries are ideal for producing affordable green hydrogen via photovoltaics / wind power and water electrolysis. These include the south-west of the USA, the African Mediterranean countries, the Arabian Peninsula and Australia; all of the above have long coastlines, meaning they have access to sufficient amounts of (salt) water. As electricity is affordable, the loss of efficiency caused by the necessary desalination of sea water amounts to far less than 10% of the total production costs. Ideally, desalination requires 4-6 kWh of energy per cubic metre of water, which amounts to < 1% of the overall costs of hydrogen production.[52] Even today, sunny regions can generate electricity for less than 1.5 cents/kWh via photovoltaics, which corresponds to a mere approx. 20-25% of the production costs of electricity generated in a comparable plant in Central Europe, and allows for a price per kilo hydrogen of below US$ 2.10.

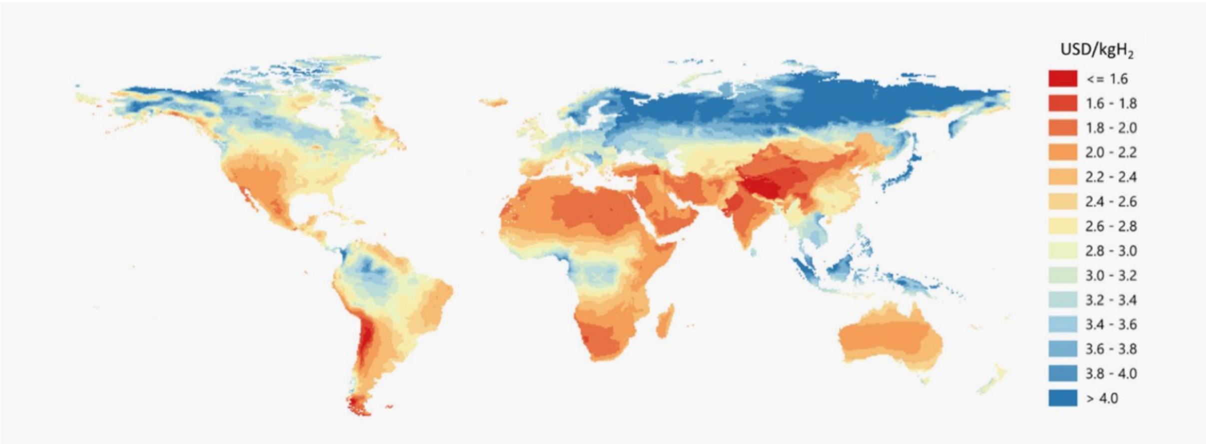

Figure 10: Cost potential of hydrogen from hybrid solar-PV and onshore wind parks53

Figure 10 shows a map of the world with the levelized cost of electricity in hydrogen production on the basis of photovoltaics. As we can see, the countries with the lowest costs are usually those with the highest amount of solar radiation and little to no agricultural use, meaning these areas can be used to generate energy without any restrictions. We can expect the most probable arrangements to be large, inland solar fields that are up to 500 kilometres from the coast. Power lines will transport the energy to large electrolysis plants on the coast, which will then use desalinated sea water to produce hydrogen. Even though tropical regions also have high levels of solar radiation, they are not ideal, as they are quite cloudy in comparison and thus cannot operate the solar cells for the production of hydrogen efficiently. Concentrated solar power systems, or CSP for short, which use mirrors to pool sunlight to generate power, can also only be considered alternatives to a certain extent due to the technical expenditure the process requires.

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[52] Renewable and Sustainable Energy Reviews 24 (2013) 343 – 356, "Energy consumption and water production cost of conventional and renewable-energy-powered desalination processes"

[53] IEA, The Future of Hydrogen, 2019

How can hydrogen be transported?

The hydrogen produced in the scenarios above needs to be transported to users in the consumer states, which in some cases means across long distances. These can be covered by pipelines and liquid gas tankers, similar to the way natural gas is transported today. At the same time, hydrogen can be transported through its derivatives, usually liquid hydrogen compounds, which, like crude oil, can be transported in low-pressure or depressurised tankers.

The large-scale transport of hydrogen via pipelines is the most affordable option, up to a distance of approx. 2,500 kilometres. Existing natural gas pipelines can be converted to transport hydrogen; in order to transition from gas to hydrogen, and supply new centres of demand, new pipelines will need to be constructed in some parts. High-volume hydrogen production plants in North Africa would be connected to Europe via pipelines just as plants in Scotland or Norway would be, for example. A functioning and well-established pipeline network is therefore the backbone Europe needs for its future hydrogen supply. Hence, more than 30 of Europe's leading energy infrastructure companies are driving the implementation of a European hydrogen pipeline network under the working title, *The European Hydrogen Backbone*.

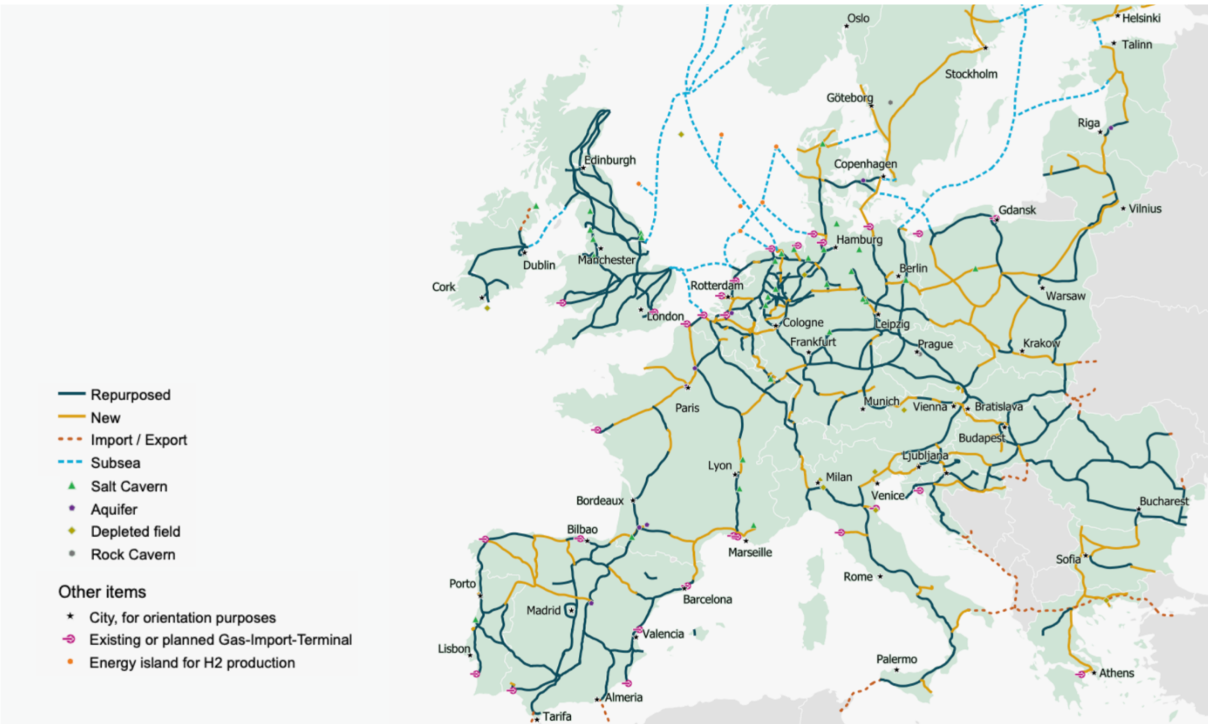

Figure 11: The European hydrogen network in 2040[54]

The transport of liquid hydrogen by means of large tankers. This corresponds to the way liquid natural gas (LNG) is transported today. Once they have been converted, existing LNG terminals

[54] Guidehouse, Covering Germany's green hydrogen demand: Transport options for enabling imports, July 2022

can remain in use, which is an advantage, as these terminals are already connected to underground storage facilities and distribution grids. The first route for the transport of liquid hydrogen by tanker was developed between Australia and Japan in mid-2021. Germany recently agreed to build new LNG terminals, a step the Federal Government considers a key measure for the future import of hydrogen today.

The transport of compressed gaseous hydrogen. This variation is not an alternative to overseas transport, as the quantities an individual tanker can transport are far lower than those of liquid hydrogen. Compressed gaseous hydrogen is therefore primarily transported by road; the current standard is to use lorries (semi-trailer combinations) equipped with tanks in which the hydrogen is stored at pressures of 200-300 bar, in the medium term at pressures of up to 500 bar. This allows for a transport capacity of one tonne of hydrogen per lorry, which corresponds to the quantity required to achieve a mileage of 100,000 km in a fuel cell car.

The transport of hydrogen after conversion into a derivative. In this variation, hydrogen is either converted into ammonia using nitrogen or into methanol using carbon dioxide. While methanol liquefies at room temperature, ammonia requires a slight increase in pressure to 9 bar at room temperature to liquefy. Both chemicals can be transported by ship as liquids with a high energy content; once they reach the terminal at their destination, the methanol or ammonia is converted back into hydrogen. Compared to liquid hydrogen, it takes fewer ships to transport these hydrogen carriers due to their high energy density.

The transport of liquid organic hydrogen carriers (LOHC). In this variation, hydrogen is chemically bonded to carrier oils, which are non-flammable and therefore safe to transport. Once the carrier oils have been reconverted at their point of destination, they can be reused in in line with a circular economy. LOHC technology is primarily being discussed as an option for the last mile on land or inland waters but is still at an early stage of development.

Each of the variations of transporting hydrogen listed above guarantees that transport ships can use the hydrogen and/or source of hydrogen for their own engines – to power a fuel cell, for example – which means that in future, hydrogen can be transported sustainably and entirely without emissions, even over long distances.

4. Various technologies for the regional and global transport of hydrogen are currently being advanced. These technologies will all involve considerable investments in means of transport and infrastructures such as pipelines, storage systems and shipping terminals.

Where will hydrogen be used the most?

Figure 12, below, shows how the production of and demand for green hydrogen is distributed worldwide. As we can see, Europe will be an economic region with a high import volume of green hydrogen. Experts therefore expect high investments in the import infrastructure in Europe by global standards, for example in conversion plants, pipelines and cavern storage facilities for hydrogen.

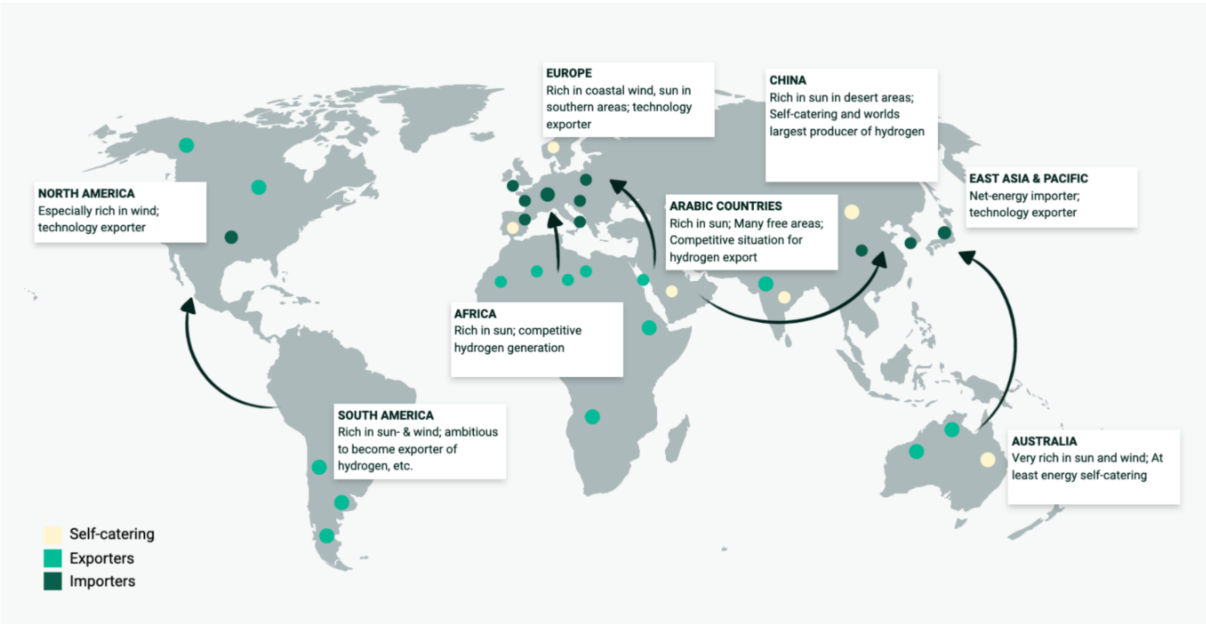

Figure 12: Global (re-)distribution of the future green hydrogen economy[55]

At the same time, Europe is a leading region with regard to numerous key technologies along the hydrogen value chain, which Europe is already exporting worldwide today, and which are being used to expand global hydrogen infrastructures.

How is hydrogen consumption expected to develop until 2050?

At the end of 2021, there were more than 520 major hydrogen reference projects announced worldwide, over half of which are in Europe. 43 gigaprojects with a hydrogen generation capacity of more than 1 GW are being planned and implemented; throughout Europe, more than 133 major projects are transporting, utilising and testing hydrogen to power ships, trains and buses.[56] Almost all western industrial countries have passed dedicated hydrogen strategies, as have Japan, South Korea, Australia, India and China. Since then, the number of larger hydrogen projects has increased to 680, out of which 61 are gigaprojects[57].

[55] Author's edit, see KPMG, Geographic Hydrogen Hotspots, homepage, accessed Q2 2022
[56] Hydrogen Council & McKinsey, Hydrogen for Net Zero Report, Nov. 2021
[57] Hydrogen Council & McKinsey, Hydrogen Insights 2022, Sep 2022

The following assessment of how the market will develop refers to the European Union (EU), the key investment region in the current SENCO fund. It is based on data provided by various recent studies, which all consistently show that the European market will grow significantly.

The main applications, and thus the main driving factors, in the development of the green hydrogen market in the EU are as follows:

- **Industry** (steel, chemicals, synthetic hydrocarbons and ammonia for fertilisers)
- **Energy** (reconversion, heating, storage and transport of electricity)
- **Mobility** (road, rail, sea and air)

For 2050, experts predict a European demand of green hydrogen of approx. 2,300 TWh or 70 million tonnes of H_2. For 2020, this value corresponds to about 400% of German energy generation, or 65% of European energy generation, or approx. 28% of European crude oil imports[58], and is distributed across the main applications as follows:

- **850 TWh** for the **industry**,
- **800 TWh** for **energy** and
- **650 TWh** for **mobility.**

This scenario is based on the assumption that these applications will all initially favour electric energy and that only those fields that cannot be supplied directly with electricity (e.g. steel, glass or ceramics production), will fall back on hydrogen. Almost all current prognoses, for example, show a private transport model that is fully battery-powered, and therefore has no impact on the environment, and assume heavy goods vehicle traffic will be driven by fuel cells using hydrogen. The value of 2,300 TWh must therefore be considered a conservative minimum level for Europe's future hydrogen needs. The details of the use predicted for 2050 are as follows:

Industry – 850 TWh / 26 million tonnes H_2
Applications for green hydrogen in the industry comprise the synthesis of ammonia for fertilisers; the manufacture of steel and iron; the production of chemicals; and heating purposes in those fields of the industry that cannot be converted to electric heating (e.g. glass and ceramic production). 850 TWh equate to almost 40% of the total hydrogen demand in Europe; demand is concentrated in existing locations of today's chemical industry. The hydrogen quantities required at each location will need to be supplied via pipelines or local production; a European hydrogen pipeline network will therefore connect Europe's major industrial hubs and harbours. However, there will be a number of cases in which it will be more beneficial on the whole to produce hydrogen regionally, despite certain disadvantages in terms

[58] Guidehouse, European Hydrogen Backbone (EHB), 2021

of efficiency. The 350 TWh of hydrogen required to manufacture liquid fuels have not been included in the total for the industry, but have been allocated to mobility.

Energy – 800 TWh / 24 million tonnes H_2
The energy economy supplies households and operations of all kinds with electricity and heat. Hydrogen can be re-converted in stationary fuel cells and take on the role of fossil fuels, for example in gas-fired power plants. Certain quantities of hydrogen can be added to the existing gas network, which is why TÜV Süd began certifying gas-fired power plants as "H_2 ready" in 2021. Initially, hydrogen will be employed in gas-fired power plants through admixture; in future, hydrogen alone will be used to generate heat and power.

In addition, hydrogen will become a key parameter in the energy system as a means of storing energy to compensate the fluctuations that arise due to the increasing share of renewable energy. Sources of renewable energy are volatile; at certain times, more energy is generated than can be consumed, while at others, not enough energy is available. Excess energy can therefore be converted into hydrogen via electrolysis and stored in caverns; when more power is needed, the hydrogen can be reconverted, generating energy that can be fed back into the power grid. Hydrogen therefore offers a solution to the fact that electricity generated using renewable sources cannot directly be stored in the long term. Alternatively, the stored hydrogen can be converted into methane by adding CO_2, which can then be fed into the natural gas infrastructure in place of natural gas.

Europe has a building stock of approx. 300 million units, which differ significantly from country to country with regard to their energetic quality. Northern Europe has a much higher demand for heating energy than Southern European countries (air conditioning systems have been included in the energy demand). In the long term, most forecasts assume that the majority of buildings will be heated with heat pumps, however, this solution cannot be realised cost-effectively for every type of building. Domestic heating will therefore continue to use an electricity mix, in which hydrogen will assume the role of natural gas, which is dominant today. The hydrogen demand for use in buildings has been estimated at 150 TWh for 2050.

Mobility – 650 TWh / 20 million tonnes H_2
Mobility comprises solutions for road and rail traffic as well as for shipping and aviation. Road traffic is dominated by applications in heavy goods vehicle traffic, in particular by tractor units for heavy goods vehicles. Fuel cell drives with 700 bar tanks for compressed gaseous hydrogen are considered the powertrain of choice; to refuel trucks with this type of drive, a service station network will need to be established, at least along motorways.

The 650 TWh include the quantities of hydrogen required to manufacture synthetic fuels; in aviation, for example, these are currently considered the only foreseeable fuel of the future for distances of more than 2,000 kilometres, and thus a key entry point to decarbonising aviation.

In this field alone, the global hydrogen demand for 2030 has been estimated at far above 100 TWh.[59]

The majority of experts agree that hydrogen will take on a dominant role in the following sectors in future: the industry, heavy goods mobility, and energy generation (reconversion). Tremendous quantities of hydrogen will be employed in all these applications, but the conversion to sustainable hydrogen will not happen “overnight”: it will be achieved through hydrogen admixtures in parallel to the market ramp-up in the hydrogen economy, and will continuously contribute to decarbonisation over the years.

5. Today, there is an overwhelming consensus among experts on the role green hydrogen will play in the relevant applications in industry, heavy goods traffic and electricity generation, as well as on the fact that these same applications will require more than 2000 TWh by 2050.

What investment needs arise from the expansion of the hydrogen economy?

According to current estimates, it will take global investments of € 600 billion by 2030, and € 5,000 billion by 2050, to achieve full green hydrogen coverage.[60] While these figures seem enormous at first, we can qualify them with a view to past performances and the period of time. The linear continuation of the annual green electricity levy of € 30 billion p.a. until 2050 would lead to a calculated income of more than € 800 billion in Germany alone.

530 of the currently announced 680 international large hydrogen projects are expected to be mainly operational by 2030. The required investment volume for these alone is estimated at US$ 240 billion. The acute need for action on the financing side is particularly evident from the fact that financing commitments have not yet been made for even 10% of this sum. In the case of the above-mentioned global investment requirement of € 600-700 billion by 2030, the share is only 3%.[61]

Past figures also allow us to draw conclusions regarding upcoming investment needs: between 2000 and 2021, more than € 300 billion were invested in the construction of plants to generate renewable energy in Germany alone; hydrogen has barely played a role in this to date. Over the same period of time, the share of renewable energy in primary energy consumption rose from 2.9% to 15.9%, and in gross energy consumption from 6.3% to 41.1%. By 2030, Germany aims to increase the share of renewable energy in energy consumption to 30% and in gross energy consumption to 60%. Doing so will require tremendous investments along the

[59] Hydrogen Council & McKinsey, Hydrogen for Net Zero Report, Nov. 2021
[60] Goldman Sachs, Carbonomics – The clean hydrogen revolution, Feb. 2022
[61] Hydrogen Council & McKinsey, Hydrogen Insights 2022, Sep 2022

entire hydrogen value chain in Germany alone to help hydrogen take on its intended role in the electricity mix.[62]

The production of green hydrogen in particular is expected to increase sharply in Europe over the next years; here, the European Union has developed a strategy which includes a roadmap and considers the quantities of green electricity that need to be made available to produce hydrogen. This strategy has been tightened by the REPowerEU strategy, recently passed in reaction to the war in the Ukraine. REPowerEU focuses on a range of aspects, including clarification on whether green hydrogen needs to be sourced directly from immediate green power sources to be classified as such or if an accountable feed[63] from the grid is sufficient – analogous to today's regulations for green power. In addition, the European Commission approved an Important Project of Common European Interest (IPCEI) in July: IPCEI Hy2Tech promotes research and innovation as well as the first commercial use of hydrogen technology in the value chain. Member States will provide public resources of up to € 5.4 billion; the European Commission estimates that this will mobilise another € 8.8 billion in private investments.[64]

For 2030, the EU further resolved to expand generation capacities for green hydrogen via water electrolysis by 40 GW; 37 GW of these have already been laid down in the strategies of individual EU countries. The immediate investments associated with this expansion have been estimated at € 36-44 billion. Together with induced investments in the fields of transport infrastructure, energy generation and the retrofit of existing industrial plants, the above results in an estimated investment need of approx. € 400 billion for the EU area. The REPowerEU programme has increased this need and accelerated the speed of investments until 2030: additional electrolysis capacities for the production of 5 million tonnes of green hydrogen will be established within the EU, for example; at the same time, the import infrastructure for another 10 million tonnes of green hydrogen will be installed.[65]

[62] The Federal Ministry for Economic Affairs and Climate Action (BMWK), Timelines for the development of renewable energy in Germany ("Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland", German only), Feb. 2022

[63] To provide a simplified example: a company in the south of Germany would like to purchase green power, but not enough green power is being generated locally. A wind farm operator in Schleswig-Holstein in the north of Germany sells the company the corresponding quantities and feeds the green power into the grid in the north. This is not a direct, "physical" supply of green power, but instead an indirect, "accountable" supply. The company is accredited with having used green power.

[64] European Commission, press release dated 15 July 2022

[65] European Commission, press release dated 18 May 2022, REPowerEU plan

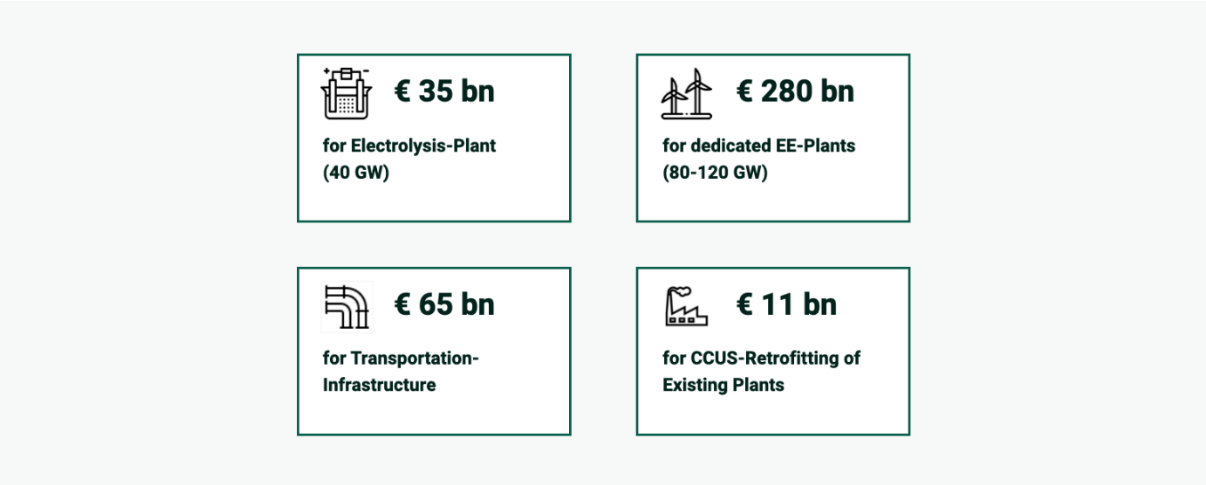

Figure 13: Predicted sector-specific investment needs for hydrogen applications[66]

Germany’s hydrogen strategy calls for electrolysis capacities of 5 GW by 2030 and 10 GW by 2040, and the provision of up to € 9 billion in federal funding, which should lead to further private investments of more than € 30 billion in Germany alone. Efforts are currently being made to raise the German target capacity to 10 GW for 2030, already, in accordance with the German government's coalition agreement.

From 2030 on, market estimates expect the hydrogen economy to reach an annual revenue of approx. € 130 billion in Europe and approx. € 44 billion in Germany. This volume comprises every step of the sustainable hydrogen value chain, from energy generation to distribution, from storage to utilisation. This will trigger a corresponding pull effect among suppliers and component manufacturers along the value chain and open up an attractive investment environment.

[66] Author’s diagram; see Goldman Sachs, The next transformational driver of the utilities industry, Sept. 2020

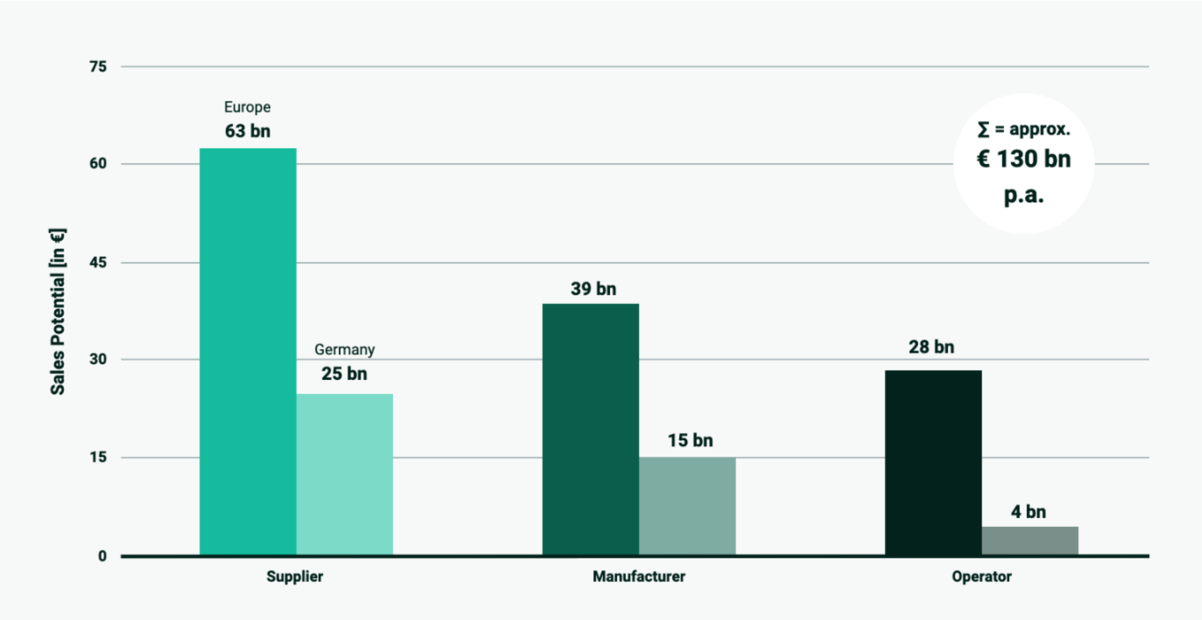

Figure 14: Potential turnover of hydrogen in Europe and Germany[67]

6. The industrial market ramp-up within the hydrogen economy will require investments of at least € 400 billion in Europe alone and will offer tremendous investment opportunities at all levels of the value chain. Past figures show that amounts of this magnitude can be financed.

How are costs and prices developing on the green hydrogen market?

The production costs of green hydrogen primarily consist of the cost of the green power used in generation, the operating costs and the depreciation of the electrolysis plants; the production costs of grey and blue hydrogen are determined by the price of natural gas and the prices for CO_2 certificates.

The following diagram shows that even today, the production of green hydrogen is at times more cost-effective than that of natural-gas-based grey and blue hydrogen, depending on the availability of sunshine and wind.

[67] Author's diagram; see Roland Berger, The potential of the hydrogen and fuel cell industry ("Potenziale der Wasserstoff- und Brennstoffzellen-Industrie", German only) in BW, Feb. 2020

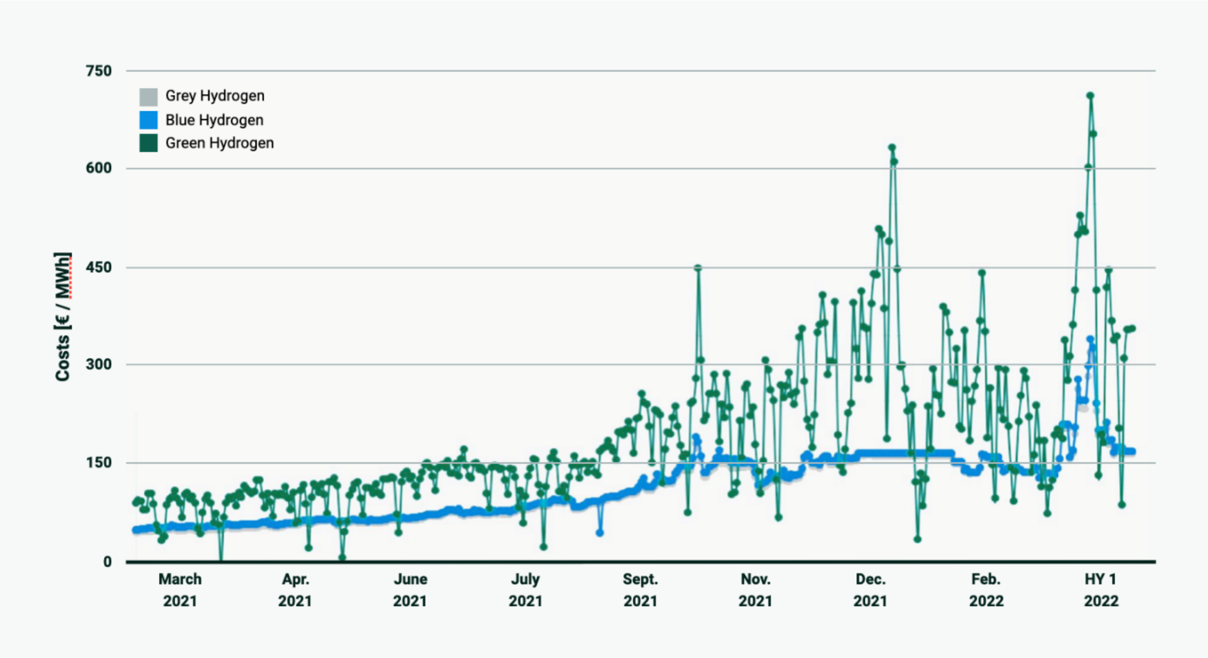

Figure 15: Historic costs of hydrogen generation by production method[68]

Prior to the sharp increase in energy prices in early 2022, production costs of € 2.0/kg were considered the target value for the generation of marketable hydrogen. This value corresponds to the transfer price for grey hydrogen production using the steam reforming method at a CO_2 price of € 100/tonne. After adding the costs of compression/liquefaction, transport and distribution, manufacturing costs of € 2/kg lead to consumer prices of € 4-5/kg. One price that is publicly available in 2022 is the price of hydrogen at 700-bar service stations for fuel cell cars – which is currently at € 12.85/kg.[69]

However, the cost situation has changed dramatically as a result of the war in the Ukraine; at times, high gas prices have led to an increase in grey hydrogen production costs of up to 400%.[70] Green hydrogen production costs have risen moderately in comparison, meaning green hydrogen will offer economic benefits sooner than predicted, and in places is already approaching the price level of grey hydrogen.

Even today, trucks powered by fuel cells (40-tonne vehicles) in particular allow hydrogen to be sold at prices in the above range. In daily operations, a price of € 12.85/kg corresponds to a diesel price of around € 2.28/litre and is only slightly above the current price of diesel fuel. On average, each fuel cell lorry requires approx. 1 tonne of hydrogen per month. If only 10%, or 180,000, of German lorries were to be converted to fuel cells, we would see a hydrogen demand of 2.16 million tonnes per year. This in turn would require an electrolysis capacity of approx. 20 GW, in other words: half of the 40 GW capacity the European hydrogen strategy plans to

[68] Author's diagram; see e-Bridge Consulting, Hydex
[69] EMCEL, leading engineering office for electromobility and hydrogen applications
[70] Expert survey conducted by SENCO

reach by 2030. What is more important, however, is the insight that truck traffic represents another segment with a demand for hydrogen, which will accelerate the water electrolysis ramp-up.

In the early development stages of green hydrogen production, electrolysers were within a range of 1-10 MW; by rule of thumb, a plant that size would currently cost € 1.5 million per MW output. In the next years, the standard size of electrolysers will increase, while procurement costs will decrease as production methods are optimised. In addition, market segments will emerge which specialise in large electrolysers for chemical plants and steelworks, for example, and smaller electrolysers for municipal companies and service stations.

Electrolysers are technologically so far advanced that they can be operated over long periods of time – even up to several decades. The electrolyser technologies available on the market are comparable in terms of investment costs and power consumption. On average, experts expect electrolysers to cost under € 0.5 million/MW in ten years.[71] For plant operators, investing in production plants at an early stage is worthwhile, as this helps ensure attractive and scalable locations with sustainable access to factors that drive value, such as green power and proximity to consumers. As these locations are scaled up, plant operators will participate in the degressive price development of future plants.

We currently expect the planned European regulations to grant privileges to existing wind parks combined with green hydrogen electrolysers by the end of 2026. The aim here is to provide targeted, short-term support to ramp up the green hydrogen market, resulting in immediate incentive for project developers to install the respective plants today. When they amended the Renewable Energy Act in July 2022, German parliamentary parties SPD, Die Grüne and FDP also agreed concrete quantities for green hydrogen tenders for the first time. According to the amendment, there will be a call for tenders for an installed capacity of 800 megawatts in 2023, followed by calls for tenders for an additional 200 megawatts per year until 2026 (section 28d of the 2023 Renewable Energy Act).

The mere costs of producing hydrogen by means of water electrolysis are primarily driven by energy and operating costs as well as by investment costs and/or the resulting depreciation of the electrolysis plants. A simple calculation can help illustrate: a small electrolyser with an output of 1 MW requires investment costs of € 1.5 million with a depreciation period of 10 years. Energy costs amount to 10 cents per kWh (price level as of early 2022), while the operating surcharge amounts to 20%. Assuming the electrolyser has an energy consumption of 50 kWh per kilogramme of hydrogen and is operated for 5,000 hours per year, manufacturing costs amount to € 7.50/kg.

[71] EMCEL, leading engineering office for electromobility and hydrogen applications

Due to the gradual increase in the electrolyser's average nominal capacity, the specific operating costs will decrease further as the degree of efficiency is optimised. If we further assume that the green power employed in production is exempt from taxes and levies, such as the green electricity levy and grid fees – resulting in a potential production cost of electricity of between 5 and 7 cents per kWh – manufacturing costs could fall to less than € 4/kg of hydrogen in the long term. Scenarios with manufacturing costs of € 1.50/kg of hydrogen after 2030 are therefore realistic, and, with a price level of 4.5 cents/kWh, correspond to the cost of imported natural gas usual in early 2022. As inexpensive opportunities to import natural gas from Russia have largely ceased to exist, today's prices for gas and LNG are much higher, with an accordingly positive impact on hydrogen opportunities.

In the near future, the situation outside of Europe promises competitive cost structures for large-volume green hydrogen production. Desert regions in particular offer large areas for photovoltaic plants; high-voltage lines can then transport the electricity generated in these regions to the coast, where sea water can be desalinated to obtain the clean water required for water electrolysis. The costs of desalination make up far less than 10% of the overall costs of the generated hydrogen.[72] A rough calculation based on 1.5 cents/kWh of solar energy – an amount that is realistic in sunny desert regions today, even when considering all costs – results in calculated hydrogen costs of approx. € 2.10/kg, or around 6.3 cents/kWh, even if we take expenditures for desalination and transport into account. With regard to energy content, this corresponds to a crude oil price of US$ 106/barrel.

In other words: assuming an ideal infrastructure, hydrogen is already comparable to the high oil prices we see today. However, the costs of hydrogen production and transport will reduce significantly over the next 10-20 years, driven by improved technologies, economies of scale and more cost-effective transport options, such as pipelines between North Africa and Europe in place of tankers.

On the whole, green hydrogen's relative competitive position compared to fossil energy sources will improve considerably in economic terms, stimulating demand and thus giving the market ramp-up an additional boost.

7. The costs of green hydrogen production and transport will decrease considerably over the course of the next years: key drivers include the exemption from levies for green power; the decreasing cost of investing in and operating electrolysers; larger plants; as well as extended operating periods. These economic conditions will stimulate demand on the market, giving the market ramp-up an additional boost.

[72] The Center for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW)

Which factors will impact the expected hydrogen market ramp-up?

From today's perspective, we can identify various key factors that will influence the market ramp-up in the hydrogen economy and that all experts expect to see. These factors reinforce one another and ensure the hydrogen economy will follow an irreversible developmental trajectory. The following are worth particular mention:

- **Technological maturity:** In terms of technology, there are no relevant obstacles; the essential technologies are known and have been established. From a technological point of view, nothing stands in the way of hydrogen achieving industrial scale.

- **Economies of scale:** The pending industrialisation of these technologies, such as electrolysers or fuel cells, will lead to sharp reductions in cost. Once technologies have been scaled up (from kilowatts to megawatts), further cost reductions will follow. Economies of scale achieved in the short term will lead to a rapid decrease in costs accompanied by an increase in system sizes.

- **Investment security:** The falling costs of electrolysers do not mean new plants will cease to be economic after just a few years and need to be shut down. Quite the opposite: a rapidly growing market will need every single installed capacity for decades to come, giving first movers locational advantages in the long term.

- **Hydrogen transport:** Experts agree that transporting hydrogen by pipeline is the most cost-efficient option by far for distances of approx. 2,500 km, a certain quantity provided. A number of alternatives is available for long-distance transport by sea, such as liquefying the hydrogen as well as other liquid storage options, including ammonia and methanol. Concrete hydrogen applications are at advanced stages of development and/or testing, whereby these largely focus on increasing capacities (of tankers, for example) and/or adapting known, mature technologies to hydrogen use.

- **Climate targets:** Without the broad use of green hydrogen as a means of sector coupling, we will not be able to reach climate targets, be they German, European or global; nor will we be able to decarbonise private households and the industry. It will therefore be necessary to both generate and import huge quantities of green hydrogen in and to Europe.

- **Governmental support:** The governments of most leading industrial nations have recognised the long-term chances hydrogen offers and initiated significant funding programmes to help ramp up the hydrogen ecosystem. With the annual increase in carbon dioxide pricing, funding policies have taken a key step towards funding carbon-free energy sources, which includes green hydrogen. Similar to the steps taken in the historic funding of solar and wind parks, governments will provide initial support for hydrogen plants – for example through Carbon Contracts for Difference – designing said support in a way that allows operators to run electrolysers profitably over the course of their typical life cycle of 20 years and more.

- **Geostrategic aspects:** Compared to Europe's extreme dependency on individual oil and gas suppliers, this is an opportunity to make a targeted effort to establish a network of future hydrogen suppliers, diversify global procurement and thus significantly reduce the risk of future shortages. In such an approach, Mediterranean states could be connected to Europe via pipelines, for example, and new supply agreements concluded with reliable states. At the same time, large areas within the EU will be occupied by photovoltaic plants and wind parks in order to reduce the demand for energy imported from outside of Europe considerably.

- **Global competition:** Global competition will boost the rapid expansion of green hydrogen, as countries with high levels of solar radiation and/or abundant wind in particular will view hydrogen production as a future source of energy and income. At the same time, the availability of green hydrogen will be a decisive factor when choosing future locations for industrial companies.

- **The capital market:** As part of their ESG strategies, institutional investors are increasingly demanding sustainable investment opportunities and are thus promoting industrial change. As hydrogen and its derivatives are a key component of the global decarbonisation process, the capital market has a positive impact on the development of the hydrogen market.

8. The factors that influence the market ramp-up reinforce one another and thus put the hydrogen economy on an irreversible developmental trajectory with tremendous potential for growth and investments.

III. SUMMARY FOR INVESTORS IN THE SENCO HYDROGEN EQUITY FUND

“Nothing is more powerful than an idea whose time has come.” Victor Hugo’s inspiring words are more apt than ever before when it comes to hydrogen. SENCO’s partners and founders share the conviction that hydrogen will contribute decisively to decarbonising the economy and creating a diversified, viable energy supply in Germany and Europe.

The fact that the hydrogen economy needs to be ramped up to the required industrial scale offers institutional investors attractive, risk-compatible investment opportunities today; these include opportunities in project development, the generation, storage or use of hydrogen as well as in companies that provide the essential components it takes to do so.

SENCO was founded by a group of experienced experts on finance, the capital market and the industry with the aim of driving the hydrogen issue in Germany and Europe as a sector-specific investment company registered with the Federal Financial Supervisory Authority (BaFin). To do so, SENCO has established a corporate network of industry, research and institutions which is unique in Germany today. The group also includes an engineering office, which has dealt exclusively with projects on the industrial utilization of hydrogen for 15 years and thus contributes outstanding technological know-how when identifying and making investments.

In collaboration with public funding bodies, lenders and co-investors, each investment SENCO makes in future will also provide impetus to implement a number of further investments and projects at various levels of the value chain, thus accelerating the broad development of the hydrogen market.

SENCO therefore considers investments as active catalyst for the hydrogen market ramp-up. Hydrogen related investments offer professional investors the opportunity to achieve both at once: attractive returns as well as contributing to climate protection and a sustainable, secure energy supply.

This meaningfulness is reflected in our company name: SENCO means “sense” in Esperanto!

Learn more about SENCO Hydrogen Capita: **https://www.senco-capital.com/**

IV. GLOSSARY

Term	Explanation	Examples of market players
Alkaline water electrolysis	Considered the most established form of electrolysis. An alkaline water solution is used as an electrolyte, the electrodes are usually made of metal. Max. efficiency when a constant power supply is maintained.	thyssenkrupp Nucera, Cummins, McPhy, Nel Asa, Sunfire
Combined heat and power plants (CHP plants for short)	Modular plants that generate electrical energy and heat simultaneously using the principle of combined heat and power.	Bosch, Buderus, SenerTec, Viessmann, Wolf
Fuel cells	Unlike batteries, fuel cells convert energy, as opposed to storing it: a fuel's chemical energy – e.g. hydrogen or methanol – is converted into electricity. In other words, this process is the exact opposite of electrolysis. However, fuel cells are also made up of two electrodes (an anode and a cathode) that are surrounded by gas and separated by an ion-conducting electrolyte layer or membrane.	Bosch, Schäffler, EKPO, SFC Energy, PowerCell, Ballard, Toshiba, Plug Power
CCUS	Stands for Carbon Capture Utilization and Storage. "CO_2 streams" are captured in refineries, power stations, etc., and fed into storage facilities, such as salt mines, where the CO_2 is compressed and stored. CO_2 is required in other manufacturing processes, e.g. synthetic fuels.	Large oil and gas groups, such as Shell, BP, Equinor; industrial groups such as Linde, Air Liquide; and cement companies such as CEMEX
Steam reforming	Steam reforming is a conventional, industrial method of producing hydrogen, in the course of which a carbonic fuel – usually natural gas – reacts with water. The majority of hydrogen manufactured worldwide is produced using this method, which has one	Large oil and gas groups, such as Shell, BP, Equinor; industrial groups such as Linde, Air Liquide

	disadvantage: it always generates CO_2 as well as hydrogen.	
Electrolysis	This technology has been around for well over 100 years and is currently experiencing a revival. Electricity and water react in an energy technology plant to create hydrogen, oxygen and heat. There are various types of electrolysers, including alkaline water and PEM electrolysis.	see alkaline water and PEM electrolysis respectively
PEM electrolysis	Polymer Electrolyte Membrane or Proton Exchange Membrane Electrolysis (PEM) is considered an emerging technology. Unlike alkaline water electrolysis, the electrolyte used in PEM electrolysis is not liquid but solid. Faster reaction times and lower energy consumption. Popular for green hydrogen systems, as highly efficient when using a volatile power supply (e.g. wind/PV)	Siemens Energy, MAN Energy Solutions (H-Tec), Plug Power, Cummins, ITM, Nel Asa
Power-to-X	Power-to-X describes the energy economic concept behind water electrolysis, in which power is used to create hydrogen, ammonia or methane as sources of energy.	Anyone who deals with electrolysis has an interest in this matter.
Pyrolysis	A promising method of creating H_2, as methane – the main component of natural gas – is decomposed in its components hydrogen and solid carbon (e.g. graphite/carbon nanotubes) under the exclusion of oxygen. If biomethane is used as the source material, CO_2 is removed from the environment – resulting in a negative CO_2 balance.	Young cleantech companies such as Graforce, Dorset
Sector coupling	Historically separated from one another, the industry, energy economy and mobility sectors are systematically "coupled" through energy, heat, material flows, etc. Sector coupling is considered a key element in achieving climate protection targets.	Any industrial company that is concerned with sustainability

EXCLUSION OF LIABILITY

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