Tampere University of Applied Sciences

The Future of Hydrogen in Groningen Seaports

Study on Hydrogen as Unique Selling Proposition for Circular Economy in the Northern Netherlands

Ajda Lotric

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ABSTRACT

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LOTRIC AJDA:
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Increasing awareness about climate change has changed the view on fossil fuel sources. To replace them in the long term, new technologies have been explored to find new energy sources. The most considerable emphasis so far has been on the development of renewable sources. However, another potential solution is also hydrogen. Hydrogen is a clean fuel that has many uses in global industries. The majority that is used today is produced from fossil fuels. New technology has helped to start producing renewable hydrogen without fossil fuels.

The thesis was commissioned by Groningen Seaports, a port authority in the Northern Netherlands. The study aimed to find opportunities for the use of sustainable hydrogen in the Northern Netherlands and Europe. Current developments of renewable hydrogen in the chemical, manufacturing and energy sector were examined from literature. A survey was conducted to recognise the potential of Groningen Seaports in the development of the green hydrogen economy. The survey focused on the relationship between industry and hydrogen and examined future hydrogen development opportunities. The survey included a target group of current and potential customers of Groningen Seaports. Both quantitative and qualitative approach was used to analyse the data.

The results of the study show that at the moment, the most obvious problem for the development of green hydrogen is the price. Investment in technologies that would not emit greenhouse gases during production is expensive. Green hydrogen production still requires more research and development. That can ensure the cost-competitiveness of green hydrogen with hydrogen from fossil sources. Another aspect that is also pointed out in the survey is that the government is not doing enough to promote the hydrogen economy. Appropriate legislation and guidelines with substantial investments are something that the responders wish to be improved.

While there are opportunities to develop a green hydrogen economy soon, there is still a long way to go. The costly investments and market that are not mature enough need further development. The cost of green hydrogen needs to come to a level that is comparable to those of fossil sourced hydrogen. Thus, research and development of new hydrogen technologies will be crucial in the upcoming years.

Key words: hydrogen, circular economy, Netherlands, marketing, recycling

CONTENTS

1 INTRODUCTION

This thesis work is based on a circular economy study on applying renewable hydrogen in everyday industrial processes in the Northern Netherlands. The thesis aims to research the possibilities that sustainable hydrogen can have on the energy and industry market in the Northern Netherlands and Europe.

In the past decades, the global need for energy has been actively increasing. With that, the production of energy has been growing too. Energy generation is regrettably the most significant contributor to greenhouse gas emissions. (Ritchie & Roser 2020.) As a result of the impact of energy production on global warming, the European Union (EU) has been focusing on implementing sustainable energy techniques instead of fossil fuels. One of the proposed schemes by the EU to produce energy with the help of renewable technologies is research and technological development of fuel cells and hydrogen energy. Although not widely used, hydrogen as an energy carrier is not a new concept. Since 2014, the EU has been aiming to boost hydrogen energy on a more extensive scale as an instrument to accomplish carbon neutrality. (Regulation (EU) No 559/2014.) At that point, the Northern Netherlands comes into the equation with a multi-step strategy to establish the Northern Netherlands as a leading hydrogen energy ecosystem.

Because of the opportunities that can be achieved with hydrogen as a sustainable carrier of energy, several points of interest for new circular economy systems can be launched. The thesis work aims to answer how Groningen Seaports and the Northern Netherlands could supply renewable hydrogen to companies that wish to settle in the area in the future as a unique selling proposition (USP). To evaluate the opportunities that hydrogen has for the Northern Netherlands, a survey will be conducted. The survey focuses on hydrogen economy and hydrogen feedstock for chemical companies in the area. Additionally, based on the survey, the opportunities for hydrogen economy in the area will be evaluated.

2 FUNDAMENTALS OF HYDROGEN

2.1 Hydrogen Production

Hydrogen is the simplest and most widely available element in the world. It is one of the most widely used chemical elements, although it rarely exists in nature as itself. Therefore, to utilise hydrogen, it has to be produced from compounds that contain it. Hydrogen is often produced from fossil fuels, hydrocarbons and renewable sources. Renewables enable the production of more environmentally friendly hydrogen. (Cipriani et al. 2014; Satyapal 2017.)

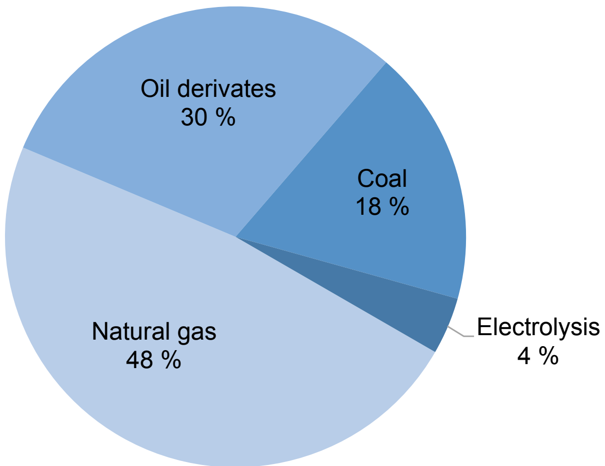


FIGURE 1. Current sources of hydrogen production (Arregi Joaristi 2017, 8)

Most of the hydrogen is produced from fossil fuels. The foremost source of hydrogen is natural gas, followed by oil derivates and coal, as seen in Figure 1. Hydrogen from electrolysis processes presents a minor role in the market (Figure 1). Since hydrogen can be produced in several different ways, it is essential to note that the hydrogen market is changing rapidly despite financial limitations. The percentages that specific sources present will grow (electrolysis) and decrease (natural gas and coal). (Arregi Joaristi 2017, 8.)

Hydrogen can be used as feedstock, energy carrier or fuel, without emitting any CO_2 emissions when burnt (Fuel Cells and Hydrogen 2 Joint Undertaking 2019, 45; Giovannini 2020). Hydrogen can be produced with several different processes, and informally, each hydrogen production method has its colour code. There are nine (9) different methods of hydrogen production, but three (3) technologies lead on the market. (World Energy Council 2019, Giovannini 2020, Petrofac Limited 2021.)

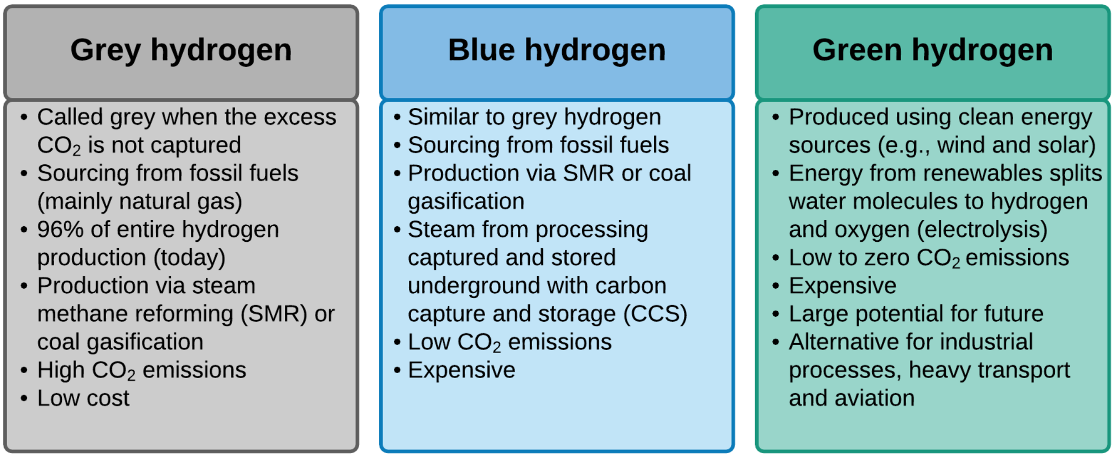


FIGURE 2. Main hydrogen production types (World Energy Council 2019, Giovannini 2020, Petrofac Limited 2021)

The three (3) hydrogen types are grey, blue and green hydrogen (Figure 2). All production types broadly differ on the level of emissions released during production. The different colour code types of hydrogen are presented in the subchapters below. Additionally, Chapter 2.2 includes a table with carbon dioxide (CO_2) emissions for the types of hydrogen. The idea is to showcase the most suitable production type of hydrogen for emissions that are as low as possible.

2.1.1 Grey Hydrogen

Hydrogen from fossil fuels or grey hydrogen presents 96% of the entire hydrogen production today. The majority of it is produced with natural gas, followed by coal. (IEA 2019, 38). Grey hydrogen is produced either through steam methane reforming (SMR) or coal gasification, with hydrogen (H_2) and carbon dioxide (CO_2) as the leading products. It is a cheap and widely available source of hydrogen.

However, hydrogen from fossil sources has many downsides. The main problem that grey hydrogen has is high greenhouse gas emissions (GHG), especially CO_2. That is due to carbon-intensive production without a process that would capture and store CO_2. (Fuel Cells and Hydrogen 2 Joint Undertaking 2019, 66; Noussan, Raimondi, Scita & Hafner 2021, 2.)

2.1.2 Blue Hydrogen

If the carbon capture and storage (CCS) method is used, the CO_2 emissions are significantly lower. The name of the product changes to blue hydrogen if CCS is used. The process of blue hydrogen production is essentially the same as with grey hydrogen, with a significant decrease in CO_2 emissions (World Energy Council 2019). With the CCS method, up to 90% of emissions are captured, significantly reducing CO_2 emissions and realising a carbon-neutral economy. (TNO n.d.a) Carbon emissions are captured and stored underground, for example, in salt caverns or underground gas storage facilities (Netherlands Enterprise Agency n.d., 6; The Institution of Engineering and Technology 2019, 25). The biggest downside of blue hydrogen is, unfortunately, the price. Due to the technology used (CCS), blue hydrogen per kilogram price is considerably larger than grey hydrogen (no CCS).

2.1.3 Green Hydrogen

Both grey and blue hydrogen are not compatible with sustainable, climate-safe energy use or net-zero emissions. A well-established and mature technology of green hydrogen fits those criteria. As it can be seen from Figure 2, green hydrogen is produced with electricity from renewable sources. Water (H_2O) is split into hydrogen and oxygen with the help of renewable electricity in electrolysis. (Lehmann, Luschtinetz & Gulden 2018; World Energy Council 2019.) The by-product of hydrogen production with electrolysis is oxygen without any carbon emissions. Also, the excess oxygen can be used in further applications, fuel cells and industrial processes. (Cornell 2017; Shiva Kumar & Himabindu 2019.)

Green hydrogen is a critical alternative for the replacement of fossil fuels in energy and industrial operations. Water electrolysis based on electricity originating from renewable sources is one of the most environmentally friendly processes. Currently, the share of green hydrogen presents 4% of the total hydrogen production. The reason for such a low portion is due to the cost of the production. (Nicita et al. 2020, 11396.) According to Cornell (2017), the predicted source of hydrogen using electrolysis will rise to 22% by 2050 (Nicita et al. 2020, 11396). That is mainly due to renewable sources becoming more cost-competitive with fossil fuels. By 2050 it is predicted that the price of green hydrogen will drop significantly (more than 65%). (Noussan et al. 2021, 4.)

2.2 Greenhouse Gas Emissions in Hydrogen Production

Since hydrogen has to be produced before it can be used, some effects of hydrogen manufacture have to be considered. As described in previous chapters, there are three (3) main types of hydrogen production. Consequently, they also have different effects on the environment, especially greenhouse gas emissions. Chapters 2.1.1, 2.1.2 and 2.1.3 have already shed some light on which have the highest and lowest CO_2 emissions. The amount of CO_2 emitted to the environment during production ranges between high emissions and low to zero emissions.

TABLE 1. CO_2 emissions in hydrogen production (Ewing et al. 2020, 3)

	Grey hydrogen	Blue hydrogen	Green hydrogen
Feedstock	Natural gas	Natural gas	Water and renewable electricity
Carbon equivalent per kilogram H_2 $\left[\frac{kg\ CO_2\ eq.}{kg\ H_2}\right]$	11,3 – 12,1	2,3 – 4,1	0 – 0,6
Production cost	Low	Low to moderate	High

Grey hydrogen has been in use for the longest time. It presents the most significant percentage of the currently produced hydrogen. The global economy has been attempting to reduce greenhouse gas emissions. With a source that implements such sizable greenhouse gas emissions as grey hydrogen, efforts must be made to reduce GHG emissions. That is why blue and green hydrogen have to replace grey hydrogen in the next few years.

Table 1 shows that while grey hydrogen is the cheapest out of all, it has the highest CO_2 emissions. On the other side, both blue and green hydrogen emit lower levels of CO_2, but they are more expensive than grey hydrogen. All the concepts presented in Table 1 must be considered when deciding about changing the technology used for hydrogen production and its source. Chapter 2.5 on Hydrogen Economy further defines this concept.

2.3 Hydrogen as Feedstock

Hydrogen is a highly versatile compound. It can be used in transportation, electricity grid network for commercial and residential use and the industry (Qyyum et al. 2021). It has a long history in the chemical industry as one of the most commonly used molecules in producing chemicals and refining petroleum. (Braga et al. 2017, 56; Satyapal 2017; IEA 2021.) If produced with the help of renewable sources and green energy, hydrogen feedstock is vital to be thought about as well (Braga et al. 2017, 5).

Hydrogen can be produced through many different chemical processes. The main three (3) processes for hydrogen production are electrolysis, photolysis and thermolysis. Hydrogen made with the help of electrolysis requires either electrical or thermal energy, which causes the water molecules to split into hydrogen and oxygen. Most commonly, these processes are known as water electrolysis and steam electrolysis (thermolysis). Similarly, photolysis uses the energy from light to produce hydrogen. Splitting of water into hydrogen is done either with the help of microorganisms and sunlight (photobiological) or with sunlight and semiconductors (photoelectrochemical). Last, thermolysis requires raw material, either from fossil or renewable sources, heat and reagents to prompt the chemical reaction in the raw material to split it into hydrogen. (Braga et al. 2017, 5.)

Green hydrogen can be used in large-scale processes where industry requires feedstock raw material and in petroleum refining. Additionally, hydrogen can also be very well applied in agricultural, mining and other industrial processes to enable the economy to reduce the carbon imprint. (Satyapal 2017; Philibert 2020, 6.)

2.4 Hydrogen as an Energy Carrier

When it comes to hydrogen in the energy sector, it is essential to note that hydrogen is not an energy source but an energy carrier. Hydrogen can store and deliver energy produced by different sources, such as fossil fuels, renewable energy, or nuclear energy (Satyapal 2017). In recent years, hydrogen production has scaled up significantly, with new technologies developing every day (IRENA 2019, 11; Hydrogen Council 2020, 2).

Hydrogen as a fuel has a low carbon emissions factor. When consumed in a fuel cell, it produces water, electricity and heat. (Satyapal 2017; Hydrogen Council 2020, 54.) Since the production sources of energy that can be used for carrying energy in hydrogen are different, the impact on the environment is also distinctive. When hydrogen is produced from renewable sources, it is termed green hydrogen. It is considered a clean and flexible energy carrier with close to zero emissions. (IRENA 2019, 9.) However, hydrogen is not only clean, but it also has a very high energy content. Together with fuel cells, it can generate power and heat that can be used in everyday industrial operations, for transport and commercial and residential operations (Amoretti 2011; Hydrogen Council 2020, 54).

2.5 Hydrogen Economy

The hydrogen economy is a recommended system where hydrogen is put forward as production technology and an essential energy carrier (Abe, Popoola, Ajenifula & Popoola 2019). Hydrogen has a long history in the production and energy world. Since hydrogen rarely occurs in nature, it has to be produced using other energy sources. Furthermore, seeing hydrogen is an energy carrier like electricity, several sources of energy can use that potential. (Lee 2011, Woody & Carlson 2020.) The use of fossil fuels strongly dominates global hydrogen production. At the same time, the world economy is set on switching from fossil-based sources to renewable technology. With decreasing costs of renewable power, there has also been growing interest in hydrogen production with the help of green technology. (IEA 2019, 37–38; Fairley 2020.)

Hydrogen was promoted as a replacement for oil and gas already in 1970. That is when the term hydrogen economy was first introduced. Since the 1990s, hydrogen has been promoted even more because of global warming awareness. (Crabtree, Dresselhaus & Buchanan 2004; Brandon & Kurban 2017; Woody & Carlson 2020.) United States, European Union and Japan are the leading states and regions in developing the hydrogen economy. Despite the hydrogen development and knowledge, the hydrogen economy cannot be achieved hurriedly. To shift the fossil fuel-intensive economy to hydrogen, several difficulties have to be solved first. Hydrogen technologies must overcome technology, efficiency, cost and safety challenges to enable the full potential of hydrogen economy (Yáñez et al. 2018, 778). For example, to replace fossil sources in the transport industry, it must be considered what should come first – vehicles or refuelling stations. Because of analyses like that, hydrogen economy development has been delayed. (Brandon & Kurban 2017.)

The shift is not that simple. Since the 2010s, the hydrogen economy has received a significant boost. Development of hydrogen technologies in the USA (H_2USA), EU (FCH Joint Undertaking in Europe) and Japan (Toyota) aim to enable a cost-effective transition to hydrogen. (Brandon & Kurban 2017; Woody & Carlson 2020.) The potential that hydrogen has for applications in fossil fuel-intensive industries is substantial. Hydrogen could significantly reduce and also eliminate carbon emissions in the future. That can be achieved with the entire global energy industry transitioning towards renewable or clean energy resources. (Fairley 2020; Woody & Carlson 2020.)

2.5.1 Natural Gas Pipelines

Several fossil-based sources are in use today, especially natural gas, coal and petroleum. All of these fossil-based sources are scarce, and new technologies are needed to find alternatives that would be affordable. The idea is to use old infrastructure from fossil sources in new, sustainable systems. The natural gas network is an exciting topic in the research of establishing a hydrogen grid. (The Institution of Engineering and Technology 2019, 6; Klabučar, Karasalihović Sedlar & Smajla 2020, 681.)

Several countries have decided to repurpose gas pipelines to carry pure hydrogen. Existing pipelines are particularly valuable since the routes could be retrofitted with little investment. The pipes would require to be fitted in a way to reduce leakage. (Fuel Cells and Hydrogen 2 Joint Undertaking 2019, 34; IEA 2019, 77.) A bonus is an extensive gas pipeline network that can be modified according to the transmission of hydrogen. Unlike other energy carriers, high-purity hydrogen has not yet been implemented at large scale operations. (The Institution of Engineering and Technology 2019, 6; Findlay 2020.) Therefore, it is vital to retrofit and invest in the existing gas pipeline network for long-distance hydrogen transmission. Appendix 1 includes a plan for hydrogen backbone in Europe. The plans consist of repurposing natural gas pipelines, newly constructed pipelines for hydrogen connections and potential opportunities for hydrogen storage systems. (Wang, van der Leun, Peters & Buseman 2020, 8). Consequently, with the European hydrogen backbone plan, hydrogen as an energy carrier would have the possibilities to reach its full potential by 2050.

3 HYDROGEN AS UNIQUE SELLING PROPOSITION

3.1 Green Chemistry

The chemical industry is one of the world's largest industries. It is one of the most growing markets, and considerable investments are made towards it annually. Globally, the European Union has the second-largest chemical industry market after China. (Valencia 2013, 163; Carus, Dammer, Raschka & Skoczinski 2020, 491.) The chemical industry requires large amounts of process energy and feedstock, mainly from oil and fossil sources. Therefore, a constant flow of feedstock is needed to keep up with the demand of the chemical industry. It also emits large amounts of greenhouse gases, especially CO_2. Different approaches have been taken to switch to more limited carbon-intensive sources of energy and feedstock to reduce these emissions. (Valencia 2013, 172; Kätelhön et al. 2019, 11187; Carus et al. 2020, 491.) It is predicted that in the future, the supply will not be met by fossil sources. To keep up with the demand, the supply of green feedstock is needed. Green chemistry is a term used for chemical substances that abolish the use of hazardous elements. (Pfaltzgraff & Clark 2014, 3–5.)

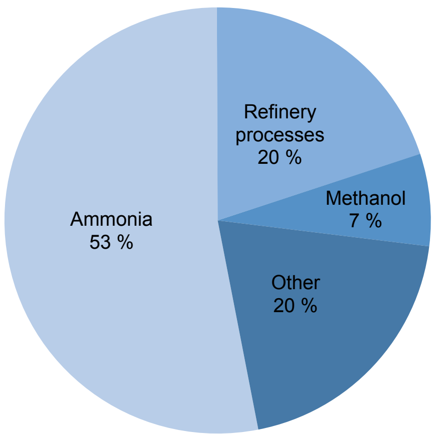


FIGURE 3. Uses of hydrogen in the chemical industry (Idriss, Scott & Subramani 2015, 13)

The market of the chemical industry strongly depends on feedstock. Hydrogen is one of the fundamental elements in the chemical industry. Together with carbon, they are one of the primary building blocks for ammonia, fertilisers, methanol and polymers (Figure 3). (Mitchell & Shantz 2015, 2375–2381.) Figure 3 also shows the demand for hydrogen in chemical refinery processes.

As the need for chemicals is growing, the prices of chemical feedstock have increased as well. Hence, to maintain a competitive and cost-efficient market for chemicals in Europe, efforts towards more sustainable production have been developed. One of the additional reasons for investments in the research and development of chemical processes with the help of hydrogen is the need for carbon feedstock. The plans for producing carbon feedstock in the future are moving away from fossil fuels and more towards renewable sources. (Huš, Kopač & Likozar 2019, 105; Carus et al. 2020, 489–497.)

3.1.1 Renewable Carbon

In a world dominated by fossil sources, it is often forgotten that there are limited fossil sources. Meanwhile, the global demand for carbon-based sources is going to increase over the years. If fossil fuels still stay the source of carbon, the greenhouse gas emissions will increase too. That opposes the idea to reduce fossil fuels while still keeping up with the global need for chemicals and plastics. Carbon is the backbone of life on Earth. Introducing a circular economy to a carbon-based industry is one of the most challenging developments in the industry. That can be achieved with the application of renewable carbon. Renewable carbon is any type of carbon that does not originate from the Earth's crust (geosphere). However, carbon from the geosphere is the type of carbon that is most in use today. (Carus et al. 2020, 489–491; White 2020; Kähler, Carus, Porc & vom Berg 2021, 6–9.)

Hydrogen is one of the essential elements required for the production of carbon based compounds. Hydrogenation is a chemical reaction between molecular hydrogen (H_2), another compound or element and a catalyst (Sedgwick & Hammond 2018). It is a process that is mainly used to produce hydrocarbon-based chemicals and fuels. These also include liquefied petroleum gas, gasoline and aromatics. (Yang et al. 2017, 4581–4595; Carus et al. 2020, 498.)

Figure 4 is a presentation of an ideal model for the production processes of renewable carbon. Since carbon is vital in industrial processes, it is crucial to recognise the applications that require a more sustainable approach. In the case of renewable carbon, ideal production aspects can be seen in Figure 4.

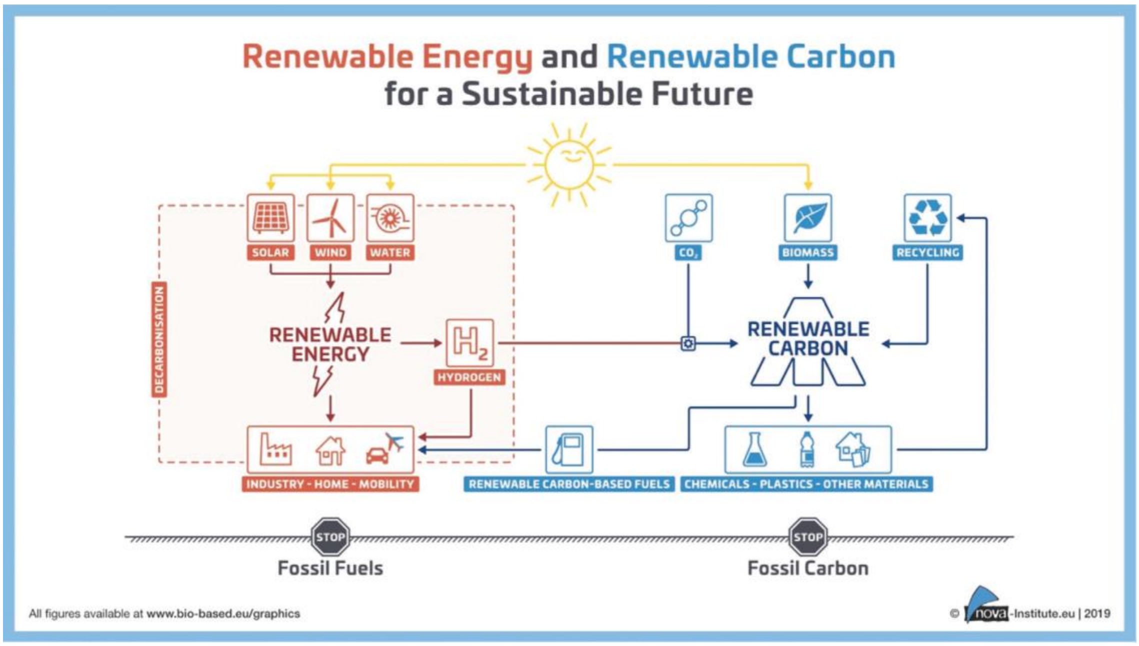


FIGURE 4. Graphic showcasing the production of renewable carbon (Carus et al. 2020)

Renewable carbon can be produced from sources other than fossil fuels. It can come either from the atmosphere, biosphere or technosphere. All of these sources have different characteristics and methods of production. Carbon from the biosphere is produced from biomasses, such as biowaste, food and non-food crops. Carbon originating from the technosphere and atmosphere is carbon that comes from direct CO_2 utilisation. Carbon capture and utilisation (CCU) is used for processes with fossil point sources, biological sources and direct air capture. Finally, renewable carbon from the technosphere is obtained from recycling plastics and other organic materials. It can be produced through mechanical and chemical recycling as well as incineration with CCU. However, to ensure that the produced carbon is renewable, it should be produced with energy originating from renewable sources.

Similarly, hydrogen as an energy carrier or feedstock plays an essential role in establishing a carbon circular economy. The introduction of green hydrogen in renewable carbon operations is fundamental for a low-carbon world (Figure 4). Here the term “low-carbon world” is used because it has to be noted that it is practically impossible to live in a no-carbon world. The global production industry is dependent on carbon. That is why a better term is the low-carbon world.

Carbon is a base for several necessary substances that will also be in use in the future. Moreover, carbon is required in several production processes as the base element for chemicals. Other applications include carbon use in fuels, plastics and other materials. Renewable carbon should have the same role in the future.

3.1.2 Hydrogen and Plastic Industry

Plastics are playing an essential role in the modern world. The global population is increasing, and with it also plastic production. The rise in plastic production also contributes to higher rates of plastic waste. World plastic recycling rates do not reach the goals for sustainable development of the global economy. Because of that, new technologies are needed for plastic waste production and refining. (Qureshi et al. 2020.)

Hydrogen plays a significant role in the entire life cycle of plastics. It can be recognised as the production source and the recycling product. In the production, hydrogen use mainly concerns the production of basic chemicals for raw plastics. On the contrary, plastic waste plays a role in the production of renewable hydrogen. Investing in hydrogen production from plastic waste instead of fossil fuels would offer an alternative, environmentally friendly feedstock. Additionally, it would help solve the plastic waste treatment problem. (Williams 2021, 3.) Both roles of hydrogen in plastic production and recycling are presented in the paragraphs below.

Methanol (CH_3OH) is a product of carbon monoxide (CO) and hydrogen (H_2). Its use in plastics production is vital since it presents the base for the production of polymers. Like many other fossil-based industries, the plastic industry aims to reach lower GHG emissions levels. Nevertheless, that is virtually impossible if the same practices are still in use in the future (Vollmer et al. 2020, 15403). Currently, grey hydrogen is most widely used in industrial applications. Therefore, it is often also used for methanol production. (Williams 2021, 3.). A more environmentally friendly approach can be taken by exchanging grey hydrogen with blue or green hydrogen in plastics production. It is vital to close the loop of plastics production with sustainable sources. That can be achieved by utilising blue and green hydrogen in plastic production alongside renewable carbon. (Carus et al. 2020, 498.)

After plastic products reach their final use, they have to be disposed of accordingly. The awareness of plastic recycling has been increasing over the past decades. Mechanical recycling is the primary way of plastic waste treatment, but it is not enough to reach a circular economy. (Qureshi et al. 2020.) Chemical recycling has been getting significant attention as a vessel for the circularity of plastics. Chemical recycling is the complete opposite of mechanical recycling. It requires a different approach, and also the end products have different characteristics than mechanically treated plastics. Mechanical recycling is termed “primary recycling” since its main purpose is to repurpose the same type of plastic repeatedly. Meanwhile, the main characteristic of chemical recycling is breaking down waste plastics at a molecular level. The products include other chemical compounds like fuel and hydrocarbons. (Vollmer et al. 2020, 15403–15404.)

The most common approach for chemical recycling is pyrolysis. Pyrolysis is a chemical process where a product is treated with high heat in an oxygen-free environment. It is one of the most critical technologies for the treatment of organic materials into fuels. Similarly, pyrolysis products of plastic waste are liquid hydrocarbons that can be used to produce oils and gases. By-products of pyrolysis are also hydrocarbon-rich gases and solids, which have a great potential for energy use. (Qureshi et al. 2020.) However, it has to be considered that the high-temperature process like pyrolysis requires high energy levels to be supplied to the systems. (Jie et al. 2020, Williams 2021, 9.). If that energy is renewable, that would be a significant step toward producing renewable hydrogen from plastic waste.

In addition to the pyrolysis of plastics, new chemical recycling technologies for hydrogen production are constantly being developed. Jie et al. (2020) researched a catalytic deconstruction process of crushed plastic waste. Generally a time-efficient and straightforward process, it applies microwaves and iron-based catalysts to transform mechanically treated plastic powder into hydrogen (H_2) and high-value carbons (Figure 5). That is an important development in the field of hydrogen production from plastic waste.

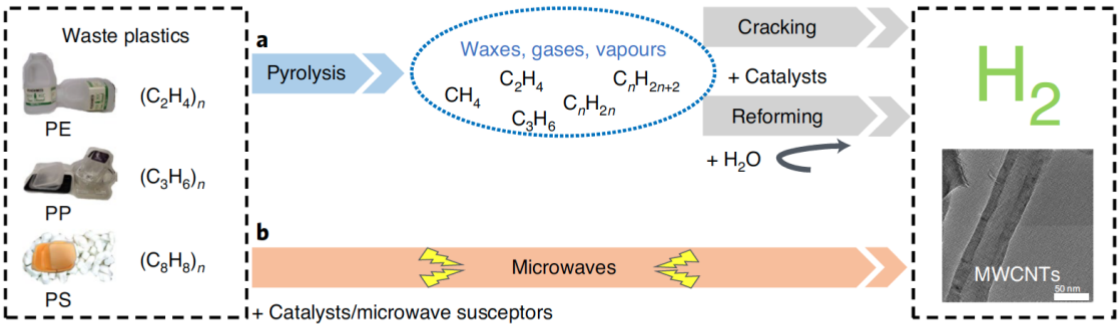


FIGURE 5. Diagram of pyrolysis and catalyst steam reforming (a) and microwave-initiated catalytic process (b) (Jie et al. 2020, 903)

The study by Jie et al. (2020) has exhibited a high yield of hydrogen from microwave and catalyst treatment. Such a process would produce more than 90% gaseous hydrogen yield. (Jie et al. 2020, 906.) All other processes (i.e., pyrolysis and catalytic steam reforming) do not reach such high hydrogen yields (Jie et al. 2020, 902, 906; Williams 2021, 6). This experiment has involved actual plastic waste and that gives this concept an even more prominent potential in the chemical treatment of plastic waste. (Jie et al. 2020, 909–910).

3.2 Hydrogen Energy Supply

The energy industry has already made significant investments in carbon-free operations. However, there are still some limitations to it. That is especially because of the costly storage for renewable energy. (Ehteshami & Chan 2014; Acha, Requies & Cambra 2015, 395.) However, in the past years, a considerable shift has been made. Renewable energy is becoming more affordable, and with it also storage technologies. (IRENA 2020, 21.)

There is a big emphasis on batteries storing renewable energy. Hydrogen as a chemical energy carrier can store energy. For that reason, it is also one of the feasible solutions for the long-term storage of renewable energy. (Pellow, Emmott, Barnhart & Benson 2015, 1939–1940.) Transportation and gas utilities are two of the up-and-coming markets for hydrogen.

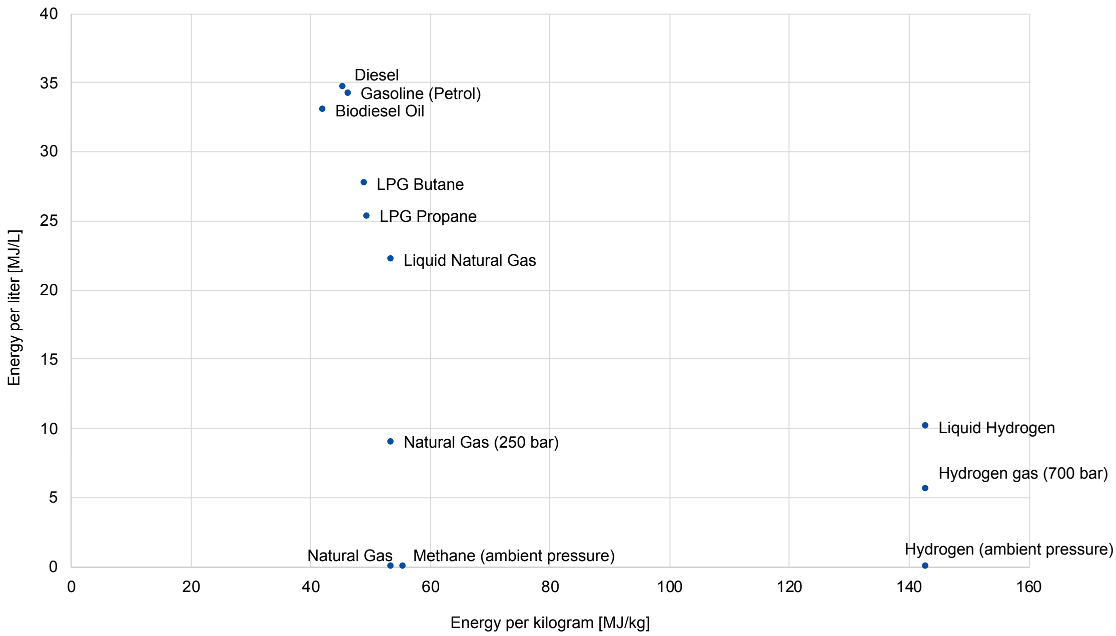


FIGURE 6. Selected energy densities of most common energy storages and fuels (Adapted from Mazloomi & Gomes 2012)

Hydrogen offers many different applications for utilisation in the energy sector. It can be used with turbines, internal combustion engines, fuel cells, and kitchen stoves. Moreover, hydrogen has energy characteristics unlike any fuel in use at the moment. For comparison, 1 kilogram of most gases and fuels has between 40 and 60 Megajoules (MJ) of energy. Meanwhile, hydrogen can yield more than 140 MJ per 1 kilogram (Figure 6). However, the most significant issue pointed out numerous times is that hydrogen's density is extremely low. That makes transforming hydrogen into different physical states difficult. Using hydrogen is, in reality, problematic. (Mazloomi & Gomes 2012, 3025–3029.) Some aspects still have to be explored to find the most efficient and environmentally friendly solutions for energy use on a larger scale.

Even though hydrogen as a fuel has not reached the full potential yet, several reports emphasise the implementation of hydrogen fuel cells for public transport. Transport modes such as buses, trains and ships could significantly contribute to cleaner public transport. For example, in the Northern Netherlands, 15 public transport vehicles are part of the Northern Netherlands Hydrogen Valley project. (Mijn Toekomst is Waterstof 2020, 27.) At the moment, the fuelling infrastructure is sufficient for the number of heavy-duty vehicles. More hydrogen fuelling stations will be required because new plans for more vehicles and projects are being carried out. The energy for these applications is intended to be sourced from renewable sources, offshore wind and solar farms. (Mijn Toekomst is Waterstof 2020, 29–31.)

For efficient operation and use, hydrogen as an energy carrier has to meet specific standards. These depend on the intended use and type of application used to produce it. High purity hydrogen is required in steel manufacture and fuel cells. Hydrogen that is not pure enough can cause significant difficulties in certain operations. That is why it is vital to recognise the potential hydrogen contamination during the hydrogen production itself. (Acha et al. 2015, 395.)

Moreover, fuel cells are susceptible to contaminants as well. That is why several standards and legislations have determined the permitted level of non-hydrogen gases in the fuel. Standard ISO 14687 on Hydrogen fuel quality specifies the fuel quality before it can be applied to operations in fuel cells (ISO 2019, 5). The standard states that there has to be at least 99,97% of pure hydrogen in the fuel. (ISO 2019, 3–5.) That is something that has to be considered when producing green hydrogen. Even when hydrogen is sourced from fossil fuels, it can get contaminated. Therefore, there is still the need to adhere to the requirements to enable efficient and environmentally operations.

3.3 Pricing

At the moment, there are more than 400 hydrogen projects ongoing globally, according to IEA (2020). These projects have different hydrogen supply technologies, end-use products and a range of application capacities (IEA 2020).

So far, these projects have been getting recognition and support from public funding. However, that has started to change now. Larger scale and privately funded projects are planned to start the shift towards the hydrogen economy. Nevertheless, first, to reach this stage, hydrogen must be produced at a competitive cost. (Moliner, Lázaro & Suelves 2016, 19502.)

Blue and green hydrogen are still not cost-competitive with grey hydrogen. The estimated costs for fossil-based grey hydrogen are low in the European Union with the overall price highly depending on natural gas prices. On the other hand, prices of blue hydrogen with CCS and electrolytic green hydrogen are too high to compete with fossil-based grey hydrogen. The CCS technology is expensive, while renewable energy has been too costly compared to fossil fuels. (European Commission 2020, 4–5.)

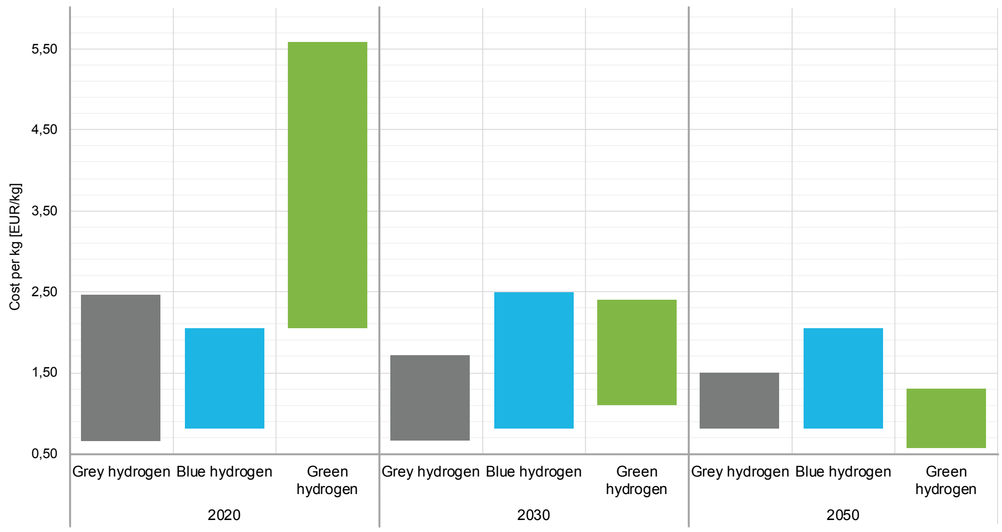


FIGURE 7. Hydrogen production cost ranges predicted for 2020–2050 (IEA 2019, 42, 52; IRENA 2019, 26–29; European Commission 2020, 4–5; Hydrogen Council 2021, 12)

Figure 7 presents predicted costs of hydrogen between 2020, 2030, 2040 and 2050. It indicates a rapid decrease in green hydrogen costs. That is due to lower price of renewable energy, which is required to produce green hydrogen. It is estimated that by 2030 green hydrogen in some locations could compete with fossil-sourced hydrogen, such as blue and grey hydrogen. (IEA 2019, 42–43; European Commission 2020, 4–5.)

As shown in Figure 7, it is projected that by 2050 the median price per kilogram of all three (3) colours of hydrogen will be comparable. Grey, blue and green hydrogen are projected to cost around 1,25 EUR/kg. Even though the graph from Figure 7 is a forecast for the future, the data for the figure was collected from other reports which support that statement. A similar result is reported by BloombergNEF (2020). The report states that green hydrogen could cost between 0,70 and 1,60 USD/kg in some regions (between 0,57 and 1,31 EUR/kg) (BloombergNEF 2020, 2).

TABLE 2. Hydrogen price estimations with system costs (Christensen 2020, 21–45)

	Minimum EUR price per kg	Median EUR price per kg
2020		
Scenario 1	6,14	13,16
Scenario 2	5,43	17,84
Scenario 3	6,91	10,64
2030		
Scenario 1	5,34	10,75
Scenario 2	4,43	14,15
Scenario 3	6,50	8,95
2040		
Scenario 1	4,97	9,54
Scenario 2	4,12	11,93
Scenario 3	6,15	7,77
2050		
Scenario 1	4,76	8,58
Scenario 2	3,85	10,22
Scenario 3	5,85	7,35

However, some reports do not agree with the prices of green hydrogen in the future. Christensen (2020) has created an economic model for hydrogen prices between 2020 and 2050. His study shows an estimation of hydrogen distribution prices (Christensen 2020, 21–45). The cost comparison between Christensen (2020), Hydrogen Council (2021) and BloombergNEF (2020) varies. That is mainly due to Christensen (2020) including system costs in the model of calculation. The price estimations by Christensen (2020) can be seen in Table 2.

Table 2 shows the results that Christensen (2020) estimated for the hydrogen prices by 2050. It includes three (3) scenarios. All of them include the implementation of green hydrogen through different applications. It has to be noted that Christensen (2020) applied a different approach than the sources from Figure 7. The cost estimates, therefore, vary significantly.

Scenario 1 – Grid Connect is an ideal situation where an electrolyser is connected to the grid. The direct connection allows hydrogen gas to give the maximum amount of energy over a particular time. The customer has direct access to the system and can use energy right away. On the other side, Scenario 2 – Direct Connect utilises energy from the electrolyser independently from the grid. It does, however, have a direct link to a renewable electricity generator (e.g., from wind or solar plant). The price of this system is lower because distribution and transmission charges are not included in the price estimation. Lastly, Scenario 3 – Curtailed Electricity is the cheapest one. This scenario uses grid-connected electrolysers, which serves solely as storage for renewable energy. In some cases, the price of energy per Kilowatt-hours (kWh) in Scenario 3 could reach zero (0) €/kWh. (Christensen 2020, 4.)

Since the production of green hydrogen is not widely available in commercial operations, there are still considerable investment costs involved in the hydrogen economy plan. The cost of electrolysers, the main component for hydrogen production, has dropped over 60% during the last decade. More significant drops are also expected to happen in the upcoming years. (European Commission 2020, 4.) However, significant investments in electrolysers still have to be applied to achieve a competitive hydrogen economy with green hydrogen. (Hydrogen Council 2021, 66.) That is why Christensen's model (2020) is a better scenario than the values from Figure 7.

3.4 Replacement of Fossil Sources with Hydrogen

In order to limit the amount of greenhouse gas emissions, the use of fossil fuel sources has to be reduced. While the energy sector has already reduced the use of fossil fuels with the help of renewable technology, that has not been the case in the production industry. Contrary to the energy sector, it is not possible to decarbonise the production and chemical industry. Additionally, fossil sources are indispensable for production in the chemical, refinery and plastic industry. The possibility to remove carbon from the chemical and production sectors is not an option. (Mitchell & Shantz 2015, 2375; Carus et al. 2020, 489–491.) There is also the fact that fossil fuel sources are not eternal. The global storage will eventually run out of it. (Milici, Flores & Stricker 2013, 109–111; Bauer et al. 2016, 580–583.) However, as already discussed in Chapter 3.1.1, renewable carbon is an available solution to replace fossil fuels. The other solution for the replacement of fossil fuels is hydrogen.

Hydrogen has been in the past years put forward as the option for the replacement of fossil fuels in the industrial, transportation and energy sector. Some industries, such as steel, cement, glass and chemicals, require high-temperature heat. In order to reach net-zero emissions, hydrogen has to be introduced to these operations. Otherwise, these industries will be unable to reach the emission reduction goals. Renewable energy is getting more available, and together with hydrogen, they present an essential interrelation of two green energy concepts. (Blank & Molly 2020, 2.)

There are substantial opportunities for hydrogen to replace fossil fuels in the future. Especially hydrogen's energy density is one of a kind, and it presents great potential. Hydrogen is a diverse substance that can be used in many different processes. An additional aspect that has to be considered is that hydrogen technology is still being developed. There are still significant costs included in the research and development of hydrogen technologies. However, there are also some disadvantages of hydrogen production, especially when it comes to storage and distribution. (Mazloomi & Gomes 2012, 3025–3026.)

3.5 Hydrogen Safety

Despite the widespread use of hydrogen, some limitations and safety aspects have to be considered before use. Hydrogen is generally a safe compound, but it still presents some risks. Its main characteristics are that it is an odourless and colourless gas. It is lighter than air, so it dissipates quickly. (Morelos 2017.)

One of the other characteristics of hydrogen is its high combustible concentration when mixed with air. It also has low ignition energy. That means it can ignite quickly, presenting a danger to entire hydrogen systems. Thus, suitable ventilation and detection of leaks are important in safe hydrogen systems design. Hydrogen embrittlement is also one of the other hydrogen risks. Embrittlement is the cracking of metals because of contact with hydrogen. Hydrogen causes damage to the metals, and that way decreases their strength. (NACE International n.d.; Office of Energy Efficiency & Renewable Energy n.d.) That is something that has to be carefully considered if hydrogen is stored in metal structures. Tears and leakages can have a catastrophic result on surrounding infrastructure. However, accidents like that can be restricted with open installations, appropriate distance from obstructions, and suitable materials for hydrogen systems. (Office of Energy Efficiency & Renewable Energy n.d.; Morelos 2017.)

Testing is another integral part of ensuring the safe use of hydrogen. Examining hydrogen systems, such as tank and garage leaks plus hydrogen tank drop tests, is vital. That can show safe production, storage and distribution of hydrogen. It is also necessary to educate the operators about hydrogen hazards, especially training in safe hydrogen handling practices. (Office of Energy Efficiency & Renewable Energy n.d.) Guaranteeing that all tests are completed effectively and hydrogen safety is increased, hydrogen can become as safe as other, more popular fuels.

4 NETHERLANDS AND HYDROGEN

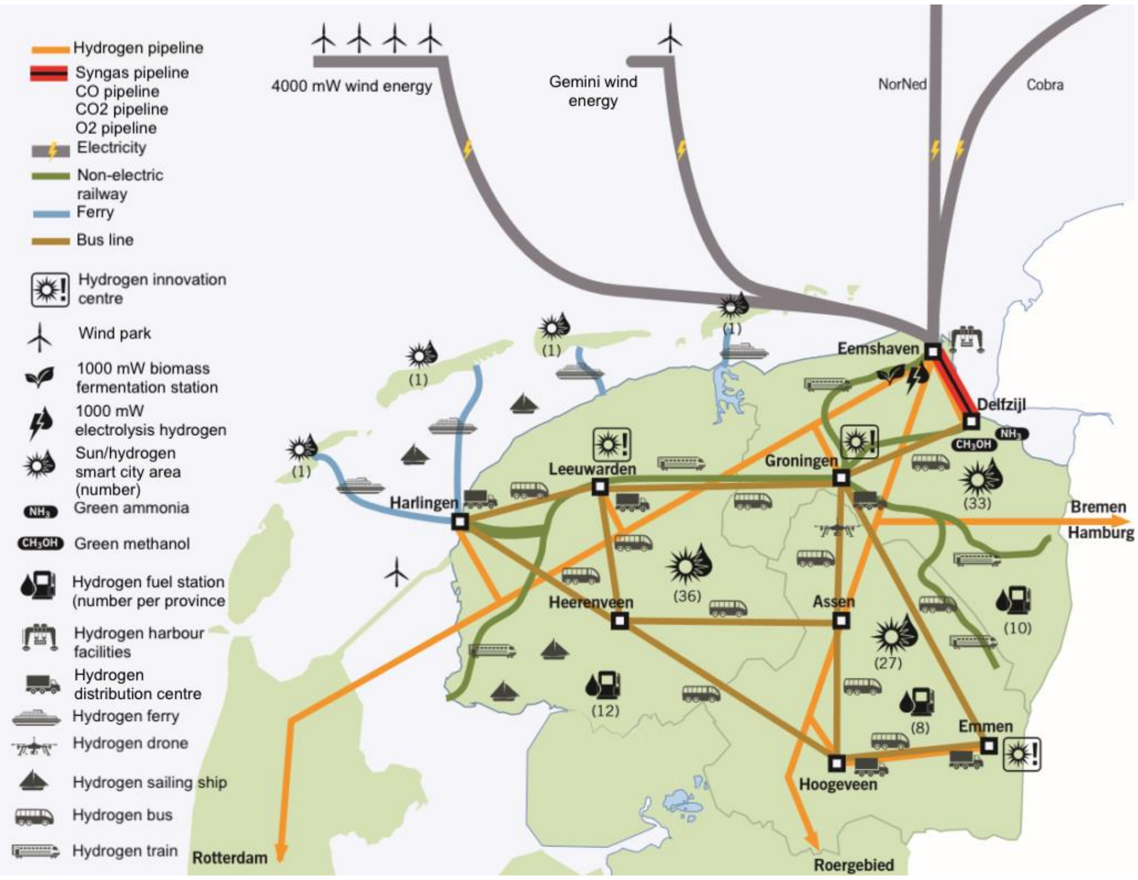
The Netherlands are one of the frontrunners in the production of grey hydrogen. However, their goals to reduce carbon emissions by 2050 cannot be reached with the current production of hydrogen. (Klimaatakkoord 2019, 5, 180.) To reduce GHG emissions, the Dutch government is giving more attention to the production and use of blue and green hydrogen. The concepts developed in the Netherlands can be implemented on a larger scale in the future. That way, a more sustainable energy supply for everyday operations could be supplied by low priced, renewable energy. (Kåberger 2018, 50; Hydrohub 2020, 7–9, 94; Cole-Bailey 2021.)

Several projects are currently ongoing in the Northern Netherland to start producing green hydrogen on a larger scale and utilise it in many different operations in the nearby area. One of the significant projects is NortH2. The project is a consortium of five (5) major organisations aiming to produce green hydrogen with the help of wind energy. The produced green hydrogen from offshore wind farms would be available to the chemical industry and transport and energy sectors. An additional bonus for the area is a subsidy from the European Commission’s Fuel Cells and Hydrogen Joint Undertaking to turn the Northern Netherlands into a Hydrogen Valley. (Cole-Bailey 2021.)

4.1 Northern Netherlands as Hydrogen Valley

In 2014, New Energy Coalition in the Netherlands introduced Hydrogen Energy Applications for Valley Environments in Northern Netherlands (HEAVENN) project to Fuel Cells and Hydrogen Joint Undertaking (The Hydrogen Valleys Platform n.d., European Hydrogen Valleys Partnership 2020). The EU members have accepted the scheme, and the European Commission approved the project’s funding (New Energy Coalition n.d.). A Hydrogen Valley concept has been established in the Northern Netherlands to contribute to the development of hydrogen in Europe.

However, to understand the Hydrogen Valley status for the Northern Netherlands, the term has to be described first. A Hydrogen Valley is a geographical area or an industrial cluster where various hydrogen applications are merged into a so-called hydrogen ecosystem that covers the entire hydrogen value chain. As a whole, Hydrogen Valleys enable a path for more achievable hydrogen applications in the world. Through the establishment of Hydrogen Valleys, hydrogen as an energy carrier can show more potential in the energy and industry sector. (The Hydrogen Valleys Platform n.d.; Ruf et al. 2018; 59.)



PICTURE 1. Hydrogen valleys project in the Northern Netherlands (Chemical Cluster Emmen 2017)

The Hydrogen Valley project in the Northern Netherlands focuses on establishing the area as a development region to launch a fully functioning green hydrogen chain (Picture 1). The project consists of several themes for the usage of green hydrogen, which are divided into four (4) sectors, covering the entire hydrogen value chain. The sectors defined by the New Energy Coalition are the production of green hydrogen as a raw material for industry, storage, transport and distribution of hydrogen, its application for energy supply and transport. (Picture 1, New Energy Coalition n.d.)

4.1.1 Green Chemistry in the Northern Netherlands

The Netherlands is one of Europe's leading countries in the production of chemicals. The chemical industry presents a large share of the country's gross domestic product (GDP). It is the second-largest industry in the Netherlands. (VNCI Koninklijke Vereniging van de Nederlandse Chemische Industrie 2021) Lately, green chemistry has been getting more attention. That is because of the Dutch agenda to reach a circular economy by 2050. By that time, GHG emissions from the chemical sector should be eliminated. In order to establish a zero-emission industry in the Netherlands, several steps must be taken. That involves the production of sustainable products with the help of renewable energy. (Klimaatakkoord 2019, 88–91.)

Green chemistry is one of the interest areas for the Netherlands. Its substantial need for the country's economy has to be adapted to GHG emissions reduction goals. Green chemistry can be enabled in the Netherlands with the support of the government and Dutch chemistry clusters. One of the essential chemistry clusters in the Netherlands is located in the Northern Netherlands. As a group of more than 30 companies, the Northern Netherlands chemistry cluster is a combined system with top possibilities of establishing green chemistry through a sustainable and circular chemical industry. (Chemport Europe 2019, 8–17, 28–46.)

Several aspects have to be thought of before the Northern Netherlands chemistry cluster can get the status of green chemistry. The entire life cycle of the production process has to be considered and carefully studied. There are 12 principles that green chemistry aims to achieve. However, according to Pfaltzgraff & Clark (2014, 3, 5), the main idea of these principles is to

- maximise conversion of reactants into a product
- minimise waste production by improving reaction design
- use and produce non-hazardous raw materials and products

- operate in safer and more energy-efficient processes
- use renewable feedstock.

After the chemical industry in the Northern Netherlands starts to develop according to these principles, sustainable processes in the chemical industry can be achieved. Green chemistry aims not to explore what is and what is not “green” but to aim towards safer and cleaner chemistry with minimal impact on the environment. (Pfaltzgraff & Clark 2014, 5.)

An added feature that the Northern Netherlands chemical cluster offers is an integrated system of all industries in the area. Chemport Europe ecosystem connects five (5) industrial systems that can together form a circular economy. These companies are located close to each other, and that allows them easy cooperation. The companies that operate within Chemport Europe can be classified into the following sectors: food, energy, chemicals, biochemicals, sustainable materials and applications and green energy and recycling. (Chemport Europe 2019, 6–7.) Such partnership between different industrial sectors is vital for developing green chemistry and a circular economy.

5 METHODOLOGY & APPROACH

5.1 Survey Research Fundamentals

According to Pulliam Phillips, Phillips & Aaron (2013), surveys are a tool that can be used to collect information. A survey is one of the most effective ways to collect information from individuals. Surveys offer a great deal of versatility, efficiency and reliability. (Check & Schutt 2012, 160.) When conducting a survey, it is vital to set a survey objective. A survey objective is needed to set questions, research design, define data source and time limitations. (Check & Schutt 2012, 163; Pulliam Phillips et al. 2013, 14.)

The type of survey depends on the data that has to be collected. There are two (2) different types of surveys, qualitative and quantitative survey. A qualitative survey is done when there is a need to learn about opinions, views and impressions. This type of survey does not include any numerical data. (Harden 2019.) On the other hand, a quantitative survey is used to collect numbers from the data. The data is used to measure unknowns that are objective and conclusive. (Check & Schutt 2012, 276.) Simply put, a qualitative survey shows opinions or feelings that cannot be presented with numbers. A quantitative survey can be easily measured or calculated. (Elliott 2020.)

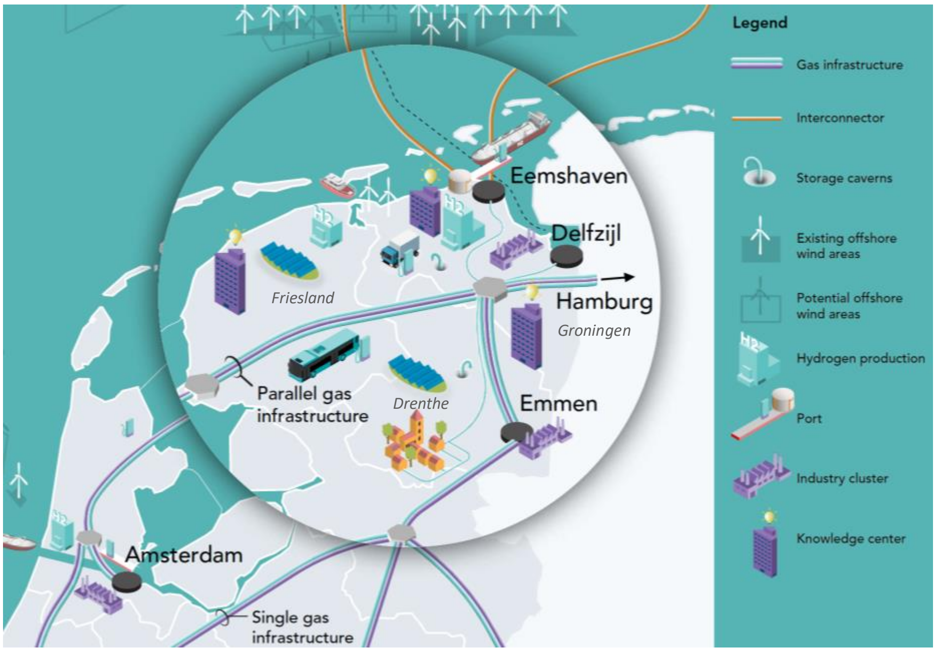
5.2 Research Plan

To be able to complete a survey, a research plan has to be designed. A research plan is an overall strategy of the study. It indicates research intentions and the method used throughout the study. A well-developed plan before conducting a survey is needed to produce a high-quality product. The plan has to be guided by study objectives and has to include several different approaches. These are the specification of research questions, the outline of proposed research methods and the timetable. The plan can, however, be modified and updated during the research. (Pulliam Phillips et al. 2013, 47; Byrne 2017.)

5.2.1 Research Purpose and Question

Every study has to start with a question. Moreover, scientific research aims to answer a hypothesis or proposition that is intended to be studied. The weight that survey questions have on the entire survey is significant. It is essential to understand the objective of the research and what it is attempting to achieve. Thus, the right questions will present relevant and useable results. (Pulliam Phillips et al. 2013, 28–29; Byrne 2017.)

The Netherlands is putting forward a government-wide circular economy programme. The goal is to reach circularity by 2050 in all municipalities. (Government of the Netherlands 2016, 5; Rijksoverheid 2019, 6.) One of the vital development areas also includes Northern Netherlands.



PICTURE 2. Planned hydrogen infrastructure for 2030 in the Northern Netherlands (Mijn Toekomst is Waterstof 2020)

Northern Netherlands is a Dutch regional territory that includes three (3) provinces: Drenthe, Friesland and Groningen (Picture 2). To reach the nation-wide goals by 2050, Northern Netherlands has launched a plan to become a hydrogen economy hotspot in Europe with Hydrogen Valley status (see 2.6) (CORDIS 2021). Hydrogen economy focuses on feedstock, transportation, energy and limiting GHG emissions from these three (3) sectors. Since hydrogen economy is such a broad topic, the Northern Netherlands have split these segments between different regions in the area (Picture 2).

That Northern Netherlands can achieve the Hydrogen Valley status, a plan must be made about which aspects of the hydrogen economy must be put forward. That is why research on the future of hydrogen economy opportunities was completed. The target group were 13 companies that are either already situated or are planning to settle in the Groningen Seaports. They were asked to fill out a questionnaire to understand their current relationship with hydrogen and their wishes for the future development of the hydrogen economy. That way, a plan can be developed to encourage collaboration with potential customers to complement other companies in the area. Consequently, the circular economy could reach its full potential in the Northern Netherlands.

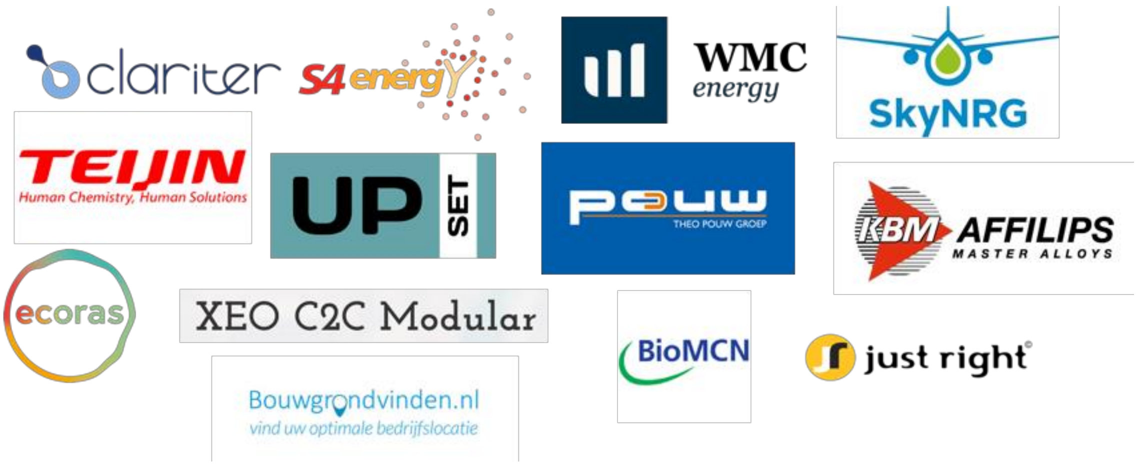
5.2.2 Data Collection

There are several different methods to collect statistical data for a survey. These include self-administered questionnaires, panel surveys, telephone surveys and intercept surveys. In some cases, a combination of methods can also be used. (68; Pulliam Phillips et al. 2013, 15.) A self-administered questionnaire consists of questions that targeted individuals are intended to answer. Such questionnaires are considered statistical surveys since the data is analysed with the help of numerical methods. (Pulliam Phillips et al. 2013, 15.) The method used in this research has been a questionnaire with both quantitative and qualitative characteristics. The questionnaire consisted of questions with two option scale (yes and no) and an open-ended question. The results were analysed by collecting numerical data from separate questions. An open-ended question was used to interpret the wishes of interviewees for future investments.

In this research, a sample was considered as the best form of data collection. A group of current and potential customers of Groningen Seaports was selected as the target group. If a sample is selected accordingly, it can reflect and present the wishes and opinions of a larger group. It also simplifies the process of data collection since not everyone has to be examined individually. (Cowles & Nelson

2015, 13–14.) Data was collected through an online Google Forms questionnaire. The targeted group was contacted through email, and a questionnaire was sent to them. All of the contenders include hydrogen in their operations, either as a feedstock or for energy. Some of them have plans to implement it to their operations. Many companies could be potentially interested in settling in Northern Netherlands in the future. Thus, their business ideas have to be studied in the upcoming plans for Hydrogen Valley in the Northern Netherlands.

The sample consisted of 13 companies that wish to implement blue or green hydrogen into their operations or settle in the Northern Netherlands. The companies all operate in different fields of industry. Picture 3 presents companies that were invited to participate in the survey.



PICTURE 3. Companies invited to participate in the survey (Lotric 2021)

As mentioned earlier, the companies presented in Picture 3 are active in different fields. Thirteen of these companies operate in seven (7) different industrial sectors. Hydrogen plays an essential role in the chemical industry. BioMCN, Teijin Aramid and ecoras all operate in the chemical industry.

Meanwhile, the chemical recycling industry is clariter's speciality. WMC Energy is a global company operating in supply chain management, while S4 energy and SkyNRG operate in the energy industry. UPSET Textiles is, as the name suggests, a company that operates in the textile industry. Meanwhile, KBM Affilips, XEO C2C Modular and just right® are companies that work in the manufacturing industry. The activities they operate in are the production of alloys, panels and cladding materials, respectively. Lastly, Theo Pouw and Bouwgrondvinden.nl work in the construction industry.

Some organisations have reservations about sharing information on business ideas and developments. To keep confidentiality along with transparency, the information that the companies provided in the survey is anonymous. A clear description was given to them about what and why the survey data is needed. That is of crucial importance to ensure good response rates and to avoid conflicts. (Cleave 2016.)

5.2.3 Data Processing and Survey Analysis

After the collection of responses, they had to be analysed. According to the questions used to conduct a survey, an appropriate method of data analysis had to be used. Pulliam Phillips et al. (2013, 125) list four (4) levels of measurement that can be used to analyse data: nominal, ordinal, interval and ratio scale (Pulliam Phillips et al. 2013, 125). In this analysis, a nominal scale has been used. It is, therefore, the sole level of measurement that is described in this chapter.

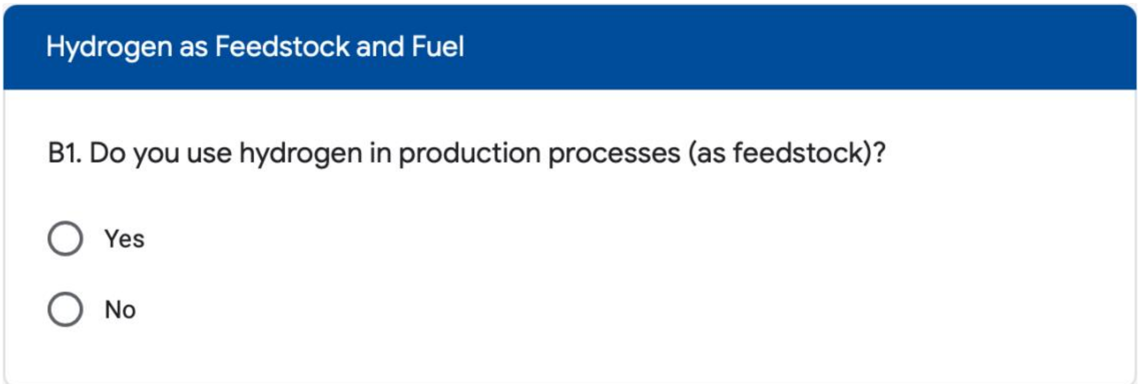


FIGURE 8. An example of a question with nominal scale response (Lotric 2021)

A nominal or categorical scale is a measurement level type where all response choices have the same value. Data is placed into categories without order or structure. This type of scale gives a non-numerical value with distinct characteristics. It does not include any mathematical computations where the survey respondents select one or multiple choices from available responses. These are later processed by counting the number of responses under the same choice and reported graphically. Figure 8 presents an example of a nominal scale question.

Question B1. in Figure 8 asked the respondents from the companies about the use of hydrogen in their everyday production operations as feedstock. The respondent could choose between two choices – yes and no. That answer would then demonstrate how many companies use hydrogen in their production processes and how many do not use it. Similarly, an open-ended question from Figure 9 questioned the respondents about their plans for future investments in hydrogen technology.

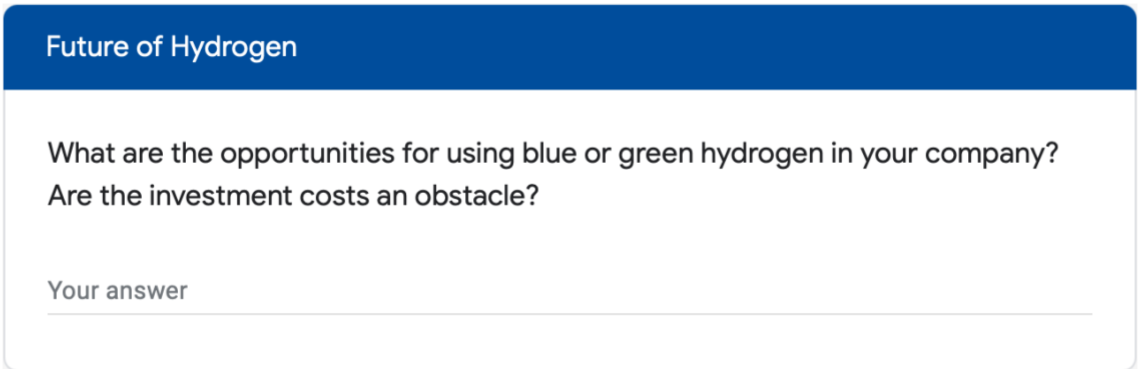


FIGURE 9. An example of an open-ended question (Lotric 2021)

An open-ended question from Figure 9 consisted of questions intended to give the responder's own opinion and plans for the future. It is a subjective matter that was analysed differently than the nominal scale response questions.

For a better and easier representation of answers from the open-ended questions, qualitative text analysis was taken. Kuckartz (2019, 187) lists a six (6) step qualitative content analysis. The data in this survey was carried out according to these steps

- step 1: preparation and collection of data
- step 2: forming main categories
- step 3: coding the data with main categories
- step 4: compiling text passages in order to form subcategories
- step 5: analysis based on categories and presentation of results
- step 6: reporting and documentation of data (Kuckartz 2019, 187).

5.2.4 Survey Errors

No survey is faultless, and all are inclined towards some form of error. It can occur even if careful measures are taken. However, it is vital to identify possible sources of error and try to minimise them as much as possible. There are four (4) types of survey errors: coverage, sampling, non-response and measurement error (Pulliam Phillips et al. 2013, 27; Cowles & Nelson 2015; 35–36). Errors most often appear in data collection and data reporting (Cowles & Nelson 2015; 36). The main error encountered throughout this study originated from the sample size. That is, as the name already suggests, a sampling error.

This study includes a small sample of respondents, and no sample is ever without any flaws. That is why sampling error is one of the most common errors in survey design. It most often appears when a sample from the population is selected. Not all answers received from respondents compliment the entire directory of companies that work with hydrogen in one way or another. However, with the help of a population sample, some preliminary plans can be made to evaluate the hydrogen economy's current state and propose new concepts for the future.

Sample size impacts the way the survey results could be interpreted and what they mean for the future development of the Northern Netherlands. In order to lessen the possibility of an error in the study, sampling error had to be recognised right away. A group of potential and current Groningen Seaports customers was carefully selected to get the most accurate outcomes. That enabled the study to be conducted with the customers to help the Netherlands reach circular economy goals by 2050.

5.3 Survey Design

The survey questionnaire consisted of 15 questions, 14 nominal responses (yes and no) and one two part open-ended question. The questions with the response options can be seen in Appendix 2. For easier separation between questions, they were divided into four (4) topics: Natural Environment, Hydrogen as Feedstock and Fuel, Hydrogen economy and Future of Hydrogen.

Questions 1 to 4 from the natural environment topic inquired the respondents about their current relationship and internal policies with the environment. The focus was specifically on renewable sources and the circular economy. The following five (5) questions from hydrogen as feedstock and fuel are more specific, emphasising the use of hydrogen in the companies' everyday operations. The hydrogen economy topic includes five (5) more questions about the investment costs in hydrogen infrastructure and challenges these companies face because of the legislation or internal policies. Finally, the first part of the open-ended question aimed to get answers from the responders on their opinion about future opportunities for hydrogen in their companies. The other question on how they feel about costs that come with the investments in suitable technology was added to the questionnaire. The last question is considered separately, and the answers are analysed in the discussion chapter.

5.4 Survey Implementation

As mentioned earlier, the questionnaire was done with the help of Google Forms for easier data reporting. The link to the questionnaire was forwarded over email to 13 contacts provided by the circular economy business manager at Groningen Seaports. The contacts had one week to answer the questionnaire. If they were unable to access the online questionnaire, a separate document was forwarded to them. Out of 13 contacts, nine (9) responded to the questionnaire. Although the sample was not significant, it still gave a valuable base for evaluating the entire survey.

6 RESULTS AND KEY FINDINGS

6.1 Survey Remark

Before the questionnaire results can be reported, it has to be stated that the results cannot reflect the general opinion of the target group because of the small sample size. The target group in this study were companies that are prepared to invest in hydrogen economy operations in the future. Thus, the questionnaire results imply an overlook of the companies that have already launched programs to implement a company-wide hydrogen proposition. These responses do not present the general opinion of the target group. Nevertheless, the results were analysed since even a small response quantity is vital for Groningen Seaports' hydrogen economy development.

Questions from the survey questionnaire can be found in Appendix 2. The questions are marked with a letter (A, B or C) in the graphs presented in the chapters below. The number of a question follows letters. Letters present the following topics from the questionnaire:

- A Natural Environment
- B Hydrogen as Feedstock and Fuel
- C Hydrogen Economy.

In total, out of 13 companies, nine (9) responded and filled out the questionnaire in either online form or a Word document. The response rate was relatively high – around 70%. It is estimated that the response rate is high enough to be able to determine the results successfully.

6.2 Natural Environment Awareness

The first part of the questionnaire focused on the awareness about the environmental impacts and the company's relationship with the circular economy. Responses to questions A1 to A4 are presented in Figure 10 below. The questionnaire results showed that all eight responders are invested in sustainable operations with an impact on the environment in mind (Figure 10). Selecting between options “yes” and “no”, the respondents were more or less unison about their answers.

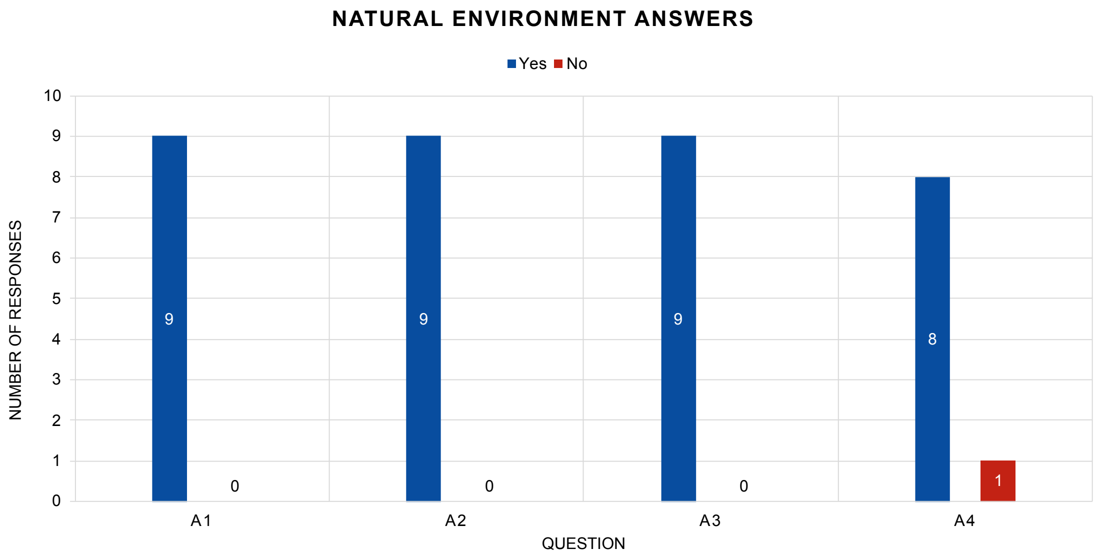


FIGURE 10. Responses to the questions from topic A

The results showed that all responders value the importance of renewable energy in their operations. All responders (100%) selected the “yes” option for A1, A2 and A3. However, there was a minor deviation in the last question (question A4 from Appendix 2). When prompted about circular economy plans in the company, most of the respondents selected the “yes” answer, and one (1) selected the “no” option.

6.3 Hydrogen as Feedstock and Fuel in Company Operations

The second topic focused on the operational use of hydrogen. The responders were prompted to answer questions about hydrogen as fuel or feedstock and the type of hydrogen they use in their operations. A question about the import of hydrogen was included to estimate the need for the industry in the area. That is included in the Discussion chapter. Figure 11 includes a graph of responses to questions B1 to B5. The results from this section of the questionnaire show more considerable diversity in responses.

Since companies invited to participate in the survey operate in different sectors, two (2) options had to be included in the questionnaire. In the first question B1 on hydrogen as feedstock, four (4) of the responders selected an affirmative response. In contrast, the rest selected the "no" option. Similarly, in question B2 on hydrogen as an energy source, two (2) respondents use hydrogen as an energy source in their operations. The remaining seven (7) do not.

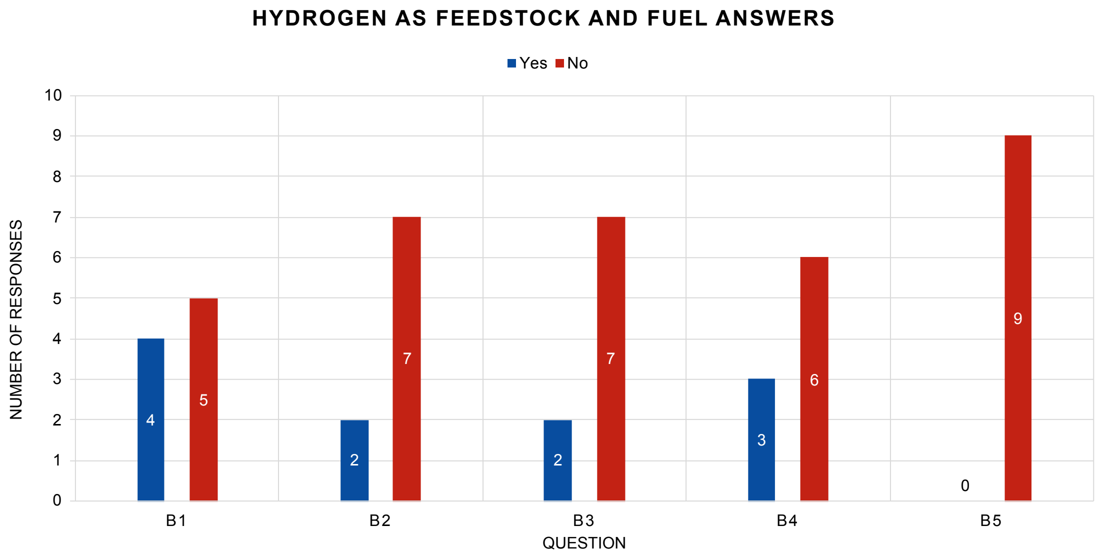


FIGURE 11. Responses to the questions from topic B

The remaining questions B3, B4 and B5 urged the respondents to answer the question about the type of hydrogen they use and if it is imported. Two (2) respondents selected the option "yes" when asked about the use of grey hydrogen (question B3). Meanwhile, three (3) respondents selected the same option in question B4 on the use of either blue or green hydrogen. The remaining five (5) do not use hydrogen in their operations at all. In the last question of this topic, B5, all respondents were unanimous in selecting the option "no" when asked if the hydrogen they use is imported.

6.4 Claims Towards Hydrogen Economy

The topic of the Hydrogen Economy was of the utmost importance. Based on the answers received in this section, plans for the future can be made, and areas that need improvement can be recognised. Figure 12 presents responses for the third section on Hydrogen Economy (C). Questions from section C focused on the future and the responder's opinions about current policies on green hydrogen production. Once again, the responses varied.

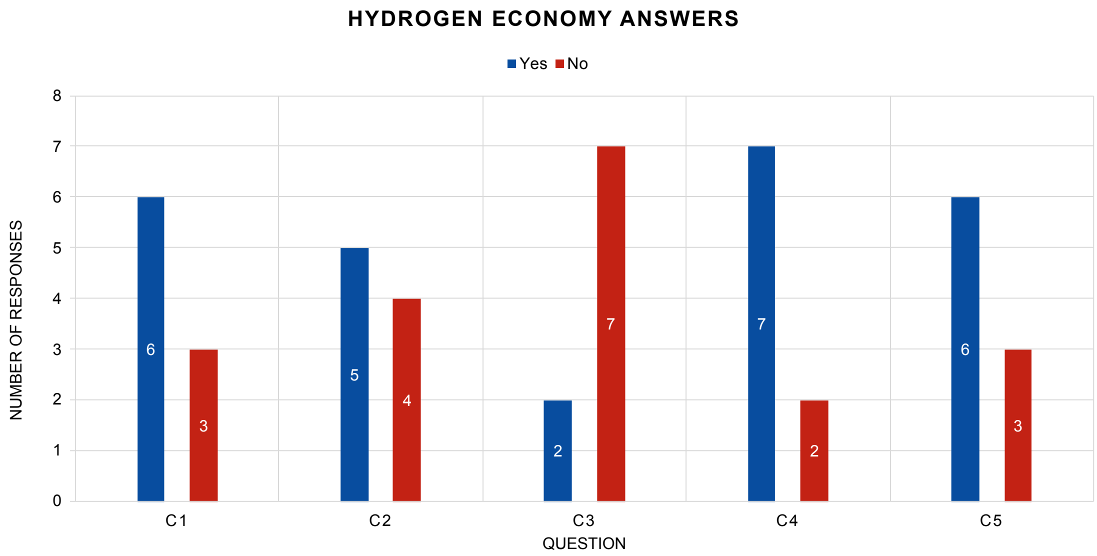


FIGURE 12. Responses to the questions from topic C

The first question on investments in sustainable hydrogen technology gave a majority to the "yes" answer. Six (6) out of nine (9) companies support the idea to invest in more sustainable hydrogen. The second question, C2, on current policies on the production of sustainable hydrogen in the companies, conceded five (5) "yes" responses with the remaining four (4) selecting the option "no".

Since the entire hydrogen economy aspect does not concern individual companies, government and international policies must be considered. The majority of the responders in question C3 on the governmental efforts to promote a green hydrogen economy agreed that there is still room for improvement. Only two (2) responders agreed with the statement, while the rest, seven (7), selected the "no" option. In question C4, most responders selected the "yes" option when asked about the challenges of the sustainably produced hydrogen. The last quantitative question enquired the responders about company costs on investment technology for blue and green hydrogen. Three (3) responders selected the "no" option, while the remaining six (6) agreed that significant investment costs would have to be applied.

6.5 The Future of Hydrogen

The last questions in the survey questionnaire consisted of two open-ended questions. The first one focused on the opportunities of blue and green hydrogen in their companies. Meanwhile, the other included a question about potential investment costs for the company. The approach taken for reporting results for this question differs from the one take for the previous 14 questions. For better clarity, the main categories from the answers to open questions were recognised. They can be seen in Table 3.

Answers from the responders have been collected altogether and compared. Those that included similar topic or application were put into the same category. Figure 13 is a categorisation of hydrogen use concepts that the responders are interested in.

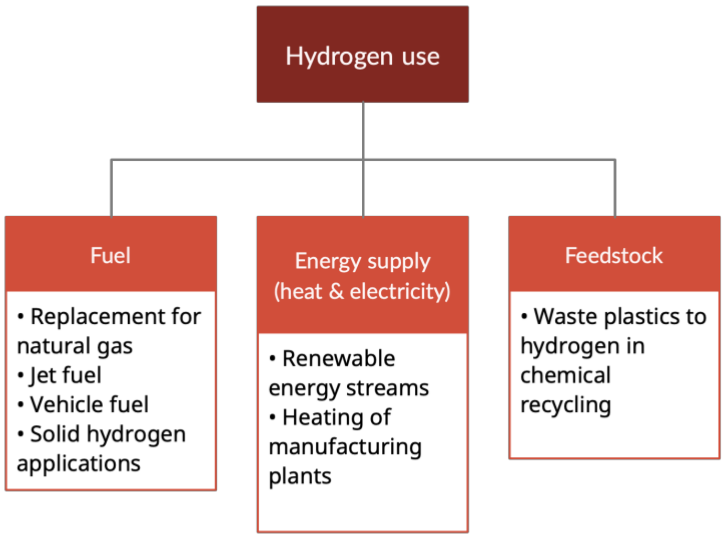


FIGURE 13. Hydrogen use categories and subcategories

Figure 13 shows categories of hydrogen use. The responders had to answer the question, “What are the opportunities for using blue or green hydrogen in your company?”. Altogether there were eight (8) answers to this question. It can be seen from Figure 13 that the answers focused on three (3) main uses of hydrogen: fuel, energy supply and feedstock. In Table 3, the main categories with several responses can be seen. Altogether there were four (4) answers that were linked to the energy use of hydrogen. Three (3) implied that hydrogen would be used for energy supply, and one (1) would produce renewable hydrogen as feedstock.

Like in the first open-ended question, the connection between answers from the second question was also recognised and analysed. The second question, however, focused on the more economical aspect of hydrogen systems. The question “Are the investment costs an obstacle?” got seven (7) answers that can be organised into four (4) categories: technology and infrastructure investments, market and geographical location (Figure 14).

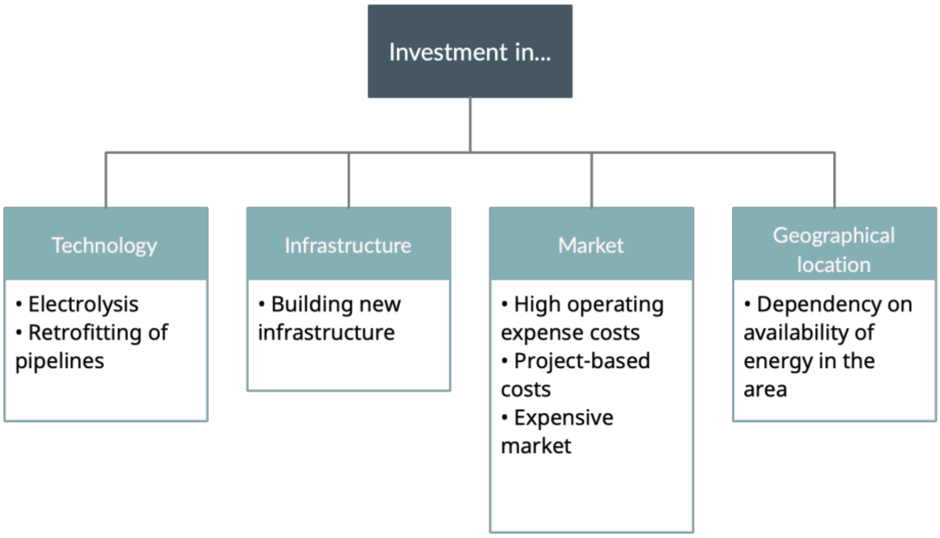


FIGURE 14. Hydrogen related investment categories and subcategories

In the investment category, most responders highlighted the infrastructure. They have put forward costs that would have to be invested in the operational system to allow hydrogen use. The main concern area was building new infrastructure with three (3) answers categorised in this area. Market and technology were the other categories that were stressed to be crucial for the company’s hydrogen economy implementation. Primarily they emphasise the hydrogen costs on the market. Lastly, one of the responders also stated that the company is dependent on the energy supply that is available in the area. That was categorised as geographical location since the investments for settling depend on the situation in the area.

All responses according to their categories and subcategories can be seen in Table 3. The numbers of answers are also marked for a more straightforward representation.

TABLE 3. Main categories from open-ended questions with number of answers per category

Category and subcategory	Number of answers
Hydrogen use	8
Fuel	4
Energy supply	3
Feedstock	2
Investment in…	7
Technology	2
Infrastructure	3
Market	3
Geographical location	1

The original answers from the responders are not included in this thesis study due to confidentiality reasons. For this study, the answers from the questionnaire were standardised and corrected. That ensured a clear overview of the answers.

7 DISCUSSION

The future of hydrogen economy opportunities and survey conducted for Groningen Seaports offered many points of interest. The main idea was to recognise the factors that contribute to the business decisions of companies about selecting the area for the most successful of their company. Based on that, plans for the future development can be made. The survey results are analysed in the chapter below to compare them to statements made in the earlier parts of the study. The analysis of responses can be recognised as a foundation for a unique selling proposition for Groningen Seaports.

7.1 Analysis of Survey Results

The results showed that despite the companies operating in diverse industries, they are aware of their impact on the environment and the changes they have to make. That is of vital importance. The majority of the responders have so far already implemented some sort of a circular economy plan (Figure 10). Operations with the environment in mind show that they are compatible with the goals of Groningen Seaports. Both the Dutch economy and Groningen Seaports aim to establish the Northern Netherlands as a circular economy hotspot. (Government of the Netherlands 2016, 53; OECD 2020.) With companies that are aware of their impact on the environment and are willing to participate in the circular economy, that goal can be reached.

Because of the diversity of companies included in the study, it is not surprising that the results in the second topic varied. The Dutch industry depends heavily on chemicals, and hydrogen is one of the building blocks for chemicals. (Weeda & Segers 2020, 11–15, 17.) Hence, it was expected that there would be more companies that use hydrogen in production processes. Even though a large percentage of hydrogen currently produced in the Netherlands is grey hydrogen, most responders selected green or blue hydrogen for use in operations. (Klimaatakkoord 2019, 180–181; Weeda & Segers 2020, 12.) That is a significant step forward for the global industry towards hydrogen economy.

Investments into new systems, especially those that work with renewable energy, will be on everyone's agenda in the future. It is still an expensive concept, as seen from the responses in questions C4 and C5 (Figure 12). Switch to blue and green hydrogen will present significant investment costs in the next ten (10) years, but lower than those today. Afterwards, it will slowly start becoming more cost-competitive with grey hydrogen. Figure 7 and Table 2 support this statement showing the predicted prices for different types of hydrogen. The companies, however, would like the government to invest more towards promoting green hydrogen. At the moment, the Dutch government is investing up to 40 million EUR annually (Klimaatakkoord 2019, 182). Nevertheless, that is not enough. The companies would wish for more policies and guidelines for the implementation of the hydrogen economy. The Netherlands will never reach their goal of the circular economy if they do not invest more resources towards promoting a circular economy with sustainable hydrogen. (Weeda & Segers 2020, 5.)

All companies included in this study are aware that hydrogen will impact the future development of the industry. Hydrogen has been named "fuel of the future" by several economy experts and industry leaders (i.e., Scott 2020, Vartiainen 2020, Deloitte 2021). Several responses in the questionnaire also emphasised the importance of hydrogen for their company and the market. Hydrogen is a versatile fuel, and its characteristics can help replace fossil fuels in many industrial operations. Combined with renewable energy, hydrogen can directly use solar and wind power for renewable feedstocks, especially in the chemical industry. (Weeda & Segers 2020, 6.)

However, there are some limitations that almost all responders agreed with. That is the price and development of hydrogen technology. All processes require significant investment costs that not everyone can afford. Responder number 5 emphasised that they are a start-up company entirely dependent on their capital. They already have enough expenses as it is, so they are currently not in a state to invest in hydrogen infrastructure (Appendix 3). That was also emphasised numerous times during the study. The costs connected to hydrogen investments are still too high at the moment. Although companies are willing to invest in hydrogen technology, there is still a lot that has not been thoroughly explored. That is why first pilot programs should be established as a collaboration between companies. That way, a working supply chain would be developed. It would be of significant importance to the entire hydrogen economy concept in Europe. (Klimaatakkoord 2019, 182.)

Lastly, the survey examined what can be potential areas of interest for them in Groningen Seaports. There is the need to implement green hydrogen into multiple operations, such as fuel, energy supply for heating and electricity and feedstock for the chemical and recycling industry. The responders have put forward establishing green hydrogen as an option for alternative fuel opportunities. Phasing out natural gas, coal, and other fossil fuel sources is essential for the future development of the hydrogen economy. These companies are aware of that. However, the sample was still relatively small. To assess all the opportunities that hydrogen could have, the target group should include a larger sample.

The thesis aimed to evaluate the opportunities that hydrogen has for the development of hydrogen economy in the Groningen Seaports and Northern Netherlands. This was established with the help of research on current applications of hydrogen and a survey on the hydrogen market currently present in the Groningen Seaports. The survey has some limitations. The size of the target group has the most considerable impact. It included 13 invited companies, and nine (9) responded. That is still a considerable number of responders. However, more would be needed to present the aims of the entire hydrogen business accurately.

Groningen Seaports and the Northern Netherlands have a prominent role in the development of the hydrogen economy. The area has received funds for establishing a Hydrogen Valley (Chapter 2.6). That can be a decisive point for companies willing to become a part of the hydrogen economy cluster. A positive response to this model is the possibilities for the circular economy. Several companies in the area are already cooperating in order to reduce their impacts on the environment. They operate in so-called cradle-to-cradle processes where everything produced in the area also returns to the spot after use. That is also an idea where hydrogen could become one of the building blocks for upgrading the current system. (Groningen Seaports n.d.)

8 CONCLUSION

The aim of this thesis was to recognise the hydrogen opportunities in the Groningen Seaports. The evaluation of the study was made through a survey of recommendations and comments from potential and current customers. Wishes to invest in the sustainable production of hydrogen was emphasised. Even though the number of participants in the survey was small, the study's purpose was met. Through received responses, an assessment of the possible success of the Hydrogen Valley project could be drawn up.

The survey results were evaluated to find the best opportunities for the Groningen Seaports. The companies' responses were categorised, and the most vital concepts were set out. Based on that, recommendations were made. From the results, it could be distinguished that the current opportunities of hydrogen technology do not depend on the Groningen Seaports. The current state of the market has a more prominent role. Most companies that operate in the industry based on fossil fuels are ready to implement hydrogen into their operations. However, significant investments have to be made first. High costs of sustainable hydrogen present the vulnerability of the market. Another problem that companies are facing is hydrogen technology and development. Several successful projects for hydrogen applications have already been carried out. Most of them were carried out on a small scale and have not generated the same results on a larger scale. That has to be improved in the following decades to reach a hydrogen economy.

By 2050 the global economy wants to reach a significant reduction in the use of fossil sources and greenhouse gas emissions. That can be achieved with hydrogen economy. There is still considerable potential for hydrogen applications in the industrial, energy and transportation sectors. No application for renewable hydrogen has so far been implemented on a large scale. Although a wide range of hydrogen applications have been researched and implemented on a smaller scale, they present a small fraction of all the other hydrogen possibilities. Research and development of new hydrogen technologies will be crucial in the following years. That is when the economy will start to decouple from fossil fuels and focus on renewables.

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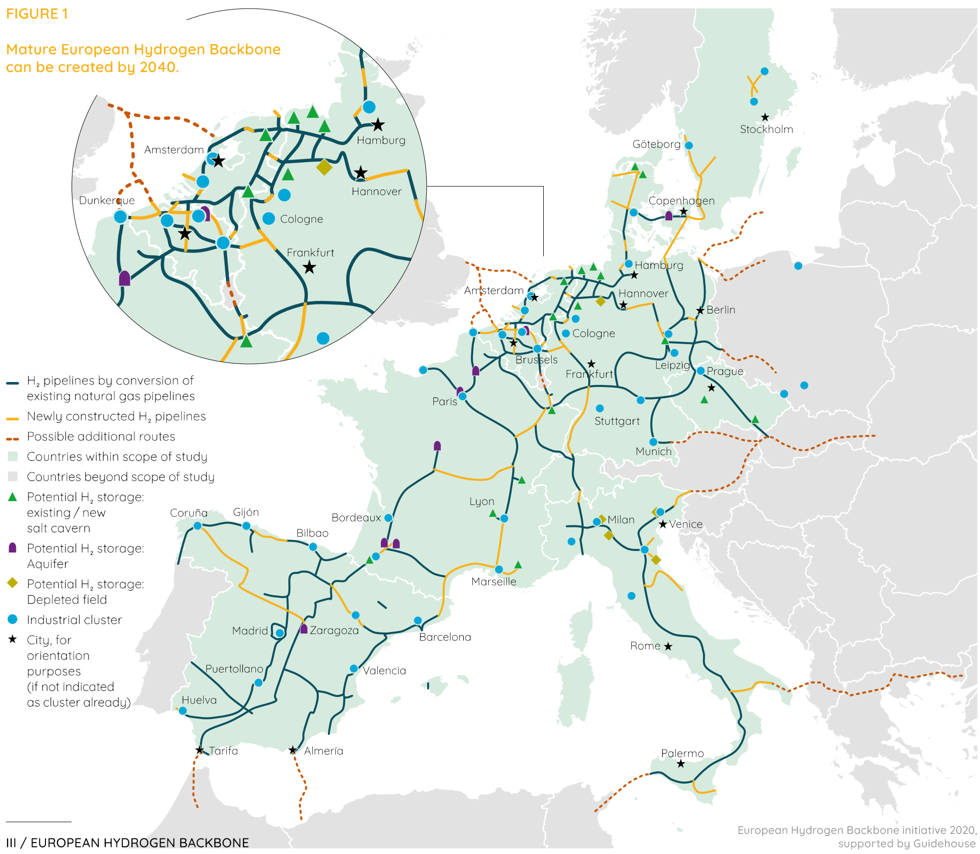
APPENDICES

Appendix 1. European hydrogen backbone (Wang, van der Leun, Peters & Buseman 2020, III)



Appendix 2. Questionnaire for customers of Groningen Seaports

Hydrogen Economy Survey

This is an internal research conducted for Groningen Seaports circular economy department. The surve focuses on hydrogen operations in industries that work with hydrogen as feedstock and/or as a source of energy.

We will appreciate the feedback greatly as it will help towards a better development of business opportunities in the Groningen Seaports.

Disclaimer: This is a survey intended for internal research at Groningen Seaports. All responses will be collected anonymously and will be reported as such as well.

Natural Environment

1. A1. Does the company feel responsible for the environment?

   Mark only one oval.

   - Yes
   - No

2. A2. Is the company aware of its impact on the environment?

   Mark only one oval.

   - Yes
   - No

3. A3. Does the company support use of renewable sources in its operations?

   Mark only one oval.

   - Yes
   - No

4. A4. Has the company drawn up a plan towards a circular economy?

Mark only one oval.

- ( ) Yes
- ( ) No

Hydrogen as Feedstock and Fuel

5. B1. Do you use hydrogen in production processes (as feedstock)?

Mark only one oval.

- ( ) Yes
- ( ) No

6. B2. Do you use hydrogen as an energy source?

Mark only one oval.

- ( ) Yes
- ( ) No

7. B3. Do you use grey hydrogen?

Mark only one oval.

- ( ) Yes
- ( ) No

8. B4. Do you use blue or green hydrogen?

Mark only one oval.

- ( ) Yes
- ( ) No

9. B5. Do you import hydrogen?

Mark only one oval.

- Yes
- No

Hydrogen Economy

10. C1. Do you want to invest in technology to produce more sustainable hydrogen?

Mark only one oval.

- Yes
- No

11. C2. Have you so far implemented any policies regarding sustainably produced hydrogen?

Mark only one oval.

- Yes
- No

12. C3. Is the Government doing enough to promote a green hydrogen economy?

Mark only one oval.

- Yes
- No

13. C4. Are there still too many challenges to using blue/green hydrogen in everyday operations?

Mark only one oval.

- Yes
- No

14. C5. Would an implementation of blue or green hydrogen systems present significant investment costs to the company?

Mark only one oval.

- Yes
- No

Future of Hydrogen

15. What are the opportunities for using blue or green hydrogen in your company? Are the investment costs an obstacle?

Thank you for your time and responses!