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HYDROGEN

As a future energy source

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ABSTRACT

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This thesis asks the question of whether hydrogen is a viable source of energy to replace fossil fuels. Hydrogen is a zero-carbon energy source as it only releases heat and water. It is also the most abundant element present. Fossil fuels are extremely harmful to the environment and is a major contributor to global warming. Hydrogen is produced and used in many different ways. There are many production methods which are still under research. They can either be used as a feedstock to produce something or as a fuel to produce energy. It needs to be transported around uniquely due to its penetrative properties and the gas's role in up and coming powertrains cannot be overstated. The element in fuel cells are extremely efficient when compared with other types of energy sources. Based on the research completed on this study, it is completely possible and likely for hydrogen to replace fossil fuels in most areas that fossil fuels currently excel in.

Keywords
Electrolysis , EU Roadmap 2050, Fuel cells, Hydrogen, Renewable energy, Power Trains, Zero Carbon Fuel,

CONCEPT DEFINITIONS

Carbon sink – anything that will absorb more carbon than it releases

End-use energy – The energy that is used directly from the user.

Circular economy – An economic system that is aimed at eliminating waste with the continual use of the resources.

Synthetic fuel – Any liquid fuel that is not made from naturally occurring crude oil.

Big data - Sets of data that is large in volume that can be analyzed to show patterns relating to humans

Internet of Things – objects that are connected to the internet that can exchange and collect data

Anode - A negatively charged electrode

Cathode – A positively charged electrode

Electrolyte – Minerals that can carry an electric charge

Reforming – A process that changes straight-chain molecules into branched molecules

Intermediate oil products – A refinery hydrocarbon stream that is not a finished petroleum product

Cogeneration – Producing electricity from hot gases and waste heat as steam in chemical processes

Power-to-x – Producing synthetic fuels and raw materials from electrical energy

Powertrain – A group of components that generates power that is transmitted onto the road, water or air

ABSTRACT
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1 INTRODUCTION

Current renewable energy is outdated; it is time for a change. The way the world is producing energy is unsustainable to nature. Newer, better, and cleaner energy sources need to be one of the main priorities going into the future. Hydrogen and more importantly fuel cells are more efficient compared to fossil fuels. Global warming is getting worse day by day. Oil prices dropping twice in 6 years is good for renewable energy. Logic would propose that it would be bad for renewable energy. Lower gasoline prices would mean that electric cars and vehicles become more expensive to own comparatively. Oil companies could start focusing on natural gas which could make renewables less attractive because natural gas prices would drop while renewables would not. Oil prices plummeting might be bad in the short term but it could be the start of something great for renewable energy in the long term. Since the oil market is volatile, many investors will be scared to invest in oil due to the fact that they could lose a considerable amount of money. Investors would be more likely safer to invest in the more stable renewable energy market.

The EU has a roadmap to produce zero-carbon energy by the year 2050 and hydrogen when produced with renewable energy is completely free of greenhouse gases. Hydrogen when used produces only water and heat. This study will explain why hydrogen should be one of the future main sources of energy. It will also include the reasons why fossil fuels need to be replaced by hydrogen, the types of hydrogen, the production of hydrogen, and its uses. Hydrogen's distribution is special because hydrogen molecules are miniscule and have strong penetrative powers so this paper also mentions its unique distribution methods and materials when compared to other fuels. EU's roadmap to 2050 is an important and major goal moving forward. EU has a vision of being completely carbon neutral by the year 2050. This vision comes with 6 different main goals. Zero carbon energy is the first. Zero-carbon energy is to provide energy without releasing any carbon oxides which is a large motivation for the push towards hydrogen. The others are electrification of end uses, green synthetic fuels, smart power grids, materials efficiency, sustainable land-use

The limitation of this study is that all information is gathered by a variety of scientists and researchers and not myself.

2 THE REASONS TO REPLACE FOSSIL FUELS

The first electricity-generating wind turbines was first introduced in the late 1800s (US Energy Information Administration 2020.) and solar farms have been providing energy for almost 52 years. (Aalborg CSP) Even with these new additions to lowering global warming the number of natural disasters directly or indirectly related to climate change has been increasing. (Asian Development Bank 2015.)

In the past year there has been a large number of natural disasters like the East African plague of locusts, which started in 2018 where 2 unlikely cyclones brought heavy rain to the Arabian deserts and helped the locusts breed freely. In just 9 months, the number of locusts in the area increased over 8000 fold. In 2019, there were even more rare storms, which made the locusts breed in larger amounts. By February 2020, these locusts are infesting over five countries and threatening a major amount of the African population. It is currently affecting over 13 million people while threatening over 20 million while also affecting parts of Iran and Pakistan, which has called for a national emergency at the beginning of February 2020. (Stone 2020.)

These storms are tied to the Indian Ocean Dipole, which changes between positive, negative, and neutral. When the Indian Ocean is negative, the western winds push warmer waters close to Australia bringing in the rain. When it is positive, the western winds are weaker, bringing warm water and rain to the Middle East and East Africa. In 2019, the weather in the North Indian Ocean was so severe that it broke many records, including the most "accumulated cyclone energy" and the most hurricane days. A research paper from 2014 and a follow-up study from 2018 found that if the planet warms by just 1.5 degrees extreme positive Indian Ocean Dipole phase could double and bring even more rain to Eastern Africa and reducing the amount of rain that that would otherwise be in Australia. With the rain generating a strain to East Africa, the lack of rain was causing extreme droughts in Australia, November of 2019 was the driest November on record. (Stone 2020.)

The early 2020 bushfires is one of the largest in Australia's history in terms of land affected, the fire ranked 3rd at 18.6 million hectares affected or 186,000 square kilometers. It has been estimated that one billion animals have been killed and some endangered animals are driven close to extinction (Rouse & Stevens, 2020.). These are just a couple of examples of what global warming has done to the Earth. There have also been increasing number of cyclones and tropical storms in recent years and the intensity of the category 4 and 5 storms have been becoming stronger. (Center for Climate and Energy Solutions)

The number of billion-dollar disasters has been increasing compared to the past. Between 2016 and 2018 they averaged 15 disasters per year compared to just 6.2 average per year between 1980 and 2018. (Eschner 2019.) With all these problems due to global warming something needs to be changed. If everything continues the way it does now there will not be a livable earth for our future generations to come. A large percentage of global warming comes from burning fossil fuel and that cannot continue. (Client Earth 2019.)

There needs to be newer forms of renewable energy that are more efficient and cheaper than fossil fuels. This type of energy needs to be researched and used. Hydrogen can be that fuel because green hydrogen produces absolutely no carbon dioxide and is supposed to be cost-competitive with other ways of producing hydrogen by the year 2030. (Edwardes-Evans 2020.) Right now, the majority of hydrogen production has natural gas as it's feedstock and it still releases harmful emissions into the atmosphere. (US Department of Energy) Once the industry scales up, Hydrogen will be cheaper and the price will be comparable to natural gas in Europe and Asia. It is extremely energy efficient and could be used as fuel for transport. China is leading the industry for hydrogen production infrastructure (Brasington 2019.)

3 HYDROGEN

Hydrogen is the most common element in the universe. It is the future of low carbon fuel. Hydrogen is 90% of all the atoms in the universe which is the same as three-quarters of the whole mass of the universe. It is nearly present in all living things. The problem with hydrogen is that pure hydrogen gas is rare on Earth. On Earth hydrogen is occurring mainly in a mixture with oxygen and water. Hydrogen also occur naturally inside living plants, petroleum, and coal. (Blaszczak-Boxe 2015.)

3.1 History of hydrogen

Hydrogen was first produced in 1671 while a scientist called Robert Boyle was experimenting with iron and acids but Henry Cavendish first recognized it as an element in 1766. He was also the first to create water using hydrogen, oxygen, and an electric spark. The practical interest of hydrogen as fuel first grew in Europe after the First World War. A Scottish scientist J.B.S Haldane campaigned for splitting hydrogen from water using wind energy. The Second World War increased the research for hydrogen fuel. A German engineer named Rudolf Erren transformed trucks, busses, submarines, and internal combustion engines into using hydrogen as fuel. (Dunn 2002.)

The U.S military also experimented with hydrogen for its air force, army, and navy but it was eventually used as liquid hydrogen in the U.S. Space program in the 1950s. In the 1960s, many scientists suggested using solar energy to electrolyze water to make split hydrogen and oxygen that would later be combined in a fuel cell. The 1970s was the first time the phrase “hydrogen economy” was used and it was by General Motors. Their engineers mentions hydrogen as “the fuel for all types of transport”. In 1973, the fuel crisis expanded the interest in hydrogen and the shock was thought to be the end of cheap petroleum. Governments from the U.S., Europe, and Japan started funding hydrogen research in the 1980s and many thought the hydrogen economy was “on its way”. For the next 20 years the prices of oil dropped significantly and so was the interest in hydrogen. Developments towards a world without fossil fuel indirectly made hydrogen as a fuel more reliable with fuel cell technology breakthroughs. The constant debate for the future of oil and people’s concern about the environment will always make hydrogen important. (Dunn 2002.)

3.2 Hydrogen Economy

Hydrogen economy means using hydrogen as a low carbon fuel. Hydrogen has many benefits. First, using hydrogen as a fuel would greatly reduce pollution. Hydrogen is extremely reactive that when hydrogen is combined with oxygen in a fuel cell, electricity is produced. This fuel cell is used to power vehicles and many other machines in the future. The greatest advantage of using hydrogen as an energy source is that the only by-products are heat and water. Second, Hydrogen production can be local and come from many different sources. The gas can either be made in one place or then distributed or onsite where it is used. Hydrogen can be prepared from many different feedstock. The element can be made from methane, gasoline, biomass, coal, or water. All of them produce a different quantity of pollution, challenges with the technical and energy requirement. Third, when hydrogen is made from water there can be a sustainable system of production. Electrolysis is a process that separates hydrogen from water. When renewable energy is used to power the electrolyzers to produce hydrogen a sustainable system that is non-polluting is created. Renewable sources used would be wind, hydro, solar, and tidal. The by-products of hydrogen in a fuel cell are water and heat so no greenhouse gases are being released into the environment. (Hydrogen Energy Center)

3.3 Types of hydrogen produced

Hydrogen in the current moment is still too expensive to be widely used. Estimates show that the prices might not come down enough to be used all the time until the 2030s. There are currently many promising signs that clean hydrogen will progress faster than expected. Right now the hydrogen being produced comes from natural gas and it generates a large amount of carbon emissions and it is known as grey hydrogen. A cleaner version is produced the same way but the carbon emissions are then captured and stored, or reused. This is called blue hydrogen. The cleanest hydrogen is called green hydrogen. It is generated using renewable source and produce no carbon emissions. The current prices of grey hydrogen changes based on the prices of natural gas and it is different around the world. The price of blue hydrogen is also driven by natural gas but is also dependent on the capturing and reusing or storing of the carbon emissions. The price of green hydrogen changes based on many different reasons. The first is the costs of electrolysis which is expected to drop by around 70% within the next 10 years and the costs of electrolysis change due to the price of green electricity that is used. The cost of generating solar and wind energy has declined in the past decade and should drop more in the future. (Van Hulst 2019.)

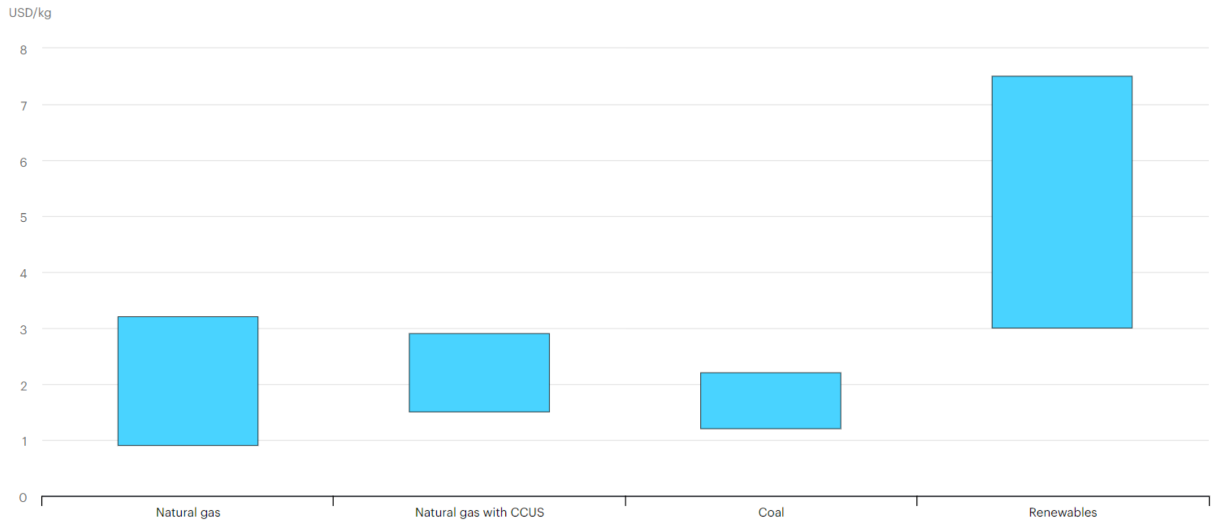

FIGURE 1. Hydrogen costs by production source (International Energy Agency 2018.)

As shown in figure 1, Grey hydrogen currently costs from 0.9 – 3.2 USD/Kg. Blue hydrogen costs from 1.5 USD/Kg to 2.9 USD/kg while Green hydrogen costs anywhere from 3.0 – 7.5 USD/Kg. Green hydrogen has a large range for prices because of the different prices of renewable energies in different areas. (International Energy Agency 2018.)

4 EU ROADMAP TO 2050

The goal of the Roadmap 2050 program is to produce a feasible and independent path to accomplish a low-carbon economy in Europe. This path will consider and implement the energy security, economic and environmental goals of the European Union. This project is from the inventiveness of the European Climate Foundation (ECF). It has been funded by the European Climate Foundation and developed by an organization of experts. (European Climate Foundation 2019.)

There are three main phases of this project. The first is the Roadmap. In July of 2009, the leaders of the European Union and the G8 proposed a target to reduce the amount of greenhouse gas emissions by a minimum of 80% compared to the amount of greenhouse gases released in 1990. In October of 2009, the European Council set the greenhouse gas emissions of Europe and other developed countries at 80-95% reduction compared to the values in 1990 by the year 2050. To have some credibility to this proposal the European Climate Foundation launched a study to acquire the ramifications for the European industry, especially the energy sector. The result of that study is Roadmap 2050. It provides a guide to a low carbon and growing economy. This roadmap discusses the usefulness and challenges of an 80% reduction in greenhouse gas objective for Europe. This includes urgent policy directives for the next 5 years. (European Climate Foundation 2019.)

Roadmap 2050 outlines valid ways to accomplish the 80% reduction target from an extensive European perspective. It is based on the best available facts obtained and developed by the experts of the industry. This roadmap has two primary objectives. The first is to investigate whether the 80% reduction in greenhouse gases would be possible technically and economically while at least retaining today's level of reliable electricity supply, security, and economic growth. The second is to assume the change of the European energy system for the next 5 to 10 years. It also addresses the high level of greenhouse gases throughout all the sectors and of the economy and power. It takes the minimum desired outcome and creates a pathway from today to 2050. A method called "back-casting" where the desired outcome is agreed upon and is worked backward to achieve that said outcome. Forecasting tends to extend the current day trends forward without any changes made to it. Multiple companies, consultancy firms, research centers, and NGOs provided help to this Roadmap. (European Climate Foundation 2019.)

The second phase is power perspective 2030. This is based on the work of Roadmap 2050 and builds on it. It provides an analysis of the steps needed for the European Power sector by the year 2030 to be fully decarbonized by 2050. This report is focused on the growth between today and 2030. It is written with the sectoral emissions trajectory in mind. This has a 60% CO_2 emission reduction in the power sector by the year 2030. This report detects that the current plans for renewables and power grids up until 2020. If done right is a good first step towards decarbonization in 2050 but needs to be developed faster and better. The pathway is going to be followed for the 2050 Greenhouse gas reduction goal. After the year 2020 there needs to be a near double of investments in low carbon generation electricity and a doubling of the electricity grid capacity by the year 2030. The European Union and its member states need to ensure that there is an acceptable policy and legal framework for the decarbonization of the power sector after the year 2020. The power perspective 2030 report has 2 main parts. The first is the technical analysis for the balancing of the power system while they're in transition. The second is what to expect for the power sector markets in Europe. (European Climate Foundation 2019.)

The third and final phase is called "from roadmap to reality" and talks about the implementation challenges of Roadmap 2050. This report explains how the current Energy framework can be enhanced to aid the power sector towards full decarbonization. From roadmap to reality mentions a fully integrated internal energy market combined with a functioning emissions trading system is the best way towards decarbonization and that policymakers need to take that action to make this a reality. Well-designed market interventions that can support renewable technologies, energy efficiency, and adequate resources are needed. This report shows that the whole European Union needs to work together to achieve their objectives for 2050. (European Climate Foundation 2019.)

4.1 Zero-carbon energy

Zero-carbon energy is the most crucial advancement towards decarbonization. Zero carbon electricity can be used either directly or indirectly for the production of zero-carbon fuels like hydrogen. With this, there will be a shift in the favour of zero-carbon primary energy source and a large development in the electricity production for the ultimate consumer. (SDSN & FEEM 2019.)

Zero-carbon electricity can be provided by a great number of different possible types of production. This can come from renewable energy (solar, wind, hydro, geothermal, tidal, ocean, and others) bioenergy, and nuclear. Carbon capture and storage of fossil fuel-generated electricity are also included. Studies affirm that renewables will be the main producers of energy mostly since the costs for renewable energy have dropped significantly. Countries and people, in general, have different opinions when it comes to nuclear energy and bioenergy. Carbon capture storage has been tried and improved however it is still not widely used in Europe. (Neslen 2015.)

Years of research prove that risk perception is an emotional combination of facts and fears, knowledge and instinct, reason, and unthinking response. It is never a purely rational process based on facts. Even though this helped us survive in the past, it is currently getting us into more trouble because this makes a person worry more about small risks while not thinking about larger ones. The fear of nuclear radiation is excessive and is unwarranted. For 65 years researchers followed the 90,000 atomic bomb survivors that were within 3 kilometers of Hiroshima and Nagasaki in 1945. The current estimate is that only 0.5% of those people have or will die from radiation-induced cancer. The World Health Organisation estimates that the population of Chernobyl which consisted of hundreds of thousands of people were exposed to ionizing radiation but only 4,000 out of hundreds of thousands of people might die from cancer caused by the leaked radiation. Like Hiroshima and Nagasaki the number of people dying from cancer is a lot smaller than many people will assume. (Ropeik 2010.)

Nuclear energy is frightening for people due to several reasons. Radiation is undetectable by our senses, the absence of power to protect ourselves makes it scary and that is true for more than just radiation. Radiation causes cancer, which is painful and torturous. The more pain and suffering something causes, the more afraid people are likely to be. Radiation from nuclear power is man-made, and man-made risks always make people more scared compared to natural disasters. Nuclear power stations can have a mistakes and an accident can happen. People tend to be more afraid of single catastrophic event rather than an even bigger devastation just because it happens over time. Society does not trust the nuclear industry, or nuclear regulators. When there is less trust, there is more fear. (Ropeik 2010.)

Despite these fears, the public's attitude when it comes to nuclear power is shifting. People are becoming more aware of the benefits of nuclear energy. When the advantage of the choice becomes bigger, the risk associated with it looks smaller. These are all psychological factors that are not based on facts, but it is usually how it is when it comes to risk perception. Emotional filters rather than facts determine how a person would feel about any situation. (Ropeik 2010.)

The fact is that nuclear power is safe and an extremely sensible option for energy production. While people fear the radiation from a nuclear power plant, it produces less radiation than a coal plant that exposes less than 100 times of radiation of natural background radiation. The average American's yearly radiation that comes from nuclear power is around 0.005% which is around the same as eating 1 banana a year. (Argonne National Laboratory 2013.)

Let's take Fukushima and Japan for example, 30% of Japan's energy comes from nuclear power. Japan has been producing electricity with nuclear power for over 50 years. Compared to other sources of energy, nuclear power is one of the safest. In the Fukushima disaster only one single person died from radiation compared to the thousands that the 2011 tsunami killed. Coal-related air pollution from power plants kill more than 100,000 people a year. The World Health Organisation estimates that pollution from biomass and coal causes over 1.5 million deaths per year. (Windridge 2011.)

There is also a concern to bioenergy. The public has concerns about the ecosystem degradation and competition to food supplies. Bioenergy is known to be carbon neutral. The concerns are the fact that bioenergy takes up limited land resources at a cost of food production and carbon storage, it also does not guarantee a reduction to the carbon emissions. The amount of land needed to produce a small amount of fuel is large. Three-quarters of the world's vegetated land is already being used for people's need for food and forest products. This is expected to rise by 70% by the year 2050. The other quarter contains natural ecosystems that either keeps carbon that increases global warming out of the atmosphere, preserve biodiversity, or protect freshwater supplies. (Steer & Hanson 2015.)

Plants are already growing in these areas and generating benefits. Diverting the land means sacrificing much-needed food, carbon storage, and timber to bioenergy. Bioenergy is an inefficient use of the land. In a study, World Resources Institute calculated that to provide 10% of the world's transportation fuel for the year 2050 it would need almost 30% of all the crops being produced this year. In just the United States of America the American population waste 150,000 tons of food a day, which is almost half a kilo per person. (Milman 2018.)

Bioenergy is a renewable energy that has many benefits. To have it live up to its potential it can be depends on a combination of things and it includes the types of feedstock, how it is being produced and transported. How efficient the technologies used to convert them to bioenergy is also extremely important. Biomass can produce heat and electricity. This can be used for heating and cooling applications in an industry or even for small communities. (Victoria state government 2017.)

Bioenergy can even improve air quality. Biomass residues would occasionally be burnt in the field or forest but instead now the biomass would be burned in an advanced emissions controlled bioenergy plant. Biofuel is biodegradable compared to petroleum-based fuels that are major surface and ground water-pollutants. International and studies from Australia prove that bioenergy would create many jobs, more than other types of renewable energy. Bioenergy will increase regional economic growth and employment because it would be providing new, diverse income streams. This would give landowners a larger market choice for their agricultural crops and trees, they would also benefit more through their waste streams like manure. During seasons where there's low rain there could be new opportunities to build trees that would be good in low rainfall when it wouldn't be ideal to grow crops. (Victoria state government 2017.)

The new jobs would come from growing and harvesting biomass, handling, and transporting. It would also come from procurement, construction, maintenance, and operation of the bioenergy plants.
Using biofuel supports the agricultural, timber, and food processing industries. It would increase their revenue while reducing their costs by selling biomass-derived heat or exporting electricity to the grid. There is a reduction in landfill too. It can also increase energy reliability and security by providing a power source coming domestically that can be ramped up at a shorter notice than larger coal-fired plants. Bioenergy production can be an alternative to forest burning, it has also been recorded that areas where biomass harvesting and removal for bioenergy have better water. (Victoria state government 2017.)

4.2 Electrification of end uses

Electrification is the procedure of powering a machine or object using electricity to reduce emissions, and welcome alternative energy with open arms while increasing efficiency.
There are multiple sectors in the industry that are presently working with fossil fuel which can be changed to work with green energy due to the existing technologies. This includes things like battery electric vehicles or (BEVs), heat pumps that are used in residential or commercial buildings, electric cooking uses either induction or microwave stoves and direct reduction of ores that are used in metallurgy. Electrification is becoming more likely nowadays compared to years ago. Car producers like Tesla, SABA, Venturi, and many other companies are producing BEVs and many companies are following in their footsteps. A big condition for this to continue would be an interconnected smart power grid that has to support the electrification of many sectors. (Carney 2013.)

4.3 Green synthetic fuels

Certain sectors cannot be electrified. Take an airplane, for example, Electrification can be used for domestic, shorter haul flights but longer flights need to use liquid fuels that have high density. There is a reason why a large range of synthetic fuel like hydrogen which can be used for direct combustion, in industry or fuel cells, synthetic methane, synthetic liquid hydrocarbons and, synthetic methanol. These synthetic fuels can be used as a green electricity and could aid in this being a circular economy which can be done by using materials from municipal and agricultural waste into energy. (Rintamäki 2019.)

4.4 Smart power grids

This would be built using big data, artificial intelligence, and the Internet of Things. The smart grid would be self-regulating, meaning that it would be able to change between many different types of power production to supply reliable and cheap operation of the system despite the uncertainty of renewable energy. There are many different elements to consider when it comes to the smart grid. For the energy supply, a smart grid will be able to combine and use different sources of energy to cover the weaknesses of renewable energy which is the variability. A large grid will have many more different sources of power generation, they will also have a lower coefficient of variation of power. There are also many storage options like batteries, compressed air, pumped hydro, and the conversion of renewable energy into synthetic fuel to secure constant energy. With smart meters it would be able to turn on and off the consumption of electricity depending on needs, importance, and change in prices that should depend on the supply-demand conditions. (SDSN & FEEM, 2019) The benefits of the smart grid include a more efficient transmission of electricity, quicker restoration of electricity when there are power problems, reduced costs for operations and management which means lower costs for the consumers, easier to integrate large-scale renewable energy are just a few of them. (US Department of Energy)

4.5 Materials efficiency

It is arranged in a way that plastics, cement, metals, and other industrial materials that discharge carbon dioxide in their production processes get used less. Enhanced materials and material flow by reusing and recycling which reduces waste while significantly improving material efficiency. (SDSN & FEEM 2019.)

4.6 Sustainable land-use

This mainly involves the agricultural sector. They contribute to a quarter of all greenhouse gas emissions. This includes the carbon dioxide from direct fossil fuel use, carbon dioxide from the production of fertilizers and other agricultural input. Carbon dioxide that gets emitted from deforestation and degradation of farmlands. The methane that is released from animals especially cows and flooded rice paddies. Nitrous oxide emissions from nitrogen-based fertilizers. Farming is essential but they harm ecosystems in so many ways apart from greenhouse gas emissions, which includes overusing freshwater, destroying their habitats, overharvesting of both plant and animal life, marine and terrestrial. There are also chemical pollutants being added to air, soil, and water which includes pesticides, hormones, and antibiotic which comes from animal feed. Destroying and degrading of topsoils. Aerosol pollution from peat burning and slash and burn agricultural. Eutrophication of some coastal environment because of phosphorus and flows of nitrogen. The large amounts of waste aggravate the environmental challenges of food production. From post-harvest loss to food waste. In high-income countries one-third of all the food is lost because of waste along the supply chain. (SDSN & FEEM 2019.)

5 PRODUCTION OF HYDROGEN

Since hydrogen can seldom be found in pure form, it would need to be produced or extracted from its compound. The extraction process can use any source of energy, either fossil or renewable. Unfortunately the majority of the hydrogen being produced nowadays is through a process called Steam Methane Reforming. One of the more important reasons why hydrogen is an important fuel source is because we can produce them using renewable energy which would make hydrogen a "green" fuel or carbon-neutral hydrogen. (Hydrogen Europe 2017.)

5.1 Electrolysis

Electrolysis is the process where water is split into oxygen and hydrogen. It needs high energy input and heat if you use high-temperature electrolysis. If renewable energy is used, the gas will have a zero-carbon footprint. It would be known as green hydrogen. This reaction takes place in a place called an electrolyzer. They can be any size ranging from an appliance size equipment to a central production facility. Electrolyzers are found with an anode and cathode, which are separated by an electrolyte. Electrolyzers will work differently based on what type of electrolyte is being used. Electrolysis offers a synergy with other renewable energies. (US Department of Energy)

5.1.1 Polymer electrolyte membrane electrolyzer

In this type of electrolyzer, the electrolyte is made of solid specialty plastic material. The reaction of water would occur at the anode to extract oxygen and hydrogen ions, which are positively charged. The electric current would move the hydrogen ions across the electrolyzer to the cathode as shown in figure 2. At the cathode, the positively charged hydrogen would be combined with the electrons from the electric current to produce hydrogen gas. This operates at around 70°–90°C (US Department of Energy)

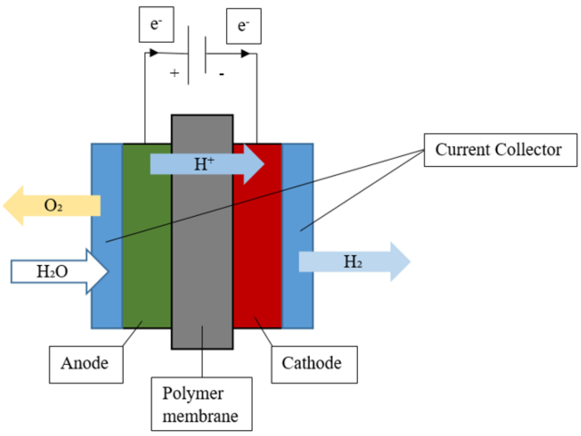

FIGURE 2. Schematic view of a polymer electrolyte membrane electrolyzer

5.1.2 Alkaline electrolyzer

This electrolyzer would operate by the transportation of hydroxide ions through the electrolyte starting from the cathode towards the anode. Hydrogen is still being produced on the cathode, the electrolytes used are either a sodium or potassium hydroxide solution. Newer research shows that solid alkaline exchange membranes might eventually be available. This operates around 100°–150°C. (US Department of Energy)

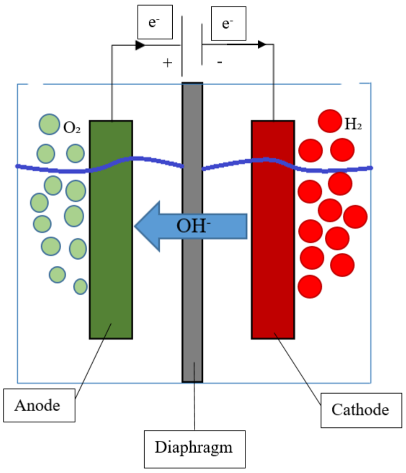

FIGURE 3. Schematic view of an alkaline electrolyzer

5.1.3 Solid oxide electrolyzer

This uses a solid ceramic material as an electrolyte. This conducts negatively charged oxygen ions at higher temperatures which would produce hydrogen differently. It is also known as high-temperature electrolysis. Water at the cathode is combined with the electrons from the electric current to form hydrogen gas and negatively charged oxygen ions. The oxygen is then moved through the ceramic and then it reacts at the anode to produce oxygen gas and electrons for the external circuit electric current. For solid oxide electrolyzers to function at its optimum production they have to operate at a temperature of around 700°–800°C. This type of electrolyzers uses heat effectively at these temperatures so the amount of electrical energy needed to produce hydrogen from water is then lower. (US Department of Energy)

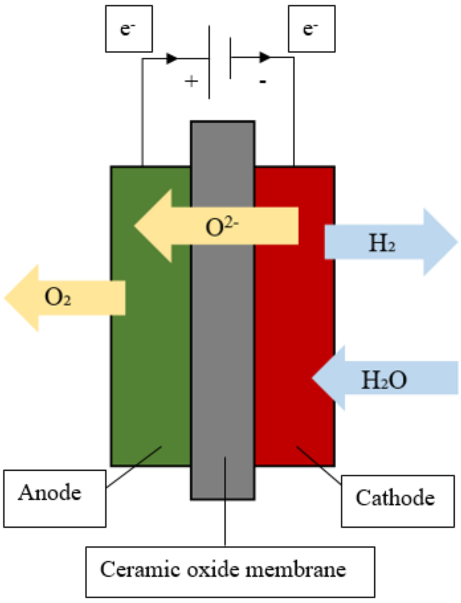

FIGURE 4. Schematic view of solid oxide electrolyzer

5.2 Steam reforming

As mentioned before this type of hydrogen production is the most common one used in current times. This is when a natural gas or biogas gets split and is then converted into hydrogen. It can be reacted in 3 different ways. It can either be done with steam, oxygen, or both in sequence. Steam reforming uses steam with temperatures ranging from 700°C - 1000°C. Methane in this example is also put under 3-25 bars of pressure with a catalyst present which produces hydrogen, carbon monoxide, and a small amount of carbon dioxide. This type of reaction is endothermic and needs the heat to work. After it is finished there is another reaction that happens which reacts the carbon monoxide and steam to produce carbon dioxide and even more hydrogen. It is called the water-gas shift reaction. (Hydrogen Europe 2017.)

Steam reforming can also be done with partial oxidation. So the natural gas or biogas is reacted with limited oxygen which is not enough to fully oxidize the hydrocarbon. If there was enough oxygen it would produce carbon dioxide and water but with less oxygen it should produce hydrogen, carbon monoxide, and small amounts of carbon dioxide and other compounds. Nitrogen would also be produced but only if air was used rather than pure oxygen. Water-gas shift reaction can also be used here to produce even more hydrogen. This process releases heat and a lot faster than normal steam reforming but the downside is the hydrogen produced per unit of feed is less than normal steam reforming. (Hydrogen Europe 2017.) Figure 5 shows the process of changing the feedstock to hydrogen.

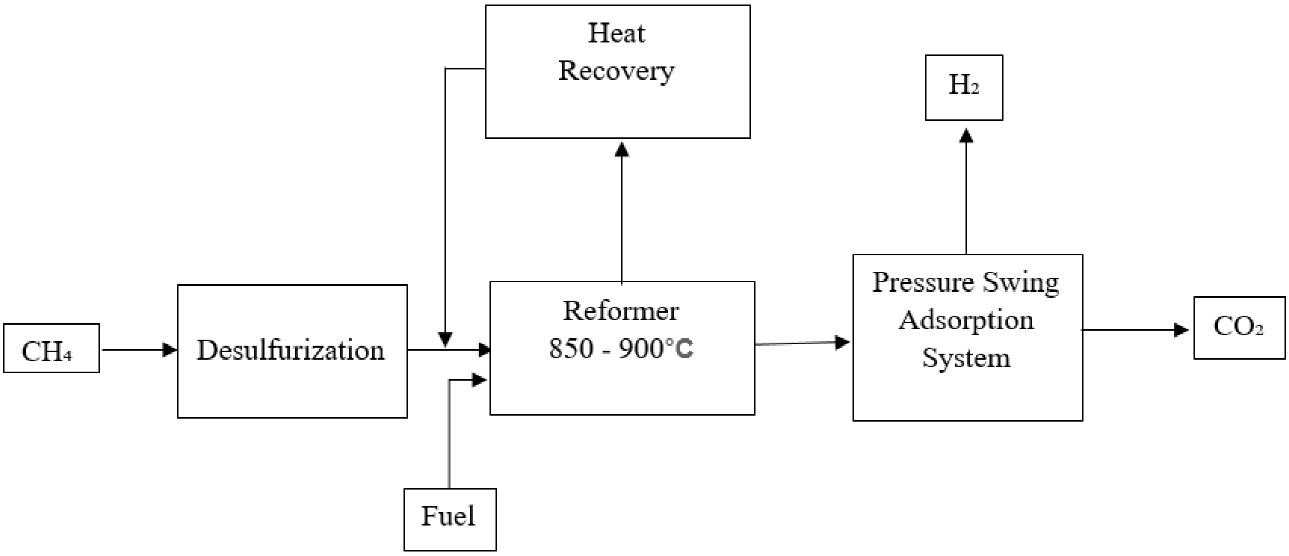

FIGURE 5. Flow chart of steam reforming for the production of hydrogen

5.3 Microbial biomass conversion

In the production of hydrogen with fermentation, it uses a microorganism that breaks down organic matter to produce hydrogen. Organic matter can range from sugars, raw biomass like corn stover, and wastewater. There is absolutely no light required so it can also be called dark fermentation. The organic matter gets broken down and can go through many different pathways to produce hydrogen. But some by-products can be mixed with enzymes to produce hydrogen. Current research on this type of production is for improving the rate of production and increasing the yield. (US Department of Energy)

Microbial electrolysis cells are one way of making hydrogen. It captures and uses the energy that is produced when the organic matter is being broken own. That energy combined with a small electric current would produce hydrogen. The current research ranges anywhere from finding cheaper materials to use to find the most effective microbe. (US Department of Energy)

The reason this particular pathway is being considered is that biomass is an abundant feedstock anywhere. Many microorganisms have evolved to produce hydrogen by breaking down the organic matter. Fermentation to create fuel is not a new thing, fermenting is already being used to create biofuels and a lot of other products. One large point for using fermentation to produce hydrogen is the fact that it can use wastewater meaning it would reduce the amount of electricity that would otherwise be used for wastewater treatment while creating clean energy that can be used. (US Department of Energy)

5.4 Types of hydrogen production still in development

There are still a lot of different ways of producing hydrogen that is still being developed. Hydrogen production is still not at its optimum rate of production. Here are some newer ways to produce hydrogen. These ways still need some extra research before it is ready to produce hydrogen on a larger scale. (US Department of Energy)

5.4.1 Photobiological

This type of production uses microbes and sunlight to turn either water or organic matter into hydrogen. It is still in the early stages of production with the potential to be a long term process of hydrogen production. The most basic explanation is that the microorganisms such as green microalgae or cyanobacteria use the sunlight provided to split the water into oxygen and hydrogen. A big challenge to this is the fact that hydrogen production is low while also producing oxygen at the same time which is a safety issue. (US Department of Energy)

Certain types of photosynthetic microbes also use sunlight to break down the organic matter which releases hydrogen. This is known as photo fermentative hydrogen production and is different from fermentation because it needs sunlight. The current problem with photobiological production is that it is inefficient with a very low production rate of hydrogen. Researchers are trying to change that by looking at ways to improve the absorption of sunlight for the microbes. (US Department of Energy)

5.4.2 Photoelectrochemical water splitting

This type of water splitting would use sunlight and a special type of semiconductor which are photochemical materials that use light energy to directly split water into hydrogen and oxygen. The semiconductor is similar to the solar power panel materials but instead is immersed in a water-based electrolyte. This PEC panel would have an either electrode or slurry-based particle system. The reason this type of production is being considered is because it is efficient even with low temperatures and uses cost-effective materials. It is still under development because the efficiencies still need to be increased with larger sunlight absorption and better surface catalysts, it also needs to be more durable while using cheaper hydrogen processing costs (US Department of Energy)

5.4.3 Thermochemical water splitting

Thermochemical water splitting uses concentrated solar power or heat from nuclear power reactions to split hydrogen and oxygen from water. It needs 500 - 2000 °C that would allow a series of chemical reactions to make hydrogen. The chemicals present are re-used like a catalyst. The challenges of this are the durability and efficiency of the chemicals used need to be improved. Reactor designs need to be enhanced to make it compatible with high temperatures and heat cycling. For the solar-powered version the price of the mirror needed is required to be dropped. (US Department of Energy)

5.4.4 Thermal decomposition of methane (TDM)

Thermal decomposition of methane produces hydrogen at high temperatures from a source of methane like natural gas. TDM without a catalyst requires a temperature of at least 1027 °C. To reach this temperature the reactor will need to be supplied with either extremely high heat or electricity. The reason TDM is better than other hydrogen production methods is the fact that TDM produces solid carbon rather than CO_2. This is would be a great way to produce hydrogen from natural gas without producing any CO_2 directly in its processes unlike the grey and blue hydrogen. The solid carbon can also be sold to further reduce the price of this hydrogen production. How much CO_2 is being released in this process will only depend on where the electricity/ heat comes from. Currently, TDM is appropriate for only small and medium industrial-sized production. Natural gas is abundant and TDM could be used in demand-driven situations. Reactor designs need to be improved before it can become commercialized. (Keipi 2017.) TDM can be further improved by the introduction of catalysts which will lower the activation energy. With tests showing solid carbon being formed at 600°C using a Ni-Cu Raney-type catalyst and methane decomposition occurring at 500°C using a Ni/SiO_2 catalyst (Ibrahim et al 2015.)

6 USES OF HYDROGEN

Currently almost all the hydrogen being used in the United States of America are being used to refine petroleum, treat metals, make fertilizer, and process food. (US Energy Information Administration, 2019) Hydrogen is flexible and can be used in many different ways. It can be divided into two major groups. Hydrogen as a feedstock or hydrogen as an energy. (Hydrogen Europe 2017.)

6.1 Hydrogen as a feedstock

Hydrogen's most important applications in the feedstock are its use in the chemical industry and metallurgic industry. Hydrogen is one of the main elements in the production of ammonia and fertilizers. It is also a large part in the production of methanol, which is used in producing many different polymers. Hydrogen is also used in refineries where it is used to process intermediate oil products. Around 55% of the current production of hydrogen is used for the production of ammonia, 25% is used in refineries, and 10% for the production of methanol. The other uses of hydrogen amounts to only 10% of the total use of hydrogen worldwide. (Hydrogen Europe 2017.)

6.1.1 Ammonia

Ammonia (NH_3) is made on a commercial scale by a process called Haber-Bosch. This process mixes nitrogen and hydrogen by synthesis, which is producing a compound by a reaction using simpler materials. Nitrogen is obtained by a low-temperature separation of air. The majority of ammonia at almost 90% is made into fertilizer. The ammonia is transformed into either solid fertilizer salts or, nitric acid and its salts (nitrates). Ammonia is also used as a refrigerant in refrigeration plants with the technical name R-717. (Hydrogen Europe 2017.)

6.1.2 Industries

Hydrogen is used in many different areas in the industry, which includes metallurgy, flat glass production, electronics, and electrical applications. Hydrogen is used in the metallurgy because of its ability to reduce and prevent the oxidation of some metals and alloys. It is used as a protective gas in the glass production and electronic industry but also used for cleaning, etching, and reduction process too. Hydrogen is also used in generator cooling and to prevent corrosion in power plant pipelines. Hydrogen and syngas are also used to reduce iron ore by reacting with the oxygen present. (Hydrogen Europe 2017.)

6.1.3 Fuel production

Hydrogen is an important element in the processing of crude oil into refined fuels that can be used, like gasoline and diesel. Hydrogen is also used to remove the impurities, such as sulfur. Hydrogen is being used more in fuel production due to three main reasons. It is because there is a stricter regulation on the amount of sulfur allowed in diesel, there is a larger amount of low-quality crude oil being used which needs more hydrogen to be refined. Oil is used in developing countries are also being increased. Around 75% of all hydrogen being used by oil refineries are being produced by hydrogen plants that generate hydrogen from natural gas and other hydrocarbon fuels. It is an important element in the production of methanol which can be used in internal combustion engines. (Hydrogen Europe 2017.)

6.2 Hydrogen in energy

Currently most of the hydrogen in the energy field is being used through fuel cells. A fuel cell uses hydrogen's reactiveness to oxygen to produce electricity, water, and heat. There is growth in the research that would allow hydrogen to be used as a zero-carbon electricity completely replacing fossil fuels. (Hydrogen Europe 2017.)

6.2.1 Hydrogen in road transport

Hydrogen is a good source of electricity to decarbonize the road transport sector. Especially if it used green hydrogen. The biggest advantage of switching from petrol to hydrogen is the fact that the only product released from cars will be water and that fuel cells are highly more efficient than internet combustion engines. Hydrogen in transport can be used in two different ways. The first is through direct hydrogen meaning H2 will be used as the only energy source. The second is through indirect use. Hydrogen would be used to further convert into gaseous or liquid hydrogen-containing fuels. The first fuel cell passenger cars were tested in the 1960s. In the 1990s there was a new boost to fuel cell development but it was not technically or economically competitive enough. There has been work on hydrogen-petrol hybrid engines and they did reduce the pollutions while increasing efficiencies. Currently passenger car development is focused almost fully on hydrogen fuel cells instead of combustion engines. The price will still be largely above what it would be for cars with internal combustion engines. (Hydrogen Europe 2017.)

6.2.2 Hydrogen in aviation

Hydrogen has been used as fuel in space travel for a while now but right now they are just potential energy providers for aircraft. Fuel cells can also supply electricity as an emergency generator or as an auxiliary power unit which would provide support to the main power units. Thus, making it a hybrid aircraft. Research is being done on a shorter flight for hydrogen as its main energy source. (Hydrogen Europe 2017.)

6.2.3 Hydrogen in maritime

Hydrogen in maritime applications currently is only as an onboard power supply. Fuel cells for ship propulsion is still in the early design phase and only for smaller ships. As of now there are currently no fuel cells that are scaled to be used in large ships. Submarines also uses fuel cells because it produces the oxygen needed to breathe and they have been developed in the US and Germany. (Hydrogen Europe 2017.)

6.2.4 Hydrogen in trains

Currently most trains are being powered by stationary current conductors but for reasons not every railway can be powered this way. The high upfront investment for electrification is sometimes not worth it. Overhead lines also cannot be used in case there's a need to transport things like cranes. Vehicles that are used for mining would also need to not have pollutants. (Hydrogen Europe 2017.)

6.2.5 Hydrogen in buses

Hydrogen as fuel and fuel cells have been used and tested since the 1990s. Several hundred buses worldwide are currently using hydrogen as its source of fuel, Mostly in North America, Europe, and Asia. While hydrogen is currently being used in internal combustion engines, researchers are focusing mostly on fuel cells. Fuel cell buses are extremely advanced technically but they are not mass-produced. The reasoning is that they cost almost 4 times as much but their maintenance is getting cheaper and operating times have increased reliably. The production costs should fall to 350,000 Euros by the year 2030. Fuel buses currently have a range of 300-450 km. Newer fuel cell buses use around 8-9 kg of hydrogen for 100 km while older ones use well over 20kg for the same distance. (Hydrogen Europe 2017.)

6.3 Stationary energy appliances

Immobile fuel cells can be used for decentralized power supply in areas with no electricity supply. Back up applications for power supplies are becoming more important nowadays to protect highly sensitive technical systems and also hospitals and such that need an uninterruptable power supply. Fuel cells are 60% more efficient compared to conventional thermal power plants. The advantages of fuel cells are that it has a long autonomous operation and service life; it is cheap to maintain and quiet while producing zero-carbon electricity. (Hydrogen Europe 2017.)

The heat is also used with the generated electricity. The process is known as combined heat and power plants. If they are used in the domestic heating sector they can also be known as micro-CHP or mini-CHP. CHP plants are operated in two ways. It can either cover most of the electricity and heat demand or if the price of electricity is high, Electricity-led mode can be used and electricity can be fed into the grid and they would be reimbursed. Electricity-led mode has a low heat output. (Hydrogen Europe 2017.)

7 FUEL CELLS

All fuel cells are designed with two electrodes, and an electrolyte between them, the reason there are many different types of fuel cells is because each type requires a certain material and fuel. A fuel cell generates electricity from an electrochemical reaction only having electricity, heat, and water as an outcome. A fuel cell can run forever as long as it gets hydrogen and oxygen. Hydrogen is the fuel in this situation but there is no combustion involved. The hydrogen gets oxidized and the hydrogen atoms create water. Electrons are released and flow through a current as an electric circuit. Fuel cells can vary in size, they can be producing anywhere from a few watts to megawatts of electricity. (Hydrogen Europe 2017.)

7.1 Solid oxide fuel cells (SOFC)

SOFC uses a solid, non-porous ceramic compound such as stabilized zirconium oxide as its electrolyte. This type of fuel cell is 50%-60% efficient at converting fuel to electricity. SOFC functions at 500-1000 °C. This type of cell is vulnerable to sulfur and needs to be removed before entering the cells. Adsorbent beds are one of the ways sulfur can be removed. SOFC has power generation from 100 W to 2 MW. Solid Oxide Fuel Cells are good with combined heat and power devices which makes the fuel cell even more efficient. SOFC does not need a catalyst and can run on hydrocarbon fuels. (Hydrogen Europe 2017.)

7.2 Proton exchange membrane fuel cells (PEMFC)

This fuel cell has a high-power density while having low weight and volume. PEMFC uses a water-based, acidic polymer electrolyte. The electrodes are porous carbon and have a platinum catalyst. This type of fuel cell does not need corrosive fluid like other fuel cells, it only needs hydrogen, water, and air to operate. They operate at 80 °C due to the deterioration of the electrolyte at higher temperatures. Operating at lower temperatures has advantages and disadvantages. The main advantage is that it is extremely easy to reach optimum temperature. The main disadvantage is that this fuel cell needs a platinum catalyst which makes it more expensive to run. Platinum catalysts can get carbon monoxide poisoning and that makes it extremely important to reduce carbon monoxide in the feedstock if the hydrogen is not pure and comes from hydrocarbon or alcohol which continues to increase the price of electricity production. This is the main type of fuel cell that will be used in FCEVs. (Hydrogen Europe 2017.)

7.3 Alkaline fuel cells (AFC)

One of the first fuel cell developed was an alkaline fuel cell. They were used in the U.S. space program for the production of electrical energy and water on the spacecraft. Potassium hydrogen in water is the electrolyte used and can use many different types of non-precious metal as a catalyst at both the anode and cathode but the most common catalyst is nickel. There are two types of alkaline fuel cells, High-temperature AFC which are older and Low-temperature AFC which are newer. High-temperature AFC runs at 100 - 250 °C and lower temperature AFC runs at 23-70 °C. AFCs are fuelled with pure hydrogen and oxygen, this fuel cell has an efficiency of 60%. The water produced is drinkable and is the cheapest fuel cell to produce, this is because the catalyst used is extremely cheap compared to the other fuel cells. One main disadvantage is that they are sensitive to carbon dioxide, the carbon dioxide can react with the electrolyte which decreases conductivity. (Hydrogen Europe 2017.)

7.4 Direct methanol fuel cells (DMFC)

DMFC uses pure methanol as fuel, it is mixed with steam and then moved directly to the anode. The anode can be fed with liquid methanol or methanol vapors and the cathode gets fed air. DMFC fits in with the family of low-temperature fuel cells because it operates between 60-130 °C. They can be considered as an evolved version of the PEMFC because they use a polymer membrane as an electrolyte. The platinum-ruthenium catalyst used on the DMFC anode can separate the hydrogen from the rest of the hydrocarbon removing the need for a fuel reformer thus lowering the costs. DMFC is good for portable power with outputs less than 250 W (Hydrogen Europe 2017.)

7.5 Phosphoric acid fuel cells (PAFC)

PAFC uses liquid phosphoric acid that is bonded in a Teflon-bonded silicon carbide matrix as an electrolyte. Porous carbon that contains a platinum catalyst as an electrode. PAFC was first introduced in the 1960s and has since improved mostly in the instability, performance, and cost department. They make good contenders for stationary appliances. They function at a temperature between 150 – 200 °C and the water produced can be converted to steam for air and water heating. Using this would allow the efficiency to increase to 70%. At lower temperature phosphoric acid is a horrible conductor and the platinum catalyst would get significant carbon monoxide poisoning. PAFCs are lucky that they are more tolerant of carbon monoxide compared to the PEMFCs and AFCs. PAFCs can tolerate around 1.5%

carbon monoxide concentration which would in turn increase the range of fuels that can be used. (Hydrogen Europe 2017.)

7.6 Molten carbonate fuel cells (MCFC)

MCFCs are being developed to replace the natural gas and coal-based power plants. MCFCs work at extremely high temperatures (650 °C and more). Molten carbonate salt mixture that is suspended in porous, ceramic lithium aluminium oxide matrix is used as the electrolyte and the matrix is chemically inert. MCFCs have an efficiency of 60% but get an efficiency of 85% if used in cogeneration. One large advantage of operating at high temperatures is the fact that the catalyst does not need to be a precious metal. The disadvantage of working at high temperatures is the fact that the life of the fuel cell is lower than others due to corrosion. It also has a lower power density while having an aggressive electrolyte. The feedstock can be natural gas, biogas, synthetic gas, methane, and propane. (Hydrogen Europe 2017.)

8 POWERTRAINS

As of now it’s a surprise to everybody as to why hydrogen has so much potential but delivers very little. Transport, heat, industry, and electricity account for two-thirds of the world’s carbon dioxide emission, and hydrogen, in theory, can work in all of these sectors. Electricity is easy to decarbonize compared to the other sectors simply because of the increase of renewable energy usage combined with it having large cost reductions. In the UK heat and transport, emissions will only by 24% compared to electricity’s 68% over the next 15 years (Staffell et al 2018.)

In 2015, 45% of all energy used in transport came from cars and motorbikes. By the year 2050, the number of cars used are expected to jump by an extra 150% from 1 billion to 2.5 billion. Hydrogen-powered cars are completely carbon-free compared to biofuels and do not have the problem of having limited range and long charging times which are always linked with EVs. The reason EVs are currently more popular is because of the cars being cheaper to produce and because of the already available infra-structure. 30% of the cars being sold in Norway are EVs compared to the UK's 2%. Air pollution is extremely costly, the direct cost due to illnesses, crop yield loss, and damage to buildings are around 24 billion euros a year. The external cost can be estimated anywhere starting from 330 billion to 940 billion euros per year. 92% of the people alive right now are living or exposed to air that’s higher than the world health organization’s limit. Large cities plans on banning all diesel vehicles by 2025 while the UK and France are planning on banning all pure combustion vehicles by the year 2040. (Staffell et al 2018.)

There are 4 ways of providing energy to a vehicle. Fuel cell electric vehicles (FCEVs), internal combus-tion engines (ICEs), Battery electric vehicles (BEVs) and plug-in hybrid vehicles (PHEVs) which uses a battery but can switch to an engine for longer journeys. (Staffell et al 2018.) FCEVs are currently more expensive to own compared to BEVs. 60,000 dollars for a Toyota Mirai compared to a 25,000 – 30,000 dollars for a Renault Zoe or Nissan Leaf. As manufacturing volume rises its possible for FCEVs to become even cheaper than a BEV. FCEVs have a higher driving range and shorter refueling time com-pared to BEVs and it is comparable to ICEs. Sensors in driverless cars, air conditioning/heating will affect BEVs more than FCEVs. (Staffell et al 2018.)

Hydrogen filling stations can handle considerably more vehicles compared to an EV charging station but they are substantially more expensive per charging post. 1.5 million dollars compared to less than 1000 dollars for a slow EV charger. The costs are expected to drop by at least two-thirds by the time the technology develops. (Staffell et al 2018.)

Battery lifetime is affected by the way it is taken care of. Climate, overcharging, deep discharging and a high charging/discharging will affect the batteries. Tesla expects its batteries to last at least 10 years. Hydrogen tanks can do all that and not compromise its lifetime. EVs have a smoother driving experience compared to an ICE but Hydrogen tanks take up a lot of space which means less luggage space is available. (Staffell et al 2018.)

FCEVs and BEVs have zero emissions and would have extremely low carbon point of production if it is made using renewable power. ICEs can be combined with biofuels to lower the overall carbon dioxide emission but the air quality does not get improved. FCEVs and their refueling stations do not need an electricity network upgrade which would be needed for a BEV station. FCEVs have similar dangers compared to a BEV or an ICE. Hydrogen is more flammable than petrol but hydrogen fires would is always localized and would cause very little damage to the vehicle. (Staffell et al 2018.)

FCEVs which are currently very expensive to own should be priced around the same as other types of vehicles by the year 2030. Platinum is a large reason why FCEVs are so expensive. A mid-sized vehicle needs 10 times more platinum compared to a diesel vehicle. Research has been able to lower platinum content. Daimler has lowered it by 90% compared to values in 2009 and Toyota is expecting it to lower by another 50% from today’s level. (Staffell et al 2018.)

FCEVs need to sell around 100,000 cars per year to drop its price to equal the BEVs. Currently 70 million cars are being sold each year. When the prices are similar 78% of automotive executive believes that the main advantage that FCEVs have is the fact that they have faster refueling. BEV recharging time is going to always be a huge thing to accept. FCEVs are currently only available in a few countries because of the lack of infrastructure. The hydrogen council is planning on pumping 1.75 billion dollars per year to accelerate the deployment of FCEV cars. The International Energy Agency expects 8,000,000 cars to be sold by the year 2030 and 150,000,000 by the year 2050. (Staffell et al 2018.)

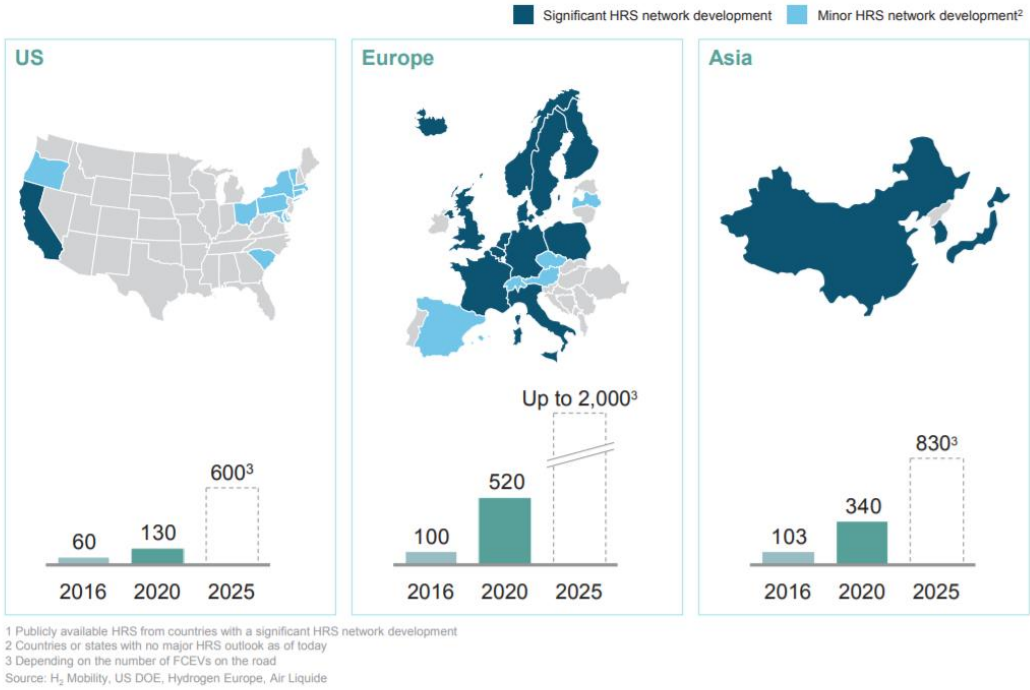

FIGURE 6. Number of hydrogen refueling stations (Hydrogen Council 2017.)

The current problem is the refueling stations. As shown in figure 6 there are only 990 refueling stations worldwide but a good increase compared to 263 in 2016. (Hydrogen Council 2017.) Just 15 hydrogen refueling stations can equal the output of 900 BEV fast chargers. The hydrogen council's goal is to have at least 3000 refueling stations by the year 2025 which can provide enough for 2,000,000 FCEVs and could increase depending on the number of FCEVs on the road. This is the breakthrough number because after this the hydrogen infrastructure should be self-supporting. (Staffell et al 2018.) FCEVs are the best option for a zero-carbon emission bus and truck. The fuel cell bus is 40 decibels lower at 60dB compared to a diesel bus which is at 100dB with water being its only by-product which in turn would minimize the air and noise pollution in urban areas. Base to base operation also means that they would not need as many refueling stations to be built. (Perry 2018.)

9 DISTRIBUTION OF HYDROGEN

Hydrogen in the present time and age is easy to transport and can be transported in many different ways. Currently hydrogen is being transported in three most common ways. It is either through compressed gas cylinders or cryogenic liquid tankers, pipelines, or by blending it with natural gas. (Hydrogen Europe 2017.)

9.1 Compressed gas containers and cryogenic liquid tankers

Hydrogen gas that is small or medium amounts may be moved in compressed gas containers using Lorries. Larger amounts can also be transported but by using a compressed hydrogen tube trailer. Compressed hydrogen tube trailer, they are semi-trailers which has 10-36 high-pressure tanks which varies anywhere from 20 – 38 feet long. There are 3 different types of tube trailers. The first is a modular tube trailer and they are designed to the international standards. It has 8 tubes which are either 20 feet tubes which is for the 3 metric ton module or 40 feet tubes which is for the 6 metric ton module. (Gas Plants Manufacturer 2016.)

The second is an intermediate tube trailer, they are assembled in groups of 5 with lengths of either 19 feet or 39 feet. The third is a superjumbo tube trailer, these are prepared with aluminium diamond plate decks that are used because they prevent slipping and reduce weight. Aluminium components keep brakes cool because of the heat dissipation. The tube loading arrangement allows easy access to all the surfaces of all the tubes. (Gas Plants Manufacturer 2016.)

Tube trailers all need to have special storage areas. The area should be put on a paved, level area. There should not be direct sunlight because of the potential over-pressurization. This storage space should be open on all the sides because ventilation is needed, the roof also needs to have a minimum height of 14 feet. It should be dry and not have any explosives, corrosives, and flammable materials. The problem with these trailers is that they usually have a high net weight so there can be restrictions due to mass related restrictions. (Gas Plants Manufacturer 2016.)

Hydrogen can also be moved around as a liquid inside a cryogenic liquid hydrogen trailer. Liquid hydrogen has a higher density than gaseous hydrogen. Liquid hydrogen is more cost-efficient to transport at larger distances. Liquid hydrogen trailers can transport hydrogen for distances of around 4,000 km.

The reasoning is that the hydrogen heats up over time and pressure would start to rise. This type of trailer can be moved by Lorries, rail, or ships. (Hydrogen Europe 2017.)

9.2 Hydrogen pipeline

A pipeline would be an ideal way to move hydrogen that is made centrally. Pipelines are expensive to build but it is worth it only if there is a large volume of hydrogen being transported. Another possibility would be building local networks and could eventually be joint to make a larger network. Right now there are more than 4,500 km of hydrogen pipelines worldwide. The majority of it in the USA, Belgium, and Germany comes next. The reason why it is hard for hydrogen to be moved in steel pipelines is the fact that hydrogen makes streel structures brittle, hydrogen penetrates the steel and changes its properties. (Industrial Metallurgists) For pure hydrogen the current steel pipelines would need to be replaced with non-corrosive and non-permeable material such as polyethylene and fiber-reinforced polymer pipes. (Fuel Cells and Hydrogen 2019.)

9.2.1 United States of America

The majority of the hydrogen used in the U.S.A is produced near or at where the hydrogen is being used. They are made usually at a large industrial site. The fueling stations needed for fuel cell electric cars still need to be established. The place with fueling stations are only in California for the time being. In the U.S.A there are only about 2575 Km of the pipeline but only in Illinois, California, and Gulf Coast. They are located near chemical plants and large petroleum refineries. (US Department of Energy)

9.2.2 The rest of the world

In February of 2020 Economics minister, Peter Altmaier released and circulated the first draft for the national hydrogen strategy for Germany. It stated that by the year 2030, 20% of Germany's hydrogen will be green hydrogen. It also stated a 5,900 km hydrogen pipeline will be used for pure hydrogen. 90% of the pipeline and storage tanks currently already exists. (Schulz 2020.) In France they would start with 6% hydrogen into the natural gas pipelines and slowly increase it to 10% in 2030 and 20% beyond that. (Morgan 2019.)

Pipelines for hydrogen are occasionally mentioned and talked about in Asian countries and Australia there is no concrete plan or draft to build a pipeline for hydrogen.

9.3 Blending with natural gas

Using current natural gas steel pipelines, the hydrogen can be mixed with natural gas for it to be transported and it would be separated down the line. Doing this as a hydrogen transport would make building the extremely expensive hydrogen pipeline not needed. Up until the late 20th-century natural gas pipelines were actually designed and build for hydrogen-rich gas but it is not yet tested over long distances. In the USA you could introduce 15% hydrogen without a large negative impact. While in Germany it could only handle up to 10% of hydrogen in its pipelines. Some pipelines would need to be slightly modified with some extra monitoring (Fuel Cells and Hydrogen 2019.)

10 ROLE OF HYDROGEN TECHNOLOGIES FOR THE FUTURE

Hydrogen is good at storing energy in either gas or liquid form. Excess energy produced from fossil fuels, renewable energy can be used to produce hydrogen which can be used as fuel later. Hydrogen unlike other energy storage types will not lose energy over time and would also not need to be recharged from time to time. While most internal combustion engines and power plants have an energy efficiency of below 35% a stationary fuel cell can have an efficiency level of over 80% (Connecticut Hydrogen-Fuel cell Coalition 2016.)

Hydrogen when used in a fuel cell only has water and heat as its by-products. Fuel cells in general are more efficient and have less of an impact on the environment when compared to conventional fossil-fuelled energy generation technologies. For example, an electric generation facility in New England produces 113.4 grams of nitrogen oxides per megawatt-hour compared to 4.5 grams per megawatt-hour when using natural gas in a fuel cell. (Connecticut Hydrogen-Fuel cell Coalition 2016.) Having hydrogen as an energy source reduces the dependence of a country to another country unlike fossil fuels making them more economically independent. Hydrogen can be produced locally, either onsite where it is used or in an area and distributed. (Hydrogen Energy Center)

11 HYDROGEN MARKET IN THE FUTURE

By the year 2050, hydrogen and equipment should equal 2.5 trillion dollars per year, 6 billion tonnes of CO_2, 30 million jobs created, and 18% of the global market energy demand. (Hydrogen council 2017.) Hydrogen power plants could be cost competitive to a fossil fuel power plant by the year 2050 if the government increases carbon pollution costs to 55 dollars per ton. (Mathis & Rathi 2020.) Currently the main inhibitor is the lack of investments, 280 billion dollars' worth of investment is needed for the year 2030. 60% of that money is needed to increase the production, storage, and distribution. Fossil fuels has had 100 years of investment and hydrogen has 30 years to make the same strides. (Vella 2019.) The international renewable energy agency's renewable energy roadmap says that 8% of electricity production in the year 2050 would be for the production of hydrogen, 66% of all hydrogen would be green hydrogen. Electrolyzers would need to have an increase of 35% per year for 30 years for this to happen. Green hydrogen costs could lower to around 3 dollars per kilogram in the next 10 years and it could halve again by 2040 – 2050. Even with this decrease the price of carbon is still needed to make it cost competitive. (Gielen & Taibi 2019.)

12 CONCLUSION

Global warming is becoming worse year after year. The UN warned us that we have 12 years to limit climate change before it becomes irreversible. We need to keep the temperature below 1.5°C. Even a half-degree increase over 1.5°C will have increasingly devastating effects on the natural disasters taking place worldwide (Watts 2018.) Due to how bad global warming was getting, The European Union set a list of goals for the year 2030 and 2050 with a roadmap showing how to get there. The roadmap was released and agreed to with hopes that it will comply with the Paris agreement of keeping the temperature increase to between 1.5°C – 2°C compared to pre-industrial times. One of the major talking points of the Roadmap 2050 is Zero-carbon energy. Hydrogen is one of those zero-carbon energies because it only produces water and heat. Clean fuels along with renewables will work with the smart grids to produce constant and clean energy to everyone in the EU. The roadmap has a goal to be completely carbon neutral by the year 2050.

Hydrogen research when compared to fossil fuels (which has been the most important fuel for a while now) is not as mature because funding and research times would be larger in favour of fossil fuel logically. This means that hydrogen production can only become more efficient in the future and with that efficiency the price of the element will definitely fall. Hydrogen has a lot of uses but the most important one will be in electricity production. The gas in a fuel cell can reach efficiencies of almost 85% compared to a power plant or internal combustion engine's efficiency of below 35%. Many different types of fuel cells can be used in many different situations. If that is not enough synthetic fuels can also be used to replace fossil fuels.

With prices of electric vehicles going down more people will buy EVs. An increase in production means that prices will drop even more. EVs will become competitive to internal combustion engine vehicles and Fuel cell electric vehicles will become competitive with EVs. One major hindrance to the success of hydrogen as a future source of energy would be the transportation of the gas. Since hydrogen molecules are small and penetrates through steel and change the properties of it, normal pipelines cannot be used to transport the gas. Since pipelines are one of the most efficient ways to transport the gas, there will be a need to upgrade the pipelines or build a completely new one to accommodate this. This pipeline will need a large initial capital and to collect that will be a problem. Cutting out fossil fuels and introducing hydrogen as a main source of energy also gives you the chance to not rely on other countries for fuel and to make the country more independent. Having a source of fuel which comes from your own country will stop the oil price wars to affect an economy (Farmer 2020)

As a result of the research done on this paper, the answer is yes. Hydrogen will be a major source for energy in the future and it will replace the majority of where fossil fuels are currently being used in. The when is a bit harder to answer, hydrogen production and usage should be making strides by the year 2030 and it should be one of the major fuels being used in Europe and the USA if not worldwide.

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