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Hydrogen Energy

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Preface

This report is intended for the intensive project "Engineering Visions" Summer School in Enschede/Netherlands. The topic of this group is the renewable energy system focused in the possibilities of hydrogen.

For two weeks the whole group collected ideas and information about renewable energy, energy production and hydrogen. The result is this report, a poster and a presentation.

Everyone in the group completed a personality test to know themselves and each other better. This personality test is called DISC and can be find in the appendix A.

Abstract

The report aims to highlight and clarify the problems with today's energy sources and to provide renewable solution in the form of hydrogen.

The challenge of energy storage and intelligent delivery systems can be solved by using hydrogen. Hydrogen can be used to store overproduction of renewable energy and guarantee security of supply. Today, the technology developed in the automotive industry can be used both in industry and in households. The forecast for the future shows that the use of hydrogen is inevitable.

In summary, it can be said that hydrogen is an energy carrier that will become even more important in the future. However, hydrogen is only a supplement to the existing system and not a universal solution.

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1 Introduction

1.1 Background

More people have begun to realize that fossil fuels belong to yesterday's thinking. Its impact on the environment is nothing but negative. With today's rate of development, humanity will have to deal with natural disasters in their everyday lives in the future. Today's carbon dioxide emissions are not sustainable and therefore need to be replaced with a greener alternative. Hydrogen energy is a suitable one. Hydrogen is the simplest element in the universe with only one proton and one electron. It is also the most abundant element in the universe and the tenth most abundant element in earth. The element will always be available even when fossil fuels are exhausted. What makes this source of energy stand out from the rest is that it is generated by water and releases clean water when it is burned. That is literally water usage as fuel and energy storage. It is like the French poet Jules Gabriel Verne once wrote:

- *"Water will be the coal of the future. The energy of tomorrow will be water that has been decomposed by electricity. The decomposed elements of water, hydrogen and oxygen, will secure the Earth's energy supply for an indefinite period of time."*

Hydrogen is one of the fuels, which can be used in fuel cells. On the earth exists only in the higher layers of the atmosphere. The access to these resources is straitened. Thus, the only method of obtaining H_2 in a molecular form is production. The most common method applied in production is electrolysis. Electrolysis is a process, in which the external electric current causes in the electrodes the phenomena of reduction and oxidation. To carry out the process water is used.

1.1 Purpose

The purpose of the report is to highlight and clarify the problems with today's energy sources and to offer a cleaner solution. Most often, it is not enough with only a good idea, there is a necessity of society's support and will as well. Without the will of the people in the society, the idea will not find surface. That is why the purpose of this initiative is important because it brings forth the will to change an unsustainable world.

1.2 Scope

The report will only focus on hydrogen energy, its properties and storage, both today and tomorrow. Comparisons between today's different energy sources and hydrogen energy will also be considered in the report. The largest focus will be comparisons with today's existing gas fuel system.

2 Hydrogen Today & Tomorrow

2.1 Current state of Hydrogen Usage

2.1.1 Hydrogen

Hydrogen, or also Dihydrogen, has an atomic weight between 1.00784 and 1.00811 moles, making it the lightest element. The chemical symbol is “H” but in nature it is only occurred as “H_2” like in water (“H_2O”). Hydrogen has a tremendous energy density of 140 [kJ/g], which is about four times higher than the density of methane for instance (Lu et all, p.7581, 2014), whereby, theoretical, it should be the most important source of electrical energy. However, it is hard to separate hydrogen. There are two different methods for extracting hydrogen out of different chemical compounds.
On the one hand the so-called steam methane reforming technic can be used to produce hydrogen. Due to the high amount of fossil fluid used during this process and the imitation of CO_2, this process will not be explained further in this paper. The second possibility for recovering hydrogen is called electrolyses which will use water as the resource and electrical energy. With this procedure the outcome will be Hydrogen (H_2) and Oxygen (O_2). This procedure will be explained in the following chapter. (Lu, et al., 2014)

2.1.2 Fuel Cell

Fuel cells were invented in 1839 by Sir William Robert Grove. Put simply, it takes hydrogen and oxygen and puts out electrical energy and water. As it can be seen in Figure 1

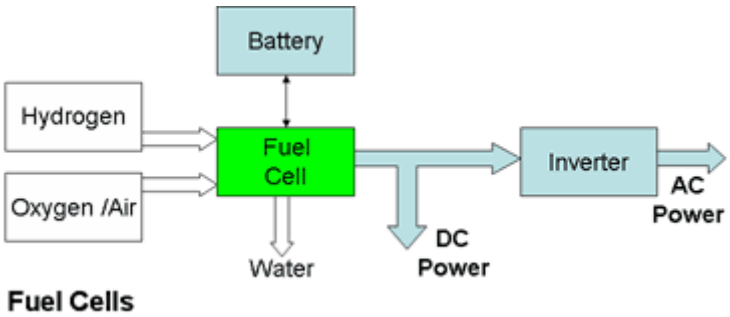

Figure 1: Principle of the fuel cell (Woodbank Communications Ltd, u.d.)

There are several different types of fuel cell, but the most common is the Proton Membrane Exchange (PEM) fuel cell. The chemical reaction is: **$2\ H_2 + O_2 \Rightarrow 2\ H_2O$**

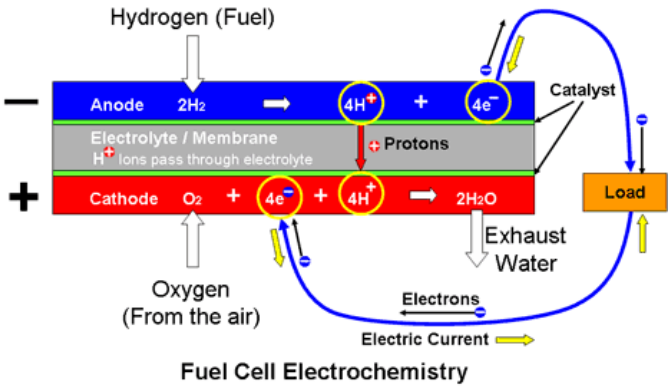

Figure 2: Chemical reaction within a fuel cell (Woodbank Communications Ltd, u.d.)

As Figure 2 shows, the hydrogen ions (protons) migrate through the membrane to the cathode, where the electrons will go the opposite direction. In this way, chemical energy will be transformed into water and electrical energy. (mpoweruk.com)
Due to expensive materials the membrane is made of, fuel cells are very expensive. But recent researches found other materials which are far cheaper. In the next future prices for fuel cells will fall. (Chenitz, et al. 2017)

2.1.3 Bacteria

There are many kinds of bacteria which are known to be able to produce hydrogen. The advantages of these bacteria are:

- The bacteria do not need light and can be stored everywhere
- During the production of hydrogen, bacteria even consume organic waste out of wastewater that would otherwise be disposed of in landfill
- Bacteria produce a huge amount of hydrogen (1.12–2.59 mole-H_2/mole-hexose) (Noike et all, p. 1367, 2002)

But the big disadvantage of the production of hydrogen with bacteria now is the unstableness of the process.
Figure 3 shows the current density of bacteria used with MFC. It was shown by Zhang et al, that bacteria coated with polypyrrole have a much higher current density as such without wrapping. (Zhang et al, p. 10652-10654, 2017)

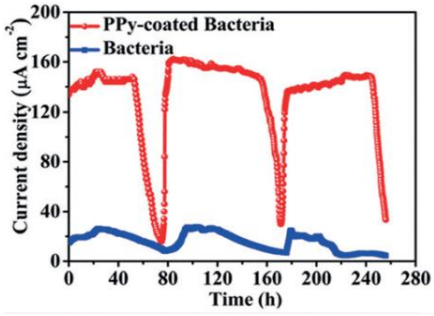

Figure 3: Current density of Bacteria (Zhang et al, p. 10654, 2017)

The general process can be seen in Figure 4. Organic waste can be used as fuel and the bacteria separate the hydrogen, which can be used to generate electrical energy, just like a general fuel cell.

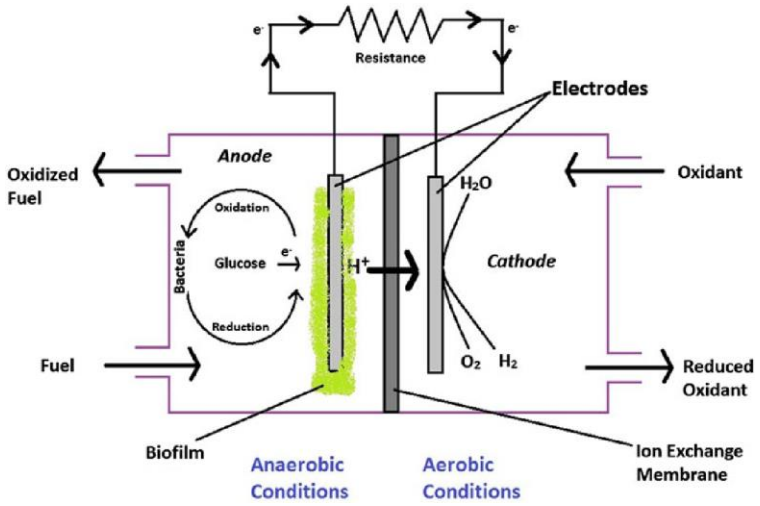

Figure 4: Microbial Fuell Cell (MFC) (Deeksha, p.121, 2013)

One can say the MFC can be used to gather hydrogen, but it would be better used as a power plant. In the end maybe, humanity will need both systems. The MFC as a regular power plant, maybe even in cars, and electrolyse systems to use unneeded electrical energy.

2.1.4 Hydrogen as an Energy Storage

Due to the high energy density hydrogen has great potential to be used within an energy storage system. With procedures like the electrolyse, the photocatalytic or photoelectrochemical water splitting method (explained in Chapter 1) everyday it is getting easier to gather hydrogen.
Hydrogen cannot be used as a primary energy source. First it has to be separated by chemical compounds like water which means that electrical or chemical energy will be needed. As mentioned before, the usage of chemical energy (using fossil fuel in chapter 1) cannot lead to a world with only green and renewable energy sources. So, the only option to use hydrogen as energy storage will be to use electrical procedures. (Office for Energy Efficiency & renewable Energy, 2018)

2.1.5 Storage of Hydrogen

Maybe the most important question in connection with hydrogen as a source for electrical energy is the question of how to store the hydrogen. Due to its low

weight it is much lighter than the air on the earth. So, hydrogen will just fly away if not stored correctly. Also, the fuel tank should be under high pressure of around 400 Bar, so the hydrogen can be stored as a fluid with lower reactivity (energy.gov). As seen in Figure 5 the pressure will not affect the gravimetric density of hydrogen. So, the energy density of hydrogen is only related to its weight.

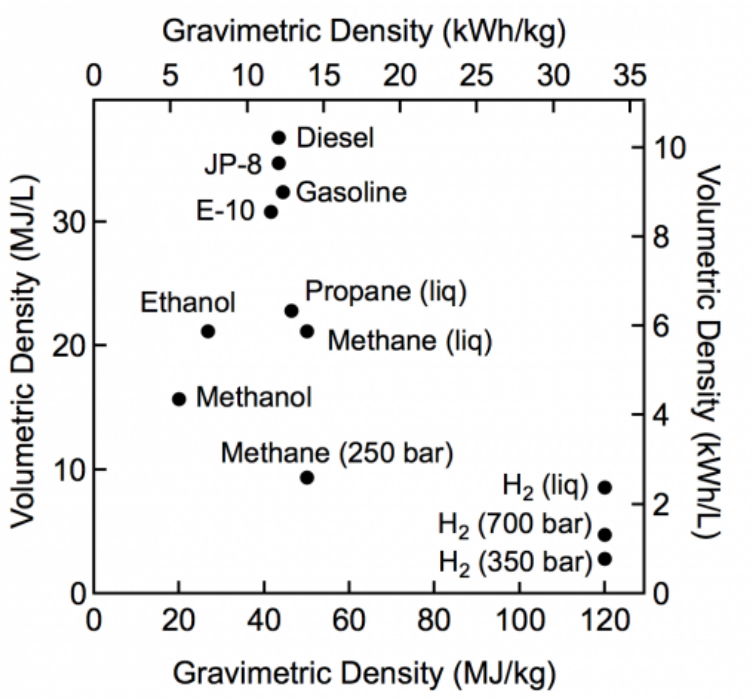

Figure 5: Energy density

2.1.6 Hydrogen System

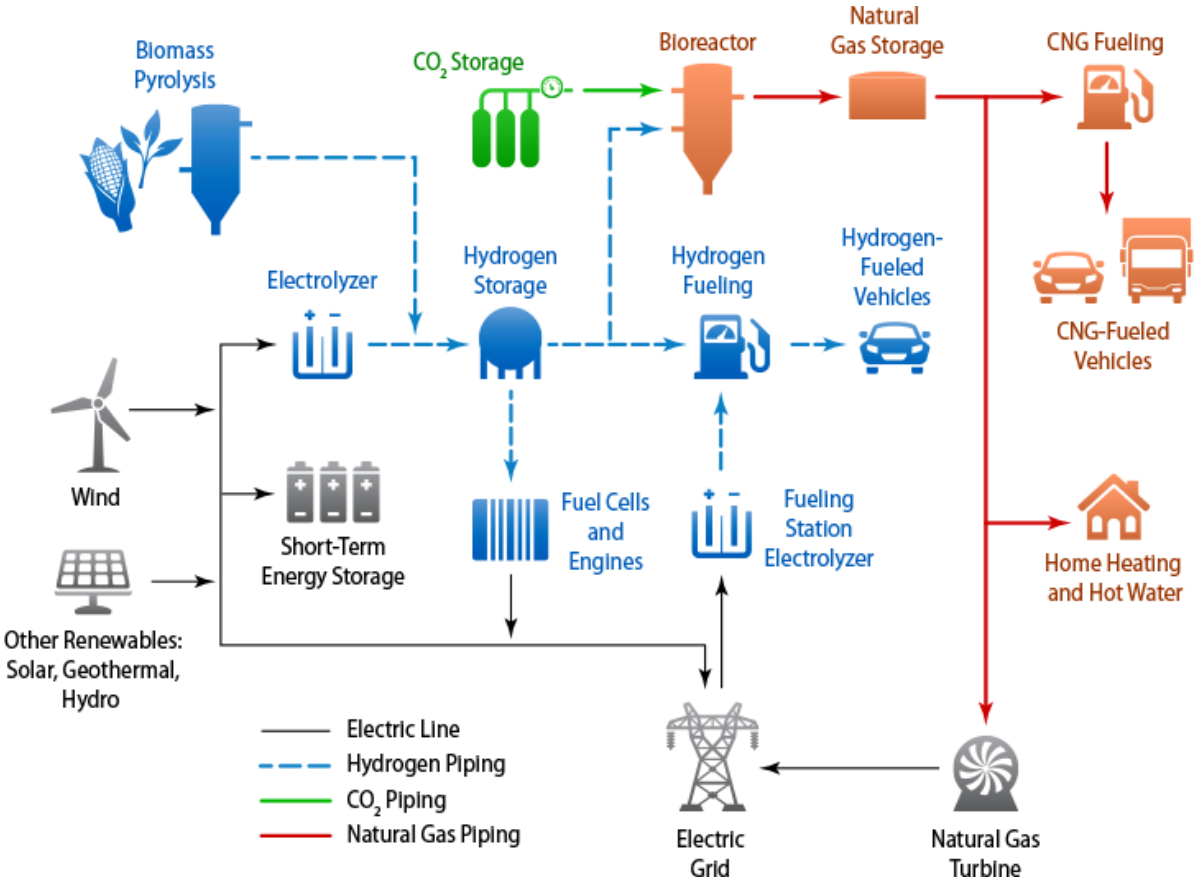

Figure 6: diagram with different solution to use hydrogen (NREL, 2011)

A possible solution today may look like Figure 6. The diagram shows different solutions for storing and using energy. Different colours are used for the different energies. The red lines could also be replaced by blue lines, then hydrogen can be used directly for vehicles and households. If hydrogen is produced, as in this scheme, only from renewable energy sources, the entire system is CO_2-neutral (NREL, 2011).

2.1.7 Energy production in the Netherlands and Germany

The following text shows the current situation of energy production in the Netherlands and Germany. This information can be used to estimate the possibilities of renewable energy and the overproduction of electricity.

The Netherlands

Almost 40 percent of the energy in the Netherlands comes from natural gas. And together with petroleum and coal, the country account for more than 90 percent of the energy consumption. The remaining 10 percent is generated from renewable energy, nuclear energy, waste and electricity from abroad. Therefore, Natural gas, petroleum and coal are still by far the most important energy sources.
The new government wants to save energy and insists on living and changing to new energy sources. This theory would work if the Dutch people will cooperate, but natural gas consumption is barely reduced. In 2016 the use of natural gasses even went up with 2 percent to 3131 petajoule. Especially the natural gas increased with 80 petajoule. More alarming, regaining the natural gas decreased with 120 petajoule. The petroleum consumption increased with 20 petajoule and the use of coal decreased with 30 petajoule. (cbs, 2017)

The ECN (energy research centre of the Netherlands), CBS (central Statistical Office), Planbureau Voor de Leefomgeving (planning agency for the living environment) and Rijksdienst voor Ondernemend Nederland (the government service for entrepreneurial of the Netherlands) predict that the share of renewable energy doubles between 2016 and 2020. The share of renewable energy and the proposed policy is expected to advance to 12.4 percent in. This expectation is based on information about projects with attributed SDE (Stimulation Sustainable Energy Production) subsidy that are still invested in the project pipeline. It increases in the four years of this expectation more than in the sixteen years before. In the case of established policy, the share of renewable energy in 2020 has increased at 11.7 percent. The expected consumption of renewable energy in the proposed policies in 2020 around 248 petajoules, of which more than half of it, 149 petajoules, is of biomass consumption. The expectation in this NEV is almost the same as last year's, which came out on one share renewable energy of 12.5 percent and a consumption of renewable energy of 253 petajoules. (ECN, 2006)

The Netherlands discovered huge natural gas resources in the 1950s and hold today more than 25% of all gas reserves in the EU. So, the energy production is dominated by gas and the renewable energies represent only 9%. Therefore 90-95% of the household in the Netherlands use natural gas for heating or cooking.

In the last years the gas extraction has caused some earth tremors and damaged several buildings. Moreover, experts estimate that the natural gas in the Netherlands run out in 30 years (Figure 7). Consequently, the Netherlands must change their energy system. The country is currently planning several offshore wind farms and is approaching the Europe 2020 target of increasing the share of energy from renewable energies to 14%. However, The Netherlands are still furthest away from this goal in comparison with the other EU countries. (eurostat, 2016)

Hydrogen could be a solution for the Netherlands, because the country has already a good pipeline system for natural gas and this system can be used for hydrogen.

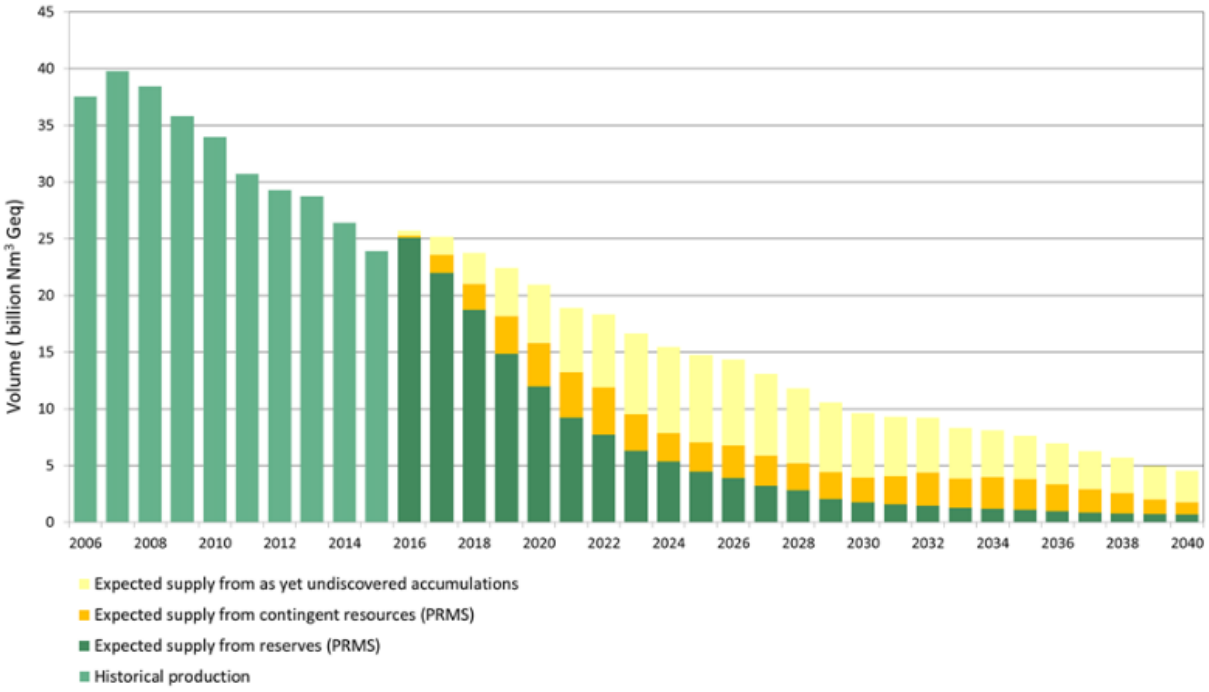

Figure 7:Natural gas resources (nlog, 2018)

Pipeline System in the Netherland

The current pipelines in the Netherlands are built during the '60. Beneath the Netherlands lies a network of thousand kilometres of pipelines for natural gas as *Figure 8* shows. The natural gas infrastructures are mostly intact and can be used for different purposes.

Figure 8: Structural network of Pipelines of the Netherlands

Yearly 370 million ton of natural gas is transported in the Netherlands. But only 35% of this amount is transported via Pipelines. In general, Holland has more than 500.000 Kilometres of pipelines. 257.000 Kilometres are used for electricity, 124.000 kilometres for gas, 115.000 kilometres for water and 18.000km for chemicals for the industry. 15.000 kilometres of high-pressured pipelines for long distance transport of gasses and 5.000 kilometres for long distance transport of petroleum, petroleum products and other chemicals. The bigger pipelines are used for interregional transport. (ECN, 2006)

In 2005, the Netherlands had more than 23 leakages. Hydrogen has a higher chance to have leakages.

Germany

Germany produces 33% renewable energy, so the situation is very different from the Netherlands. The renewable energies have a large capacity, but their output varies over a day and year. Therefore, these sources cannot guarantee a constant supply. Nowadays, wind power plants sometimes must be shut down when there is a surplus of electricity. Coal-fired power plants cannot be regulated well because Germany are too inertial.
Germany has no suitable storage facilities and therefore exports the overproduction of electricity to neighbouring countries. Sometimes the country even must pay for the export of electricity because there is no demand. In 2017 Germany exported with deduction of import 52 TWh of electricity. Figure 9 shows the overproduction of electricity during the years. This overproduction can be used to produce hydrogen and store it. Therefore, the wind power plants no longer need to be shut off and coal-fired power plants can be replaced.

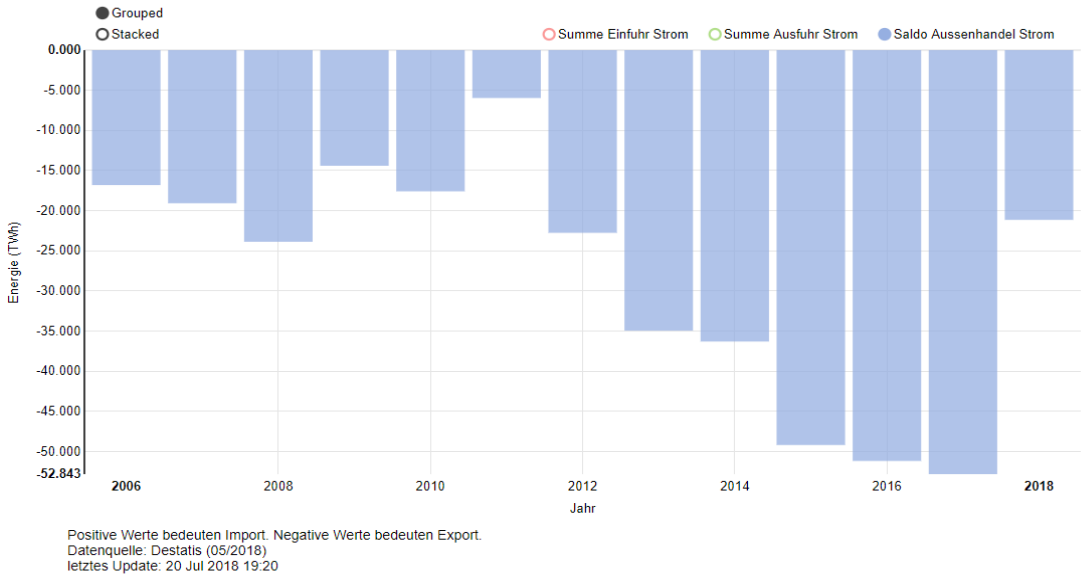

Figure 9: external trade in electricity (Destatis, 2018)

When the overproduction of electricity in Germany is converted into hydrogen with an efficiency of 70%, a quantity of 21 008 tonnes of hydrogen could be disfigured. Frauenhofer IWES indicate efficiency ranges of between 34 and 44 % for the hydrogen production, storage and re-generation chain. So, after the transformation back to electricity the overproduction amounts maximum 440 GWh. If this hydrogen is used for four-person households (3500 kWh per month), 1666 households could be supplied with energy for 10 years.

2.1.8 Discussion

The Netherlands have not enough renewable energy to produce clean hydrogen. But the country has a large system of pipeline, so the usage of the existing system and change it in hydrogen pipelines. The CO_2 emission depend on the system to produce the hydrogen. Maybe in the future there is a possibility to produce hydrogen with less or none energy. In that case the Netherlands can produce clean hydrogen.

There is a huge overproduction of electricity in Germany, but there is no precise indication of how much of it comes from renewable energy sources. Therefore, a prediction is difficult. Nevertheless, renewable energies will increase, and hydrogen is a good storage medium for these energy sources. In conclusion, it can be said that hydrogen can already be produced today from the overproduction of renewable energy sources.

2.2 Vision for tomorrow state of hydrogen usage

2.2.1 The Vision of the Future

The history shows that predictions of the future are not evident. The breakthroughs such as the disruptive invention of printing or internet proved: The world is changeable. The constant development of technology and growth of the population affect not only the live conditions, but also the demand and new needs.

The following Figure 10 shows the predictions of growth of total population in the world. In the next thirty years, the amount will increase rapidly. The year 2050 will bring an amount of 11.2 billion (growth of almost 50% in comparison to present year). Thus, the demand for the energy, space, food etc. will increase with the exponential trend. Due to lack of space in the world and limited resources (e.g. coal, oil), a massive change is required. The world in the future must be sourced by renewable energy only. The heat is forced by hydrogen which is an up-and-coming solution. The inevitable application of hydrogen as the main source of heating the houses will cause the development in the whole energy industry as

well as in the infrastructure of the homes. Considering the unpredictability of the world changes, both the transportation and the storage of hydrogen can be not too realistic visions.

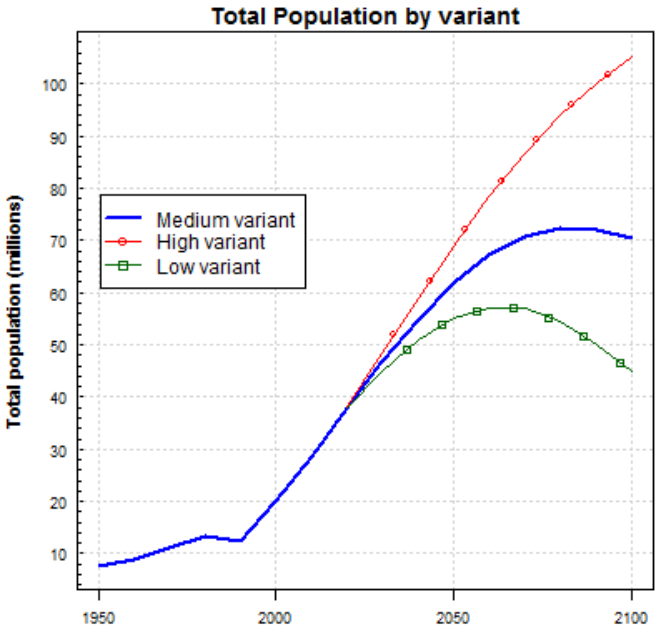

Figure 10: Prediction of total population (UNITED NATIONS, 2017)

2.2.2 Transportation

Transportation of the hydrogen plays a significant role in the system, where it is a main powering source. The delivery from the place of production H_2 to the point of end-use requires the developed technology, expanded infrastructure and well-adjusted means of transport. Nowadays there is a developed technology, which exists mainly in the automotive industry. Besides that, the infrastructure and transport, which constantly increase are not well prepared to face the problem of creating an energy system, where hydrogen is the main source. Generally, infrastructure consists of the pipelines, trucks, storage facilities and compressors. All the mentioned parts work collectively and create a system for hydrogen transportation and storage. The transportation of large amounts of hydrogen requires pressurized H_2, which is in a gas or liquid state. The lightweight of H_2 allows to diminish the costs of transportation and use not only a conventional means of transport in order to conveyance. These days hydrogen is transported mainly in the pipelines and tanker trucks. Nonetheless, in step with the growth of hydrogen application as an energy source all over the world, conventional means of transport could be not sufficiently efficient to transport it in a safe and quick way.

Rapidly growing demand for the H_2 and settle of new areas, where energy is required affects the broader system of transportation. Thereupon in the future, there will be a huge demand for fast and safe hydrogen transport system. Current development in the industry is promising and tends toward improvements in the speed as well as the safety of transport. The most probable predictions assume the world with autonomous means of cargo transport only. Considering the expectations for the future, which are not easy to satisfy, some of the currently existing types of cargo will be certainly replaced. The vision consists of five main ways of delivering the hydrogen to target point: Highly developed pipelines, Autonomous tank tracks, Hyperloop, Autonomous cargo drones and Space Rockets. All the mentioned means will exist and cooperate simultaneously in a very safe and ordered way. There will be a central control station, which will prevent the accidents, time inaccuracies and wrong targeting.

Highly Developed Pipelines

This is probably the fundamental way of transporting the hydrogen. The application of that will appear in the general transport system as well as in the smaller systems in houses and industry. This way of H_2 conveyance will be much broader, than gas pipelines existing currently. Due to use of a special environment condition gas will flow faster and pipelines will be more reliable

Autonomous Tank Trucks

The trucks forced by hydrogen engines will be not driven by human anymore. This mode of transportation will carry the hydrogen to indicated places. It will enable people to order a hydrogen to factories, hydrogen stations (today's petrol station) and central hydrogen storage facilities in estates.

Hyperloop

The commonly used trains and aircraft will be replaced by Hyperloop. This is a proposed mode of passenger and freight transportation, which is as fast as an Aero plane and cheap as traditional (road) system. Hyperloop will be going in a special tube, in which the pressure is significantly decreased (up to 1% of atmospheric pressure), which will cause a diminution of air resistance. The mean speed is the speed of sound.

Autonomous Cargo Drones

Due to the replacement of Aeroplanes by Hyperloop, drones will be an "optional" hydrogen delivering way for homes and an "accidental" option of hydrogen delivering for cars. The flexibility in hydrogen transportation can play an important role, in order to avoid the intervals in heat productions. Moreover, in the world, in which most of cars are driven by hydrogen engines, the fast and easy to order drones, will create a safe source of H_2.

Space Rockets

The possibilities of hydrogen production, storage and maybe even end-user should be not limited to earth only. For now, the only one planet in the space, in which life is “possible” and can be either a production place or target place is Mars. To transport hydrogen between two planets, the space rockets are appropriate and from the technical point of view, it is manageable convey H_2 this way.

2.2.3 Energy storage of the future

In the Future the ability to store hydrogen will become much easier and cheaper. Due to achievements in the fields of sensors, materials and robotics, storage systems for hydrogen will become more and more reliable. It will be possible to create small robots that fly through the stores and close leaks from inside. Sensors in the surface of the stores will be able to detect even the smallest pressure drops to prevent leaks before that happens.

The storage system itself could be near every neighbourhood or in every household. Also, it will be possible to build huge tanks or use the existing ones which are used for conventional gas like natural or methane gas. The only problem with the existing storage system will be to implement a leak-preventing-system like mentioned before.

But apart from the storage itself it is important to improve the existing pipe system for a better compatibility with hydrogen and ensuring the safety of the whole system.

3 Conclusion

Hydrogen has many uses both today and in the future. Hydrogen can be used to store electrical energy, power transportation, produce chemicals or heat buildings. However, the efficiency for the hydrogen production, storage and re-generation chain is not so good yet. Research is intensively focused on improving the efficiency of the chain and is looking for different ways of producing hydrogen. Thus, in the future, hydrogen may be generated directly without the need for electrical energy.

Renewable energies and the demand for storage facilities are increasing in every country, whether with batteries or in hydrogen. Unfortunately, these energies do not cover the demand and therefore not all fossil power plants can be switched off yet. Germany's overproduction also covers only a small part of the demand. That is why renewable energies must be expanded even further.

There are already many ideas and projects for integrating hydrogen into the existing energy grid. For example, natural gas pipelines can be used to transport

hydrogen. In addition, the hydrogen filling stations are constantly being expanded.

In the future, the population will grow and so will the demand for energy. At the same time, the technology will also develop further. This will open completely new possibilities for energy production, storage and, of course, transport. Who knows, perhaps humans will soon be populating Mars.

In summary, it can be said that hydrogen is an energy carrier that will become even more important in the future. However, hydrogen is only a supplement to the existing system and not a universal solution.

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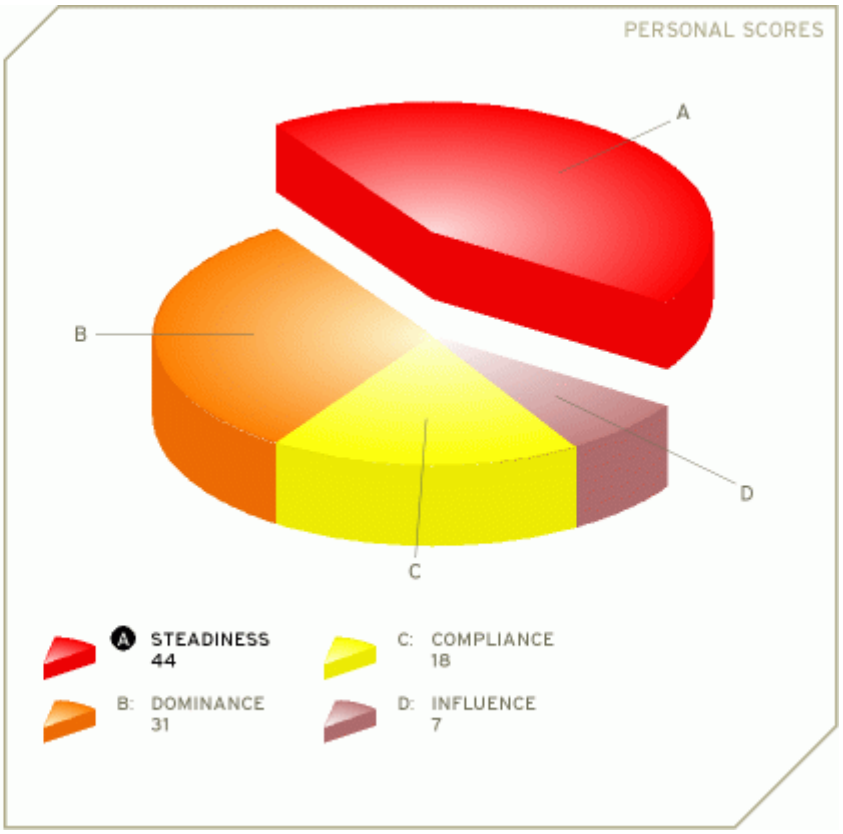
Appendix A: Disc Personality Tests

Petra

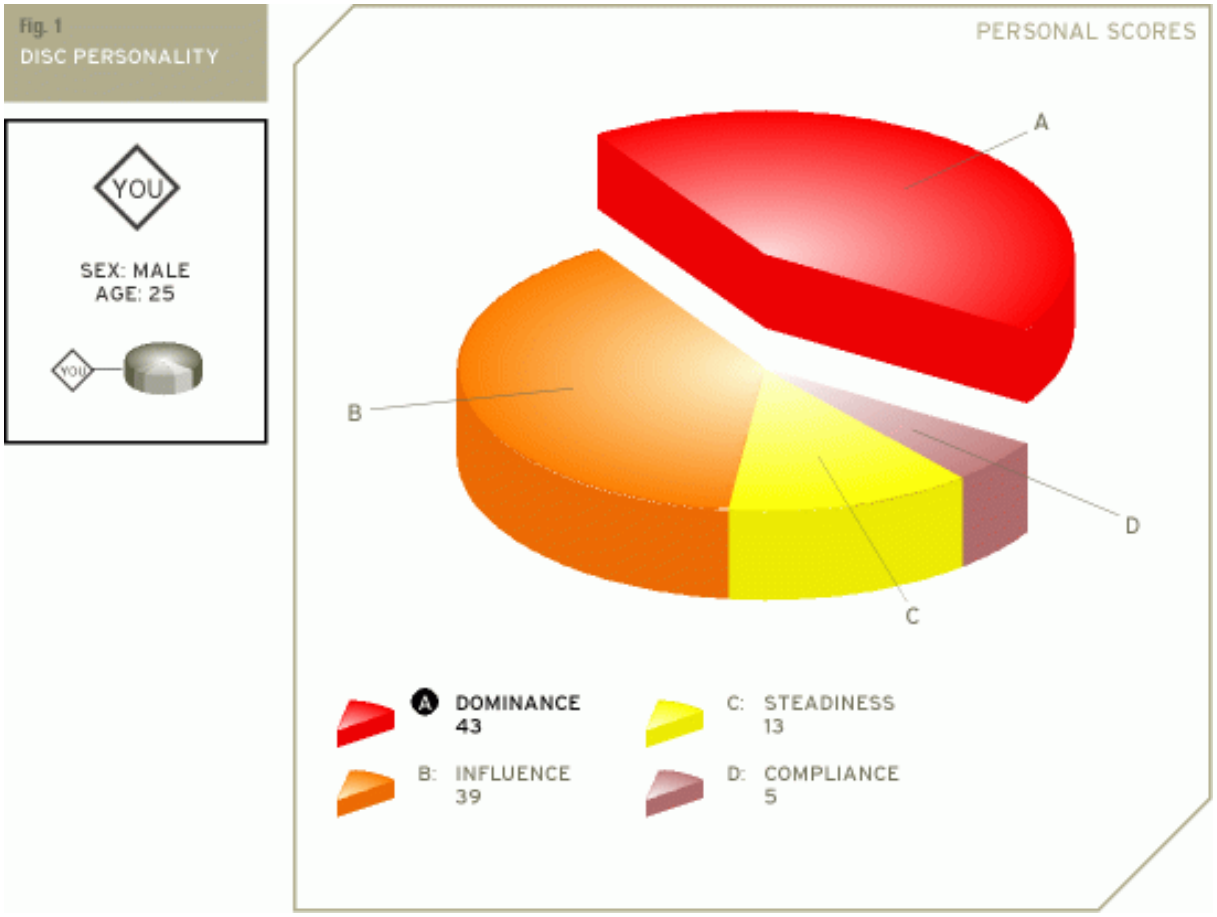
You are a clear thinker. You have an inner need to be objective and analytical. You like to pursue a definite course of action. You respond to logic rather than emotion.
You are likely to be particularly good at handling challenging technical assignments. You have a strong inner motivation to attain personal goals. You like to become 'the expert' in your chosen field.

Fig. 1
DISC PERSONALITY



Petrus

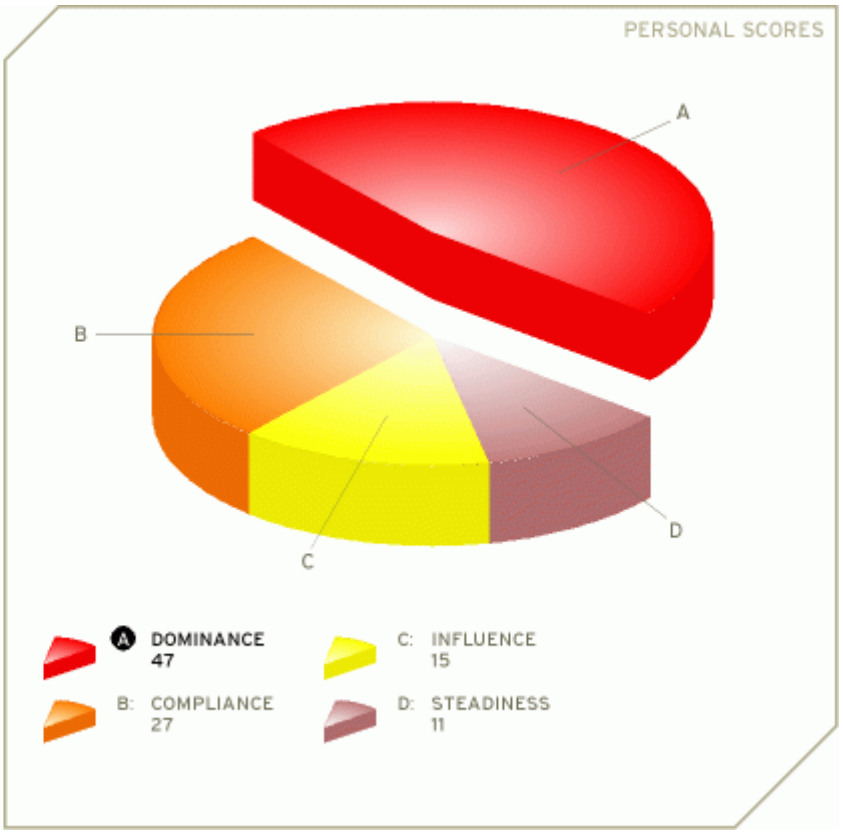
You have a strong inner motivation to influence people and circumstances. You thrive on competitive situations and challenging assignments. The stresses and pressures of everyday work and life are unlikely to reduce your effectiveness and enthusiasm.



Lukasz

You have a strong inner motivation to assertively create and implement new ideas. Share quote. You handle pressure well - you strive for excellence and expect others to do the same. You are innovative but tend to avoid risk taking.

Fig. 1
DISC PERSONALITY



David Haffner

You have a strong inner motivation to influence people and circumstances. You thrive on competitive situations and challenging assignments. The stresses and pressures of everyday work and life are unlikely to reduce your effectiveness and enthusiasm.

Fig. 1
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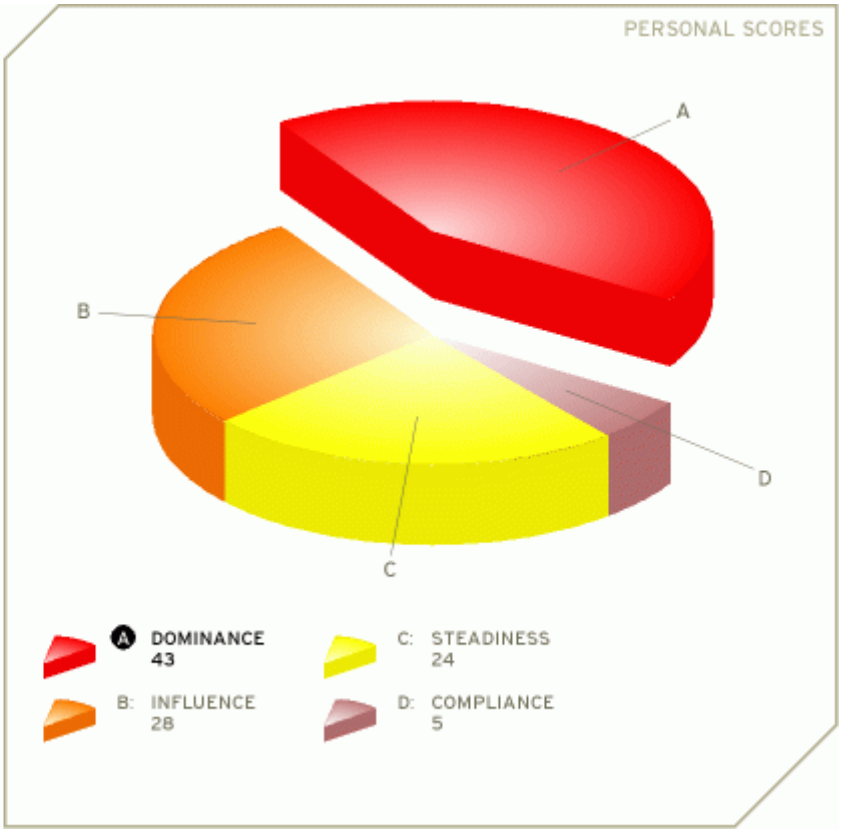

Marie-Claire Stalenburg

You are tenacious and determined to follow a course of action to achieve objectives. You are a clear thinker. You have an inner need to be objective and analytical. You like to pursue a definite course of action. You respond to logic rather than emotion. You are likely to be particularly good at handling challenging technical assignments.