GRADUATION THESIS

HYDROGEN ENERGY STORAGE IN THE URBAN ENVIRONMENT

‘What are the obstacles involved with the implementation of hydrogen storage facilities in the urban environment in the Netherlands?’

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I. Colophon

Title of the thesis: 'Hydrogen energy storage in the urban environment'
With the subtitle: 'What are the obstacles involved with the implementation of hydrogen storage facilities in the urban environment in the Netherlands?'
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II. Glossary

Within Table 1 there is a list of typical Dutch terms that are translated to English and in Table 2 a list of abbreviations and their explanation.

Table 1: Translation of terms

DUTCH	ENGLISH
Bestemmingsplan	Land-use Plan
Besluit Externe Veiligheid Inrichtingen (BEVI)	Public Safety Decree
Besluit Omgevingsrecht (BOR)	Environmental Licensing Decree
Bouwbesluit	Building Decree
Bouwverordening	Building Ordinance
Exploitatieplan	Development Plan
Omgevingsvergunning	Environmental Permit
Publicatiereeks Gevaarlijke Stoffen (PGS)	Publication Series Hazardous Substances
Vereniging van Nederlandse Gemeenten (VNG)	Association of Dutch Municipalities
Wet Algemene Bepalingen Omgevingsrecht (WABO)	Environmental Licensing Act
Welstandscommissie	Welfare Committee
Wet ruimtelijke ordening (Wro)	Spatial Planning Act
Woningwet	Housing Act

Table 2: Explanation of abbreviations

ABBREVIATION	EXPLANATION
CAES	Compressed Air Energy Storage
DSO	Distribution System Operator
ETS	Emission Trading System
EV	Electric Vehicle (may include Battery EV, Hybrid EV & Fuel Cell EV)
FC	Fuel Cell
FCEV	Fuel Cell Electric Vehicle
H2	Hydrogen, also hydrogen molecule [H_2]
HRS	Hydrogen Refueling Station
HSF	Hydrogen Storage Facility
NEN	Dutch Standardization Institute
NG	Natural Gas, Methane
NGO	Non-Governmental Organization
P2G	Power to Gas, sometimes put as PtG
P2H	Power to Hydrogen
RES	Renewable Energy Sources
SNG	Substitute Natural Gas / Synthetic Natural Gas
TSO	Transmission System Operator, for the electricity grid
TSO-G	Transmission System Operator, for the gas network

III. Summary

In order to cope with climate change, renewable energy sources are added to the energy grid to replace fossil fuels and minimize greenhouse gasses. Renewable Energy Sources (RES) have a weather dependent electricity supply that often doesn't meet with the electricity demand. This occurs on daily bases, as well as on seasonal bases between summer (surplus of supply by RES) and winter (shortage on supply of RES). In order to balance the grid solutions are needed. Energy storage is one of the options. There are many different mediums that can store energy. For seasonal storage, a medium is needed that has a low discharge time. Hydrogen is such a medium that offers the opportunity to balance the energy grid.

During the energy transition, changes are being made. Buildings are using less fossil fuel, becoming more energy efficient and are also producing electricity through solar panels. Electric vehicles are being charged at home and smart grids try to accommodate the daily supply and demand. When the Dutch remuneration legislation stops, the storage of own generated electricity will become interesting.

Research is needed to find out what the obstacles are for implementing hydrogen energy storage. Based on literature, interviews with experts and reference projects that involve elements of hydrogen energy storage, six obstacle groups were identified:

- Integration in the Energy Grid – Addition and/or combination with current grid
- Integration in the Built Environment – Addition and/or combination with land usage
- Law and Regulations – Safety, building decree, national laws
- Technique – Generation, storage, usage
- Economy – Financial driven, business case
- Public Acceptance – Image of hydrogen, willingness to adapt hydrogen

Based on a stakeholder analysis, three different profession groups are seen as experts, namely experts in the energy network, authority and counselors. Between these profession groups are differences which are identified with a Mendelow power-interest grid. Each profession group has a weight in relation to the power-interest level.

The Fuzzy Delphi Method is selected to find the prevailing opinion on this topic amongst experts. A survey with an online anonymous questionnaire was used to ask the experts if they recognize the given obstacle. There were three answering options: Yes, No, I don't know. The data from the questionnaire needed a fuzzification in order to eliminate interpretation differences of the given answer. Then the defuzzification to makes the data crisp. This data was adjusted with the individual weight of each profession group, based on the power-interest score. This is needed to incorporate the level of knowledge of the profession group. Therefor the more important and valuable opinion has a higher impact on the results.

The obstacle group 'public acceptance' is recognized by the experts as the largest. Second is 'economy'. These should be dealt with first to accommodate hydrogen energy storage.

It is recommended to create a strategic plan to eliminate the falsely perceived negative image of hydrogen. Two of the possible thing that should be addresses is the familiarization of hydrogen and the elaboration of the environmental benefits of hydrogen.

Dutch
Om het hoofd te bieden aan de klimaatverandering worden hernieuwbare energiebronnen aan het energienet toegevoegd om fossiele brandstoffen te vervangen en de uitstoot van broeikasgassen tot een minimum te beperken. Hernieuwbare Energie Bronnen (HEB's) hebben een weerafhankelijke elektriciteitsvoorziening die vaak niet voldoet aan de vraag naar elektriciteit. Dit gebeurt op dagelijkse basis, maar ook op seizoensbasis tussen zomer (overschot aan elektriciteit uit HEB’s) en winter (tekort aan elektriciteit uit HEB’s). Om het evenwicht tussen de netoplossingen te herstellen zijn er oplossingen nodig. Energieopslag is een van de opties. Er zijn veel verschillende soorten middelen die energie kunnen opslaan. Voor seizoensopslag is een medium nodig die weken en soms juist maanden ‘opgeladen’ blijft. Waterstof is zo’n medium en biedt de mogelijkheid om het energienet in evenwicht te brengen.

Tijdens de energietransitie worden er veranderingen doorgevoerd. Gebouwen gebruiken minder fossiele brandstoffen, worden energiezuiniger en produceren ook elektriciteit via zonnepanelen. Elektrische auto's worden thuis opgeladen en Smart Grids proberen aan de dagelijkse vraag en aanbod te voldoen. Wanneer de Nederlandse salderingswetgeving stopt, wordt de opslag van eigen opgewekte elektriciteit interessant.

Onderzoek is nodig om te achterhalen wat de obstakels zijn voor de implementatie van waterstofenergieopslag. Op basis van literatuur, interviews met deskundigen en referentieprojecten met elementen van waterstofenergieopslag, zijn zes obstakel-groepen geïdentificeerd:

- Integratie in het energienet - Toevoeging en/of combinatie met het huidige net
- Integratie in de gebouwde omgeving - Toevoeging en/of combinatie met landgebruik
- Wet- en regelgeving - Veiligheid, bouwbesluit, nationale wetten en voorschriften
- Techniek - Opwekking, opslag en gebruik
- Economie - Financiële gedrevenheid, business case
- Publieke acceptatie - Imago van waterstof, bereidheid om waterstof te gaan gebruiken

Op basis van een stakeholderanalyse worden drie verschillende professiegroepen als experts gezien, namelijk experts in het energienetwerk, autoriteit en adviseurs. Tussen deze beroepsgroepen zijn er verschillen die geïdentificeerd worden met een Mendelow power-interest matrix. Elke beroepsgroep heeft een waarde in verhouding tot het niveau van het machtsbelang.

De Fuzzy Delphi Methode is geselecteerd om de heersende mening over dit onderwerp onder deskundigen te vinden. Een enquête met een online anonieme vragenlijst werd gebruikt om de experts te vragen of ze het gegeven obstakel herkennen. Er waren drie antwoordmogelijkheden: Ja, nee, ik weet het niet. De gegevens uit de vragenlijst moesten worden gefuzzificeerd om interpretatieverschillen van het gegeven antwoord te elimineren. Vervolgens de defuzzificatie om de gegevens scherp te maken. Deze gegevens zijn aangepast met de individuele waarde van elke professiegroep, gebaseerd op de power-interest score. Dit is nodig om het kennisniveau van de beroepsgroep te integreren. Daarom heeft de belangrijkere en waardevollere mening een hogere impact op de resultaten.

De obstakelgroep 'publieke acceptatie' wordt door de experts als de grootste onderschreven. Ten tweede is er de 'economie'. Deze twee obstakelgroepen moeten als eerste worden aangepakt om met de opslag van waterstofenergie te kunnen starten.

Het wordt aanbevolen een strategisch plan op te stellen om het onterechte negatieve beeld van waterstof weg te nemen. Twee van de mogelijke oplossingen zijn het zich vertrouwd maken met waterstof en het nader toelichten van de milieuvoordelen van waterstof.

IV. Preface

I believe that the reason for my research topic was defined by three elements. First there was a moment during my childhood when my father challenged me and my sister to save energy in our house. The energy savings would be paid to us as an extra allowance. This triggered me and my sister to take action. We switched off the lights, lowered the temperature of the thermostat and annoyed our mother with this behavior. Every week I eagerly checked the energy meter to see how much we had saved. No matter how small the earnings were, this financial incentive worked for us as kids. It made clear to me what the impact is of changing our habits related to the energy consumption. And therefore, it made me more energy conscious.

Secondly, due to my interest in cars, I already heard about hydrogen as a new, interesting alternative and clean fuel for vehicles. So clean that it produces only clean water instead of polluting exhaust fumes.

Thirdly, during my study the building designs needed to be more durable and sustainable, and in the end even energy neutral. These three combined well during my search for a suitable research topic: 'How hydrogen could be used in the built environment to make it energy neutral', what in the end has evolved into the research topic 'Hydrogen Energy Storage in the Urban Environment'.

I would like to thank all the people that I interviewed for their time and effort, thank all the respondents who took part in the survey and in particular I would like to thank the people that helped me during the complete process:

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Enjoy reading,

Alex Jacobs

V. Contents

1 INTRODUCTION

In this introduction the research context and problem statement are explained. Followed by the research questions and the methodology. Lastly the information about the company that cooperated during this research.

1.1 Research context

During the Conference of Parties (COP21) in Paris, December 2015, 195 countries signed a legally binding agreement to keep the rise of the earth's temperature below 2^0C. This ambitious goal, to limit global warming, requires the de-carbonization of all the economies around the world. Large amounts of Renewable Energy Sources (RES) must be installed and integrated in our energy systems. Currently around 6,6% (CBS, 2018) of our energy comes from renewables but, according to European legislation in 2020 the RES should have a 14% share in the total energy consumption (Dutch Ministry of Economic Affairs and Climate Policy, 2018).

The integration of RES in our energy systems comes with some difficulties. These RES have a variable supply pattern which often doesn't meet our demand. For example sun power can only be generated and used during the day and wind power only functions when there is wind. Also the RES are added to the grid at different places, as well centralized as the large scale wind parks, but also decentralized such as solar panels on people's roofs. This could bring stress to the electricity grid when there is a surplus of electricity generation but no demand. A need arises to store energy in order to cope with peaks in the energy generation to comply with the energy consumption.

A quarter of all energy consumed in the Netherlands, is for domestic use (ECN; et al, 2014) (CBS, 2016). This domestic usage has specific energy consuming patterns. In the morning and evening there is a larger demand for energy than during the day and the evening. Besides this daily cycle are also seasonal cycles. During the winter there is a higher energy demand than during the summer, but during the summer more electricity could be generated by RES. In the future situation with a de-carbonized energy system, that adheres the Paris agreements, all the demanded energy must come from RES. Therefore, seasonal energy storage seems to become inevitable when becoming fully dependent on RES.

Energy can be stored within multiple different energy carriers such as thermal, chemical or electrical carriers. Depending on different parameters such as the amount of energy and the expected storage time, some carriers are more interesting than others. Electric batteries work properly when used for daily cycles, but not for storing surplus electricity for longer periods of time such as seasonal cycles. At this point Power-to-Gas (P2G) techniques become interesting. This P2G technique turns surplus electricity into hydrogen.

Hydrogen is a very versatile energy carrier. It produces zero emissions at point of use and it can be stored and transported with a high energy density in liquid or gaseous form.
Besides the re-use of hydrogen for power and heat, it can be used for mobility purposes or as a feedstock within the industry. Therefore, hydrogen is promising to play a role in the energy transition besides the re-electrification part.

The conversion of surplus electricity into hydrogen should be done as close to the energy source as possible. This will minimize unnecessary transport losses and prevent additional investments in the cables of the electricity grid to let them deal with the extra loads. Domestic RES have great potential, resulting in more decentralized generation of electricity in urban environments on district level. Therefore, the surplus should be converted and stored at this more decentralized district level.

1.2 Problem definition

The introduction of hydrogen energy storage in the urban environment is a new phenomenon. Hence making it interesting to define usable concepts, involved stakeholders and possible obstacles when it comes to implementation.

Hydrogen energy storage is a technique that possibly will not be needed in the upcoming ten to fifteen years. The share of RES in the energy generation mix isn't high enough to make it interesting on energetic or financial level. During this intermediate period, the techniques and specific equipment can change a lot. Especially the efficiency and price of the equipment is expected to be greatly improved. Therefore this thesis does not focus on the technical details of existing solutions, but more on the different type of concepts of hydrogen energy storage.

Besides the difficulty around the technical aspect, it is also very impractical to make accurate estimations about the financial and economic aspects. The market mechanism makes the cheapest energy solution the most favorable without taking the environmental benefits into consideration. When the pricing level for instance is connected to the amount of emission the energy source creates, a large change can be expected in favor of RES and energy storage systems. Also, the political preferences, concerning the environmental aspect, weighs heavily on the potential impact of hydrogen energy storage.

Hydrogen is often compared with natural gas which we currently use for in-house domestic applications such as hot water boilers and cooking stoves. Due to the specific characteristics of the hydrogen gas, it is not seen as a direct replacement of natural gas. However, large parts of the existing gas network could potentially be re-used for hydrogen gas transport and distribution. That is why often hydrogen is compared with natural gas.

The stakeholders involved with the current energy network would also have a role during the energy transition. Especially those who are responsible for balancing the electricity grid. These are the Transmission System Operator (TSO) and the Distribution System Operator (DSO). Within these organizations it is known that energy storage becomes necessary within the future. The difficulty is that it's not known exactly when, on what scale and who should be responsible for this. It is interesting to find out what stakeholders there are, besides these two parties, within hydrogen energy storage.

Energy networks have connections with other countries and energy is being traded on the wholesale market. In order to limit the research scope, this research focuses on the Dutch situation and its energy network.

1.3 Research question

Based on the explanation from the research context and the problem definition, the main research question for this thesis is formulated:

'What are the obstacles involved with the implementation of hydrogen storage facilities in the urban environment in the Netherlands?'

The following questions are so called sub-questions and help answering the main question during the thesis.

1) Which stakeholders are involved in the Dutch energy network besides the TSO and DSO's?
2) Is hydrogen stored on a local scale interesting to cover 'long stay' storage of energy?
3) What is the experience of current users of hydrogen products such as:
    a) Pilot projects
    b) Chemical industry (basic physics of hydrogen)
    c) Manufacturers Hydrogen cars and FCEV
4) What is the current legislation concerning hydrogen and are there prohibitions?
    a) Regulations
    b) Standards like NEN PGS 35
    c) Spatial Planning Act & Land-use Plan
5) Is there a willingness to store seasonal energy in hydrogen by DSO's?
6) What are the roles and needs of TSO's, DSO's and other users in the future system for hydrogen storage?

1.4 Methodology

The research objective is identifying the obstacles that are involved with the implementation of hydrogen storage in the urban environment. In order to reach this goal, a research design is needed.

1.4.1 Scope

This research is aimed to find the perceived importance of obstacles by experts. To stay on topic of this research, there is only a focus on the system of hydrogen energy storage and not on hydrogen usage for transport or feedstock. A technical solution or calculation including efficiencies of equipment should be part of further research as well as financial calculations.

1.4.2 Characteristics

The use hydrogen in the urban environment is a new technological application. Besides this characteristic of this research, obstacles that are identified don't have a value compared to each other. In order to find this value, experts should give the obstacles a ranking. The Fuzzy Delphi Method is chosen as the most suitable research method for this research.

The Fuzzy Delphi Method (FDM) is based on the Delphi Method. This is an analytical decision making method that uses expert opinions in an anonymous way to find the prevailing opinion about a certain topic. This is often used when there is no (historical) data available or when there is a new technology. The addition of the Fuzzy Theory is been proposed by Ishikawa and combines the Fuzzy Theory with the Delphi Method (Ishikawa, et al., 1993). This Fuzzy Theory helps to center and even-out human perceptions, vagueness and feelings (Lin & Chuang, 2012).

With the FDM a large group of experts and/or stakeholders can be questioned to gain forecasting knowledge about a topic. The keys to success for this research method are (Rowe & Wright, 1999):

- Maintaining anonymity of experts to make sure no 'group thinking' will start

- A proper collection/structure of the initial data allows a good starting point
- Cyclical feedback to the experts until there is clear prevailing opinion about the topic
- Statistical structure allows for quantitative analysis to get means and medians

There four main steps identified in the execution this method (Hsu, Lee, & Kreng, 2010):

1) Collect opinions of decision group
2) Set up triangular fuzzy numbers
3) Defuzzification
4) Screen evaluation indexes

1.4.3 Research framework

The implementation of each step of the FDM is elaborated in this research framework.

1) Collect opinions of decision group

The collection of opinions within the FDM must be done anonymously (Rowe & Wright, 1999). The method to provide this anonymity is a survey with an online questionnaire. The decision group should consist of a group of experts from different fields of expertise where hydrogen energy storage can play a role. A stakeholder analysis is needed in order to select these experts. In 1.4.5 there is more about the selected respondents for the survey.

Because the research question starts with 'what' (What are the obstacles…in the Netherlands), there will be a close-ended answer. The research approach is based on a constructivism world view. It is known for learning and understanding the environment based on multiple participant meanings (Creswell, 2014). This is needed because the information about hydrogen in the urban environment was very limited. Therefore it was necessary to inform the participants about the scenario in which hydrogen can be placed in order to create context and give them a hypothetical situation.

In the process of collecting obstacles, several sources of information are needed. Due to the lack of available scientific sources such as journal articles, other sources are used as well. Such as technical literature, semi-structured interviews with experts and reference projects. Information from these sources are as well usable in the search for obstacles, as for the understanding of the context and answering the sub questions.

With some overlap between the individual obstacles, rubricating obstacles into groups minimizes interpretation differences and makes the obstacles more unique. The final result is a collection of individual obstacles, obstacle groups and a description of the perceived Dutch energy situation in which hydrogen energy storage can take place. These two elements are the base of the survey and require a verification from a small group of experts before they can be used in the survey. Then the survey can be send out. In order to create a high response rate the questionnaire was given in Dutch, lowering a possible reluctance to complete the questionnaire due to a language barrier.

2) Set up triangular fuzzy numbers

Participants of the survey must choose between yes, no and I don't know for each obstacle if they consider it as an obstacle or not. This gives the raw numbers 1, 2 and 3. With the fuzzification of the answers, a common denominator is taken. With the three choice options, the three points Likert-scale is needed. There are different techniques to aggregate the data, some of which are experimental. Within this research the ‘fuzzy average’ method is been used (Habibi, Jahantigh, & Sarafrazi, 2015), see Figure 1. The three numbers which make up the fuzzy average (L,M,U) represent the mean value from the respondents about a certain obstacle.

$$\mathrm{Fave} = \frac{\sum \mathrm{L}}{\mathrm{n}}, \frac{\sum \mathrm{M}}{\mathrm{n}}, \frac{\sum \mathrm{U}}{\mathrm{n}}$$

Figure 1: Fuzzy Average (L = Lower-, M = Middle-, U = Upper bound).

3) Defuzzification

The equation $\frac{\mathrm{L+M+U}}{3}$ is used to defuzzify the mean values and make it into crisp values. This results in an overall score where all the respondents’ opinions aggregated as equally into an average.

4) Screen evaluation indexes

Based on the power-interest level of each profession a weight is added to value the more important profession higher as the other. There is a difference in profession groups and the initial profession. When there are less than ten respondents for each profession, it can’t be considered homogeneous (Delbecq, Gustafson, & Van de Ven, 1975).

1.4.3.1 Case description

The hypothetical situation for the participants, in order to create context about the scenario in which hydrogen can be placed is called the case description. This section describes the perceived Dutch energy situation in which hydrogen energy storage can take place. This case description is composed from the sections 2.1 to 2.5 and is based on a future all-electric autonomous community/district. Without gas and/or heat pipes, but with a local smart grid. The houses are built according to the near-zero-energy principle and are equipped with a heat pump, solar panels and a small home battery to cover day-night differences in their electricity demand.

The houses in this community/district are energy neutral; in the winter more energy is used than generated and the opposite is the case during the summer. When looking at the energy usage over the year, such a house uses nearly zero energy. This is called the near-zero-energy principle.

Here a system is explained that can be placed in the local power grid to save the locally generated sustainable energy for a long-term period. It is actually like a seasonal battery. It functions as follows:

- The smart grid detects surpluses of electricity from the district;
- The energy is stored locally as hydrogen;
- When there is a demand for energy in the district, the hydrogen is converted back into electricity and fed into the local power grid.

The conversion of hydrogen into electricity is done with an electrolyzer, and reversed by a fuel cell as seen in Figure 2.

There are several ways in which hydrogen can be saved: as gas, liquid or as a hydride (bound to other substances or materials). The location for the hydrogen storage may lie close to the electrolyzer and fuel cell. Next to that it is possible to store hydrogen on a more distant location while being connected through an underground gas network.

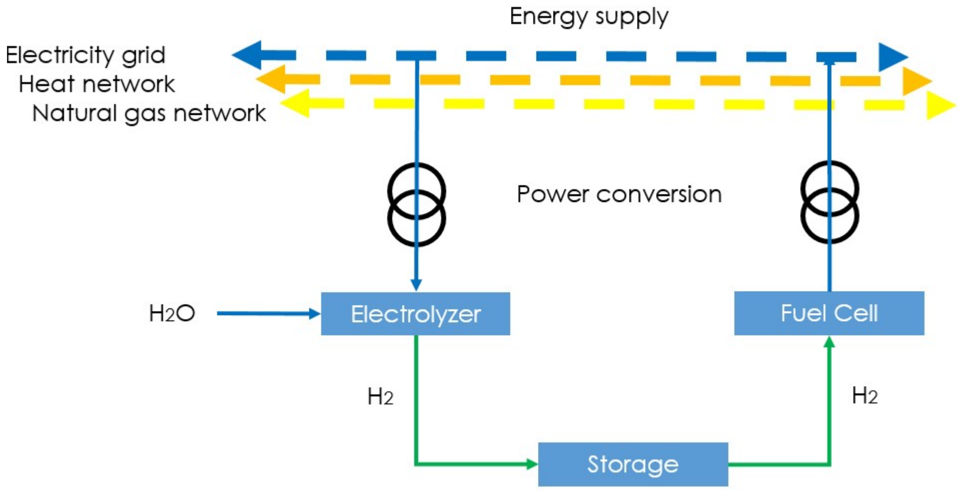


Figure 2: Basic principle of a hydrogen storage facility

1.4.4 Survey results

The outcome of the survey is a ranking of obstacle groups which is done by individual experts, but also based on the profession groups. In addition is also possible to see how many people have responded and what the response rate is.

1.4.5 Selected respondents

There was no database of possible respondents available for the survey because this research topic is relatively new. In order to recreate a respondent group, help was needed in the creation of such a database. All of the needed respondents were hand selected with help of multiple experts, amongst others the company supervisor. Within the selection it was intended to have a broad scope of professions, all of which are related to the research topic. In total 102 contacts were collected with the corresponding profession groups[1] (see Table 3). The difficulty remained that the respondents needed to have, at least a little, knowledge about the energy network and about hydrogen in order to understand the questions. Not every person was therefore considered to be qualified to join the survey. That is also one of the reasons why there are no direct end users been questioned. Besides the lack of knowledge, often the interest for energy related topics is low (BusinessGreen, 2019).

Table 3: Contacted respondents

Profession	Number	Profession groups	Number
Advisory	8	Counselor	48
Automotive	3		
Industry	28		
Association	7		
Consultant	2		
Energy supplier	1	Energy network	16
DSO	15		
Education	11	Authority	38
Government	16		
Politics	7		
NGO	4		
Other	0		0
TOTAL	**102**		**102**

1.5 Collaborating company

This research is conducted in collaboration with Siemens, a company that has proven knowledge about the energy networks and hydrogen. This internationally operating technology company has nine different divisions (see appendix 1, Organogram Siemens), varying from the more specific divisions 'Healthcare', 'Mobility' and 'Building Technologies, to the more energy related topics such as 'Energy Management', 'Power and Gas' and 'Wind Power and Renewables'. Therefore Siemens knows the energy markets very well, including generation, transmission and distribution of energy. In addition, a specialized branch of Siemens developed the electrolyzer 'Silyzer', a product that can produce hydrogen from purified water and electricity. For both reasons, Siemens was a very interesting company to collaborate with during this research.

[1] When the list of possible respondents was collected, the requirement was unknown that it only can be considered a group if there are at least 10 respondents. Therefore some groups are initially not large enough and therefore are combined afterwards.

2 LITERATURE REVIEW

This literature review section consists of six parts which explain concisely the topics that are related to the research. These parts are written with the combined knowledge obtained from the review of literature and the input from the semi-structured interviews which are further explained and listed in Table 21 in appendix 7. The objective is to get familiar with the related topics surrounding hydrogen energy storage and collect the needed information for the survey.

Obstacles are marked with [#nr] and are not put in chronological order in the thesis because they are numbered based on the point in time that they are found during the research.

2.1 Climate change and -agreements

The emission of greenhouse gases heavily influences climate change. To limit this emission, climate agreements are created to force a needed change in our energy consumption. To get a better understanding of the problem, it is important to explore the specific energy consumption and identify the energy sources.

The Conference of Parties (COP) from 2015, is a legally binding agreement to limit the rise of the earth's temperature by 2°C (COP21, 2017). On European level there are goals for 2020, 2030 and 2050. For 2020 a 20% cut in greenhouse gas emissions (based on 1990 levels) is needed, a 20% share of renewables within the energy use and a 20% improvement on the energy efficiency (European Commission, 2017). In 2030 the emission of greenhouse gases must be cut to 40% of 1990 levels, a share of 27% of renewables must be reached and at least an improvement of 27% in energy efficiency must be accomplished (European Commission, 2017). And finally in 2050 the emission of greenhouse gases must be cut even further to 80-95% of 1990 levels.

In the Netherlands the 'Energieakkoord' (energy agreement) is been signed in 2013. It adds an extra (in-between) goal to have a 16% share of renewable energy in 2023.

With the 'Energierapport – Transitie naar Duurzaam' (Energy report, transition to durability) from January 2016, the Dutch government formulated a vision on how the goals of the energy agreements will be reached. This vision is based on the following three cornerstones:

Vision on how goals will be reached (Dutch Ministry of Economic Affairs, 2016):

1) CO2 reduction

In 2050 the production of CO2 must be lowered with 80-95%. This is part of European agreements. With the Emission Trading Scheme (ETS) emissions of CO2 can be traded. This system relies on the scarcity of CO2 certificates. Unfortunately there is no scarcity now, making the system malfunction.
Currently the Dutch energy supply depends for 95% on fossil fuels. For electricity specifically there is a dependency on coal. These coal power plants must be phased out in the upcoming (decades or) years. These power generation will be replaced with RES such as wind power. Within the upcoming years multiple wind power parks will be installed, mostly in the North Sea. But within the transition time, natural gas will still play a large role as an energy supplier. Mostly because it is less polluting compared with coal.

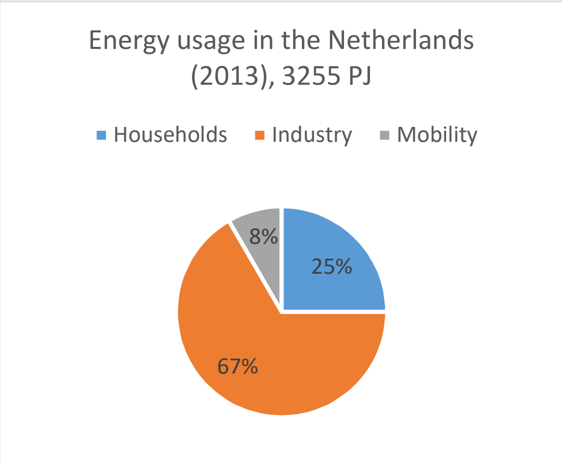
2) Economic possibilities

There is an ambition to keep promoting and supporting new and innovative solutions and bring those in practice. This will support Dutch companies and hopefully improve their business on national and international level.

3) Energy integration

The appearance of our urban environment such as neighborhoods, industrial and rural areas will change during the energy transition. The complete energy grid will be redesigned. From generation, transmission, distribution and consumption, the complete chain is changing. Wind power parks are added, pv-panels will be placed on roofs, etc. Because this involves a lot of different parties, a good and solid base for communication should be created. The responsibility for that is with the initiator.

The emission of greenhouse gases is heavily influenced by the energy usage. This energy is being used within three main segments, households, industry and mobility as shown in Figure 3.



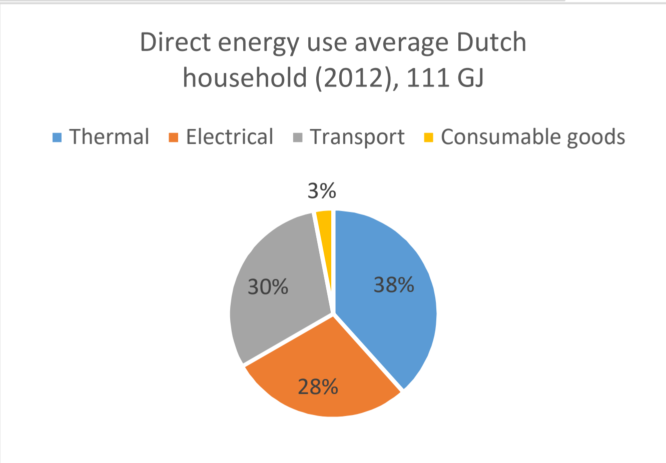


Figure 3: Energy usage in the Netherlands (ECN; et al, 2014) (CBS, 2016)

Industry takes the largest portion of the energy consumption. However, it is difficult to address this field as one, because industrial activities are so diverse. Second are households and thirdly mobility. Within households, energy is roughly being used for four main reasons:

- Thermal energy: Comfort like space heating and warm water
- Electrical energy: Appliances such as the oven, fridge, computer, etc
- Transport: All mobility like car, bus, plane, etc
- Consumable goods: production of food, clothes, furniture, appliances, etc

In the average situation the thermal energy comes from a combined boiler which runs on natural gas, the electrical energy comes from the electricity grid based on centralized power generation and the transport/mobility runs on an oil based fuel like petrol or diesel.

In the past decades there has been an annually increase in the total amount of energy consumption. However, this is changing. In the study from ECN, Energie-Nederland and Netbeheer Nederland called 'Energietrends 2014', is shown that Dutch households are using less energy. Mostly because houses are being more and better insulated, electrical appliances use less electricity (besides the growth of the amount of appliances) and cars are becoming more fuel efficient (ECN; et al, 2014).

For the generation of electricity there are multiple different sources. It is interesting to see that within different countries, a variety of sources are used. The majority of them are still based on fossil fuels. The Netherlands is one of the countries that is the furthest away from a durable, centralized electricity production (ECN; et al, 2014). [#18[2]] Natural gas and coals are still the main energy sources for electricity generation and probably will be used for decades to come (NOS) (de Rooy, 2016) (FluxEnergie, 2016). This is considered as an obstacle for the introduction of hydrogen energy storage.

There has been a growth in RES between 1998 and 2013 from 2 billion kWh to 12 billion kWh. This results in 12% of RES within the electricity generation. In 2020 this should be 37% (CBS, 2015).

2.1.1 Conclusion

The most important climate agreement currently is still the COP Paris 2015. Countries agreed to reduce the emission of greenhouse gasses to limit the rise of earth's temperature with maximum 2 degrees. Greenhouse gas emission is related to the energy usage. Most of the energy comes from fossil fuels. The major obstacle in this subsection is: [#18] that energy systems based on fossil fuels are still to be used for decades. That is stalling a nearby introduction of green hydrogen.

[2] The obstacles are identified with [#nr] and are not chronological. See 2.7.1 for the complete list with obstacles.

2.2 Energy network

Introducing hydrogen in the built environment is intended to convert surplus of locally generated electricity into hydrogen. This means that the energy network should be able to deal with the introduction of hydrogen. That is why it is necessary to know how the energy network works and what the obstacles are.

The energy network consists of the electricity network, the natural gas network and the heat network. Within this research there is a focus on the two main energy networks, gas and electricity. Therefore, the heat network isn't explained as thoroughly as the other two and will not be a further part of this research.

The 'electricity grid' can be described as a real-time energy delivery system which generates, transports, and supplies energy (Blume, 2007). The Transmission System Operator (TSO) is responsible for transmitting the electricity over a large distance on a national level to the more regional distribution network. The Distribution System Operator (DSO) is responsible for the distribution of the electricity to the consumers from the regional and local level to distribution substations. Then the electricity goes into the streets, to bring it to the houses in the neighborhood. This low voltage electricity network is the most widespread network in the Netherlands.

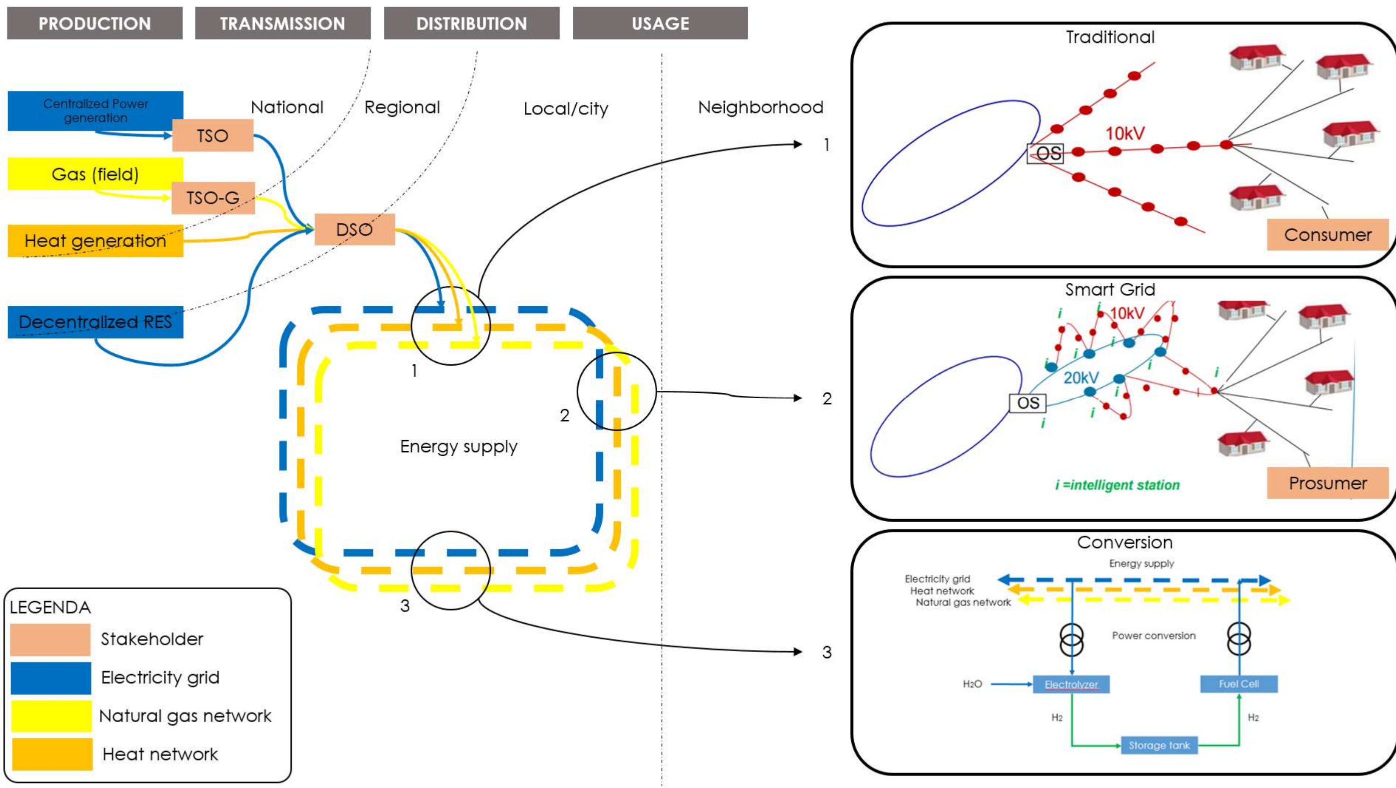


Figure 4: Energy network visualization with three scenario's (see appendix 3 for a larger display)

Figure 4 shows the current energy network in the Netherlands and possible alternative solutions for the traditional scenario. Part 2.6 'Stakeholders' provides a stakeholder analysis and focusses more on the corresponding stakeholders.

Within the neighborhood level of Figure 4, three scenarios are seen. The first is the more traditional situation where the energy moves in one direction. Second is a more future scenario with the use of a Smart Grid. Surplus electricity that is send back on the electricity grid can be used elsewhere in the neighborhood. To do so, an extra loop is created to balance the supply and demand in an intelligent way. Thirdly there is the scenario with energy storage where surplus of electricity can be stored.

The Netherlands relies on gas as an energy supply. It is considered to be a typical 'gas country' (Murthy Konda, Shah, & Brandon, 2012; 7). A large and widespread network is available to distribute this gas all over the Netherlands, as seen by the yellow color in Figure 4. Natural gas is extracted from a well in a gas field and is processed by a treatment plant (downstream process). Then, via transmission pipelines to the distribution network systems and to the consumers (Nasr & Connor, 2014). The main transmission network is operated by the TSO-G, a transmission operator specialized in gas. Second is the regional distribution network and thirdly a local network. The last two are operated by DSO's. Often the same DSO's as for the electricity grid.

There are neighborhoods which aren't connected to the gas network but instead to a heat network (see orange in legenda in Figure 4). Heat networks recover low grade thermal energy from industries in order to use it to supply heating and hot water to nearby domestic, commercial and industrial buildings. It can provide cost-effective and low-carbon energy to local populations (Swithenbank, et al., 2013). The DSO distributes it to the consumer.

2.2.1 Problems within the current energy network

In the current situation in the Netherlands, the energy network works properly. [#15] It is believed that there is no need for any form of energy storage and therefore also no need for hydrogen as an energy storage carrier (Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016) (Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016) (Joode, 2014). Within the existing boundaries of the electricity grid, there is flexibility available to absorb the imbalance caused by the current variations between supply and demand. However, the total of climate agreements, planned national actions and energy trends will change as well the supply as the demand side and therefore have a strong impact on the reliability of the current energy system. For this reason, alternative solutions should be examined.

2.2.1.1 Future scenario's energy network

The report 'Market and flexibility' by the Dutch research institute CE Delft, has indicated a few trends in the electricity network. They predict a strong growth of variable electricity generation by solar and wind and an increase in the application of electronic devices with a significant electricity demand and a specific demand pattern. For instance heat pumps for all-electric houses and charging of EV's at home. These new developments will increase the need for flexible measures to balance demand and supply (Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016).

With the increase in the local generation of electricity, or better referred to as Distributed Generation, it is interesting to balance the local supply and demand. Although there isn't an official description, the Smart Grid (already visualized as a scenario in Figure 4) is considered as a suitable tool to deal with these problems in the electricity network by using demand and supply data. There is also a research been conducted which focuses on the creation of an optimization model for the energy networks (Mazairac, 2016). It is based on the city structures and the existing energy networks to define where it would be beneficial to create energy conversion points. All arranged by a Smart Grid system.

Two Dutch examples for smart grid applications are the 'Smart Solar Charging' in the Lombok district of Utrecht and the 'All Electric Neighborhood' in the Hoog Dalem district of Gorinchem. Whereas in Lombok the electric car is used to store excess solar electricity, in Hoog Dalem a home battery is used. These two examples have been used as a reference project and further mentioned in the appendix 5.1.1and 5.1.2. These applications balance the local supply and demand for energy on a short term without converting the electricity into another form or transporting it to other areas.

The goal is to prevent the expensive strengthening of the underground power cables but with the preservation of the existing comfort level. Although there has been a lot of research, tests projects and pilot phases, there is not yet a common standard in Smart Grids. [#30] Therefore, there is no complete functioning Smart Grid yet (IEC, 2016).

The software function behind Smart Grid is important for the functioning of Smart Grid. An example is the Siemens DEMS (Decentralized Energy Management System) (Siemens, 2017). An operation software to intelligently manage distributed energy resources and virtual power plants. [#33] But it is directed to the DSO's and not the prosumers who want a trustworthy and transparent administration and pay-off system for their delivered energy. So for local and domestic electricity generation, there are no systems available (Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016) (Netbeheer Nederland, 2013). (Obstacle #33)

2.2.1.2 Intermittency

RES have a variable supply pattern which often does nog meet demand. This is called intermittency. An example of this intermittency phenomenon is visualized in Figure 5. The energy demand is visualized in blue with a peak in the morning and during the evening. But the peak in solar power occurs during the day, at the moment when there is almost no demand.

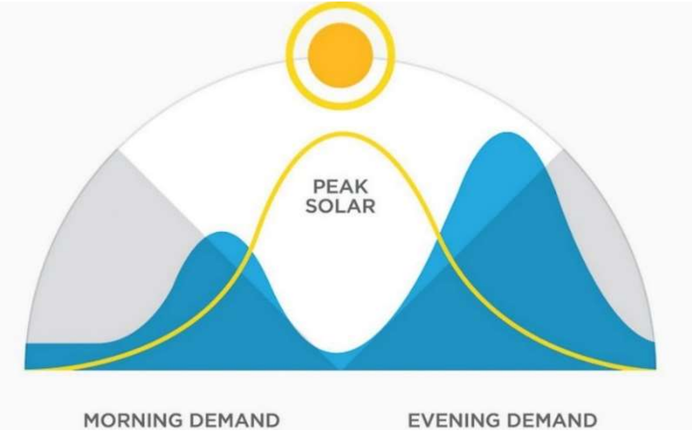


Figure 5: Demand vs Supply with solar power (Tesla Motors, 2015)

In the current situation electricity is always available on demand. This comfort is also needed during and after the energy transition. Intermittency by RES puts extra stress on the electricity grid resulting in an increased demand for more flexibility options in the near future.

Besides daily differences between supply and demand, there are also seasonal differences as can be seen in Figure 6. It is possible to accurately estimate the amount of solar and wind electricity that can be collected. This can be a similar graph for a lot of countries which are at the same geographical location on earth like the Netherlands.

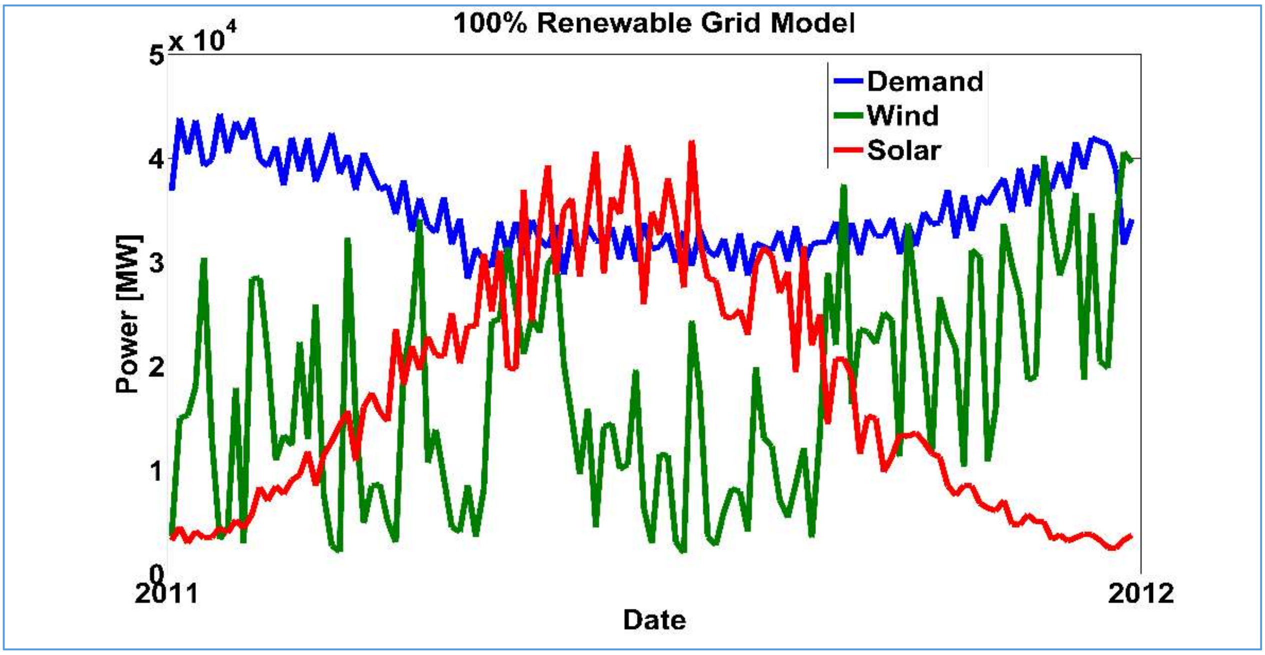


Figure 6: Example energy system without storage (University of Glasgow, 2016)

Figure 6 shows that:

- Demand during the year changes. During the winter period there is a higher demand for energy (for example: heating and lighting), and during the summer there is less demand of energy.
- Wind power production has very large fluctuations throughout the year but with a mean value of power generation that is higher during the autumn and the spring.
- Solar power production also has some fluctuations, but that is mainly because of the daily cycles. During night there is no production of course. Also there are more hours of sun available during the summer than during the winter time.

In 2050 the complete energy demand must be based on RES. This has as a result that the needed energy for the winter, with the higher energy demand, must be generated during the summer and put in storage as seen in Figure 7.

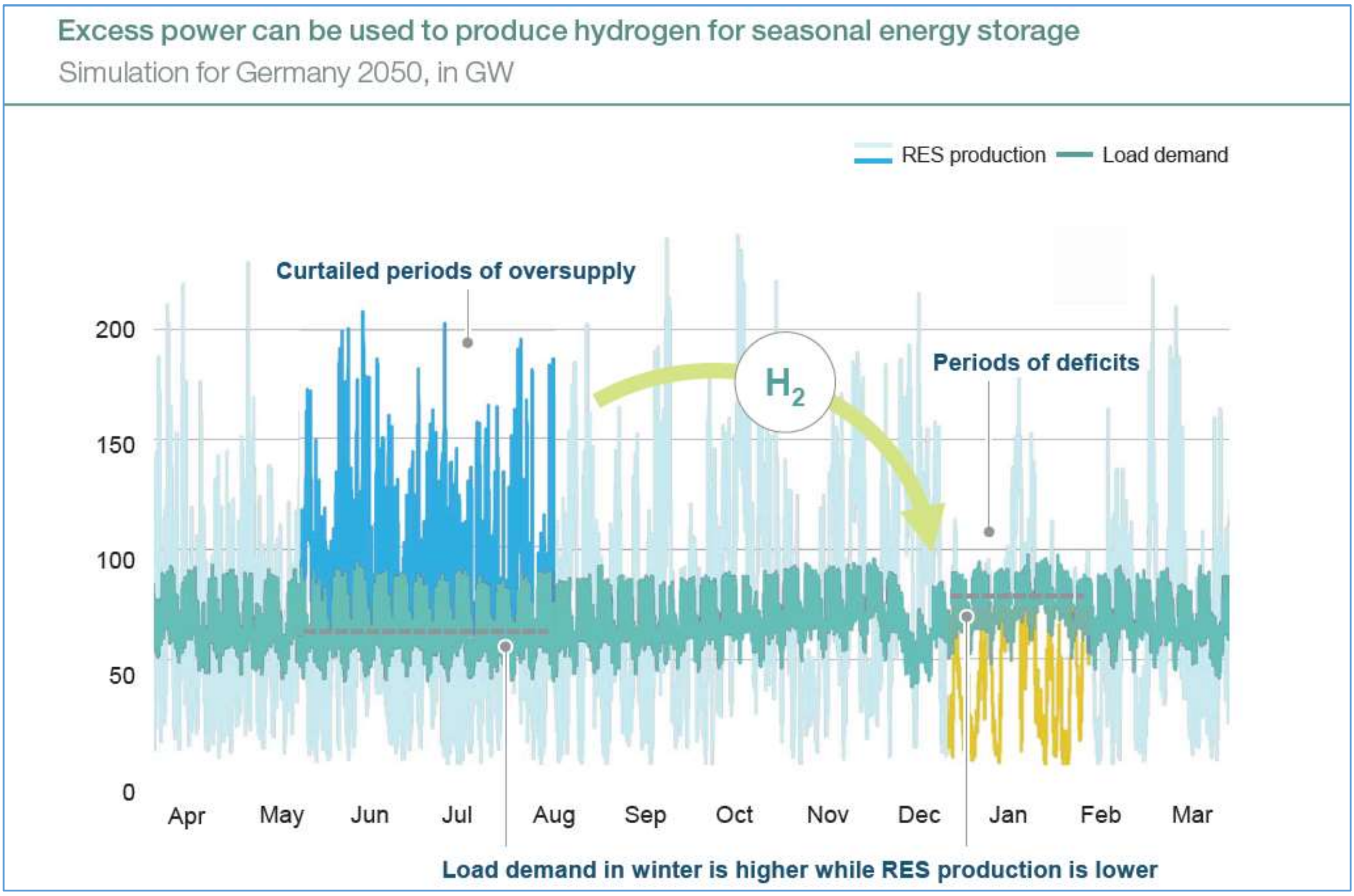


Figure 7: Example of seasonal balancing (Hydrogen Council, 2017)

2.2.1.3 Integration in current energy network

Flexibility is needed in the electricity system. There are three levels identified by DNV-GL in the report about the roadmap energy storage (DNV GL, 2015): the wholesale market, imbalance market and energy management 'behind the meter'.

The Dutch report 'Markt en Flexibiliteit' states as well that there is a need for flexibility in the electricity system on three levels (Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016):

1) electricity generation (Commodity market),
2) balancing between supply (Imbalance market) and with
3) network congestion (Transmission capacity)

Although the exact words are chosen differently, both researches describe the same three levels where flexibility is needed.

The current methods for providing flexibility are rapid responding power supply based on gas turbines (STEG's) and congestion management. These methods are designed to work with the first two levels of flexibility, commodity- and imbalance market. Other techniques are needed to fulfill the future required flexibility for balancing the seasonal effects.

The third type of flexibility, network congestion, refers to the balance between the supply and demand of electricity within the limits of available transmission capacity. When the demand for transmission capacity exceeds the available capacity network components could overload. This situation may arise on a local or district scale where the sum of local electricity generation exceeds the local available transmission capacity. A local/district based system, that could offer flexibility, would be needed in such situations.

This also makes sense when considering that the electricity grid is very dense and widespread on the local level. Additionally it is laid out in a one-way direction which makes it more challenging to accommodate the local electricity generation and the corresponding additional back and forth transport. Keeping the electricity in the same district, with the use of storage techniques, helps to prevent over-usage of the grid and therefore to prevent expensive investments in strengthening the network.

The impact of this consequence is difficult to predict and heavily depends on the ultimate choice of seasonal storage method. The stakeholders in the energy system are already aware of this but the difficulty is to predict when, how, to what costs, etc. [#19] When for instance hydrogen would be implemented now into the energy system, it could be disruptive to the network (Dutch Ministry of Economic Affairs, 2016). As mentioned before the current energy system is designed to supply the energy that is demanded. There is not a surplus of energy from RES which could be turned in 'green hydrogen'. Therefore the electrolysis process which produces the hydrogen would run on electricity that was generated out of fossil fuels.

Also the hydrogen has currently not a function for seasonal balancing and would therefore be used as a fuel for hydrogen vehicles, or as feedstock. These amounts of energy are normally not fed through the electricity grid and therefore it's putting extra stress on the grid with the result that investments are needed to strengthen it. In addition, when the hydrogen would be fed into the gas network, it is now limited to a certain amount. Even when the gas network can be used for hydrogen, the now projected transport of hydrogen is apparently not enough. The Dutch Hydrogen and Fuel Cell association thinks it can be feasible to operate a special hydrogen gas network in certain conditions (van der Meer, 2016).

It is difficult for DSO's to decide whether to keep investing in the current gas network (and make it suitable for hydrogen) or follow the idea that the natural gas will be out of date within a few decades. This would make the investment a terrible idea because of the stranded assets. [#3] There is still an uncertainty if hydrogen will be the long-term solution. With the existing techniques the costs per kWh are relatively high (van der Molen, Interview about verification of findings, 2016).

2.2.2 Economic implications

The current business model for the energy system is based on a system where the consumer pays for the used energy and for the use of the energy network that was used to transport the energy to the consumer. The price of the energy is dependent on the source material.

Within the electricity industry there are limitations on the amount of fossil fuels that are allowed to be emitted for the generation of the electricity. For every ton of CO_2 a certificate is needed as part of the ETS (Emissions Trading Scheme) regulations. Until 2012 these certificates were given for free, but since 2013 industries must pay for the certificates. The ETS covers around 11.000 energy-intensive installations which are used in the generation of electricity, but also for the industrial sector and flight traffic between European destinations. In total it covers around 45% of the EU greenhouse gas emissions (European Commission, 2016).

The amount of emissions (the cap) lowers over time. Within the cap, companies can trade emissions. The idea is that the value of ETS certificates will go up, making it financially more interesting to invest in RES. But the current pricing of tradable emission certificates is too low making [#5] fossil energy a cheap option for electricity generation (van der Meer, 2016).

[#1] As long as the current CO2 emission pricing is too low, the introduction of sustainable energy for central and decentralized levels is limited and not financially interesting (van der Meer, 2016) (Joode, 2014). Creating a scarcity of ETS certificates could change the market in favor of RES. But this needs to be done on a European scale, which makes it rather difficult. Therefore action on national level could provide a possible solution. Within the report of DNV-GL a market model is been described. First of all, offering flexibility in the grid should be appreciated more. This could be done with the implementation of a new payment scheme for electricity. Instead of being based on the cheapest fuel, it should be based on the price of the complete energy system. This could be a good incentive for energy storage (DNV GL, 2015). Without such a new payment scheme, [#20] local sustainable produced hydrogen remains more expensive as fossil fuels (Töpler & Lehmann, 2014) (van der Meer, 2016) and will not be accepted by the public. [#21] Also the remuneration of electricity from pv-panels should stop. It works disturbing on the physical electricity grid and doesn't help within the business case of energy storage (Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016).

[#7] A step further would be taking the long term effects of the fossil fuel based energy system into account. Because the fossil fuels are one of the causes of climate change, the impact of the climate change could be calculated back on the fossil fuel based energy system. This has a potentially really wide range of increased social costs such as increased usage of health care, needed investment to protect against extreme weather or lost revenues due to climate change. In such a situation an emission free energy system would have a positive business case. But this is not taken into account during a comparison (van der Molen, Interview about verification of findings, 2016) (Würtenberger, Bleyl, Menkveld, Vethman, & Tilburg, 2012)

2.2.3 Conclusion

There are three separate networks, the gas network, the electricity network and the heat network. The gas and electricity networks have the focus because they are affected by the introduction of hydrogen.

These networks are expected to change significantly due to foreseeable trends such as the growth of locally generated RES, increasing electricity demand in the residential area by EVs, fewer gas connections and ultimately off-gas. In addition, there is a visible difference in the demand and supply curve of electricity both daily and yearly. Possible solutions are the reinforcement of the electricity grid and the smart grid.

It is expected that these solutions do not yet go far enough to solve the differences in supply and demand, the so-called intermittency. Certainly not for the yearly supply and demand cycle.

Part of the solution is the addition of more flexibility in the energy network. Energy storage, and therefore hydrogen technology, can play a role in this. Temporary surpluses of electricity can be converted into hydrogen. When the demand for electricity increases again, the hydrogen can be converted back into hydrogen.

Obstacles obtained from this part 'Energy network' are:
[#15]: there is currently no need to use hydrogen as a part of grid balancing systems.
[#30]: there is no complete functioning Smart Grid yet.
[#33]: there are no administrative and pay-off systems available for remuneration schemes of locally produced sustainable energy and the use of this in neighborhoods.
[#19]: hydrogen has a disruptive effect in the local energy system, both in generation, during storage and with re-use in as well gaseous form or as electricity.
[#3]: there is uncertainty whether hydrogen is the long-term solution due to the relatively high cost per kWh.
[#5]: fossil energy is cheaper.
[#1]: the current CO2 emission pricing is too low for the introduction of sustainable energy, including neighborhood level.
[#20]: local, sustainable produced hydrogen is more expensive to citizens as fossil fuels.
[#21]: there is a remuneration for solar PV, making local energy storage less interesting for the owners of the PV.
[#7]: not all social costs of the fossil energy system are included in the comparison with a sustainable local energy system.

2.3 Energy storage

Energy storage is a solution for the defined problems (e.g. a lack of flexibility to overcome intermittency) in the current energy network (see part 2.2). The type of energy storage which is most favorable in each situation depends on different criteria, for example when the energy is available, when it should be available again, the duration of storage, the size of storage and for what purpose it is stored. These criteria are defined and explained below.

[#16] It is estimated by the DNV-GL in the 'roadmap energy storage' that there is enough affordable flexible capacity available within the existing electricity network that before 2030 there will still be no market for energy storage. This observation that the current network still has sufficient transmission capacity to accommodate peaks and increased demand was also confirmed by the research of CE Delft in their report 'Markt en Flexibiliteit' (Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016) and also during the interview with the energy supplier (Ouillet, 2016). But with the European agreements in mind, it seems clear that over time the electricity system is fully relying on RES and seasonal, long term energy storage becomes needed as mentioned in part 2.2.1.

2.3.1 Storage technologies

Energy can be stored in many different ways as can be seen in Figure 8. This is the result of research conducted by the Hanze University of Applied Sciences which was commissioned by the 'Netbeheer Nederland'. It offers an overview of different techniques and for what applications it potentially can be used.

Technology Name	Application: Frequency Control	Hourly Balancing	Daily Balancing	Seasonal Balancing	T&D Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak Shifting & Firming	Demand Shifting & Peak Reduction	Energy Arbitrage	Reactive Power	Uninterruptible Power Supply	Transp
Electric Energy														
Flywheel	●	○	○	○	○	○	○	○	○	○	○	●	◐	○
Pumped Hydro	●	●	●	○	○	◐	○	○	◐	○	●	●	○	○
CAES	●	●	●	○	○	◐	○	○	◐	○	●	◐	○	○
Pb Acid Battery	○	●	○	○	◐	●	●	○	◐	●	○	○	●	●
Li+ Battery	○	●	○	○	◐	●	●	○	◐	●	○	○	●	●
Vd Redox Flow Battery	○	●	○	○	◐	●	●	○	●	●	○	○	●	○
Supercapacitors	●	○	○	○	○	○	○	○	○	○	○	○	○	◐
SMES	●	○	○	○	○	○	○	○	○	○	○	○	●	○
Thermal Energy														
Hot Water	○	○	●	●	◐	○	●	●	○	●	○	○	○	○
Underground Storage	○	○	●	●	◐	○	●	●	○	●	○	○	○	○
Molten Salts	○	○	●	○	○	○	○	○	○	○	○	○	○	○
Latent Heat	○	○	●	●	◐	○	○	●	○	●	○	○	○	○
Gas and Liquid Fuel														
Hydrogen Gas	●	●	●	●	●	○	○	○	◐	○	●	◐	○	◐
Salt Caverns	○	●	●	○	●	○	○	○	○	○	●	○	○	○
Aquifers & DGF	○	○	●	●	◐	○	○	○	○	○	○	○	○	○
LNG	○	●	●	○	◐	○	○	○	○	○	○	○	○	○

● indicates full suitability
◐ indicates potential or moderate suitability
○ indicates no suitability

Figure 8: Technology suitability energy storage carriers (Pierie & van Someren, 2015)

There are a lot of different aspects on which a storage technology can be chosen. The easiest and most widely suggested solution is to store surplus electricity in batteries so it can be used when needed. [#12] These home batteries are getting more attention at the moment than more centralized storage systems (Gawalo, 2016). Although electric batteries are suited for storing electricity from a few seconds up to a few weeks (Etherden & Bollen, 2013 july, vol. 4, no.3), the downside is that batteries will lose their energy over time. Therefore, they are not a good solution for long term energy storage. And because this research focuses on seasonal balancing, other techniques are needed.

As seen in Figure 8 [#17] there are plenty of techniques which are able to balance the grid on seasonal basis. This is also been pointed out within the research of the Dutch research institute CE Delft. There the following techniques are been distinguished as options for surpluses (Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016):

- G2V (Grid-to-Vehicle and Vehicle-to-Grid)
- CAES (Compressed Air Energy Storage)
- CHP (Combined Heat Power)
- Electrolysis in combination with a gas engine, STEG
- Power-to-heat

In both reports is seen that instead of keeping the energy as electricity, it needs to be converted for longer storage. It has already been researched what system can hold a lot of energy without losing it over time. In Figure 9 it is seen that H_2 (hydrogen) and SNG (Substitute Natural Gas or Synthetic Natural Gas) are the best energy carriers for this application. They can hold Gigawatt Hours to even Terawatt Hours of energy with discharging times up to months. These are considered to be part of the 'Power-to-Gas' principle' whereby electricity is converted to a gas.

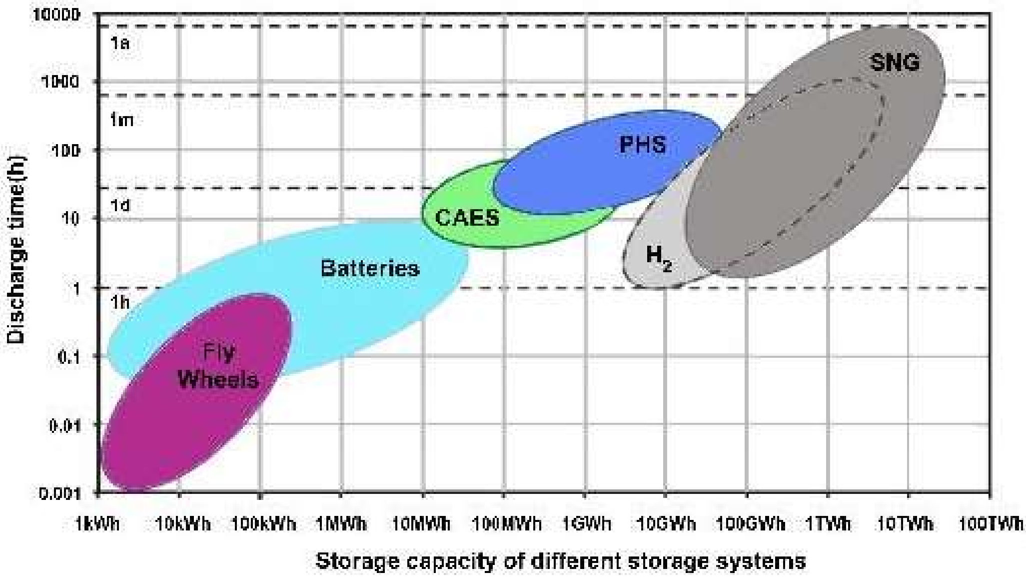


Figure 9: Energy Storage Capacities (Renewable Energy World, 2016)

Now surplus electricity must be converted to this new energy carrier and stored for a longer amount of time. When needed, the energy carrier must be converted back to electricity or it needs to be used for other purposes. With the conversion from electricity to hydrogen there is a technical downside. [#27] The downside is that the response time of the system is not yet quick enough. This so called 'black start' time of the system should be very short (within 10 minutes) in order to deal with the surplus of electricity (Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016). This is also seen in Table 15. But the most important is that the total well-to-well efficiency must be as high as possible without harming the environment.

In order to make a good decision between these two P2G techniques, it's important to know how SNG and H_2 are created and how they are being used. SNG needs to be formed out of hydrogen, therefore the hydrogen production process is looked at first.

2.3.2 Power-to-gas

An electrolyzer is needed to produce hydrogen. It uses electricity to split the water molecule into hydrogen and oxygen. The efficiency of a PEM electrolyzer is around 65%[3] (Siemens AG, 2016). This results in the following chemical formula R1:

$$\text{R1:} \quad 2\,\mathrm{H_2O} + \text{Electricity} \rightarrow 2\,\mathrm{H_2} + \mathrm{O_2}$$

For the formation of SNG, energy is needed to let the hydrogen react with carbon dioxide. This will form methane, which is known as Synthetic Natural Gas. The efficiency of this reaction is around 73% (DNV-GL, 2015). This results in the following chemical formula R2 :

$$\text{R2:} \quad 4\,\mathrm{H_2} + \mathrm{CO_2} + \text{Electricity} \rightarrow \mathrm{CH_4} + 2\mathrm{H_2O}$$

As an energy carrier intended for balancing the grid, it is now important to see how the energy can be converted back to electricity again. With hydrogen the most logical is a fuel cell. This device uses the opposite chemical reaction of the electrolyzer. Depending on the type of fuel cell the efficiency is within the range of 40 to even 80% (Virginia Tech, 2016). The following formula R3 shows the reaction:

$$\text{R3:} \quad 2\,\mathrm{H_2} + \mathrm{O_2} \rightarrow 2\,\mathrm{H_2O} + \text{Electricity}$$

In contrast to the hydrogen, SNG isn't easily converted back to electricity. There are no devices or machines that can do it in an affordable or efficient way. It needs to be burned before electricity can be converted to electricity again. The following formula R4 shows the burning process:

$$\text{R4:} \quad \mathrm{CH_4} + 2\mathrm{O_2} \rightarrow \mathrm{CO_2} + 2\mathrm{H_2O}$$

During the process of burning, the CO_2 that was added during the formation of SNG is released again. If this is a closed cycle, it is fine. But when the CO_2 comes from a different source, the cycle isn't emission free and therefore not interesting as an energy carrier for balancing the grid. This concludes that hydrogen is a better nonpolluting energy carrier for balancing seasonal effects in the electricity grid. More about the production, transport and utilization of hydrogen is explained in the next part 2.4.

For both of the systems, [#6] the well-to-well efficiency, or the yield, is considered as quite low when being compared with storage techniques that are used for hourly balancing (Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016). But this system focuses on seasonal storage based on the use of surplus energy. Then the unique benefits such as the low discharge rate and low environmental impact score higher. Therefore, this is still considered as a promising solution.

[3] On a side note, both of the reactions have large amounts of waste heat. In an ultimate situation this heat will find a new use. In the urban environment that is often possible because the largest amount for energy is used for heating purposes. This won't improve the efficiency rates of both reactions but it will improve the total efficiency of surplus electricity.

2.3.3 Conclusion

The flexibility that is offered by energy storage can solve the intermittency problems of the energy network. There are several storage techniques, depending on the circumstances and preconditions which fits best. For a yearly or seasonal cycle, energy must be stored for a longer period of time. Power-to-gas techniques such as hydrogen and SNG are the most suitable for this application.

Surplus of electricity is converted into gas via electrolysis and stored. When there is an extra demand for electricity, the gas is converted back into electricity.

Obstacles obtained from this part 'Energy storage' are:
[#16]: there is still sufficient transmission capacity in the national and regional electricity grid to accommodate peaks and increased demand.
[#12]: private energy storage systems per dwelling, for example home batteries, get more attention than a central storage in the neighborhood.
[#17]: there are plenty of other local systems available which allow both local grid balancing and seasonal energy storage.
[#27]: the system can't respond fast enough on a surplus of electricity (about 10 minutes at a 'black start').
[#6]: hydrogen storage systems as a whole, have a low yield.

2.4 Hydrogen

This part provides an understanding of the definition of hydrogen and how it can be used as an energy carrier at the moment. Currently, hydrogen is primarily used in the industry sector (Holladay, Hu, King, & Wang, 2008). More specifically, this part describes hydrogen as a chemical element, how it is being produced, stored and transported. And of course how it is being used. Finally there is some more about the safety issues.

2.4.1 Chemical element

Hydrogen is a chemical element with the symbol H. Two hydrogen atoms make one hydrogen molecule as seen in Figure 10. Its properties were discovered in 1766 by the English scientist Henry Cavendish (West, 2014). But it took until 1839 to discover the electrolysis process (production of hydrogen) and the principle of the fuel cell (re-electrification of hydrogen).

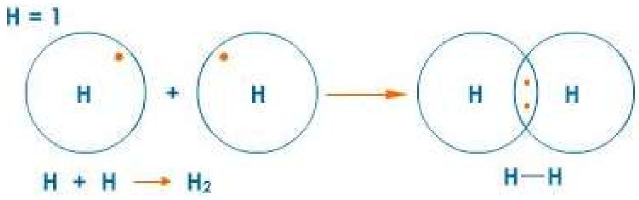


Figure 10: Formation of molecule of hydrogen (Shrestha, 2016)

When working with hydrogen, it's necessary to know what it does and how it works. It is the lightest element (1/14 the density of air) and also the most abundant substance in the universe. On earth it only exists when it is combined with other chemical elements. It is colorless, doesn't have a smell, is tasteless and is not toxic. At room temperature and with normal pressure, 10 liters of hydrogen gas only weighs 0.9 gram. This makes it a very light gas but with a relatively large volume. When it burns the flame is invincible (Bruijn, Hoeven, & Steen, 2006). At the very low temperature of minus 252 degrees Celsius, hydrogen becomes a liquid. The melting point is even lower at -259^{0}C. This is really close to the ultimate coldest point of -273^{0}C, which is 0 Kelvin (Publicatiereeks Gevaarlijke Stoffen, 2015).

When hydrogen is released inside by accident or with maintenance activities, it can accumulate inside in the highest place under the ceilings and roofs based on its very low density. When accumulated, only a small amount of energy is needed to let the hydrogen explode. Although most people are used to working with gas in their houses, not all the gases behave the same. When gas is introduced in houses, this is natural gas. With natural gas such specific accumulation doesn't happen because the density is higher and the diffusion coefficient is lower. Also the needed ignition energy in air is much higher with natural gas than it is with hydrogen (Pritchard, Royle, & Willoughby, 2009).

Because hydrogen is often compared with natural gas and the indoor usage of it, such [#22] technical downsides feed the already existing uncertainty surrounding the safety of hydrogen (Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016). Take into account the wrong and infamous image it already has based on the Hindenburg and the reference with bombs and it is clear that the reputation of hydrogen isn't good. In the end the public acceptance of hydrogen, and also other power-to-gas systems, will depend on the assurance of safety, protection of life, property and environment (Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016). The issue with the public acceptance was also confirmed by several experts during the interviews (Konings, Exploratory interview about hydrogen, 2016) (van Schagen, 2016) (Welsing, 2016).

2.4.2 Production

Hydrogen is mainly used in different industries as a feedstock (Bowman & Klebanoff, 2012). For instance within the chemical- and food industry it has been used for decades. As mentioned in 2.4.1, hydrogen only exists on earth when it is bound to other chemical elements. It isn't a resource such as coal, oil or gas. To conceive hydrogen, it must be produced by splitting it from a source. Therefore, multiple methods are being developed, such as: Steam Methane Reforming (SMR), Partial Oxidation (POX), Chlor-alkali electrolysis and Polymer Electrolyte Membrane (PEM) electrolysis (Holladay, Hu, King, & Wang, 2008). Hydrogen production by wind- and solar power is preferably done via electrolysis (Chang, Hsu, & Chang, 2011).

The base materials, or feedstock, differ between the different technologies and really set apart each method. Among the types of feedstock, there are two main types: hydrocarbons (fossil fuels) and water+electricity (Töpler & Lehmann, 2014). In all of the production methods energy is needed to separate the hydrogen from its base material.

Steam Methane Reforming (SMR) is the most widespread production method at the moment (Linde Gas, 2016) (Holladay, Hu, King, & Wang, 2008). But it isn't the most environmentally interesting way of producing hydrogen because it still uses fossil fuel as feedstock resulting in 'black hydrogen'. Methods are needed that don't need fossil fuels and have a low to no impact on the environment. Therefore, the methods based on water and electricity are interesting which use the electrolysis technology.

When the electricity that is used for the electrolyzers comes from RES, the produced hydrogen is considered as 'green'. [#37] Besides the fact that it can improve the value of hydrogen, this green hydrogen can be used in different industries as a durable feedstock and lower their carbon footprint. However there is currently not a certificate available which can provide that (van der Meer, 2016), it still is foreseen that green hydrogen becomes the new standard in industry (Kranenburg, et al., 2016).

The basic of electrolysis is splitting the water molecule into its hydrogen and oxygen parts with electricity. Two inert metal plates are placed in water. These electrodes are connected to a DC power source. The direct current splits the water molecule and the hydrogen ends at the cathode, where the oxygen ends up at the anode. The gas rises up above the water. Because there are more parts hydrogen then oxygen, there is a two to one ratio in production.

There are currently two main electrolyzer systems, the 'Alkaline' and 'PEM'. The technology of the PEM electrolyzer promises to deal better with the cold start, or known as 'black-'start' time and have a higher efficiency, but the maturity of the technology is still a bit behind the alkaline. [#28] Considering the European workgroup on Hydrogen the reliability of the electrolyzer system is too low. To reduce degradation and increase lifetime expectancy, more research is needed on better materials (Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016).

The purity of the hydrogen is quite important, especially when the hydrogen is going to be used in a fuel cell. Then a purity level of 99.999% is needed (Reijerkerk, Exploratory interview about hydrogen, 2016). In order to reach this high level, a 'dryer' is needed which takes out the few last pieces of H_2O from the hydrogen. With the current available PEM electrolyzers, including transformers, coolers and dryers, a system efficiency is reached between 60 & 65% (Siemens AG, 2016).

2.4.3 Transport, storage

Hydrogen can be stored, distributed and transported in different states. This can be done as a gas or as a liquid. The choice between these types depends on the amounts of hydrogen which are needed, and the route it has to follow. The current and alternative new, techniques are described below.

2.4.3.1 Existing techniques

Amongst the current existing techniques there are (local) pipelines for continuous hydrogen demand and batch transports. These batch transports use pressurized gas cylinders or tanks which stores the hydrogen as a liquid (Töpler & Lehmann, 2014). When hydrogen is being stored as a gas it typically requires high-pressure cylinders, capable of storing at 350-700 bar (5000-10.000 psi). For storing as a liquid cryogenic temperatures are needed of -252.8°C (Energy.gov, 2016). This is more energy intensive way, but it saves space compared to the gas form.

An example of a pipeline is the Dutch 'buisleidingenstraat'. It measures 75km and connects the harbors of Rotterdam, Moerdijk, Zeeland and Antwerp with each other (Air Liquide, 2016). Around those harbors, there are a lot of chemical industrial areas. A lot of different gases and liquids are being transported for easy access and use amongst industries. Many chemical processes, especially at refineries, have hydrogen as a waste product. This is put in the 'buisleidingstraat' and transported to other industrial areas which can use it again.

[#14] Because hydrogen is one of the smallest molecules that exists, it can diffuse through other materials' molecule structure. Therefore not all materials that are normally used are applicable. This is an issue for as well the storage as transport in pipelines. Only a small amount of materials are suitable for these applications (Publicatiereeks Gevaarlijke Stoffen, 2015). Even when the material is suitable, a small amount of hydrogen can over time bound with the molecule structure of the material. This enhances fatigue of the material. [#26] There is lack of available results of accidents/incidents by hydrogen enhanced fatigue of materials for transport and storage (Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016). This makes it challenging to create proper safety standards about transporting and storing hydrogen for longer periods of time.

However, within some specific parts of the chemical industry, there is already a lot of experience with the transport and storage of hydrogen, especially from the companies who are in the industrial gas industry such as Air Products, Air Liquide and Linde Gas.

2.4.3.2 New techniques

Besides the pipeline and traditional batch transports, there are some new 'exotic' technologies to store hydrogen. A space saving way is binding the hydrogen to another element such as a metal to form a hydride. The techniques for this are still in development. Magnesiumhydride is currently the most promising hydride (Technisch

Weekblad, 2016) but the issue remains that hydrides are quite inefficient, not profitable and because they are heavy and therefore not suitable for vehicles (Reijerkerk, Exploratory interview about hydrogen, 2016).

Another new technology is Liquid Organic Hydrogen Carriers (LOHC). This technology uses organic chemical components that can easily bond hydrogen to them to form synthetic fuels. A form of these is formic acid. This is an easy to store liquid with a high energy density that is not easily flammable. With a two-way catalyst reactor the hydrogen can be bound and unbound of the organic chemical. There is currently a project team busy to develop a public transport bus that can drive on formic acid (Tiemessen, 2016) (VDL, 2016). These LOHC are seen as an alternative fuel for heavy mobility, such as trucks and large vessels, which have a fuel cell that can run on these synthetic fuels.

In general can be said that all the new technologies seem very promising but it will take a long time to develop. Currently there must be a focus on the implementation of the first hydrogen products. When these are accepted and have a promising business case, these new technologies have a chance as well (Reijerkerk, Exploratory interview about hydrogen, 2016).

2.4.3.3 Large scale techniques

The above mentioned new technologies don't promise to be capable enough to store energy for balancing the seasonal effects. Surplus of electricity from RES that is being converted to hydrogen with PEM electrolyzers needs to be stored. Currently the most recognized large scale storage capabilities of hydrogen are in underground salt caverns (Ahn & Purewal, 2012) (Töpler & Lehmann, 2014). Such storage is already in use for natural gas and it should also be able to work with hydrogen. The stored hydrogen can be used in different ways. It can be re-electrified at times when there is no supply of RES but there is still a demand for electricity. Or it can be mixed in the natural gas network (only during the energy transition of course because in the end around 2050 the natural gas network will be out of order), or the hydrogen can be transported/distributed for other uses depending on the demand level and price. Examples are uses in mobility or as feedstock for mobility.

The mixing of hydrogen in the existing natural gas network is not unlimited unfortunately. [#35] The current rules are very limited, hydrogen may only have a share of 0.02% in the natural gas network (van der Molen, Interview about verification of findings, 2016). Research has already shown that this could be increased to higher percentages without the need of expensive investments of the natural gas network. It can even safely be raised to a share of 30% (see the reference project about Ameland at part 5.1.3). But this high percentage would only be possible if all the end users adapt their appliances such as cooking stove and boiler to work with this mixture. And for that, more research is needed to know what the impact is (Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016) (Pritchard, Royle, & Willoughby, 2009). Also, this requires the use of existing local/regional gas network. This network is in contrary to the main, national gas grid, not suitable for the transport of purely hydrogen (Janssen & Lambregts, 2016) (van der Molen, Interview about verification of findings, 2016).

In Germany there are different rules concerning the mixture of hydrogen. Already several P2G plants are developed and convert surplus of RES into hydrogen

(Reijerkerk, Interview about verification of findings, 2016). But even in Germany, where there are large scale P2G stations, it is only a small amount of energy that is been converted and stored relatively to the total energy use. The large scale in which the storage ultimately is needed doesn't exist.

To overcome this issue with mixing hydrogen, it is possible to further convert the hydrogen into methane (natural gas) as seen in Figure 11. But as mentioned in part 2.3.2 about P2G, the well-to-well efficiency of such a conversion is considered too low. It may be an option in some situations where other options will not work, but it has not the future potential to become the main energy source.

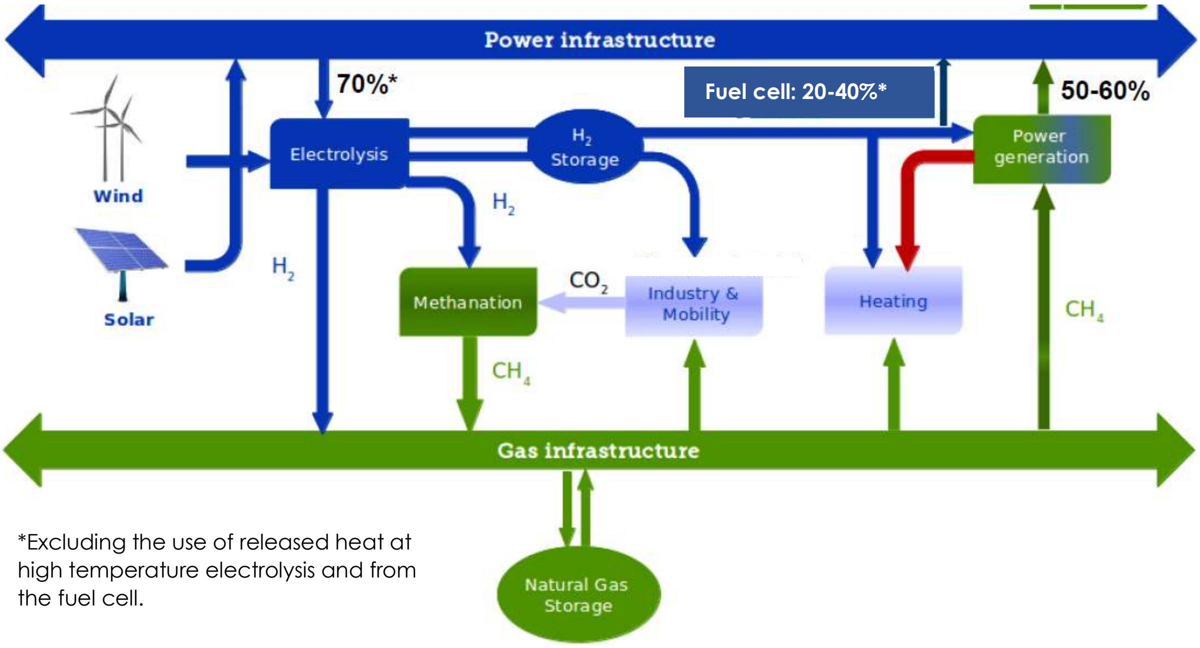


Figure 11: Hydrogen as a connecting link (Groenenberg, 2013)

[#2] A separate hydrogen network is also opted as a solution for large scale storage and an interesting transport technique. But the expected costs of implementing such a network are really high (van der Meer, 2016). It would only work if there is are enough customers for the hydrogen. This demands for a large adaptation of hydrogen usage which is difficult to force users into.

Hydrogen can be converted to ammonia (NH_3) when it is combined with nitrogen. Although ammonia is a toxic gas, it is easier to store as hydrogen when it is being turned into a liquid. Then it is almost similar as storing LPG (Liquefied Petroleum Gas). Nitrogen can be easily collected by filtering the air because normal air exists around of 78% out of nitrogen. Currently the energy supplier Nuon is researching the possibilities for large scale energy storage based on ammonia to balance the electricity grid (Nuon, 2017).

Amongst the listed possible large scale storage techniques, [#32] there aren't really matured and tested systems available yet to store seasonal energy within hydrogen (Joode, 2014). This makes it really difficult to make a choice between one of them. Also a specific choice at this moment could mean a technique lock down.

2.4.4 Utilization

This research looks at the utilization of hydrogen in a broad and worldwide vision, also referred to as the 'Hydrogen Energy Web' as Jeremy Rifkin refers to in his book 'The Hydrogen Economy' (Rifkin, 2003). The idea and vision behind this are great, but the practicalities of the real world must be faced.

"In the future we start sharing surplus of energy like we do with information on the internet"

(Jeremy Rifkin, 2006)

There are many ways in how hydrogen is used and can be used such as fuel for generators or propelling vehicles (see appendix 5.2 for examples). The main aspect of this research (Rifkin, 2003) is the use of hydrogen as seasonal energy storage, and for the utilization aspect the re-electrification is important. To do so, a fuel cell is needed.

A fuel cell works in an opposite way as an electrolyzer. It uses the chemical energy of the hydrogen and combines it with oxygen collected from the air to turn it into water and electricity (see the explanation about P2G in part 2.3.2). This process happens in a membrane. 80 till a 100 membranes are needed to create a stack, and multiple stacks of are needed for one fuel cell. There are also some peripheral equipment needed to let it function as a complete system, such as transformers who convert the DC output in the desired electricity output. Such a fuel cell system has a total efficiency of around 50% (ten Have, 2016).

There are many different types of fuel cells developed over time. The fuel cell that seems the most interesting for stationary usage as a distributed generation plant is the PEM fuel cell (Virginia Tech, 2016). A fuel cell which would be used as a distributed generation plant needs to fulfill different needs as a fuel cell used for mobility purposes (more about the FCEV at part 2.4.4.1). [#29] But in all cases it is needed that the fuel cell is durable and reliable, and that still can't be ensured currently (Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016).

Within the thought of the hydrogen economy, hydrogen can be seen as a zero-emission energy carrier that will help with the decarbonization as seen in Figure 12. This involves a change in how the transport, industry and built environment consume their energy. For all of these fields technical solutions are needed.

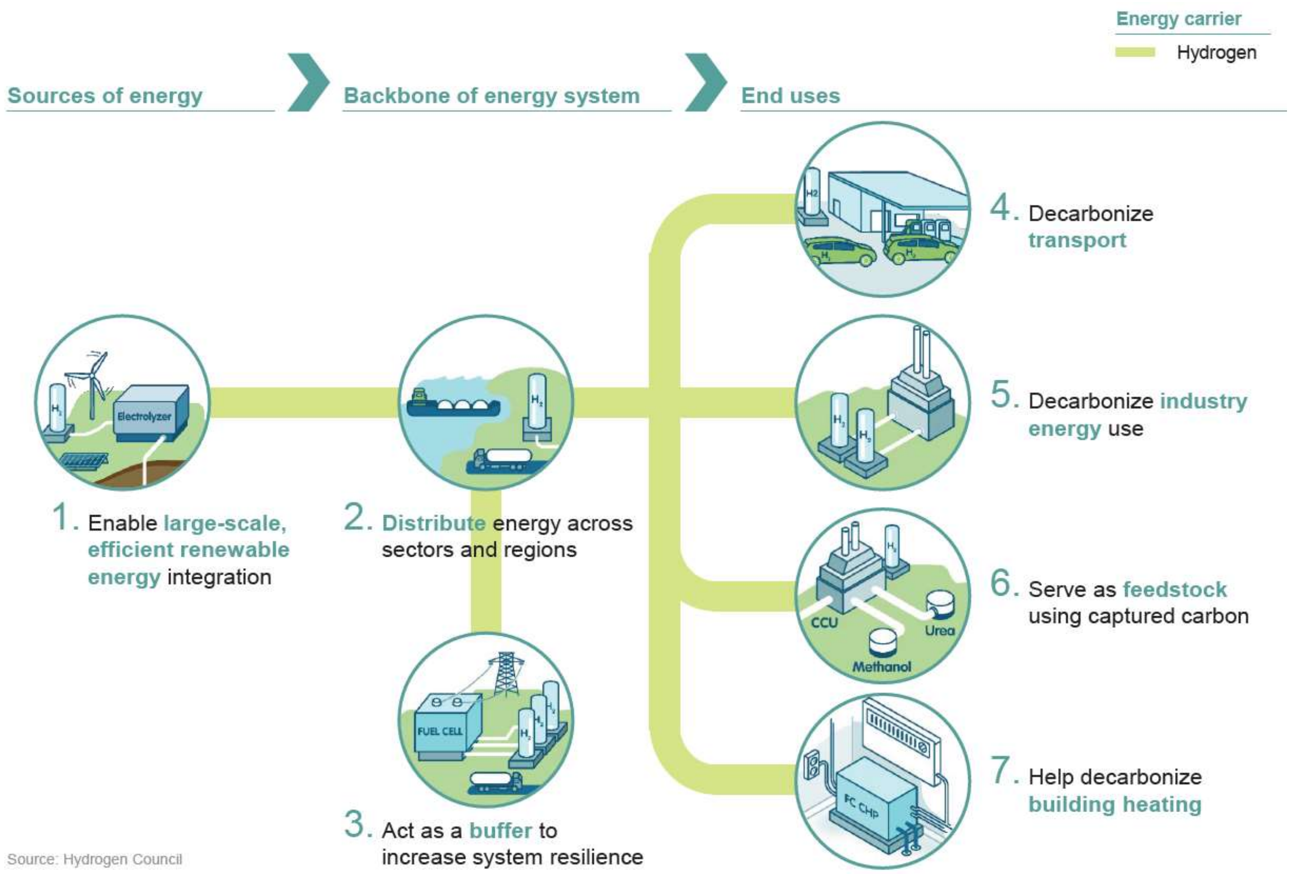


Figure 12: Hydrogen as a tool for decarbonization (Hydrogen Council, 2017)

2.4.4.1 Decarbonize transport

Referring to number four in Figure 12, the FCEV market is part of the transport/mobility sector. Especially car manufacturers are busy with the hydrogen aspect mostly because of the environmental benefits it has in comparison with fossil fuel cars (ICE, HEV, PHEV). With a FCEV there is no emission at all when it is fueled with green hydrogen. This is a main benefit in order to reach zero emission in 2050. There are different opinions on how this target should be reached. They differ between a linear or s-shaped growth curve.

The FCEV has mainly competition of the battery electric vehicle (BEV). The BEV is also zero emission at point of use and completely Z.E. when it is 'fueled' with electricity from RES. Currently the technique and introduction of BEV has a head start on the FCEV. They are cheaper to buy and have an almost sufficient refueling infrastructure but the range anxiety of BEV's helps in the move to hydrogen vehicles. After all, a hydrogen car refills in a few minutes and has a decent range instead of BEV's which take a long charging time. But the prices of FCEV need to be lowered to make them price competitive with BEV's. The most expensive part, and there for the bottleneck, are the membranes which are needed in the fuel cell itself. The production of these membranes needs to be scaled upwards in order to lower the prices of fuel cells (van der Meer, 2016). If prices for those membranes will drop, FCEV's will become more competitive.

Car buyers and users are sensitive to a lot of different aspects, but the most important part with a new engine/fuel type is the refueling infrastructure, followed by a competitive price (Meijer, 2016). [#4] Therefore car buyers and users are only prepared to accept hydrogen when it reduces the energy/fuel bill of the user (Meijer, 2016). The refueling infrastructure remains to be a focus point. Within the upcoming years, more HRS such as the one in the Dutch place Rhoon (see appendix 5.2.1 for the reference project HRS Rhoon) are planned to be realized. Target number is 20 stations in 2020 (van Dijk, 2016). All capable of refueling on the 350 bar and 700 bar standard. For the BEV the company Tesla made big impact by realizing and financing a new infrastructure themselves. The so called supercharger network. Due to Tesla's supercharge network, there is a better infrastructure for BEV compared to FCEV. This is one of the reasons why a large-scale introduction of BEV is to be expected earlier than that of FCEV.

Consumers assume that FCEV are as safe as existing cars (Meijer, 2016). They have a large faith in the technique car manufactures come up with. But according to another source, [#24] there is a fear of hydrogen because of the association with explosions and accidents (Töpler & Lehmann, 2014).

A Fuel Cell is basically an electricity generator. This means that in theory a FCEV car could be turned into a power plant. At the Dutch Delft University of Technology, researchers from The Green Village are busy with the project 'Car as Power Plant' by taking an actual FCEV and turning it into a stationary power plant. Hereby especially focusing on a local and domestic market as visualized in Figure 13.

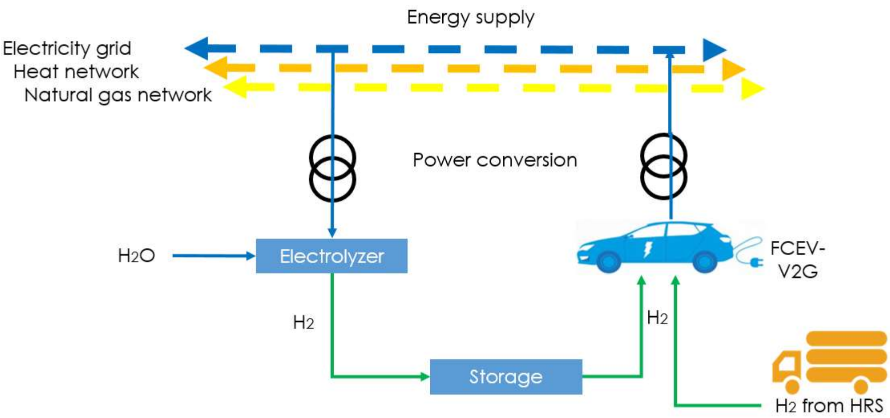


Figure 13: H2 for re-electrification with a FCEV

[#23] Until now the automotive industry has not yet adopted hydrogen as an energy source and also the supply of FCEV models is insufficient (Meijer, 2016) (van der Meer, 2016). It is seen that bus operators are interested in the use of hydrogen busses. Most of the busses are used in dense urban areas where the emission of gases, fumes and particles is limited more and more. Therefore hydrogen gives them the possibility to maintain a decent range but with no emissions while driving. They try to combine hydrogen busses and electric busses within their fleet. Overall they try to use electric buses for in the city, and hydrogen buses for the longer lines.

2.4.4.2 Act as a buffer

The mentioned energy buffer (number three in Figure 12) is seen in combination with industry energy, feedstock and building heating (five, six and seven). There are a few different concepts of hydrogen usage which are applicable in the energy network in the urban environment. These are all considered to be Power-to-Gas systems, but the way how the produced hydrogen is been used differs. Four main different types are found in literature and amongst reference projects. The basics of these four concepts are shown in Figure 14 till Figure 17.

The focus remains on the use of hydrogen as a buffer to increase system resilience and create seasonal storage. There are already a few test cases in which hydrogen is been used. More about these test cases and the reference projects in appendix 5.

Figure 14: The basic principle depends on the feed in of hydrogen directly into the natural gas network (Töpler & Lehmann, 2014). Also see the reference project Hydrogen in NG network | The Netherlands | Ameland in the appendix 5.1.3.

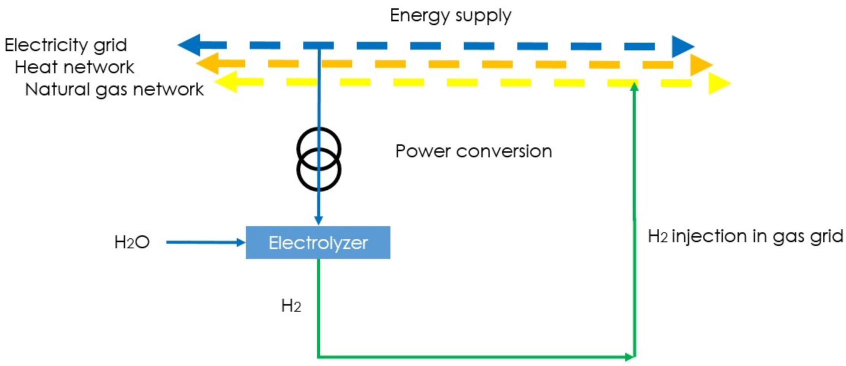


Figure 14: H2 in gas network (see Ameland in appendix 5.1.3)

Figure 15: It has almost the same basic principle, but depending in the price level the hydrogen can be sold as feedstock to the industry besides the option to feed it into the natural gas network (GTAI, 2017) (Energypark Mainz, 2016). Also see reference project P2H | Germany | Mainz-Hechtsheim in the appendix 5.1.5.

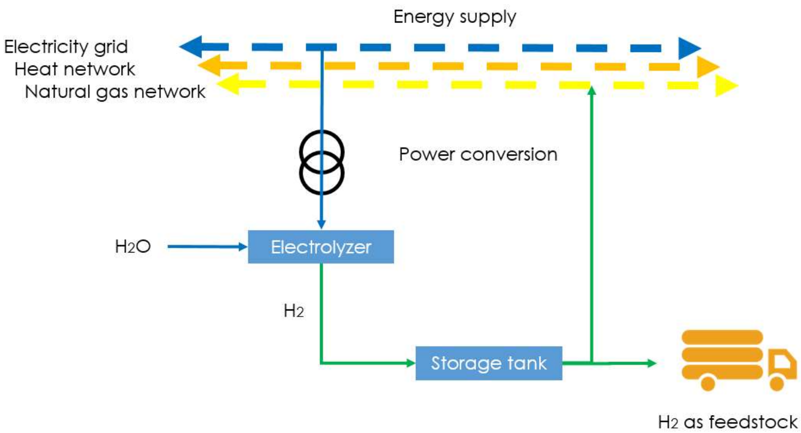


Figure 15: H2 for feedstock (see Mainz in appendix 5.1.5)

Figure 16: Instead of directly feeding in the hydrogen into the gas network, it is first converted into methane (CH4), the same chemical element as natural gas itself (Töpler & Lehmann, 2014). Also see the reference project P2NG | The Netherlands | Rozenburg, Rotterdam in the appendix 5.1.4.

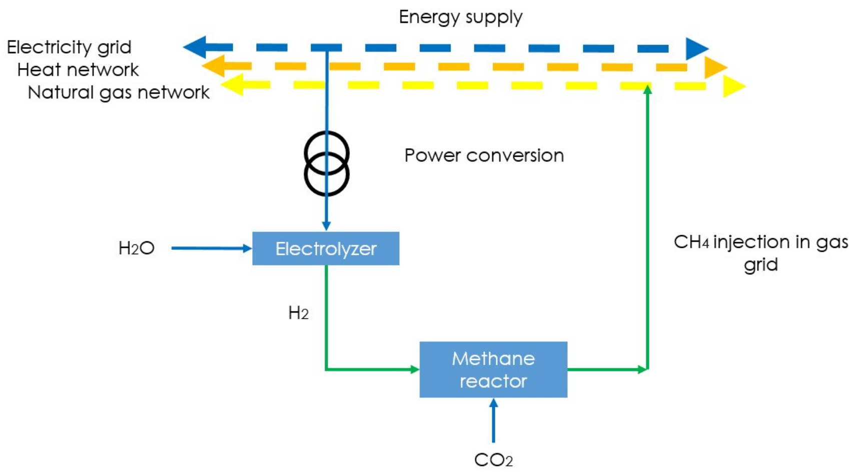


Figure 16: H2 turned into methane, then in gas network (see Rozenburg in appendix 5.1.4)

Figure 17: The hydrogen is stored with the purpose to be used during situations of shortage in the electricity grid and therefore ready to be re-electrified with a fuel cell and function as Distributed Generation (Töpler & Lehmann, 2014) (Ahn & Purewal, 2012). Within this concept also a mobile fuel cell is applicable in the form of a FCEV (Rifkin, 2003).

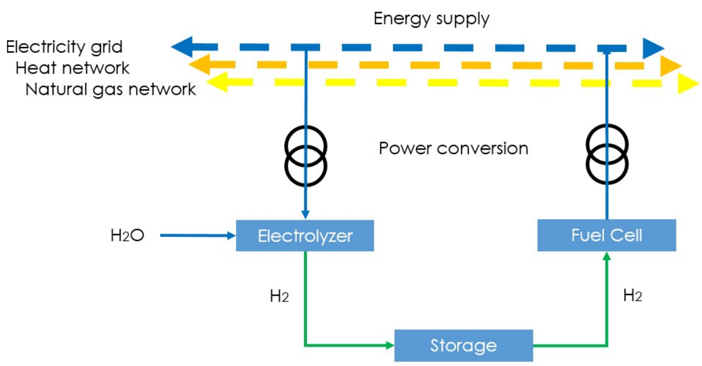


Figure 17: H2 for re-electrification

2.4.5 *Safety aspects*

To be able to use hydrogen, strict rules and regulations must be followed. But hydrogen does not have to be considered as more dangerous as other fuels. For example, because hydrogen evaporates easily, it is safer to be used in a vehicle as petrol/gasoline which will spread over a surface in case of a leak after an accident.

The regulatory framework (standards, regulations, permitting procedures, safety, environmental regulations and spatial planning) concerning hydrogen is now completely focused on the large scale industry and mobility (FCEV and HRS) and not at the more local urban environment. Mainly because such regulations follow after the market demand.

In the urban environment an environmental permit is needed to build something (more about these juridical aspects in part 2.5.3). Applicants of such an environment permit for a hydrogen energy storage will, presumably, have to deal with the Major Accidents (Risks) Decree (Dutch: Besluit Risico's Zware Ongevallen or BRZO). It depends on the amount of hazardous substances (BRZO.nu, 2017).

Companies meant within the BRZO need to fulfill the safety regulations within the Public Safety Decree (Dutch: Besluit Externe Veiligheid Inrichtingen or 'Bevi') such the ATEX, which deals with explosive atmospheres. ATEX originated in France (Atmosphères Explosibles) and has two directives. One about the equipment, which deals mainly with trading. And the second about the use and is meant primarily for the employees who need to work in the hazardous atmosphere of the installations (IECEx, 2017).

Amongst the current regulations there is already expertise by experts on how to use hydrogen and regulated in standards (Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016). Those experts are busy on international, European, national, and application related levels to develop new standards for new utilizations of hydrogen in new, non-industrial, places (Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016) which was also explained during the interview with the NEN (de Jong & Morren, 2016). [#38] But for now there are no sets of standards which explain to what rules a hydrogen energy storage has to comply with which is an obstacle in the meantime (Konings, Interview about verification of findings, 2016).

Appliances must meet the safety regulations before they can enter the market. For gas related products these are gathered in the PGS 15 (PGS is Dutch for Publication Series Hazardous Substances) (ten Have, 2016). This series has as set of rules considering occupational safety, environmental safety, transport safety and fire safety. But hydrogen energy storage is new in this field. Checks and controls are needed. Also equipment to test these appliances, and people to conduct these tests. [#31] There is currently a lack of available, affordable and certificated measurement and control systems for such hydrogen energy storage appliances (Ministerie van Infrastructuur en Milieu, 2013).

What can be learned from the current standards is that the use of hydrogen inside of buildings is not something that will be done easily. The risks involved with this are far bigger than the benefits of using hydrogen indoors. It is possible to make it safe, there are guidelines for the installation: 'Installation permitting guidance for hydrogen and fuel cell stationary applications: UK version' by (Pritchard, Royle, & Willoughby, 2009). But this is all tailored to a specific situation and it's not considered as a universal standard. [#34] So there is a lack of regulations about production, storage and the use of hydrogen in the urban environment, also indoors (Konings, Interview about verification of findings, 2016).

2.4.6 Conclusion

Hydrogen is very different from the well-known natural gas in terms of properties and manners of use. It does not exist as a loose element on earth, only when it is bound to other elements. Therefore, energy is needed to obtain hydrogen.

The production of hydrogen should be 'green' as much as possible. Therefore it is best to use RES (wind and sun) in combination with electrolysis and no steam methane reforming (SMR).

Hydrogen gas is a very light and volatile gas with a relatively large volume. This makes it more difficult in terms of transport and storage compared to natural gas.
Apart from energy storage, there is also a market for green hydrogen in various industries. For example, as a feedstock. In this way, there is a smaller carbon footprint.

In addition, there is uncertainty about the safety of hydrogen. On the one hand this is due to the fact that hydrogen is highly flammable, on the other hand due to the poor reputation of hydrogen among the general public.

Obstacles obtained from this part ‘Hydrogen’ are:
[#22]: the uncertainty surrounding the safety of hydrogen prevents the social acceptance.
[#37]: there is no certification system which ensures that the produced hydrogen always has a sustainable source (the missing of a green-certificate).
[#28]: the reliability of the electrolyser is too low.
[#14]: natural gas pipelines are not suitable for the transport of hydrogen.
[#26]: there still is a lack of knowledge about the impact of hydrogen on the material of transport pipelines, the behavior of burners, etc.
[#35]: the addition of hydrogen in natural gas is only possible to a limited extend (up to 0,02%).
[#2]: the construction of a separate hydrogen gas network is too expensive.
[#32]: there are no hydrogen storage systems available for storing seasonal energy on a large large-scale in the built environment.
[#29]: the reliability of the fuel cell is too low.
[#4]: they only are prepared to accept hydrogen when it reduces the energy bill of the user.
[#24]: there is fear of hydrogen because of the associations with explosions and accidents.
[#23]: the automotive industry has not yet adopted hydrogen as an energy source and that the supply of FCEV is insufficient.
[#38]: there are no sets of standards which explain to what rules hydrogen has to comply with.
[#31]: there is a lack of available, affordable and certificated measurement and control systems for hydrogen.
[#34]: there is a lack of regulations about production, storage and the use of hydrogen in the urban environment, but also for closed spaces and certification of equipment.

2.5 Urban environment

With ‘urban environment’ is meant the city area including the surrounding less denser areas. Within the urban environment there is a focus on energy reduction. Also, there are projects being undertaken which are interesting as reference projects to see what elements are involved and how they are being developed.

2.5.1 Energy reduction

All newly built buildings must comply with the Energy Performance Coefficient (EPC). This is a measure for energy efficiency. New buildings become more energy efficient with the final target of zero emission in 2020 (Bouwend Nederland, 2017).

Of all the buildings that there will be in 2050, 90% already exists today. Houses make up the most of the existing urban environment. There are, rental and private owned combined, 7.9 million dwellings in early 2016. These houses should implement energy saving measures over time as part of the first step of the Trias Energetica.

There are already some initiatives and examples of how housing blocks, or even complete neighborhoods are being made energy efficient. Very often housing blocks, which are owned by housing associations, are quite similar. This makes it easier, and therefore cheaper, to make these house more energy efficient.

[#13] Another approach that is becoming more widespread, is a complete inner city renewal. All the old houses are demolished and a complete new neighborhood is built. This makes it possible to also renew the underground cables and pipes; something which is not possible in existing neighborhoods where there is still a large dependency on the existing energy supplies (Ekker, 2016) (Idema & de Koning, 2014) (BewustNieuwbouw.nl, 2016).

When there is a complete inner city renewal, it is even possible to switch to an autarkic area. This means a district or region is energy self-sustaining. This kind of intentional islanding creates ‘energy-islands’ which are mostly self-sufficient. Within such an autarkic system, surplus produced energy needs to be stored. If the internal storage capacity reaches its limit, the rest of the surplus energy can be distributed to other ‘energy-islands’. [#8] During the interview with the energy supplier it was mentioned that such a system could potentially be too expensive to be placed in inner cities and neighborhoods (Ouillet, 2016).

For every location the most ideal energy situation should be considered separately. [#11] There is still too much focus on a single, uniform nationwide energy solution (van der Molen, Interview about verification of findings, 2016). In some areas such a uniform energy solution won’t work. This can be due to the preservation of a typical look such as (monumental) city centers or large industrial areas, or for other reasons. For these situations a tailored solution should be created.

This can result in some areas that will consume more energy than others as seen in the example in Figure 18 about the three different energy islands. There is also still the belief that there will remain a need for centralized power generation in the future (Dutch Ministry of Economic Affairs, 2016) (Ouillet, 2016). But still, these are exceptions and should not hold back initiatives to make the urban environment more energy efficient.

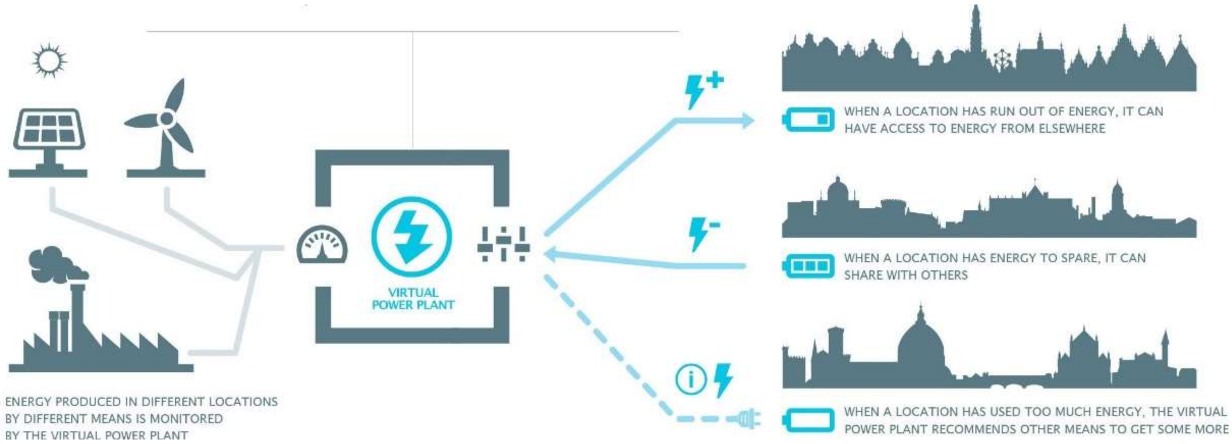


Figure 18: Energy Islands (Altran, 2017)

2.5.2 Near Zero Energy

In order to make the move to less energy consuming neighborhoods and districts, steps are also needed at the building level. A building with a zero net energy consumption is often called a Near Zero Energy building. On an annual base, the amount of energy that is consumed is roughly equally generated on site with RES. Some buildings generate even more energy than they use themselves. These are called 'energy plus' and will get a refund from their energy supplier for the surplus of electricity. This increases the value of that specific building within the right market.

It needs to be mentioned that every building is used differently. Within normal dwellings the energy consumption rate depends on the size of the household; how many people live there, do they all have day-jobs, do they charge an EV at home, etc? All these variables make it difficult to create a generic system that can be implemented in each dwelling in order to make it near zero energy.

With the start of 2020, all newly built buildings need to be near zero energy based on European agreements. The typical elements of a near zero energy building are described by the independent Dutch foundation 'Milieu Centraal' (Milieu Centraal, 2017):

- Very good insulation of the roof, walls and floors
- HR++ glass or triple glazing
- Seamless construction with no or hardly any gaps
- A ventilation system with heat recovery
- A low temperature heating system based on a heat pump or solar water heater
- PV-panels to generate power
- Measuring equipment that can show the energy consumption and generation

Although there are currently buildings that are near zero energy that have a connection to the gas network, it is more likely that new near zero energy buildings will be all-electric, mainly because all the generated energy is in the form of electricity.

2.5.3 Juridical

Before something can be built, an environmental permit (Dutch: Omgevingsvergunning) is needed. It is forbidden to realize a project without a permit in the Netherlands. It is the duty of the local municipality to check the compliance of the application of a building plan before granting the environmental permit. A permit can be rejected based on six different levels. The first three are the most important and relevant for this research. First of all based on the building decree (Dutch: Bouwbesluit), secondly based on the municipal building ordinance (Dutch: Bouwverordening) and thirdly on the municipal land-use plan (Dutch: Bestemmingsplan).

The fourth, fifth and sixth are about the requirements of external appearance, the safety regarding road tunnels and when there is a conflict with a development plan (Dutch: Exploitatieplan) (Hobma & Jong, 2014).

"Always start with the most optimal energetic scenario. Then the regulations will be arranged accordingly in the next step."
(Francoise de Jong, consultant at NEN, 2016)

2.5.3.1 Compliance check environmental permit application

As mentioned above only three levels in which a building plan can be rejected are considered as important for this research.

Building Decree (Dutch: Bouwbesluit)
Within the building decree, mostly the technical details are checked in order to secure health and safety. This document very often refers to safety codes and regulations such as European or national standards (In part 2.4.5 there is more about these safety aspects and standards concerning hydrogen). But in general the building decree, the latest version from 2012, doesn't include hydrogen related standards. It must be said that it has never been the idea within this research to introduce hydrogen inside of buildings such as houses and/or offices due to the low density of hydrogen. Therefore, the building decree isn't considered as an obstacle for now.

Building Ordinance (Dutch: Bouwverordening)
The building ordinance consists of requirements relating to the construction, renovation, operation and demolition of buildings within a municipality as found in Article 8 from the Housing Act. It focuses in particular on the prevention of the construction of new buildings on contaminated soil (Woningwet, 2017). Within a lot of municipalities these requirements are quite similar because they are based on the model from the Association of Dutch Municipalities (Dutch: Vereniging van Nederlandse Gemeenten) (Hobma & Jong, 2014).

This document doesn't include regulations about the energy networks or other sections about the implementation of gas such as hydrogen. It still is focused on the buildings itself just like the building decree. Therefore this building ordinance isn't considered as an obstacle for now.

It only includes the rule that the owner of a new buildings should be able to hand over a report regarding the electrical and/or gas installation issued by a qualified company (article 7a.4.17) (Municipality Tilburg, 2017).

Land-use Plan (Dutch: Bestemmingsplan)
The municipal land-use plan is about what can be built where and with which regulations. It is a document that consists of urban planning regulations. The land-use objectives indicate the allowed land-use such as agricultural, residential or industrial usage. In principle the land-use plan prohibits the placement of an industrial application in a residential area when this isn't set in the corresponding land-use plan. Every ten years the land-use plan must be revisited and possibly renewed. At that point it is possible to make changes to it. There are some possible exceptions in which a land-use plan can be overruled by the municipality. Then an exemption can be granted.

The land-use plan can be an issue with the conversion of electricity into hydrogen and the storage of it. This system could be issued as industrial usage, depending on the scale, and therefore only allowed on the specific areas designated as industrial areas. It depends on the specific locations and land-use plans as to how this will influence a possible implementation of such a system.

Within the current built environment, cities are still growing. As well as expanding in size, they are also becoming denser due to high rise buildings. Physical space inside of these cities and neighborhoods is therefore becoming rarer and also more expensive. [#10] It can be said that there is insufficient physical space for placing energy storage (Dutch Ministry of Economic Affairs, 2016). The land-use plan accounts for this and tries to regulate such issues.

2.5.3.2 Statutory Spatial Plans
The laws and regulations relating to the spatial planning are closely interlinked. This is made visual in Figure 30 in appendix 2. The building decree, building ordinance and land-use plan are all regulated within an overlaying layer, the public law. Of these three, the land-use plan has possible issues with the implementation of hydrogen energy storage, therefore this deserves some more attention. Far above the land-use plan (abbreviated in Dutch to 'best-pl' and seen in the third rectangle from the right) is the Environmental Licensing [General Provisions] Act (Dutch: Wet Algemene Bepalingen Omgevingsrecht or Wabo). This consists of several important parts which will be explained.

The Environmental Licensing Act (Dutch: Wet Algemene Bepalingen Omgevingsrecht or Wabo)
In October 2010, an important part of the Environmental Management Act (EMA) (Dutch: Wet Milieubeheer or Wm) changed into the Environmental Licensing Act. This law regulates the environmental permit. Within this permit, it also arranges the control over the business activities which have impact on the environment. Details of the Environmental Licensing Act are further explained in the Environmental Licensing Decree (Bor) and Ministerial Regulation Environmental Licensing (Dutch: Ministriële Regeling Omgevingsrecht or 'Mor') (Milieuhulp, 2017). This is also visually seen in Figure 30 where the 'Wabo' directs to the 'Bor' and 'Mor'.

The Environmental Licensing Decree (Dutch: Besluit Omgevingsrecht or Bor)
Within this decree there is more detailed information about obtaining an environmental permit. Because the exact type of conversion and storage of surplus electricity in hydrogen isn't clear yet, a broad understanding is used. In collaboration with the safety region Rotterdam (DCMR), it is found that it is possible that a system

concerning hydrogen energy storage would need to follow the decrees found in the Bor under appendix 1, part C, category 2 (Besluit Omgevingsrecht, 2017).

The Public Safety Decree (Dutch: Besluit Externe Veiligheid Inrichtingen or 'Bevi')
This Decree includes zoning about how many meters there should be at least, between sensitive objects and dangerous activities which are regulated in the Major Accidents (Risks) Decree (Dutch: Besluit Risico's Zware Ongevallen or BRZO). It obliges the authorities to keep account of these and it must be implemented in the Environmental Licensing Act and the Spatial Planning Act (Hobma & Jong, 2014). Through experimental research the zoning of each BRZO location will be regulated. Presumably it will first be based on assumptions from the current hydrogen industry (Reijerkerk, Interview about verification of findings, 2016). The companies which fall within the scope of the BRZO need to fulfill the safety regulations such as ATEX, see also part 2.4.5.

The Spatial Planning Act (Dutch: Wet ruimtelijke ordening or 'Wro')
The 'Wro' regulates the land-use plans (abbreviated to 'best-pl' in Dutch, see the gray hatched surface third of the right with 'Wro' in Figure 30). The Spatial Planning Act consists of 'structure visions' proposed and developed by the provinces. It needs to follow the decrees which are described in the Environmental Licensing Act (Wabo). In the end, the municipalities are responsible for the land-use plan which they will try to base on the structure visions given in the Spatial Planning Act.

2.5.4 Conclusion

There are 7.6 million dwellings in the Netherlands which strive to become near zero energy. The energy that still is needed comes from an existing energy network which is difficult to change due to the large dependency on it.

Unfortunately there is not one general solution for all the dwellings or for the whole urban environment. For each location, the most ideal situation should be considered separately.

It now can be concluded that in order to arrange the installation of a system providing hydrogen energy storage, an environmental permit is needed from the concerning municipality. The full process around the provision of such an environmental permit is arranged in the Environmental Licensing Act (Dutch: Wet Algemene Bepalingen Omgevingsrecht or 'Wabo').

Within the Environmental Licensing Act there are references to multiple different acts and decrees based on the parameters of the building plan. These parameters are, among others: the planned location, type of construction, size and capacity, etc. In this situation the land-use plan seems to require the most attention, therefore emphasis needs to be laid on this plan, especially considering the impact from the Environmental Licensing- and Public Safety Decree.

The obstacles obtained from 2.5 'Urban environment' are:
[#13]: it is only possible in new neighborhoods to take a complete sustainable energy system into account in which hydrogen can play a viable role (energy wise, economic, spatial integration).
[#8]: it will be too costly to place an own energy system in inner cities and neighborhoods.

[#11]: there is too much a focus on a single, uniform, nationwide energy solutions while there should be focus on the best energy situation viewed by location.
[#10]: there is insufficient physical space within inner cities and neighborhoods for placing energy storage.

2.6 Stakeholders

This research focuses on the introduction of hydrogen in the traditional energy system as an energy storage carrier. In order to better understand the obstacles within this implementation, it is necessary to know the parties who are involved within the present system, the so called stakeholders. The observations in this part are gathered during the semi-structured interviews with key stakeholders (see part 1.4.5) and during the literature review.

In part 2.2 the functioning of the energy networks is explained. This part provides a better understanding on other involved stakeholders and their responsibilities and relationships within the network.

2.6.1 Energy Network

Amongst the three energy networks, the electricity network is considered as the one with the most future potential. The RES directly generate electricity and therefor the electricity grid is needed.

The gas network currently depends on natural gas as the main energy source, and is therefore not future proof. There are some exceptions of course. For instance when green-gas is fed into the gas network. (Netbeheer Nederland, 2011).

Besides all the different parties mentioned earlier, there are only three main stakeholders to look at in the first place. These are: energy supplier (also responsible for production/generation), system operator (TSO for national, DSO for regional) and the end user.

2.6.1.1 Energy supplier

Role of the energy supplier is to supply electricity, gas and heat to the end users (Ouillet, 2016). Traditionally the energy supplier had its own electricity generation plants. But nowadays electricity can be bought on stock exchanges and there are a lot of new energy suppliers who don't have own generations plants anymore. On the stock exchange capacity of generated electricity is been sold. Depending on the kind of generation, certificates are provided. With RES these are officially called 'GvO's'(Garanty of Origin) but are also often referred to as 'green certificates'. Certiq is the institute that is legally allowed to provide these certificates. It is part of the Dutch TSO, Tennet.

When the energy supplier hasn't purchased enough capacity to fulfill the needs of its customers, extra capacity needs to be bought. This extra capacity is more expensive.

When an energy supplier has a large share of renewable energy, the amount of generated electricity isn't known on forehand. This makes it more expensive as the currently common electricity from fossil fuels.

Storage of energy would become interesting for energy suppliers when there is a large share of RES in their purchased electricity capacity mix. In Germany the share of RES is larger as in the Netherlands. The conversion and storage of energy already has become interesting here and energy suppliers started converting electricity. Mainly with Power-to-Gas plants (Reijerkerk, Interview about verification of findings, 2016) (Germany Trade and Invest, 2016).

2.6.1.2 System operator

The deregulation of the energy market made the DSO and energy supplier split from each other. The DSO has a monopoly position on the midrange and low voltage grid. This is due to the pipes and cables that are underground. Therefore people cannot choose for a different DSO. However, they can choose for a different energy supplier.

Due to the monopoly position, the DSO's are strictly regulated and became partially public. The ACM (Authority for Consumers and Markets) checks if the DSO is functioning effective enough and if their pricing level is accurate. The main expenses from a DSO come from managing the network including expansion of the network, maintenance and fixing occurring failures (Janssen & Lambregts, 2016) (ECN; et al, 2014). Because of this strong regulation to serve the public, it is not allowed to make profit. [#36] The storage of energy is considered as trading by the ACM, and with trading profit can be made. Therefore storage of energy is not allowed by the DSO (van der Molen, Interview about verification of findings, 2016).
However, the DSO has the legal obligation to balance the grid and keep enough voltage available to ensure grid stability. The DSO monitors the supply and demand throughout the time and has a good indication about at what time electricity is needed and when there is almost no demand. But for the small differences back-up power is needed. The DSO contacts with electricity suppliers to generate more or less electricity based with these back-up generators. With the introduction of variable RES, this balancing becomes more difficult because the weather is difficult to predict. Also the generated green electricity is given priority on the grid. This gives a technical imbalance.

The TSO is responsible for the national high voltage network. It has connections with the connected surrounding countries and also contacts between the energy supplier and the DSO (TenneT, 2016). Together with the several DSO's, they are combined in an association, the 'Netbeheer Nederland' (Dutch System Operator).

Within this association, the discussion has risen about the rate at which the energy transition takes place. There is a large uncertainty amongst the system operators about when the RES are the preferred energy source. When this moment is there, the energy system must be ready to accommodate that (Nebeheer Nederland, 2017). This is the system operators' dilemma: Investing to late will result in an unreliable energy network, investing to early can result in wrong investments and will cost too much money (van der Molen, Interview about verification of findings, 2016).

2.6.1.3 End User

There are three basic types of end users. The normal domestic consumer, the prosumer and large consumers such as industries.

The consumer is the end user of the energy system. It pays for the energy it consumes. There are the direct costs of consumption and a fee for the use of the energy grid which are both paid to the energy supplier. They direct the fee for the energy grid towards the DSO and TSO. Only the energy supplier has direct contact with the consumer. The consumer has therefore no contact with the energy producer/generator and the TSO and DSO. Because of this, the consumer has no say in how the TSO and DSO should do their job or how the investments in the energy grid should take place.

The market is very price driven, energy suppliers try to lure consumers with lower prices. [#25] In general consumers aren't very interested in their energy situation (Konings, Exploratory interview about hydrogen, 2016) and their knowledge about the energy system and its sustainability is very low (van der Lelij, de Graaf, & Visscher, 2016). But with lower prices this changes slightly. Consumers can influence the energy system with their choice of energy supplier. For instance when energy suppliers are chosen who promise to deliver a very large share in RES. If this would happen, the environmental goals would be reached faster and the tipping point of when energy storage would become needed get closer.

When the end user is generating its own electricity, for instance with solar panels, it is considered to be a prosumer (producing and consuming). When the own generated electricity isn't used directly, it is send back on the grid. Viewed from an administrative point of view this has no problems. At the end of the year the amount of returned electricity is subtracted from the actual energy usage. This can result in a lowered energy bill, or even a refund of money if more electricity is been generated as consumed. This is called 'salderen'(remuneration). From a technical point of view, it is more complex. The demand and supply patterns don't match, often resulting in a surplus of electricity when there is a lot of generation from pv-panels. The DSO is responsible for handling this local surplus of electricity. In other countries, such as Spain and Belgium, it is not allowed for prosumers to put their surplus of electricity on the grid in order to protect the system of the DSO (Ouillet, 2016). As long as it is allowed for prosumers to remunerate surplus of generated electricity, storage isn't interesting for them (Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016).

With some large consumers it is possible to apply congestion management. Basically this is a form of balancing the energy grid on the demand side by the DSO. Normally balancing is been done on the supply side. With these large consumers special agreements are made which allows them to shortly shut down the electricity use, or consume extra during their processes is there is a surplus on the grid.

2.6.2 Authorities

Within this group 'authorities', parties are included who are considered as authorities. The largest part amongst these is the government. But beside those, also the politicians, education/research institutes and NGO's are grouped. These parties have responsibilities in advising and warning about energy related matters based on their knowledge which is interpreted as an authority. Besides their valuable opinion this doesn't make them a direct stakeholder.

It is the task of the government to implement the environmental policies. Often based on European agreements, but also national agreements, steps are taken which help with the implementation. There are three layers which need to be considered within the government: central government, provinces and municipalities. Within the central government, there are several ministries engaged with the energy aspect and especially with the energy transition (Ministry of Infrastructure and Environment & Ministry of Economic Affairs). It is known that a need arises for energy storage (Dutch Ministry of Economic Affairs, 2016). However, there is no expression of a preferred choice of energy storage carrier. It is considered too early for such a choice. On the one hand because such a choice is too specific for the level where the ministries are operating, on the other hand because it could create a technique lock-in where new and maybe better techniques can't be applied (Bijkerk, 2016).

The energy network needs to follow the environmental agreements where the government has agreed upon. That is why the central government in particular is a stakeholder. Their decisions directly influence the energy network. Provinces and (large) municipalities have to deal with the energy system on district level and have therefore still a large influence (together with the DSO) on how they want to set up the energy system. Therefore, that they are also been considered as stakeholders. [#9] There is unfortunately still a lack and/or little amount of knowledge considering hydrogen and its applications amongst local governments (van Schagen, 2016).

Another stakeholder which is part of the government are the safety regions. Officially those are part of the Ministry of Security and Justice. The Netherlands is divided in multiple regions and each region has the task to ensure safety. Amongst the tasks are fire prevention and the prevention of the event of disasters and crisis's. Within the safety regions a lot of knowledge about hydrogen is available, especially the safety region around Rotterdam where there are a lot of industrial activities involving hydrogen. The safety regions use this knowledge to advise the government in their decisions (de Jong & Morren, 2016).

2.6.3 Counselor

In addition to the group of stakeholders within the energy network, and the authorities, there are also involved parties within the current hydrogen consulting and supply industry. Amongst these parties are companies involved with: advisory, automotive, petrochemical industry, associations and consultants (Dutch Hydrogen Coalition, 2009). These are the specialists who see a key role for hydrogen and already have a business based on it. Considering the role within the hydrogen energy storage, the hydrogen industry can be seen as a supply industry with an operational role. This applies for advice and knowledge, and also for the actual appliances that can produce, store and re-use hydrogen. This makes them a stakeholder due to their knowledge of the existing market, production, uses and techniques. Without these appliances and knowledge about the product, there is no possibility to create a system with hydrogen as an energy storage carrier.

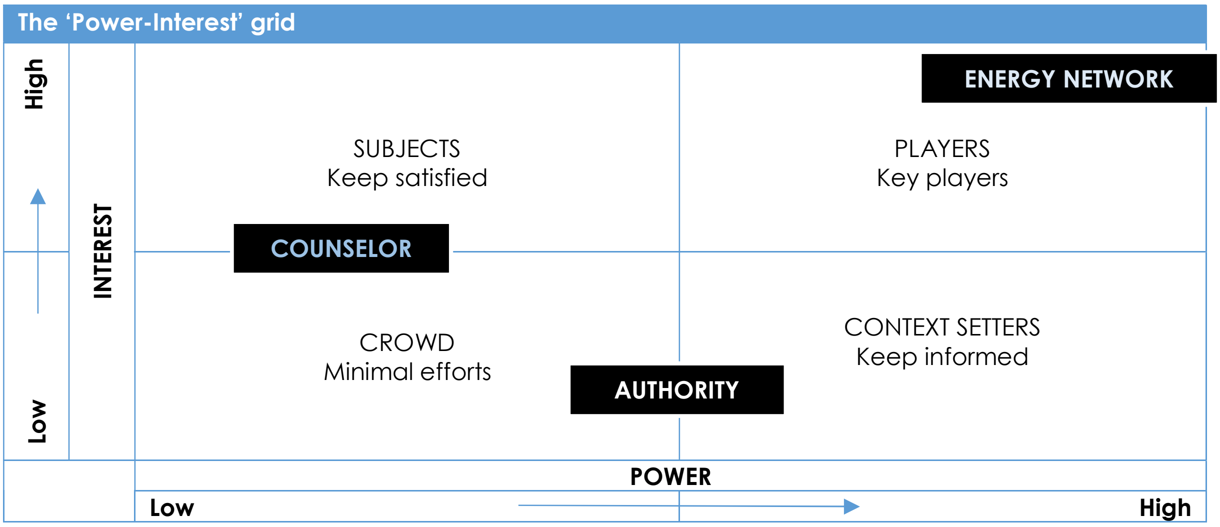
The way the market is going to develop in the future is difficult to predict of course. [#39] But there is a chance that new parties and industries will arise amongst the current existing companies. Especially because the role of the current national energy companies in the energy applications is still unclear (Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016). In the meantime current companies are trying to work together in multiple associations. The goal is to create opportunities by collaborative information provision and create awareness through events. For now all these different parties which are concerned in the hydrogen consulting and supply industry are clustered and considered as one stakeholder group.

2.6.4 Power – Interest

In order to rank the stakeholders, a power-interest grid is been used. Due to the requirement from the methodology, that the profession groups should be homogenous (Delbecq, Gustafson, & Van de Ven, 1975), the stakeholders needed to be narrowed down into three groups (for further explanation see appendix 6.4.1).

In Table 4 the power and interest level of each identified profession group is shown, based on the Mendelow power-interest grid.

Table 4: Power-interest grid with the profession groups



Profession	Power	Interest
Counselor	1	2
Energy network	3	3
Authority	2	1

Stakeholders in the Energy Network are the key players. They have a high power due to their function and role in the energy system. Also their interest is very high because it is their core business. Especially those who are responsible for balancing the grid, which are the TSO and mainly the DSO.

The authorities, and especially the central government have a relative high power. But due to the lack of knowledge, this power isn't as high as the energy network. Therefore, it is considered to be between the context setters and the crowd. The interest level of the authorities only relies on the need to follow the environmental requirements.

For the group seen as counselors, there is only a minor place on the power ratio. There is no direct link with the decision makers and the legislator. But their interest in the subject is very high. After all, they thrive on the market concerning energy storage in hydrogen.

2.6.5 Conclusion

Three profession groups are considered based on the aggregation of stakeholders, namely the Energy Network, Counselor and Authorities. Each profession group has a different ranking in the power-interest grid. The profession group 'Energy Network' is considered to be the group with the most power and the most interest.

Obstacles obtained from the part 'stakeholders' are:
[#36]: the DSO may not facilitate energy storage because it is seen as a commodity.
[#25]: there is little knowledge about the energy system and its sustainability by the public.

[#9]: local governments, agencies and service providers have little to no knowledge and experience with hydrogen and its applications.
[#39]: the role of national energy companies in local energy applications is still unclear.

2.7 Conclusion literature review

This part concludes chapter 2, the literature review and collects the input for the survey. In the parts 2.1 to 2.6, obstacles are gathered based on literature, semi-structured interviews and reference projects. The following sections provide an overview of the gathered obstacles and the obstacle groups.

2.7.1 Obstacles

In the sections 2.1 to 5 are 39 obstacles identified. Within the previous sections, the obstacles are within context. In Table 5 the individual obstacles are shown listed.

Table 5: Individual obstacles (see appendix 4 for a full list with references and the groups)

	It is an obstacle that:	Obstacle group
1	the current CO_2 emission pricing is too low for the introduction of sustainable energy, including neighborhood level.	Economic
2	the construction of a separate hydrogen gas network is too expensive.	Economic
3	there is uncertainty whether hydrogen is the long-term solution due to the relatively high cost per kWh.	Economic
4	they only are prepared to accept hydrogen when it reduces the energy bill of the user.	Economic
5	fossil energy is cheaper.	Economic
6	hydrogen storage systems as a whole, have a low yield.	Economic
7	not all social costs of the fossil energy system are included in the comparison with a sustainable local energy system.	Economic
8	it will be to costly to place an own energy system in inner cities and neighborhoods.	Economic
9	local governments, agencies and service providers have little to no knowledge and experience with hydrogen and its applications.	Integration in built environment
10	there is insufficient physical space within inner cities and neighborhoods for placing energy storage.	Integration in built environment
11	there is too much a focus on a single, uniform, nationwide energy solutions while there should be focus on the best energy situation viewed by location.	Integration in built environment
12	private energy storage systems per dwelling, for example home batteries, get more attention than a central storage in the neighborhood.	Integration in built environment
13	it is only possible in new neighborhoods to take a complete sustainable energy system into account in which hydrogen can play a viable role (energy wise, economic, spatial integration).	Integration in built environment
14	natural gas pipelines are not suitable for the transport of hydrogen.	Integration in energy grid
15	there is currently no need to use hydrogen as a part of grid balancing systems.	Integration in energy grid
16	there is still sufficient transmission capacity in the national and regional electricity grid to accommodate peaks and increased demand.	Integration in energy grid
17	there are plenty of other local systems available which allow both local grid balancing and seasonal energy storage.	Integration in energy grid
18	energy systems based on fossil fuels are still to be used for decades.	Integration in energy grid
19	hydrogen has a disruptive effect in the local energy system, both in generation, during storage and with re-use in as well gaseous form or as electricity.	Integration in energy grid
20	local, sustainable produced hydrogen is more expensive to citizens as fossil fuels.	Public acceptance
21	there is a remuneration for solar PV, making local energy storage less interesting for the owners of the PV.	Public acceptance

22	the uncertainty surrounding the safety of hydrogen prevents the social acceptance.	Public acceptance
23	the automotive industry has not yet adopted hydrogen as an energy source and that the supply of FCEV is insufficient.	Public acceptance
24	there is fear of hydrogen because of the associations with explosions and accidents.	Public acceptance
25	there is little knowledge about the energy system and its sustainability by the public.	Public acceptance
26	there still is a lack of knowledge about the impact of hydrogen on the material of transport pipelines, the behavior of burners, etc.	Technique
27	the system can't respond fast enough on a surplus of electricity (about 10 minutes at a 'black start').	Technique
28	the reliability of the electrolyzer is too low.	Technique
29	the reliability of the fuel cell is too low.	Technique
30	there is no complete functioning Smart Grid yet.	Technique
31	there is a lack of available, affordable and certificated measurement and control systems for hydrogen.	Technique
32	there are no hydrogen storage systems available for storing seasonal energy on a large large-scale in the built environment.	Technique
33	there are no administrative and pay-off systems available for remuneration schemes of locally produced sustainable energy and the use of this in neighborhoods.	Technique
34	there is a lack of regulations about production, storage and the use of hydrogen in the urban environment, but also for closed spaces and certification of equipment.	Law and regulations
35	the addition of hydrogen in natural gas is only possible to a limited extend (up to 0,02%).	Law and regulations
36	the DSO may not facilitate energy storage because it is seen as a commodity.	Law and regulations
37	there is no certification system which ensures that the produced hydrogen always has a sustainable source (the missing of a green-certificate).	Law and regulations
38	there are no sets of standards which explain to what rules hydrogen has to comply with.	Law and regulations
39	the role of national energy companies in local energy applications is still unclear.	Law and regulations

2.7.2 Obstacle groups

Initially the obstacles where seen as individually valuable obstacles. During the research process it showed that the individual obstacles sometimes had overlap and were not defined uniquely enough. Also in the feedback of the questionnaire, respondents gave the feedback that the formulation of the obstacles could be clearer to minimize interpretation differences.

Because of the overlap that was seen between individual obstacles, it was possible to rubricate them into groups namely: economy, integration in the built environment, integration in the energy grid, public acceptance, technique and law & regulations. See Table 6 for an overview of these groups and their description. By this move, the obstacles where better defined and became more unique. This clustering of obstacles was based on the expertise of the company supervisor and the obstacle groups are checked during verification interviews.

Table 6: Obstacle groups

	Obstacle groups:	Description (incl. source):
1	**Economic**	Obstacles regarding the financial situation of an organization and involved costs. This involves the production of hydrogen itself out of electricity (Murthy Konda, Shah, & Brandon, 2012; 7), but also the costs of adapting and/or creating a hydrogen network. Financial investments as well for private persons as for commercial parties as for society (see parts 2.2, 2.4 and 2.5).
2	**Integration in built environment**	Obstacles that are connected to the integration of energy storage in the Built Environment. This includes the spatial planning (Smit, Weede, & de Groot, 2007), land usage (Cherry, 2004) but also how organizations should deal with the implementation side (see part 2.2).
3	**Integration in energy grid**	Obstacles that describe the interaction between the energy networks and energy storage facilities (see part 2.2 and 2.3). Hereby considering the interactions between hydrogen production and the electricity sector in a wider context (Ball & Weeda, 2015).
4	**Public acceptance**	Obstacles that involve the adaptation to a new energy source, including the perception of risks, image/reputation, way of usage, pre-known knowledge or unawareness, sense of urgency (environmental concerns) and the total public attitude towards hydrogen. Among the scientific community there is a so called 'unspoken consensus' (Cherry, 2004). The public acceptance is seen as one of the aspects that influences the transition (Smit, Weede, & de Groot, 2007) (see parts 2.4 and 2.5).
5	**Technique**	Obstacles that involve a lack of availability and or knowledge of soft- and hardware which is needed for hydrogen energy storage facilities (see parts 2.3 and 2.4).
6	**Law and regulations**	Obstacles regarding the law and regulations that are involved with hydrogen, focusing on the usages that are related to the production, storage and distribution (see parts 2.4 and 2.6).

3 METHOD AND RESULTS

With the Fuzzy Delphi Method it is possible to get the prevailing opinion of the most important obstacles by using the opinions of a group of stakeholders and experts. As explained in the methodology, there are four steps within the FDM (Hsu, Lee, & Kreng, 2010):

1. Collect opinions of decision group
2. Set up triangular fuzzy numbers
3. Defuzzification
4. Screen evaluation indexes

The first step of FDM to collect opinions of the decision group (Hsu, Lee, & Kreng, 2010). The chosen method for the first FDM step is a survey, based on an online anonymous questionnaire. The input for this questionnaire is given in 2.7, the conclusion of the literature review, namely the obstacles and the case description. In order to check the reliability of the input, there has been a verification. In collaboration with the company supervisor, five experts from different backgrounds were selected to interview.

At the end of the survey, data is collected which needs processing by the other three FDM steps. Finally, there should be a clear, assignable prevailing opinion about the importance of the obstacles.

3.1 Verification of input

During five semi-structured interviews with people from different backgrounds, the obstacle groups and case description were tested. These interviews can be found in appendix 7.19 until 7.23. The interviews themselves were semi-structured. The interviewees were all asked the same kind of questions about the findings and assumptions. The way in how the conversation went differed depending on the given answers. Therefore, there are differences between the interviews. In general they can be compared. Table 14 in the appendix 6.1 shows an overview about the additions and remarks that were given.

Two main things were concluded from this verification. First was the addition of a few obstacles that didn’t pop up earlier. And secondly, that the case description shouldn’t be too precise and just considered as a ‘black box’ (Konings, Interview about verification of findings, 2016). These two points were added in the questionnaire before it was sent.

3.2 Method

In this part the collection of opinions from the decision group is further explained. For a separate and more elaborate explanation of the questionnaire, see appendix 5.

3.2.1 Survey - Collect opinions of decision group

A total of 102 people from different professions were selected to participate in the survey by filling in an online questionnaire anonymously. After a week, 45 completed questionnaires were collected, giving it a response rate of 44%. The questionnaire consisted of an introduction where the topic of the research was explained. Secondly the respondent had to make a choice between 12 profession options in order to determine their background and level of knowledge. This was needed because it was an anonymous questionnaire and otherwise the background of the respondent would be unknown. Then the case description was explained where the respondent got more familiar with the research objective.

Finally the obstacles were presented. The start of every following question was: ‘Is it an obstacle that…?’. For each obstacle a choice was needed from the respondent about if they thought it was an obstacle or not. Based on the three-point likert-scale the answering questions were: ‘Yes’, ‘No’ and ‘I don’t know’. In this way, a large shift could be made between the more important and recognized obstacles and the ones with a lower impotency.

3.2.2 Set up triangular fuzzy numbers

The raw data was collected after the questionnaire, it was processed into usable data by the fuzzification. This is necessary in order to obtain the purer value of the choice. Within this questionnaire, there were only closed questions. Suppose someone doubts between two options but has to choose because these are closed questions, then his real opinion is not considered.

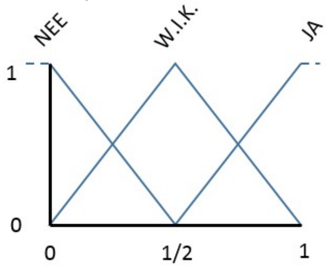


Figure 19: Three point Likert-scale (‘NEE’ = No, ‘W.I.K’= I Don’t Know, ‘JA’= Yes).

Table 7: Three-point Likert scale (L, M, U) (L = Lower-, M = Middle-, U = Upper bound).

No	I Don’t Know	Yes
(0, 0, 1/2)	(0, 1/2, 1)	(1/2, 1, 1)

With the fuzzification of the answers, a common denominator is taken. In case of this questionnaire, with the three choice options, the three points Likert-scale has been used (see Figure 19 and Table 7). Consider someone chooses the answer ‘I don’t know’ then the range from zero to one is applicable with a peak at ½. Hereby zero is the ‘lower bound’, ½ the ‘most probable’, and 1 the ‘upper bound’.

For every obstacle from each respondent such data is collected. In order to gather the mean value of the respondents, the data needs to be aggregated. There are different techniques for this aggregation, some of which are experimental (Habibi, Jahantigh, & Sarafrazi, 2015). Within this research the simplest method is been used for the fuzzy aggregation of respondents’ opinions, the ‘fuzzy average’ (see Figure 20). Mostly because all the respondents’ opinions are considered as triangular fuzzy numbers because the range between the answers isn’t that big with only three options.

$$\mathrm{Fave} = \frac{\sum \mathrm{L}}{\mathrm{n}}, \frac{\sum \mathrm{M}}{\mathrm{n}}, \frac{\sum \mathrm{U}}{\mathrm{n}}$$

Figure 20: Fuzzy Average (L = Lower-, M = Middle-, U = Upper bound).

3.2.3 Defuzzification

The three numbers which make up the fuzzy average (L,M,U) represent the mean value from the respondents about a certain obstacle. The equation $\frac{L+M+U}{3}$ is used to defuzzify the mean values and make it into crisp values. This results in an overall score where all the respondents’ opinions aggregated as equally into an average as seen in Figure 21. In this figure is seen in what order the obstacles are ranked by the average respondents opinion. This is in the situation where all the respondents are considered equal, so without taking their background into consideration.

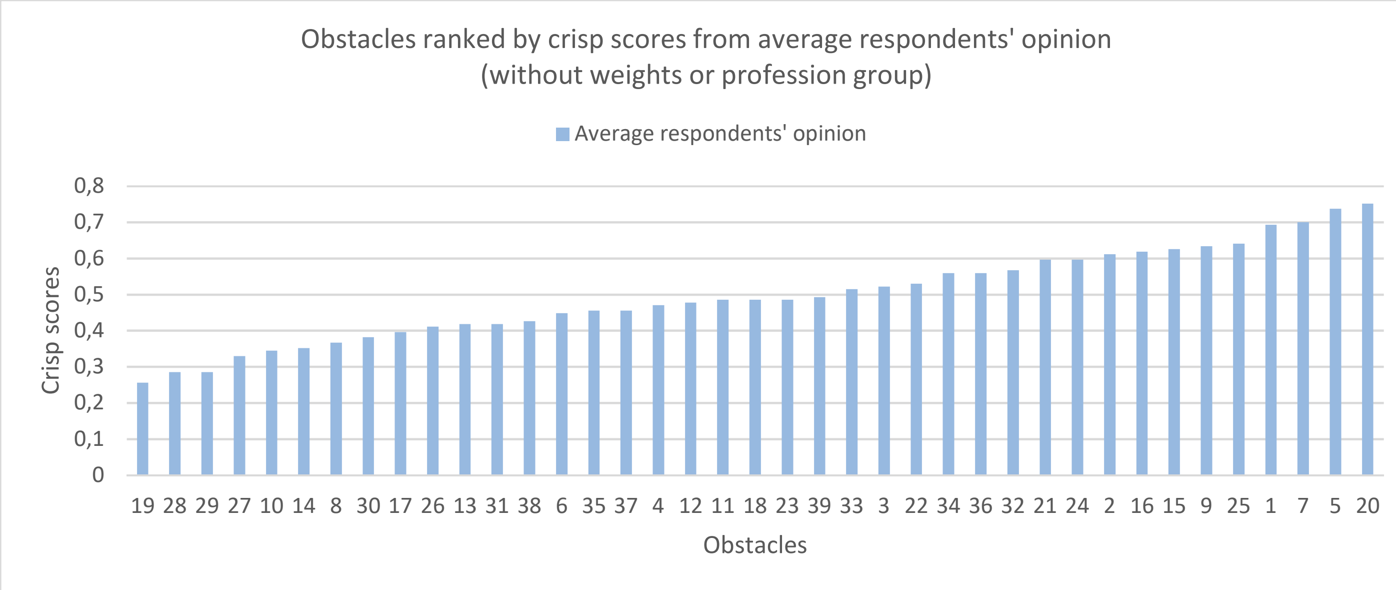


Figure 21: Obstacles ranked by crisp scores

3.2.4 Screening criteria

Besides the three profession groups; Counselor, Energy network and Authority, the obstacles are gathered in different obstacle groups. Both are used as different screening criteria. Each profession group has a different background, with a different power and interest level concerning the topic, as seen in the stakeholder part 2.6.4. Therefore, a weight was added to each profession group. The profession group with a higher valued opinion and knowledge level was considered as more important and had therefore a higher impact on the results as the other two profession groups.

Second criteria is the way in how the respondent's opinion is shown. There are three levels been distinguished:

1) the average respondent's opinion as seen in Figure 21;
2) the profession group (in which the average respondents' opinion is shown of those belonging to the same profession group), and;
3) the weighted profession group which shows the profession group but with the addition of the weights.

Because of the differences in aggregation, the values between the different levels can't be compared. These outcomes of the questionnaires are shown in the next part, questionnaires results.

3.3 Survey results

In this part the results are observed and discussed. The way in how the following graphs are created is explained in appendix 5.

After the defuzzification step of the data from the questionnaire, the information was put in sequence. In Figure 21 is shown what individual obstacles are considered as important by the average of all the respondents combined. This results in a graph where on the right part the most important obstacles are shown. These are #20, #5, #7, and #1. The corresponding description for these obstacles can be found in Table 8.

Table 8: Obstacle descriptions

#	Description
20	It is an obstacle that local, sustainable produced hydrogen is more expensive to citizens as fossil fuels.
5	It is an obstacle that fossil energy is cheaper.
7	It is an obstacle that not all social costs of the fossil energy system are included in the comparison with a sustainable local energy system.
1	It is an obstacle that the current CO_2 emission pricing is too low for the introduction of sustainable energy, including neighborhood level.

It is interesting to see how each profession group values the obstacles in each obstacle group. In Figure 22 the popularity of each obstacle group is shown in relation to the opinions of each profession group. The first bar of each of the six groups shows the average respondents opinion on the obstacle group. The other three bars show how each profession group scored within that group. During the questionnaire the obstacles within the group 'Technique' where chosen least frequently, followed by 'Integration in Energy Network', 'Integration in Built Environment', 'Law and Regulations' and 'Economy'. The obstacles within the group 'Public Acceptance' where chosen most frequently.

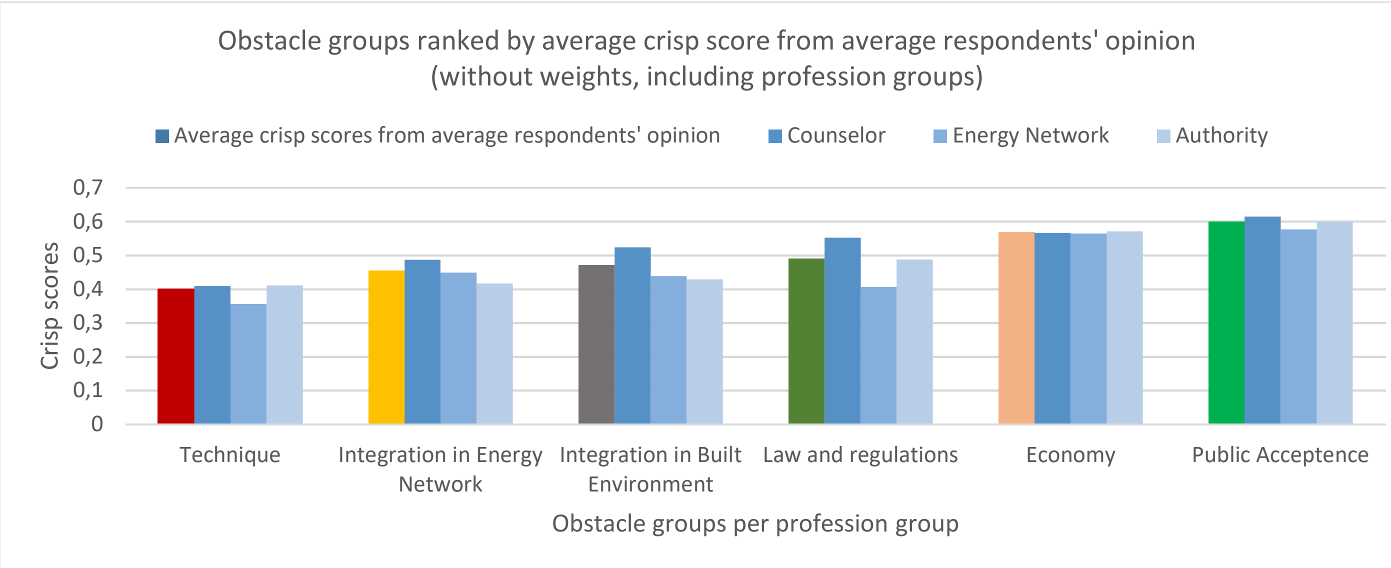


Figure 22: Obstacle groups ranked by profession group

When looking at each obstacle group, it is shown that the counselors more often score above the average. Especially when being compared with the energy network that scores below average at all obstacle groups. The authorities however score around average. It is not sure what this could mean. Might the energy network be very optimistic or naive? And has the group of counselors the opposite opinion? Further research would be needed to find that out.

In Figure 23 the obstacles are now put in sequence within their obstacle group. Also the weights are now added to the respondent's opinions. The threshold (red line) is determined to make a shift between the less and the more important obstacles. The obstacles that rise above the threshold are #20, #5, #1, and #15.

It is to be noticed that the high scoring obstacles from in Figure 21 are slightly different as those who score high after the weights are added. This is because the impact of the value from the respondent's opinion is now also considered. With the weights added, the order of importance per obstacle group didn't change. This can be seen when comparing the order of obstacle groups between Figure 22 and Figure 23.

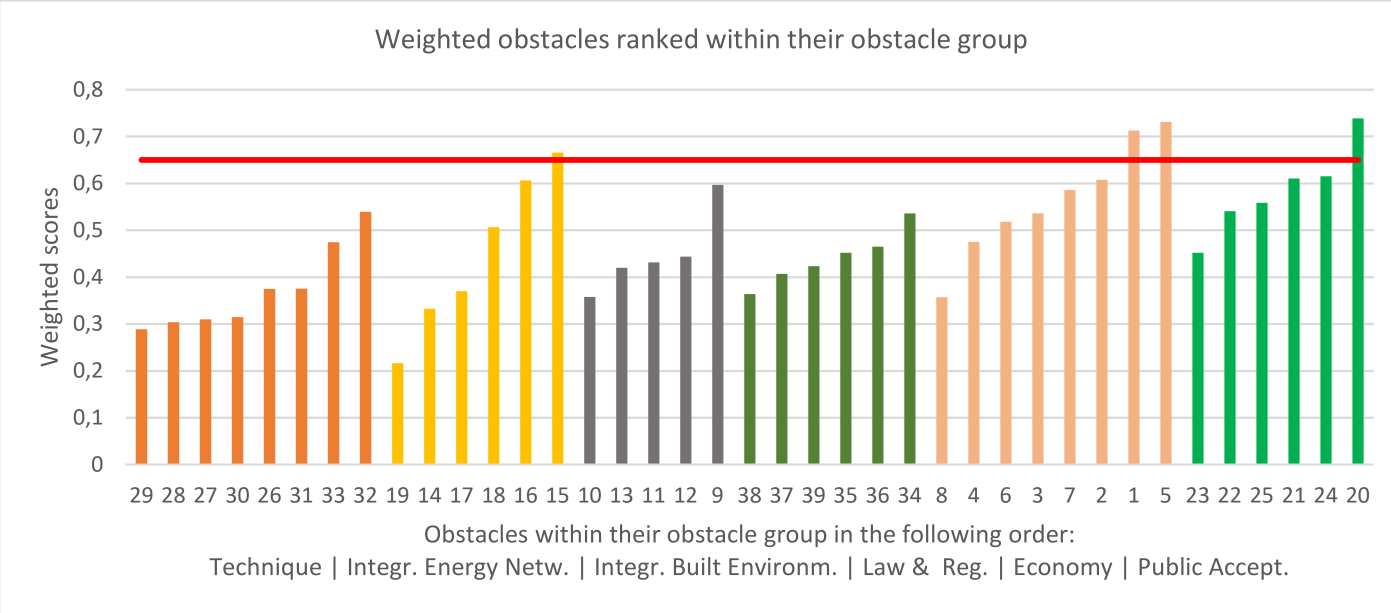


Figure 23: Weighted obstacles ranked within their obstacle group

The four obstacles that score above the threshold level are put together in a graph as seen in Figure 24. For these obstacles specifically it is interesting to see how the profession groups ranked them. Especially at obstacle #15 it is seen that the profession group 'authority' ranks this specific obstacle lower on average. This could also be the answer why this obstacle isn't amongst the four highest ranked obstacles when no weights are added as seen in Figure 21.

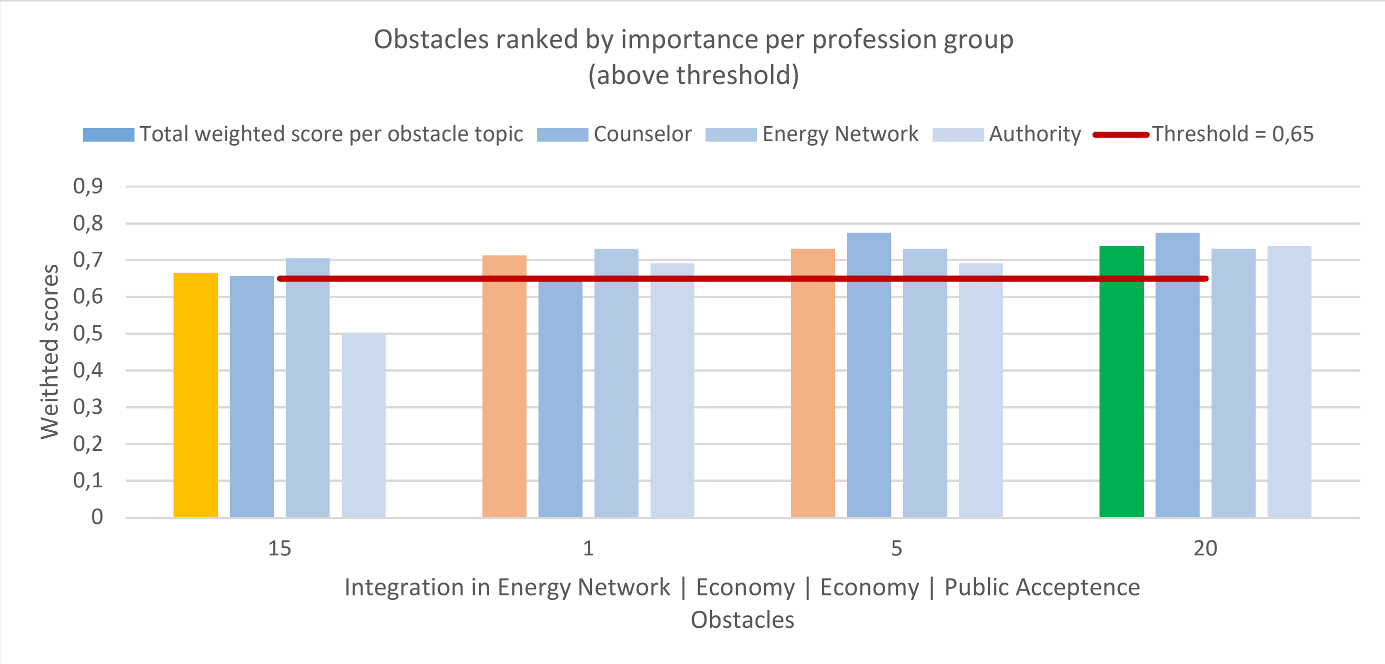


Figure 24: Obstacles ranked by importance by profession group

Besides the preferences from the profession groups for the obstacle groups, now it also can be seen how they ranked the obstacles individually. See Figure 25, Figure 26 and Figure 27 for the counselor, energy network and authority. In this breakdown the individual obstacles are put in sequence for each profession group. This shows in what order the profession groups rank the individual obstacles. These rankings are without the weights added. The obstacles accentuated in red are the four which ranked above the threshold. For the counselor and authority the top 4 also consists of obstacle # 7. This specific obstacle is ranked not very high by the energy network. In Table 9 the highest scored obstacles are shown with their full description.

Table 9: Obstacle descriptions

#	Description
20	It is an obstacle that local, sustainable produced hydrogen is more expensive to citizens as fossil fuels.
5	It is an obstacle that fossil energy is cheaper.
1	It is an obstacle that the current CO_2 emission pricing is too low for the introduction of sustainable energy, including neighborhood level.
15	It is an obstacle that there is currently no need to use hydrogen as a part of grid balancing systems.

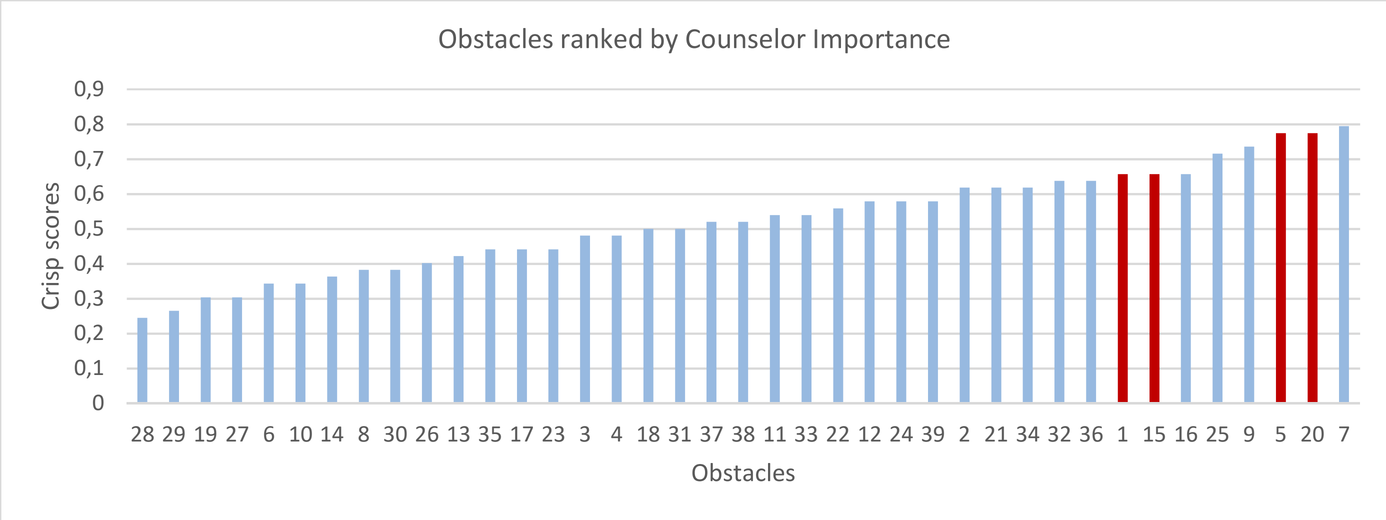


Figure 25: Obstacles ranked by Counselor

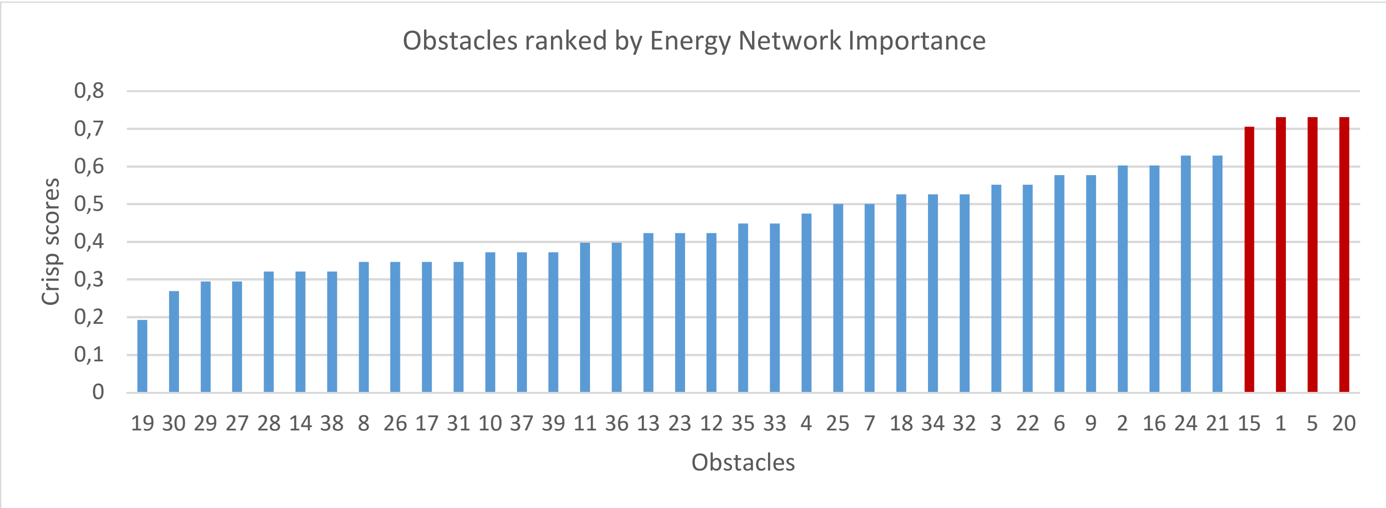


Figure 26: Obstacles ranked by Energy Network

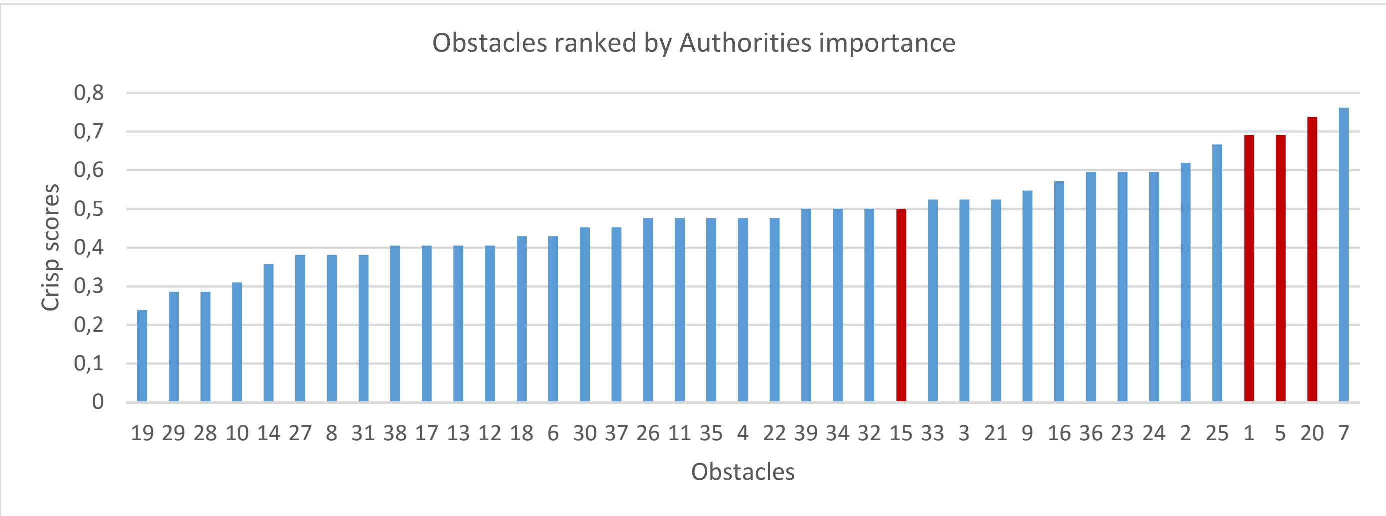


Figure 27: Obstacles ranked by Authority

3.4 Conclusion of survey

The anticipated survey results which are mentioned in the methodology are a ranking of obstacle groups by individual experts and a ranking based on the profession groups.

For the individual obstacle ranking, without using the profession group, the obstacles #20, #5, #7 and #1 are ranked highest above the threshold (Table 8).

The individual obstacle ranking with the inclusion of profession groups, the obstacles #20, #5, #1 and #15 are ranked highest above the threshold (Table 9).

In the ranking of obstacle groups by the profession groups, the group public acceptance is ranked highest by all profession groups (Figure 22).

4 CONCLUSION

In this final chapter of this thesis the findings of the research are presented. In order to answer the main research question, six sub questions were formed at the beginning. These are first answered in the part below and are based on the knowledge gathered from the literature review, semi-structured interviews and reference projects. The second part gives the main conclusion and answers the research question. After the main conclusion, there is the recommendation, relevance and reflection.

4.1 Sub question answers

Part of the conclusion are the answers to the sub-questions. The sub-questions were drawn up at the beginning of the study in order to be able to understand the subject matter and to be able to explore specific parts in more detail. At the start of the research, these questions helped to provide a framework in which the research should be placed and within which scope. They also helped to provide the answers to the main question.

1) *Which stakeholders are involved in the Dutch energy network besides the TSO and DSO's?*

The Dutch energy network consists of three independent systems for electricity, gas and a heat. In each of these three energy networks the same three roles are identified, the energy supplier, system operator and the end user. The role of energy supplier is to supply energy to the end user. The TSO and DSO together are the system operator and have the responsibility to balance the energy grid to meet supply with demand.

Besides these parties, the government has a large steering role because of its legislative power. Together with education/research institutes, safety regions and NGO's these groups have responsibilities towards the energy network and are therefore considered to be authorities.

During this research also the counselors are identified. These are specialist who see a key role for hydrogen and already have a business based on it. For hydrogen energy storage these counselors are considered as a key stakeholder. The counselors have however a small role within the Dutch energy network.

The broad scope of professions is narrowed down in this research to three homogenous profession groups, the energy network, authorities and counselors. Derived from the stakeholder analysis, the profession group 'Energy Network' is considered to be the one with the most power and interest.

2) *Is hydrogen stored on a local scale interesting to cover 'long stay' storage of energy?*

Local scale refers to the neighborhood level for hydrogen energy storage. Availability of space and stringent safety regulations are possible issues why any kind of storage would not be interesting. Hydrogen can only be stored after it is produced. This requires an area where there is surplus of electricity from RES, for instance from prosumers. Therefore not every neighborhood is suited for hydrogen energy storage.

Hydrogen has a storage potential based on its chemical characteristics for 'long stay' (weeks/months) which means for seasonal storage. There are different forms in which hydrogen can be stored. As a normal gas, highly compressed gas, as a liquid, bound to other elements or converted to NG or NH^3. Depending on the planned usage of hydrogen, different storage techniques are favored. Locally stored hydrogen can therefore be interesting in certain situations where there is available space, a surplus of electricity from RES and a planned usage of the hydrogen.

3) *What is the experience of current users of hydrogen products such as:*
    a. *Pilot projects*

The hydrogen refueling station in Rhoon is a pilot project where hydrogen is introduced as an energy carrier in the urban environment. An interview with the project manager (see appendix 7.10) revealed his experiences. In this case hydrogen is used for refueling cars and busses. The technical part and juridical procedures of this project weren't seen as a difficulty. Biggest obstacle was the public acceptance. In this project a personal approach really helped smoothening the acceptance. For this personal approach, experts where used to educate people about hydrogen. As a close second obstacle came the business case for this hydrogen refueling station. There were not enough projected customers to sell the hydrogen to in the beginning.

    b. *Chemical industry (basic physics of hydrogen)*

Within the chemical industry hydrogen is very common and already been used for over a hundred years. There are many safety regulations that help creating a safe environment and there is some good education for people who work with hydrogen. There is a common believe that everything can be made safe, depending on the amount of risk that will be accepted.
The hydrogen generation plant in Mainz is an interesting pilot project. At an industrial park, outside a larger city, there is a green hydrogen production plant which uses the surplus of electricity of a nearby windmill park. A large site filled with multiple equipment to produce, compress and store hydrogen. The hydrogen can be transported by tube trailers for industrial or mobility purposes, or it can be fed into the local gas network. These two options could be interesting scenarios in addition to seasonal storage. Especially when the business case for energy storage alone won't be feasible.

    c. *Manufacturers Hydrogen cars and FCEV*

Strict laws are presented to limit the CO_2 emission of cars. In 2050 new cars must be Zero Emission (Z.E.). Car manufactures are testing with new powertrains and techniques such as Battery Electric Vehicles (BEV) and Fuel Cell Electric Vehicles (FCEV). Where BEV's have a small range and a long charging time, FCEV's are quick to refill and have a larger range. Unfortunately FCEV are more expensive due to Fuel Cell. Either way, both new types are still more expensive as regular vehicles with an Internal Combustion Engine (ICE) and until the last moment of 2050, these type of cars are allowed to be sold. There are different opinions on how the shift from cars with internal combustion engines to Z.E. should go; a linear change or as an S-shaped change curve.
An important obstacle for car manufactures considering FCEV's is the lack of a refueling infrastructure. For instance Tesla has seen the same obstacle but with their BEV's and decided to create a refueling infrastructure themselves by introducing the supercharge network. But this development is not beneficial for the market development of FCEV.
Bus operators are also busy with making their fleet Z.E. Overall they try to use electric buses for in the city, and hydrogen busses for the longer lines.

4) *What is the current legislation concerning hydrogen and are there prohibitions?*
    a. *Regulations*

The current regulations focus on the current uses of hydrogen, which is in the chemical- and food processing industries. These highly regulated environments aren't comparable with the urban environment where this research is focusing on. There are new standards and regulations being developed on national and European levels but these are still under development.

b. Standards like NEN PGS 35

During the research, the PGS 35 was a relatively new standard. Therefore it was an interesting piece. PGS 35 is specifically written for hydrogen refueling stations and for the specific situations those stations are being used. There are however specialized codes for stationary fuel cell systems and gas infrastructures. These are really aimed on the devices themselves so on a technical basis instead of the surroundings where they are being planned. Therefore the direct impact on the surrounding urban environment in general is unknown.

c. Spatial Planning Act & Land-use Plan

Just like all planned construction work, an environmental permit (Dutch: Omgevingsvergunning) is needed from the concerning municipality. The requirements for this permit are described in the Environmental Licensing Act (Dutch: Wet Algemene Bepalingen Omgevingsrecht or 'Wabo'). This document refers to multiple different acts and decrees which depend on specific parameters of the building plan. Specificly the land-use plan (Dutch: Bestemmingsplan) requires the most attention of the described acts and decrees in the Wabo, especially considering the impact from the subparts of the land-use plan, the Environmental Licensing- and Public Safety Decree (Dutch: Besluit Omgevingsrecht or Bor and Besluit Externe Veiligheid Inrichtingen or 'Bevi').

It remains important to mention that it has been advised not to aim on hydrogen usage indoors. The risks involved with the use indoors are far bigger than the foreseen benefits.

5) Is there a willingness to store seasonal energy in hydrogen by DSO's?

The main three DSO's are busy with developing scenarios on how they should handle the energy transition. More specifically, how to deal with the upcoming imbalance between the demand pattern and the supply of RES. Some are further as others in accommodating this. Some are already busy with test cases and pilot projects involving different energy storage systems and energy conversion techniques. Also when the RES are becoming cheaper in comparison with energy from fossil fuels, a rapid change of the network is needed. The DSO's are busy with developing models which can predict when and where these first changes of main energy source will occur. One major difficulty within the storage of energy, is that storing energy is considered by the government as trading. DSO's are by law not allowed to trade energy due to their monopoly position. Therefore, the DSO's aren't really interested in storing seasonal energy yet but foresee a need for energy storage in the future.

6) What are the roles and needs of TSO's, DSO's and other users in the future system for hydrogen storage?

There is not one vision about what and how the role of DSO's will be in the changing energy system. It is expected that a lot of changes are emerging in the upcoming years. Due to the trading prohibition of DSO's, it is possible that new companies will arise who take over the role of balancing the grid by trading energy storage space. It is also mentioned that the future function of the DSO will probably be more important as it is nowadays due to more investments in hardware (cables and pipes) and software (Smart Grid) which makes the DSO's data analysts and energy handlers.

4.2 Main research question answer

Existing energy networks will have a problem with balancing seasonal differences between supply and demand. Until now the widely used option to deal with the increasing need for flexibility is increasing the cable capacities. This is an expensive solution that isn't feasible with the expected growth of supply from RES within the urban environment. It is predicted that around 2030 new balancing systems are needed. Hydrogen energy storage has the potential to fulfill in the need for seasonal balancing by converting surplus of electricity into hydrogen without any emissions.

To help ease the introduction and implementation of hydrogen energy storage, this research was focused on identifying the obstacles involved with the implementation. This resulted in the following research question:

'What are the obstacles involved with the implementation of hydrogen storage facilities in the urban environment in the Netherlands?'

Based on the analysis of literature, reference projects and semi-structured interviews, a total of 39 individually formulated obstacles were collected (see appendix 4 for the full list). In order to find the most important obstacles, a survey with an online questionnaire was held amongst 102 participants with professions related to the research topic. With the help of the Fuzzy Delphi Method (FDM), insight has been made into the prevailing opinion amongst the respondents, about what obstacle(s) are considered as most important. In Table 10 four individually formulated obstacles are ranked which reached above the threshold.

Table 10: Outcome of the questionnaire; the most important obstacles considered by the respondents

Rank	Nr	Description	Obstacle group
1th	20	It is an obstacle that local, sustainable produced hydrogen is more expensive to citizens as fossil fuels.	Public Acceptance
2nd	5	It is an obstacle that fossil energy is cheaper.	Economic
3rd	1	It is an obstacle that the current CO_2 emission pricing is too low for the introduction of sustainable energy, including neighborhood level.	Economic
4th	15	It is an obstacle that there is currently no need to use hydrogen as a part of grid balancing systems.	Integration in energy grid

It turned out that within the individually formulated obstacles, the top three most recognized obstacles (#20, #5 and #1) were financially driven. Although the four ranked obstacles remain to be the formal outcome of this research, they are not that valuable because this was easily expected on forehand and didn't need this research to prove that.

In accordance with the received feedback from the questionnaire, the formulation of the individual obstacles could be more specific. The respondent felt that it needed more information about each obstacle in order to make a good choice. It was expected that more specific obstacles would make them more distinct. Also it was expected that the level of knowledge amongst the respondents would be on the same level, which wasn't the case. That's why there is a big chance that obstacles were falsely interpreted or understood. Therefore the value of the individually ranked obstacles is perceived lower.

In order to find more valuable information out of the data of the questionnaire, an overlaying layer was identified. This involved the obstacle groups in relation to the votes of each respondent group which presented interesting outcomes. These less specific outcomes can be used within a bigger picture which is needed to create a framework or roadmap for the introduction of hydrogen energy storage in the Urban Environment.

The individually formulated obstacles where gathered in the following groups: 'Economy', 'Integration in the Urban Environment', 'Integration in the Energy Grid', 'Law and Regulations', 'Public Acceptance' and 'Technique'. Based on the average score of the individual obstacles from the questionnaire, the groups received a score themselves. This indicates what group is chosen most often. Figure 28 shows that the obstacles within the group 'Public Acceptance' (green bar) where chosen most frequent by the respondents. Closely followed by the group 'Economy'. The group 'Technique' is seen as the least of an obstacle amongst the given choices.

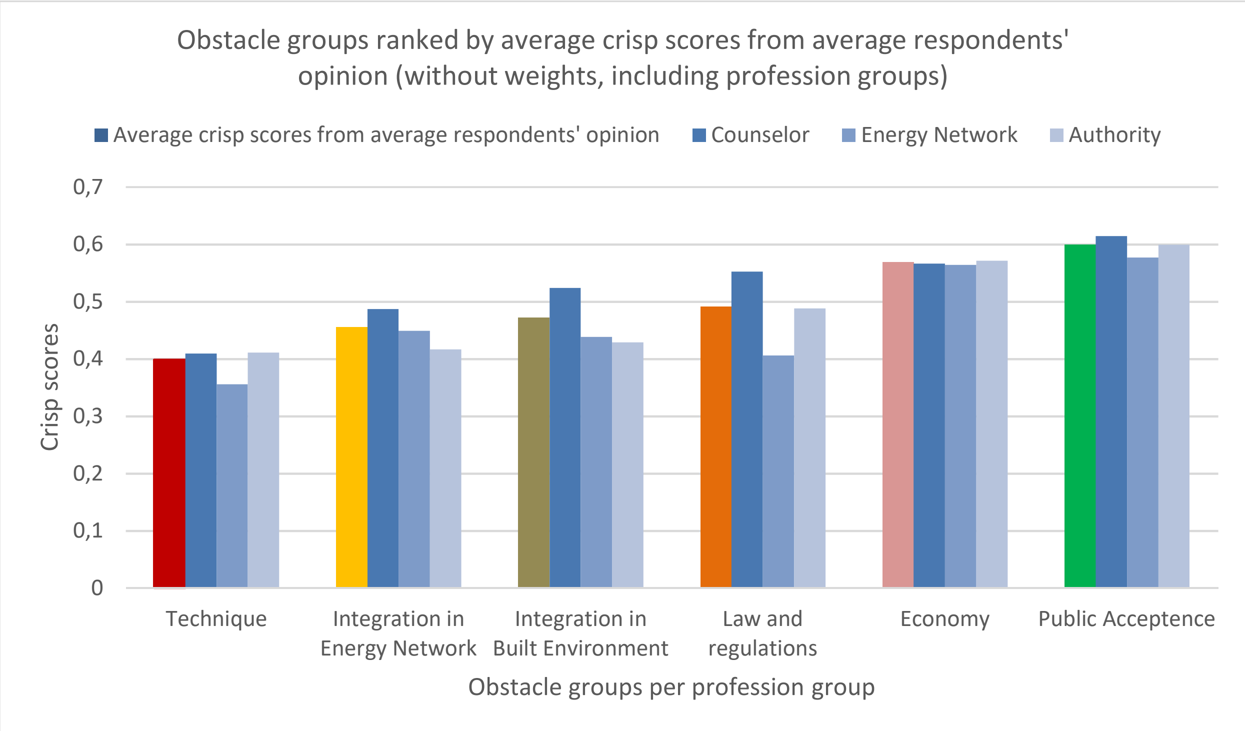


Figure 28: Obstacle groups ranked by profession group

The respondents were identified within three main profession groups: 'Authority', 'Energy Network' and 'Counselor'. In comparison between the groups, the 'Counselors' recognized more obstacles in each obstacle group as the other two profession groups. This is seen in Figure 28 where the bar of the 'Counselor' often reaches above the other groups. It remains a guess why, but it could be that the 'Counselors' are more negative concerning hydrogen because they know more about the topic as the other two profession groups and therefore have a more honest opinion. However, based on the power-interest chart, the profession group 'Energy

Network' is considered as the most influential. Their general opinion considering the implementation of hydrogen energy storage was the most positive of the three profession groups.

In order to help with the implementation of hydrogen energy storage, it is advisable that each profession group should act in a certain way. This could be that:

- 'Authorities' (including policy makers) should be aware of the upcoming flexibility problem and respond correspondently with the creation of long-term policies.
- 'Counselors' should remain critical and help with the technical development of the required systems.
- 'Energy Network', and especially the DSO's, should be better prepared to accommodate more flexibility. Because they are currently responsible for a reliable and continues power supply, but they aren't allowed to store energy. Besides 'doing their job' it remains important to help in the creation of awareness at the 'Authorities', together with the 'Counselors'.

It remains difficult to make a practical approach, or even a timeline, based on the outcomes of this research for the implementation of hydrogen energy storage. It requires a good vision, mission and strategy to make hydrogen energy storage a success. Many things will influence this, such as: the development of the actual techniques, the rate in which RES are introduced, if there becomes a financial burden on the emission of GHG but also if there becomes a change in the regulations which will allow DSO's to store energy.

However along the way the focus should be on overcoming the obstacles whereby the first focus should be on gaining awareness of the technique, make it financially interesting and above all seek for 'Public Acceptance'.

4.3 Recommendation

This study focused on the identification and ranking of individual obstacles but showed that the obstacle groups, and in particular the group 'Public Acceptance' was more important. Therefore the first recommendation is to conduct more research in this field including consumer analysis and the experiences of existing projects to find out what exactly is needed to create the acceptance of hydrogen. Is it due to the end-user's acceptance, or for now only the policy makers? Are only risks involved or are consumers prepared to take more risks if the price becomes interesting?

Secondly it is recommended to look further in the financial part of the energy market including: feed-in tariffs, curtailment management, seasonal balancing capacity remuneration and taxation, while taking into account the benefits hydrogen can deliver to the energy system.

Thirdly it is recommended to create a technical test case. It would help to overcome a lot of individual obstacles and show that it is, besides theoretical also technically possible in real life. Furthermore it would give a more accurate perspective about the involved system costs.

A problem with a lot of durable concepts is that there are huge initial costs. These are passed on to the energy bill as fixed costs. But with a lowering energy demand, the variable costs are decreasing, resulting in a wrong ratio fixed costs versus variable costs. The result is that energy saving measures won't be financially interesting anymore. Therefore the fourth recommendation is to develop new pricing schemes that allow new technologies to be developed.

4.4 Relevance

The Netherlands has a quite special energy situation and therefore can't use the solutions of other countries. This is due to the dense population of the country, the reliable and widespread electricity and gas network and the lack of natural RES such as hydropower. Because of this special situation, the Netherlands should be open to other kind of innovations that can help within the energy transition. This research is, within the existing knowledge, the first time that the Dutch stakeholders involving a hydrogen energy network are inventoried. Also this is the first time that these stakeholders are been asked about the obstacles with FDM.

4.5 Reflection

This reflection starts in the period of the research proposal. Firstly, there was not enough knowledge about the research methods and on how to structure a research. This lack of knowledge on the method complicated the further progress and lead to an initial weak structure of the thesis. This should have been aligned from the beginning of the research.

Secondly, the drafting of the sub questions was done with limited foresight in retrospect. Some of the questions were too superficial, while others did not contribute directly to answering the research question. It would have been beneficial for the research if more experts were consulted during this stage of research. It would have funneled the research more stringently in an earlier stage. It now took a long period of time finding the right but also a good amount of obstacles.

When these obstacles where found, they were gathered within obstacle groups. The verification of these groups was not done by an independent third party. All of the experts used for the verification were related to the research topic themselves.

A questionnaire was created to collect opinions on the obstacles. It started with a case description without an exact timeframe. In order to rank the obstacles more properly this should have been added. After the case description, the ranking of the obstacles started. The way in which the individual obstacles were explained in the questionnaire could be more elaborate. It would have made them more distinctive from each other and clearer. The downside would've been that it would take too much time for the respondents to read all of it, making the response rate drop to a low point.

Within the selection of respondents for the survey it would've been interesting to have included a few more respondent groups such as hydrogen critics. But also more groups related to the urban and built environment such as housing corporations and municipalities.

During the analysis of literature, there could've been more attention to alternative financial possibilities to help during the energy transition. Such as ESCO's or a look at other (European) countries how they are accommodating the shift to less energy use and more RES. It would've been also interesting to take the circular economy or CO2 labels on products into account within this research. This would've involved a research into the interest of people in the environment and the (public) acceptance of energy-saving measures.

Finally, the complete research was about finding obstacles. This is quite negative approach. Maybe there would be a different outcome if the survey was held in in a different, more positively oriented way where the search was to find and overcome ‘challenges’.

V. References

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VI. Appendixes

1 Organogram Siemens

The graduation thesis is carried out at Siemens. This international operating company originates from Germany. It has multiple divisions with each of them their own specialties as seen in Figure 29. Within the division Digital Factory the hydrogen related part is placed. Siemens creates and sells electrolyzers within the so called Business Development. This is located in The Hague..

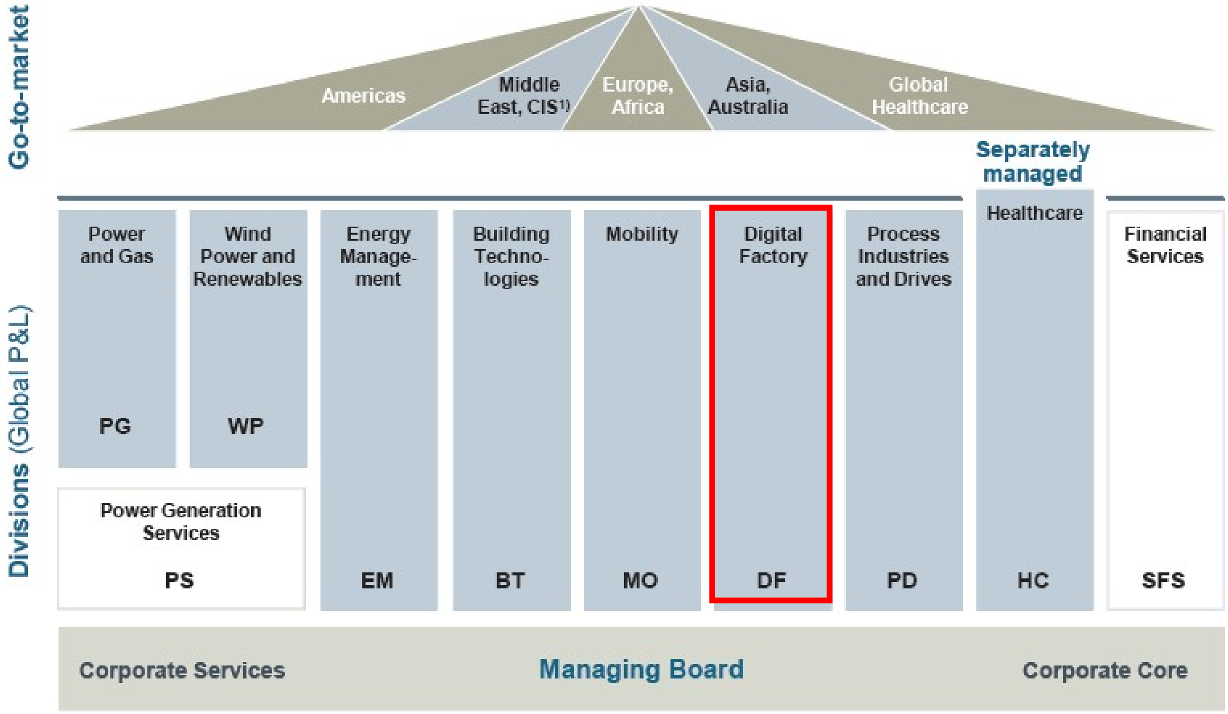

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Figure 29: Organization Structure Siemens (Siemens AG, 2016)

2 Position of the Dutch building decree

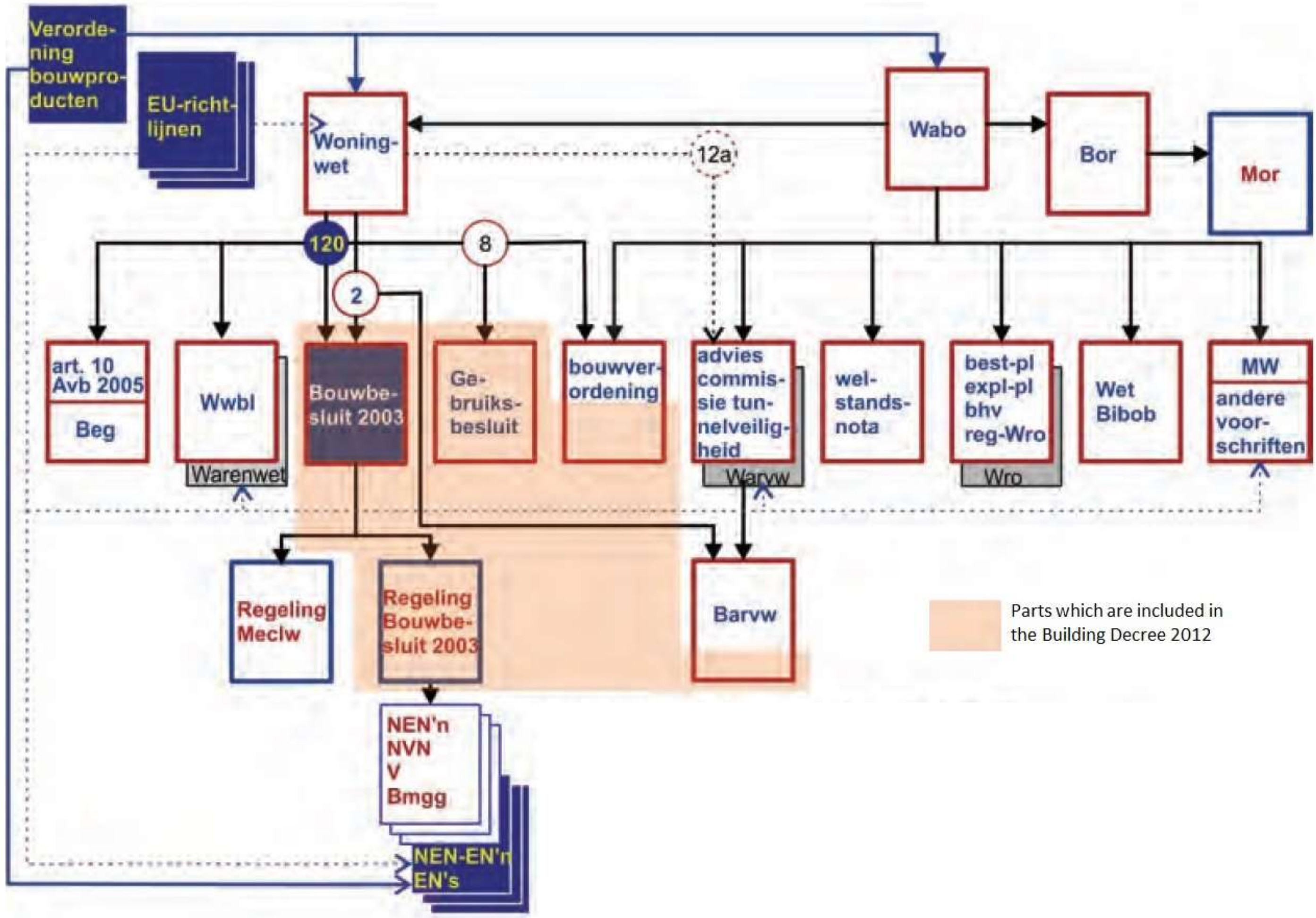


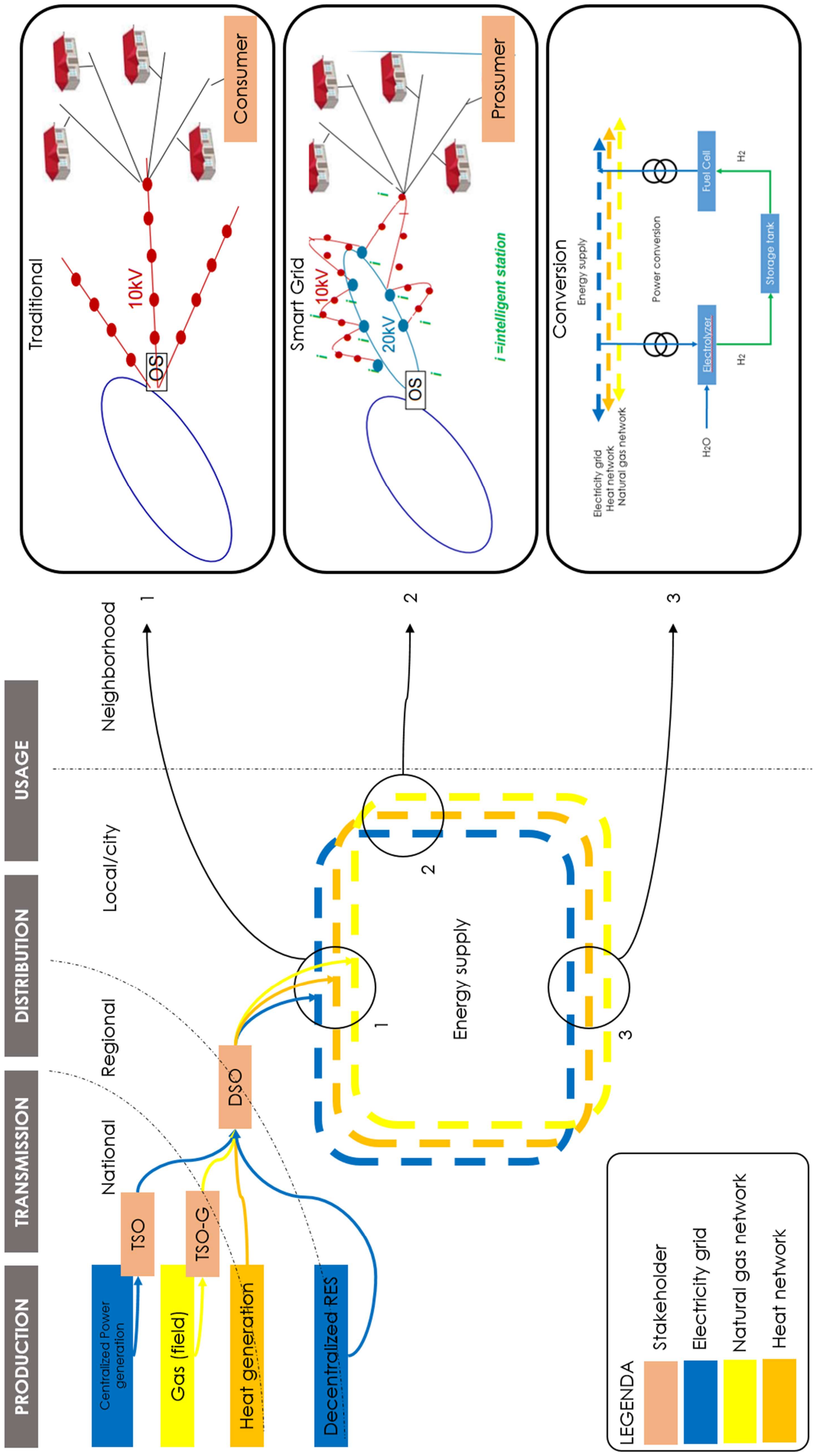
Figure 30: Positioning of Dutch building decree from the book: 'Praktijkboek bouwbesluit 2012' (Overveld, Graaf, Eggink-Eilander, & Berghuis, 2011)

Table 11: Definitions belonging to 'Praktijkboek bouwbesluit 2012'

Term	Dutch	English
AvB 2005	Asbestverwijderingsbesluit 2005	Asbestos Removal Decree 2005
Barvw	Besluit aanvullende regels veiligheid wegtunnels	Decree additional rules road tunnel safety
Beg	Besluit energieprestatie gebouwen	Decree Energy Performance of Buildings
Best-pl	Bestemmingsplan	Land-use Plan
Bhv	Beheersverordening	Control regulation
Bmgg	Bepalingsmethode milieuprestatie gebouwen en GG-werken (uitgave SBR)	Methodology for determining the environmental performance of buildings
Bor	Besluit omgevingsrecht (bijlage II: bouwactiviteiten zonder omgevingsvergunning voor het bouwen)	Decree environmental law (annex II: construction activities without environmental permit)
Mor	Ministeriële regeling omgevingsrecht (indieningsvereisten)	Ministerial regulation environmental law (issue requirements)
MW	Monumentenwet 1989	Monumental law 1989
Regeling Meclw	Regeling materialen en chemicaliën leidingenwatervoorzieningen	Regulations materials and chemicals in drinking water
Reg-Wro	Regels via artikel 4.1, lid 3, of artikel 4.3, lid 3 van Wro	Rules of article 4.1, paragraph 3, or article 4.3, paragraph 3 of the Wro

V	Leidraad (uitgave NEN)	Guidelines (NEN publication)
Wabo	Wet algemene bepalingen omgevingsrecht	Environmental Permitting (General Provisions) Act
Warvw	Wet aanvullende regels veiligheid wegtunnels	Additional rules road tunnel safety act
Wet Bibob	Wet bevordering integriteitsbeoordeling door openbaar bestuur	Public Administration Probity Screening Act
Wro	Wet ruimtelijke ordening	Spatial Planning Act
Wwbi	Warenwetbesluit liften	Commodities Act Decree lifts

3 Energy network visualization



4 List of obstacles

In the table below a full list is presented with the found obstacles. Within the presented sources, there is a difference between what is found within literature and what from interviews. The interviews are identified with the date of the interview (yyyymmdd) and can be found in appendix number 5, Interviews.

	It is an obstacle that:	Sources:	Obstacle group
1	the current CO_2 emission pricing is too low for the introduction of sustainable energy, including neighborhood level.	20160905 Jan Piet van der Meer De rol van power-to-gas in het toekomstige Nederlanse energiesysteem - Samenvatting (Joode, 2014) (page 4)	Economic
2	the construction of a separate hydrogen gas network is too expensive.	20160905 Jan Piet van der Meer	Economic
3	there is uncertainty whether hydrogen is the long-term solution due to the relatively high cost per kWh.	20160822 Albert van der Molen	Economic
4	they only are prepared to accept hydrogen when it reduces the energy bill of the user.	20160809 Frank Meijer	Economic
5	fossil energy is cheaper.	20160905 Jan Piet van der Meer	Economic
6	hydrogen storage systems as a whole, have a low yield.	Sector Forum Energy Management | Working Group Hydrogen - Final Report (Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016)page 83	Economic
7	not all social costs of the fossil energy system are included in the comparison with a sustainable local energy system.	20160822 Albert van der Molen Business models for renewable energy in the built environment (Würtenberger, Bleyl, Menkveld, Vethman, & Tilburg, 2012) (page 15)	Economic
8	it will be to costly to place an own energy system in inner cities and neighborhoods.	20160822 Laetitia Ouillet	Economic
9	local governments, agencies and service providers have little to no knowledge and experience with hydrogen and its applications.	20160527 Sander van Schagen	Integration in built environment
10	there is insufficient physical space within inner cities and neighborhoods for placing energy storage.	Energierapport - Transitie naar duurzaam (Dutch Ministry of Economic Affairs, 2016) (page 53)	Integration in built environment
11	there is too much a focus on a single, uniform, nationwide energy solutions while there	20160822 Albert van der Molen	Integration in built environment

	should be focus on the best energy situation viewed by location.		
12	private energy storage systems per dwelling, for example home batteries, get more attention than a central storage in the neighborhood.	Proef met 50 thuisbatterijen in netwerk (Gawalo, 2016)	Integration in built environment
13	it is only possible in new neighborhoods to take a complete sustainable energy system into account in which hydrogen can play a viable role (energy wise, economic, spatial integration).	'Geen gasaansluiting meer voor nieuwbouwhuizen' (Ekker, 2016) Bestaande bouw Energie Neutraal, Reisgids voor een gebiedsgerichte aanpak (Idema & de Koning, 2014) (page 39) In steeds meer nieuwbouwwijken wordt echter geen (nieuw) aardgasnet aangelegd. Daar zijn de huizen all electric. (BewustNieuwbouw.nl, 2016)	Integration in built environment
14	natural gas pipelines are not suitable for the transport of hydrogen.	20160822 Albert van der Molen	Integration in energy grid
15	there is currently no need to use hydrogen as a part of grid balancing systems.	(Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016) (page 83) Markt en Flexibiliteit – Hoofdrapport (Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016) (page 3) De rol van P2G in het toekomstige Nederlandse energiesysteem (Joode, 2014) (page 5)	Integration in energy grid
16	there is still sufficient transmission capacity in the national and regional electricity grid to accommodate peaks and increased demand.	20160822 Laetitia Ouillet Markt en Flexibiliteit – Hoofdrapport (Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016) (page 3)	Integration in energy grid
17	there are plenty of other local systems available which allow both local grid balancing and seasonal energy storage.	Markt en Flexibiliteit – Hoofdrapport (Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016) (page 21)	Integration in energy grid
18	energy systems based on fossil fuels are still to be used for decades.	Komende 30 jaar meer autos op diesel en benzine (NOS) (de Rooy, 2016) Shell topman roept op tot realisme energietransitie (FluxEnergie, 2016)	Integration in energy grid
19	hydrogen has a disruptive effect in the local energy system, both in generation, during storage and with re-use in as well gaseous form or as electricity.	Energierapport - Transitie naar duurzaam (Dutch Ministry of Economic Affairs, 2016) (page 99)	Integration in energy grid
20	local, sustainable produced hydrogen is more expensive to citizens as fossil fuels.	20160905 Jan Piet van der Meer	Public acceptance

		Hydrogen and Fuel Cell Technologies and Market Perspectives (Töpler & Lehmann, 2014) (page 226)	
21	there is a remuneration for solar PV, making local energy storage less interesting for the owners of the PV.	Markt en Flexibiliteit – Hoofdrapport (Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016) (page 5)	Public acceptance
22	the uncertainty surrounding the safety of hydrogen prevents the social acceptance.	Sector Forum Energy Management | Working Group Hydrogen - Final Report (Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016) (page 87)	Public acceptance
23	the automotive industry has not yet adopted hydrogen as an energy source and that the supply of FCEV is insufficient.	20160809 Frank Meijer 20160905 Jan Piet van der Meer	Public acceptance
24	there is fear of hydrogen because of the associations with explosions and accidents.	Hydrogen and Fuel Cell Technologies and Market Perspectives (Töpler & Lehmann, 2014) (page 40)	Public acceptance
25	there is little knowledge about the energy system and its sustainability by the public.	Energievoorziening 2015-2050: publieksonderzoek naar draagvlak voor verduurzaming van energie (van der Lelij, de Graaf, & Visscher, 2016) (page 31)	Public acceptance
26	there still is a lack of knowledge about the impact of hydrogen on the material of transport pipelines, the behavior of burners, etc.	(Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016) (page 75) Installation permitting guidance for hydrogen and fuel cell stationary applications: UK version (Pritchard, Royle, & Willoughby, 2009)(page 6)	Technique
27	the system can't respond fast enough on a surplus of electricity (about 10 minutes at a 'black start').	(Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016) (page 2 & page 28)	Technique
28	the reliability of the electrolyzer is too low.	(Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016) (page 31)	Technique
29	the reliability of the fuel cell is too low.	(Weidner, Honselaar, Ortiz Cebolla, Gindroz, & de Jong, 2016) (page 83)	Technique
30	there is no complete functioning Smart Grid yet.	International Electrotechnical Commission, Challenges - Interoperability (IEC, 2016)	Technique
31	there is a lack of available, affordable and certificated measurement and control systems for hydrogen.	Op weg naar duurzame mobiliteit, Ruimte voor rijden op waterstof (Ministerie van Infrastructuur en Milieu, 2013) (page 10)	Technique
32	there are no hydrogen storage systems available for storing seasonal energy on a large large-scale in the built environment.	De rol van power-to-gas in het toekomstige Nederlanse energiesysteem – Samenvatting (Joode, 2014) (page 8)	Technique
33	there are no administrative and pay-off systems available for remuneration schemes of locally produced sustainable	(Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016) (page 27) (Hers, Rooijers, Afman, Croezen, & Cherif, Markt en Flexibiliteit - Achtergrondrapport, 2016) (page 78)	Technique

	energy and the use of this in neighborhoods.	Actieplan Duurzame Energievoorziening (Netbeheer Nederland, 2013)(page 29)	
34	there is a lack of regulations about production, storage and the use of hydrogen in the urban environment, but also for closed spaces and certification of equipment.	20160826 Guy Konings	Law and regulations
35	the addition of hydrogen in natural gas is only possible to a limited extend (up to 0,02%).	20160822 Albert van der Molen	Law and regulations
36	the DSO may not facilitate energy storage because it is seen as a commodity.	20160822 Albert van der Molen	Law and regulations
37	there is no certification system which ensures that the produced hydrogen always has a sustainable source (the missing of a green-certificate).	20160905 Jan Piet van der Meer Kortsluiting op de groene energiemarkt (Hartlief & Kiezebrink, 2016) (page 3) Hydrogen and Fuel Cell Technologies and Market Perspectives (Töpler & Lehmann, 2014)(page 181)	Law and regulations
38	there are no sets of standards which explain to what rules hydrogen has to comply with.	20160826 Guy Konings	Law and regulations
39	the role of national energy companies in local energy applications is still unclear.	(Hers, Rooijers, Afman, Crouzen, & Cherif, Markt en Flexibiliteit - Hoofdrapport, 2016) (page 29)	Law and regulations

5 Reference projects

The reference projects show a mix of different concepts of energy storage and other balancing systems related to the energy grid. These are used as a proof of concept in order to gather knowledge about energy storage concepts in general and in particular about hydrogen energy storage concepts.

The projects are not limited to Dutch projects only, but it is tried to include as much of these projects as possible because those are already focused on the Dutch energy system and specific circumstances and stakeholders. It is interesting to see how these progressive projects with the involvement of energy storage (short term as well as long term) are implemented in the energy networks in the urban environment.

In Table 12 an overview is given of the different usages of energy storage in order to balance the electricity grid. Table 13 shows reference projects with specific uses of hydrogen. Right after the tables, the individual projects are being discussed. The information about the projects is collected during online research, some project visits and interviews with involved stakeholders.

Each reference project has a figure which shows the basic energetic concept and which energy networks are involved. This is done in order to make proper comparisons. They are visualized using the same system as used in Figure 4 which explains the three scenarios in part 2.2 about the energy network.

Table 12: Balancing the electricity grid

Balancing the electricity grid using Smart Grid technology						
	Short Term		Short/Long Term		Long Term	
	Electric		P2G		P2G	
	EV	Home	Gas Grid insertion		Storage	
References	(V2G/G2V)	battery	H2	CH4	Use Elsewhere	Fuel Cell
A. Lombok	x					
B. Hoog Dalem		x				
C. Ameland			x			
D. Rozenburg				x		
E. Mainz					x	
F. Re-electrifica-tion of P2H*						x

**The references mentioned here are added in a later stage of the thesis*

Table 13: Hydrogen Utilization

Hydrogen Utilization		
References	Built Environment	Vehicle related
G. HRS Rhoon	x	x
H. H2 Generator	x	

5.1 Balancing the electricity grid

5.1.1 Smart Solar Charging | The Netherlands | Lombok, Utrecht

General information

The neighborhood Lombok in Utrecht wants to use the batteries of the local EV’s for storing surplus electricity that is produced from local solar panels. In this way the electricity produced during the day can be used during the night. They call it ‘Smart Solar Charging’. All the EV owners indicate how much range they want with their EV so that battery capacity will always be available. The main key in this system is the Smart Charging Station. It deals with the flow of electricity between production, storage and usage. This makes it the first (European) bi-directional electric charging station, which also takes the solar production into account. This system is called Grid to Vehicle (G2V) when the battery is being charged, and Vehicle to Grid (V2G) when the battery delivers electricity to the grid.

In June 2015 the project was officially opened together with all the involved stakeholders. This included the municipality of Utrecht, DSO Stedin, Lomboxnet, General Electric, Nissan, BYD, Last Mile Solutions and Vidyn. (Lomboxnet, 2016)

Involved elements

-100 kW of solar panels on the roofs of houses and schools (Christelijk Gymnasium Utrecht)

-20 Smart Charging Stations: charge by the rate the sun shines and also able to de-charge

-EV’s for car sharing

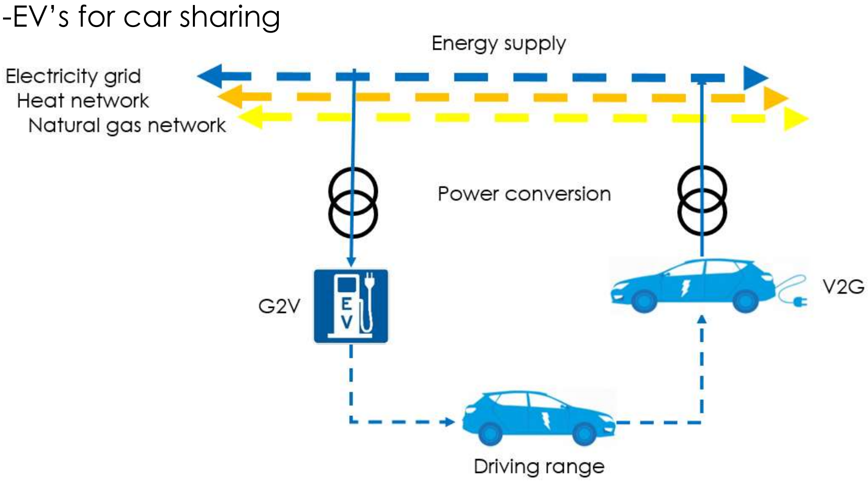


Figure 31: Basic principle of Lombok

Why chosen as reference project

This project was the introduction of the Smart Charging Station. It is an implementation of a Smart Grid application. This shows that there already is a system available that reacts to customer input such as user data and preferences, but also arranges storage so when there is a demand for electricity, it can be supplied by the batteries. This is graphically shown in Figure 32.

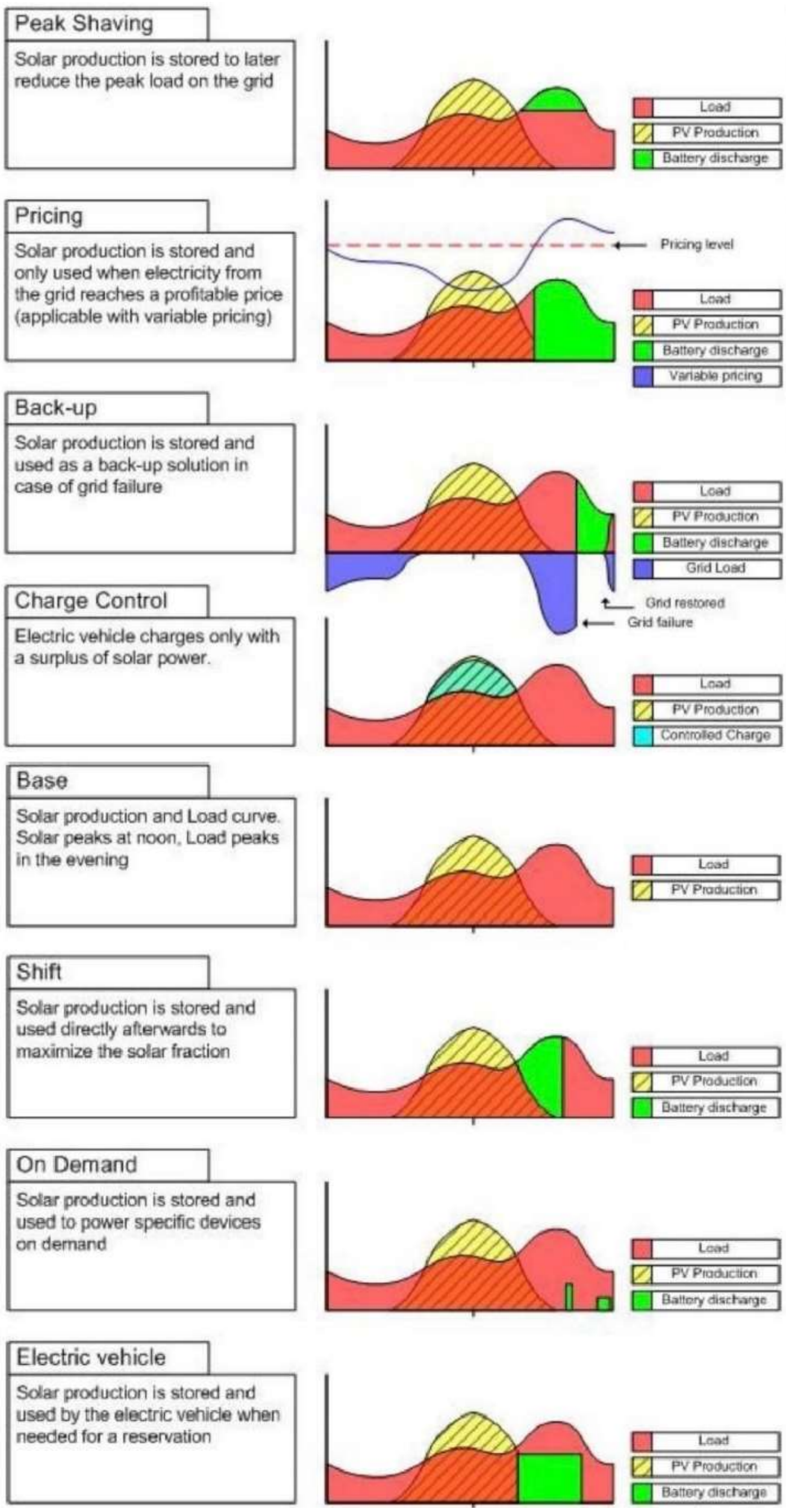


Figure 32: Possibilities with Smart Charging Station (Last Mile Solutions, 2016)

5.1.2 All Electric Neighborhood | The Netherlands | Hoog Dalem, Gorinchem

General information

There is a new neighborhood in Gorinchem called Hoog Dalem. This is an all-electric neighborhood with no gas network. Therefor the electric cables have a capacity that is three times larger than normal. For heating and cooling the houses use heat pumps. From the 1400 dwellings, 42 take part in a pilot project. It focuses on the local distribution and storage of electricity produced by local solar panels as seen in Figure 33. Therefore, the houses are equipped with solar panels, a 2,3kWh battery and smart measurement devices. This is done with four main stakeholders: Heijmans, Stedin, KPN and ABB. Their main goal is to see if it is possible to balance the grid. The project was firstly initiated in 2010 with an official start of the pilot phase in December 2015 (Kaupmann, 2016).

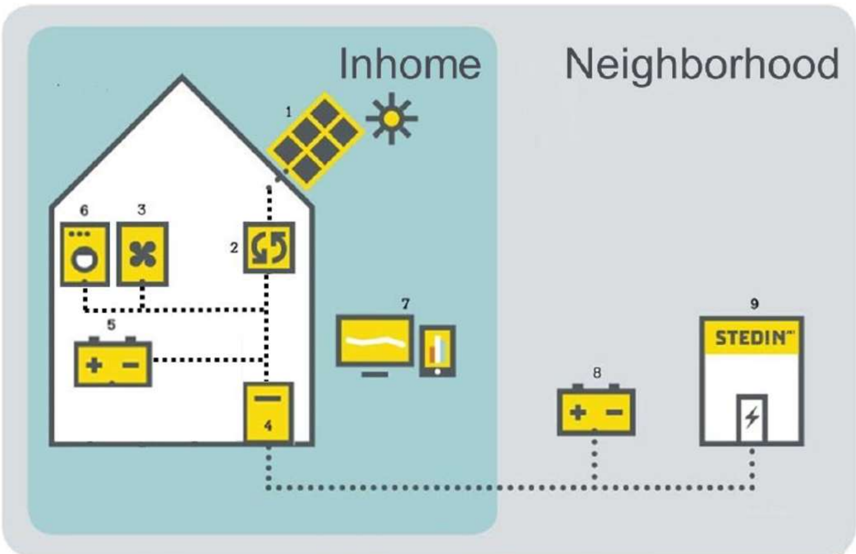


Figure 33: Involved elements per house. Figure adopted on the base of (Heijmans, 2016)

Involved elements

-42 houses with solar panels

-42 home batteries with a capacity of 2,3 kWh

-Smart Grid with smart appliances

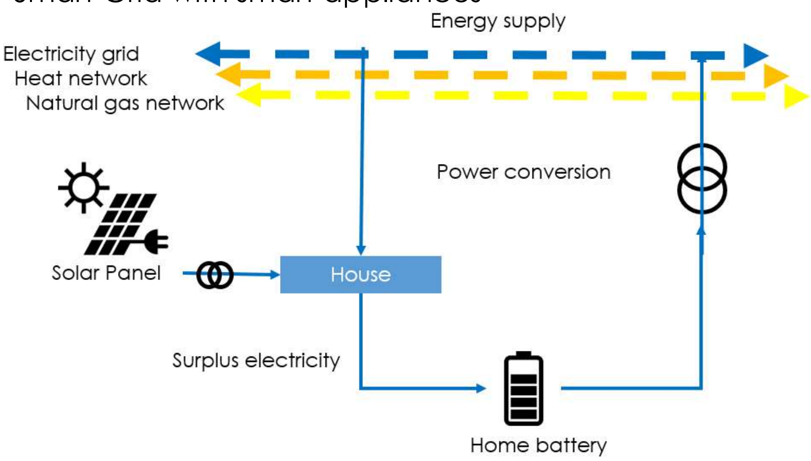


Figure 34: Basic principle of Hoog Dalem

Why chosen as reference project

This projects goal is to see if the energy within the neighborhood can be balanced. It has hereby overlap with scenario two which as mentioned in part 2.2 and seen in appendix 3. With electric batteries day and night differences can be balanced, but the seasonal effects are still difficult to deal with and not taken into account. Therefor this makes it really interesting to add seasonal storage and see how this will improve the situation.

5.1.3 Hydrogen in NG network | The Netherlands | Ameland

General information

The project from Stedin was aimed to test the introduction of hydrogen in the natural gas network. This was the first test in the Netherlands. In the first phase, at the end of 2007, hydrogen from pressurized bottles was introduced in the grid to test the reliability of the mixture installation. 14 apartments from "Noorderlicht" were depending on this gas network for cooking and heating (Gemeente Ameland, 2016). When this proved to work well, the bottles were replaced by an electrolyzer (see Figure 35) which was fed by solar panels, so fully depending on RES. During time, different mixture percentages were tested. From 5% to even up to 20%. The cooking and heating equipment was tested before the project started to safely work with mixture percentages up to 30%.

By mixing hydrogen into the gas network, the energy value of the gas mixture was lowered. This results in a lower burning temperature. On the other hand the burning gases contain less CO_2 and CO.

In April 2011 the project ended after roughly four years. The participating people from the apartment building were asked to fill in a questionnaire after every rising of percentage, which happened five times. This was done during the project to see if the comfort level remained the same, which was the case at the end. All the involved materials such as pipes, connectors, pressure valves, gas burners, etc. were replaced for extensive research. It turned out that for the time exposed to hydrogen, there were no significant changes in the material. This had been often considered as a technical problem. (Kippers & Ophoff, 2012)

Involved elements

-Solar powered electroyzer

-Gas mixing installation

-Measurement devices

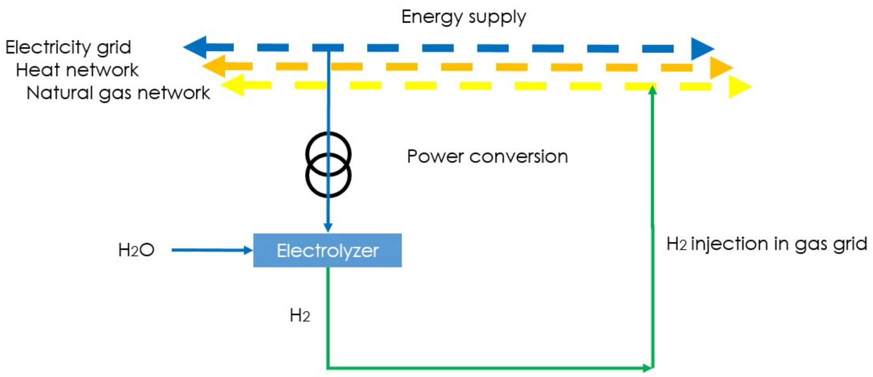


Figure 35: Basic principle of Ameland

Why chosen as reference project

This project was one of the first (maybe even the first) project where hydrogen is been tested as an energy storage carrier. In this case by putting it into the gas grid. In concept this could really balance the grid, especially when there is a large amount of installed solar power, but in this situation it only has been a small pilot project.

The conceptual idea of using the gas network as storage capacity for surplus energy is very interesting and maybe one of the solutions. But in the end the total emission of greenhouse gases must stop, which makes a large gas network not future proof and only valuable during the energy transition.

5.1.4 P2NG | The Netherlands | Rozenburg, Rotterdam

General information

This power-to-gas plant is a pilot project from the DSO Stedin in the Netherlands. In 2014 it is officially opened and will remain in function for at least 5 years. It is located near the Rotterdam neighborhood Rozenburg at the 'Laan van Nieuw Blankenburg' on a special terrain as seen in Figure 36 and Figure 37. It measures around 22 by 22 meters. The aim is to see if it is possible to create a functioning P2G plant which converts electricity into methane gas, which is fed into the gas grid (Stedin, 2016). In the future, this technique can be used to balance the electricity grid. The idea for this pilot came from a previous pilot on Ameland where hydrogen was fed into the gas grid. There are limitations about the maximum amount of hydrogen that is allowed in the gas mixture, so the idea was to produce 'normal' gas, which is methane. The yearly production is 2000m3 and is directly fed into the gas connection of a nearby apartment building with 30 apartments. (Stedin, 2016) (van der Molen, Exploratory interview about hydrogen, 2016).

Involved elements

-One container with the electrolyzer. Previously used at the Ameland project.
-One container with the reactor for conversion to methane
-One container where the CO_2 is stored that is been used for conversion

Figure 36: Location power-to-gas plant near neighborhood. Adopted on the base of (Google Maps, 2016)

Figure 37: Rozenburg Power-to-gas plant (DNV-GL, 2015)

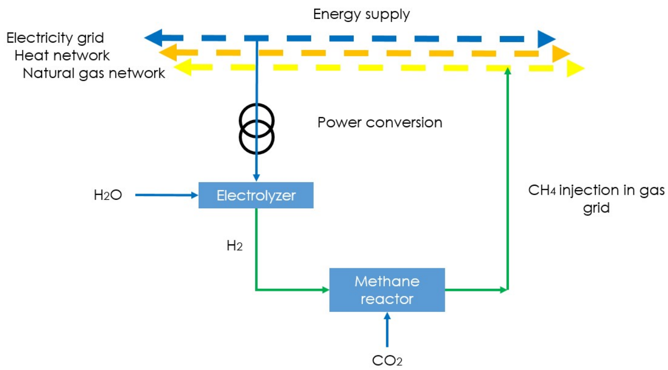


Figure 38: Basic principle of Rozenburg

Why chosen as reference project
The use of hydrogen as an energy carrier in the built environment is something that is really similar to the proposed situation. Therefor making this to a very good reference. Of course the hydrogen is reformed to methane after a reaction with CO_2, but still the idea that hydrogen is being produced in the close area of a neighborhood is interesting.
It needs to be mentioned that, as well as seen at the Ameland reference, the gas network here is used as storage capacity but the total emission of greenhouse gases must stop, which makes a large gas network not future proof and only valuable during the energy transition.

Because this project is realized in the direct proximity of residences, it was interesting to see how the safety was guaranteed. As seen in Figure 39 the location of the pilot plant is marked as an area with a dangerous substance.

Figure 39: Map indicating Major Safety (Risks) Decree at Rozenburg (Risicokaart.nl, 2017)

5.1.5 P2H | Germany | Mainz-Hechtsheim

General information

‘Energiepark Mainz’ is a Power-to-gas plant and is located on a terrain of +/- 100m x 45m at the crossing of the ‘Eindhoven-Allee’ and the ‘Florenz-Allee’ at the ‘Mainz-Hechtsheimer Wirtschaftspark’. It is realized for the ‘Stadtwerke Mainz’ in combination with: Linde Group, Siemens, Energie Speicher, University of RheinMain and the German Ministry of Science and Energy. The project started in 2012 and in 2015 on July 2nd the park was opened. The total costs where €17 million.

It is a hydrogen production plant, see Figure 40, based on the power-to-gas principle. It uses the surplus of electricity of the local 10MW wind-farm to convert electricity to hydrogen. The hydrogen is being produced by three PEM electrolyzers from Siemens which will work up to 6 MW. Afterwards, the hydrogen is dried and compressed by an ionic compressor. This compressor has a cooling based on liquid salt. All the hydrogen will be stored on site until it is sold for commercial purposes, then tube-trailers arrive to be filled up for transport. Surplus produced hydrogen which isn’t or can’t be sold, can be fed into the natural gas grid.

Involved elements

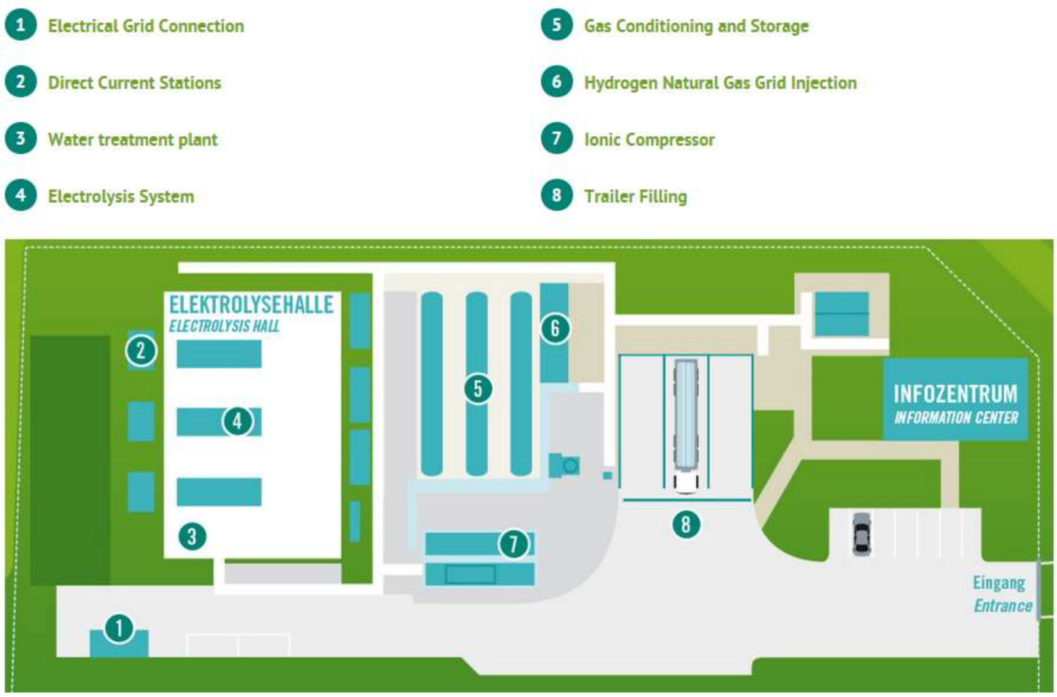


Figure 40: Involved elements Mainz (Energypark Mainz, 2016)

-Local wind-park, producing a total of 10MW peak
-3 PEM electrolyzers (Siemens Silyzer-200). Combined max total peak of 6,3 MW with each 1250 kW / 2,1 MW peak. They can produce each max 225Nm³ hydrogen an hour. All three have an own transformer and pack of cooling fans. The total efficiency is between 60% and 65%.
-Ionic compressor (Linde Gas). It conditions the hydrogen by putting it under pressure and it dries it.
-2 storage tubes (Linde Gas). Combined capacity of 1000kg H2 (2x500kg) with a total of 33 MWh of energy.
-3 spots for tube trailers separated by concrete walls for safety during the filling procedure
-connection to natural gas network for direct fed
-Total annual target production is 200 tons
(Energie Speicher, 2016)
(De Ingenieur, 2016)
(Siemens AG, 2016)

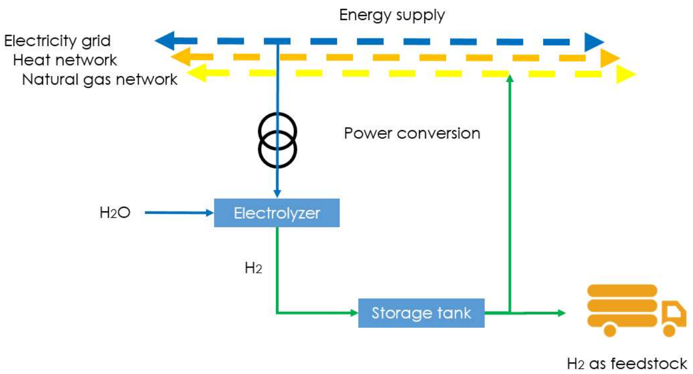


Figure 41: Basic principle of Mainz

Why chosen as reference project
This system is the largest power-to-gas plant used for balancing the energy grid by producing H2 out of the surplus of electricity. Also Siemens has worked on this innovative project making it easier to collect information from.
Within this system many components that will be needed in the researched model are already implemented. The only missing element is a large fuel cell to produce electricity again from the hydrogen.

5.1.6 Re-electrification | Norway / Japan

General information
Part of the hydrogen energy storage concepts which are described in 2.4.4 'Utilization' is the re-electrification of surplus hydrogen. Two projects which use this concept, as seen in Figure 42, didn't make it to the initial list of reference projects because they were discovered in a later stage of this thesis. But because these projects do use the concepts in which this research is focused, they are still worth mentioning.

The first is based on the Norwegian island Utsira where they created a system following the basic principle of the concept as shown in Figure 17. During four years ten households where supplied with hydrogen produced out of electricity from two wind turbines including storage capacity for two to three days (IPHE, 2017).

Secondly a project in the Japanese town Kitakyushu where the project 'Hydrogen Supply - Utilization Technology' takes place. Hydrogen, a by-product from a local steel production plant, is fed into a gas grid which powers decentralized domestic fuel cells (Fukuoka Strategy Conference for Hydrogen Energy , 2017).

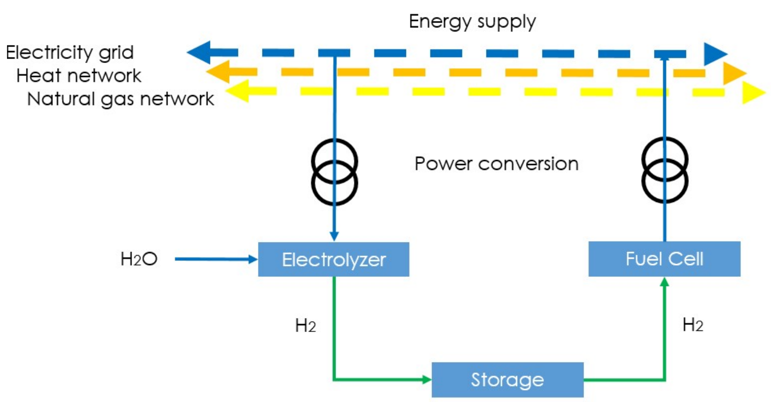


Figure 42: H2 for re-electrification

5.2 Hydrogen Utilization

5.2.1 HRS | The Netherlands | Rhoon

General information
The mobility industry currently produces on a small vehicles which run on hydrogen, so called Fuel Cell Electric Vehicles (FCEV). It is impossible to sell such vehicles without a proper infrastructure. Therefore, hydrogen refueling stations (HRS) are needed. In 2013 there was an initiative to realize a HRS in Rhoon, which is located close to the 'buisleidingstraat' as mentioned in part 2.4.3.1. During 2013 the first information

evening was organized to start with informing the neighborhood about the plans and in September 2014 the HRS already was finished.

Initially the Land-Use plan didn't allow a hydrogen refueling station because it was especially planned for traffic use. But there is a good and solid explanation why it should be allowed based on nationwide, province wide and on municipal level visions. There still must be taken care of the special conditions from the DCMR, the local environment agency. Figure 45 shows a map with potential risks. The 'buisleidingstraat' is marked in red. On the plot of the HRS are no safety lines or restrictions visible.

Involved elements

-Hydrogen supply by pipes from the nearby 'buisleidingstraat' (see the green supply in Figure 43)

-Compressor unit for 350 bar (busses) and 700 bar (cars)

-Risk contour for the site specific risk in which no vulnerable objects may stand as seen in Figure 44.

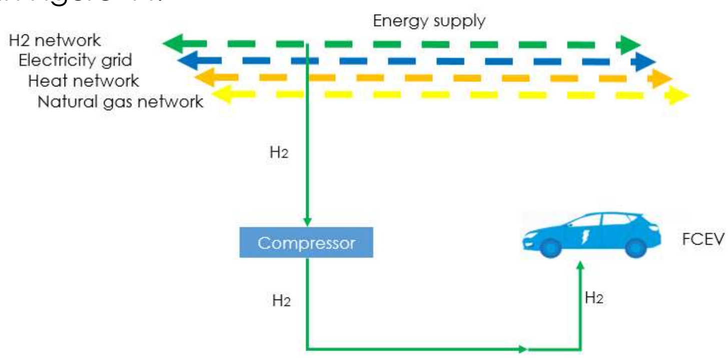


Figure 43: Basic principle of the HRS

Why chosen as reference project

This is the first time that a hydrogen installation is been implemented for non-industrial use in the Netherlands. This involved a lot of communication and participation of local communities. This approach in creating acceptance is very interesting to research more in-depth. Therefore it is a good reference project.

Also this project bridges between the gas network and mobility industry. The FCEV can be seen as small power plants which can fulfill a crucial role in some of the energy concepts.

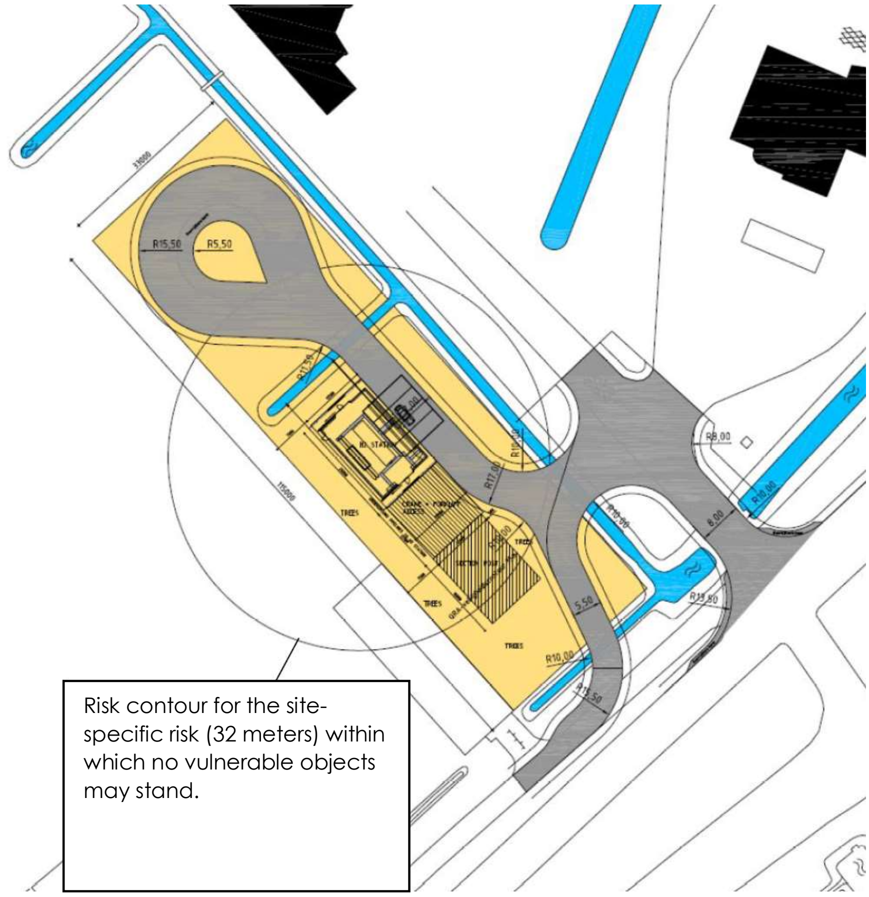


Figure 44: Hydrogen Refueling Station Rhoon (Tebodin, 2013)

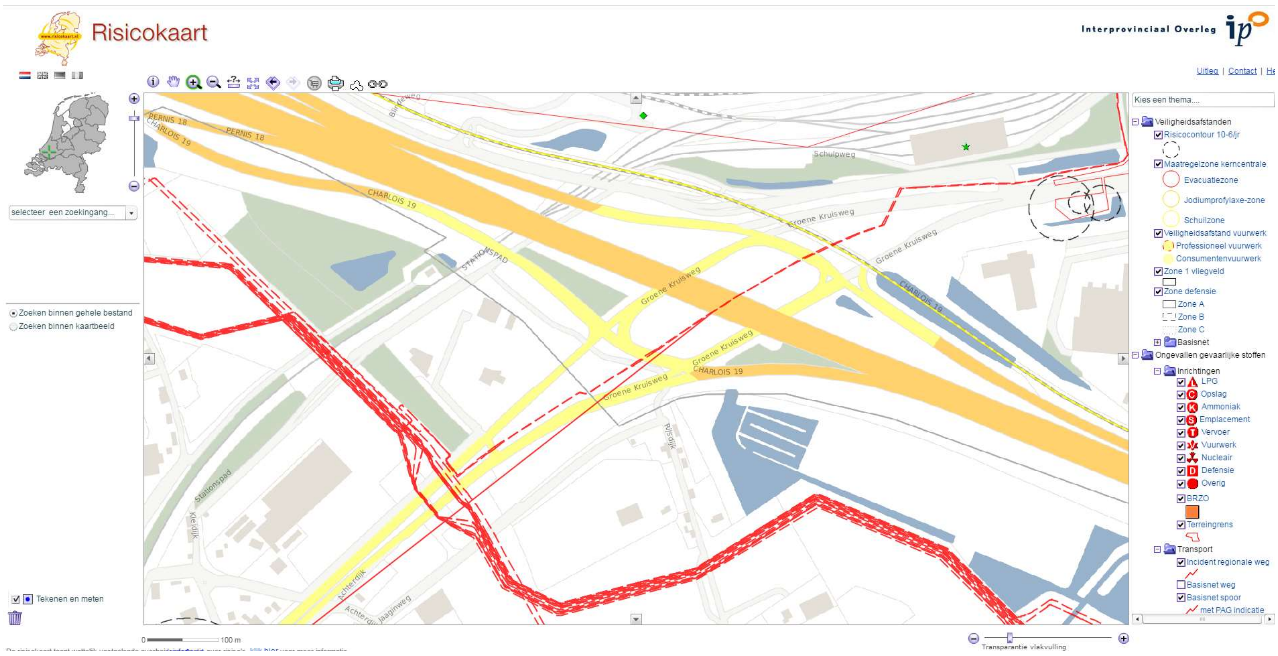


Figure 45: Map indicating Major Accidents (Risks) Decree at Rhoon (Risicokaart.nl, 2017)

5.2.2 H2 generator | The Netherlands

General information

The hydrogen generator is designed to be an alternative to the existing diesel-powered generators (Bredenoord, 2016). These generators emit large amounts of

GHG and small particles. The benefit of this generator is mainly that it has no emission on location and can still generate a sufficient amount of power (van der Meer, 2016). It is a test case for a big rental organization of mobile power generators called Bredenoord (Welsing, 2016).

Involved elements
-Bottles with Hydrogen
-Nedstack FuelCell
-DC-AC converter

Why chosen as reference project
This generator is a power supply system used for re-electrification. It normally is placed in urban areas with pressurized hydrogen. Because it still is within a test case period, there isn't any knowledge yet about the arrangements with municipalities to place these pressurized hydrogen tanks in denser urban areas.

6 Questionnaire

In this section is explained how the data has been collected and converted into usable information.

6.1 Verification of the input

In order to check the reliability of the obstacles and the case description (the input for the questionnaire), there has been a verification. In collaboration with the company supervisor, five experts from different backgrounds were selected to interview. See Table 14 for the overview.

Table 14: Overview of verification interviews. For the full text see appendix 7.19 until 7.23.

	Laetitia (7.19) Energy supplier	Albert (7.20) DSO	Guy (0) DSO	Jaco (7.22) Industrial Gas	Jan Piet (7.23) H2 Association
Hydrogen usage	-Look at Torrgas. A synthetic gas. -Look at Nuon with their ammonia generation	Maybe more, but presented ones the most important.	Supermarket Belgium uses self produced green hydrogen for forklifts	-Look at P2G plants in Germany. -NaturalHy testing with H2 in NG grid.	-Special H2 network to connect industries. -Methanisation in Rozenburg not interesting due the efficiency. -Hydrogen generators on construction sites.
Stakeholders	Energy system responsible for imbalance. Not the end user (no small corporations)	-Storage of energy possible new business for energy suppliers. -Also new type of companies. Now no regulations for. -DSO follows the consumer demand: cheapest option.	TSO & DSO natural role for handling imbalance. Law change needed.	No comments	Decision makers need to accept hydrogen first to put it on the agenda.
List of obstacles	-Look at the green certificates. -A seasonal problem with heat, not with electricity	-Look at the complete social costs of the system.	According to Guy: -No set of standards where hydrogen storage should coop with -No legislation -Public acceptance -No financial benefits	-Perception of safety has more impact as safety itself. -H2 storage not thought of doing in urban environment. Make it as safe as possible, but to what costs.	-Receiving green certificates -Techniques HSF to expensive. -Energy to cheap and available at any time.
Case description	No comments	-Synthetic gas in existing urban environment.	Addition of numbers important to make it solid.	Don't be too precise. It is a futuristic idea. Don't put all existing techniques in it. To narrow.	-Storage in salt caverns possible -Don't explicitly mention the type of storage. -Keep seeing it as a black box.

6.2 Collection of data

A number of parts were seen as important during the creation of the questionnaire. First it was crucial for the respondents to get a clear view of this research, so a comprehensive explanation was given. Second, in order to create a high response rate the questionnaire was given in Dutch, lowering a possible reluctance to complete the questionnaire due to a language barrier. Print screens of the questionnaire itself can be found in appendix 8.

As seen in Table 15, at the end of September, the questionnaire was sent to 102 people. After three days a reminder was sent which resulted in a significant increase in filled in questionnaires. Two days later, the questionnaire was closed. In total 45 individual people completed the questionnaire. 80 times the questionnaire was started, but these are not all unique attempts. The response rate was 44%.

Table 15: Filled in questionnaires

Date	Event	Started / Ended
September 29th, 2016	Questionnaire sent to 102 respondents	0 / 0
October 4th, 2016	Reminder sent	52 / 35
October 6th, 2016	End of questionnaire	80 / 45
		Response rate: 45/102 = 44%

6.3 Processing data

After downloading the data, the conversion process started. Because the chosen answers of the online questionnaire were logged as raw numbers '1', '2' and '3', the link needed to be made into the options of the questionnaire 'Yes', 'No' and 'I don't know'. After that the values needed to be fuzzified. This is necessary in order to obtain the purer value of the choice. Within this questionnaire, there were only closed questions. Suppose someone doubts between two options but has to choose because these are closed questions, then his real opinion is not considered.

With the fuzzification of the answers, a common denominator is taken. In case of this questionnaire, with the three choice options, the three points Likert-scale has been used (see Figure 46 and Table 16). Consider someone chooses the answer 'I don't know' then the range from zero to one is applicable with a peak at ½. Hereby zero is the 'lower bound', ½ the 'most probable', and 1 the 'upper bound'.

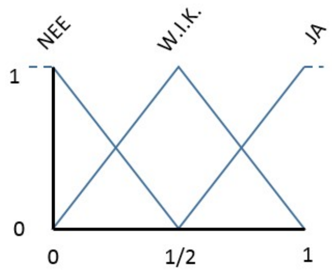


Figure 46: Three point Likert-scale ('NEE' = No, 'W.I.K'= I Don't Know, 'JA'= Yes).

Table 16: Three-point Likert scale (L, M, U) (L = Lower-, M = Middle-, U = Upper bound).

No	I Don't Know	Yes
(0, 0, 1/2)	(0, 1/2, 1)	(1/2, 1, 1)

For every obstacle from each respondent such data is collected. In order to gather the mean value of the respondents, the data needs to be aggregated. There are different techniques for this aggregation, some of which are experimental (Habibi, Jahantigh, & Sarafrazi, 2015). Within this research the simplest method is been used for the fuzzy aggregation of respondents' opinions, the 'fuzzy average' (see Figure 47). Mostly because all the respondents' opinions are considered as triangular fuzzy numbers because the range between the answers isn't that big with only three options.

$$\text{Fave} = \frac{\sum L}{n}, \frac{\sum M}{n}, \frac{\sum U}{n}$$

Figure 47: Fuzzy Average (L = Lower-, M = Middle-, U = Upper bound).

The three numbers which make up the fuzzy average (L,M,U) represent the mean value from the respondents about a certain obstacle. The equation $\frac{L+M+U}{3}$ is used to defuzzify the mean values and make it into crisp values. This results in an overall score where all the respondents' opinions aggregated as equally into an average as seen in Figure 48. In this figure is seen in what order the obstacles are ranked by the average respondents opinion. This is in the situation where all the respondents are considered equal, so without taking their background into consideration.

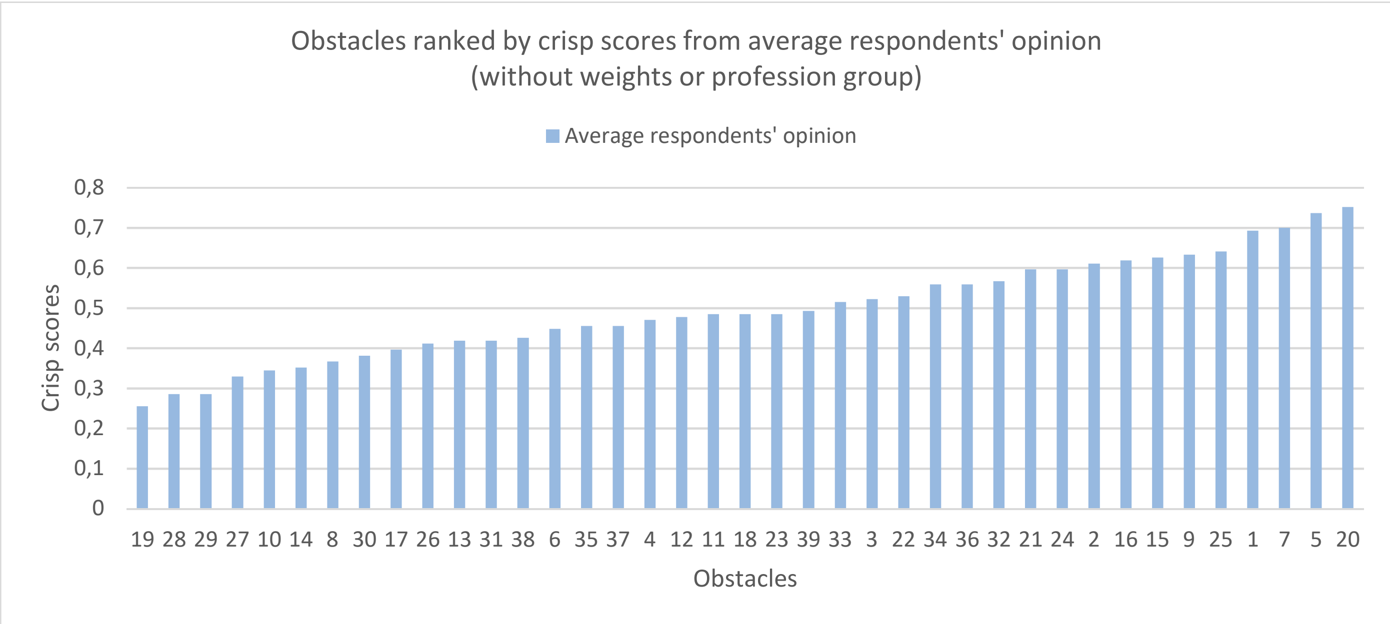


Figure 48: Obstacles ranked by crisp scores

6.4 Screening criteria

Besides different profession groups, the obstacles are grouped in different obstacle groups. Both are used as different screening criteria.

6.4.1 Profession groups

Not all the respondents are from the same background. Some respondent opinions are considered more important and valuable as others. Therefore, the respondents are grouped in different professions. In order to be able to group the respondents into expert groups/profession groups, they were asked about their profession in the questionnaire. There were twelve possible profession choices, including an option 'other', see Table 17. It turned out in the end that there were not enough respondents for each profession to consider it as homogeneous. For this at least ten of the same profession were needed (Delbecq, Gustafson, & Van de Ven, 1975). Therefore, a higher abstraction level is used in order to indicate the professional groups as homogeneous. The distribution[4] of professions can be seen in Table 17.

Besides the average respondents' opinion, also the average opinion of each profession group is calculated. In this way it can be compared what profession group considers which obstacle as more important. This is seen in

Table 18. For each profession group the crisp value is been calculated by obstacle.

Table 17: Respondent numbers by profession from the questionnaire

Profession	Number	Profession groups	Number
Advisory	6	Counselor	17
Automotive	2		
Industry	4		
Association	0		
Consultant	5		
Energy supplier	3	Energy network	13
DSO	10		
Education	3	Authority	14
Government	8		
Politics	2		
NGO	1		
Other	1		
TOTAL	**45**		**44**

Table 18: Obstacle top 10 by each profession group

		Importance level									
Counselor	**Obstacle**	**32**	**36**	**1**	**15**	**16**	**25**	**9**	**5**	**20**	**7**
	Score	0,64	0,64	0,66	0,66	0,66	0,72	0,74	0,77	0,77	0,79
Energy Network	**Obstacle**	**6**	**9**	**2**	**16**	**24**	**21**	**15**	**1**	**5**	**20**
	Score	0,58	0,58	0,60	0,60	0,63	0,63	0,71	0,73	0,73	0,73
Authority	**Obstacle**	**16**	**36**	**23**	**24**	**2**	**25**	**1**	**5**	**20**	**7**
	Score	0,57	0,60	0,60	0,60	0,62	0,67	0,69	0,69	0,74	0,76

[4] The initial profession of the respondent in Table 7 is assigned by the researcher. The respondent had the option to fill in their own profession in the questionnaire. Depending on their background and also the choice options they could have filled in another profession group. This must have happened because there is a difference in numbers.

6.4.2 Obstacle groups

The obstacles with a cohesion bond where grouped together in an obstacle group. Based on the average score of the obstacles within the group, a ranking is made. See

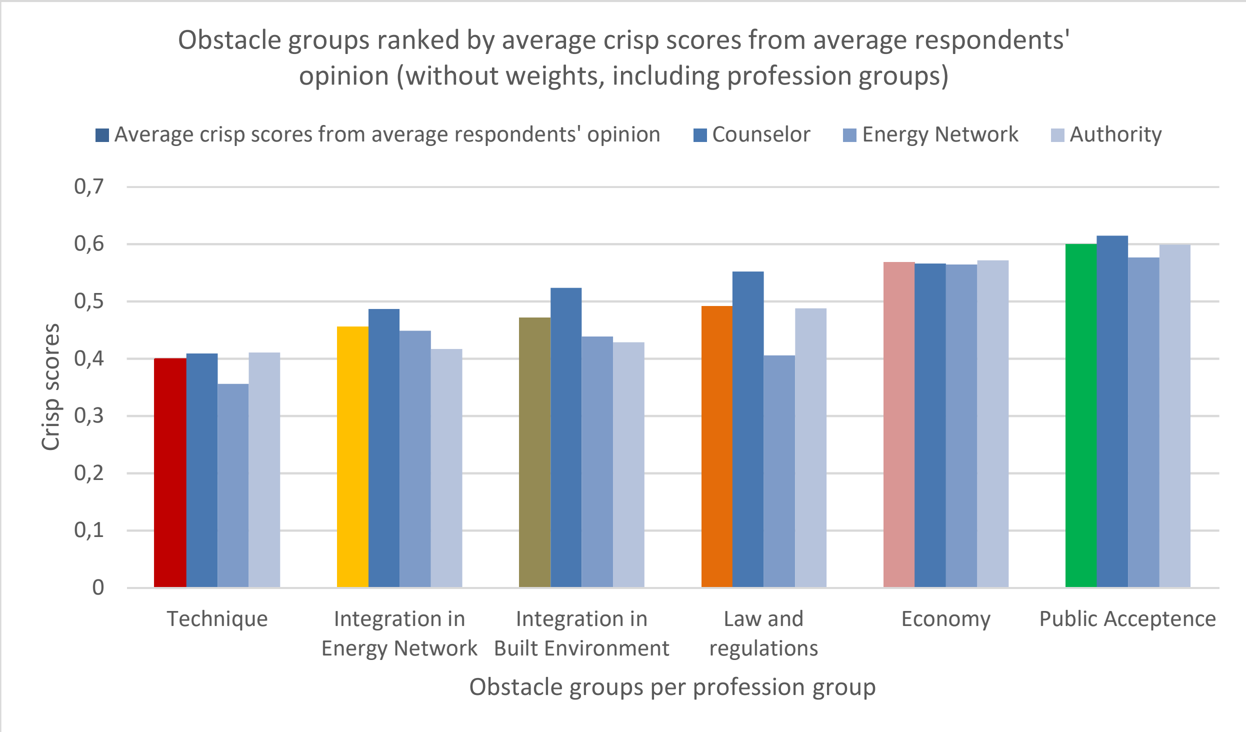


Figure 49. It represents the group in which most obstacles are recognized. Besides an average based on the respondents' opinion, the popularity of each obstacle group is also presented for each profession group. There are six obstacle groups. The first bar represents the average crisp scores from average respondents' opinions. This color is used to separate the groups more from the profession groups.

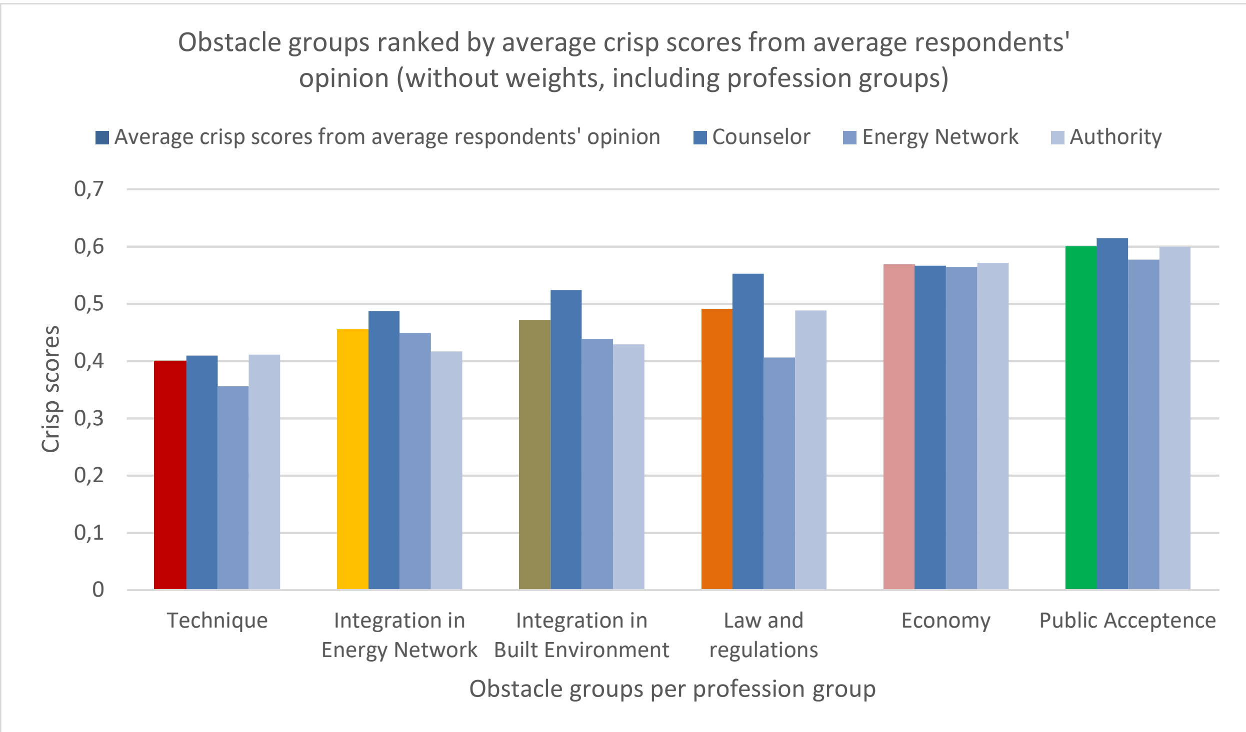


Figure 49: Obstacle groups ranked by profession group

6.4.3 Adding weights and threshold

To each profession group a certain weight was given in relation to the power interest level. By doing so, the opinion of the profession groups which are considered as more important and valuable have a higher impact on the results. Table 19 shows how the weights were established. After the weights for each profession were multiplied with the aggregated data, there is an overview of the most recognized obstacles. This is visualized in Figure 50. Due to the multiplication, the scores aren't crisp anymore.

Table 19: Weight by profession

Profession	Power	Interest	Value [P x I]	Weight
Counselor	1	2	2	0,153846
Energy network	3	3	9	0,692308
Authority	2	1	2	0,153846

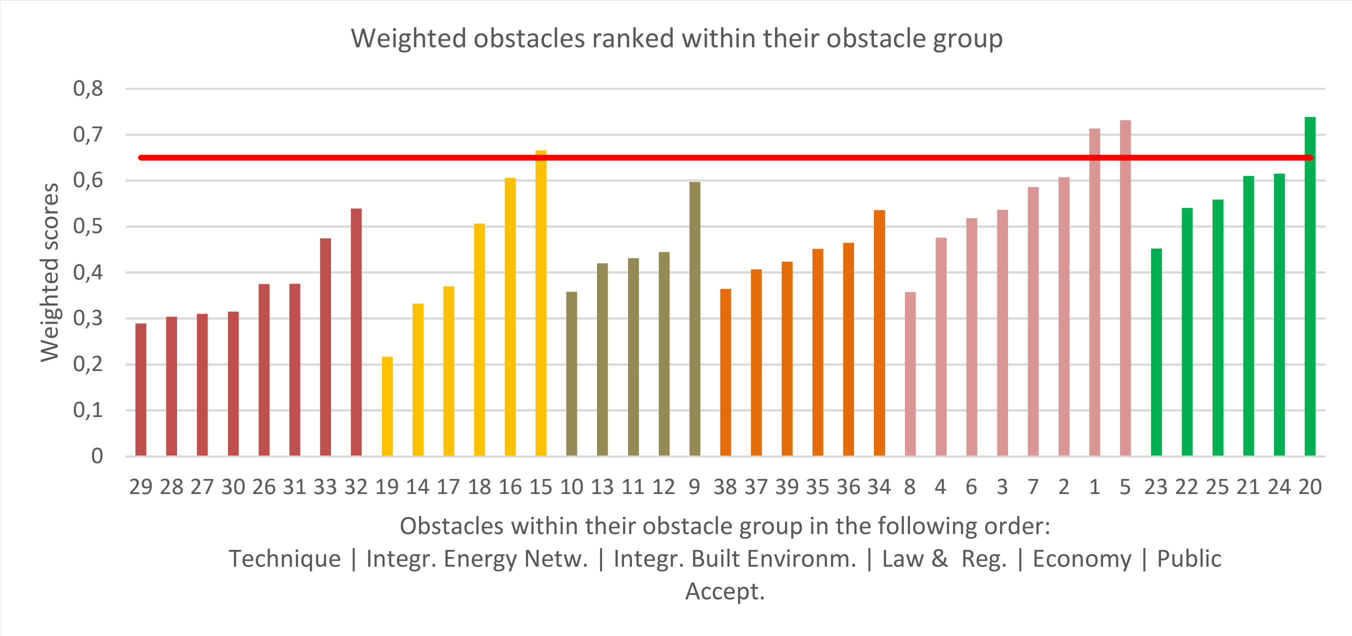


Figure 50: Weighted obstacles ranked within their obstacle group

The threshold to which the weighted values should rise to be considered viable was set at 0.65. Typically it is 0.70 but it can vary based on the opinion of the researcher (Habibi, Jahantigh, & Sarafrazi, 2015). The goal was to have five main obstacles. But in this case, as seen in Figure 50, there were four values that clearly rise above the rest at 0.65. Therefore, this score was assumed to be the threshold number. In Figure 51 and Table 20 the four obstacles are shown more specifically that scored above the threshold. From this overall view, a split view is made for each profession group which are seen in Figure 52 till Figure 54.

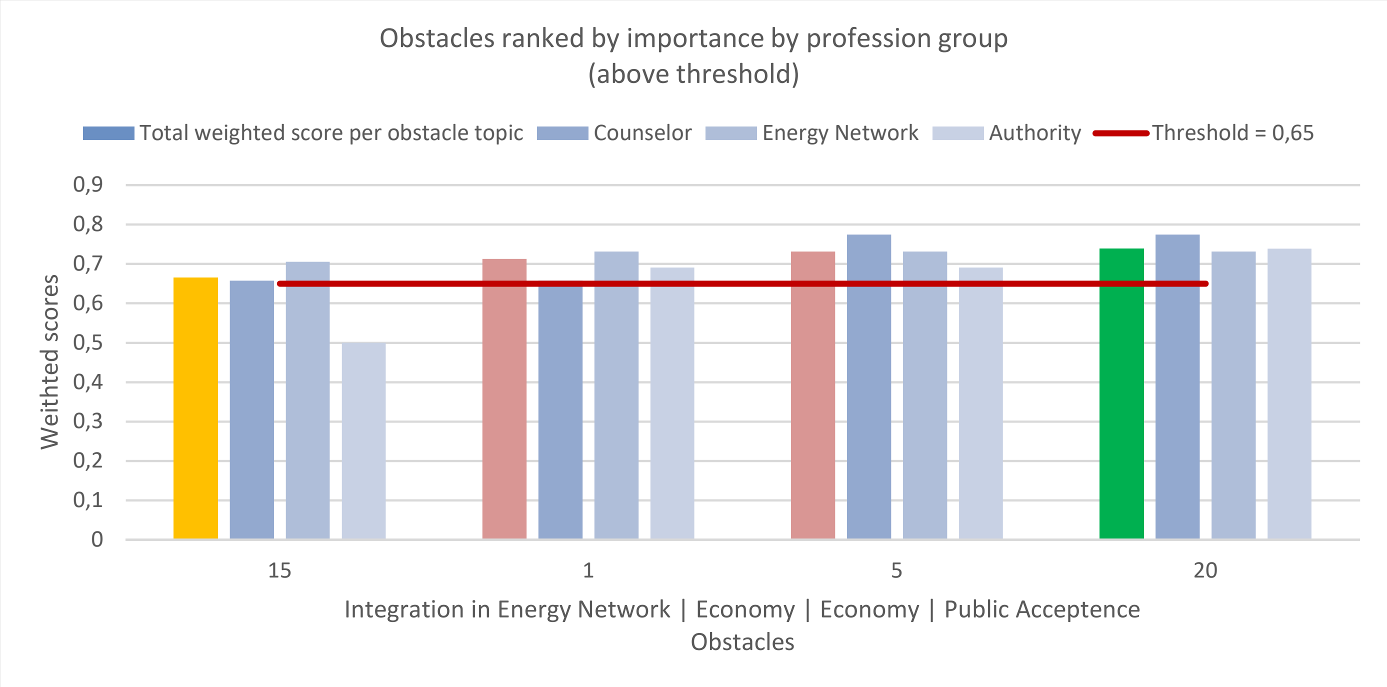


Figure 51: Obstacles ranked by importance by profession group

Table 20: Outcome questionnaire

Importance	Obstacle number	Value total weight	Description
1th	20	0,7386	It is an obstacle that local, sustainable produced hydrogen is more expensive to citizens as fossil fuels.
2nd	5	0,7313	It is an obstacle that fossil energy is cheaper.
3rd	1	0,7132	It is an obstacle that the current CO_2 emission pricing is too low for the introduction of sustainable energy, including neighborhood level.
4th	15	0,6661	It is an obstacle that there is currently no need to use hydrogen as a part of grid balancing systems.

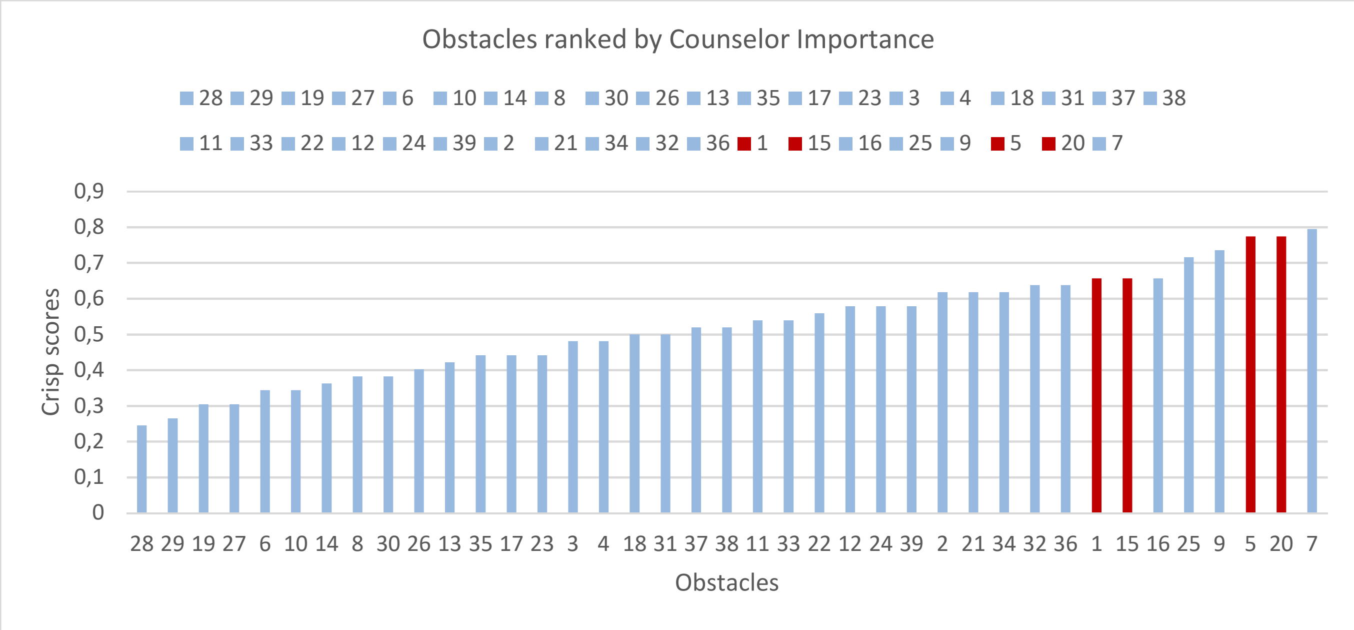


Figure 52: Obstacles ranked by Counselor

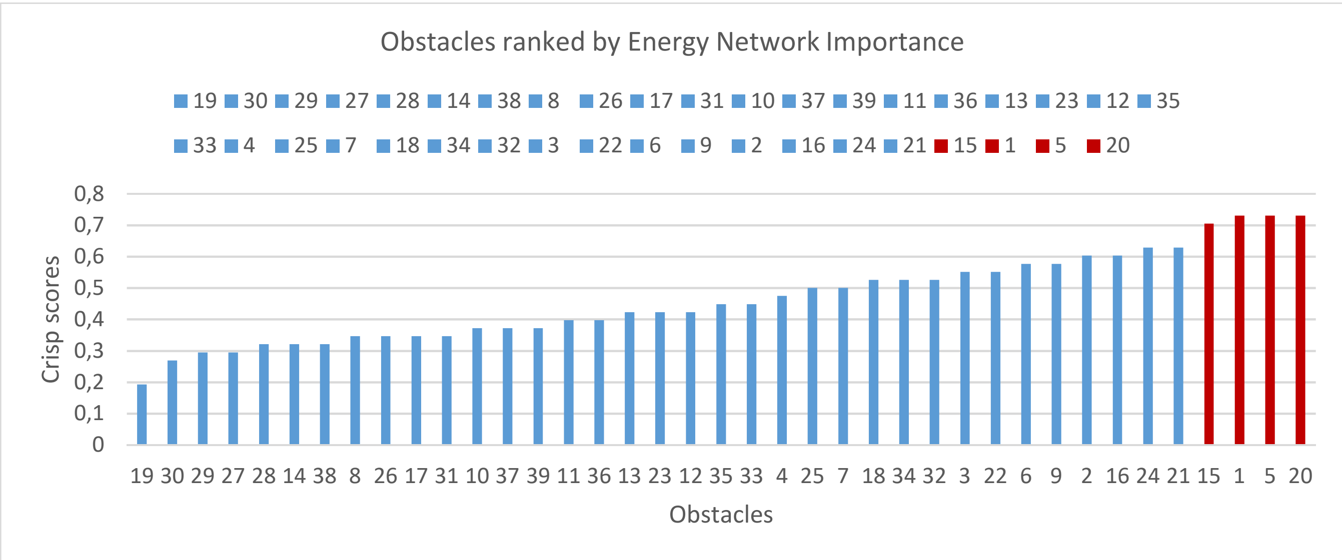


Figure 53: Obstacles ranked by Energy Network

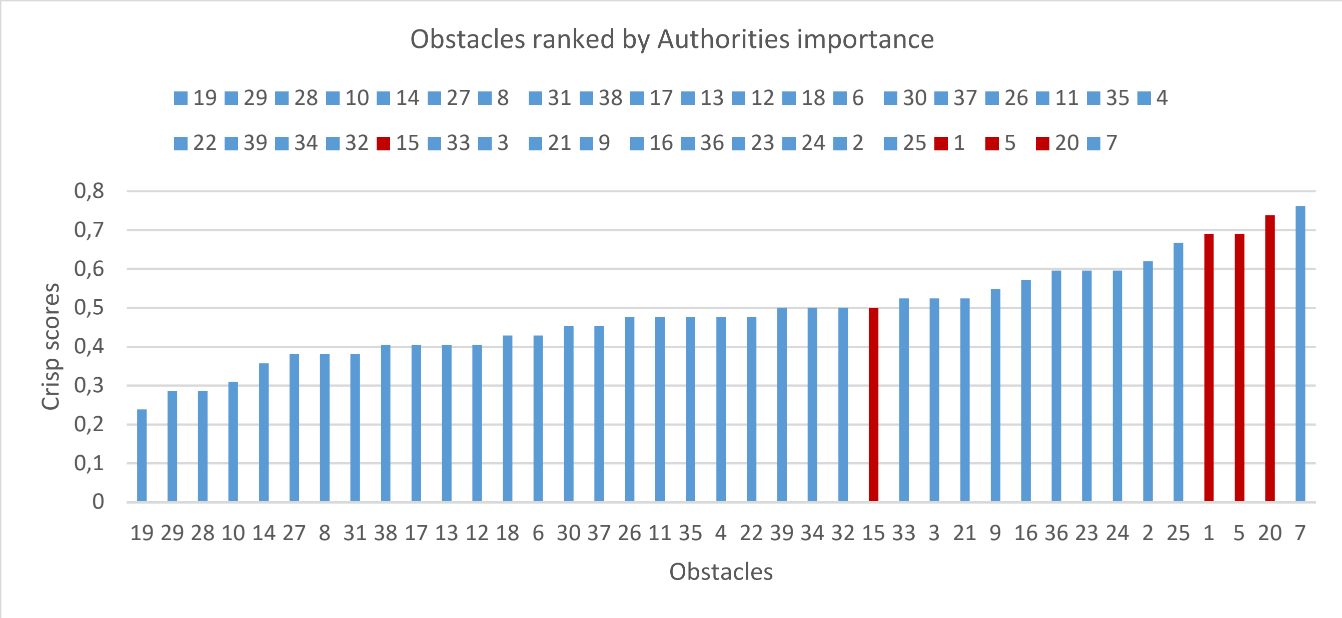


Figure 54: Obstacles ranked by Authority

7 Interviews

The following people in Table 21 are being contacted during the graduation project for collecting information. The contact forms differ depending on the availability of time and the necessity to meet in person. For each of the contacted persons, there is a (small) summary in Dutch about what is been discussed and/or questioned.

Table 21: Persons questioned during project

Date	Contact form	Person	Organization
20160302	Meeting	Wiet Mazairac	TU/e
20160420	Meeting	Jan Piet van der Meer	NWBA (hydrogen association)
20160422	Meeting	Guy Konings	Stedin (DSO)
20160503	Meeting	Anton Janssen & Ben Lambregts	Liander (DSO)
20160504	Meeting	Senja Boom	Student expert
20160510	Meeting	Marvin Tiemessen	Team Fast
20160511	Meeting	Jaco Reijerkerk	Linde Gas (industrial gas company)
20160523	Mail	Vincent Oldenbroek	TU Delft
20160525	Meeting	Francoise de Jong & Jan Morren	NEN & DCMR
20160527	Phone	Sander van Schagen	Municipalitiy Albrandswaard
20160617	Phone	Joost Welsing	Bredenoord
20160622	Phone	Chris van Dijk	Rai vereniging
20160628	Meeting	Bart Colijn	Siemens
20160701	Meeting	Albert van der Molen	Stedin (DSO)
20160726	Phone	Rob van der Sluis	MTSA
20160729	Mail	Jan ten Have	MTSA
20160729	Meeting	Lisette Kaupmann	Stedin (DSO)
20160809	Phone	Frank Meijer	Hyundai
20160822	Meeting	Laetitia Ouillet	Eneco / TUe
20160822	Meeting	Albert van der Molen	Stedin (DSO)
20160826	Meeting	Guy Konings	Stedin (DSO)
21060901	Meeting	Jaco Reijerkerk	Industrial gas company
20160905	Meeting	Jan Piet van der Meer	NWBA
20160926	Meeting	Jan Langendijk & Marcel Versteegen	Siemens

7.1 20160302 Meeting Wiet Mazairac | TU/e

Details	
Subject	Hydrogen in the built environment
Date	March 2, 2016, Wednesday
Interviewee	Wiet Mazairac
Organization represented	PhD researcher TU/e
Language	Dutch

Als PhD onderzoeker aan de faculteit bouwkunde van de TU/e is Wiet Mazairac bezig een optimalisatie model te ontwikkelen voor het energie netwerk. Hierin wordt rekening gehouden met de groeiende decentrale opwekking van elektriciteit, intermitterende productie, mogelijke energy conversie systemen en opslag mogelijkheden. Vervolgens wordt dit model over bestaande stadstructuren gelegd en zo inzichtelijk waar er 'energie knooppunten' zijn. Hierbij kan waterstof een rol spelen als energiemedium door overschotten van elektriciteit hierin om te zetten.
Meer informatie is gegeven in de paper en presentatie genaamd: 'Towards an optimal topology for hybrid energy networks'.

7.2 20160420 Meeting Jan Piet van der Meer | NWBA

Details	
Subject	Hydrogen in the built environment
Date	April 20, 2016, Wednesday
Interviewee	Jan Piet van der Meer
Organization represented	NWBA
Language	Dutch

Voorafgaand aan dit oriënterende gesprek was er al volop contact geweest via Skype en per mail. Hierin is geholpen met het vinden van een geschikt bedrijf waar dit afstudeeronderzoek plaats kon vinden.
Gedurende dit gesprek is gesproken over de rol van waterstof zowel in mobiliteit als in de gebouwde omgeving. Daarnaast is er over de hoofdlijnen van het onderzoek gesproken, welke mensen er zeker bevraagd moesten worden.

7.3 20160422 Meeting Guy Konings | Stedin (DSO)

Details	
Subject	Function and role of the DSO
Date	May 22, 2016, Friday
Interviewee	Guy Konings
Organization represented	Stedin
Language	Dutch

Stedin als netbeheerder nog onderdeel van Eneco. Guy bezig met energie transport in brede zin, daarom ook opslag en conversie in portfolio. Investeren in infrastructuur.

Netbeheer (DSO) taken vastgelegd. Onder andere in Wet Onafhankelijke Netbeheer (WON 2008). Vanuit Ministerie van Economische Zaken aansturing ACM (Autoriteit Concument en Markt). ACM controleert de DSO. Voorheen was er de 'Wet Stroom' die beschreef wat de DSO's moeten doen.

DSO's monopoly positie in Nederland. Enexis, Stedin & Liander verdelen de markt (nog paar kleine spelers). Pag 67 (ECN; et al, 2014). Functie is aansluiting verzorgen voor energie, zowel elektra, gas, warmtenet, etc. Tevens zorgen dat het net het blijft doen. Netbeheerders hebben de verplichting om het net voldoende te versterken zodat alle elektriciteitsproductie de weg naar de afnemer kan vinden. Hierbij proberen vooruit te kijken, namelijk moeilijk snel zaken te veranderen. Daarom veel interesse in Smart Grid en mogelijk ook opslag. VB: is de congestie gebieden. Afspraken met bedrijven die tijdelijk elektriciteit extra kunnen opnemen of juist kunnen vrij maken.

Mbt mijn onderzoek de aanname dat er thuis opgeslagen zal gaan worden. Die markt bestaat nu nog niet. Zeker niet in Nederland. In Duitsland opkomend. Daar een regeling waarbij er een zeer gunstige prijs voor lokaal opgewekte energie gegeven wordt. Dit werd te populair waardoor de markt scheeftrok. Rijken investeerden maximaal en verdienden dik. Armen alleen maar dure energie. Nu 80% verrekend, 20% niet. Daardoor investeringen in accu opslag toegenomen. Tussen de 20 á 30000 thuis batterijen geïnstalleerd. Proberen nu koppelingen te maken tussen die accus.

In Nederland proeftuinen (Pag 63, ECN Energietrends 2014, Smart Grid proeftuinen NL). Focussen op Lombok in Utrecht en Hoogdalem in Gorinchem. Met dit soort Smart Grids pas net begonnen. Toepassingen daarvoor dus ook in de kinderschoenen. Tesla Powerwall, Toon van Eneco, etc.
Smart Grid is stap 1, seizoensgebonden opslag is stap 2. Lastig om dit in de tijd uit te zetten. Zeker is dat het nog decennia duurt.

Mensen weinig tot geen interesse in energie. Slechts 1 op de 10 kijkt ernaar. Daarnaast willen mensen best veranderen (gedrag, energie gebruik) maar wel uit eigen wil en niet omdat een andere partij dat hun oplegt. Daarom kan een Smart Grid ook alleen als de mensen daar zelf om vragen of na goede info hier voor kiezen. Daarom is het belangrijk om via marketing mensen vast voor te bereiden. Anders is het accepteren een groot obstakel. VB met Tesla en Apple. Het maakt de mensen niet uit wat voor technologie erin zit, maar hoe cool en 'geil' het is. Hoe kan waterstof buffering geil gemaakt worden? Wellicht ook door de autoindustrie. Zodra er gave autos zien op waterstof, en zichtbaar is dat men dat zelf kan gaan produceren (eerste idee werkte ook met elektrische auto's eigen brandstof verzorgen) kan dat als een katalysator werken voor de acceptatie.

Obstakel kosten/verdienmodel
Bij een gedeeld gebruik van energie, hoe gaat het met de bemetering en de verrekening? Gaat dit uit van een nieuw platform, of bestaande partijen? Zijn die te vertrouwen?
Tevens het regelen van de investering die gemoeid is met het waterstof bufferen. Wie betaald de electrolyzer? En de opslag tanks? En de brandstofcel? Aansluiting op het net? Gedeelde investering van de gebruikers of van de netbeheerder omdat die zo de congestie tegen kan gaan?

Schaalniveau bepalen waarin de case zich afspeeld. → een van de punten die met begeleiders besproken moet worden.
VB waarbij AlbertHeijn zich gaat richting op de energiemarkt. Combinatie van producten, cross-selling. Bij de afname van waterstof korting op biologische artikelen.

7.4 20160503 Meeting Anton Janssen & Ben Lambregts | Liander (DSO)

Details	
Subject	Function and role of the DSO
Date	May 3, 2016, Tuesday
Interviewees	Anton Janssen & Ben Lambregts

Organization represented	Assets Manager & Manager External Relations
Language	Dutch

Anton Janssen – Assets manager
Ben Lambregts – Manager External Relations Asset Management
Rob Nispeling (niet aanwezig) Jaap op borrel gesproken. Fuel cell systeem Chinese markt. MTSA, 2MW
Bert Heerbaart gesproken op CME congres 2015 TU/e. Manager Smart Grids

1. Taken van netbeheerder. En volgens Liander?
   Liander is netbeheerder. Gereguleerde markt waarbij de netbeheerder de aansluiting op energie moet faciliteren. Daar valt dus onder de aansluiting en meter bij klanten en ook het onderhoud.
2. Toekomst beeld van netbeheerder volgens Liander? Elektra vs Gas? Warmtenetten?
   Volgens Ben (Gas man) heeft gas een toekomst. Ook icm waterstof.
   Volgens Anton (Elektra man) heeft gas een mindere toekomst.
   Combinatie van meerdere energiebronnen zal het tezamen gaan doen. Nu nog is de netbeheerder verantwoordelijk voor het type aansluiting dat de klant wenst. Niet wat de meest handige is.
3. Gehoord dat het gasnetwerk sterk verouderd is. Klopt dit en zijn er specifieke delen?
   Het hoofdnetwerk is onlangs op vele plekken gemoderniseerd. Het straatnetwerk niet. Dat is verouderd. Gas al lange tijd voorname energie voorziening. Steden produceerden hun eigen gas. Toen gas uit Slochteren kwam pas een landelijk netwerk aangelegd.
4. Hoe moet de energie transitie lopen om daar te komen? Welke stappen voorzien zij?
5. Al nagedacht over volledig afhankelijk zijn van hernieuwbare energiebronnen?
6. Vanaf waar worden de windparken toegevoegd in het systeem? 150kV of ook 10/20kV?
   Op netwerk van DSO
7. Hoe om te gaan met decentrale productie? Terugleveren aan netwerk? Intermitterend

8. Hoe om te gaan met laden EV’s? Vanaf welke percentage wordt dit kritisch?
9. Hoe wordt er gekeken tegen lokale energie opslag? Bij mensen thuis? In de wijk als collectief?
   Werken door middel van pilots toegestaan mits bezien als Demand Side Management. Anders is er sprake van handel. DSO’s in NL mogen geen handel bedrijven.
10. Hoe denkt Liander het financieel te willen doen gedurende de transitie?
    Techniek is er in basis al, business modellen nog niet.
    Nu nog een probleem. Geen eenduidige oplossing. Antwoord zal bestaan uit meerdere verschillende systemen.
11. Wat ziet Liander als obstakels bij de implementatie van energieopslag in waterstof?
    Nu DSO geen rol als het achter de meter (bij mensen thuis) gebeurd. Op grote schaal nu niet interessant. Te veel speculatie. Geen incentive om grootschalig energie op te gaan slaan.

12. Wat zouden als eisen gesteld moeten worden aan de veiligheidsaspecten? Minstens zo veilig als de huidige technieken.

7.5 20160504 Meeting Senja Boom | Student expert

Details	
Subject	Storage of surplusses of energy
Date	May 4, 2016, Tuesday
Interviewee	Senja Boom
Organization represented	Bachelor student TU/e
Language	Dutch

Senja doet onderzoek naar het opvangen van fluctuerende energieproductie door duurzame bronnen in synthetische gassen/vloeistoffen in Duitsland. Hierbij heeft ze vooral een focus op het verschalen van dit soort praktijken en de perceptie die het heeft bij het publiek. Vooral het kijken naar andere vormen van energieopslag in waterstof maakt het interessant. Hierbij is het wel nóg een stap verder in de toekomst.

7.6 20160510 Meeting Marvin Tiemessen | Team Fast

Details	
Subject	Formic acid fuel cells
Date	May 10, 2016, Tuesday
Interviewee	Marvin Tiemessen
Organization represented	Member of Team Fast
Language	Dutch

Hoe verloopt de vorming van Mierenzuur? Rendement?
-Waterstof uit electrolyse, CO_2 uit lucht (zeer energie intensief). Reactor heeft temperatuur van zo'n 80graden nodig. Lange opstart tijd. Proberen om de warmte van brandstofcel te gebruiken om reactor op gang te brengen.
CO2 als bron, maar uit de lucht of uit industrieel proces?
-Uit lucht halen om circulair te zijn. Wat vrijkomt bij industrieel proces is nieuwe CO_2. Niet circulair.

Hoeveel ruimtewinst (volume) tov waterstof gas/vloeistof?
-Twee keer meer energie uit zelfde volume. Daardoor interessant voor zwaarder transport zoals bussen en vrachtwagens (wellicht ook boten?)

Veiligheid risico verschillen met waterstof?
-Niet brandbaar, geen ontploffingsgevraag. Wel een zuur. Contact met lichaam vermijden.

Lokaal geproduceerd of juist op centrale plekken?
-Productie nu nog ingekocht bij BASF (chemicaliën producent). Daar nu niet echt focus op. Uitgaan dat mierenzuur gewoon bij tankstation te verkrijgen valt. Zeker omdat er nu nog meer marge gepakt kan worden op het product zal het voor pomphouders interessant kunnen zijn.

Transporteren over de weg of via leidingen?
-Geen antwoord op gekregen

Rekenwaarde: 1kg H2 → 100km auto / 10km bus. En met mierenzuur?
-Mierenzuur in liters gesproken

7.7 20160511 Meeting Jaco Reijerkerk | Linde Gas (industrial gas company)

Details	
Subject	Hydrogen
Date	May 11, 2016, Wednesday
Interviewee	Jaco Reijerkerk
Organization represented	Linde Gas
Language	Dutch

1. Waterstof wat is het
    a. Chemisch element
    b. Hoe te verkrijgen
    c. Waarvoor gebruiken
2. Productie van waterstof op industriële schaal
    a. Welke methodes?
       -SMR = Steam Methane Reforming. $CH_4 + H_2O \rightarrow H_2 + O_2$
       -POX = Partiele Oxidatie van kolen en/of olie
       -PEM Elektrolyse
       -Chloor-alkali-electrolyse
       -Allemaal verschillende vormen van puurheid.
       2.5= 99,5% zuiver
       3.0= 3 digits dus 99,9% zuiver
       5.0= 5 digits dus 99,999% zuiver → benodigd voor PEM FC
       8.0 pas bereikt bij vloeibaar maken
    b. Hoeveel?
       -Productiefaciliteiten vaak gecombineerd met directe leveringen ' at the fence' Hierdoor veel productie, maar daardoor ook direct gebruik. Sec productie getallen zouden verkeerd beeld geven.
    c. Verschil in gevaar bij verschillende schaalgrootten?
       -Allemaal even gevaarlijk/even veilig. Gaat om acceptabel veiligheidsniveau. Kans = risico x impact. Verschillende risico contouren (10^-6).
       -Middels FMEA (Failure Mode and Effects Analysis) en HAZOP (Hazard Analysis and Operability Analysis)
3. Veiligheid
    a. Welke instanties zijn betrokken als het op veiligheid aankomt?
    b. Zijn er incidenten geweest in het verleden? En zo ja, wat is er gebeurd? (bij klanten?)
       -Tankwagen/trailer met waterstof dwars op de autobahn. Daarbij lek ontstaan waaruit waterstof ontsnapte. Dit is gaan branden. Toen helemaal uit laten branden. Daarna extra veiligheidsmaatregelen doorgevoerd.
    c. Aan welke/hoeveel regels moet er voldaan worden?
4. Transport
    a. Huidige methode voor transport? Gas/vloeistof/hybride?
       -Gas vorm in trailers
       -Als vloeistof alleen voor zeer grote hoeveelheden. Moet enorm koud zijn, -253 graden. Alleen helium is kouder met -273 (koudste temperatuur

op aarde). Daardoor alle onzuiverheden makkelijk eruit te halen. Maar vloeibaar maken kost wel veel energie.
-Hybride inefficiënt want te zwaar en niet rendabel
    b. Weg/spoor verschil in regels?
    -Verschil voor voertuigen en cilinders.
    c. Pijpleidingen?
    -Geen lange pijpleidingen, vooral direct naar gebruiker
5. Gebruik
    a. Wat voor klanten heeft Linde gas voor waterstof?
    -Vooral chemie bedrijven
    b. Hoe gaan die er mee om?
    -Over het algemeen direct gebruik. Weinig tot geen opslag.
6. Opslag
    a. Lange termijn opslag (seizoensgebonden), wat dan geschikt?
    -Mits goeie tanks gebruikt worden is waterstof geschikt.
    -Andere synthetische gassen ook mogelijk. Methanol bijvoorbeeld. Maar autofabriknten hebben dit soort synthetische vloeistoffen afgeketst. De reactoren die ervoor nodig zijn, zijn te instabiel, niet op grote schaal voor auto-industrie te fabriceren.
    b. Hoeveel % verdwijnt/verdampt er gedurende de tijd?
    -Metalen tank uit juiste legering verliest geen waterstof
    -Verkeerde metalen tank (pis bakken staal), daarbij zal het waterstof in de molecuulstructuur opgenomen worden. Zorgt voor bros metaal. Op den duur lekken.
    -Bij voertuigen carbonfiber tanks met een speciale binnencoating.
7. Toekomst
    a. Hoe wordt door Linde de energietransitite bezien?
    b. Wordt daarin waterstof een rol toebedeeld?
    c. Hoe zit het met waterstofgebonden producenten? Mierenzuur, etc? Team Fast
    -Focus houden. Leuke initiatieven maar duurt te lang voordat het op te schalen valt. Nu de techniek met H2 wel zo ver. Daar gebruik van maken. Als men eenmaal gewend is aan waterstof, kunnen waterstof gebonden producten alsnog komen.
    -Methanol bijvoorbeeld. Maar autofabriknten hebben dit soort synthetische vloeistoffen afgeketst. De reactoren die ervoor nodig zijn, zijn te instabiel, niet op grote schaal voor auto-industrie te fabriceren.

7.8 20160511-20160523-20160816 Mail Vincent Oldenbroek | TU Delft

Details	
Subject	Hydrogen in the urban environment
Date	August 16, 2016, Tuesday
Interviewee	Vincent Oldenbroek
Organization represented	TU Delft, PhD candidate, Car as Power Plant
Language	Dutch

Er is nu wel een PGS richtlijn mbt waterstoftankstations, "afleverinstallaties", klinkt niet echt als opslag, maar goed binnen tankstations is er ook wel degelijk opslag aanwezig.

http://www.publicatiereeksgevaarlijkestoffen.nl/publicaties/PGS35.html

Die richtlijn is door de PGS organisatie (weet niet echt hoe die heet) in samenwerking met industrie gebeurt. Zie bijlage ook presentatie over de PGS en contactpersoon op laatste slide. AJ: PGS is mij bekend

Jouw onderzoeksvraag:

"obstakels wil identificeren die er zijn bij het implementeren van waterstofopslag in de gebouwde omgeving"

Stel je neemt waterstof onder hoge druk. Dit kan gewoon, is commerciële techniek. Vanuit mijn technisch en veiligheidsoogpunt geen probleem. Alleen ik weet dat het in de praktijk erg lastig is, maar dit is meer een juridisch en sociaal probleem. Juridisch, denk aan verzekeringsmaatschappijen, dit wordt nog maar heel weinig of niet gedaan, dus zijn er geen ongevallen statistieken dus is het lastig een verzekeringspremie te berekenen , als men dit uberhaupt al wil verzekeren. Sociaal, als mensen waterstof horen denken ze aan een oude zeppelin van 100 jaar geleden die ontploft is en brandstoftanks onder druk vinden mensen altijd gevaarlijk klinken AJ: Sociaal zeker. Vaak nog referenties aan de waterstof bom en de zappelin. Juridisch nog niet veel over bekend. Verzekeringsmaatschappijen is een goeie. Ik ga eens na bij pilot projecten hoe dat is gedaan.

"Zeker wat jullie professionele mening is omtrent de energie opslag in waterstof."

Naar wat voor type opslag kijk je? Welke ordegrootte? Voor welke toepassing (electriciteitsopslag, brandstof, beide, chemische grondstof?) AJ: opslag van surplus van energie op wijk of zelfs stadsniveau. Energie die lokaal opgewekt is en die niet direct gebruikt kan worden, of niet direct thuis opgeslagen (EV/thuisbatterij/powerwall) kan worden. Mogelijk om SmartGrid principe te gebruiken en ook voor buurtbewoners direct te leveren, en/of bij te laden. Uiteindelijk zal er bij voldoende overstap op hernieuwbare bronnen een groot genoeg vermogen overblijven die omgezet kan worden in waterstof. Dit kan gebruikt worden om de seizoensvariaties op te vangen. In de zomer kan meer energie opgewekt worden als in de winter, terwijl in de winter meer energie verbruikt wordt. Afhankelijk van de ordegrote van surplus, kan er ook waterstof uit de centrale opslag gebruikt worden voor mobiliteit. Middels Smart verreken systemen kan eea verrekend worden.

VO: helemaal in lijn met onze visie.

Kijk elektriciteit, als opgewekt door een variabele duurzame bron (zon of wind), moet je afnemen wanneer die opgewekt wordt. Elektriciteit is alleen wat waard als het op het goede moment in de tijd op de juiste locatie is. M.a.w. als het ver weg wordt opgewekt (off-shore wind oid) of op een verkeerde tijd (overdag zon, 's avonds energieverbruik) dan heb je of een groot en sterk (lees duur) electriciteitsnetwerk nodig. Qua opslag in de tijd zijn er natuurlijk vele opties, alleen grootschalig, lange tijd zonder zelfontlading, op alle locaties mogelijk (er zijn bijv. niet overal stuwmeren), relatief snelle laad en ontlading, scoort waterstof relatief goed. AJ: Bekend!

http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapHydrogenandFuelCells.pdf

Los van electriciteitsopslag is waterstof gewoon bijzonder veelzijdig, het kan ook weer als transportbrandstof dienen voor 100% duurzame brandstofcelvoertuigen, die nu net op de markt komen.

Waterstof is ook een belangrijke grondstof voor de chemische industrie (kunstmest - ammonia, methanol), van bepaalde industrien ook weer restproduct (bijvoorbeeld chloorproductie). AJ: Onlangs met Linde Gas gesproken. Veel kennis van productie, opslag en transport van waterstof. Ook de huidige toepassingen besproken voor de chemische industrie.

Of opslag van waterstof onder 350 bar of 700 bar de beste opslag manier is hangt ook erg van de toepassing af, los daarvan ook kosten. Maar er is erg veel onderzoeken naar andere manieren van waterstof opslaan, vloeibaar, cryo-compressed, metaalhydride, mierenzuur met 2-weg catalysator (TU/e), Liquid organic hydrogen carrier (http://www.hydrogenious.net/en/home/), etc. AJ: Deze week met Team Fast (Mierenzuur) gesproken. Zij zien het als een oplossing voor zware mobiliteit, vooral bussen en vrachtwagens. Tevens zijn ze bezig te onderzoeken of het ook als buffermethode kan dienen. Iets waar ik mij nu ook mee bezig houdt. Nadeel blijft dat er altijd extra stappen nodig zijn, en met name extra energie erbij gemoeid is. Het lijkt mij interessant om dat soort vloeistoffen te gaan gebruiken zodra er enigszins sprake is van een ‘waterstof-economie’ en dat een groot deel van de populatie gewend is aan het idee van waterstof.

VO: Klopt extra stappen andere of meer “balance of plant” technieken en apparatuur. Soortgelijk zijn Liquid Organic Hydrogen Carriers LOHC;

http://www.hydrogenious.net/en/technology/ en
http://www.sciencedirect.com/science/article/pii/S036031991201868X

Je kunt ook denken aan waterstof opslaan in de vorm van een ander molecuul dus methaan, ammonia . Zolang dat molecuul niet een eindproduct is, maar puur een energiedrager, moet je altijd bedenken, dmv welke techniek je deze energiedrager gaat omzetten in een bruikbare vorm van energie?

AJ: Voor mij is waterstof overigens ook alleen een optie als het puur uit hernieuwbare bronnen wordt verkregen. SMR, Chloor-Alkali, cracking en wat dan ook is niet future-proof. Daarnaast zijn de output van deze processen nog zeer onzuiver. Elektrolyse is daarbij in het voordeel. PEM brandstofcellen kunnen daar veel beter mee overweg.

VO: helemaal mee eens maar mbt lokale integratie kan het soms interessant zijn. Vergis je niet bij elektrolyse moet er ook nog ontvochtigd en wat restjes zuurstof worden weggehaald, maar dat kunnen ze je allemaal bij Siemens vertellen.

In mijn project is deze omzettingstechniek een PEM fuel cell, en die vereist zeer pure waterstof. Dus opslag van zo puur mogelijke waterstof is handig. Een PEM fuel cell is ook erg schaalbaar en de eerste producten naast auto’s verschijnen nu al op de markt, van drones tot ingebouwd in een Iphone, back-up power systemen, MW+

electrolyzers van Siemens etc. Dus de techniek vind in dit beginstadium nu al veel toepassingen.

Persoonlijk denk ik dat de combinatie van elektriciteit en waterstof als energiedragers gewoon bijzonder bruikbaar is en toekomst heeft. Je moet vooral naar het doel kijken, een duurzame maatschappij. Waterstof en elektriciteit kunnen zowel de gehele transport en energiesector verduurzamen. Waterstof kan zo goed als alle vormen van transport verduurzamen, alleen elektriciteit kan dit niet. Los daarvan is waterstof dus zo veelzijdig als eerder gezegd. Uiteraard is biogas oid ook 100% duurzaam, maar wel inefficiente verbranding en alsnog kans op NOx en andere deeltjes. AJ: Eens. De manier om volledig af te stappen van fossiel naar hernieuwbaar kost tijd, maar ik denk dat er in de toekomst mensen meer zelf hun energie gaan regelen. In corporaties op wijk/stad niveau gezamenlijk investeren (mogelijk ESCO constructie) in hernieuwbare bronnen. Tevens investeren in kort-schalige opslag. Daarnaast ook opslag voor seizoen variaties (zeer goed mogelijk in waterstof). De overschotten in waterstof kunnen worden aangesproken voor mobiliteitsdoeleinden.

VO: Helemaal mee eens. Steeds meer energie corporaties bv in Duitsland. Nederland is vaak een slecht voorbeeld mbt duurzaamheid ed.

Ook al worden batterijen lichter, compacter en goedkoper en zullen ze minder zelf-ontladen en gaan ze meer laadcycli mee en is snelladen minder schadelijk en kun je ze tot zeer hoge vermogens snelladen zonder dat ze smelten (dan heb je het zo ongeveer over de ideale batterij), dan zal alsnog veel duurzame energie in de toekomst niet worden opgewekt op plekken waar elektriciteit verbruikt wordt of op tijden dat elektriciteit verbruikt wordt. AJ: Ik vermoed dat er een markt blijft voor batterijen. Zeker voor korte termijn opslag van energie. Daarnaast is deze techniek op dit moment nog voordeliger voor compacte EV's tov FCEV. En omdat de toekomst nog onzeker is, vlak ik ze niet helemaal uit. Anders krijg je een lock-in.

VO: Ik denk ook dat er zeker een markt blijft voor batterijen, ik wilde alleen zeggen dat louter en alleen batterijen ook niet de oplossing zal zijn dus dat er wel ruimte is voor waterstof (hetzij in gecomprimeerde opslag, cyro-compressed, mierenzuur of LOHCs, metaalhydride of….)

Dus of je hebt een heel sterk en duur netwerk(inflexibele langetermijninvestering van 30+jaar) nodig voor soms maar 100 uur per jaar, batterijen transporteren is ook onhandig, lege batterijen zijn net zo zwaar als volle, productie van waterstof dmv elektrolyser is misschien nog niet heel efficient, maar hebben waterstof en brandstofcellen wel heel veel andere voordelen tov batterijen. Los van de grondstof voor batterijen, is de grondstof voor waterstof bij elektrolyser (puur) water…. Maar ik moet eerlijk zeggen van de grondstofvoorraden voor batterijen inclusief productie en recycling en effecten hiervan ben ik niet van op de hoogte. AJ: Grondstofvoorraden voor Li-ion zijn schaars aan het worden. Elon Musk en consorten hebben het merendeel van de productie al opgekocht naar het schijnt. Zoektocht is nu naar andere goede batterij componenten. Winning daarvan is weinig duurzaam en heeft grote impact om het lokale milieu. Voor de westerling een 'ver van de bed show'. Immers het meeste wordt gewonnen in Afrika en China.

VO: Interessant, over deze effecten wordt vrijwel nooit gesproken en vaak wordt dit afgedaan met "valt voor 99.x % te recyclen, de batterijen". Als hier toevallig al iets over gepubliceerd is mag je altijd doorsturen.

20160512

Veel punten die je aanhaalt heb ik inmiddels (nu een maand bezig met afstuderen) ook al eens langs zien/horen komen. De kant van de verzekeraar (juridisch) is nieuw voor mij overigens.

Dan een antwoord op jou eerste vraag; wat ik nu precies wil weten. Ik ben heel benieuwd hoe jullie binnen The Green Village tegen het waterstof gedeelte benaderen:

-Wat ik weet is dat jullie een FCEV (iX35) ombouwen om ook als generator te kunnen functioneren. Hoe zien jullie schaalbaarheid hiervan tov de investering? Nu is dit custom-made gedaan. Maar de Toyota Mirai en de Honda Clarity FCV hebben deze optie al en wordt al gemotiveerd door de Japanse overheid als back-up power voor gebouwen in geval van natuurrampen. Prijs voor de honda power exporter kun je hier vinden; http://world.honda.com/news/2016/4160310eng.html , ik denk uiteindelijk dat bij veel gebouwen zo een power exporter, eigenlijk gewoon een ontlaadpaal die van DC naar AC gaat, op veel plekken gewoon aanwezig zal zijn en je auto gewoon inplugt, dus dat de auto-eigenaar dit kast je niet hoeft te betalen.

-Maar waar komt volgens jullie idealiter de waterstof vandaan waar die FCEV op draait? Waar vindt de productie plaats? De waterstof wordt gemaakt waar veel duurzame energie opgewekt wordt. Zie als voorbeeld het in aanbouw H2 tankstation van Tonnie van peperstraten, waar volgens mij Siemens de electrolyzer levert. Zie ook onlangs het nieuwsbericht van shell over h2 fabrieken op oude platforms in de Noordzee; http://www.telegraaf.nl/dft/bedrijven/royal_dutch_shell_a/25770324/__Shell_wil_waterstoffabrieken_op_zee__.html . Vooral ook op plekken waar het te duur wordt een zeer zwaar electriciteitsnetwerk aan te leggen of om bestaand netwerk extra te verzwaren.

Maar zou ook in steden bij het lokale tankstation kunnen. Alle zonnepanelen van de omringende huizen werken samen en tijdelijke overschotten worden bij lokale tankstations omgezet in H2.

-Hoe wordt dat dan gedistribueerd, die waterstof? Via gasleidingen wijdverspreid, via tankwagens naar pompstations?

Zoveel mogelijk lokaal, dus minimale distributie. Als er een H2 net al ligt zoals van Rotterdam naar Antwerpen en Noord Frankrijk gebruik je dat. Verder tube trailers (tankwagens)
https://www.hydrogen.energy.gov/pdfs/review15/pd021_baldwin_2015_o.pdf

-Wordt de energie van de FCEV voor eigen gebruik ingezet (autarkisch) of ook voor de wijk? Voor de wijk

-En zo ja, hoe wordt dat dan verrekend? Hoe? Ik denk dat daar de nodige IT systemen en communicatie al voor bestaand. En V2G omgevingen met battery electric vehicles zullen dit al deels opgelost hebben.

Electric grid operator Tennet TSO (Netherlands and Germany) is already doing a pilot with charging pole infrastructure operator The New Motion (for battery vehicles);

http://news.smart.pr/thenewmotion/electric-vehicles-play-an-important-role-to-ensure-a-stable-electricity-network-2

http://v2city-expertgroup.eu/2016/02/23/v2g-by-the-hand-of-tennet-and-the-new-motion/

And so now they are asked people having small scale distributed/decentral small scale primary reserve power, ranging from 100kW to 1 MW.

https://www.thenewmotion.com/blog/technologie/wereldprimeur-bijzondere-rol-voor-elektrische-autos-voor-stabiel-elektriciteitsnet/ (scroll down to see image)

-Zijn er, of per wanneer zijn er daadwerkelijk zaken te zien/bezichtigen omtrent 'The Green Village'?

Op het moment het zero-energy huis en solar car park ik verwacht dat volgende maand (onder voorbehoud)

Verder is men nu ook druk bezig de infrastructuur aan te leggen, dus veel graafwerkzaamheden op het moment;

https://www.facebook.com/TheGrnVillage/photos/pcb.964581130315546/964581060315553/?type=3&theater

Maar the Green Village is meer dan alleen het Car as Power Plant project, dat is maar 1 van de vele projecten op zeer uitlopende gebieden.

20160816
Hallo Alex,

Ikzelf ben met het ontwerp van onze "Smart Hydrogen City", redenen achter techniekkeuzes en technologie en kosten projecties naar 2050 met een paper bezig, maar dat concept paper kan ik je nu helaas niet opsturen.

Wel heb ik de presentatie toegevoegd die ik op de world hydrogen energy conference heb gegeven, zie bijlage. Zoals je kunt zien is bij ons het ontwerp dat tijdelijke stroom overschot van zonnepanelen in waterstof wordt omgezet en in tube trailers wordt opgeslagen. Dit wordt dan naar een H2 tankstation gebracht en wordt deze waterstof op 250 bar (nu, toekomst 500 bar) verder op druk gebracht tot 875-900 bar in een stationaire tank.

Een MSc student is bezig met hetzelfde ontwerp dit op uurbasis door te rekenen voor verschillende klimaatgebieden in Europa, deze student is nu op vakantie maar verwacht dat die tegen het einde van het kalenderjaar zeker wel is afgestudeerd.

Verder nog een paar foto's toegevoegd van onze aangepaste FCEV aan het net gekoppeld op het Green Village terrein. Alleen hebben we (nog) geen waterstofopslag op de Green Village.

De hoofdcategorien klinken mij zeer relevant. Mijn eigen werk houd zich niet direct bezig met public acceptance, maar is zeker erg relevant, een projectcollega bij een andere faculteit kijkt daar dacht ik wel wat meer naar, maar weet het niet zeker. Je kunt haar evt. mailen Esther Park Lee - TBM H.ParkLee@tudelft.nl .

Kwam dit nog toevallig tegen, wat er echt in het kastje zit is wat onduidelijk, door een Belgisch bedrijf gemaakt, wie weet is het interessant.

http://online.fliphtml5.com/oaeh/npkp/#p=1

Lijkt op waterstofproductie dmv elektrolyse en kleinschalige opslag, maar ben er verder ook niet acheraangegaan, belletje wagen kan nooit kwaad.

Met vriendelijke groet,

Vincent Oldenbroek

7.9 20160525 Meeting Francoise de Jong & Jan Morren | NEN & DCMR

Details	
Subject	Safety involved with hydrogen
Date	May 25, 2016, Wednesday
Interviewees	Francoise de Jong & Jan Morren
Organization represented	NEN & DCMR
Language	Dutch

Françoise sinds 2014 bezig met waterstof. Daarvoor met gas algemeen. In december 14 begonnen met europees project. In een jaar rapport over normalisatie van power-to-gas. 80 experts, gecoördineerd vanuit JFC HU. Download uit EC bookshop.

Jan vanuit veiligheidsregio Rotterdam (DCMR) betrokken bij luchtkwaliteit. Via project ook bij brandstofvisie R'dam gekomen. Vanuit daar ook waterstof erbij, vooral uit eigen interesse. Daardoor geen kennis vanuit zichzelf. Daarvoor doorverwijzen naar Luc Vijgen & André de Jong → QRA = quality risk analysis.

Mening wordt gedeeld dat:
-waterstof goede en interessante energiedrager is
-huidig netwerk gaat door energietransitie veranderen. Niet één maar brede scope aan oplossingen. Waterstof is daar een van die naast batterijen zal gaan bestaan.

CASE HFS Rhoon
Direct aangevoerd op buisleidingstraat. Daardoor praktisch geen opslag (compressie van 13bar naar 700bar wel iets van opslag).
Volledig buiten en onbemand. Gunstig voor veiligheidsbepalingen
Druk vanuit meerdere kanten waardoor project gemakkelijk(er) doorgang heeft gehad

'*Altijd uitgaan van het energetisch beste scenario. Vervolgens gaan we er vanuit dat de regelgeving goed geregeld gaat worden.*' Francoise de Jong quote

CASE Afstuderen
Gesloten systeem. Lokaal overschot van elektriciteit die wordt aangevoerd naar locatie met elektrolyse apparaat. Die zet het om naar waterstof. Deze wordt opgeslagen (methode maakt niet uit) op dezelfde locatie. Bij een dreigend tekort aan energie wordt het waterstof dmv een brandstofcel weer omgezet naar elektriciteit.
Belangrijk voor de locatie is:
-de aanwezigheid van een elektriciteitsnet.
-wie is de eigenaar? Oftewel, wie is de energie producent → extra regels aan verbonden
-afhankelijk van de grote van de opslag, en daarmee de explosieveiligheid, hoe groot moet de veiligheidscirkel zijn?
-wie gaat het onderhoud plegen en hoe is die opgeleid?

Idee en voorstel voor een pilot project. Immers hoe kan het anders beter getest worden. Mogelijke contacten worden benaderd vanuit Jan in regio Rotterdam.

Extra informatie via:
-JFC HU. Europese organisatie die al veel onderzoek gedaan heeft op het gebied van waterstof.
-NWP. Op 7 juni weer een bijeenkomst. Mogelijk interessant om hier kennis uit te halen
-PGS 15. Opslag van gevaarlijke stoffen
-Atex. Voorziening voor explosieveiligheid.
-Indra te Ronde. Collega Francoise bij NEN.

7.10 20160527 Phone meeting Sander van Schagen | Gemeente Albrandswaard

Details	
Subject	Project hydrogen refueling station in Rhoon
Date	May 27, 2016, Friday
Interviewee	Sander van Schagen
Organization represented	City planner at the municipality of Albrandswaard

Language	Dutch

Obstakels bij implementatie:
1) Publieke opinie
2) Vinden van afnemers
3) Techniek
4) Juridisch

Oplossing per obstakel:
1) Zelfde als bij alle andere planologische projecten: persoonlijk contact! Tot aantal van 10 personen nog persoonlijk te benoemen.
   Buurtbewoners informatie avond. Ook AD aanwezig met reporter. Die had naderhand nog een bewoner gesproken. Zeer negatief artikel gepubliceerd. Sander nagegaan wie bewoner is geweest. Bleek een medewerker van Shell te zijn. Persoonlijk contact opgenomen en uitgehoord. Sander veel kennis opgedaan via AirLiquide en dit met medewerker Shell gedeeld. Ongerustheid weggenomen en aan eigen zijde weten te winnen.
   Boekje gemaakt met plan om publieke opinie mee te krijgen
   http://www.albrandswaard.nl/wonen-werken/marktinitiatieven_47058/
2) AirLiquide in Frankrijk al aantal waterstof tank stations. Wil in Nederland ook voet aan de grond krijgen. Zien toekomst hierin. Daarom nu station plaatsten. Tevens mogelijkheid om subsidie gelden te benutten. Business case was niet rond. Geen afnemers in eerste instantie.
   Uiteindelijk RET met 2 waterstof bussen (pilot van minimal 3 jaar), RWS met 2 auto's (iX35 en subsidie van TEN-T.
   DEO-drive bezig om meerdere waterstof stations te bouwen.
3) Alle partijen konden alles al leveren individueel bekeken. Echter nog niet eerder samen geplaatst.
   LNG veel gevaarlijker als waterstof, maar al meer toepassingen.
   Af- en aankoppelen gevaarlijker dan opwekking.
4) In 15 maanden tijd hele project doorlopen. Langzame start, veel tijd genomen voor buitenwettelijk voortraject. Daarna snelle verloop. In 3 weken alle vergunningen geregeld. Door voortraject niet nodig geweest om 2e inzage te regelen. Daarmee traject richting Raad van State voorkomen. Vanuit min IenM support. Ergens in project nodig geweest hoge manager in te schakelen om project door te zetten. Tevens vanuit Brussel support voor het project.

7.11 20160617 Phone meeting Joost Welsing | Bredenoord

Details	
Subject	Mobile fuel cell generator
Date	June 17, 2016, Friday
Interviewee	Joost Welsing
Organization represented	Bredenoord
Language	Dutch

Geen waterstof aggregaat inzet op grote schaal. Alleen voor kleine promotie doeleinden. Geen ervaring met gemeenten mbt plaatsen. Wel toekomst!
Pilots nodig om de markt open te breken, maar ook het kip-ei dilemma te doorbreken. Tevens de pilot projecten gebruiken om publieke opinie te laten wennen aan het idee

van waterstof. Hierbij het Schiphol project erg belangrijk. Business case makkelijker rond te krijgen bij commerciële toepassing ipv studie objecten.

7.12 20160622 Phone meeting Chris van Dijk | Rai vereniging

Details	
Subject	Hydrogen in mobility
Date	June 22, 2016, Wednesday
Interviewee	Chris van Dijk
Organization represented	Policy advisor of the Rai vereniging
Language	Dutch

Regels beperken uitstoot CO_2. 2021 95gr, 2050 geen uitstoot meer. Hoe dit te bereiken: linear vs S-shaped curve vs kromme. Autofabrikanten weten het zelf ook niet. Tevens niet welke aandrijving tussen 2021 - 2050: BEV, FCEV, (iets nieuws?). Zolang het maar Z.E. (Zero Emission) is.

Mbt BEV. Vooral Tesla is hier hard aan het groeien. Het is hun business case om EV te verkopen. Daarom zetten ze zich hevig af tegen FCEV.

Mbt H2. Waterstof zien als energie medium, niet als brandstof. Grootste obstakel voor nu is het ontbreken van een infrastructuur van tankstations. Er wordt geprobeerd dit te doorbreken op meerdere fronten. Dmv Europese subsidies van TEN-T die HRS op hoofdwegen helpen te financieren. Daarnaast samenwerkingen met autofabrikanten zoals Hyundai die rondom een voorgenomen HRS, potentiele klanten/afnemers van waterstof zoeken door hun auto (iX35) aan te bieden. Ook wordt er met regionale vervoerders (bus maatschappijen) gekeken of hun voertuigen niet omgewisseld kunnen worden voor waterstofvoertuigen.
Doel voor 2020 is om 20 HRS in NL te hebben. Voor de korte termijn, medio 2017, zouden er al 5 moeten zijn (note, nu zijn het er 2, Helmond & Rhoon) die op beide standaarden kunnen tanken. Dus zowel 350bar als 700bar.
In de meeste landen zijn er samenwerkingsverbanden tussen belanghebbenden van waterstofproducten. In Nederland het NWP, in Duitsland het Clean Energy Partnership.

7.13 20160628 Meeting Bart Colijn | Siemens

Details	
Subject	Distributed power generation
Date	June 28, 2016, Friday
Interviewee	Bart Colijn
Organization represented	Siemens
Language	Dutch

Diergaarde Blijdorp in Rotterdam heeft een groot dak vol PV panelen. De opbrengst hiervan is gemonitord. Dit is een goede indicatie voor een 'gemiddelde' zonopbrengst profiel. Op het calzip dak is in 2002 zo'n 0,5 MW geïnstalleerd, dit zijn zo'n 3500 panelen.
Mogelijkheid voor groencertificaten bij het gebruik van waterstof?

7.14 20160701 Meeting Albert van der Molen | Stedin (DSO)

Details	
Subject	Reference projects Rozenburg and Ameland

Date	July 1, 2016, Friday 1000-1130
Interviewee	Albert van der Molen
Organization represented	Stedin
Language	Dutch

- Wat waren de beweegredenen voor dit P2G project?
  a. Dit was een vervolg op het project in Ameland waar getest werd om waterstof in het gasnetwerk te injecteren. Maar omdat dit tot slechts een bepaald percentage mag gekeken naar andere gassen die geinjecteerd konden worden. En wat werkt dan beter als methaan zelf in een methaan (aardgas) netwerk?
  b. Het testen van een power to gas systeem om als netbeheerder niet verrast te worden zoals bij het ontstaan van groen gas is gebeurd
  c. Als netbeheerder is het belangrijk actief bezig te zijn met de energietransitie. Daarnaast kweekt zo'n project ook goodwill.
- Is er sprake van veel onbalans?
  a. Dit moet in twee kanten bezien worden: Administratief & Fisiek.
     i. Administratief voor de energieleverancier. Op plek A wordt er geproduceerd terwijl er op plek B vraag is. Dit moet verrekend worden. Die flexibiliteit in het verreken systeem is er nu nog niet.
     ii. Fisiek voor de netbeheerder. Hoe komt de elektriciteit van A naar B? Daarvoor is de TSO (Tennet) en de DSO verantwoordlijk, en daar zijn op dit moment nog niet (echt) problemen mee.
  b. Seizoenschommelingen zijn er nog niet echt. Netbeheerder is daar dus ook niet mee bezig.
     i. Albert op persoonlijke titel wel een mening over: Dmv P2G kan het gasnetwerk als buffer gebruikt worden om de pieken in elektriciteitsproductie op te kunnen vangen. Voor de nabije toekomst kan het geproduceerde waterstof als methaan geinjecteerd worden. Op termijn als waterstof bijgemengd. Ultiem zou zijn om het helemaal op waterstof om te zetten. Dan kan er in oude wijken, waar het niet mogelijk is om het gasnetwerk te vervangen, gestookt blijven worden op gas, terwijl in nieuwe wijken dmv een brandstofcel elektriciteit opgewerkt kan worden.
- Welke partijen zijn allemaal betrokken geweest bij dit P2G project?
  a. 5 partijen: Stedin, DNV-GL, TKI Gas, Gemeente Rotterdam, Ressort Wonen.
- Wat waren de vooraf verwachte problemen?
  a. Vergunning aanvraag werd als lastig verwacht. In totaal heeft dat ook 2 jaar geduurd.
  b. Bewoners/omgeving meekrijgen in het project. Hier zijn ook een aantal voorbeelden van:
     i. Uiteindelijk hebben de bewoners ook besloten waar het terrein zou komen tijdens een bewoners meeting
        1. Quote Albert van der Molen: "Zonder acceptatie, geen innovatie"
     ii. Ballen die over het hek komen van de naastgelegen handbal vereniging mogen ze niet zelf pakken ivm gevaren zones. Als gebaar 20 ballen gegeven.

  iii. In de gemeenschap een stukje zichtbaarheid door de ijsbaan in Rozenburg te sponseren. Klein bedrag van €1k, grote impact en goede naam/imago.
  iv. Zorgen dat er één gezicht is, daardoor is er één aanspreekpunt en creëert vertrouwen.
 c. Partners vinden voor het project. In het begin was het lastig partijen te overtuigen omdat het helemaal nieuw is. Men kent het niet en laat zich leiden door verouderd onderzoek. Nu het project loopt wil iedereen zijn naam eraan verbinden. Belangrijk om zelf aan het roer te staan en te bepalen wie erbij mag en wie niet. Tevens ook om de groep niet groter te maken als nodig. Anders gaan dingen een eigen leven leiden.

- Welke zaken waren onverwacht tijdens het project?
  a. De gebouwde omgeving bleek wat lastiger.
    i. Omdat er een dijk nabij ligt heeft de waterschappen eea in te brengen. Zo mocht de riolering niet naar het nabijgelegen handbalvereniging gebouw gelegd worden.
    ii. Er liggen allerlei buizen, pijpen, etc. Voor de CO_2 aanvoer zou dit een gemakkelijke bron zijn, echter staan er de nodige wijzigingen op stapel waardoor het gratis CO_2 aftappen niet meer interessant bleek.
  b. Ontwerpfout
    i. Tijdens de uitvoering bleek de op afstand te bedienen kill-switch aan te sturen op een systeem dat zelf zou kunnen uitvallen en daardoor niet gegarandeerd te allen tijde te kunnen werken. Er is een extra systeem aangelegd, extra kosten +/- €30k
- Wat zijn de opgedane ervaringen? Voor zowel de bewoners als voor het projectteam?
  a. De bewoners van het appartementen complex zijn enthousiast. Zij krijgen het groene gas gratis (2000m3 per jaar, totale waarde €1000,-). Merendeel blijft echter gewoon het grijze gas waarmee de centrale ketel gestookt wordt.
  b. Het projectteam heeft een goede samenwerkingsband. Mensen zijn enthousiast. Veel testwerk bezig om onderlinge systemen te 'bench-marken'.
- Wordt deze P2G installatie nu gebruikt om pieken in elektriciteitsaanbod op te vangen?
  a. Er zijn 4 pv-panelen geïnstalleerd, maar het merendeel komt vanuit het elektriciteitsnet met Eneco als leverancier. De capaciteit van de electrolyzer is te klein om echt te balanceren.
  b. Black-start voor de electrolyzer, die dus de echte piek eerst opvangt, is 4 minuten. Het methanisatie proces doet er ong 40 minuten over. Dit vooral omdat de katalysatoren moeten opwarmen tot zo'n 400/500 graden.
- Hoe is de locatiebepaling gegaan van deze installatie?
  a. Gemeente heeft de stuk grond gratis verhuurd. Hierdoor is Stedin wel verantwoordelijk voor het terrein.
  b. Bewoners hebben mee uitgekozen waar het moest komen.
  c. Alle aansluitingen etc zijn speciaal aangelegd: blusaansluiting, speciaal halfverhard pad voor de brandweer, riolering, elektriciteitsaansluiting, gasaansluiting

  d. Normaal bij bijv trafohuisjes in nieuwbouwwijk houdt de projectontwikkelaar hier rekening meer. De trafo's worden als een service gezien. Zou raar zijn als netbeheerder hiervoor zou moeten betalen. Dit wordt verder geregeld door afdeling grondzaken van Stedin.

- In wat voor situaties is zo'n P2G interessant?
  a. Bij bestaande wijken waar meer en meer PV-panelen worden geïnstalleerd. Niet bij nieuwbouwwijken, zeker niet als daar geen gasnetwerk ligt.

7.15 20160726 Phone meeting Rob van der Sluis | MTSA

Details	
Subject	Fuel cells
Date	July 26, 2016, Tuesday
Interviewee	Rob van der Sluis
Organization represented	MTSA
Language	Dutch

Achtergrond informatie
AkzoNobel heeft een membraan ontwikkeld dat gebruikt kan worden in PEM brandstofcellen (Proton Exchange Membrane). Om dit in de markt te zetten is vanuit AkzoNobel, het bedrijf NedStack ontstaan. Zij maken brandstofcel stacks. In iedere stack zitten tussen de 80 á 100 membranen. MTSA is een bedrijf dat onderdelen samenvoegt om kant-en-klare brandstofcellen te maken die van waterstof de gewenste elektriciteit kunnen maken. Het is nog een uniek product waarvan er tot op heden maar twee zijn geleverd. Een 1MW in Antwerpen en een 2MW in Yingkou, China.

Brandstofcel systeem
Het product dat MTSA maakt is een complete brandstofcel systeem waarbij de brandstofcellen van NedStack met meerdere tegelijk worden gekoppeld en voorzien van de benodigde randapparatuur. Zo wordt de zuurstof uit de lucht gehaald, bevochtigd en in de stacks geleid. De geproduceerde gelijkstroom wordt omgezet tot wisselstroom en vervolgens tot het gewenste voltage getransformeerd.

Voor het 1MW systeem is het passend gemaakt in twee over de weg vervoerbare 40ft containers. Hierbij is de container met de brandstofcellen breder en hoger als een normale 40ft container. De andere container is gevuld met de omvormer, transformatoren en een controlekamer. Kosten van dit plug-and-play systeem ligt rond de 3,5 á 4 miljoen euro.

Ontwikkelingen
Ongeveer de helft van de kosten van dit systeem komt voor rekening van de stacks. Dit komt doordat het produceren van de membranen erg arbeidsintensief is en er een duur materiaal voor nodig is. De verwachting is dat de prijs van de membranen zal gaan dalen door de auto-industrie. Hier is men namelijk bezig een massaproductie op te zetten voor de productie van FCEV's. Een grote speler in de productie van membranen is Jonson Matthey (http://www.jmfuelcells.com/page.aspx).
Voor chemische industrie bedrijven die overschotten hebben van rest-waterstof, kan het interessant zijn om een brandstofcel aan te schaffen. Hiermee kan voorzien worden in een eigen elektriciteit en warmte productie. Echter is het nu zonder subsidie niet mogelijk om terugverdientijden korter als 3 tot 5 jaar te realiseren.

In principe is het voor MTSA mogelijk om in de range tussen 70kW en de 1MW verschilde soorten brandstofcellen te maken. Afhankelijk van de marktvraag.

Afmetingen
1x normale 40ft container l x b x h: 12,2 x 2,4 x 2,6m
1x vergrootte 40ft container lxbxh: 12,2 x +/-3 x +/-3m

7.16 20160729 Mail Jan ten Have | MTSA

Details	
Subject	Fuel cells
Date	July 29, 2016, Friday
Interviewee	Jan ten Have
Organization represented	CFO of MTSA
Language	Dutch

Bij toepassing van een brandstofcel in de gebouwde omgeving (rand van de stad/wijk of op een industrieterrein), waar moet dan aan gedacht worden op het gebied van veiligheid? Zijn er bijvoorbeeld speciale veiligheidscirkels?
De veiligheidsregels omtrent opslag zijn in zijn algemeen van toepassing de PGS 15. Niet bekend is of voor uw project additionele / aanvullende regels gelden.

Wat is de rekenwaarde van de efficiëntie van de PEM fuel cell?
Een typische efficiency is 50 %^

7.17 20160729 Meeting Lisette Kaupmann | Stedin (DSO)

Details	
Subject	Referenceproject Hoog Dalem
Date	July 29, 2016, Friday 1300-1400
Interviewee	Lisette Kaupman
Organization represented	Stedin
Language	Dutch

Hoog Dalem project valt onder 'proeftuinen'. Hierbij is er in 2010 begonnen met het eerste idee voor energieopslag. Hiervoor was subsidie beschikbaar. Binnen de SEC samenwerking tussen meerdere bedrijven om dit te realiseren. Pas in 2013 alle partners gevonden en technische basis voor het project. Echter nog geen deelnemers/bewoners. Het project zal tot eind Q1 2017 lopen. Dan pas een volle winterperiode meegemaakt.

Doel van het project is het wegnemen van de pieken in energievraag veroorzaakt door gelijktijdig gebruik van de elektrische warmtepomp. Door middel van de thuisbatterijen kan energie opgeslagen worden. Vooraf werd dit als voornaamste obstakel gezien, kan dit systeem echt die pieken opvangen. Tevens werd bezien dat de deelnemers participatie van belang is. Zonder bewoners, geen pilot.

Het project heeft 32 woningen met accu's, waarvan er 29 ook PV-panelen hebben. 3 woningen hebben dus alleen een accu. 7 andere woningen worden ook be-meterd om te zien wat het energieverbruik is ter referentie. Er is in een vroeg stadium gesproken over een mogelijke wijk accu, maar die is er niet gekomen. De kosten-baten waren hiervan niet helder.

De wijk is all-electric waarbij de woningen een eigen warmtepomp hebben en er een gezamenlijke WKO is. De elektra is 3x verzwaard uitgevoerd waardoor er per woning zo'n €1000,- extra is uitgegeven aan de aansluiting.

USEF = Universal Smart Energy Framework. HIerin wordt een nieuw (internationaal) marktmodel beschreven waarin een 'arrogator' namens energie producerende bewoners optreed en de vraag-aanbod voor ze regelt.

Andere mogelijk interessante projecten:
-BAM met de 'stroomversnelling'
-Goes dat werkt met een ijs buffer

7.18 20160809 Phone meeting Frank Meijer | Hyundai

Details	
Subject	Hydrogen used for mobility purposes
Date	August 8, 2016, Tuesday
Interviewee	Frank Meijer
Organization represented	Head of the FCEV devision of Hyundai
Language	Dutch

Belangrijkste obstakels bij FCEV introductie voor de fabrikant:
1) Tank infrastructuur
2) Concurrerende prijs tov ICE
3) Geen eenheid tank procedure
    a. In Duitsland speciale pas nodig
    b. Denemarken & Noorwegen gewoon op creditcard mogelijk

Er zijn binnen Hyundai studies gedaan (niet openbaar) naar de consumenten reactie. Hierbij bovenstaande twee punten duidelijk naar voren gekomen. Mbt de veiligheid van het systeem gaat de consument er vanuit dat de fabrikant dit goed voor elkaar heeft. Die ziet het als een 'normaal' gas. Vooral vanuit de huidige waterstof industrie wordt met veel voorzichtigheid en terughoudendheid gereageerd op waterstof bij mobiliteit.
De reden dat er omgeschakeld moet worden naar bijvoorbeeld waterstof is het emissie loos rijden. Dat is voor veel consumenten geen reden om over te stappen naar een FCEV. Hierbij blijft het financiële aspect zeer belangrijk.
Regelgeving is nog een belangrijk aspect.
Pilot met het thuis produceren en tanken van waterstof door Linde en Airbus

7.19 20160822 Meeting Laetitia Ouillet | Eneco & TU/e

Details	
Subject	Verification of findings
Date	August 22, 2016, Monday 1100-1215
Interviewee	Laetitia Ouillet
Organization represented	TU/e and former employee of Eneco
Language	Dutch

Van origine een econoom, werkzaam bij Eneco als directeur corporate strategie en bij de TU/e als director of strategic Area Energy.
- Alex: Wat is de rol van de energieleverancier?
- Laetitia:

  - Enerzijds de rol van de energieleverancier zoals hij wil dat die is, en hoe die daadwerkelijk is. Nu is het zo dat de energieleverancier gas, elektriciteit en warmte levert. Tevens is er dagelijks contact met de klant.
  - Voorheen werd geprobeerd zo goedkoopmogelijk, dus met zo min mogelijk contactmomenten, met de klant om te gaan. Tegenwoordig kan juist door goede integratie en synergie voordelen behaald worden.
  - Voorheen energieleverancier dé energieportaal, mogelijk in de toekomst meerdere partijen. Bijvoorbeeld dat de CV-ketel producent gas aanbiedt.
  - Energieleverancier niet verantwoordelijk voor de transitie. Probeert wel te kijken hoe ze hierin mee kunnen gaan. Want dat de energietransitie komt/gaande is, dat staat vast. Decentrale transitie (pv-panelen, EV's) nu nog een one-off aankoop. Het hebben van deze elementen is niet gelijk een transitie. Daar slim mee omgaan, dat maakt het verschil. Dus van Top-Down naar Bottum-Up van de elektriciteitsvoorziening.
  - Quote: 08:37min "Ik geloof dat je niet afgaat van centraal geproduceerde elektriciteit"
  - Er moet een organisch systeem komen waarbij er afstemming is tussen centraal en decentraal opgewekte duurzame elektriciteit. Zonder centrale systemen wordt de energie te duur.
  - Quote 0912min "In de huidige situatie is er geen enkele centrale die winstgevend draait"
- Alex: Wie is verantwoordelijk voor het oplossen van de onbalans?
- Laetitia:
  - Variabele prijzen hanteren. Dus betalen voor wanneer je gebruikt. Bij overschot prijs omlaag. De beperkende factor hierin is nog het te kleine aantal slimme meters. Maar dat wordt in de loop der tijd (+/- 3 jaar) aangevuld. Quote: 0435 'Happy Hour of the power'.
  - Niet de energiegebruiker verantwoordelijk maken voor het opvangen van de balans. Energie moet een vast gegeven zijn.
  - In de toekomst meer bedrijven die 'all-in' pakketten gaan aanbieden. Bijv Tesla met EV's, thuisbatterijen, pv-panelen, etc.
  - Op dit moment wordt de term onbalans alleen gebruikt op het hoofdnet (Tennet niveau) en opgevangen en betaald door de producenten van de elektriciteit en grote afnemers. Dmv congestie maatregelen wordt er op het laagspanningsnet onbalans opgevangen.
  - Het systeem gaat er nu steeds meer naartoe dat de lokale onbalans het probleem zijn van de netbeheerder. De kosten van de oplossingen worden vervolgens in de tarieven versleuteld. Zo lijkt het nu te gaan.
  - VB van landen (België en Spanje) waar boetes gelden bij het plaatsen van zonnepanelen en thuisbatterijen. Dit veroorzaakt onbalans op die markten.
- Alex: Is er nu al sprake van onbalans?
- Laetitia:
  - De transitie is al gaande. Onbalans bestaat al sinds 2000 als systematiek/betaalsysteem. Maar disbalans tussen vraag en aanbod heeft de afgelopen jaren een heel ander karakter gekregen door de nieuwe technologieën zowel aan de opwek als aan de verbruikerskant

Meer en meer zonnepanelen en daar ook veel verbeteringen in. Nu nog mogelijk om dit in het net op te vangen. Tevens is het zo dat duurzame energie voorrang heeft op het net.
    - Als er een overschot is aan elektriciteit, dan centrales stil gezet. Ze draaien niet onder hun marginale kosten (vaste kosten niet meegerekend).
    - NL heeft een onwijze overcapaciteit op zijn net.
    - NL is een van de meest interconnecte landen. Mogelijk om naar andere landen door te voeren van overcapaciteit.
    - Te weinig energie is iets waar we gemakkelijk wat aan kunnen doen door extra centrales te laten draaien. Te veel energie niet.
    - Overschotten alleen lokaal een probleem. Lokale netwerk is gedimensioneerd dat ongeveer 40% maar gebruikt wordt.
    - Plekken waar nieuwe wijken worden aangelegd, daar wringt het. Je hebt daar zogenaamde 'nul-op-de-meter' woningen. Dat is nul bekeken over een jaar maar niet per uur. Ook wijken waar massaal overgestapt wordt op elektrische auto's en/of opwekking via zonnepanelen. Hierbij veel kans op lokaal wringen van het net.
- Alex: Welke schaal moet daarbij gedacht worden?
- Laetitia:
    - Nu commercieel zeker niet interessant om grootschalige energieopslag te bouwen.
    - Komende 15 jaar ook nog wel zonder opslag op stad/regio niveau.
    - Kleinschalige thuisopslag middels batterijen of met een EV, dat is een ander verhaal en wel actueel. Zeker ook demand management.
- Alex: Zijn er nog meer toepassingen van waterstof naast de volgende systemen/referentieprojecten?
    - Gevonden toepassingen
        - Eigen model, re-elektrificatie van waterstof
        - Rozenburg, methanisatie van waterstof
        - Ameland, inmengen van waterstof
        - Mainz, basis voor industrie en mobiliteit
- Laetitia:
    - Torrgas als voorbeeld van synthetisch biogas.
    - Nuon die met ammonia wil gaan werken.
- Alex: Hoe denk je over de volgende criteria?
    - Criteria
        - Safety
        - Public acceptance
        - Integration energy grid
        - Integration built environment
        - Technique
- Laetitia:
    - Bij het gebruik van lokale duurzame bronnen zal er gekeken moeten worden naar certificaten. Dan is het systeem wel duurzaam maar maakt het wel, misschien onnodig, gecompliceerd.
    - Windenergie is vaak in buitengebieden en dan maakt de ruimte niet zo veel meer uit.
    - We hebben niet zo zeer seizoen problemen met elektriciteit, maar wel met warmte.

7.20 20160822 Meeting Albert van der Molen | Stedin (DSO)

Details	
Subject	Verification of findings
Date	August 22, 2016, Monday 1430-1530
Interviewee	Albert van der Molen
Organization represented	Stedin
Language	Dutch

- Alex: Wat is de rol van de netbeheerder?
- Albert:
    - De netbeheerder beheert het reguliere aardgasnet (geen andere gasnetten) en het elektriciteitsnet.
    - De netbeheerder verkoopt niets, produceert niets, maar transporteert wel. Dit valt onder de wet onafhankelijk netbeheer met als idee dat als een commerciële partij omvalt/failliet gaat, dat dan het netbeheer wel doorgang houdt. Het transporteren van energie via de energiedragers elektriciteit en aardgas is een exclusief recht van de regionale netbeheerder.
    - Op dit moment is er bij de netbeheerder een kleine commerciële tak waar speciale projectjes gedaan worden die buiten het gereguleerde domein vallen maar die wel aanpalend zijn aan de taken van de netbeheerder. (VB: Stedin Diensten)
    - ACM controleert of de netbeheerder wel doelmatig opereert en daarmee ook of de gehanteerde prijzen wel kloppen. Door het natuurlijk monopolie van de netbeheerder kan een klant niet overstappen zoals bij een energieleverancier dat wel kan.
    - Nu de basis vier eenheid: producent, leverancier, transporteur (controle door ACM), eindgebruiker
- Alex: Wat is de toekomstige rol van netbeheerder?
- Albert:
    - Gaswet zal naar verwachting wat gaan verruimen v.w.b. gasspecificaties. Hoe, hoeveel en wanneer zal nog moeten blijken.
    - Gasnet is het probleem niet zozeer. Het gaat om de apparaten van de eindgebruiker die wel op andere gasmengels aangepast moeten worden. Quote: 0210 'We moeten het gas van A naar B transporteren en als B niet klaar is voor verandering, houdt het op."
    - Netbeheerder is zich aan het oriënteren maar de meningen verschillen. Moet er direct op ingespeeld worden of kan er nog gewacht worden. Maar Albert durft te stellen dat de urgentie duidelijk begint te worden, dit uitgelegd aan de hand van het 'netbeheerdersdilemma': Te laat investeren, dan is er een probleem zoals al in Groningen is gebleken met overschotten van elektriciteit uit zonnepanelen. Te vroeg investeren geeft een financieel probleem en tevens een probleem met de ACM. Die zal zeggen dat het nu nog niet nodig is en daarom te duur.
    - Netbeheerders krijgen inmiddels in beeld wat de mogelijke consequenties kunnen zijn bij zowel te vroeg als te laat investeren. Nu bezig om de gevolgen van wel en niet investeren presenteren aan de omgeving (politiek) die hier keuzes in maakt.

  - Netbeheerder moet de klant volgen. De klant wil over het algemeen de goedkoopste oplossing. Op dit moment is dat gas, die verzorgt dan ook de grootste energievraag in de gebouwde omgeving; warmte.
- Alex: Wanneer komt de grote toename in RES?
- Albert:
  - Positief inzetten, we halen de overheidsdoelstellingen
  - Zodra gas even duur gemaakt wordt als elektriciteit (nu is gas nog een factor 4 goedkoper), of wanneer CO_2 eerlijk geprijsd gaat worden
  - Stedin met CBS buurten: Per buurt gekeken wat de meest logische warmtevoorziening is. In de buurt van bijv warmtenet, dan niet all-electric uitvoeren.
  - Aardgas nu belangrijkste bron van warmte. Stel de prijs gaat omhoog van 25 naar 85 cent. Dan nu inzichtelijk dmv kleuren welke wijken als eerste de pijn gaan voelen. Er is maar een klein tijdgebied waarin er omgeschakeld kan worden van gas naar elektriciteit in dit scenario. Daarom is de urgentie hiermee wel al duidelijker gemaakt. Het gaat niet geleidelijk, het gaat abrupt. Want wanneer het bij jou aantrekkelijk wordt de CV ketel in te wisselen voor een warmtepomp, is het mogelijk ook in de rest van de buurt zo. Daarom nu al bezig om de netten anders te dimensioneren: gasnetten minder dik uitvoeren, en de hoeveelheid aansluitingen per 'elektriciteitsnetstreng' gaat omlaag.
- Alex: Dus 1) Aanpassen van de daadwerkelijke dimensionering. 2) Eigen organisatie anders inrichten. 3) Omgeving beïnvloeden
- Alex Is er al sprake van onbalans?
- Albert:
  - VB in Groningen niet alleen het net de schuld, ook de installatie van de zonnepanelen zelf
  - Administratief en technisch
    - Administratief vooral bij de energieleverancier. Die moet zorgen dat vraag en aanbod op elkaar afgestemd is. Hierbij is er technisch nog geen probleem. De energieleverancier heeft balansvermogen nodig die dat in de markt moet kopen bij tekort, en bij overschot wordt betaald aan Tennet. Maar hiervoor dient betaald te worden en dat gaat om substantiële bedragen. Vooral energieleveranciers met veel hernieuwbare energiebronnen hebben hier last van).
    - Technisch vooral bij de netbeheerder. Al speelt het nu niet of nauwelijks. Dit zou vooral zijn als er kabels overbelast raken. Je hoopt/gaat ervanuit dat wat er (lokaal) geproduceerd wordt, ook (lokaal) geconsumeerd wordt. En dan komt opslag in beeld. Maar wanneer het geconstateerd wordt dat er overbelasting is, is de netbeheerder eigenlijk al te laat.
  - De energieleverancier kan zeggen: al mijn klanten consumeren exact evenveel als wat ik produceer, maar ondertussen treden er lokaal wel problemen op in het elektriciteitsnet.
- Alex: Waar zit nu de technische onbalans en waar in de toekomst?
- Albert:
  - Nu dus nog niet of nauwelijks, maar straks bij een hoge concentratie van opwekking en ook bij hoge concentratie van afname. Dit is zeer locatie afhankelijk.

  - Op basis van kerngegevens uit wijken kan beter voorspeld worden waar onbalans te verwachten valt. In bijstandswijken minder kans op EV's en zonnepanelen als in yuppenbuurten.
- Alex: Wie zijn allemaal stakeholders binnen energieopslag?
- Albert:
  - Nieuwe commerciële bedrijfstak. Bijvoorbeeld voor energieleveranciers.
  - Inherent aan innovaties, daar is bijna nooit al regelgeving voor.
- Alex: Zijn er nog meer toepassingen van waterstof naast de volgende systemen/referentieprojecten?
  - Gevonden toepassingen
    - Eigen model, re-elektrificatie van waterstof
    - Rozenburg, methanisatie van waterstof
    - Ameland, bijmengen van waterstof
    - Mainz, basis voor industrie en mobiliteit
- Albert:
  - Er zijn wellicht wel meer toepassingen, maar dit zijn de belangrijkste.
- Alex: Hoe denk je over de volgende criteria?
    - Safety
    - Public acceptance
    - Integration energy grid
    - Integration built environment
    - Technique
- Albert:
  - Streven naar de ideale invulling afhankelijk van de locatie/omgeving. Niet mogelijk om de systemen los van elkaar te vergelijken.
  - Kijken naar de **maatschappelijke kosten** die voorkomen kunnen worden. Welke opslag methode hangt af van de locatie.
  - Bestaande bouw is moeilijk te verduurzamen. Dan is het op die locaties wellicht beter om synthetisch gas te maken zodat er wel volledig duurzame energie gebruikt kan worden.

7.21 20160826 Meeting Guy Konings | Stedin (DSO)

Details	
Subject	Verification of findings
Date	August 26, 2016 Friday 0900-1000
Interviewee	Guy Konings
Organization represented	Stedin
Language	Dutch

Vragen

- Alex: Vanaf welk percentage RES is er sprake van onbalans?
- Guy:
    - Weet niet goed hoeveel procent RES er aan het systeem toegevoegd moeten worden voordat er daadwerkelijk onbalans optreedt. Zal waarschijnlijk tussen de 20-30% liggen. Hiervoor beter om Jan Pellis ter bevragen van Stedin Strategie.
- Alex: Wie is er verantwoordelijk voor het oplossen van de onbalans?
- Guy:
    - Vanuit een natuurlijke rol bekeken zou energie opslag bij de netbeheerder passen; de TSO & DSO. Zij zijn namelijk verantwoordelijk voor het op peil houden van de voltage en frequentie van het elektriciteitsnetwerk. Bij een overproductie zou dit tot overvoltage leiden. Echter is het nu zo dat netbeheerders (zowel TSO als DSO) niet commercieel mogen handelen. Zo is bijvoorbeeld de balansmarkt alleen voor commerciële partijen om zo het dmv regel- en reservevermogen geld te kunnen verdienen. Deze markt wordt door de TSO TenneT beheerd. Dit is een benadering voor de huidige top-down structuur. Met een bottom-up structuur dan is er kans voor lokale regel- en reservevermogens.
    - De nieuwe elektriciteit- en gaswet, Wet STROOM, is niet door de kamer gekomen. Hierdoor enkele belangrijke afstemmingen niet doorgevoerd.
- Alex: Zijn er nog meer toepassingen van waterstof naast de volgende systemen/referentieprojecten?
    - Gevonden toepassingen
        - Eigen model, re-elektrificatie van waterstof
        - Rozenburg, methanisatie van waterstof
        - Ameland, inmengen van waterstof
        - Mainz, basis voor industrie en mobiliteit
- Guy:
    - De Belgische supermarkt keten Colruyt heeft in Halle geïnvesteerd in installaties die hun duurzame energiebronnen kunnen omzetten naar waterstof en daar vervolgens hun vloot van heftrucks op kunnen laten rijden. Het tankstation is gebouwd door Hydrogenics, producent van elektrolyzers.
    - http://www.innovatiesteunpunt.be/nl/inspiratie/achter-de-schermen-bij-de-colruyt-groep
- Alex: Hoe denk je over de volgende criteria?
    - Safety
    - Public acceptance
    - Integration energy grid
    - Integration built environment

    - Technique
- Guy:
  De volgende obstakels zijn er:
1. Geen set normen waar waterstof opslag aan moet voldoen
2. Geen wetgeving gereed
3. De acceptatie van waterstof als energiemedium
4. Nederlanders denken met hun portemonnee. Zolang er geen solide business case is (zeker voor particulieren) geen HSF.
- Alex: Hoe denk je over het 'eigen model' waarin re-elektrificatie van waterstof aan bod komt? De zogenoemde HSF case?
- Guy:
    - Rekenvoorbeeld zeer belangrijk. Technische basis moet grondslag zijn. Anders niet hard te maken.

7.22 20160901 Meeting Jaco Reijerkerk | Industrial gas company

Details	
Subject	Verification of findings
Date	September 1st, 2016, Thursday 1300-1430
Interviewee	Jaco Reijerkerk
Organization represented	Former employee of Linde Gas
Language	Dutch

- Nog meer toepassingen als de reeds gevonden cases?
    - In Duitsland al op grote schaal P2G gebruik. Zie afbeelding van UniPer.

    - Ameland proef met bijmengen waterstof om te zien hoe het netwerk hierop reageert. Uiteindelijk is nu de beperkende factor de 'eindappliences'. Zodra die ook op grote schaal vervangen dienen te worden, wordt het minder interessant waterstof bij te mengen. Tevens houdt de huidige regelgeving beperkingen voor het bijmengen van waterstof.
    - NaturalHy is een wat ouder Europees project waar gestest is met waterstof bijmengen
    - Waterstof via Power-to-chemicals ook toe te passen.
    - Het gaat erom wat je ermee wil doen: opslaan voor re-electrificatie, gebruik als brandstof voor FCEV, gebruik als grondstof voor de chemische industrie
- Gebouwde omgeving
    - Hoe zit het 'nul op de meter' in elkaar? Bij een woning geen probleem, maar bij een hele wijk is dat wel zo. Zijn die wijken er al? Moet er in de toekomst nog wel een kabel heen? Wat voor andere issues kunnen er ontstaan en hoe zullen we daar mee om moeten gaan? Wellicht interessant om met Sustainer Homes of met The Green Village hier over te praten omdat zij hier al mee omgaan.

- Zolang salderen aan de orde blijft, zal er een kabel moeten blijven lopen.
- Hoe veel 'nul op de meter' woningen zijn er nu? Percentage ten opzichte van rest van Nederland? Wat is de verwachting in de toekomst?
- Er zijn altijd uitzonderingen, huizen of appartementen die niet in dit systeem lijken te passen. Hiervoor is maatwerk nodig. Maar blijf bij het generieke plan.

- Reactie op HSF
    - Energiehuishouding van de woningen die op de HSF worden aangesloten erg van belang. Hoe hoog liggen de verbruiken gedurende het hele jaar? Bijv 'nul op de meter' woning, goede isolatie zodat er weinig warmte verliezen zijn en de verwarming kleiner gedimensioneerd hoeft te worden. Daardoor lagere energievraag.
    - Niet precies de techniek beschrijven. Die is er nu niet. Ook niet te veel in details, die zijn ook niet beschikbaar. En uiteindelijk zijn er echte experts van de systemen die veel beter weten hoe het werkt en welke veiligheidseisen er precies gelden.
    - Het systeem kan gedimensioneerd worden op een gemiddelde, maar moet de pieken op kunnen vangen. Hierbij kun je uitgaan van een bestaande electrolyzer en brandstofcel, maar laat de opslagmethode even in het midden. Ga na hoeveel het is in Nm3 (Norm kuub) en laat de druk buiten beschouwing. Dit maakt het verwarrend. Hoeveel kilo gaat erin en hoeveel eruit. Daar gaat het om.
    - VB van een afname patroon obv een normaal tankstation langs een snelweg. De tank curve van de werkdagen kwam praktisch overeen en in het weekend zag die er anders uit. Dit werd gekoppeld aan de hoeveelheid energie die getankt werd. Op basis hiervan werd aangenomen dat 10% van de voertuigen op waterstof zou rijden, dus 10% van de energie hoeveelheid moest uit waterstof gaan bestaand. Als de waterstof door een electrolyze apparaat gemaakt moet worden, hoe groot moet dan de opslag zijn? Uiteindelijk werd dus duidelijk hoeveel kilo die opslag moest kunnen herbergen.
    - Het is natuurlijk mogelijk om een rekenvoorbeeld te maken met hoeveel de opslag zou zijn als er in standaard buizen waterstof opgeslagen zou worden. Maar niet volledig relevant omdat de technologie in de komende jaren nog een vlucht neemt met bijvoorbeeld hydrides.
    - Het is ook mogelijk om de electrolyzer in de wijk te plaatsen en het gas vervolgens naar een opslag buiten de wijk te transporteren door een (bestaande) gasleiding. En als er weer een behoefte is aan elektriciteit het gas aan te voeren door de gasleiding naar de brandstofcel in de wijk. Hiermee kun je het mogelijke risico al verlagen.
- Obstakels
    - Veiligheid heeft veel met perceptie te maken. Waterstof als energiedrager is nieuw voor heel veel mensen. Daar moet aan gewend worden. Net zoals er aan aardgas gewend moest worden na stadsgas.
    - PGS 19, PGS 11
    - Opslag van waterstof is nog niet eerder bedacht om dat te doen in een woonomgeving, daarom is er vanuit de PGS'n niet duidelijk op te maken waaraan het minimaal moet voldoen. Uiteraard kun je het zo veilig maken als je zelf wil.

  - Het gaat om adequate veiligheidssystemen die een acceptabel veiligheidsniveau waarborgen. Dit staat nog los van een veiligheidscirkel. Door een externe risico analyse, QRA (Kwantitatieve Risico Analyse), kan de minimale veiligheidscontour van 10^{-6} bepaald worden (kans 1 op een miljoen). Soms past een apparaat/systeem niet op een geplande plek door het veiligheidsrisico en worden er dan mitigerende maatregelen getroffen zodat het wel past.
  - BRZO (Besluit Risico's Zware Ongevallen) mogelijk een obstakel. Hierin is afgesproken hoeveel van een bepaalde stof in een omgeving of op een locatie opgeslagen mag worden. Via risicokaart.nl is dit op te zoeken.

7.23 20160905 Meeting Jan Piet van der Meer | NWBA

Details	
Subject	Verification of findings
Date	September 5th, 2016, Monday 1400-1530
Interviewee	Jan Piet van der Meer
Organization represented	NWBA
Language	Dutch

- Alex: Zijn er nog meer toepassingen van waterstof naast de volgende systemen/referentieprojecten?
  - Gevonden toepassingen
    - Eigen model, re-elektrificatie van waterstof
    - Rozenburg, methanisatie van waterstof
    - Ameland, inmengen van waterstof
    - Mainz, basis voor industrie en mobiliteit
- Jan Piet:
  - Rozenburg en Ameland maken gebruik van het huidige aardgas net. Dat netwerk ligt er en daarom zou het zeer interessant zijn om dat te kunnen gebruiken. Ook gericht op de mobiliteit. Als die overstapt op waterstof, kunnen tankstations ook gebruik maken van het waterstof in het gasnetwerk. De hoofdleiding zit op 40 bar, bij een tankstation moet er op 700 bar getankt worden (nieuw protocol), van 40 bar af comprimeren naar 700 bar bespaart relatief veel energie dan dat van 0 bar zou zijn. Ook electrolyzers kunnen 40 bar H2 produceren vanwege dit argument.
  - Verder over het aardgasnetwerk, daar is volop in geïnvesteerd in de afgelopen jaren. Het gebruik van aardgas neemt af, het is al 30% minder dan enkele jaren terug. Om stranded assets te voorkomen die leiden tot geforceerde afschrijvingen van het aardgas leidingen net kan er dmv waterstof nog een nieuwe gebruiksmogelijkheid aangegeven worden, dat is dus vandaag al financieel interessant. Het aardgasnetwerk ingezet als waterstofnetwerk (hoge- en middendruk) heb je zowel distributie als opslag van H2 georganiseerd. Omdat het netwerk zo wijdverspreid is, en allang geleden is betaald kost het nu relatief weinig geld. Tevens is de waterstof rotonde al geschikt gemaakt voor waterstof (zo heeft Jan Piet zich laten vertellen).
  - Een speciaal waterstofnetwerk zou volgens Ad van Wijk een veel betere optie zijn. Er is wel eens een rekenvoorbeeld gemaakt voor een leiding van ongeveer 70km rond Rotterdam startend bij de chloor electrolyse

van Akzo Nobel, richting Den Haag. Dit zou zo'n 70miljoen kosten. Aan deze leiding kan bijvoorbeeld: een groot datacentrum geplaatst worden die al 200kg per uur nodig heeft, diverse tankstations van 100 a 200kg per dag en dan nog een aantal andere toepassingen. Ervanuitgaande dat dit netwerk er zo'n 50 jaar ligt, wordt de investering gereduceerd tot 1,2miljoen per jaar, en vervolgens zal het transport van die waterstof zelf nog enkele centen per kilo kosten.

  - De methanisatie stap die in project Rozenburg gemaakt wordt is niet de meest interessante kijkende naar het conversie rendement. Maar het is mogelijk wel een goeie (nood) oplossing zolang de concentratie waterstof in het aardgasnetwerk niet omhoog kan/mag in bepaalde wijken of gebieden. Maar een heel serieuze oplossing vindt Jan Piet het niet. Tevens door dit soort technieken blijven we de transitie uitstellen en dat moeten we niet willen, we moeten om!
  - Waterstof kan natuurlijk ook opgeslagen worden in zoutcavernes net als aardgas. Door lokaal H2 middels elektrolyzers te produceren bij bijvoorbeeld een windpark, te transporteren via het aardagasnetwerk en dan op te slaan in zoutcavernes kan er met bestaande technieken mogelijk een goed seizoensbuffersysteem gemaakt worden. In duitsland zijn er zo'n 40 van dit soort putten. Mochten deze allemaal gevuld zijn met H2, dan kan Duitsland hier 10 a 12 weken aan energie uit putten zowel stationair als voor het transport.
  - Extra optie: In Gorichem ligt een ouderenflat bovenop een waterstofleiding van AirProducts. Door daar een brandstofcel te plaatsen kan de elektriciteit en warmte leveren aan dat gebouw tegen een aantrekkelijke H2-prijs. De grootste kosten van H2 zit nu in de distributie van H2.

- Alex: Hoe denk je over de inpassing in de gebouwde omgeving?
- Jan Piet:
  - De elektrificatie is al bezig. Men wil in nieuwbouwwijken liever geen gasnet meer aan leggen.
  - Waterstofaggregaten al gebruiken tijdens de bouw. Dan een volledig uitstoot loze energievoorziening die zeker in drukke binnensteden wenselijk kan zijn. Deze aggregaten zijn vaak nodig om de gewenste 'bouwstroom' te leveren. Dit vereist een tijdelijke (hogere) aansluiting om diverse apparaten op te laten draaien. Deze waterstof aggregaten kunnen vervolgens weer gebruikt worden als basis stroom voorziening of als backup power voor dat gebied, mits de H2 aanlevering geregeld is, bijv via het gasnet.
- Alex: (Legt het principe van de HSF uit, waarin waterstof gebruikt wordt voor re-elektrificatie). Wat vind je van dit principe?
- Jan Piet:
  - Het daadwerkelijk benoemen van het type opslag is niet zo handig. Dit relatief kleine systeem met compressoren en opslag vaten zal extreem duur worden. Vermeld wat de bedoeling is (seizoensopslag) en laat de daadwerkelijke keuze (opslag in gasnetwerk, zoutcavernes, gecompresseerde opslagtanks) maar over aan de omstandigheden en mogelijkheden (ik heb in het midden laten gezegd☺).
  - Blijf het benaderen als een black box. De technische ingrediënten bestaan, ze zijn te koop maar het is helemaal niet interessant om het nu te dimensioneren en uit te rekenen wat het gaat kosten. Dit omdat het

pas over zo'n 10 a 15 jaar pas echt gaat spelen en dan is de markt mogelijk helemaal veranderd door de schaalvergroting uit de mobiliteitsbranche (veel FCEV's) en zijn dat soort uitspraken die nu over HSF gedaan worden helemaal niets waard. Waar het om gaat is dat de overschotten aan elektriciteit omgezet naar waterstof, die opslaat, en die naar de markt/consumenten brengen als die het nodig heeft, dit is het opgang breneg van het markt mechanisme, het moet zin hebben om die H2 te maken, op te slaan en te kunnen distribueren dan zullen sommigen nog steeds zeggen dat deze keten niet energie-efficiënt is, maar dan vergeten ze dat dit wel volledig 'groene energie' met de mogelijkheid het lange tijd te kunnen opslaan.

- Alex: Hoe denk je over de volgende criteria?
  - Safety
  - Public acceptance
  - Integration energy grid
  - Integration built environment
  - Technique
- Jan Piet:
  - Mogelijk obstakel is het verkrijgen van groencertificaten. Omdat het systeem mogelijk op een wijk is aangesloten, die nog een 'back-up' aansluiting heeft, hoe kan gegarandeerd worden dat het volledig groene stroom betreft? In brede zin speelt de certificering van H2, hopelijk gaat het EU initiatief CertifHY hier uitkomst bieden.
  - Prijs van de apparatuur is nu nog te hoog waardoor systemen nog niet rendabel te maken zijn. Door afnemers van waterstof te vinden, kunnen apparaten verkocht worden. Een jaar of 10 geleden is besloten om via de automarkt dit te proberen te doorbreken. Daarom is nu zichtbaar dat automerken met waterstof auto's beginnen te komen. Als door de productie aantallen van de autoindustrie de membranen op een grotere schaal geproduceerd kunnen worden, wat de duurste onderdelen zijn (ca. 50-100x te duur) van bijvoorbeeld en brandstofcel, dan wordt het gehele apparaat ook goedkoper.
  - De automarkt is echt nodig als aanjager van schaalvergroting om de prijzen omlaag te krijgen en de vraag naar H2 omhoog te krijgen.
  - Bestaande waterstof uit de H2 leidingen vanuit de industrie worden niet beschouwd als CO_2 neutraal omdat meestal gemaakt uit aardgas. De waterstof die vrijkomt komt uit de fabricage van Koolmonoxide voor bijv. polymeren. Aardgas wordt door middel van SteamReforming gesplitst tot koolmonoxide (CO) en waterstof (H2). Als uiteindelijk het polymeer verbrandt wordt, indien niet meer recyclebaar, komt er CO_2 vrij. Dit hoort bij de kunststof en niet bij het waterstof. Hiermee zijn we nog niet fossiel neutraal, maar wel bezig met het terugbrengen van de CO_2 uitstoot, de basis waarop wij de afspraken van Parijs gebaseerd hebben.
  - Waterstof niet in gebouwen/woningen introduceren. Ga uit van elektrificatie van de gebouwde omgeving Dat houdt het systeem zo veel mogelijk idiot proof. In professionele omgevingen hoeft dit niet te gelden.
  - Probeer vervolgens het systeem zo veel mogelijk DC te houden. Opwekking gebeurd in DC, gebruik is veelal in DC, alleen elektriciteit transport middellang wordt eigenlijk in hoogspanning AC gedaan.

Iedere conversieslag geeft energieverliezen en dat moeten we zien te voorkomen.
- Energie is nog te goedkoop. En dat maakt de transitie zo moeilijk. Er is nu geen financiële prikkel.
- Safety: waterstof systemen móeten gewoon veilig zijn. Inmiddels weet men hoe het veilig gemaakt kan worden maar is het nog niet in een norm vastgelegd voor de gebouwde omgeving. Dat gebeurd pas als het ministerie de opdracht geeft aan de NEN om dat te doen. Met de PGS 35 voor de bouw van H2 tankstations is recent laten zien dat dit heel efficiënt kan.
- Public acceptence: zeker een issue. Vooral beginnen met de decision makers. Die maken vooraf de lange termijn keuzes. Misschien is dit wel de belangrijkste en de meest urgente. Er moet een strategie liggen hoe men hierover geïnformeerd wordt. Als de decision makers namelijk niet voor waterstof zijn, of nog wantrouwen hebben, komt het niet op de agenda te staan en zal grootschalige adoptie van dit energiemedium er niet komen. Een voorbeeld hoe de bevolking geïnformeerd kan worden is hoe ze het op ijsland gedaan hebben. Hier hebben ze destijds alle opa’s en oma’s uitgenodigd voor een proefrit in de nieuwe waterstofbus. In een halfuurtje werden ze rondgereden en werd uitgelegd waarom dit nu zo nieuw en belangrijk is. Met als gevolg dat de dag erop de rest van het eiland via de kleinkinderen de familie, dit ook wisten.
- Integration Energy Grid: er zijn al overschotten van elektriciteit aanwezig, bijvoorbeeld in Oude Tonge. Er is gesproken over conversie naar waterstof alleen is er nu praktisch geen netwerk aanwezig. Tevens zijn er geen afnemers (OBSTAKEL). Daarom moeten alle stappen in een keer gebeuren: conversie, opslag, afnemers. Een nog betere volgorde is afnemers, distributie, opslag en productie klaarzetten, en bovendien liefst allen tegelijker tijd klaar voor de start.
- Integration Energy Grid: het koppelen met voertuigen is nog steeds een mogelijkheid (Car as power plant). Maar ook andersom, een waterstof systeem kan een volledig geïntegreerd energie systeem zijn alles aan elkaar geknoopt en daardoor betaalbaar en betrouwbaar.
- Integration Built Environment: dit type van seizoensopslag heeft een veel minder grote impact (oa op milieu en ecosysteem) dan stuwmeren.
- Technique: De H2-technologie is al klaar en werkt. Maar er ontbreekt nog een netwerk van installateurs en onderhoudsmonteurs. Ook al merkbaar in de autobranche.

7.24 20160926 Meeting Jan Langedijk & Marcel Versteegen

Details	
Subject	Verification of findings
Date	September 26th, 2016, Monday 0930-1030
Interviewee	Jan Langedijk & Marcel Versteegen
Organization represented	Siemens
Language	Dutch

Jan is corporate Accountmanager Tennet en ervaren met Smart Grids.
Marcel is Business Unit Lead en ook ervaren met Smart Grids.

- Alex: Nog meer toepassingen van waterstof naast deze vier?

  - Mainz
  - Ameland
  - Rozenburg
  - ‘eigen model’
- Marcel/Jan:
  - Hoe bekijk je deze toepassingen? Aan de hand van de gebruikte businessmodellen of de technische inpassingen? Belangrijk om de business case helder te hebben. Hierbij vooral belangrijk de bandbreedte aan te geven waarbinnen de waterstof oplossingen opereren.
    - Alex: ervan uitgaan dat fossiel straks niet meer gebruikt mag worden of dat er zware CO_2-taks komt. Anders nu financieel geen mogelijkheden om waterstof seizoensopslag te ontwikkelen. Voor nu vooral de focus op de inpassing in de gebouwde omgeving van waterstof technieken.
  - Wellicht interessant project om zelfvoorzienend te worden op Texel (contact via Rick van der Tol) onder de noemer CloudPower.
  - In Duitsland sinds dit jaar al wetgeving die DSO’s verplicht extra capaciteit te hebben (opslag?).
    - Alex: In Nederland is de wetgeving nog zo strikt dat opslag door DSO’s niet toegestaan is omdat dit wordt gezien als handel. En doordat DSO’s een monopolie hebben in de markt, mogen ze niet handelen.
  - Vlak energie collectieven niet uit. Die zouden eventueel een schakel kunnen zijn tussen de DSO en de energieleverancier.
- Alex: Wat is volgens jullie een Smart Grid?
- Jan:
  - Quote: “Een Smart Grid is net als Coca-Cola, iedereen kent het maar niemand weet precies wat erin zit.”
  - De reden dat het Smart Grid is ontstaan is om verzwaringen aan het net te voorkomen. Dit door op een slimme manier met het bestaande elektriciteitsnet om te gaan. Met de hulp van extra meters en sensoren wordt het net beter bemeten. De Big Data die hiermee gegenereerd wordt kan vervolgens worden geanalyseerd en op basis daarvan betere beslissingen genomen worden om grote pieken in zowel vraag als aanbod te voorkomen. Dit kan door de reductie van de elektriciteitsvraag, maar ook door de vraag te verschuiven naar een ander tijdstip.
- Alex: Herkennen jullie de verschillen in energiegebruik tussen Winter-Zomer?
- Marcel/Jan:
  - Alleen kijkende naar elektriciteit valt dat erg mee. Het verbruik is vrij constant. De grootste energie vraag komt voort uit warmte en die wordt in Nederland vooral opgevuld door gas.
  - Bij all-electric wijken waar verwarmt word dmv een warmtepomp van zo’n 3 a 4 kW komen er al problemen, al zijn dat nog maar weinig plekken. Als in de toekomst nog meer woningen een airco plaatsen kan het elektriciteitsverbruik zeer sterk toenemen.
  - Een volledige energievoorziening gebaseerd op hernieuwbare energiebronnen zou binnen de gebouwde omgeving eerder met zon-pv gebeuren dan met wind. PV-panelen zijn steeds kleiner en kunnen

verwerkt worden in allerlei oppervlakken. Hierdoor kan er op grotere schaal lokaal geproduceerd worden en is er minder opslag nodig.

8 Questionnaire | Example

The questionnaire is placed in the same way as it was presented to the respondents. Therefore, the print screens are added. But because the questionnaire was in Dutch, the main parts such as the topic and the case description are also added in English.

8.1 Topic

It is hard to have missed the public debate about the energy transition. By using renewable energy sources such as wind and solar energy, we seek to reduce greenhouse gas emissions and limit global warming. This endeavor is once again clearly endorsed last year, in a climate agreement in Paris by all world leaders. Our energy transition will therefore take shape; both in central and decentralized districts as in homes and buildings.

The new energy sources are weather dependent, so we are not assured of a continuous energy supply. However, in our society we desire a reliable energy system that matches our demand at all times. Storage of energy becomes a necessity. The manner of storage will depend on a number of factors. Therefore, there probably will not be one solution, but rather a mix of different solutions. For instance storage in home batteries, or electric vehicles, community batteries, thermal storage, conversion to hydrogen, etc. All depends on when the power is available, when it should be available again, the duration of storage, the size of storage and for what purpose it is stored.

This research focuses on hydrogen as an energy carrier for the seasonal storage of locally generated renewable energy with the aim of re-electrification of the stored hydrogen. The advantage of hydrogen with respect to batteries for example, is the storage potential in the longer term. Batteries lose their energy over time, while hydrogen has no loss of energy when it is stored for a long time.

Hydrogen is seen as a part of the transition in our energy system. In the near future, hydrogen will be used within the mobility and energy sector. Thereby lessons are learned from current practices in the (petro-)chemical industry, and the food and process industries. However, hydrogen as an energy storage system, remains to deserve political attention.

8.2 Case description

The case is based on a future all-electric autonomous community/district. Without gas and/or heat pipes, but with a local smart grid. The houses are built according to the near-zero-energy principle and are equipped with a heat pump, solar panels and a small home battery to cover day-night differences in their electricity demand.

The houses in this community/district are energy neutral; in the winter more energy is used than generated and the opposite is the case during the summer. When looking at the energy usage over the year, such a house uses nearly zero energy. This is called the near-zero-energy principle.

The following questions refer to a system that can be placed in the local power grid to save the locally generated sustainable energy for a long-term period. It is actually like a seasonal battery. It functions as follows:

- The smart grid detects surpluses of electricity from the district;
- The energy is stored locally as hydrogen;

- When there is a demand for energy in the district, the hydrogen is converted back into electricity and fed into the local power grid.

The conversion of hydrogen into electricity is done with an electrolyzer, and reversed by a fuel cell.

There are several ways in which hydrogen can be saved: as gas, liquid or as a hydride (bound to other substances or materials). The location for the hydrogen storage may lie close to the electrolyzer and fuel cell. Next to that it is possible to store hydrogen on a more distant location while being connected through an underground gas network.

8.3 Presented questionnaire

TU/e Technische Universiteit Eindhoven University of Technology 'Waterstof als energiedrager in de gebouwde omgeving'

Page: Introductie vragenlijst

Introductie

Geachte heer/mevrouw,

Allereerst dank voor het deelnemen aan mijn onderzoek door het invullen van deze vragenlijst. Dit is de eerste uit een reeks van twee. Eerst volgt een uitleg over het onderwerp, daarna volgen de vragen. Deze dienen beantwoord te worden aan de hand van een gegeven casus. Leest u deze zometeen goed door.

Mocht u vragen of opmerkingen hebben dan kunt u altijd contact met mij opnemen via: a.h.h.jacobs@student.tue.nl.

Met vriendelijke groet,
Alex Jacobs

Uw gegevens zullen niet gepubliceerd worden of voor commerciële doeleinden gebruikt worden.
De gegevens worden vertrouwelijk en anoniem verwerkt en enkel gebruikt voor dit afstudeeronderzoek.

Vorige | Volgende

Onderwerp

De maatschappelijke discussie over de energietransitie zal u niet zijn ontgaan. Door de inzet van hernieuwbare energiebronnen, zoals wind- en zonne-energie, proberen we de uitstoot van broeikasgassen te beperken en de opwarming van de aarde tegen te gaan. Dit streven is vorig jaar door alle wereldleiders in Parijs nog eens duidelijk onderschreven in een klimaatakkoord. Onze energietransitie zal dus vorm krijgen; zowel centraal, als decentraal in stadsdelen, woningen en gebouwen.

De nieuwe energiebronnen zijn weersafhankelijk, waardoor wij niet altijd verzekerd zijn van voldoende energie. Echter de maatschappij verlangt te allen tijde een betrouwbaar energiesysteem. Opslag van energie wordt hiermee een noodzaak. De manier van opslag zal van een aantal factoren afhangen. Daarom zal er waarschijnlijk niet één totaal oplossing zijn, maar eerder een mix aan verschillende oplossingen. Denk hierbij aan opslag in thuisbatterijen, opslag in elektrische voertuigen, wijkbatterijen, thermische opslag, conversie naar waterstof, etc. Allemaal afhankelijk van wanneer de energie beschikbaar is, weer beschikbaar moet zijn, de duur en de omvang van de opslag en voor welk doel het opgeslagen wordt.

Mijn onderzoek richt zich op waterstof als energiedrager voor het seizoensgebonden opslaan van lokaal opgewekte duurzame energie met als doel het re-elektrificeren van de opgeslagen waterstof. Het voordeel van waterstof ten opzichte van bijvoorbeeld batterijen is het opslagpotentieel voor de langere termijn. Batterijen verliezen namelijk hun energie over tijd terwijl waterstof zonder energieverlies gedurende lange tijd kan worden opgeslagen.

Waterstof wordt gezien als een onderdeel van de transitie in ons energiesysteem. In de nabije toekomst zal er dan ook gebruik gemaakt worden van waterstof in de mobiliteit- en energiesector. Hierbij kan geleerd worden van huidige toepassingsgebieden van waterstof in de (petro-)chemische industrie, voedsel- en procesindustrie. Maar het onderwerp verdient ook politieke aandacht.

Vorige | Volgende

Beroepsgroep

Omdat uw visie rondom dit thema van belang is, wordt daarom als eerste gevraagd vanuit welke invalshoek u dit onderwerp bekijkt. Wat is de beroepsgroep die het meest voor u van toepassing is?

- Adviesorgaan
- Autobranche
- Industrie
- Branchevereniging
- Consultant
- Energieleverancier
- Netbeheerder
- Onderwijs
- Overheid
- Politiek
- NGO
- Overig (hieronder in te vullen)

Andere beroepsgroep

Vorige Volgende

Casus omschrijving

De casus is gebaseerd op een toekomstige 'all-electric', autarkische woonwijk of stadsdeel. Zonder gas- en/of warmteleidingen, maar met een lokaal 'Smart' elektriciteitsnet. De woningen zijn gebouwd volgens het principe 'nul-op-de-meter' en zijn voorzien van: een warmtepomp, hebben eigen zonnepanelen en een kleine thuisbatterij om dag-nacht verschillen op te vangen.

Hoewel over een jaar bezien het energiegebruik van zo'n woning nul is, gebruikt iedere woning in de winter meer energie dan dat het zelf opwekt. In de zomer is dit juist andersom en is er sprake van een energieoverschot.

De hierna volgende vragen hebben betrekking op een systeem dat geplaatst kan worden in dit lokale elektriciteitsnet om de lokaal opgewekte duurzame energie langdurig op te slaan. Het is eigenlijk een soort seizoensbatterij. Het principe is als volgt:
-het smart grid detecteert een overschot aan elektriciteit uit de wijk of stadsdeel
-de energie wordt lokaal als waterstof opgeslagen
-bij een tekort in de wijk of stadsdeel wordt de waterstof weer omgezet in elektriciteit en geleverd aan het lokale elektriciteitsnet
De omzetting van elektriciteit naar waterstof gebeurd door een elektrolyser, en omgekeerd door een brandstofcel.

Er zijn meerdere manieren waarop waterstof opgeslagen kan worden: als gas, als vloeistof of als hydride (gebonden aan andere stoffen of materialen). De locatie voor de opslag van waterstof kan nabij de elektrolyser en brandstofcel liggen. Maar ook een verder afgelegen locatie is mogelijk en dan verbonden door middel van een ondergrondse waterstofgasleiding.

Vorige Volgende

Keuze obstakels

Uit literatuuronderzoek, referentieprojecten en door het voeren van expertinterviews zijn een aantal obstakels naar voren gekomen die succesvolle implementatie van seizoensgebonden energieopslagsystemen gebaseerd op waterstof mogelijk kunnen verhinderen. Graag zou ik uw mening willen weten of volgens u deze obstakels van belang zijn. Een volgorde tussen de obstakels is nu niet van belang. Door op vorige te klikken kunt u de casus nog eens lezen.

Het is een obstakel dat:

	Ja	Nee	Weet ik niet
De huidige CO2-emissiebeprijzing te laag is voor de introductie van duurzame energiesystemen, ook op wijkniveau.			
De aanleg van een apart waterstof gasnetwerk te duur is.			
Er onzekerheid bestaat of waterstof wel de oplossing is voor de lange termijn door de relatief hoge kosten per kWh.			
Men pas bereid is waterstof te accepteren als het de energierekening van de bewoner verlaagd.			
Fossiele energie goedkoper is.			
Het waterstof opslagsysteem in zijn geheel gezien een te laag rendement heeft.			
Alle maatschappelijke kosten van een fossiele energievoorziening niet meegerekend worden in de vergelijking met een duurzaam, lokaal energiesysteem.			
Het te kostbaar zal zijn om in binnensteden of wijken een eigen energieopslagsysteem te plaatsen.			

Keuze obstakels

Door tweemaal op vorige te klikken kunt u de casus nog eens lezen.

Het is een obstakel dat:

	Ja	Nee	Weet ik niet
Lokale overheden, instanties en dienstverleners nauwelijks tot geen kennis en ervaring hebben met waterstof en de toepassingen daarvan.			
Er binnen steden of wijken onvoldoende fysieke ruimte aanwezig is voor het plaatsen van energieopslagsystemen.			
Er te veel naar één generieke, landelijk toepasbare energie-oplossing gezocht wordt, terwijl er juist per locatie bekeken moet worden wat de beste energievoorziening is.			
Private energieopslagsystemen per woning, bijvoorbeeld een thuisbatterij, meer aandacht krijgen dan een centrale opslag in de wijk.			
Alleen in nieuwe wijken vanaf het begin af aan rekening gehouden kan worden met een duurzaam energiesysteem, waarin waterstof een haalbare rol kan spelen (energie-technisch, economische, ruimtelijke inpassing).			
Aardgasleidingen niet geschikt zijn voor het transport van waterstof.			
Er momenteel geen noodzaak is om waterstof te gebruiken als onderdeel van netbalancerende systemen.			
Er nu nog voldoende transportcapaciteit is in het landelijke en regionale elektriciteitsnetwerk om pieken en verhoogde vraag te kunnen accommoderen.			
Er voldoende andere lokale systemen beschikbaar zijn om zowel lokale netbalancering mogelijk te maken als te voorzien in wisselingen van de energievraag door seizoensinvloeden.			
Op fossiel gas gebaseerde energiesystemen nog voor decennia gebruikt zullen worden.			
Waterstof verstorend werkt in het lokale energiesysteem, zowel bij opwekking, als bij opslag en hergebruik in gasvorm of in de vorm van elektriciteit.			

Keuze obstakels

Door driemaal op vorige te klikken kunt u de casus nog eens lezen.

Het is een obstakel dat:

	Ja	Nee	Weet ik niet
Lokaal, duurzaam geproduceerd waterstof voor de burger duurder is dan fossiele brandstoffen.			
Er een salderingsregeling voor zon-pv bestaat, waardoor lokale opslag van duurzame energie voor de bewoner minder interessant is.			
De onduidelijkheid rondom de veiligheid van waterstof de maatschappelijke acceptatie verhinderd.			
De automobiel industrie nog niet over is op waterstof en er onvoldoende aanbod is uit brandstofcel auto's.			
Er angst is voor waterstof door associaties met explosies en ongevallen.			
Er publiekelijk te weinig kennis is over het energiesysteem en de verduurzaming daarvan.			
Er nog onbekendheid is rondom de impact van waterstof op het materiaal van transportleidingen, het gedrag van branders, etc.			
Het systeem niet snel genoeg (ca. 10 minuten bij een zogenaamde 'black start') kan reageren op een te veel aan elektriciteit.			
De betrouwbaarheid van de elektrolyser te laag is.			
De betrouwbaarheid van de brandstofcel te laag is.			
Er geen goed functionerend Smart Grid systeem bestaat.			

Vorige Volgende

Keuze obstakels

Door viermaal op vorige te klikken kunt u de casus nog eens lezen.

Het is een obstakel dat:

	Ja	Nee	Weet ik niet
De beschikbaarheid, betaalbaarheid en certificatie van meet- en regeltechnische systemen voor waterstof ontbreken.			
Er geen waterstofopslagsystemen bestaan voor de bebouwde omgeving die grootschalige energieopslag voor seizoensvariaties mogelijk maken.			
Er geen administratief- en verreken-systeem bestaat voor de lokale saldering van duurzame energie leverantie en energieverbruik van de bewoner op wijkniveau.			
Dat wet- en regelgeving ontbreekt omtrent productie, opslag en gebruik van waterstof in de bebouwde kom, afgesloten ruimtes en certificatie van apparatuur.			
Het bijmengen van waterstof in aardgas (tot 0,02%) te beperkt mogelijk is.			
De netbeheerder geen energieopslag mag faciliteren, omdat dat wordt gezien als handel.			
Er geen certificatiesysteem bestaat die verzekert dat de geproduceerde waterstof altijd uit een duurzame bron komt (ontbrekend groen-certificaat).			
Er geen set normen is waar seizoensopslag met waterstof aan moet voldoen.			
De rol van landelijke energiebedrijven in lokale energietoepassingen nog onduidelijk is.			

Mocht er volgens u nog een obstakel(s) ontbreken, dan kunt u dat hier laten weten:

Contact vragenlijst deel twee

Over ongeveer twee weken zal vragenlijst deel twee verstuurd worden. Door ook deel te nemen aan deel twee, levert u een belangrijke bijdrage aan het onderzoek. U ontvangt daarnaast als dank ook de resultaten aan het einde van het onderzoek per mail.

Als laatste de vraag om hieronder uw e-mail adres achter te laten ter confirmatie. Uw e-mail adres wordt uitsluitend gebruikt om u de volgende vragenlijst door te sturen en om u de resultaten van dit onderzoek toe te sturen. Daarna zal uw e-mail adres worden verwijderd. U ontvangt dus daarna geen andere berichten op basis van uw deelname.

Vorige Volgende

Opmerkingen

Mocht u nog opmerkingen of vragen hebben kunt u dat hier laten weten.

Vorige Verzenden