UNIVERSITY OF TWENTE.

Faculty of Behavioural, Management, and Social Sciences (BMS)

What are the barriers in the development of hydrogen in the transition process towards sustainable mobility in the Netherlands?

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M.Sc. Thesis

Submitted on: 08.12.2019

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Abstract

The purpose of this thesis is to focus on the barriers in the development of hydrogen for car-based mobility in the Netherlands. Road vehicles are occupying a large fraction of what is responsible for GHG emissions in the country. According to the Ministry of Health, Welfare, and Sport (2018), road cars which ran on fossil fuels were responsible for 14.8% of total GHG emissions in 2016. As a member of the EU, the Netherlands is expected to reach 20% share of renewable energy by 2020, and especially 10% in transportation, whereas the country had only 7.4% in 2018 (Statistics Netherlands, 2019). In this context, mobility transition processes have been garnering significant attention in the past years, as climate change mitigation has become one of the main policy focuses also in the Paris Climate Agreement (190 parties signed including the Netherlands), recognizing the need for global emissions to peak as soon as possible (UNFCCC, 2016). Today, the regime of fossil fuels in the Netherlands is still dominant in mobility, causing environmental harm by releasing air pollutants in the form of emissions. For this purpose, the Netherlands has the opportunity to focus its attention on the possibility of using hydrogen as a zero-emission sustainable mobility fuel.

Keywords: hydrogen, mobility transition, GHG emissions, car-based mobility, Netherlands

Acknowledgement

During the writing and preparation of this Master Thesis I received great amount of support, understanding, and guidance. I would first like to thank my leading supervisor, Dr. Maarten Arentsen (Professor of Energy Management and Innovation at the University of Twente) whose expertise was inestimable in formulating the research topic and especially the methodology of the research. He was of major support in the structure of the thesis as well, providing regular feedback and adequate advice.

In addition to Mr. Arentsen, I would also like to acknowledge the tremendous support from my second supervisor - Dr. Victoria Daskalova (Assistant Professor at the University of Twente) for aiding the research proposal as well as guiding myself in adhering the proper academic writing standards. Her critical view improved my work substantially.

Last but not least, I would like to thank my family for their ongoing and constant support. Their presence has always motivated me. Also, I would like to address my closest friends which were providing a rest to my mind, by taking me away from research when I felt preoccupied.

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List of Abbreviations

Abbreviations	***Explanations***
BEV	Battery Electric Vehicle
CCUS	Carbon Capture, Utilization, and Storage
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CHP	Combined Heat and Power
DOE	Department of Energy
DRIFT	Dutch Research Institute for Transitions
EBN	Energy Management Netherlands
EIB	European Investment Bank
EU	European Union
FC	Fuel Cell
FCV	Fuel Cell Vehicle
FIP	Feed-In Premium
FMO	Entrepreneurial Development Bank
GHG	Greenhouse Gases
GTR	Global Technical Regulation
HEV	Hybrid Electric Vehicle
HPGH	High-Pressure Gaseous Hydrogen
ICE	Internal Combustion Engine
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
IRO	The Association of Dutch Suppliers in the Oil and Gas Industry and Offshore Renewable Industry
MEA	Ministry of Economic Affairs
MLP	Multi-level Perspective
NMP	National Environmental Policy Plan
NOGEPA	Netherlands Oil and Gas Exploration and Production Association
NWBA	National Hydrogen and Fuel Cell Association
PEM	Proton Exchange Membrane
RED	Renewable Energy Directive
SDE	Sustainable Energy Production Incentive Decision
SER	Social and Economic Council
SMR	Steam Methane Reforming
SNM	Strategic Niche Management
TM	Transition Management
TTW	Tank-to-Wheel
WTW	Wheel-to-Wheel

Chapter 1: Introduction

1.1 Hydrogen's role for mobility

Energy is one of the key factors in determining a country's economy, infrastructure, transportation, standard of life, and the problem faced globally is the disparity between the consumption and the availability of energy, where almost all nations (including the Netherlands) are presently dependent upon fossil fuels for energy production, whereas fossil fuels are not sustainable sources (Hosseini, Andwari, Wahid & Bagheri, 2013; see also Granovskii, Dincer & Rosen, 2007). Production of fossil fuels, and oil in particular, is expected to reach its maximum in the next two decades and then to decline despite enhanced recovery techniques, as the rate of discovering new wells continues to diminish (Renne & Fields, 2013). Prices will inevitably increase, which are dependent on the day-to-day market situation and on political issues such as cartel ceilings on production and warfare in the regions of production (Adolf et al., 2019). Therefore, the conclusion is that to supply the energy demands of the more rapidly increasing global population, it is essential to upgrade to an alternative sustainable energy source that does not negatively affect the environment.

In this regard, fossil fuel transport is responsible for an average of 25% of the GHG emissions in the EU, and is a key contributor to air pollution in cities, thus demand for zero-emission vehicles has been rising, and the automobile industry is significantly criticised for not addressing the problem sufficiently (Rodriguez, 2017). Consequently, the development of alternatives to fossil fuels in mobility is becoming more attractive, both for economic and security of supply reasons. Because renewable energy sources are more evenly available geographically (albeit the best mix of renewable sources may vary from one region to another), they are seen as plausible in scenarios placing emphasis on local control, often referred to as "decentralisation", although they certainly do not eliminate the need for transmission and trade of electricity and renewable-based fuels or for developing suitable forms of energy storage (Hulshof, Jepma & Mulder, 2019).

However, the possibility of using hydrogen as a fuel for mobility has been recognised and currently gaining momentum (Blagojevic & Mitic, 2018). Hydrogen is the most abundant element on earth, having potential for zero carbon footprints if produced from renewable energy, it can be transported over long distances, and serve as a feedstock to capture CO_2, to produce methane and other gases (Singh, 2015). Due to the high energy content of hydrogen, it is employed as a fuel in a system known as the fuel cell (FC), and automobiles with this propulsion system have been categorized as fuel cell vehicles (FCVs). FCVs are inherently more efficient than internal combustion engine (ICE) cars with Tank-to-Wheel (TTW) efficiency lying at over 40% (European Commission, 2015).

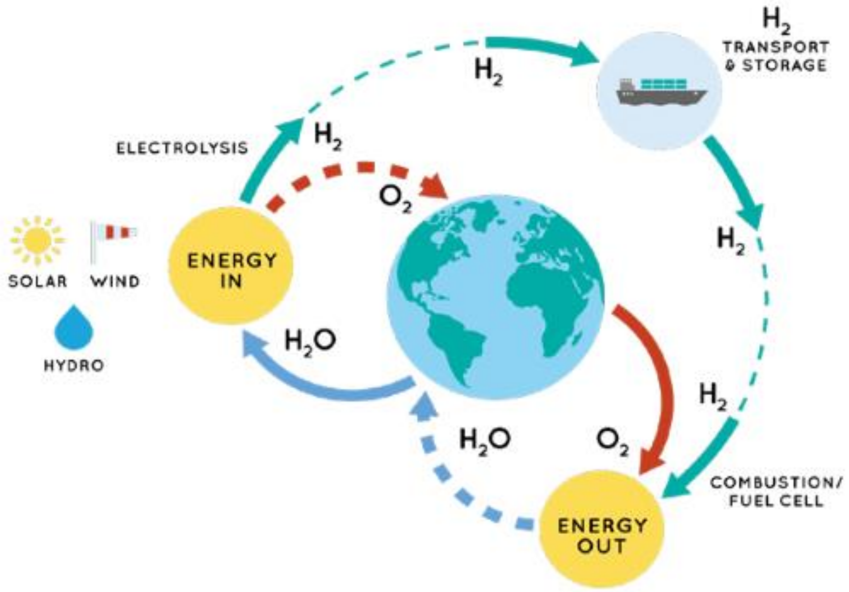

Figure 1. The global hydrogen lifecycle (Van Wijk, Van der Roest and Boere, 2018)

Nevertheless, several issues with hydrogen have been raised for attention including production, storage and transmission, and the use of hydrogen, notably as fuel for fuel cells. Firtst of all, fuel cell vehicles must experience a significant price drop along with the development of new fields of application and infrastructure problems have to be solved (Ehret, 2019). In order to compete more successfully with fossil fuels, the price of producing hydrogen fuel is yet another cost factor that has to decline, and for that purpose, the markets have to expand and production technology must be refined (Farla, Alkemade & Suurs, 2010). The cost of local hydrogen storage, typically using pressure containers, is not negligible but still has a modest influence on overall cost, whereas the critical cost item remains the fuel cell converter used, where the end-use energy form is electricity, including traction through electric motors (Ministry of Infrastructure and the Environment, 2014).

Overall, the critical development item for allowing the penetration of the so-called hydrogen niche, is the fuel cell. In other words, the transportation sector is regarded as crucial for an introduction of hydrogen as a general energy carrier, replacing the dominant fossil fuel regime. With this intention, a reasonable place to evaluate such transition is the Netherlands, Europe's second largest producer (after UK), and among the leading exporters, of natural gas (Eurostat, 2019). Moreover, transport remains of key economic and environmental significance for the Netherlands and one of the most important energy transition areas overall. The country is a major transport hub for fossil fuels because of its geopolitical location and large ports. In particular, Rotterdam and Amsterdam are Europe's first and second largest coal ports respectively, placing the Netherlands among the main importers and exporters of coal in the world (International Energy Agency, 2016). Nevertheless, the country itself has not produced coal since 1974 and, with domestic oil production only fulfilling half the country's demand; gas fields in the Netherlands are close to exhaustion, and limits have been imposed on production to reduce earthquakes resulting from gas extraction in the North, consequently the Netherlands is expected to give in its position of net exporter, and become a net importer of fossil fuels by 2021 or 2022 (TNO, 2017). According to the United Nations Climate Change Secretariat (UNFCCC, 2012), the Netherlands owes 86% of its GHG emissions to CO_2, where road transport is responsible for 21% of the GHG emissions in the country in 2012. Therefore, the Netherlands must increase its commitment to the implementation of stricter CO_2 emissions requirements for road transport, as an EU member state. In this line of reasoning, the Energy Agreement, Agenda, and Dialogue are built upon long-term agreements for reducing the transport emissions by 2050 of at least 60% of the emissions of 1990 (Ministry of Economic Affairs of the Netherlands, 2019).

1.2 Research Objective

The objective of the thesis is to assess the impeding obstacles towards the development of hydrogen fuel for sustainable car mobility in the Netherlands, in contrast to traditional fossil fuel cars. With this in mind, the current thesis outlines the development of the hydrogen fuel niche, along with the fuel cell technology that is expected to gain further momentum based on improvements and the ability to provide zero-emissions driving in comparison to the traditional fossil fuel combustion engines. Challenging the dominant regime also holds a social element, and therefore this process must be regarded as socio-technical change. Different actors (i.e. government, producers, consumers, interest groups) are responsible to initiate and support the breakthrough of a technology, such as the fuel cell vehicle. The current thesis aims to provide answers to whether such transition is possible in the Netherlands, by outlining the state-of-the-art and the impediments towards realization. Consequently, the goal of the thesis is to remain as objective as possible, and offer a new perspective on car-based mobility and the potential of hydrogen fuel in the Netherlands.

Chapter 2: Research Framework

The goal of this chapter is to design a comprehensive research framework, by peeking at previous research on transitions and provide information about the impediments that these transitions have experienced, in order to outline the state of the art on the topic. In particular, the chapter will start by describing the relevant theories on transition management, followed by a literature review to explore findings on the topic, and thus ideally arrive at the questions that have received little scientific attention so far. The main research question and the sub-questions will thus be formed on the basis of the issues regarding sustainable hydrogen mobility in the Netherlands. The chapter will conclude with a definition of the key concepts.

2.1 Theoretical Framework

Research and innovation programs on 'transitions' towards a more sustainable fulfilment of social needs, have emerged in the Netherlands at the beginning of the 21st century (Loorbach, 2010; see also Kemp, Rotmans and van Asselt, 2001). The normative goal that these research and innovation programs on transitions have is, improving the way social needs such as the need for mobility and energy are met, where social innovation could be defined as - innovation, minimising negative social effects and improving issues such as the stress on natural environment (Kemp & Loorbach, 2005). Alternatively, transitions could also be categorized as major shifts in 'socio-technical regimes' or the dominant path in which social needs such as energy supply and mobility are achieved, from their pre-development phase towards the sustainable mobility phase (Loorbach, 2013).

Theoretically, two models are capable to explain these energy transitions (and transitions in general), namely Transition Management (TM) and Strategic Niche Management (SNM). The first is based on the analytical perspective of society as a patchwork of complex adaptive systems. These systems evolve, change and adapt and sometimes undergo structural changes or as the name suggests, transitions (Hoogma, 2002). On the other hand, the latter defines the process of deliberately managing niche formation processes through real-life experiments (Loorbach & Rotmans, 2006).

With this in mind, an important model that has become widely used in transition research is a multi-level perspective (MLP) on transitions (Geels, 2019). It has been developed through a large number of case studies on historical transitions to understand long-term socio-technical change, and distinguishes three analytical concepts: regimes, niches and the landscape (El Bilali, 2019). The first concept of this multi-level perspective – the regime, is often used in a negative way to explain why new innovations do not breakthrough, its rules and institutions guide regime actors in a specific direction and make them ‘blind’ for alternatives or even discourage or punish the development of alternatives (Geels, 2019). On the contrary, the niche concept is often used in a positive way and as a counterpart for regime problems, where they represent ‘the innovative solutions’, radical change and the promise of improvement and progress (Geels, 2019). In the multi-level perspective, niches are the location where radical innovations are developed and from where they can grow and replace regime practices, and therefore enable transition experiments in which visionary actors can innovate with social goals and learn about social challenges (Geels, 2019). The landscape is the third element of the MLP, and a metaphor for the background setting and background developments for regimes and niches, but also the source of pressure for the regime to change (Geels, 2002; 2011; 2019).

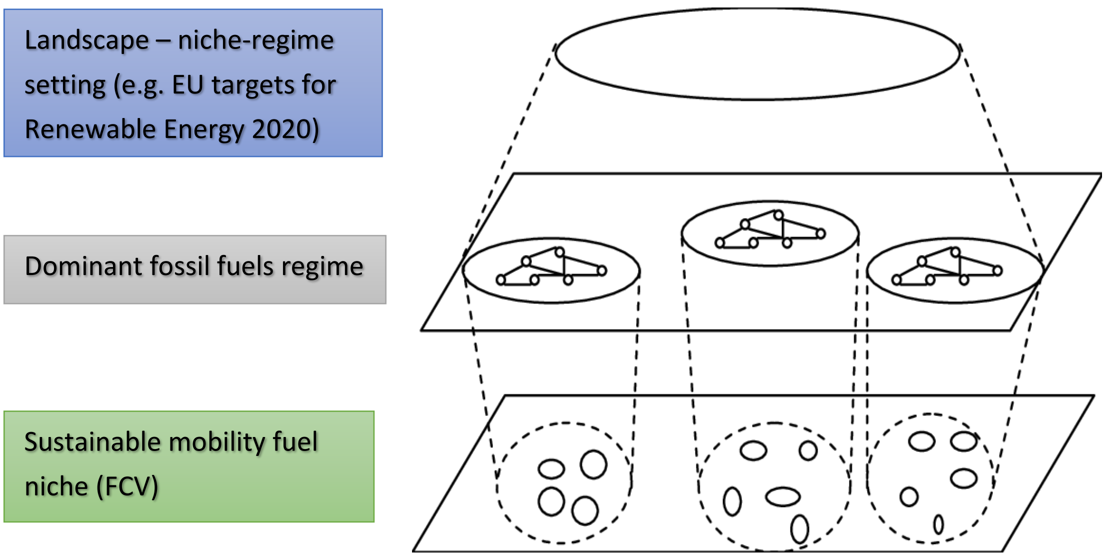

Figure 2. Multi-level perspective on socio-technical changes in the context of sustainable mobility in the Netherlands, adapted from Geels (2019)

The multi-level concept has been the basis of a number of approaches that analyse innovation and transformation processes. Firstly, it has been applied for the historical analysis of transition processes by which a dominant socio-technical regime is gradually replaced by another regime (Schot 1998; Geels 2002). Secondly, in a policy-oriented perspective, transition management aims at bringing about regime changes which are supposed to lead to radically more sustainable ways of fulfilling a societal function (Kemp & Loorbach 2006). Thirdly, the method of socio-technical scenarios aims at exploring potential future transitions of a specific socio-technical regime, e.g. the fossil fuel transport regime. Drawing on various mechanisms and patterns that have been identified in historical studies of transition processes, diverging paths are developed, which may lead from today's regime structures to radically different structures (Elzen et al. 2002).

The role of the MLP on socio-technical changes in the thesis concerns all three applications mentioned above, serving as an analytical tool of the position and development of hydrogen in a sustainable mobility context. Furthermore, the framework provides the opportunity to contrast this position with the position of fossil fuels, where both positions are dependent on the national (Dutch) as well as international (e.g. EU) laws and developments in regards to sustainable transportation. Therefore, the use of the MLP will allow for a theory guided analysis on the stance of hydrogen as an alternative fuel and the barriers towards its development. In that regard, the three levels of the framework (niche, regime, and landscape) were created by Geels (2002), in order to be employed when performing research on transitions, could thus be conceptualized. In this thesis, the niche level is represented by the perspective of hydrogen for sustainable mobility transitions, the regime by fossil fuels as a main source of fuel in the Netherlands, whereas the landscape that serves as a background to both, are the national and international developments, regulations and targets towards the transition of mobility and the transportation sector overall. To define the landscape Geels explains that, rather inflexible or slowly changing structures external to a socio-technical regime are defined as part of the socio-technical landscape at the macro level, where such external structures are for example macro-economic developments, demographic trends, cultural changes, broad political changes or environmental problems (Geels, 2002b: 109).

In order to translate the above-mentioned factors from the MLP into an operational approach, Loorbach and Rotmans (2010) have created a recursive multi-level framework for transition management based on the premise that transitions and the issue of sustainability are inherently social issues, and thus governance strategies are supposed to involve a wide range of actors. It categorizes:

- *A strategic level*: consisting of vision development, strategic discussions and long-term goal formulation processes. Crucial at this level are the activities that provide direction to social and cultural developments through leadership capacity, long-term orientation and top-down decision-making.
- *A tactical level*: resting on the processes of agenda-building, negotiating, networking, coalition building, etc. At this stage, regime-structures of a societal system are redefined through the creation of completely new structures envisaged to facilitate a sustainable system, often through co-evolution between actors' interests, agendas and strategies.
- *An operational level*: including processess such as experimenting, project building, implementation, new practices, etc.

The transition management framework further separates four activity clusters captured in a cyclical model (Figure 3):

- *Problem structuring and envisioning (strategic level)*: this cluster identifies innovative pioneers and trendsetters, responsible for defining issues and the formulation of inspiring alternative visions and images at system level.
- *Agenda building and networking (tactical level)*: the part where relevant actors, networks, and representatives - negotiate, exchange and co-produce regulations, strategies and intermediate goals (transition images and paths) at sector and the subsystem level.
- *Experimenting and diffusing (operational level)*: cluster where entrepreneurs, project managers and (government) officials implement and execute daily operations and actions.
- *Monitoring, evaluating and adapting (tactical level)*: a mixture of cross-cutting processes that occur at all levels and throughout all phases - designed to raise learning and reflexivity.

In practice, the transition management framework allows context-specific implementation of the MLP approach based on evolving analysis of the state of a societal system. For example, the analysis of the energy transition shows that there is a growing concern about sustainability issues and the need for change, while not much debate is ongoing about the implications of a fundamental transition in terms of restructuring economies, consumption and production. In other words, after developing an alternative drive system with zero-emissions (FCV), the relevant actors in the system have to consider its practical institutional concern, such as: regulation, implementation, economic effects and so on. In terms of strategic transition management, this would imply creating space for innovative ideas and thinkers and facilitating the development of sustainability visions and images that challenge current ways of thinking and acting by establishing transition arenas (Loorbach, Frantzeskaki & Avelino, 2017).

In this research, the MLP requires an operational approach to explain the barriers of transition of the Dutch transportation system towards sustainable mobility. For that purpose, the multi-level framework of transition management provides the basis for evaluating the actions that the wide range of actors in the transportation sector undertake at the various levels, and through its activity clusters. Therefore, it could be considered as the practical reflection of the multi-level perspective that will further distinguish the barriers at the different levels and among the various actors of development of the hydrogen niche.

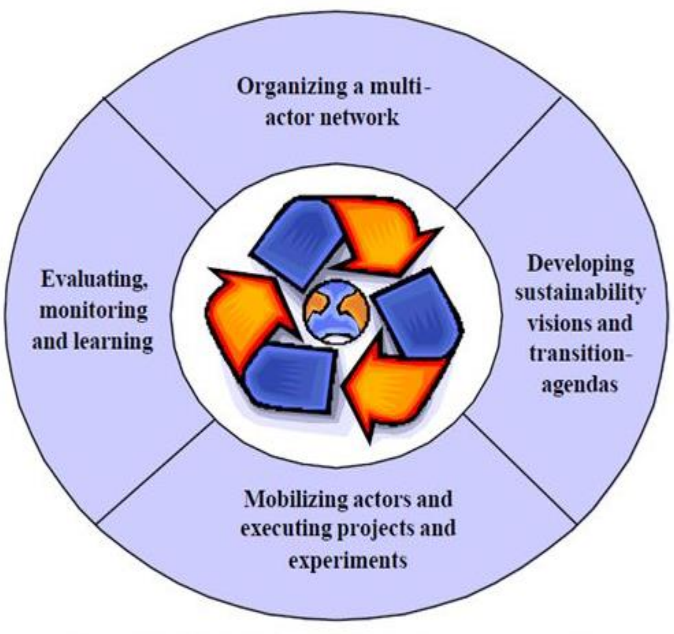

Figure 3. Activity clusters of the transition management framework (Loorbach, Frantzeskaki & Avelino, 2017)

2.2 Scientific Overview of Sustainable Mobility Transitions in the Netherlands

In the face of the growing threat of climate change, academic interest in possible pathways to sustainable transportation in the Netherlands have increased rapidly over the past decade. There is a widespread consensus that a sustainable mobility system will require major socio-technical transitions in the technologies and practices currently employed in the Netherlands. Such transitions will not automatically implement themselves when sustainable alternatives are present in specific niches. The core reason for such inertia holds that pre-existing technologies and practices are supported due to vested values, routines and interests associated with current unsustainable regime (Kemp et al., 2011; Geels, 2019).

Initially, the ‘transition to sustainable mobility’ was referred to under the transition to sustainable energy, one of the three ‘necessary transitions’ mentioned in the fourth Dutch National Environmental Policy Plan (Ministry of Infrastructure and Environment, 2001). Afterwards, ‘transition-to-sustainable-mobility` emerged as a combination of words that has been increasingly used throughout the Netherlands. An early attempt to apply transition management ideas to the field of mobility policy has its origins in the beginning of the century, when transition scholars Kemp and Rotmans criticised Dutch policies on sustainable mobility for being too biased on technological fixes, too fragmented and opportunistic, with experiments being carried out more or less ad hoc, without a coherent future vision and without sustainability considerations (Kemp & Rotmans, 2004). Transition management was proposed as a new mode of governance to orient policy and societal interactions in the field of mobility more towards transitional change. In the Knowledge Network on System Innovations and Transitions (KSI) programme that lasted from 2004 to 2010, further research was done on transition management as a model of reflexive governance for sustainable development, which has gained prominence as the “DRIFT” model of transition management because Rotmans, Loorbach and Kemp worked or have worked at DRIFT (Dutch Research Institute for Transitions), which is a research organization established at the Erasmus University of Rotterdam in 2004 (Kemp and Loorbach, 2006, Loorbach, 2007, Rotmans and Loorbach, 2009).

Later on, these transition researchers have argued in their research that even though the transition management approach has gained a great deal of attention in the past years from policy-makers, managers and other practitioners in the Netherlands, the Ministry of Economic Affairs and the Dutch Government only stared using it to change its relation with business and to have a more active agenda for energy innovation, aligned with climate policy and business creation goals (Kemp, Avelino, & Bressers, 2011). In addition to these developments, there has been relatively little active support for transition management in the energy sector within the Ministry of Transport, and despite that concepts such as 'transition' and 'sustainable' were initially addressed and discussed as an explicit aim of mobility policy, most of these ideas have met little applicability so far, where this becomes visible in the Energy Agenda of the Ministry of Economic Affairs (2017), also silent on the role of the Ministry of Transport in sustainable mobility, and stating:

> *"The mobility and transport sector still mainly runs on fossil fuels. Additional policy is needed to implement the transition to a sustainable sector by 2050."*

Regardless of the relatively weak formal support for transition management within the Deparment for Transport, the idea of 'a transition to sustainable mobility' has emerged and recently spread throughout the Netherlands, amongst a variety of policy-makers (e.g. Ministry of Infrastructure and Environment, Ministry of Economic Affairs etc.), business representatives and NGO-representatives (Loorbach, Frantzeskaki & Avelino, 2017). In this line of reasoning, researchers have previously attributed key roles to governments and policy reforms, and authors suggest the employment of a wide range of instruments to internalize the external costs of existing technologies (e.g. taxes or emission standard regulation), as well as increased efforts at building a vision, stakeholder engagement and small, medium and large-scale policy and program experimentation, where the government is seen as a facilitator–stimulator–controller–director, depending on the phase of the transition actually underway (Kemp & Rotmans, 2005). In support of this point, Loorbach (2010) put forward the argument that the present energy system is more than a technological lock-in, and the direction of development is shaped by more than innovation or economy alone. He goes on further to point out that, a transition requires changes in paradigms, infrastructure, institutions, behaviour, networks, etc., where many of these elements have co-evolved and remained stable, despite existing positive and negative feedbacks. Consequently, all these aspects provide opportunities for intervention and neither can be looked at in isolation. In the same paper, he suggests that variation, selection and retention play a role and can in part be influenced through stimulating new energy technologies, business models, end-use applications and alternative selection environments (e.g. market niches or semi-protected areas of experimentation) and retention of positive results in new or existing structures (e.g. through schooling, policy plans, new organisations). Central for dealing with transitions is therefore an understanding of the interactions between different levels of scale, in particular niche–regime interactions.

Overall, the use of the term transition is supposed to help the articulation of the complex challenge involved in moving away from present transport practices and technologies and assist in the creation of a bottom-up and top-down process of change, which could be explained with the help of the MLP on socio-technical transitions in the mobility system as well. Details of what to do must be defined at different levels by different actors; TM is in that sense should not be considered a tool, rather a framework for thinking and decision-making. The transition perspective holds that policy should be less concerned with short-term outcomes and more focused on long-term outcomes. Institutional capabilities and knowledge are yet to be developed for this. Sustainable mobility is likely to require different knowledge and expertise than currently is being used, due to the scarce research on the topic in the Netherlands. It helps to insert greater reflexivity in systems of governance which is a precondition for sustainability mobility.

Consequently, the main scholars on transition management (Kemp & Loorbach, 2005; Geels, 2011; also Loorbach & Rotmans, 2010) have not sufficiently addressed the reasons behind sustainable mobility problems and even though some researchers have pointed out that actors (e.g. government, NGOs, market parties) are of primary importance for reaching an acceptable implementation of sustainable mobility in society, more information is needed on what guides the focus of these relevant actors. For instance, subsidies for fossil fuels have not been fully transparent and phased out, whereas the country falls behind the targets for renewable energy set by the Dutch Government and the EU. In this context, the rationale behind the so far impending factors will be the focus of this research, by studying the niche-regime interactions between fossil fuels and hydrogen in the Netherlands.

In fact, while most researchers agree that hydrogen development for mobility in the Netherlands is at a standstill due to a lack of infrastructure, storage technology, reasonable costs etc., additional knowledge is required not only in terms of the regulatory aspects that are currently blocking this important development, but also on the basis for encouraging hydrogen for sustainable mobility in the country (Farla, Alkemade, & Suurs, 2010; Ehret, 2019; Rene & Fields, 2013). For instance, on what grounds are subsidizing processes for alternative drive systems founded, especially the hydrogen fuel cell vehicle. As the hydrogen FCV technology emerged more rapidly in the last years, subsidies for its growth are obviously required within private and public stakeholders (Rodriguez, 2017).

2.3 Research Questions

Based on the literature review performed in the previous section, and the scientific gaps that have been identified the study now proceeds to define the research questions. The main research question of the thesis is identified as: What are the barriers in the development of hydrogen in the transition process towards sustainable mobility in the Netherlands?

To answer this question, several sub-questions have been formulated:

1. What is the current development of hydrogen and the FCV in the Netherlands?
2. Which technical and non-technical aspects hinder or facilitate the further development of hydrogen and FCV in the Netherlands?
3. Which actions/initiatives of stakeholders could facilitate the replacement of the fossil fuel regime in car based mobility by hydrogen and FCV?

These questions will be answered with the help of the MLP and the transition management framework explained above.

2.4 Key Concepts

During the course of research, a number of key concepts can be distinguished. Their use is repetitive and important for the research, hence, this section of the thesis provides an explanation of the most important, as follows:

- **Energy Transition** – the process of long-term overhauling of the structure of the current energy system into an eco-friendlier and sustainable direction
- **Sustainable Mobility** - a policy for developing and managing local areas and cities that supports practical, low pollution, environmentally friendly mobility, as well as the living environment
- **Niche –** element of the MLP on socio-technical changes, where innovations are developed and from where they can grow and replace regime practices
- **Regime –** part of the MLP, which serves as the dominant position in an area of life, often blocking new ideas and thus it is usually expressed negatively in research.
- **Landscape –** oversight function in the MLP, the background of niches and regimes. Also, inserting pressure upon the regime to change.

- **Fuel-Cell Vehicle (FCV)** – vehicles that work by converting the chemical energy from a “fuel” into electricity through a chemical reaction. The most common fuel for fuel cells is hydrogen, using oxygen as the oxidizing agent
- **Internal Combustion Engine (ICE)** - is a heat engine where the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit. The hydrogen internal combustion engine (ICE) is still being considered most notably by BMW and Mazda, as it is a less costly alternative to fuel cells.

Chapter 3: Methodology

This chapter explains the methodology of the research in more detail and describes the collected data that is used for the analysis.

3.1 Methods

As already mentioned above, more than one method is used in the research. It involves the use of multiple methodologies, where in this research more than one type of qualitative data collection procedure is used – desk research (scientific literature, governmental documents) along with empirical research (gathering data via interviews and observations). The choice of this approach rests on the idea that, when using multiple methods and data collection procedures, the researcher has the possibility to obtain a more complete picture of the situation being investigated, particularly when researching areas are politically sensitive, such as sustainable mobility, the energy transition, and the development of the hydrogen fuel cell. In other words, triangulation could enhance the validity of research through the use of these multiple methodological resources, namely: diverse methods (interviews and desk research), multiple data sources, and different data analysis techniques (inductive and deductive approaches) – and could also serve as a check on biases and inaccuracies that any one data source, method, or analysis protocol may have.

In this line of reasoning, the first approach used in the thesis is desk research. Its application in the thesis concerns the secondary data which was gained aside from the interviews. Thus, it is beneficial not only in terms of online research due to the vast sources of research already carried on hydrogen and sustainable mobility in the Netherlands (i.e. available in the online library of the University of Twente), but also with the focus on government published data related to social and economic aspects of hydrogen. In addition, desk research was employed for a time-saving purpose (e.g. provided access to more data) and to eliminate the inevitable bias of the interviewed parties.

The second approach in the thesis relies on own data collection, based on three semi-structured interviews conducted as complementing part for objective results, and aiming to gather an in-depth information about the hydrogen fuel cell. Semi-structured interviews, are similar to structured interviews as they also hold an outline of questions and topics, however, they lack the rigid adherence of structured interviews. The purpose of using the interview method for the empirical part of this thesis is to fill data constraints of desk research.

3.2 Interviewed Parties

The empirical research has at its foundation three interviewed parties, conducted as follows:

1. An interview with Prof. Ad van Wijk from the Technical University of Delft – an avid researcher on hydrogen and author of The Green Hydrogen Economy in the Northern Netherlands (Wijk & White, 2017), where his belief is that hydrogen will facilitate the energy transition in terms of chemistry, transportation and electricity. In addition, he is a member of the Northern Netherlands Innovation Board to realize the energy transition.
2. With cH_2ange, the Air Liquide supported subsidiary/initiative, focusing on the role of hydrogen in the energy transition, and also providing detailed information about the fuel cell vehicle and its benefits. Furthermore, the subsidiary has been created on the premise that hydrogen is part of the solution to achieve a post-carbon society. In their vision, hydrogen will change the future of mobility in the Netherlands.
3. With a representative from Forze Hydrogen Electric Team, responsible for the creation of hydrogen race cars. In fact, this is also the first hydrogen electric racing team in the world, created by students from the Technical University of Delft.

Based on the premise that the above-mentioned professionals have a good overview of the field, because they work with a lot of different actors and organisations, they were selected as respondents. The interviews have been carried through an interview schedule with a prepared set of questions, where each participant has been asked fifteen questions (unless previously answered in the interview), available in the appendix section of the thesis. In specific, the nature of the questions was oriented towards social, economic, and technological issues, where they have been formulated according to the focus of research (e.g. to get an insight in which stakeholders these respondents perceive as part of the Dutch mobility regime, landscape, and niche according to the MLP). The interviews were held over the phone (from April to July 2019) due to time constraints of the parties, and lasted on average approximately half an hour. The selection of the respondents is also based on the assumption that they will provide a broad overview and support a coherent analysis of hydrogen in the research, based on their different disciplinary perspectives, thereby providing objective information which will support an answer to the research questions.

3.3 Data Analysis

For the general parts of the research, data is required on: the share of renewable energy in transportation of the Netherlands, GHG emissions, policy agendas and reports about the energy transition process in transportation, targets for the mobility sector in the future. For the niche-regime interaction in the MLP, data is needed on the subsidies for fossil fuels and hydrogen in the Netherlands, as well as number of the cars, refueling stations, and storage technologies. In addition, details for the leading FCV manufacturers (e.g. Toyota, Honda etc.) are also required. The analysis and search for this data in the research is performed through the use of the content analysis approach. It is applicable in determining the presence of certain words or concepts within texts or sets of texts which makes it a suitable approach for research that uses a variety of sources, such as journals, books, interviews, etc. The approach is split into a thematic content analysis for the primary data, and a conceptual analysis for the secondary data.

3.3.1 Primary Data

A thematic content analysis has been performed to analyze the interview data gathered from the participants. This is a technique, used specifically for analyzing interview data. This was achieved through the following techniques (steps): coding the text, searching for themes with broader patterns of meaning, reviewing them to ensure they fit the data, developing an in-depth analysis and choosing a name of each theme, and contextualising the analysis in relation to existing literature. In this research, the data gathered from the interviewees was contextualized with the literature review and the theoretical framework that represents the secondary data collection procedure.

3.3.2 Secondary Data

In the case of this thesis a research framework has been outlined that has at its base the theory of transition management, where the multi-level perspective and the TM activity clusters has been utilized in order to lay a foundation of the secondary data analysis. The framework is followed by an in-depth literature review of the areas of interest was conducted examining the previous and current work of experts in the field of hydrogen, sustainable mobility, and transition management. Throughout the literature review other researchers on this topic were identified, that have conducted related studies (e.g. Transition management theorists - Loorbach, Kemp, Avelino).

As part of the desk research, a conceptual analysis has been performed, based on journals, books, papers, and articles that have been reviewed in the thesis. This was initiated by the use of keywords, such as: energy transition, transition management, sustainable mobility, hydrogen, FCV etc. For example, the journals were identified based on a check of their purpose section/page, which defined whether the journal prioritizes similar research interests.

For instance, the International Journal of Hydrogen Energy has a similar scope and aim to this research, because it aims to provide a ground for exchange and dissemination of ideas, technology developments and scientific results in the area of hydrogen energy between scientists and engineers throughout the world, and elaborates on the obstacles towards creating an integrated energy infrastructure in the Netherlands. Another important journal example used for the research, is the Environmental Innovation and Societal Transitions journal, which offers a platform for reporting studies of innovations and socio-economic transitions to enhance an environmentally sustainable economy, thereby solving structural resource scarcity and environmental problems, notably related to fossil energy use and climate change. In addition, the use of Current Opinion journal which expresses the views of experts on current advances in environmental sustainability, and offers authoritative, systematic synthesis of emerging and hot topics.

3.4 Operationalization of the Concepts

Table 1. Key concepts and their operationalization

Research Interest	**Concept**	**Operationalization**
Barriers towards hydrogen for sustainable mobility in the Netherlands	Energy Transition	Share of renewable energy in transportation in the Netherlands. Also, measures that the stakeholders/actors undertake towards the promotion of the hydrogen fuel cell vehicle
	Sustainable Mobility	Targets for renewable energy in transportation, in the context of zero-emissions driving. Electric driving is the short-term decision, hydrogen – the long-term
	Niche	The current stage of development of hydrogen for sustainable mobility. Experiment/Innovation
	Regime	The opposite of hydrogen for car-based mobility – fossil fuels and their dominant position
	Landscape	Institutions, setting the targets for mobility in the future, controlling the niche-regime interaction process, actors that have influence on the development of hydrogen and the FCV.
	Infrastructure	Number of hydrogen refueling stations in the Netherlands
	Storage	Technologies for storing hydrogen
	Fuel Cell Vehicle (FCV)	Desired technology in the future of sustainable mobility – runs on hydrogen.
	Internal Combustion Engine (ICE)	Currently dominating technology in mobility – runs on fossil fuels

3.5 Research Limitations

The purpose of this section is to frame the limitations of the methods of research and data collection. In this regard, some the most important downsides of desk research in the thesis included: the lack of sufficient information on the regulation and implementation of hydrogen fuel in the Netherlands, as well as the non-specific data on the share of FCVs in the Netherlands and the social attitude towards them. This method also led to the research objective and the set of research questions being dependent on the material found. Consequently, the research objective and the set of research questions had to be adjusted.

As regards to the structured interview method, its flexibility could be questioned as it does not deviate substantially from the interview structure. In addition, interviewee bias on certain topics, or suggested solutions to the issues under question, is another limitation. Because ensuring access to parties with strong expertise for interviews can be difficult, the study has remained with relatively small numbers of respondents. Indeed, some published studies relied on as few as three or four elite respondents, as it is in this study. Nevertheless, there are other parties that could have supported the elaboration and accuracy of this research, for example: Hydrogen Europe (European Hydrogen and Fuel Cell Association); Hydrogen Mobility Europe (project of pan-European network of hydrogen refuelling stations), which could have provided more accurate information on the development of infrastructure; Lagerwey (Dutch wind turbine manufacturer that produced the hydrogen wind turbine, which incorporates electrolysis), however they refused to take part.

Chapter 4: Sustainable Hydrogen Mobility in the Netherlands

This chapter elaborates on the current status of hydrogen and the FCV in the Netherlands, as well as the technical and non-technical barriers that hinder or facilitate its further implementation. It contrasts this development with fossil fuels in car based mobility, thus outlining the relevant stakeholders and their actions in support of the future expansion of hydrogen and the FCV technology.

4.1 Path to Sustainable Mobility in the Netherlands

The road towards sustainable mobility in the Netherlands requires that a wide range of objectives are met. In practice, this means a transport system that has zero or minimal impact on the environment and which has no – or minimal – adverse social and economic impacts, while at the same time meeting social needs and supporting a sustainable economy. This encompasses many different elements, but above all, it requires a change in perspective with regards to the energy source used. In this line of reasoning, the Dutch mobility and transport sector still functions on fossil fuels, whereas the share of renewable energy in mobility (fig. 4) has remain stagnant, despite the 10% targets of the EU for 2020 (Eurostat, 2019).

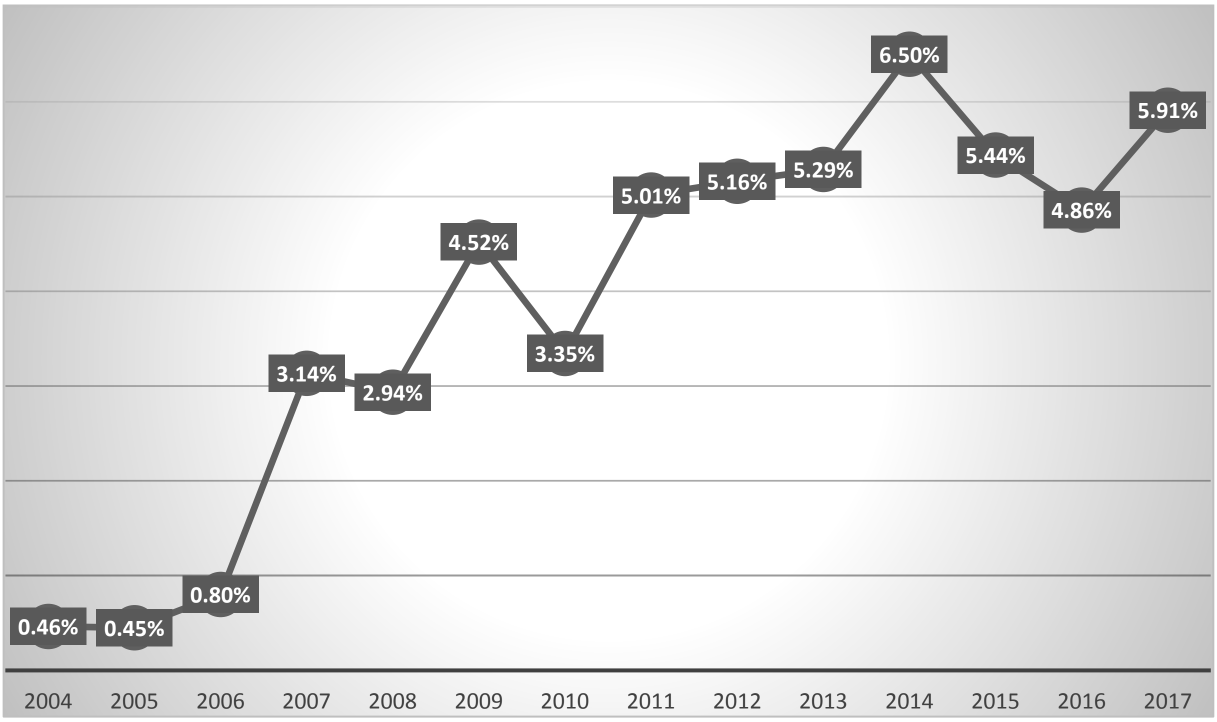

Figure 4. Share (in %) of renewable energy in transportation in the Netherlands 2004-2017 (Eurostat, 2019)

By the time great progress has been made in making vehicles more fuel-efficient and as a result air quality in terms of nitrogen and particulates has improved, however, the demand for transport has grown and with it CO_2 emissions, whereas these improvements have had almost no contribution to the climate task (European Environment Agency, 2018). Therefore, the replacement of fossil fuel cars seems inevitable and much needed, and alternative drive niches that have recently emerged, have the opportunity to reform car based mobility towards a more sustainable direction (Gigler & Weeda, 2018). Logically, a first step in the process of cutting CO_2 emissions, is as far as possible choosing the means of transport that has the least or no CO_2 emissions. Consequently, the aim must be to increase zero-emission vehicles. It is assumed that a vehicle remains on the roads of the Netherlands for fifteen years, and therefore, the target is to have all new vehicles that are sold to run emission-free by 2035, which will fulfill the aim of the Energy Agenda to have all vehicles without emissions on the Dutch roads by 2050 (Ministry of Economic Affairs of the Netherlands, 2017). In that regard, the Netherlands could set its focus on hydrogen not only for mobility but also for developing a hydrogen economy (Simon, 2019).

4.2 Current position of hydrogen and the FCV in the Netherlands

The first fuel cell electric vehicles are already on the roads in the Netherlands, with the first taxi fleet running entirely on hydrogen - the thirty-five Toyota Mirai vehicles represent the aim of the municipality of The Hague to achieve zero-emission transport (Randall, 2019). In this line of reasoning, the fuel cell technology and hydrogen are expected to gain further significance in the Netherlands not only because of the ability to provide entirely emission-free driving in comparison to the traditional fossil fuel combustion engines, but also will diversify the fuel mix and thus increase the energy security. The main advantage of hydrogen-based FCVs is the fact that they are able to cover longer distances than the other sustainable fuel-based technologies which makes them suitable for car-based mobility, especially in the Netherlands which is a relatively small country and thus less refueling stations will be needed to create an infrastructure (Interview, Ad van Wijk, Appendix section 2.1). In that regard, the building of hydrogen refueling stations has been gradually becoming the focus of the Dutch government, whereas if hydrogen is produced and distributed on a large scale in the Netherlands as an industrial gas, it can serve as well for storage and buffer of renewable energy (Government of the Netherlands, 2013). However, as part of the national and international energy system, hydrogen has yet to receive the levels of attention that have been paid to oil & gas, particularly in the Netherlands, where the creation of a hydrogen market, its regulation, and social awareness, is thus expected to play a crucial role in securing the successful development of hydrogen mobility (Honore, 2017).

In accordance with the MLP on socio-technical changes, hydrogen could be depicted as a newly-emerging niche in the Netherlands, which aims to support the transition of the mobility system in the country in the long-term as opposed to the dominant car-based fossil fuel regime. Moreover, it fulfills the niche requirements to bring a technology to induce social change – the fuel cell vehicle, offering zero tailpipe emissions and approximately the same range with a similar refill time, therefore the hydrogen niche could therefore be beneficial to both, the environment and society, by reducing the CO_2 emission stress caused by the dominant fossil fuel regime (Interview, ch2ange, Appendix section 2.2). Structurally, features such as hydrogen infrastructure and the cost of producing, storing, and transporting hydrogen, are key notions consolidating hydrogen as a niche. For the fuel cell technology and its design to become dominant, they are yet to become a so-called market niche. From there on, the hydrogen FCV will have the opportunity to compete successfully with the car-based mobility regime of fossil fuels, only if large-scale hydrogen production is realized to lower hydrogen production costs of €2-3 per kilogram, which is more or less what present fossil fuel prices in mobility are (Interview, Ad van Wijk Appendix section 2.1). However, the emerging markets for hydrogen in car-based mobility and grid balancing can by no means absorb this hydrogen volume at the current stage of development, therefore it is important to invest in transportation facilities.

Based on Loorbach (2013), niches (transition experiments) are aimed at learning, cost reduction and the gradual build-up of a technology-specific innovation system, where technologies can be in specific phases of development, and transition management identifies a pre-development, take-off, acceleration and stabilization phase (fig. 5). In each phase, there are separate obstacles that have to be overcome before reaching the next phase, thus it is important to identify the specific development phase for the hydrogen niche to understand the barriers that will be encountered (more detail on the obstacles is presented in the next two chapters). According this classification, hydrogen could be placed in the take-off stage in the Netherlands, as vehicles have emerged and infrastructure is being built.

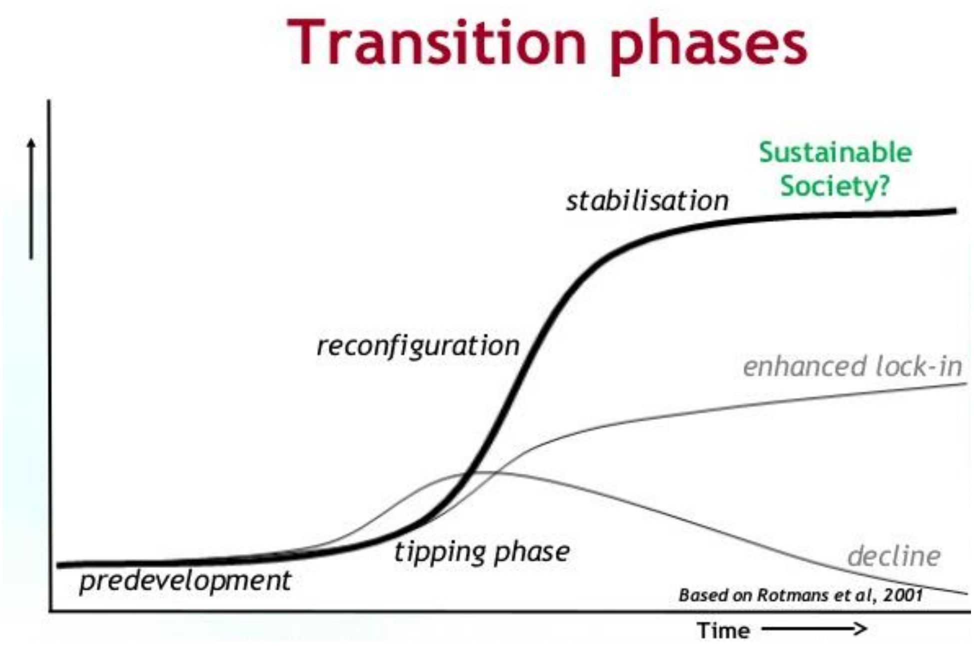

Figure 5. Phases of transition management (Loorbach, 2013)

In contrast, the current car-based mobility system in the Netherlands is stabilized by the alignments between technologies, policies, user patterns, infrastructures, and cultural discourses that have been already established in the past, where system elements are reproduced, maintained and incrementally improved by incumbent actors, such as: firms, engineers, users, policy-makers and regulators, and special-interest groups, whose perceptions and actions of these are shaped by entrenched shared rules and institutions, which Geels (2002) defined as socio-technical regime. In other words, fossil fuels are at the center of the contemporary Dutch mobility system, and could thus be thought of as the dominant regime. They have a stable position and can be regarded as “vested” in the regime, due to the alignment of regulations by the Dutch state and international organizations (e.g. EU), policies and infrastructures, as opposed to the fuel cell which as an evolving hydrogen technology is still lacking such enforcement features (Moreto & Nrel, 2017). The share of renewable energy in transportation (see figure 4) supports the argument that biofuels are still a novelty concerning their application in the mobility sector of the Netherlands, with approx. 6% share in 2017 (Eurostat, 2019).

In that regard, interactions of and development between the incumbent socio-technical regime and niche innovations, are influenced by the wider context or the socio-technical landscape (Geels, 2002). Geels characterizes this element of the MLP by the external and social context that enable and constrain the possibilities for regime change, including structural socio-economic, demographic, political and international developments, also including environmental disasters. In that sense, the landscape for sustainable car-based mobility and the large implementation of hydrogen in the Netherlands, is formed by several factors – the priorities, regulations, and laws of the Dutch Government, the society’s position, the targets and directives on climate change and renewable energy of the EU, the FCV manufacturing automakers, and the support of international banks. Consequently, the landscape will be changed through co-evolutionary processes, which would later stimulate self-organization. Afterwards, the changes in these processes will form pressure to the regime and push it to change. An example of this characteristic of the landscape, are the targets for renewable energy in transportation (as share of total energy consumption) of the European Union, which create space for the development of sustainable mobility and the hydrogen FCV in the Netherlands. In addition, the Paris Agreement on climate change (which was also signed by the Netherlands) indicated that countries need to work on reducing the GHG emissions, where road transportation is responsible for approximately 20% of these in the Netherlands during the past decade (EEA, 2013; see also Gigler & Weeda, 2018). Internally, the only relevant target for renewable energy in the Netherlands was set by the Energy Agreement for Sustainable Growth, framed by the government with the support of employers, trade unions, environmental organisations and others, and contains provisions on energy conservation, as well as increasing energy from renewable sources (Government of the Netherlands, 2013). The government regards this agreement as a major step towards a fully sustainable energy supply, which is key in switching from oil & gas to hydrogen in transportation. Therefore, the role of the landscape (background processes, policies, targets etc.) is important in the scenario of hydrogen mobility in the Netherlands.

4.3 Technical Aspects in the Development of Hydrogen and the FCV in the Netherlands

In recent years, the Netherlands has stated its ambition to be a hydrogen leader and to utilize the FCV in an attempt to reduce CO_2 and GHG emissions (Ministry of Economic Affairs of the Netherlands, 2017). Over the past two decades the use of hydrogen and the development of the FCV have seen more and more implementations (Randall, 2019). Moreover, substantial technological obstacles such as: the range of the vehicles, the weight and size, and even bringing the FCV into existence, have been to a larger extent resolved with the innovation of the technology. In particular, the fuel cell technology has progressed significantly and production costs have been reduced by more than half in less than a decade; FCV's need five times less platinum than ten years ago (it is expected to decline further), whereas 95% of the vehicle can be recycled; fuel cell durability has multiplied fourfold since 2006, and fuel cells can now be used for more than 190 000 km; between the years 2006 and 2015, the size of fuel cells has shrunk by 33%, which according to cH_2ange will allow constructors to fit the system into the engine compartment (Interview, cH_2ange, Appendix section 2.2). Similar results were reported from the National Renewable Energy Laboratory in an evaluation report, containing data from six original equipment manufacturers GM, Mercedes-Benz, Hyundai, Nissan, Toyota, and Honda and 55 vehicles (22 are retired as of June 2015) with nearly 2.9 million miles traveled and nearly 96,000 fuel cell operation hours; the project claims that that fuel cell durability has steadily and significantly improved over the last decade (Kurz et al., 2019). The report further claims that FCEVs have made steady progress towards the Multi-Year Research, Development, and Demonstration Plan (MYRD&D) of the United States Department of Energy (US DOE) 2020 target of 5,000 hours with less than 10% loss of performance (with an ultimate target of 8,000 hours at 10% loss of performance); this performance loss is characterized by the point at which 10% voltage degradation occurs when a new fuel cell stack enters service, fuel cell power systems must be equivalently durable and reliable to compete with internal combustion engines; therefore, a target of 5,000 hours has been chosen as it is equivalent to approximately 150,000 miles of conventional vehicle driving range.

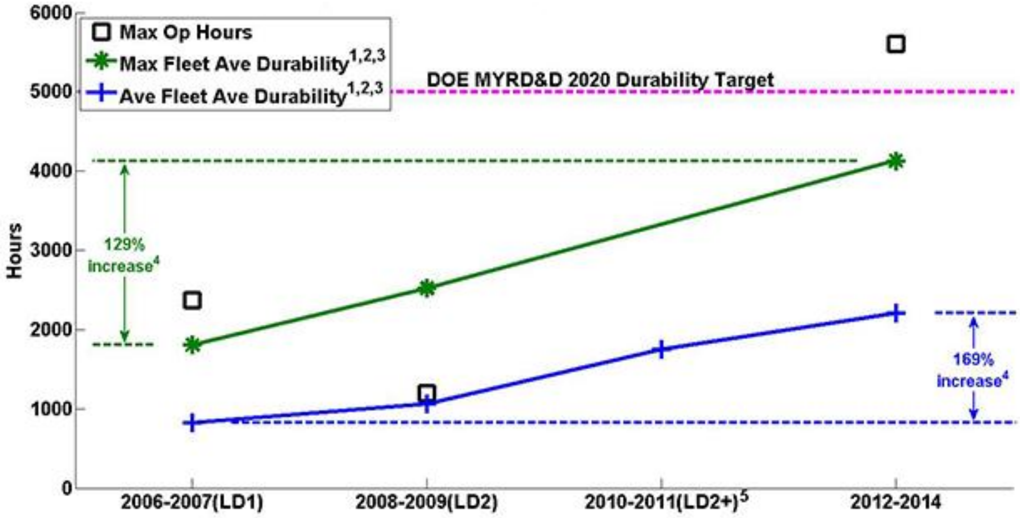

Figure 6. Fuel cell vehicle durability improvement for the period 2006-2014 (Kurtz et al., 2019)

On the other hand, Farla, Alkemade & Suurs (2010) have outlined part of the barriers towards sustainable hydrogen mobility in the Netherlands which still need to be tackled. Their research, also in line with transition management, claims that hydrogen and the FCV have in front have several technological barriers. For the most part, they attribute these obstacles to the fuel cell itself (cost reduction and lifetime increase), and to hydrogen storage solutions (cost reduction and energy density of storage). As regards to hydrogen storage and distribution their research identifies that, more knowledge is also demanded with respect to safety issues and user acceptance.

In fact, fuel cell vehicles have higher capital and operating cost than their alternatives (battery-electric vehicles, internal combustion engine vehicles and hybrid vehicles) today that could be attributed to the small manufacturing volumes of car producers, and the sales that have been realized, which drives up the cost of the dominant fuel cell systems in cars (proton exchange membranes - PEMs), where these costs are also based on the expensive parts from which they are built (Elnozahy et al., 2014). For instance, platinum is by far the most effective element used for PEM fuel cell catalysts, and nearly all current PEM fuel cells use platinum particles on porous carbon supports to catalyze both hydrogen oxidation and oxygen reduction. However, due to their high cost, current Pt/C catalysts are not feasible for commercialization (Manoharan et al., 2019). Decreasing the size of the platinum catalyst and alternative processing is necessary to maximize surface area and minimize loading (Wilson, Kleen & Papageorgopoulos, 2017). Nevertheless, it is expected that the development of the hydrogen market niche in the upcoming years will alleviate these costs and support the improvement of the PEMFC technology, in order to challenge the dominant position of ICE cars in the Netherlands (fig. 7).

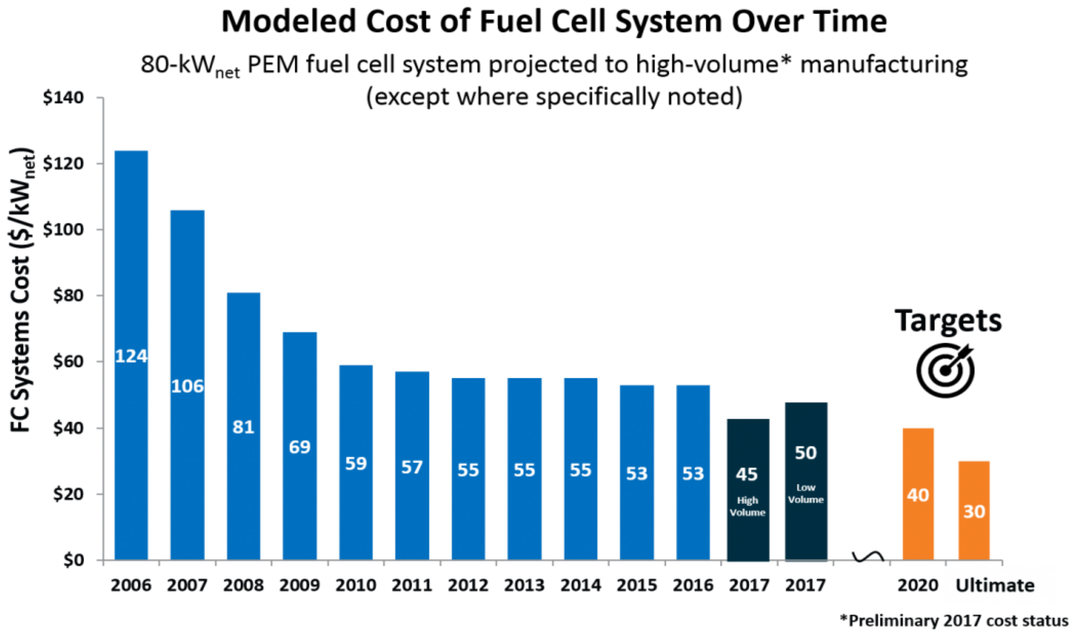

Figure 7. PEMFC cost projection (Wilson, Kleen & Papageorgopoulos, 2017)

In addition, hydrogen storage is the one of the most important research issues in the development of FCVs, and hydrogen storage systems are under development to introduce new methods to meet the needs of customers. Due to hydrogen’s low energy density, it is difficult to store enough on-board a vehicle to obtain adequate driving-range without the storage container being too large or too heavy; the most favorable method of hydrogen storage is physical containment, specifically in compressed tanks, because they are readily available, where all composites (Type IV) are primarily used, and sometimes metal lined composites (Type III) are used; the fill time of these tanks is competitive with fossil fuels when the hydrogen is cooled in advance (Manoharan et al., 2019). Cost is the main setback for the wide scale use of compressed hydrogen (CH_2) tanks, because the material and the assembly are expensive (Dagdougui et al., 2018).

In order to enable the further development of the hydrogen fuel cell technology in the Netherlands, the most important obstacle is an all-encompassing hydrogen infrastructure which has to be built. This technological aspect has been suggested also by fossil fuel regime representatives in the Netherlands, stating that the sense of urgency in social and environmental dimensions for a sustainable mobility hydrogen transition is often not fully matched by the technical opportunities to support such development. The association for oil and gas exploration and production companies in the Netherlands (NOGEPA), together with EBN (the state-owned company that by law participates in all upstream oil and gas projects in the Netherlands) and KVGN (Royal Association of Gas Companies in the Netherlands), stated in their strategy in 2016 that fossil fuels will continue to be used when there are no sustainable alternatives (KVGN, 2016).

In this line of reasoning, a study carried out by two companies (Tennet & Gasunie, 2019) outlines the necessity to build up a network of hydrogen fuel stations, where a hydrogen distribution system is identified as a barrier in this transition path. This view has also been supported and elaborated further by Wijk & White (2017) in their paper called "The Green Hydrogen Economy in the Northern Netherlands". They argue that during the initial phases of establishing a hydrogen fueling network, building large-scale stations throughout the region with a low degree of market saturation of hydrogen fuel cell cars lacks economic rationality, whereas at the same time, car owners do not want to drive too far to refuel. In order to avoid such situation, they have suggested the use of medium-scale HRS containers, which can rapidly enlarge the network filling points at a fraction of the cost. In that regard, they claim that once a local area (Emmen, Sneek, Veendam, etc.) has sufficient number of cars to justify a large-scale station, the medium container unit can be transferred to another location and, in this way, extend the network; once the entire network has been developed, the medium scale units can be shipped to a final destination elsewhere. That being the case, initial capital expenditures are limited and start-up of the hydrogen fueling network is faster. Similar conclusion was reached by Smit, Weeda & Degroot (2007), where they assumed that a hydrogen pipeline infrastructure will start to evolve if the large-scale centralized system can supply hydrogen at lower cost than the system with small-scale on-site production.

4.4 Non-Technical Features of Dutch Hydrogen-Based Mobility

Based on the above, the development of a hydrogen infrastructure has remained the most important feature of the hydrogen niche, and in that sense, an important barrier to the widespread uptake of hydrogen and the FCV. There is, however, also a perception that an all-encompassing hydrogen mobility must be established with enormous cost and duplication of existing energy infrastructure. In line of this perception, Staffell et al. (2019) points out that the Netherlands and Germany have the highest legal limits for hydrogen blending (using the existing gas pipeline infrastructure), approximately 10-12% by volume, in comparison to the US and UK, having 0-0.1% (fig. 8). As a result, there are only a few refueling stations for hydrogen fuel in the Netherlands, because of the high cost to build such infrastructure and the legal requirements to do so. Consequently, the largest car manufacturers will not prioritize their hydrogen models for the Netherlands also because of the lack of incentives which this market offers at the current setting.

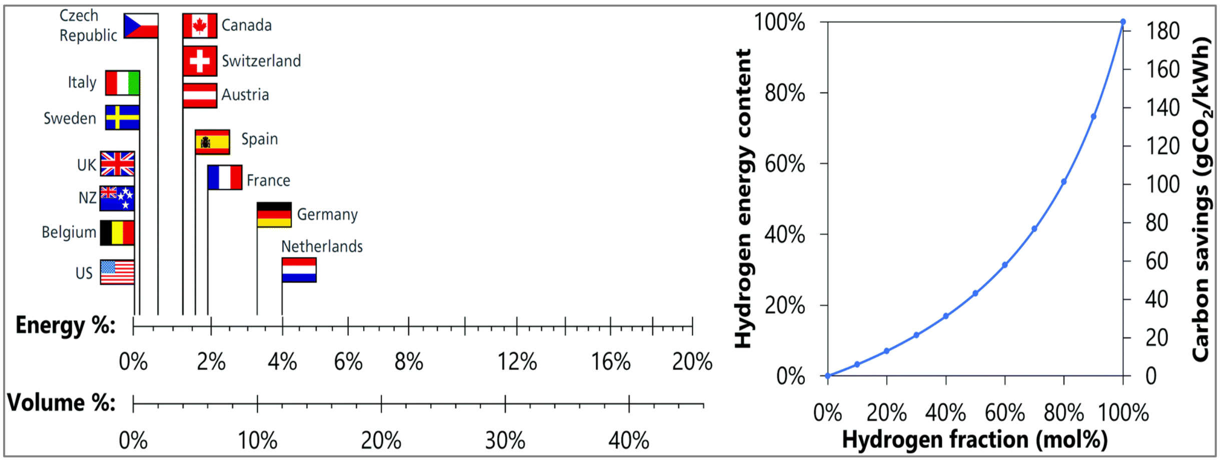

Figure 8. Constraints on hydrogen blending into national gas pipelines over the world (left); and (on the right) the relationship between energy content, carbon savings and hydrogen injection mixtures (Staffell et al., 2019).

The implementation of hydrogen in the mobility sector and development of the FCV depends not only on the investments and public support to cover the financial gap compared to the alternative fossil fuel regime, but also on the use of the right mix of instruments, background developments, and the involvement of a wide range of actors (Northern Netherlands Alliance, 2019). First of all, national and international policy developments have an important role. Policy and regulation can support the implementation of this plan in the following areas: inclusion of hydrogen production in an SDE+ type of scheme (subsidy for financial gap of renewable energy), as from what it has become aparent above there will be a financial gap for hydrogen production in the coming years. At this moment, companies are not able cover the full financial gap as green hydrogen related investments up to 2030 will be between 5.5 and 10 billion euros only in the Northern Netherlands, but this can be quickly reduced by investing on a large scale (Interview, Ad van Wijk, Appendix section 2.1). Therefore, support is needed to cover the operational costs of hydrogen production and distribution, where a subsidy for the financial gap seems the most appropriate for this purpose. Consideration of the whole value chain instead of individual parts in the granting of aid, as well as clarification of the different functions of hydrogen in regulation (e.g. storage medium, transport, production/conversion, renewable fuel or feedstock) are also required. For example, the creation of an appropriate legal framework for hydrogen. In this line of argumentation, an unambiguous certification framework for emission-free hydrogen, for example by implementing CertifHy, the European certification system for green hydrogen (Vanhoudt, 2019), and in this context setting up new instruments to stimulate the demand for hydrogen. The Netherlands could choose to promote the use of hydrogen in mobility through a legal framework, for example in the implementation of the Renewable Energy Directive II (RED II). Member States have discretionary freedom in implementing this Directive. (Detailed perspective on the propositions for the development of hydrogen and the FCV in the mobility sector are available in the next sub-chapter).

Alternatively, an external event could prevent the further development of hydrogen. For instance, because of the rising electrification of the society and closure of nuclear power plants and coal within a decade, demand for electricity could increase by 2050 (Vink, 2017). In contrast, growth in renewable sources would not realistically be able to meet this potentially increasing demand. Unless a breakthrough in energy technology is achieved, another source of power production is required in order to balance the grid when the solar and wind energy cannot (Beckman & van den Beukel, 2019). Natural gas is the only relatively clean source with a high energy density able to be stored and transported over long distances (KVGN, 2016). Although this may not have a direct relation on hydrogen and the fuel cell vehicle in particular, investments may need to be oriented towards another energy source direction, which will inevitably shift the focus away from hydrogen in the Dutch economy.

4.5 Evaluating Sustainable Hydrogen Mobility in the Netherlands

This section of the chapter has the purpose to provide an in-depth information on the actors, their agendas and actions, as well as the issues towards evolution of the hydrogen for car-based mobility, through the lens of the transition management framework. It is the operational approach of the MLP.

4.5.1 Problem Structuring, Envisioning, and Actors in Dutch Hydrogen Mobility:

The current transportation system of the Netherlands is unsustainable - a drastic reduction in greenhouse gas emissions is required in the short term to be able to mitigate global warming and climate change. Large fraction of the GHGs and CO_2 emissions stem from car-based mobility, where the energy-supply has to change significantly (Ministry of Economic Affairs of the Netherlands, 2019). Energy supplies in the Netherlands are currently based on natural gas, oil, and coal (Vink, 2017). The natural gas is mainly extracted from the gas fields in the north of the country, and oil and coal are mostly imported; in terms of use, natural gas has applications in the industry and for the production of heat and electricity (power plants and domestic use); Coal is dedicated to large-scale electricity production, wheras oil is refined to produce transport fuels and base chemicals for the chemical industry, and a substantial part of the refined and chemical products are exported (KVGN, 2016).

The problem, however, is that fossil fuels are causing environmental damage in mobility through the emissions mentioned above. Therefore, zero-emission solutions are required and the most suitable choice for this is hydrogen because its production and use could be entirely emission-free in comparison to the production of hybrid and battery-electric vehicles (Interviews, Ad van Wijk, Appendix section 2.1; cH_2ange, Appendix section 2.2; Forze Team Delft, Appendix section 2.3).

In mobility, hydrogen could be presented as a valuable addition to the electric vehicle. Instead of a battery, which causes some environmental damage when produced, the hydrogen fuel cell vehicle is powered through a chemical process which fuels the electric motor of the car. The efficiency of the fuel conversion is about two to three times higher than a conventional combustion engine, whereas it emits zero-emissions. (Forze Hydrogen Racing Team, 5 April 2019). The complexity of hydrogen implementation in the Netherlands lies in the timely development and wide availability of the FCV, as well as major investment in areas such as production and infrastructure and an on-going assessment of the spatial effects – fuel cell vehicles are maturing at a steady pace. Although the initial hype of hydrogen in the Netherlands has passed, hydrogen mobility became relevant again, after the introduction of the first vehicles five years ago. The transition to a low-carbon hydrogen energy supply in mobility requires substantial effort from the general public, businesses and public authorities. In other words, involvement of a wide-range of actors is necessary in order to create a transition path for hydrogen based mobility - robust arrangements and reliability regarding supply security will be essential topics in project designs (Gigler and Weeda, 2018), where industrial hydrogen producers and system integrators, and companies with no stake in the current energy infrastructure will be important, and such will be the role of the Dutch natural gas industry that cannot be neglected (e.g. the local reforming of natural gas into hydrogen and/or adding hydrogen to gas pipelines depends on their network and cooperation). In this line of reasoning, among the most important actors (but not limited to) in transportation are:

- The Government of the Netherlands
- Local Authorities – DutchHy (initiated by the local authorities in Amsterdam, Rotterdam and Arnhem, and aiming to accelerate the market introduction of hydrogen and fuel cells, both in transport and stationary applications)
- The Dutch Gas Industry – NOGEPA (Netherlands Oil and Gas Exploration and Production Association), IRO (The Association of Dutch Suppliers in the Oil and Gas Industry and Offshore Renewable Industry)
- European Union
- International cooperation – seek finance through World Bank, EIB (European Investment Bank), FMO (Entrepreneurial Development Bank), and cooperation from forums such as: IEA (International Energy Agency), IRENA (International Renewable Energy Agency) and the Energy Charter
- Hydrogen and FCV initiatives – e.g. WasserstofNet, NWBA (National Hydrogen and Fuel Cell Association), H_2 Platform
- Business Parties in the Netherlands

4.5.2 Agenda Building and Networking

The current plans for the foreseeable energy supply in the Netherlands resolve around the exhaustion of the gas fields and the closure of the coal-fired stations, meanwhile the Dutch Government is steadily orienting the country towards renewable energy, however, with a pace which is far from satisfactory (Vink, 2017). In terms of mobility, the short and medium-term goals set from the Government in the Energy Agenda (Ministry of Infrastructure and Environment, 2017) are:

- a contribution to total energy conservation of 15 to 20 petajoules (PJ) in 2020;
- a reduction to 25 megatonnes (Mt) of CO2 equivalent at most in 2030; compared with 1990 (–17%);
- all newly sold passenger cars capable of zero emissions performance from 2035;

Another document that the Government drafted earlier, is the Energy Agreement signed under the auspices of the Social and Economic Council (SER) in September 2013, in which ambitious Tank-to-Wheel (TTW) objectives were agreed in order to reduce the CO_2 emissions of the mobility and transport sector (Government of the Netherlands, 2013). It is stated as important in the Agreement that, the activities conducted for this purpose should help in reducing Well-to-Wheel (WTW) carbon emissions, and improving factors unrelated to fuel or vehicles, such as behavioural change, logistic efficiency, and better use of infrastructure.

The problem with these agreements is that they have similar or even almost the same goals, meaning that between the Energy Agreement (2013) and the Energy Agenda (2017) little has changed for mobility in the Netherlands. The goals have remained similar and despite both agreements and their targets, the Netherlands lags behind the EU target for 2020 in the share of renewables in mobility (10%), where the country is currently around 6% (Eurostat, 2019). Moreover, the construction of an optimal mobility infrastructure within a few years is not feasible because it requires significant improvements in the road network and public transport system, and it is thus still regarded as the long-term goal by the Ministry of Infrastructure and Water Management (2019) that has advised that it will be working on a mobility system that is user-friendly, however, terms of completion are again unclear. Consequently, one could conclude that the contemporary energy transition efforts from the government might not reach their desired outcome. In that regard, the Netherlands is also still dependent on oil, especially in the transport sector, where it is used as a main fuel. Because the supply is not always guaranteed, the government keeps strategic reserves, which in the long-term have to be utilized and thus slow the development of sustainable hydrogen mobility (Government of the Netherlands, 2019).

With this in mind, the Renewable Energy Directive (RED) has been implemented by the Dutch Decree on Energy in Transport (Ministry of Infrastructure and Environment, 2011). First of all, this law obliges fuel suppliers bringing fuels on the Dutch market to sell a certain share of biofuels on the market based on the energy content, which will increase in the coming years. In 2018, a limit to conventional biofuels and an obligation for advanced biofuels have been introduced, where suppliers of liquid and gaseous biofuels must demonstrate European binding sustainability criteria for the whole biofuel supply chains (biofuel sustainability can be proved by certification through voluntary schemes recognised by the European Commission).

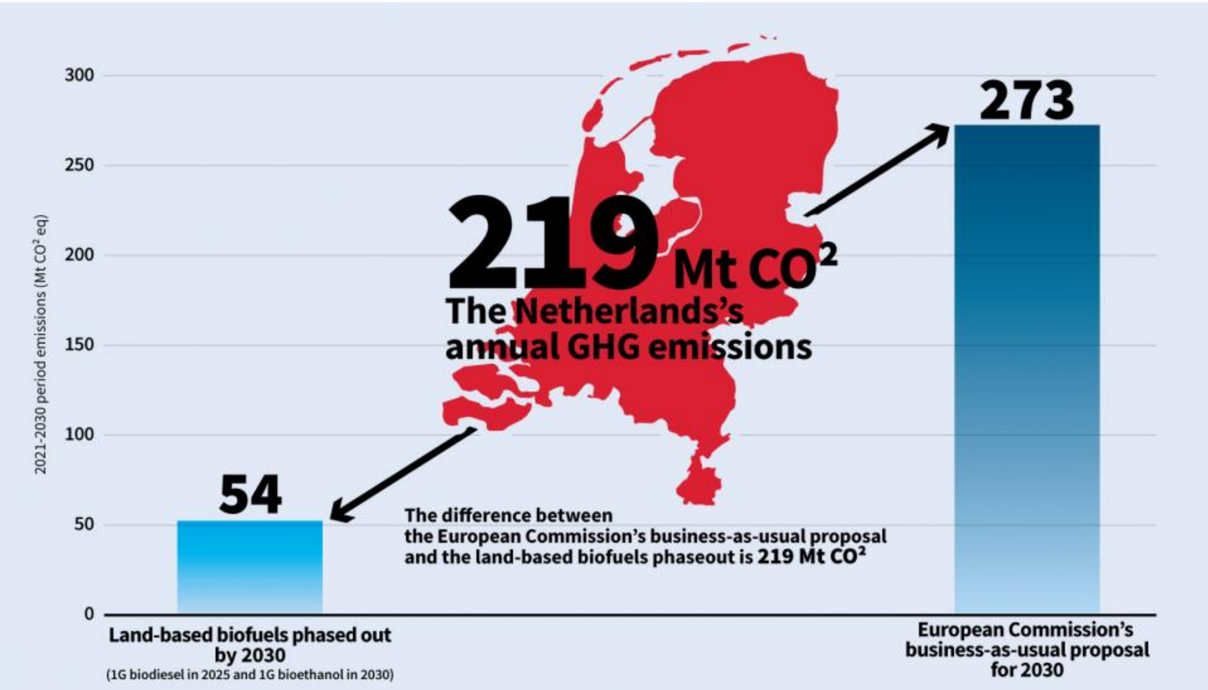

Figure 9. Extra emissions in the EU if land-based biofuels are not phased out by 2030 (Muzi, 2016)

However, by 2030, this decision is likely to impact the EU if these biofuels are not removed in a plausible timeframe. From the chart above, it is visible that the EU will suffer an increase of exactly the same amount of the GHGs that are in the Netherlands. This was concluded in a research carried by Transport & Environment (a campaign group evaluating EU's decisions), where they warned of this trend (Muzi, 2016). The mobility sector in the Netherlands will remain focused on biofuels and renewable gas in the next ten years (RED directive), however, the goal should be to gradually shift the focus towards emission-free vehicles. Based on the short distances in the country, the Netherlands could focus on electric vehicles for short distances, and development regarding the production and distribution of sustainable hydrogen fuel as a long-term solution for long-distance driving (Interview, Ad van Wijk, Appendix section 2.1).

4.5.3 Mobilization and Implementation of Hydrogen and FCV in Mobility

One of the largest FCV and hydrogen projects in the EU is Hydrogen Mobility Europe (Hydrogen Europe: European Hydrogen & Fuel cell Project Database, 2018), a flagship project aiming to give fuel cell vehicle drivers access to the first pan-European network of hydrogen refuelling stations (in nine EU countries including the Netherlands), which is a joint initiative of the EU and the Fuel Cells and Hydrogen Joint Undertaking (public private partnership supporting research, technological development and demonstration activities in fuel cell and hydrogen energy technologies in Europe).

Figure 10. H2ME initiative in Europe – infrastructure corridors (Hydrogen Europe: European Hydrogen & Fuel cell Project Database, 2018)

The first part of the project has started in 2015 and will have a duration of five years (mid - 2020), which is supposed to increase the number of fuel cell vehicles (FCVs) operating on Europe's roads, resulting in the establishment of a pan-European hydrogen fuelling station network. The project is one of the most ambitious coordinated hydrogen deployment projects attempted in Europe so far, with hundreds of FCVs deployed and tens of refueling stations. The second part of the project has started in May 2016 and is built on this expertise. It is supposed to significantly expand the European hydrogen vehicles fleet and by doing so, aims to confirm the technical and commercial readiness of vehicles, fuelling stations and hydrogen production techniques. With its over one thousand vehicles, and twenty hydrogen refueling stations, it will generate recommendations and identify any gaps that may prevent full commercialisation, as well as collating results to support future investments. Overall, the project demonstrates the significant commitment to hydrogen-fuelled road transport as a European solution to the need of having competitive and viable alternatives to fossil fuels.

On a national scale, in July 2017, the Ministry of Economic Affairs and Climate Policy asked TKI Gas to manage the process of setting the framework for hydrogen (Gigler & Weeda, 2018). The H2 Platform (formerly the National Hydrogen Platform), the members of the NWBA (National Hydrogen and Fuel Cell Association), WaserstofNet, and DutchHy, had already been developing hydrogen initiatives and various coordinated activities on a regional level, like in the north of the Netherlands, the Rotterdam region and on Goeree-Overflakkee (Netherlands Enterprise Agency, 2019). In the discussions about the transition pathways of the Energy Agenda, it also became apparent that sustainable and/or climate-neutral hydrogen could play a key role in fulfilling the need for sustainable car-based mobility.

Furthermore, the Dutch provinces of Groningen and Drenthe have created a €2.8 billion plan, thereby positioning among the pioneers in innovative hydrogen solutions, which has been disclosed by Ulco Vermeulen, Director Business Development at Gasunie (Gasunie & TenneT, 2019). The goal of the Dutch initiative is to achieve scale, which is the only solution to reduce the costs of green hydrogen (hydrogen produced from renewable energy), whereas the means to this are an energy expertise and pipeline infrastructure that the Northern Netherlands has built up over many decades thanks to its abundant natural gas resources. Today, the region is firmly focused on emissions-free hydrogen as the next generation of gas. It has a unique combination of experience, space, infrastructure and diversity of demand — from the chemical industry, power generation, logistics and heating, that put it in a strong position to lead a new hydrogen economy (Hydrogen: the Northern Netherlands is ready, 2019).

Moreover, the change is also expected to provide new employment opportunities, as the investment plan lists over thirty concrete projects, predominantly led by one or more companies of the following: Shell, Nuon, Engie, BioMCN (bio-methanol production), Gasunie (the Dutch gas grid operator) and Nouryon (formerly AkzoNobel Speciality Chemicals); they include plans to build small and large-scale electrolysers of 1 megawatt (MW) to ultimately 1 gigawatt (GW), and “hydrogen wind turbines” where an electrolyser is built into the turbine to produce hydrogen rather than power (Netherlands: Groningen, Drenthe and Friesland become a “Hydrogen Valley”, 2019). There are projects (e.g. HyStock) to transform natural gas pipes and create storage sites for both hydrogen and carbon dioxide (the by-product of blue hydrogen production), including hydrogen caverns (the large-scale storage of hydrogen in salt caverns that can then act as gigantic batteries for the power system), and projects promoting hydrogen use to roll out hydrogen fuelling stations, supply a new residential area with hydrogen space heating and (partially) convert the 1.32 GW Magnum power plant at Eemshaven, Groningen, from natural gas to hydrogen (Gasunie & TenneT, 2019).

4.5.4 Evaluating, Monitoring, Learning

The Dutch government has already expressed its support to the Hydrogen Valley project, recognising that it is in line with federal plans for climate action and regional development, also commending the initiative’s cross-sectoral approach and support from public and private stakeholders, education institutions and civil society; the Netherlands has recently backed the Commission for Climate and Energy Security of the EU (in its quest for carbon neutrality for the EU by mid-century), by not signing a recent declaration on Sustainable and Smart Gas Infrastructure for Europe – an initiative from EU Presidency holder Romania – because it did not explicitly reference this goal; the Netherlands also wants Europe to increase its 2030 emissions reduction target from 40% to 55% below 1990 levels (Northern Netherlands Alliance, 2019). According to Miguel Arias Cañete (EU climate and energy commissioner), the project fits with the climate and energy goals of the Netherlands and Europe - hydrogen has a role in the de-carbonization of the energy system, however, the commissioner has expressed his concerns that the share of renewable energy in the Netherlands is worrisome (Hydrogen: the Northern Netherlands is ready, 2019).

In that sense, it is important for the Netherlands to increase its participation in projects similar to H2ME, in order to improve in terms of sustainable hydrogen mobility. The Government of the Netherlands should be reliable and execute its monitoring responsibility, by taking normative, enforcing, or sanctioning actions, if necessary. Furthermore, its capability give direction and set frameworks for further hydrogen projects could alleviate many of the current obstacles. Expressing support and encouraging the involvement of other parties is crucial (as in the Hydrogen Valley project). Another question that is relevant, is how the government, the citizens, businesses and civil society organisations will cooperate inbetween to hydrogen and the FCV in mobility in order to achieve a low-carbon energy supply that is affordable, reliable and safe by 2050. The role of the Dutch gas industry could not be neglected, as it could contribute in the duplication of the existing natural gas infrastructure and thus increase the odds of sooner mainstream hydrogen implementation in the mobility sector of the Netherlands. Similar to other EU countries, a large share of the energy policy in the Netherlands is dictated by European policies and the future of natural gas demand will be led by the idea of transition to a low-CO_2 energy mix. Nevertheless, there is a need to re-define the role of gas in delivering EU's security and decarbonisation objectives. The Netherlands is heading towards a major transition: climate change is one of the main issues in Dutch mobility policies and, as a large producer, natural gas used to have a fairly positive image in the country as a relatively safe, affordable and clean fuel, but the political impact of the earth tremors has been drastic and consideration for the safety and health of the people of Groningen has dramatically changed public opinion about gas (Osborne, 2019). Therefore, the strong desire to be energy-neutral and a swift transition towards electrification of mobility, without fossil fuels, requires a huge effort and important investments.

Chapter 5: Conclusion

The current car-based mobility system in the Netherlands is dominated by fossil fuels, which are stabilized by long-term alignments that have been created in the past, where incumbent actors, such as: firms, engineers, users, policy-makers and regulators, and special-interest groups, have their perceptions and actions shaped by indoctrinated shared rules and beliefs.

Based on the MLP and transition management framework, for the emerging hydrogen niche to compete with the dominant regime of fossil fuels several developments must take place. On one hand, there must be symbiosis between society, government, industry and the relevant stakeholders. This research has thus shown that the involvement of actors is vital in the process of hydrogen implementation. With this in mind, the government should be the leading actor, however, the role of society and the Dutch gas industry are no less important. In addition, the European Union is setting the framework in renewable energy mobility and therefore could be considered as a key factor in promoting the realization of the fuel cell vehicle. As shown in the thesis, hydrogen projects are very costly and therefore financial cooperation from the prominent international banks is crucial. Apart from actor involvement, there are also significant technical and non-technical shortcomings that are currently blocking the development of hydrogen and the FCV in the Netherlands.

First and foremost, hydrogen infrastructure has to be created in order to stimulate car producers to sell their vehicles in the Netherlands, and motivate people to buy these vehicles. In that regard, the successful completion of the Hydrogen Valley project and the increased effort in the H2ME initiative across EU are key, as they are both large infrastructural activities that will also contribute to the further deployment of vehicles. Second, a hydrogen market niche has to be established, along with an increase in production of hydrogen, in order to target the lower oil and gas prices – the Northern Netherlands is part of the answer to these issues, as it already has significant experience with natural gas, whose infrastructure could be duplicated. Third, and in regards to the second, the Netherlands has among the highest blending costs of using the existing gas infrastructure, therefore policy actions are required. In practice, the government provides incentives (the SDE) in the form of feed-in premium allocation for renewable electricity and renewable gas projects. However, the threat of increasing energy demand in the upcoming years could shift the focus to investing into more accessible and affordable energy sources in comparison to the high initial cost of hydrogen. Last but not least, the fuel cell technology and on-board storage of the vehicles have to evolve, not significantly in terms of efficiency but in cost perspective. This is a blocking factor because hydrogen cars will only be competitive if they could travel similar distances for the same or lower cost in comparison to internal combustion fossil fuel cars.

To sum up, the entire way people and goods travel needs to change. Nowadays, mobility has been largely responsible for damaging the environment, and the increasing viability of electric and alternative powertrains is much needed. The path to sustainable hydrogen mobility in the Netherlands has many objectives in front, but above all the future of cars has to be emission-free. Therefore, the emergence of a new ecosystem of hydrogen mobility could offer faster, cheaper, cleaner, safer, more efficient, and more customized travel. Achieving the targets, set out by the Government of the Netherlands in the Energy Agreement and the Energy Agenda, for de-carbonization of mobility whilst simultaneously stimulating green growth, will be a major challenge that requires courage, decisive action, cooperation, consistent strategies, and the willingness to invest. Moreover, increasing the sustainability of an important socio-technical system requires large-scale changes and system innovation. Consequently, if the blocking factors (outlined in this thesis) towards hydrogen mobility are jointly alleviated in the

Netherlands, this novelty is likely to come from the FCV because resources are running out and hydrogen is abundant, provides greater fuel efficiency, is zero-emission, and could be refilled within minutes.

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Appendix

Section 1: Interview Questions

1. What is the perceived potential of hydrogen as a fuel in the transportation sector (for private and industrial use in cars, buses etc.) in the Netherlands?
2. What are the obstacles?
3. What are the most pressing issues with hydrogen?
4. Is hydrogen really the fuel of the future?
5. Fuel cell or internal combustion engine as dominant technology?
6. What are the costs in the Netherlands and is there really an issue with storage, transportation and the infrastructure required as a whole?
7. Are there any subsidies for hydrogen development as a fuel?
8. What are the leading companies, institutions, players on the field?
9. Is it worth over other sustainable fuels (etc. electric cars, engines)?
10. Are people in the Netherlands buying into the idea of having a hydrogen-fueled car?
11. Price against fuel, natural gas?
12. What is the current state-of-the-art technology in regards to hydrogen for transportation?
13. Are there going to be any incentives for people to switch to hydrogen?
14. How will taxes be formed? Are there going to be any at all?
15. Which regions could start first with developing, transporting, selling, organizing mass stations? Rotterdam, Amsterdam, Groningen?

Section 2: Interview Transcriptions

Below are the full transcriptions of the interviews conducted for this research.

2.1 Prof. Ad van Wijk – 10.04.2019

Radi: Good morning, Mr. van Wijk. It's Radi Parlev calling you in regards to our appointment for an interview regarding hydrogen's development as a fuel in the Netherlands. Before we start, I would like to clarify that my research is interested only in the mobile application of hydrogen and not the industrial.

Ad van Wijk: Good morning, sorry that I first ask: What is your position in the University?

Radi: I am a Master's student.

Ad van Wijk: Ok, and you are student in Bulgaria or here?

Radi: I am a Bulgarian student in the University of Twente. The study is based in Leeuwarden.

Ad van Wijk: Oh ok. I saw a Bulgarian number. Regarding hydrogen, the main obstacle for introducing hydrogen as a fuel for mobility is infrastructure, the fueling stations. But you see today, for example, in Germany they are building a consortium of Shell, Total, and the car manufacturers for a hundred hydrogen fueling stations throughout Germany. That means that by 2023 you can drive throughout Germany and fueling your car with hydrogen. And then, of course, 2021-2022 you will see that all these car manufacturers will sell their hydrogen cars on the markets. If there is no infrastructure, you will never sell a car.

Radi: I see.

Ad van Wijk: When you look to the Netherlands, we have a different policy that is to give a subsidy to complete the supplies for a fueling station. What you see today is that everybody can apply also small companies that don't know how to install a fueling station and then you see that we don't have fueling stations throughout the Netherlands. Then you see a concentration of fueling stations around subsidies but then not in places where you need to have fueling stations if you want to travel to them. So I think this is one of the main obstacles in the Netherlands to get really hydrogen cars on the market. Today there are only two stations in the Netherlands and when you look to Germany there are sixty. Therefore, car manufacturers do not deliver their vehicles to the Netherlands. Most of the cars go to Germany, France, California and these areas because there you have some infrastructure.

Radi: I understand, well, you have already answered one of my other questions, about the subsidies, I was about to ask whether there are any subsidies in the Netherlands for hydrogen fuel. But what is your opinion: Is hydrogen really the fuel of the future? Is it going to replace fuel cell cars, or is it seen as an addition to electric cars? What do you think?

Ad van Wijk: You have to see of course that hydrogen is also electric driving. Because what you do you have hydrogen in a fuel cell and drive electric. The only difference is that the electricity is not coming from a battery but from a fuel cell that is fueled by hydrogen. There is not really a difference or a big debate whether people use hydrogen or electricity. It depends on range and type of the car and what you want to use. What you see today is for instance if you have two cars at your house – the one you drive for work will run on hydrogen, whereas the other you drive your kids to school with will be an electric vehicle with batteries. So what you do with your car, how big is your car, is what will determine what type of car people will buy. In the Netherlands, of course, you can also drive with a battery-electric car because of the short distances. When you look to Germany, the distances are much larger – people work in a place that they sometimes live 600 km from that place. Every Sunday evening they go there, and every Thursday they go back. In Germany percentagewise more cars than in the Netherlands. But hydrogen will also be the preferred fuel in the Netherlands.

Radi: Yes, and what do you think – Is the fuel cell the only alternative when it comes to hydrogen because I saw that some companies like BMW also develop an Internal Combustion Engine as a dominant technology?

Ad van Wijk: The fuel cell preferred, although BMW have developed Internal Combustion Engine in 1997, and they have done it for maybe 1-2 years but then they abolished that development because there is a lot of liquid and when you try to get hydrogen in the ICE, plus the efficiency is only 25-30% and the fuel cell have 50-60 and above percentage so that means that you need to take in your care at least two times the amount of hydrogen to drive the same distance. So that is not a solution because of the range. I don't know what you have seen but this is an old development.

Radi: Yes, I came across a paper that lists some companies which have done research in this direction but maybe as you said it is not efficient. But then probably the most important question will be: What is going to be the price of the fuel? Is it going to be really cheaper than driving on petrol?

Ad van Wijk: At first you have to compare the kilometer price. It is not that you compare the same amount of liters or energy content because, as I have already said, if you have a fuel cell with over 50-60% efficiency you need two times less energy to drive a kilometer than when you have an ICE. You have to compare kilometer price. The price of hydrogen could be 10 Euros per kilo, however, that is an artificial price. At the moment, we see that grey hydrogen is produced at 1- 1.50 Euro, green hydrogen 2-3 Euros per kilo. You can go lower that these prices of 10 Euros per kilo. At the end it will not be different if you drive with hydrogen or petrol. We have to compare the real prices. Hydrogen will be competitive because of efficiency.

Radi: I see, and do you think there will be any type of taxes for this type of mobility?

Ad van Wijk: At the moment you see there are no taxes, but in the future you never know. Costs and difference in efficiency will place hydrogen on a break-even or even cheaper position with regards to ICE.

Radi: Ok, and as one of my last questions: Which regions will start first with developing, transporting, organizing, of the first mass stations in the Netherlands? I heard about Amsterdam, Rotterdam, Groningen, but do you think that other places might be involved in the discussion as well?

Ad van Wijk: When you want to organize hydrogen for cars then it is not possible to have a single region. You need infrastructure around the country, otherwise people will not buy the car. The first stations might be in these regions but the whole country must have refueling points.

Radi: Do you think that there are going to be any particular incentives for the people to switch to hydrogen, whether they will buy quickly into the idea of driving a fuel cell vehicle, as you know they have driven long on gasoline? It's a question about the social acceptance.

Ad van Wijk: I think that social acceptance is not a problem – you have a car that drives the same way or better and it is not more expensive than gasoline or a diesel car. So I don't think that is really a problem. Many people think there is a social acceptance problem but I don't think so. With battery vehicles the charging time and the limited range that you have is the problem. Therefore, you see that people will be reluctant to buy hydrogen cars. Refueling 3-4 minutes a hydrogen or a diesel car is the same. Driving is the same it is a quiet car. When the price of the fuel and the car is good I don't see a problem.

Radi: As a final question of this conversation: Would you consider that there are other problems that the infrastructure, for example I have heard that there are some problems with the hydrogen itself – having low density? Do you think that there are other problems for hydrogen to develop?

Ad van Wijk: There are no technical problems. What you mean low density per volume is true, but the density per kilo is as high as or higher than diesel or gasoline. You have to compress it with a tank, but that is not a difficult thing to do. So no, you have to take on board enough energy to drive 5-6-700 hundred kilometers, but that is not a tough thing to do.

Radi: Alright, thank you very much for your time and support this morning. It has really been of help to me. I will make sure that I use some of these ideas in my thesis.

Ad van Wijk: A lot of success. Bye.

Radi: Bye. Have a nice day!

2.2 cH_2ange – 06.07.2019

Radi: Good afternoon. It's Radi Parlev calling you in regards to our interview appointment about hydrogen's development as a fuel in the Netherlands.

cH_2ange representative: Hello. Yes, you may start with your questions.

Radi: Thank you. The first questions regards the potential of hydrogen in the transportation sector. Do you think it is applicable in the Netherlands?

cH_2ange representative: Our view is that hydrogen will support the development of a post-carbon society. We hold the belief that the molecule of hydrogen is one of the key factors towards making the private transportation of the future sustainable. Hydrogen fuel is as safe as any other, if not safer, but it is bringing way more benefits in the environmental aspect.

Radi: Are there any obstacles towards such development in the Netherlands?

cH_2ange representative: In the Netherlands, the mainstream implementation of hydrogen cars cannot be realized until the development of a widescale fueling network. To realize it, financial aid and recognition from public authorities is of vital importance.

Radi: In your opinion hydrogen is part of the future of sustainable mobility, however, do you share the belief that hydrogen has drawbacks in car use?

cH_2ange representative: Well, the technologies used in producing, storing and transporting hydrogen have improved significantly in the last fifteen years. The fuel cell technology itself has seen significant progress. Production costs were reduced by more than 50% in less than a decade. Not only fuel cell vehicles need five times less platinum than ten years ago, but also 95% of it can be recycled. Our expectancy is that even less platinum will be used in the future. Fuel cell durability has increased fourfold since 2006. Fuel cells can now be used for more than 190 000 kilometers. Between the years 2006 and 2015, the size of fuel cells has shrunk by 33%, which now allows constructors to fit the system into the engine compartment.

Radi: But is it a better technology than for instance battery-electric vehicles?

cH_2ange representative: We think that people have to understand that battery electric vehicles are designed essentially for short-distance driving. That is not the case with fuel cell electric vehicles, which are capable to pass a greater range, and are planned for long-distance driving. Let me make a comparison to you. Fuel cell vehicles can cover an average of 600 kilometres on a single tank with a refueling time of around five minutes, which is similar to today's cars, and when one compares it with battery-electric vehicles, he will note that they need from 30 minutes the least, to several hours. Hydrogen is in that sense, the right solution for large vehicle fleets.

Radi: Then, could you please share what your view of the hydrogen price is?

cH_2ange representative: There are several important factors when it comes to the price of hydrogen The main one is what is a famous notion in economics - scale. Typically, with increase in production, stations, etc. prices will decrease. The incentives which might stimulate consumers to switch from petrol and diesel cars are yet another factor, for instance the thought of driving a vehicle which doesn't damage the environment at the same cost or even cheaper. Of course, here we have to mention infrastructure again in terms of reducing the price because it will inevitably stimulate hydrogen vehicle producers such as Toyota and Honda to boost production and reduce prices of their cars.

Radi: What would you then consider as a state-of-the-art in terms of hydrogen technology?

cH_2ange representative: Well, one part are hydrogen tanks. Today, they are built from a material which is one of the strongest in the world, also stronger than steel, and called carbon-fiber reinforced polymer. What is also important, is that hydrogen cars have sensors installed which have a similar function to airbags in conventional vehicles. When an accident occurs, the valve in the tank closes automatically to isolate hydrogen to the tank. Also of prime importance, and in the uncommon event of a pierced tank, hydrogen scatters quickly as it is much lighter than air. Even in the case of fire there is some protection as there is an emergency valve built in the car, which opens and the flames go out in under two minutes.

Radi: Thank you very much for your time today. What you shared with me can help me a lot with my thesis.

cH_2ange representative: Good luck. Bye.

2.3 Forze Hydrogen Racing Team Delft – 05.04.2019

Radi: Good afternoon, it's Radi Parlev calling you. I am a Master's Student in the University of Twente in the Netherlands and would like to ask you a couple of questions regarding the development of hydrogen as a fuel in the Netherlands. My research is strictly connected with its mobility purposes. I am fascinated by your idea to put hydrogen into a racing car, and therefore I have decided to contact you in hope of helping me for my research.

Forze Team representative: Hello, I am glad you like our cars. What are your questions?

Radi: First of all, what is your perception about the potential of hydrogen as a fuel in the Netherlands, and for your cars?

Forze Team representative: We are convinced that hydrogen-powered vehicles will overtake combustion-engine cars in the Netherlands. The potential of hydrogen takeover in the Netherlands is therefore vast. As pioneers in hydrogen racing technology, we aim to be a serious contender for high-tech petrol racing cars, proving that this technology is reliable, feasible and exciting for the future we envision.

Radi: And what about the issues? Are there any particular obstacles towards hydrogen in your opinion?

Forze Team representative: The disadvantages are way less than the advantages of the development of hydrogen in the Netherlands. However, a main issue is of course the limited infrastructure available in the country. You can't have vehicles without refueling stations. Another negative aspect is the price of the cars, as they are costlier than battery-electric vehicles. Maybe also the fact that not all sources used for the production are sustainable. Hydrogen is currently produced mainly from fossil fuels which has to change in the future. Many European countries are investing in hydrogen filling station networks to implement these cars. Germany is a perfect example, aiming for 100 hydrogen refueling stations in 2020. But outside of Europe, hydrogen is gaining even more attention. Japan for example aims to have 40,000 FCVs on the road and 150 operational hydrogen refueling stations by the same year. Moreover it plans to have entire buildings of the Olympic Village powered by hydrogen fuel cells during the 2020 summer Olympics in Tokyo.

Radi: You have mentioned battery-electric vehicles. One of my questions is whether hydrogen is worth over other sustainable vehicles such as battery-electric cars. Could you share your view?

Forze Team representative: Hydrogen cars are better suited not only for racing, but also for mainstream use, as they can be refilled within minutes, like a conventional combustion car, whereas battery-electric vehicles currently need hours to recharge. As I said earlier, hydrogen cars are also better than fossil fuel cars because the efficiency of the fuel conversion is about two to three times higher than a conventional combustion engine, and you also get zero-emission driving with the same refil time.

Radi: What could be possible incentives for the people to switch to hydrogen cars, apart from emissions?

Forze Team representative: Fossil fuels are getting scarce. People need to realize that they have to pay attention to the alternatives. Apart from the zero-emissions driving that hydrogen fuel cell vehicles offer, they are also recyclable and quiet. This is what we could so far share with you. For detailed and further questions, we believe you could turn to hydrogen institutions or even prof. Ad van Wijk from the University of Delft.

Radi: Thank you very much for your time. Good luck with developing further your race cars.

Forze Team representative; Thank you. Success with your thesis. Bye.

Radi: Bye.