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Key Success Factors and Risks for Hydrogen Based Road Transports

Bachelor’s thesis in Industrial Management and Production Engineering

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DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
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Abbreviations and word meanings

FCEV - Fuel Cell Electric Vehicle.

HRS - Hydrogen Refueling Station.

Electrolyzer - A Hydrogen Producing Unit.

CAPEX - Capital Expenses, e.g initial investment costs.

OPEX - Operating Expenses, e.g employee salaries, rents etc.

BEV - Battery Electric Vehicle

ZEV - Zero Emission Vehicle

Abstract

Climate change is one of the world's most serious and defining challenges today, threatening mankind as a whole. Because today's transportation system is heavily reliant on fossil fuels, the present transportation sector is a significant contributor to the problem. To substitute fossil fuels, one solution is to use renewable hydrogen as a power source for vehicles. The hydrogen is being transformed into electricity through a fuel cell onboard the vehicle and the only emission is water, making this a both emission-free and renewable solution.

The aim of this report has been to identify key success factors and risks that could affect the further development of a hydrogen based road transport sector through the whole value chain. By reviewing previous hydrogen based road transport projects, interviewing industry experts and conducting a workshop, we have identified factors and risks that should be considered for future projects. These are;

- It is concluded that a collaboration between the stakeholders is needed. Many of the risks we have identified are common to the entire value chain.

- Public support is needed, financially and by establishing a framework to support the development.

- A cross-sectoral integration would decrease the costs along the value chain due to increased usage.

- Ambitious and engaged stakeholders will benefit the development.

- Stakeholders within the hydrogen transport sector need to be aware that there might be a conflict of interest between the Ministry of Finance and the Ministry of the Environment, due to the current tax system and the high revenues from the fossil-based transport sector.

Key words: Hydrogen, transportation, value chain, cross-sectoral integration, FCEV

1. Introduction

The introduction includes background, purpose, limitations and clarification of the research questions.

Climate change is one of the world's most significant and defining crises today, posing a threat to all of humanity. The existing transportation sector is a significant contributor to the issue, due to the fact that today's transport system is hugely fossil dependent. The use of fossil fuels affects the climate and the environment by contributing to the greenhouse effect, degrading air quality in cities and causing acidification in soil and watercourses (SCB, 2016). Transportation accounts for 21% of global carbon emissions (Brand, 2021). In Sweden, domestic transport accounts for approximately 43% of the total emissions, including emissions from foreign transports (SCB, 2016).

To solve this issue changes are required. One solution is to use renewable hydrogen as a power source instead of fossil fuels for vehicles. Hydrogen from renewable energy is a key enabler for global energy transition and, in particular, for decarbonizing the transport sector since the only emission is water (Zohuri, 2019).

In the field of hydrogen, a lot is going on. The European Union is investing in providing hydrogen with the support it requires to be adopted on a large scale. For example, the Clean Hydrogen Partnership has been granted one billion euros for further market distribution for the period 2021 to 2027 (FCH, 2019). Several regulatory packages have been implemented, or are in the process of being developed, to enable the introduction of hydrogen on a broad front. LKAB, SSAB, H2 Green Steel, and a number of other large and small companies in Sweden have committed to develop hydrogen-based technologies.

A significant amount of money and other means must be invested in new technology in order for this transition to occur (Sweco, 2022). Such investments are risky at an early stage when the future is uncertain, thus the EU, the government, and municipalities will play a key role since they can mitigate risk through funding and regulations, accelerating technological change. Based on previous hydrogen-related projects in the transportation sector, what will be success factors for these projects, and what should be kept in mind regarding the development along the hydrogen value chain?

The purpose of this study is to identify key success factors and risks that could affect the further development of a hydrogen based road transport through the whole value chain.

The study will partly be based on a hydrogen based road transport project carried out in the Nordic countries, which goes by the name The Blue Move and various projects carried out in California, since they have come a long way in the development of hydrogen usage in the transport sector. Further in the study, we will name the entire California development as a project. The purpose of this is to identify and learn from their findings. The information in these reports could be affected by interest, for example, to influence financiers. To obtain a more comprehensive understanding, we will conduct interviews with industry experts to

question and open up for discussion.
A workshop will also be conducted with these experts in order to identify stakeholders to use as a ground for a risk analysis. Through this method we will cover a wide spectrum of experiences and knowledge regarding the hydrogen development.

This study will have some limitations and they are as follows:

- Regarding the risks, it is seen from an investment perspective. For instance, the fire risk for the hydrogen tanks, how to handle high pressurized hydrogen and so on will not be covered.
- The study will not take into account how the hydrogen is produced.

2. Overview

This chapter presents the facts and theories on which the study is based on.

2.1 Renewable Hydrogen Production

Hydrogen consists of only one proton and one electron, making it the simplest and most abundant element on Earth. Unlike fossil fuels such as oil or natural gas, hydrogen will never run out (Zohuri, 2019). Just like electricity, hydrogen can store and supply usable energy, but it does not exist in nature by itself. It must be made from compounds that include it, which can be made from a variety of domestic resources (Zohuri, 2019). Currently, the majority of hydrogen is created by fossil fuels, primarily from natural gas. About 70 million tonnes of hydrogen is being produced worldwide each year (Jenné & Pecqueur, 2021). 71% of the world's hydrogen is estimated to be produced using steam methane reforming (SMR) processes, which involves natural gas. It is called 'grey' hydrogen, as greenhouse gasses (GHG) are emitted during the steam reforming process (Jenné & Pecqueur, 2021). The production of hydrogen has to be generated completely by renewable energy to be referred to as 'green' hydrogen, which is making up 2% of today's total hydrogen production worldwide. The remaining part of the production is categorized as 'brown', 'blue' or 'black' hydrogen, referring to different production methods and GHG emission profile of the source used to produce the hydrogen (Jenné & Pecqueur, 2021).

Hydrogen can be produced via water electrolysis without emitting any carbon dioxide by using an electrolyzer (Godula-Jopek & Stolten, 2015). The electrolyzer consists of an anode (positive charge), a cathode (negative charge) and a membrane. Energy in the form of electricity and water are converted in a chemical process to oxygen and hydrogen according to the formula below (Godula-Jopek & Stolten, 2015).

$$H_2O \rightarrow H_2 + \frac{1}{2}O_2$$

The water splits into its component molecules, oxygen and hydrogen, when electricity is supplied to the anode and cathode through the proton exchange membrane (Zohuri, 2019). There are different types of water electrolytes technologies that function in different ways. These are polymer electrolyte membrane electrolyzers (PEM), alkaline electrolyzers (AEM) and solid oxide electrolysis (SOEC) (Department of Energy, n.d). The different technologies have their own set of suitable environments as they have different strengths and weaknesses (Zohuri, 2019).

Once the hydrogen is produced, it has many different uses. One of them would be to fuel a car or truck. The hydrogen would then be converted back to electricity by using a fuel cell to power the electric motor. A fuel cell works in a similar way to the previously mentioned water electrolysis process but reverted (Corbo et al, 2011). Hydrogen is inserted at the anode and oxygen at the opposite side at the cathode. The hydrogen is divided into positively charged protons and negatively charged electrons in a catalytic process. The electrons are then transferred to the cathode, resulting in an electric current that can power an electric motor (Corbo et al, 2011).

2.2 Electrolyzer Cost

The process of creating hydrogen through electrolysis requires a lot of energy. For the electrolysis process to be cost competitive with steam methane reforming (SMR) hydrogen, the kilo price per green hydrogen should be cheaper than the cost to deal with the CO2 emitted through the SMR process, which is estimated to be between 14 and 19 SEK (Jenné & Pecqueur, 2021). Jenné and Pecqueur explain that the cost of renewable energy has decreased in the last couple of years. The process can be speeded up by an increase in the price of natural gas or the carbon prices. The CEO and founder of the Japanese company Enapter claims that the latest generation of electrolyzers will be able to produce green hydrogen for 15 SEK per kilogram by 2030, as opposed to the current price of 70 SEK per kilogram of green hydrogen.

There are mainly two factors for the price of the electrolysis process. It's the price of the electricity used in the process and the price of the electrolyzers (Jenné & Pecqueur, 2021). The electricity is a running cost (OPEX), being linear to the amount of hydrogen being produced. The electrolyzers is a one time investment (CAPEX), which according to Jenné and Pecqueur (2021) is an uncertain investment as the future is uncertain regarding return on investment (ROI) and performance as well as the initial capital cost is relatively high. One could therefore believe that these factors have hindered investors' interest in electrolyzers.

2.3 Hydrogen Storage

Compact, dependable, safe, and cost-effective hydrogen storage is a critical technology requirement for the mass commercialization of fuel cell electric vehicles (FCEVs) and other hydrogen fuel cell applications (Zohuri, 2019).

There are many different ways to store hydrogen. The most proven, tested and commercially available methods is to store hydrogen pressure in gaseous form or in liquid form (Godula-Jopek & Stolten, 2015). The authors explain that the energy per mass of hydrogen is much greater than that of most other fuel systems, however the energy by volume is lower than most other fuels, such as gasoline. Therefore to achieve a satisfying energy density the hydrogen has to be pressurized to an operating pressure of 700 bar. In a liquid state the hydrogen has to be lowered to a temperature of -253 degree celsius. The process of reaching such high pressure or low temperature requires a lot of energy compared to storing other energy carriers, thus costing more money. (Godula-Jopek & Stolten, 2015).

2.4 Hydrogen Transportation

Hydrogen can be transported and distributed in four different ways according to Fossilfritt Sverige (2021). For instance, hydrogen can be transported by trucks, railroads and ships in its gaseous form. The same ways of transportation can be utilized to move liquefied hydrogen as well. The third way of transportation is by distributing hydrogen through a pipeline network. Fourth and final, hydrogen can be produced close to where it will be used, removing the need of transportation, called on-site production (Fossilfritt Sverige, 2021). The different methods all have their strengths and weaknesses. For instance, liquid hydrogen is preferred during longer transportation distances due to its higher density, thus allowing for more hydrogen to be stored and distributed. On-site production eliminates the distribution cost but does come with an increased cost per kilo of hydrogen produced, as it is a small-scale production (Fossilfritt Sverige, 2021).

Today, the most common way of distributing hydrogen in Sweden is in compressed form on trucks (Fossilfritt Sverige, 2021). When the distances are long and the hydrogen flow is high, hydrogen distribution through pipes is the most cost-effective option but that is not a reality today. The initial investments (CAPEX) to establish such a network of pipelines is high and might not be viable given the small quantities of hydrogen demanded in an early phase (Fossilfritt Sverige, 2021).

2.5 Regulations and Policies

The development of a comprehensive regulatory framework is a crucial challenge that must be addressed in any expanding industry, and the hydrogen sector is no exception (Strachan, 2020). According to Sweco (2021), there is a lack of regulations that are specific and or directly applicable for hydrogen technology. This applies to all parts of the value chain. There is a need for regulations regarding safety aspects and testing conditions for production, distribution and use of hydrogen (Sweco, 2021). It is said that the lack of laws, regulations and guidelines at national and EU level leads to unclear conditions that can slow down the introduction of hydrogen.

Slow or uncertain permission processes, whether for electricity lines or hydrogen plants, are the biggest a major barrier to hydrogen’s introduction (Sweco, 2021). Large amounts of electricity are necessary for large-scale electrolysis hydrogen production. In many cases, including the primary system for energy, a significant increase in grid capacity is necessary. Because the licensing process for new power lines takes so long, there's a possibility that large-scale hydrogen production will go uninvested in, according to Sweco (2021).

Today, there is uncertainty among stakeholders regarding how hydrogen gas should be distributed in pipelines and should be handled legally (Sweco, 2021). The lack of control means that each project is forced to be handled differently. A clear framework for testing and approval would be very welcome among the stakeholders, according to Sweco (2021).

2.6 Technological Change

New technologies often follow a pattern when they are successful in being implemented and finding their market. A slow start which then accelerates before slowing down again as the level of saturation is being approached, known as a S-curve (Ekins, 2010).

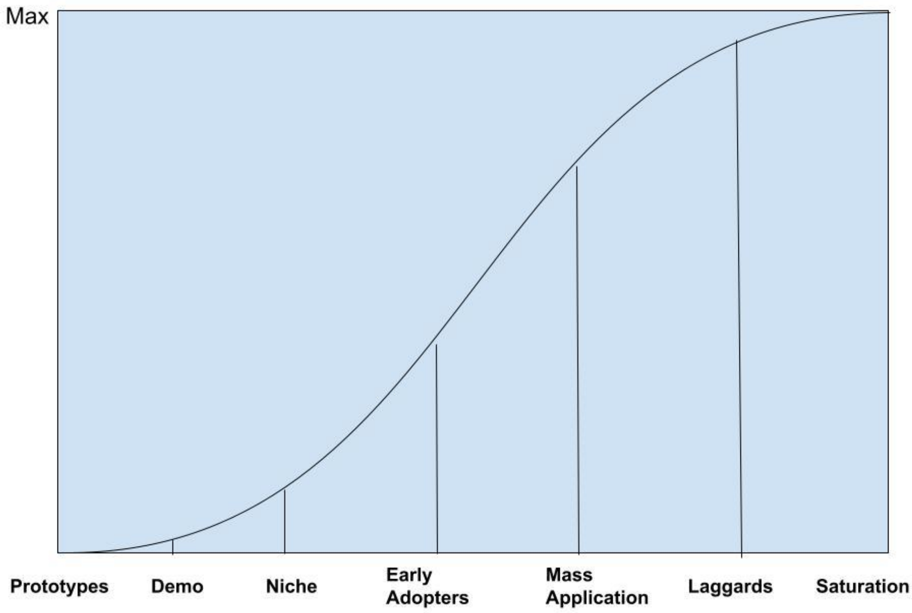

Figure 1: Stages in the introduction of a new technology (Ekins, 2010).

It is common, and especially true for hydrogen technologies, for new technologies to be significantly more expensive than the ones with which they compete at first. Ekins (2010) explains further that any increases in uptake of these technologies, or advances up the S-curve in Figure 2, are usually contributing not only to increased awareness of the technology, but also to improvements and cost reductions that happens during the diffusion process, thanks to economies of scale and learning effects. Learning curves or experience curves can be used to indicate cost reductions as a function of increasing production (or sales) of a certain technology (Ekins, 2010).

There are different theories about how technologies are developed and diffused in society. One of the most common deals with the concept of ‘technology-push/market-pull’ (Ekins, 2010). It can be divided into two parts, push and pull. The primary drivers of technology development are policy and business decisions in the early stages. These include government investment in research and development (R&D), and the actions and interests of engineers and scientists. The first, pre-market phases of the process are referred to as ‘technology push’ (Ekins, 2010). The second part is followed by having the commercialization and diffusion processes significantly more driven by consumer-pull in the markets that have been targeted or into which the technologies will have established to some extent by then. As demonstrated in figure 3, both sets of drivers are present to some extent in all the phases, even in the earliest stages of technology R&D, possible market demand is a major interest and even throughout diffusion, research-driven technological change may occur. Ekins (2010) explains that it is essential with continuous learning and feedback throughout the development for the process to be effective and take place successfully.

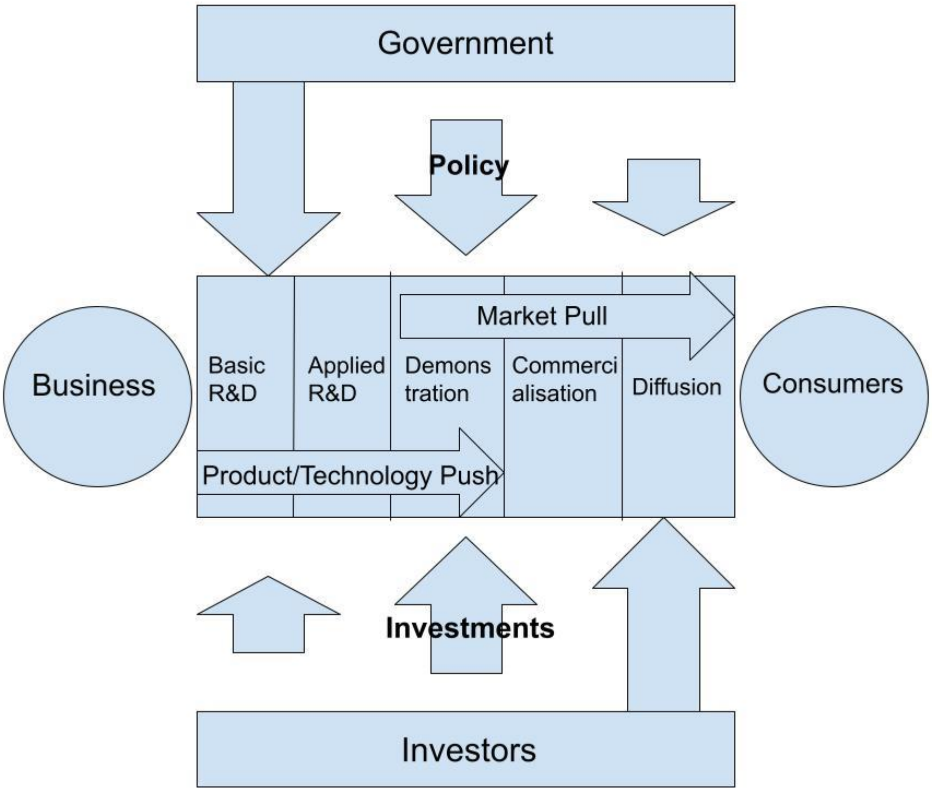

Figure 2: Roles of innovation chain actors (Ekins, 2010).

Private investments or public interventions may be required or needed at each stage of the process, which may include government investments as well. It is explained by Ekins (2010) that policy interventions are likely to be relatively important during the ‘technology-push’ stages, at least for innovations and technologies that are believed to have a large potential social benefit, such as dealing with climate change. Private investments are going to be vital from demonstration and onwards during the ‘market-pull’ (Ekins, 2010). But even so, it is likely that public support and policy interventions will be necessary, especially for technologies with public benefit but uncertain market demand (such as hydrogen technologies), both to help the innovation or technology from the demonstration to commercialization stages due to business bankruptcies and the downfall of potentially good technologies and ideas (Ekins, 2010).

The theory of ‘technology-push/market-pull’ as of how technologies are developed and diffused into society has met criticism. It does highlight some important aspects of technological change according to Ekins (2010). However, the linear development presented by the theory is rarely a reality according to critics, suggesting a more interactive ‘chain-linked’ model, containing elements in regards to the social environment in which such a change occurs (Ekins, 2010). The critics would suggest that the term ‘technological transition’ requires a more integrated approach that considers the social and economic structure in which technologies are integrated, as well as the context in which they flourish and fall (Ekins, 2010).

2.6.1 The dynamics of technological transitions

While taking the social and economic context in account, looking at the dynamics of technological transitions, it is possible to illustrate a transition in the following four different steps according to Ekins (2010).

1. *Novelty evolves in a present structure and landscape. The ‘technology-push’ forces mentioned in figure 3 will be present, in which firms or governments pursue basic and applied R&D in the hopes of public benefits or private returns.*

2. *Technical consolidation and creation of new functionalities in market niches. Once established in niches, decisions will be made in order to benefit from the technological ‘lock-in’ process. From here on no new technologies will be established, so a technological trajectory will be established. Meanwhile, additional functionalities for the technology will be created in order to position it for development into new niches and, eventually, into the mainstream socio-technical regime.*

3. *Widespread adoption and penetration of the new technology in direct competition with the existing, established system.*

4. *Replacement of the existing system over time, as well as broader socioeconomic developments. As new functions arise, cost-to-performance ratios improve, new skills can be taught and old investments are replaced. Technological transitions take time.*

2.7 Hydrogen Economy

There are different ways to define a hydrogen economy. Some would describe it as a ‘widespread and diverse production and use of hydrogen’. Ekins (2010) defines it as an economic system in which hydrogen serves as the energy carrier for a significant portion of the country's energy-based services and commodities.

The current energy system in industrial countries such as Sweden, which is largely based on fossil fuels, is mature, pervasive and reasonably efficient in meeting a wide range of energy service demands, such as heat, light, power and mobility according to Ekins (2010). It has an extensive infrastructure that is long-lasting and has been developed over many years with big investments. In order for the hydrogen economy to emerge, a significant shift away from the fossil-fuel economy and its related energy infrastructure will be required (Ekins, 2010). To enable this process enormous technical innovation and changes in all areas of the hydrogen technology will be required (production, storage, transport and end-use). This will require very large investments over long periods of time (Ekins, 2010).

The operation of markets has the majority of important technological changes in modern society. Producers have made new technology to create new ways of producing and distributing goods and services with improved functionality or quality, cheaper costs, or a combination of the three (Ekins, 2010). These items and services were purchased by consumers for these reasons. Even in such circumstances, however, the development, deployment, and spread of new technologies is far from straightforward, and much research has been done into why and how certain technological breakthroughs become rooted while others do not, even when their market advantages appear to be similar (Ekins, 2010). In the case of hydrogen technologies, Ekins explains that they have limited current commercial benefits over the existing technologies which they compete with. Interest in these technologies is almost completely motivated by public interest concerns, such as lowering the carbon emissions and possibly increasing energy security. As can be seen, private customers have not historically been motivated to trade off traditional consumer benefits such as functionality, quality, or affordability for such public interest considerations, hence public policy plays an important role in supporting hydrogen technology (Ekins, 2010).

2.8 Hydrogen Refueling Stations (HRS)

A refueling station requires a certain amount of delivered hydrogen to be considered economic or profitable. Therefore, it is important to locate these HRS at places where the demand of hydrogen is high. There are two possibilities for the HRS, either to be stationary or mobile (Hecht & Pratt, 2017).

More practically, end consumers fill their FCEVs from nozzles, similar to a normal combustion engine car that uses diesel or gasoline. (Ram B. Gupta et. al, 2015). As mentioned earlier, the hydrogen could either come delivered via trucks, or the refueling station could have its own on-site producing unit.

2.9 Fuel Cell Electrical Vehicles

FCEV possesses different benefits. One can say it is a combination of the benefits of an electric car together with the benefits of a combustion engine car. Since it uses hydrogen as fuel and develops electricity to drive the drive shafts forward it has zero emissions, except water. A main difference between a FCEV and a BEV is the fact that the FCEV does not have a battery, which in itself has its benefits. The manufacturing process of the batteries used in cars causes large carbon dioxide emissions (IVL, 2019). Therefore, the total emissions will be reduced by using fuel cells to produce the electricity, instead of storing the electricity in the batteries.

In the current situation, some companies do produce and sell FCEVs. For instance, Toyota, with their car model called Mirai. Also Hyundai have made a model called NEXO available on the market. A prerequisite to enable the daily use of FCEVs is to have a developed hydrogen infrastructure, which at the moment is not the case.

2.10 Hydrogen Projects

There are several projects in Sweden that are working with hydrogen. An ongoing hydrogen project is the so-called Hybrit project, which is a cooperation between the steel producing company SSAB, the iron manufacturing company LKAB and the electricity producing company Vattenfall, where the aim is to produce fossil free steel from the usage of hydrogen. (Hybrit, n.d). Another Swedish company involved with hydrogen is Ovako, who manufactures steel which has developed a technique to heat up the steel with hydrogen before the rolling process. Earlier, they have been using gasol as fuel which in itself causes CO2 emissions. By implementing this new technique, they can mainly reduce their emissions, but also show the whole industry that hydrogen could be used in many areas. (Ovako, n.d)

2.10.1 Nordic Hydrogen Corridor

Hydrogen Sweden is leading an EU-project - The Nordic Hydrogen Corridor,
which is a pilot project that will pave the way towards large scale market rollout of renewable hydrogen usage in road transports in the Nordics. One of the project goals is to broaden the knowledge about how this new value chain will co-exist with the already established businesses and with new market entries, to create sustainable and robust business model needed for further market rollout. (NHC, 2022).

The project objectives consists of (i) build 8 different hydrogen refueling stations (HRS), (ii) establish a hydrogen production unit to produce renewable hydrogen via an electrolysis without a CO2 emission which will use renewable energy from wind or sun, (iii) establish a seamless hydrogen distribution to the HRS, and (iiii) ensure availability of fuel-cell vehicles, driven by hydrogen to its end customers. (NHC, 2022). The purpose of the project is to promote a hydrogen infrastructure in Sweden by forming a hydrogen corridor to connect the capitals Oslo, Stockholm and Copenhagen. The overall aim is to increase the mobility when it comes to hydrogen usage in the transport sector and it will also contribute to a wider understanding for further development of a wider roll-out of HRS and Fuel Cell Electric Vehicles (FCEVs). (European Commission, n.d). The project is funded by the European Union with a total budget of 20M£. (Nordic Hydrogen Partnership, n.d).

2.10.2 The Blue Move

The Blue Move for a Green Economy is a project conducted between 2015 and 2018, joined by 18 business, government, and research institute partners from Sweden, Norway, and Denmark. The project, which had a budget of 1.4 million euros, intends to encourage the use of hydrogen based on renewable energy by developing and expanding knowledge of business models for production, distribution, infrastructure and use of hydrogen vehicles

(Vätgas Sverige, 2018). Its purpose was to encourage and guide private and public stakeholders in making successful investments in hydrogen as a fuel.

2.10.3 Hydrogen development in California

In California, USA, the prevalence of hydrogen vehicle usage has come relatively far. By 2021, 48 hydrogen refueling stations had been opened in total. This, together with an increasing amount of FCEVs sold in California demonstrates how the usage of hydrogen in the transport sector could be used (CARB, 2021).

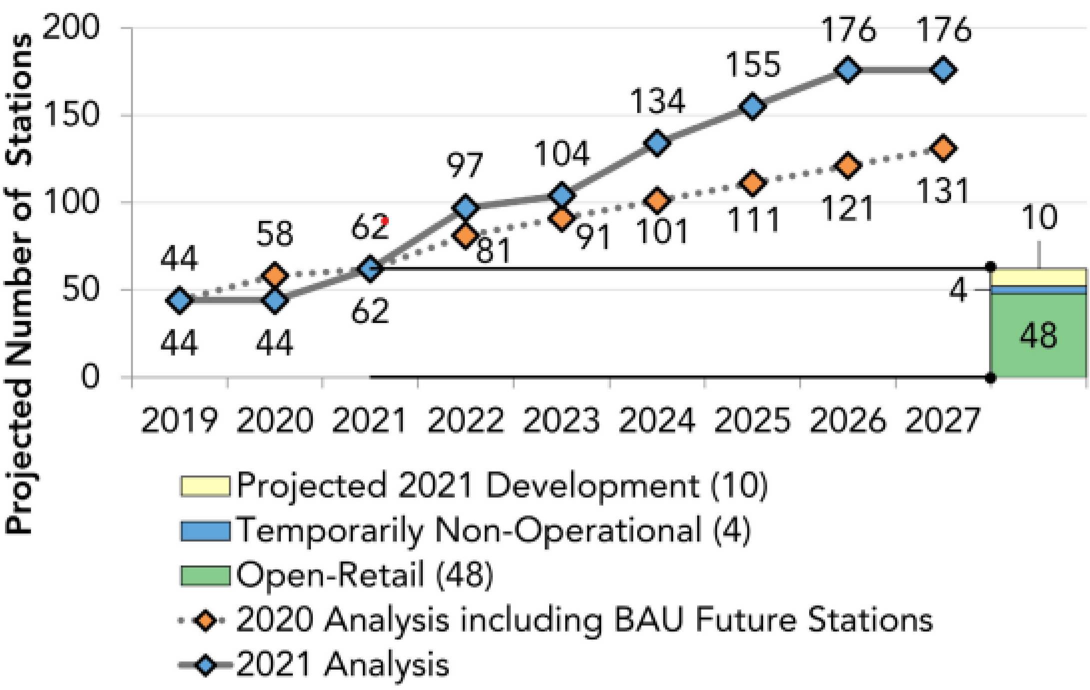

Figure 3: Overview of refueling stations in California (CARB,2021).

2.11 Value Chain

Porter (1985) describes competitive advantage as the way an organization chooses to implement a generic strategy to reach and sustain a competitive advantage. It focuses on how the two elements of competitive advantage, cost and differentiation interact with the scope of a company's operations. Porter (1985) further explains how the value chain, which divides an organization into the discrete activities it does, is the most basic tool for diagnosing competitive advantage and discovering activities to improve it. These activities are divided into designing, producing, marketing, and distributing the firm's product. Through its influence on the value chain, the scope of a firm's activities, which Porter refers to as competitive scope, can play a significant role in competitive advantage. He explains how personalizing the value chain can provide you a competitive edge, and how a larger scope can bring you a competitive advantage by leveraging interrelationships between value chains that service different segments, industries, or geographic locations (Porter, 1985).

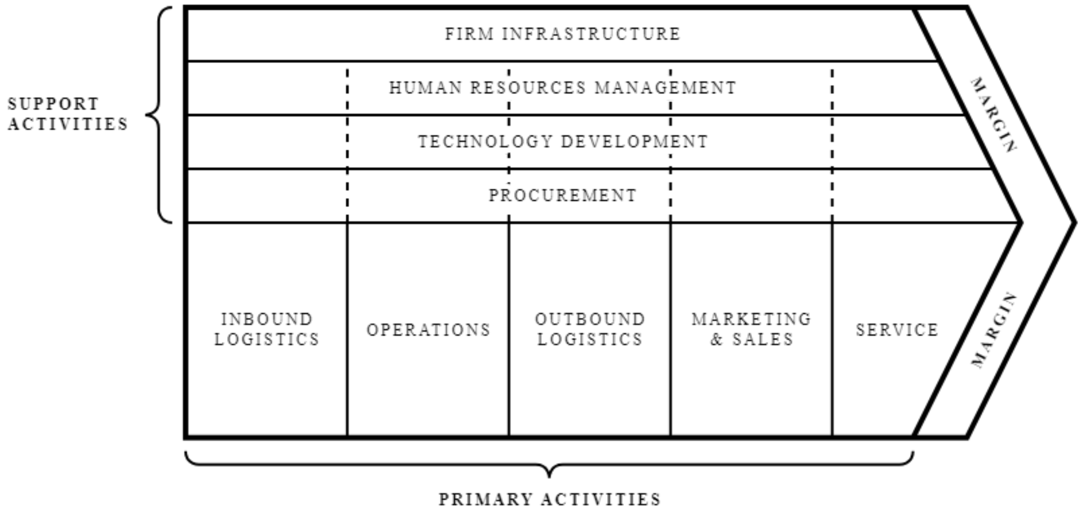

Figure 4: Illustration of Porter's value chain (Porter, 1985).

Above is an alternative explanation of the value chain that will not be used in this study, here we will instead focus on how the different actors within the hydrogen industry for road transports are linked to each other via a so-called value chain mapping. Mapping a value chain, including its many components, links, and actors, helps promote an organized debate about the opportunities and constraints that producers and other actors face, as well as what can be done to address them (Stein & Barron, 2017).

2.12 PESTLE-analysis

The external environment for an organization or a whole industry could be analyzed via a PESTLE-analysis. PESTLE is a theory used to understand the world around us and how it can be imagined to influence one's own business, a planned business or an industry. It is an abbreviation for Political, Economic, Social, Technology, Legal and Environmental (Jobber & Ellis-Chadwick, 2019).

Down below, there is a list of the six factors and some things to consider regarding each factor:

- **Political factors:** Political stability and instability, level of corruption in the country, freedom of the press, trade union rights, competition regulations and government subsidies.

- **Economical factors:** Inflation rate, growth rate, interest rates, credit availability, levels of available income for consumers and consumers' propensity to spend money.

- **Social factors:** Acceptance, demographics, cultural aspects and education.

- **Technological factors:** Technological development, life cycles for technology, infrastructure for communication, level of innovation, access to new technology and technological incentives.

- **Legal factors:** Terms of employment and laws, copyright protection and patent laws.

- **Environmental factors:** Climate, environmental and climate policies, climate change and global warming.

2.13 Business models

To capture value for your organization, embed your value offer in a viable business model. You can accomplish so by using the Business Model Canvas, which is a tool for describing how a company develops, delivers, and collects value. The Value Proposition Canvas and the Business Model Canvas are inextricably linked, with the latter acting as a plug-in for the former, allowing you to zoom in on the specifics of how you create value for customers (Osterwalder et al., 2014). Osterwalder (2014) further describes how the Business Model Canvas is divided into nine different parts which is being presented below:

1. *Customer Segments* - These are the groups of people or organizations a company strives to reach and create value for by the given value proposition.
2. *Value Propositions* - These propositions are made up of a collection of products and services that add value to a specific consumer segment.
3. *Channels* - Defines the communication and delivery of a value offer to a consumer segment via communication, distribution, and sales channels.
4. *Customer Relationships* - They illustrate how consumers are gained and retained, as well as what type of relationship is developed and maintained with each customer segment.
5. *Revenue Streams* - The result of a successful value proposition presented to a customer segment. It's the process by which a company captures value at a price that customers are willing to pay. Also how the revenues are being gained.
6. *Key Resources* - Presents the most essential assets necessary to provide and deliver the aspects previously outlined.
7. *Key Activities* - Are the most crucial activities that a business must successfully complete in order to be able to deliver the value proposition.
8. *Key Partnership* - This presents the network of suppliers and partners who bring in external resources and activities in order to be able to deliver the value proposition.
9. *Cost Structure* - Presents all costs incurred to operate a business model.

Different business possibilities for the different steps in the value chain will be presented in the form of four different cases. The first case concerns a hypothetical possible application of the business canvas model for a hydrogen-producing company, the second for a distribution company, the third for a refueling station company and the forth for a car fleet owning company.

2.13.1 Case 1: Hydrogen producing company

In this case, it is assumed that the production takes place on a fixed facility where the finished product is picked up by distribution trucks.

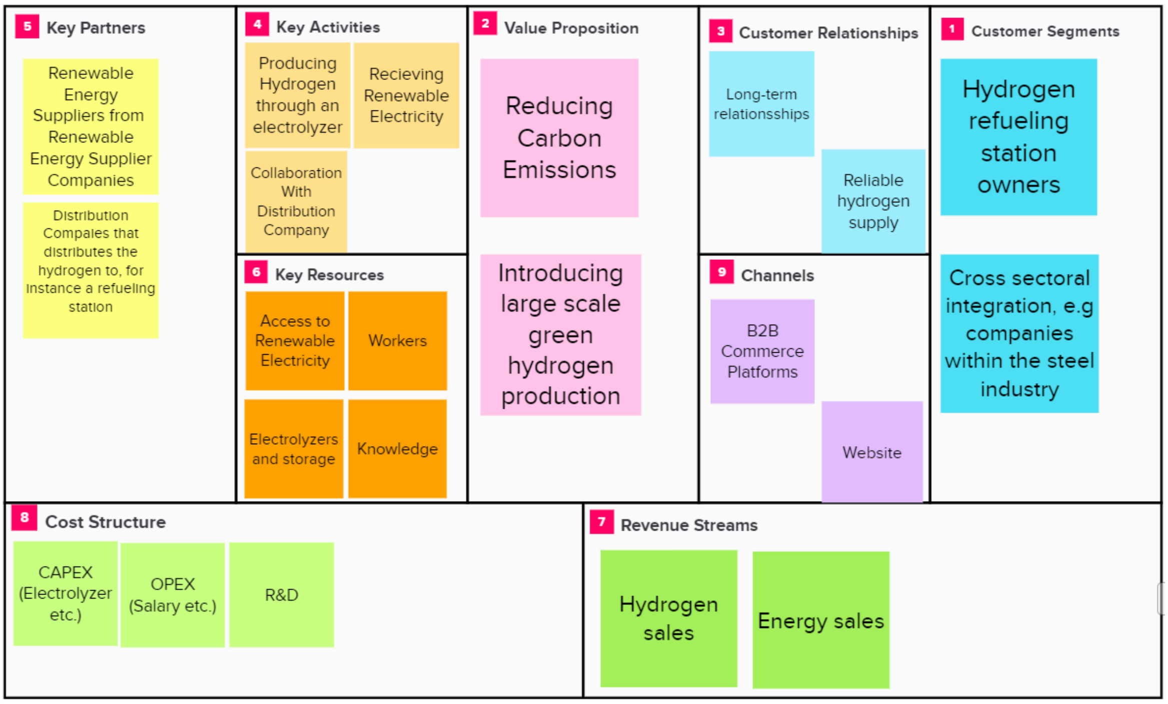

Figure 5: Business canvas model for a hydrogen producing company

2.13.2 Case 2: Distribution company

In this case, it is assumed that the company is using trucks to distribute the hydrogen, and not pipelines. We also assume that the distribution company buys the hydrogen from the supplier, until the refueling station owner buys it from the distribution company.

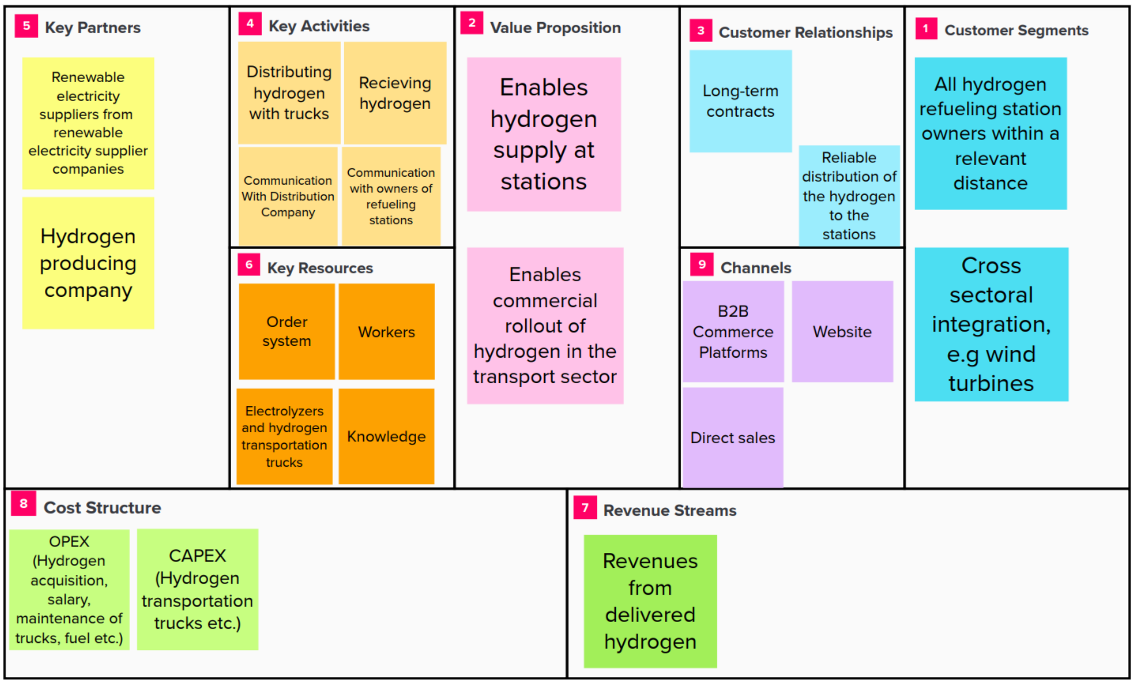

Figure 6: Business canvas model for a distribution company.

2.13.3 Case 3: Hydrogen refueling station company

It is assumed to be a stationary HRS, not a mobile station.

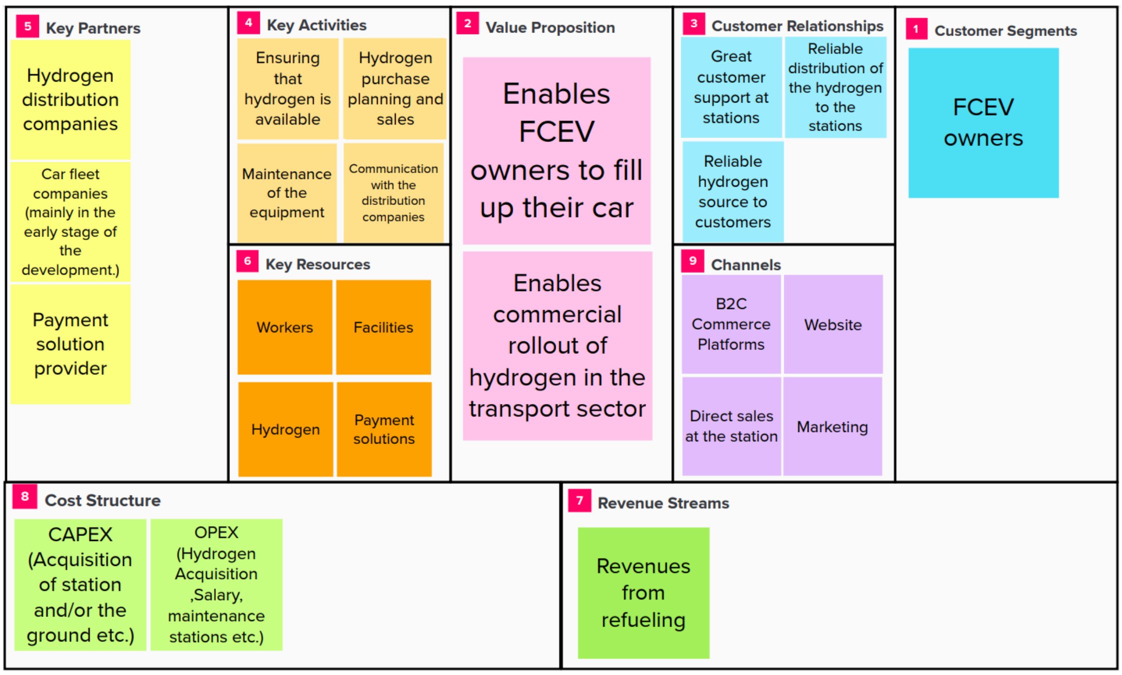

Figure 7: Business canvas model for a hydrogen refueling station company.

2.13.4 Case 4: Car fleet company

In this case it is assumed that the car fleet company buys the FCEVs and not leasing or renting them.

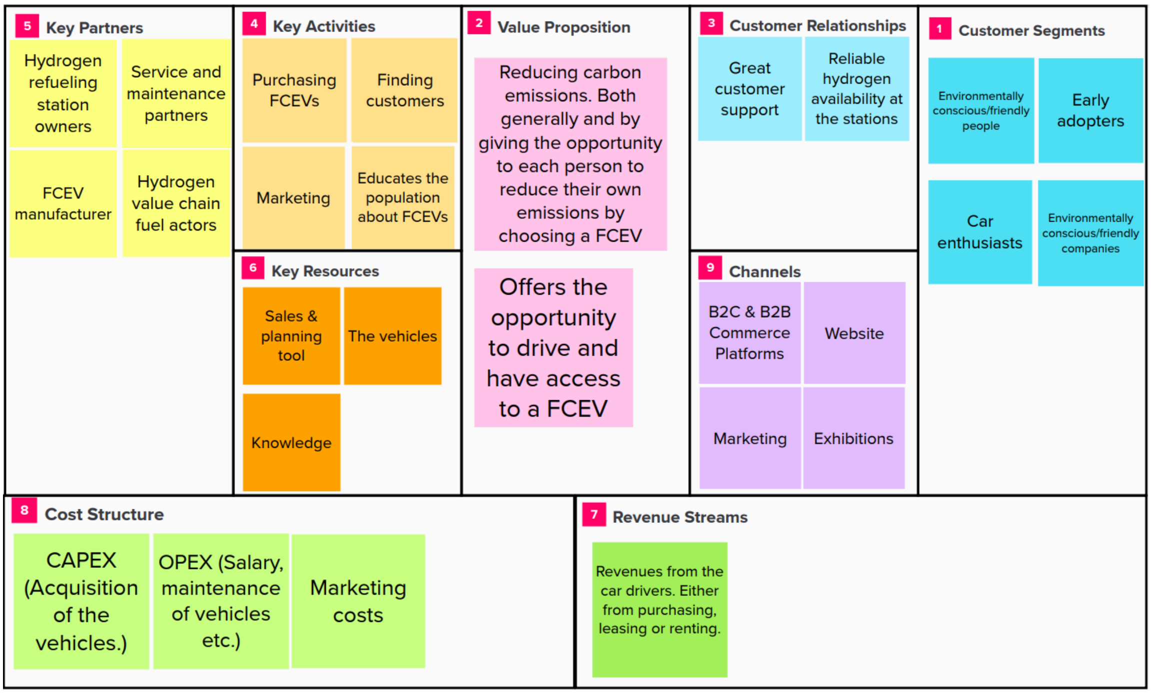

Figure 8: Business canvas model for a car fleet company.

3. Methodology

This chapter will go through the different methodologies that were used during this study. These were literature reviews, interviews and a workshop.

3.1 Procedure

This study collects information from three different approaches. The first approach is information and findings based on the reports from hydrogen based road transport projects carried out in the project The Blue Move and various projects carried out in California. The second method is semi-structured interviews conducted with industry experts in order to gain a more deep understanding of things that might not have been said in the reports.
A workshop with these experts was also held in order to identify stakeholders to use a basis for a risk analysis. Using this strategy, we were able to cover a wide range of hydrogen development experiences and information.

3.1.1 Research approach

Research, in general, can be divided into two different categories, qualitative research and quantitative research. The two methods differ on four major grounds according to Firestone (1987) and Bergman (2008), which is (i) assumptions about the world, (ii) purpose of the research, (iii) approach, and (iiii) role of the researcher. For a better understanding of these key methodological paradoxes, a brief exposition of these grounds of difference is presented below:

- Assumptions about the world: Bergman (2008) describes quantitative research as based on positivism and sees the world as an objective reality independent of individual actors' beliefs. Further, the author describes qualitative research emerging organically from the experiences of the actors/individuals involved.

- Purpose of the research: Through data measurement and quantitative analysis, quantitative research aims to understand the cold causes of changes in social facts (Bergman, 2008). Regarding qualitative research, Bergman (2008) explains that qualitative research is based on gaining an understanding of social phenomena from the perspective of the actors involved in the topic the research examines. Understanding is the spirit of qualitative research that pervades the conceptualization of questions and the conduct of research. It relates to first-person participatory understanding, which is typically a never-ending process that takes into account the individuals' history, culture, and previous endogenous experiences (Bergman, 2008).

- Approach: To eliminate error and bias, quantitative researchers frequently use experimental or correlational research designs, whereas qualitative researchers seek to properly report endogenous stories in the anthropological tradition of research. (Bergman, 2008)

- Role of the researcher: Finally, Bergman (2008) expresses that to prevent bias, quantitative researchers must "go native" and immerse themselves in a social context, whereas qualitative researchers must "go native" and immerse themselves in a social context to provide a ciable account of research.

Since the purpose of this report was to identify factors and risks in the development of a hydrogen road based transport sector and to connect different sectors in this development, which is currently an undeveloped area, a qualitative research method was preferable in order to get a comprehensive understanding of the topic and develop conclusions from it.

3.3 Data collection methods

The data collection methods in this study will be literature reviews, interviews and a workshop.

3.3.1 Literature review

In order to gain basic knowledge of the subject areas, the work began on literature studies where books, scientific articles and reports from previously performed hydrogen projects were studied. The literature was retrieved from Chalmers library and Chalmers databases. Reports were obtained from various sources, for example published by Vätgas Sverige and articles were recommended by the supervisors. By reading and studying the literature on the subject, it helped to gain knowledge and create an understanding about hydrogen development and earlier projects. The information and knowledge gathered was utilized to create interview questions as well as to analyze the information collected during the interviews.

Since the process of producing hydrogen through electrolysis has been around for about 300 years but has recently gained popularity, more recent publications written in the last ten years have been prioritized and chosen in the study if possible. However, older publications concerning previous projects have had an impact on the study. Further, because hydrogen use is a current study subject with new ideas and publications being released on a regular basis, the literature review was worked on iteratively and updated throughout the writing process.

3.3.2 Interviews

One of the ways to collect information was through interviews with firms and organizations that will be participating in the hydrogen transition. The goal of these interviews was to gather qualitative data and subjective opinions in order to better understand how different actors along the value chain believe the hydrogen transition will happen and hear about their previous experience in related projects. Structured, semistructured, and unstructured interview studies are the three basic forms of interview studies that can be used (Galletta & Cross, 2013).

A semi structured approach was chosen due to the exploratory nature of the study and the goal of obtaining the respondents' experience from earlier projects, ideas and insights. A predefined questionnaire is used in a semi structured interview, although it is possible to alter the order of the questions and follow up with additional, non-scripted, questions, based on the interviewee’s response (Galletta & Cross, 2013). As a result, a semi structured interview offers more flexibility than a structured one, which was considered necessary for this particular study. By allowing the respondents to express their thoughts and experiences without being guided by the questions, the answers will result in information free of the interviewer's hypothese and preconceptions (Galletta & Cross, 2013). When using a semi structured method, the interviewee may offer solutions or insights that would have been overlooked if a structured interview had been used, thus offering a good combination of efficiency and exploration. Unstructured interviews, on the other hand, tend to risk spending lots of time talking about topics that lack interest for the study, because they are asked without a questionnaire or specified topics to discuss (Galletta & Cross, 2013).

Role	**Company or organization**
Production	Everfuel
Distribution	Everfuel
HRS	Hydrogen Sweden
End Use	Hydrogen Sweden

Figure 9: Summary of actors interviewed.

A total of three interviews were conducted, totaling more than three hours of interview time. As the different interviewees had different roles in the hydrogen value chain, the goal was to cover a wide spectrum of experiences and knowledge regarding the hydrogen development. The interviews were based on the same base of questions (found in Appendix) but the follow-up questions tended to vary a lot.

3.3.3 Workshop

In order to gather knowledge and shared experiences from the hydrogen industry, a workshop was held together with two industry experts from Vätgas Sverige. The goal was to map out different stakeholders along the hydrogen value chain and list them in order of how important they are for the investment process in each stage, as well as how they interact with each other in a Tier Model. The workshop was held for one hour.

A workshop is a short educational meeting in which a group of individuals engages in intense conversation and activity on a certain topic or project (Nash, 2010). There are many reasons for wanting to use a workshop as a way of gathering information and knowledge. Some of these advantages are the following (Nash, 2010):

- When the time for a more comprehensive effort is not available, a workshop gives a method to generate an intensive educational experience in a short amount of time.

- Fail-safe environment where participants can try new techniques and brainstorm ideas.

- Can serve to build a sense of community or common purpose among its participants, especially for those who work together.

There are however disadvantages with workshops as well, mainly the lack of time which is in the nature of a workshop (Nash, 2010).

3.4 Research quality

According to S. . Taylor (2013), validation in research entails a rigorous examination of logical reasons and empirical facts to see if they support theoretical assumptions.

As mentioned earlier, a qualitative research method was preferable for this study. Shenton (2004), on the other hand talks about the concerns regarding the acceptance of a qualitative research being trustworthy or not. One tool to be able to determine this is to use Guba's composition of four factors that affect the credibility of the research. These factors are credibility, transferability, dependability and confirmability. Investigators strive to exhibit credibility by demonstrating that a true picture of the phenomenon under investigation is being given. Further, Shenton (2004) argues that in order to facilitate transferability, the authors of the study present enough background about the fieldwork's context for a reader to determine whether the current scenario is similar to another context with which he or she is familiar, and whether the findings may be applied legitimately in that context. In qualitative research, achieving the dependability requirement is tough, but researchers should strive to make the study repeatable for future researchers (Shenton, 2004). Finally, in order to attain confirmability, researchers must show that their findings are based on the facts rather than their personal biases.

4. Findings

The findings from the interviews, literature studies and workshop are given in this chapter.

4.1 Findings from the Interview Study

During the study's interviews different aspects of hydrogen technology were discussed and findings were made. In general, it was said that ambitious and engaged stakeholders are a key factor to promote good cooperation and achieve synergies.
Regulations and clear guidelines are important, not necessary to speed up the development but to not hinder it. The private sector plays an important role as well, and most of all the different stakeholders need to cooperate in order to reach the scale of economies and successfully develop hydrogen technology.

It was said from multiple respondents that the public sector plays a huge role in the development of hydrogen. As of right now, a hindrance for the development are the lack of a framework of regulations and policies for hydrogen. A clear framework for the development of hydrogen solutions should be created by the public sector, making it easier and more evident for companies to invest in. It was both believed and expected that emission rules will become more strict, making hydrogen solutions more appealing and supporting the development is crucial. Furthermore, it was said that the public sector should financially encourage actors to invest in hydrogen solutions,at least in the early stages, because renewable hydrogen solutions and electrolyzers are expensive. It was proposed that the public sector could develop a business model which involves sharing the risk of investing in hydrogen at an early stage for private actors.

It was explicitly said that there is a perceived resistance today from the public sector in the development of alternative, sustainable transportation fuels, by not acting faster with the influence and control that the public sector actually has. The public sector incomes are currently heavily dependent on the system that currently exists for fossil-based fuels through various taxes and fees. By assisting hydrogen development with financial support, it could ultimately lead to decreased revenues and increased expenditures, which could be the reason why it is perceived as such.

The many possibilities of hydrogen and what it allows were discussed. One respondent saw many opportunities in involving hydrogen into the energy sector, through wind power parks or solar power. Hydrogen could help the energy sector by balancing the electricity grid by storing energy through hydrogen, and then using it when power is required. The breakthrough of hydrogen lies within the upscaling and economy of scale, which the respondent said could be sped up through using hydrogen cross-sectorial.

According to two of the respondents, there was no denying that the public sector plays a big role in development. However, the same is true for the private sector and local businesses. With big, market leading companies such as Volvo, SSAB, H2 Green Steel and LKAB, Sweden is in a good position for leading the development of hydrogen as a nation. There are already projects involving hydrogen deployed by these companies, indicating that a breakthrough is on its way.

4.2 The Blue Move

Several major insights on how hydrogen should be implemented on a larger scale and key factors to keep in mind were established during the project The Blue Move. Different areas were focused on to show the versatility of hydrogen beyond transportation, such as the use of hydrogen within the industry of renewable energies. The use of wind power for hydrogen production, grid stabilization, and energy storage in existing natural gas infrastructure offers an interesting business case. Because of the long-term benefit to society, the government and officials should promote support and reward initiatives for the commercialization of this sort of operation.

There are different things to consider depending on where in the value chain you are looking at. While looking at end-use of the hydrogen transportation value chain, a coordinated roll-out of FCEV and HRS is necessary, which was a key-finding for The Blue Move. For each HRS in Sweden and Norway there are about 10 cars, which is a small number.
The focus should therefore be on getting as many fuel cell cars out as possible and ensuring that they are used as much as possible. Users who drive a lot, such as taxi businesses, should be prioritized. The cost of site preparation and operation can be reduced by establishing a partnership with other fuels.

An important point made during the project was that larger, stationary HRS are profitable and more reasonable to invest in once the market has reached a steady volume with a steady growth and demand. Before this point, it is possible to use temporary HRS to stimulate the market and act as a catalyst for increased market development. It is recommended to see the temporary hydrogen filling stations as part of a larger business model where efforts are made to make the permanent infrastructure more profitable. Only small or temporary stations (without a larger plan) are not recommended in the first place.

One of the many key points made during the project was that there is no such thing as a "one-size-fits-all" solution. The strategy for buying or developing hydrogen refill stations is determined by the market to be served, and the solution chosen should match this. When selecting a technical solution, it is crucial to consider the demands and expectations of the end users. The development of local fleets and regular consumers provides a steady market. As a result, it makes sense to map and assist a local market or local fleets in order to establish regular consumers and therefore reduce project and investment risk.

4.2.1 10 Step Guide to Hydrogen Transportation

What steps do we need to take to get more hydrogen cars on the road? To help with the development of necessary infrastructure, the Blue Move Project has created a checklist with ten route options to help with possible hydrogen investments.

Step	Why?
1. Clusters before corridors	Local fleets need to be established within selected clusters and have infrastructure support before the focus is shifted towards the development of corridors. Allowing corridors to form as a means of connecting the clusters becomes reasonable. New jobs and industrial synergies can then be created more easily.
2. Individual car sales later - not first.	Hydrogen projects should aim for businesses such as taxis or municipal vehicles. This segment is characterized for high mileage and a low tolerance for long charging times, making other forms of electric vehicles less appealing.
3. Regional buses rather than local ones	When distances are greater than what can be covered by fast charging at terminals or nightly bus charging, hydrogen gives clearer benefits. Because commercially available hydrogen buses for regional routes are limited, this finding needs market development support.
4. Where the electricity grid is limited than strong	The demands on the energy system will be higher when converting to more intermittent electricity production. When the grid is weak, hydrogen's balancing potential is particularly appealing, as seen by huge cities like London and well-defined locations like Svalbard in Norway and Gotland in Sweden.
5. Cities rather than states	The trend indicates that cities or municipalities are leading the hydrogen conversion, often in close collaboration with local businesses. A greater focus on cities also makes it easier for cities to collaborate across national borders in regional clusters.
6. Slow can be better than fast	The advantage of fuel cell vehicles over BEV is their fast refueling time, however in other cases, a longer refueling time for hydrogen may be acceptable. Because the high fuel pressure is a significant cost driver. This could be relevant for public transportation, where the vehicles could be refueled during longer breaks.
7. As a part of BEV - Not instead of	FCEVs and BEVs can be a complement for each other. The different types of vehicles should be used where their benefits fit the most.
8. Where electrification is ineffectual	Railway lines have been electrified or run on diesel so far in railway history. More railway lines should be electrified for environmental reasons, however it is often not economically viable, and in other regions, electrification is impossible due to geography. The train can be emission-free with hydrogen.
9. Exporting electricity and	Several countries, like Sweden, have growing amounts of

create business development	intermittent electricity generated from renewable sources. Energy must be stored since the electricity network connecting countries is still underdeveloped. The electricity can be easily exported if it is stored in hydrogen. If the electricity is exported to countries with high emission levels the climate benefit can be significant.
10. Where the action is	Hydrogen as a transport fuel is now quite well established in some parts of the Nordic region.The Oslo region in Norway has the best accessibility, while Mariestad in Sweden are the top performer. This type of cluster offers a better foundation for further expansion and faster profitability than any theoretically developed strategy for where the most suitable expansion takes place since it is founded on local enthusiasm and drive.

Figure 10: 10 Steps to Hydrogen on the roads (Aronsson et al, 2018).

4.3 California Project

This chapter consists of three different reports regarding the development of hydrogen in California.

4.3.1 Hydrogen development 2019

As previously mentioned in the report, California is a state that has come a long way in its development and use of hydrogen, in relation to the rest of the world. According to an Annual Evaluation of Fuel Cell Electric Vehicle Deployment & Hydrogen Fuel Station Network Development by California Air Resources Board (CARB) in 2019, there is a network of 41 open hydrogen fueling stations that has established the early fueling market that enabled the launch of the FCEV consumer market in California. This development is something that continues and new stations are being scheduled. The report further explains that the FCEV market is being considered launched in a successful way and that this is a market that can be scaled up as it is considered to be viable.

To be able to launch and scale up a FCEV consumer market, the first step in the development, according to the report, is to establish refueling stations. The next step, partly in line with the development of the stations, is to form a fleet of vehicles. When this is established, both some form of grant programs and credit provisions are necessary to provide the station developers with ongoing support for both the capital-intensive costs of building a hydrogen fueling station and the cash-flow issues faced in the early years of FCEV implementation.

Throughout the report by CARB, grant fundings and credit provisions are two subjects widely discussed. This is an important role in the development, not least in the early stage to initiate the market development and therefore encourage private investment in own refueling stations by demonstrating profitability. This could be seen as a key success factor to the development of a hydrogen based road transport network.

It is being said that some disruptions in the hydrogen supply to the fueling stations had occurred during 2019 due to limited available production sites. This could be seen as a risk when it comes to the development and upscaling of the hydrogen infrastructure and usage. If there is no available hydrogen at the refueling stations, the consumer (user) will not be able to fill up their car which creates dissatisfaction and also difficulties in owning a FCEV. That being said, a prerequisite for the development is to ensure the availability of hydrogen. This is, most likely, only a problem in the early stages of the development. When the value chain is further developed there will be a larger amount of hydrogen supplifers. Thus, the risk of lack of hydrogen should be lower.

CARB also writes about the cross-sectoral opportunities and challenges that a developed hydrogen fueling network may involve or solve. For example, a way to include the hydrogen production from an electrolyzer is to use the overload of renewable energy that comes from an electrical grid, when the electricity generation outpaces the demand. Instead of either shutting down or disconnecting renewable generation devices, one could excess this overload of energy to an electrolyzer, which could, in a very effective way, convert the energy to hydrogen and store it for later use in different sectors. From an economical perspective, this could be seen as a positive investment factor which could increase the bankability of the electrolyzers and therefore the whole value chain of the hydrogen usage.

Down below, the findings of the report are being presented:

Finding 1	As of May 28, 2019, California’s hydrogen fueling network consists of 41 open retail hydrogen fueling stations, five more than reported at the same time last year. These are all markets likely to see the highest concentrations of FCEV first adopters.
Finding 2	Previous projections had anticipated that 40 hydrogen fueling stations would be available in the network by the end of 2018. By the end of last year, the network had 39 open hydrogen fueling stations. This shows that the projections reflect reality and thus the same method can also be used to project the continued development in a trustworthy way.
Finding 3	According to CARB's study of the most recent Department of Motor Vehicles (DMV) registration records available, California's FCEV fleet now consists of 5923 vehicles on the road. Auto manufacturer estimates indicate that acceleration will occur in the coming years.

Finding 4	A 200-station station network under EO B-48-18 (an executive order) gives up to three times the fueling capacity of manufacturers' current FCEV deployment expectations for 2025.
Finding 5	For the next round of Energy Commission grant money, CARB recommends a streamlined station placement. This strategy can take advantage of CHIT-led analysis already presented in the 2018 Annual Evaluation, and it's in line with EO B-48-aim 18's of 200 stations.
Finding 6	The overall FCEV market has launched and grown in a good way. It was also realized that not as many stations were needed as intended. However, in order to achieve State ZEV implementation and emission reduction goals, progress must be maintained and accelerated greatly.
Finding 7	CARB and the Energy Commission are working on a technique to establish the requirements for self-sufficiency in hydrogen fuelling networks in order to increase efficiency.
Finding 8	SB1505 (a senate bill) requires that the open and planned hydrogen fuelling stations comply with the renewable hydrogen requirements. Participation in the Hydrogen Refueling Infrastructure credit program of the Low Carbon Fuel Standard will help ensure compliance.

Figure 11: Findings from California projects of 2019 (CARB).

4.3.2 Hydrogen development 2021

CARB also recently published their Annual Evaluation of Fuel Cell Electric Vehicle Deployment & Hydrogen Fuel Station Network Development by California Air Resources Board (CARB) from 2021. According to the report, California's network now consists of 48 hydrogen refueling stations compared to 41 stations in 2019. The number of FCEVs are 7993 compared to 5923 in 2019.

It is also being said that the state agency California Energy Commission co-funds the development of retail hydrogen fueling stations until there are at least 100 stations operating in California. The CEC awarded up to $115.7 million in awards under this request on December 9, 2020, to co-fund the building of up to 94 new hydrogen refueling stations as well as renovations to four existing stations. Furthermore, private industry has already begun working on 8 stations without requesting state grant funding, and an additional 15 stations have subsequently been announced through totally private financing (for a total of 23 fully private stations planned or under development). This shows that private interest may increase when the overall infrastructure and usage of hydrogen is active.

To enable the FCEV population to increase at a faster rate in the future, the report addresses several challenges that need to be faced, including limited model availability, high FCEV prices, high hydrogen fuel prices, and limited consumer awareness. Also in this report, like the one from 2019, it is being told that a low station reliability had occurred during the year, mostly due to hydrogen supply chain disruptions. This is an issue that concerns and impacts today's drivers, and if not addressed, it could become a barrier to a continued FCEV adoption.

CARB's recent analysis shows that California's hydrogen fueling network has the ability to become financially self-sufficient by 2030. The rate of station development and cost reductions, FCEV deployment rates, and state funding are all important key factors in achieving self-sufficiency. In some ways, the network growth now planned for California resembles a route that leads to self-sufficiency if FCEV deployment accelerates in the future. Beyond the existing objectives, network development and FCEV deployment are crucial key factors that will play a big role in achieving that goal.

Down below, the findings of the report are being presented:

Finding 1	California’s hydrogen fueling network has grown to 52 stations, with 48 Open-Retail stations available for customer fueling in June, 2021.
Finding 2	CEC (California Energy Commission) estimates that by 2026 there will be a total of 176 stations established.
Finding 3	Planned network development will achieve the goals of AB 8 and narrow the gap to the target of Executive Order B-48-18. The target of EO B-48-18 is 200 stations by 2025 which means that this estimation does not not meet the requirements of the target.
Finding 4	California is planning to provide benefits of this hydrogen fueling network for everyone, regardless of the background for a community or an individual.
Finding 5	Through grant fundings efforts like the GFO-19-602 and others, the plan is to focus on developing emerging markets to fill gaps in the refueling network, but also to focus on already established markets.
Finding 6	Car manufacturer estimates that 30,800 FCEVs will be on the road as early as 2024. These projections demonstrate greater long-term development, compared to earlier.
Finding 7	Because there is a gap between network capacity and FCEV forecasts where the funded network could meet the fueling need of up to 250,000 FCEVs', car manufacturers now have the opportunity to deploy up to four times the number of FCEVs currently expected.

Finding 8	California's hydrogen network meets the requirements regarding the approved limit for what is renewable and non-renewable hydrogen (40% renewable).

Figure 12: Findings from California projects of 2021 (CARB).

4.3.3 Energy commissions guidelines

In order to develop the hydrogen usage in California, the Report of California Zero-Emission Vehicle Market Development Strategy by California Energy Commission from 2021 presents five principles to serve as the foundation for decision-making through their strategies.

The first principle is to make sure every decision is based on equity. One argues that people who are most affected by social, economic, and environmental problems are also the ones closest to the solutions. By meaningful involvement, it will be ensured that the market offers guaranteed benefits to people most impacted by the problems

The second principle is that California embraces all zero-emission pathways. Here it is emphasized that not only one solution should help all problems. Instead, support in forms of e.g policymaking, fundings and other decisions together with new technological solutions will lead the way for the development.

The third principle is collective problem-solving. Also here, engagement is emphasized. Collaboration between actors in the value chain should be prioritized.

The fourth principle is that public actions drive greater private investment to scale investable markets. In order to reduce private investment risks, public policies and actions should be utilized. An example of this could be to use fundings from public sectors to show a market profitability.

The fifth and last principle - design for resilience and adaptation. California is developing ZEV systems for the benefit of all and with an open mind. One strives to see the big picture and, for instance, support energy systems.

4.4 Value Chain

The following findings were made during our workshop concerning different stakeholders throughout the value chain and how crucial they are for the investment decision.

Value Chain	Production and Storage	Distribution	Refueling Station	End User/Car Fleet
Tier 1	Producing companies, distributors, energy companies (producers, both fossil and renewable energy), developers, operation & maintenance	Distribution companies, pipeline owners	Station owners	Vehicle manufacturers, consumer (business and private), public transport
Tier 2	Investors, licensors, landowners, politicians, municipalities, electrolyzer manufacturers, inspections	Truck owners, landowners, investors, operation & maintenance , surroundings/environment	Landowners, Investors, licensors, consumers, station producers, inspections, operation & maintenance, surroundings/environment	Policy (Environment bonuses etc.), component manufacturers, workshops (car service & maintenance), urban planning
Tier 3	Gas stations, component manufacturers	Component manufacturers (pipelines), licensors, "flatbed manufacturers", municipalities, investors, inspection of pipelines	Component manufacturers	

Figure 13: Table of value chain actors.

4.4.1 Production

While analyzing the production part of the hydrogen value chain it was made clear that the company who owns and produces the hydrogen will be listed as a tier one stakeholder together with the companies who are producing the electricity for the production. Investors, licensors and landowners are classified as a tier two stakeholder, among others. These divisions are made based on how close they are in the value chain facing the end consumer.

4.4.2 Distribution

It became known while studying the distribution part of the hydrogen value chain that the different stakeholders can have different tiers depending on how the hydrogen will be transported. There are, as previously mentioned, two ways of transporting hydrogen, by trucks or by pipelines. Right now hydrogen is mostly being transported by trucks in Sweden, but as the market grows and hydrogen is scaling up it will be more profitable with pipelines. Depending on which scenario is being looked at, there will be different stakeholders at tier two, such as landowner.

4.4.3 Refueling Stations

While researching the refueling station section of the hydrogen value chain, it was discovered that station owners are classified as tier one stakeholders. Capital coming from investors and licensors will have an impact as well, but is classified as a tier two stakeholder together with the landowner due to how close they are to the customers. The same goes with inspections and station producers.

4.4.4 End Use

The producers of the FCEV, the public transport sector as well as consumers (private and business) are ranked as tier one stakeholders. Policies from the public sector will have a big impact as well, but is classified as a tier two stakeholder.

5. Analysis

In this chapter the analysis of the findings are being made, together with a risk analysis for each step in the value chain.

5.1 PESTLE-Analysis for hydrogen based road transport

Below, a pestle analysis is being presented that shows factors that can affect the circumstances for a development of a hydrogen based road transport sector.

Figure 14: PESTLE-analysis for hydrogen based road transports.

5.2 Key Success Factors

The identified key success factors from the findings are being analyzed down below.

- ***Collaboration between stakeholders.*** In order to ensure that there is a reliable supplier of hydrogen, a reliable distribution company, enough refueling stations in operation and a reasonable number of hydrogen cars out on the road, some kind of collaboration is needed. This could be done as projects, where one or more actors from every part of the value chain including production, distribution, refueling stations and end user/car fleets is involved to make sure there will be a demand and supply. If there is a demand, but not a supply of hydrogen, there is no business case. Or in the worst case scenario, the end users are not able to fill up their car. If there is a supply, but not a demand, then the investments and projects could be seen as unnecessary. On the other hand, actors could try to push the demand when the supply is ensured.

- ***Upscaling to achieve cost reductions.*** As described in chapter 2.10, Ekins (2010) talks about how prices for different technologies vary in relation to what stage of the development phase it is in. For hydrogen in the transport sector, to compete, or at least to be more implemented in the market, cost reductions is a critical factor. Basically, all companies are driven by having a profitability which at the moment is hard, due to the high prices along the value chain for hydrogen. By upscaling the usage of hydrogen, lower prices will be reached and hence more business opportunities will be provided which benefits all stakeholders, including the end users due to the reduced emissions by for example going from a diesel car, to a hydrogen car. To make this possible, other factors must be achieved which is being analyzed later in this chapter.

- ***Integration with different sectors.*** By working on the development of the hydrogen transport road based sector, cost reductions will be reached within its time, provided that the usage of hydrogen increases and works well. To accelerate this process and hence expand the usage, the usage could be increased by integrating the techniques with sectors other than the transport sector. With this comes not only benefits in the form of a reduced price. With a greater area of application, more businesses and hence business models can be established and the overall knowledge and understanding about hydrogen and its applications is being known to the public, or at least more actors.

- ***Financial Support from the public.*** As mentioned in the second paragraph, things must be done to be able to achieve this upscaling. The difficulty is to remain profitable while introducing hydrogen cars due to the high prices along the value chain. For companies to be able to afford this, financial support from the public will be necessary, especially in the earlier stages of the development. This will enable the implementation of hydrogen vehicles, even though the companies results would be negative (at least for the hydrogen “segment”) for a certain period of time, but thanks to this support, the companies would still survive. Here, the idea is that when the development has come further and thus the cost reductions are achieved, the financial support could be gradually reduced.

- ***Framework policies.*** Since the hydrogen market is in an early stage of development, it is highly important to design an adapted framework of policies and regulations. According to Sweco (2021) there is a lack of laws, regulations and guidelines at national and EU level that leads to unclear conditions that can slow down the introduction of hydrogen. When one comes across any hindrance or difficulties in the development, it takes a lot of work and time to find solutions which are unnecessary and may even lead to the closure of certain projects. All of the work being done in the area of hydrogen utilization is critical at this early stage, and this framework is considered as a key success factor with the objective of not hindering, but encouraging effort and projects.

- ***Ambitious and engaged stakeholders.*** To have ambitious and engaged stakeholders may involve a great trust between the stakeholders. It could lead to a quicker pace of the projects. Actors may be more aware of common risks and increased overall awareness regarding circumstances that could affect the development may be reached. The market may be allowed to establish itself faster, new innovations and techniques may be discovered through a high level of ambition and finally it will promote a great teamwork through various aspects, for instance the opportunity to create common strategies.

To visualize from which sources the different key success factors were mentioned, an overview table is seen below. “-” means that it was not stated explicitly, however, it does not mean that this may not be the case.

Key Success Factors	***California***	***The Blue Move***	***Interviews***
Deploy more cars	✓	✓	-
Financial Support from the public	✓	✓	✓
Integration with different sectors	✓	✓	✓
Collaboration between stakeholders	✓	✓	✓
Upscaling to achieve cost reductions	✓	✓	✓
Framework update	✓	✓	✓
Ambitious and engaged stakeholders	-	-	✓

Figure 15: Key Success Factors.

5.3 Risks

Down below, the risks for each actor in the value chain is being presented and analyzed.

5.3.1 Production and Storage

A prerequisite for being able to produce hydrogen through electrolyzers is the accessibility to renewable energy. If this energy is not available, there is no possibility to produce hydrogen, thus, the risk in this scenario is the insufficient amount of renewable energy available. Another risk regarding the energy and electricity is the uncertainty of the price since it is due to external reasons. This means that an actor within the producing part could have unpredictable OPEX costs which also is seen in the economic part of the PESTLE-analysis. Another uncertainty and risk is the demand for hydrogen. This is based on the amount of refueling stations and the amount of hydrogen vehicles/users which is related to the social aspect in the PESTLE-analysis. Clearly said, there will be a lack of demand if there are no stations or end users.

5.3.2 Distribution

For an actor within the distribution area, two things are necessary to sustain the businesses. These are a safe access to hydrogen from the producing unit, followed by a demand from refueling stations. Hence, a risk may be either that there is an insufficient amount of hydrogen to distribute, or that there is a lack of or unpredictable demand for hydrogen from the refueling stations. Another risk could be any regulations that could hinder the distribution.

5.3.3 Refueling Station

The main risk is an insufficient amount of cars/users, then there is no hydrogen to deliver and therefore no business case. This is what decides the demand. When the demand is secured, it has to be ensured that there is hydrogen available from the distribution actors and that the downtime of the station operations is minimized, which is a challenging task when service and maintenance business is still in an early development phase. A further aspect to consider is how the local environment regarding the amount of already existing hydrogen refueling stations looks like. If there already is a high amount of established stations, it could be a risk since the competition will be high, although at the same time the customers who want to refuel their FCEVs will be offered a backup soluation when one station suffers from a temporary downtime. On the other hand, it could be seen as evidence that there is a business case and that there is a demand for hydrogen.

5.3.4 End User/Car Fleet

The most significant risk for the end users is if there is an insufficient amount of refueling stations. Obviously it means that users do not have a place to refuel their car, or they have to travel a long distance for it. Another risk is the uncertainty of the OPEX costs. For example, the hydrogen price is relatively high since it is so low-scale at the moment. Also maintenance costs may be uncertain since it requires extra knowledge from the workshops which tends to implicate higher prices. Further risk for FCEV owners is invertainty of residual value of their vehicle after a few years of ownership since fuel cell technology is perceived as niche in the second-hand vehicles market.

For the car fleet actors, a risk may be the fact that hydrogen (especially FCEVs) is not widely known in the population. Hence, there is a risk of insufficient number of potential buyers due to uneducated people. Another risk is the high purchase costs (CAPEX) for FCEVs, which is due to the low-scale situation. This leads to a low diversity among cars which could be seen as a risk for the manufacturers and fleet actors.

Actor	***Production and storage***	***Distribution***	***Refueling stations***	***End user/car fleets***
Risks	- Insufficient amount of renewable energy - Price Uncertainty - High OPEX costs - Low-scale	- Insufficient amount of hydrogen to distribute - Lack of or unpredictable demand for hydrogen from the refueling stations - Low-scale	- Insufficient amount of cars/users - Few distributors available - Low-scale	- Insufficient number of potential buyers - Insufficient amount of refueling stations - Uncertainty of the OPEX - High maintenance cost - Low-scale

Figure 16: List of risks.

Business risks are an inevitable part of doing any business and for the growing industry of hydrogen mobility the main ways to mitigate the risks are dedicated public support and implementing cross-sectoral integration, discussed further in the report.
As seen above, many risks depend on each other and therefore it is recommended that projects are carried out in connection/collaboration with each other to minimize the common risks. By this collaboration one can also see that if all actors get involved and engage, it benefits each actor.

5.4 Public Support

It has been said from the interviews, the reports from The Blue Move and projects in California that the public sector has an important role for the development of hydrogen transportation. During the study's workshop the public sector was identified as a stakeholder along most of the whole value chain as well.

Ekins (2010) made it clear that in theory, public interventions will be helpful (and sometimes necessary) for a technological change to happen. However, it was also said that technologies with a large potential social benefit can justify investment and financial support from the public, to which hydrogen technologies belong. It was seen during the development of hydrogen transportation in California that the public sector could demonstrate profitability for private investors, making the market and technology of hydrogen more attractive to invest in, thus accelerating the development which in return will have a social benefit.

Investing money into hydrogen must be more thoughtful from the public sector than by only contributing with initial capex. As previously mentioned, hydrogen is early in the technology-development S-curve, which indicates a high unit-cost. Opex will be high and demanding for businesses to deal with at an early stage without an established financial support from the public sector. Developing business models that help investors and stakeholders with capex and opex will be a key success factor for mitigating their business risks.

5.5 Cross-Sectoral Integration

Based on interviews and results from The Blue Move and projects from California it has been clear that an aspect of hydrogen to take in consideration is the ability to integrate with different sectors, for example the energy sector. Hydrogen will act as a buffer for the fluctuations in demand and supply for renewable energy from wind power. As the wind turbine is producing more than what the grid can use, hydrogen will be produced on-site and stored. The stored hydrogen can be used to supply the end goal of the wind turbine or to be transported and used in any of the other uses of hydrogen, such as hydrogen vehicles.

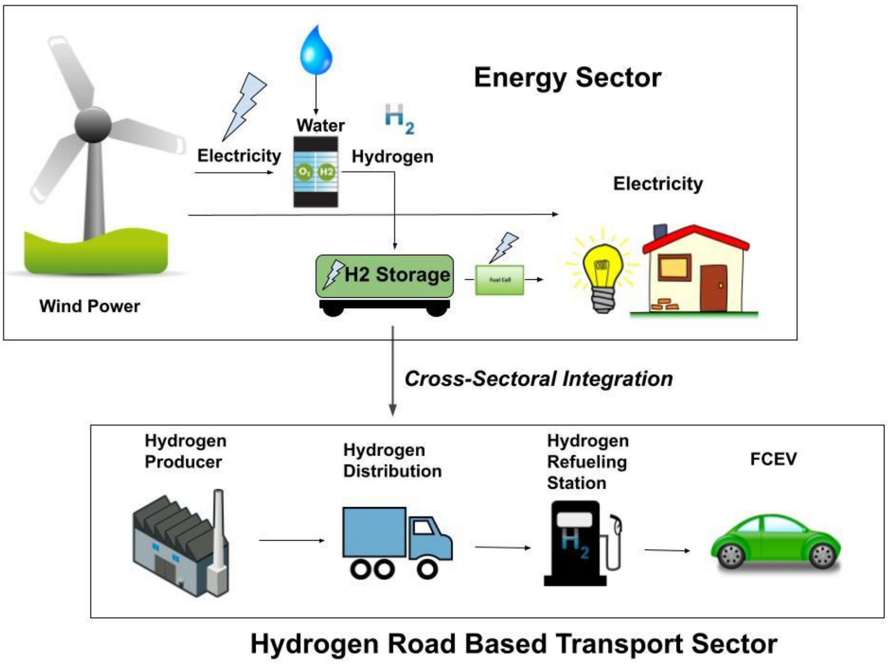

Figure 17: Cross Sectoral Integration between Hydrogen Transport Sector and Energy Sector.

It is possible for the hydrogen road based transport sector to have an integrated supply chain together with the energy sector and wind power, thus a cross-sectoral integration. This would lead to a more stable supply of hydrogen which will benefit the fast-growing market. There are other ways for the sectors to integrate as well to create synergies. Shared business models, shared competence, shared facilities or participating in the same projects as a collaboration are other possibilities.

With a solid base load for the renewable hydrogen production, there will be a greater amount of hydrogen to depreciate the investment over. It is crucial to utilize hydrogen in all its areas of use to support the development of hydrogen-based transports. This has been noted to be an important factor for a successful implementation of hydrogen on the roads and could help the market reach a production price of 15 SEK per kilogram by 2030 as the CEO of Enapter claimed (Jenné & Pecqueur, 2021). The authors explained that the cost of creating renewable hydrogen depends mainly on two factors, the price of the electricity and the price of the electrolyzers. It is primarily the cost of electrolyzers that would decrease through a cross sectoral integration with the energy sector, as the technology for renewable energies have developed further in the S-curve than electrolyzers have.

It was said from one of the interviews that the breakthrough of hydrogen lies within upscaling the technology, reaching economies of scale. Cheaper electrolyzers, established pipelines for cheap hydrogen distribution and a well developed car fleet with many hydrogen refill stations. Such a scenario would be a good complement to the existing BEV infrastructure and a strong competitor to the fossil fuel transports market. However, to reach this point of high renewable hydrogen use and demand, thus the low unit price of hydrogen, within the transportation sector it is possible to accelerate the development with the support of hydrogen within other sectors.

6. Discussion

During the work, we came across a lot of information, findings, recommendations etc. Based on this, we have identified several different key success factors for future projects and development of the hydrogen usage in the transportation sector. The different factors and risks have been reviewed by us in order to present the most relevant and significant. The reports and interviews have been of equal value for us, so when all three sources agree on similar success factors it has been highly valued by us. The projects and interviews all agreed on the importance of the public sector for the development, thus it was concluded that it was a key success factor. However, many great points and arguments were made from each individual project and each interview as well that did not make it to the final, due to the lack of resonance from the other sources.

While analyzing two different hydrogen projects in regards to finding key success factors it has become clear that there are differences between the two projects. They were carried out in different environments, with different conditions and different rules and regulations. One in California and the other one around Sweden. As of 2021, there are 48 functional hydrogen refueling stations, while in Sweden there are a total of four operational stations spread across the country. This difference implies that it is easier to own and live with a FCEV in California than it is in Sweden, indicating that the development has come further. However, the project reports show similar key success factors despite the different conditions that they are deployed in. According to us, this gives the study credibility in our findings, and could indicate that the development of hydrogen in a different area or country would have use of and consider our findings.

Since this study deals with such a large area, there are of course completed projects that this study does not take into account. However, as mentioned above, many findings were similar even though they are based on different conditions which could indicate that other projects also result in similar findings. If the findings from other completed projects differ or look the same, we leave for future studies.

While looking and examining previous projects and their reports to learn from their experiences, information and data is coming from the companies or projects themself without being peer reviewed or examined from an independent source. There may be an interest in how data and information are presented and angled, for example to influence investors. This was important for us to have in mind.

In order to find a stronger confidence in the conclusions from the interviews, more had to be done, as three interviews could lead to less objective results. However, while combining different types of data such as interviews and literature reviews, it is possible to minimize bias influences.

Regarding the investments, except from the purchasing or manufacturing investments, it may also require investments from car manufacturers or car fleet companies to raise interest and demand for hydrogen cars. In California, Toyota offers everyone who buys their hydrogen car Toyota Mirai complimentary fuel for up to six years or $15,000, whichever comes first (Toyota, 2022). Similar offers here in Europe, together with the development of the infrastructure we think could promote the usage and attract new customers. Similar offers in forms of free life-time charging were given by Tesla back when battery cars were not as common as they are today and it can be discussed that it may well be a factor that contributed to it becoming so popular and large-scale. A prerequisite for this is to have available refueling stations, in the same way as the Tesla charging stations needed to be available. Of course, many other factors also affected the development of battery cars.

As a recommendation for future projects, based on our learnings through the different projects reviewed and the knowledge gathered from interviews we would like to highlight the impact a contribution in the form of free access to hydrogen refueling can mean for the users of hydrogen-powered cars. In our opinion, this can increase the interest of the general public about hydrogen cars and thus realize that you can contribute to the climate, while refueling the car for free. Whether this contribution is best suited as a subsidy, funded from the state directly to a car manufacturer, or an investment from the car manufacturer themselves could be discussed further. This could create a larger demand for hydrogen cars, which in turn creates a larger demand for hydrogen overall, resulting in economies of scale, leading to decreasing all the costs along the value chain for each actor.

Speaking of decreasing costs along the value chain, we recommend examining the opportunities to cross-sectoral integration of the hydrogen transportation sector with other sectors, mainly the energy sector. More practically, this could be done in several ways. One way is to use the overload of renewable energy that comes from an electrical grid when the electricity generation outpaces the demand. Instead of either shutting down or disconnecting renewable generation devices, one could excess this overload of energy to an electrolyzer, which could, in a very effective way, convert the energy to hydrogen and store it for later use in different sectors. By doing this, the usage and demand will increase and in that way lower prices along the value chain will be reached due to the upscaling and all actors along the chain will be benefited. There are also many other ways to utilize this cross-sectoral integration, but this is something we leave to other studies.

It was stated during the interviews that taxes and fees from fossil fuels constitute significant income for the public. By assisting hydrogen development with financial support, it may result in lower revenues and more expenditures, as we believe that the development may depend on the support by the public sector. We further believe that there might be a conflict of interest between different departments of the government. We assume that the Ministry of the Environment wants to promote hydrogen-based road transportation, but that the Ministry of Finance does not want to prioritize it as strongly because it would result in lower tax revenues. Ultimately, the Ministry of Finance is in charge of the capital needed for developing hydrogen.
After all, it is in the public's interest to create a post-fossil society, which includes sustainable transportations. It is possible to discuss what obligations the public sector has. We believe that the public should prioritize faster development because the technology already exists. Long-term sustainability goals and future generations must be given priority over short-term economic goals.

7. Conclusion

This report set out to identify key success factors to take into consideration for later projects. Down below, the most relevant and significant is being presented:

- It was found that a collaboration between the actors in the value chain is needed, due to the market for green hydrogen transports being heavily dependent on minimizing business risks. To clarify - building and establishing hydrogen refueling stations without a supply and demand of hydrogen can be riskful. Both from an investment perspective and a usage perspective, there has to be available refueling stations for the cars to be filled with gas. In the same way, there has to be a producing unit to supply the stations with gas. Through this collaboration, cost reductions will also be reached due to the increased usage.

- The study shows that fundings and grants from the public sector are needed for the development. This will not only promote and enable the development itself, but also encourage private investments which contribute to a further development.

- It was discovered that a key success factor is ambitious and engaged stakeholders. Stakeholders must all contribute, and the project's overall success should benefit each individual stakeholder.

- It was also said that a framework of regulations and policies need to be updated in order to support the development and not hinder it.

- It was also found that by increasing the use of hydrogen through integration with other sectors such as the energy sector, the production and transportation cost of hydrogen will be lowered which contributes to a further development in many aspects.

- Every stakeholder needs to be aware that there might be a conflict of interest between the Ministry of Finance and the Ministry of the Environment, due to the current tax system and the high revenues from the transport sector. Praises from the public sector means nothing if no financial support takes place. This can affect the development of hydrogen.

References

Bergman, M., M. (2008)., *The Straw Men of the Qualitative-Quantitative Divide and Their Influence on Mixed Methods Research., SAGE Publications Ltd.*
Retrieved from: https://dx.doi.org/10.4135/9780857024329.d3

Brand, C. (2021). *7 Reasons why Global Transport is so hard to Decarbonize.*
World Economic Forum. Retrieved from:
https://www.weforum.org/agenda/2021/11/global-transport-carbon-emissions-decarbonise/

California Air Resources Board. (2021). *2021 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development.* Retrieved from:
https://ww2.arb.ca.gov/sites/default/files/2021-09/2021_AB-8_FINAL.pdf

California Air Resources Board. (2019). *2019 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*. Retrieved from:
https://ww2.arb.ca.gov/sites/default/files/2019-07/AB8_report_2019_Final.pdf

CARB. (2020). *2020 Annual Evaluation of Fuel Cell Electric Vehicle Deployment & Hydrogen Fuel Station Network Development.* Retrieved from:
https://ww2.arb.ca.gov/sites/default/files/2020-09/ab8_report_2020.pdf

Corbo, P., Migliardini, F., Veneri, O. (2011). *Hydrogen Fuel Cells for Road Vehicles. Green Energy and Technology.* Springer. Doi: https://doi.org/10.1007/978-0-85729-136-3

Dahllöf, L. & Emilsson, E. (2022). *Ny Rapport om Elbils Batteriers Klimatpåverkan.* Svenska Miljöinstitutet. Retrieved from:
https://www.ivl.se/toppmeny/press/pressmeddelanden-och-nyheter/pressmeddelanden/2019-11-28-ny-rapport-om-elbilsbatteriers-klimatpaverkan.html

Department of Energy. (n.d). *Hydrogen Production: Electrolysis.*
https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis

Ekins, P. (2010). *Hydrogen Energy: Economic and Social Challenges.*
Taylor & Francis Group. Retrieved from:
https://ebookcentral.proquest.com/lib/chalmers/reader.action?docID=517191

Fossilfritt Sverige. (2021). *Vätgasstrategi för fossilfri konkurrenskraft. En strategi av Fossilfritt Sverige.* Fossilfritt Sverige. Retrieved from: https://fossilfrittsverige.se/strategier/vatgas/

Fuel Cells and Hydrogen. (2019). *Hydrogen Roadmap Europe: A Sustainable Pathway for the European Energy Transition.* Joint Undertaking. Retrieved from:
https://www.fch.europa.eu/publications/hydrogen-roadmap-europe-sustainable-pathway-european-energy-transition

Galletta, A. (2013). *Mastering the Semi-Structured Interview and Beyond*. New York University Press,. Retrieved from: https://ebookcentral.proquest.com/lib/chalmers/detail.action?docID=1187368

Godula-Jopek, A. & Stolten D. (2015). *Hydrogen Production: By Electrolysis.* John Wiley & Sons, Incorporated. Retrieved from: https://ebookcentral.proquest.com/lib/chalmers/reader.action?docID=1956440#

Gupta, R., B., Basile, A., Nejat Veziroğlu, T. (2015). *Compendium of Hydrogen Energy*, Volume 2: Hydrogen Storage, Distribution and Infrastructure. Woodhead Publishing. Retrieved from: https://doi.org/10.1016/C2014-0-02673-1

Hecht, E., Pratt J. (2017). *Comparison of conventional vs. modular hydrogen refueling stations, and on-site production vs. delivery.* U.S. Department of Commerce. Retrieved from: https://www.energy.gov/sites/prod/files/2017/03/f34/fcto-h2first-reference-station-phase2-2017.pdf

Hybrit Development. (2022). *Fossilfritt stål – en gemensam möjlighet!.* https://www.hybritdevelopment.se/

International Energy Agency. (2019.) *The Future of Hydrogen. Seizing today's opportunities.* Retrieved from: https://www.iea.org/reports/the-future-of-hydrogen

Jenné, P. & Pecqueur, M. (2021). *Running on Water. The Hydrogen Way. (First edition)*. Drukkerij M. Janssens, Melsele. Retrieved from: https://ebookcentral.proquest.com/lib/chalmers/detail.action?docID=1051585

Jobber, D. & Ellis-Chadwick, F. (2019)., *Principles and Practice of Marketing"* (9th Edition)., McGraw-Hill Education (UK) Ltd.

Nash, R. (2010). *The Active Workshop: Practical Strategies for Facilitating Professional Learning.* Sage Publications.

Nordic Hydrogen Corridor. (2022). *Nordic Hydrogen Corridor.* https://nordichydrogencorridor.com/nordic-hydrogen-corridor/

Nordic Hydrogen Partnership. (n.d). *Greener transport in the Nordic region with hydrogen initiative.* http://www.nordichydrogenpartnership.com/nhc/

Osterwalder, A., Pigneur Y., Bernarda G., Smith, A., Papadakos T. (2014). *Value Proposition Design: How to Create Products and Services Customers Want, 2014.* Retrieved from: *https://ebookcentral.proquest.com/lib/chalmers/detail.action?docID=1887760*

Ovako. (2021). *Fossilfri vätgassatsning av Ovako, Volvokoncernen, Hitachi ABB Power Grids Sverige, H2 Green Steel och Nel Hydrogen.* https://www.ovako.com/sv/nyheterevents/nyheter--pressmeddelanden/ovako-press-release-detail/?releaseId=DF2A5B58DD20AB4E

Ovako. (n.d). *Ovako först i världen att värma stål med vätgas.*
https://www.ovako.com/sv/nyheterevents/nyheter--pressmeddelanden/ovako-press-release-detail/?releaseId=FF22FD2DE0198640

Porter, M, E. (1985.), *Competitive Advantage, Creating and Sustaining Superior Performance,* Chapter 1. THE FREE PRESS, A Division of Macmillan, Inc.
Retrieved from:
https://www.albany.edu/~gs149266/Porter%20(1985)%20-%20chapter%201.pdf

Report of California Zero-Emission Vehicle Market Development Strategy by California Energy Commission, 2021
https://static.business.ca.gov/wp-content/uploads/2021/02/ZEV_Strategy_Feb2021.pdf

Shenton, A., K. (2004)., *Strategies for ensuring trustworthiness in qualitative research projects*. Education for Information.

Solér, A., Bye, Å., Aronsson, B., Wiberg, E., Leisner, P., Cornander, A., Nilsson, K., Alexanderson, A., Eriksen, J., Carsten, J., Lyche, E., Kalland, L., Goldmann, M., Pervik, M., Tibbelin, A., Baden, N. (2018). *The Blue Move for a Green Economy. Ramvillkor och strategier för vätgas inom transportsektorn.* Vätgas Sverige.

Taylor, C., S. (2013), *Validity and Validation.* Oxford University Press.
Retrieved from: https://ebookcentral.proquest.com/lib/chalmers/detail.action?docID=1480995

Vätgas Sverige. (n.d). *Om oss*. Retrieved from: https://vatgas.se/om-oss/

Vätgas Sverige. (2016). *Ren energi med Vätgas.*

Statistiska Centralbyrån. (2016). *Utsläppen från transporter en växande utmaning.* Statistikmyndigheten.

Stein, C. & Barron, J. (2017). *Mapping Actors along Value Chains: Integrating Visual Network Research and Participatory Statistics into Value Chain Analysis.* Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE). 24p. (WLE Research for Development (R4D) Learning Series 5). doi: 10.5337/2017.216

Toyota. (2022). *Mirai.*
https://www.toyota.com/mirai/

Zohuri, B. (2019). *Hydrogen Energy - Challanges and Solutions for a Cleaner Future.* Springer International Publishing AG. Retrieved from:
https://doi.org/10.1007/978-3-319-93461-7

Appendix

Interview Guidelines

- How do you view the general knowledge about hydrogen today in Sweden?

- What do you think is hindering the development of hydrogen?

- Is there a step in the hydrogen value chain where you think the public (EU, government, municipality) needs to play a bigger role than in others?

- How do you think the development of renewable hydrogen refueling infrastructure can benefit from integration with different sectors, i.e. transport-, energy-, industrial sector?

- In your previous project linked to hydrogen, what did you see for success factors and risks linked to:

    - Production and storage
    - Distribution
    - Hydrogen Refill Station
    - End use
    - In general