

GREEN HYDROGEN FOR THE ROAD TRANSPORTATION SECTOR IN THE  
EUROPEAN UNION

A TECHNOLOGICAL INNOVATION SYSTEM ANALYSIS

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## Resumo

Título: Hidrogênio verde para o setor de transporte rodoviário na União Europeia uma análise do sistema de inovação tecnológica

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Objetivo: Esta tese tem como objetivo identificar os principais desafios e oportunidades associados à implementação do hidrogênio verde (GH<sub>2</sub>) na União Europeia (UE) no setor de transporte rodoviário. A pesquisa utilizou a estrutura do Sistema de Inovação Tecnológica (TIS) como ferramenta para analisar a implementação do GH<sub>2</sub> e explorar seu potencial de contribuição para um futuro descarbonizado.

Metodologia: Foi realizada uma revisão abrangente da literatura para estabelecer a base teórica da estrutura do TIS e reunir percepções sobre o GH<sub>2</sub>. Também foram realizadas entrevistas com especialistas e partes interessadas do setor de transporte rodoviário, do setor de GH<sub>2</sub> e dos setores de políticas para obter percepções práticas e apoiar as conclusões da análise da literatura.

Resultados: Os resultados destacam os desafios na implementação do GH<sub>2</sub> em todas as funções do TIS. Os desafios identificados incluem requisitos financeiros fundamentais, falta de conscientização pública, disponibilidade de recursos, dinâmica de oferta e demanda, limites regulatórios e a necessidade de infraestrutura. Além disso, foram identificadas várias oportunidades de desenvolvimento: de padrões de segurança, aumento das iniciativas de colaboração e o apoio do governo.

Limitações: A transição para o GH<sub>2</sub> foi identificada como uma alternativa de longo prazo, prometendo energia mais limpa, redução das emissões de gases de efeito estufa (GHG), possível crescimento econômico e maior segurança energética. A pesquisa conclui que um esforço coordenado de várias partes interessadas é fundamental para superar os desafios identificados, e a UE pode aprender com países com setores de GH<sub>2</sub> mais maduros para apoiar a transição.

Palavras-chave: Hidrogênio verde, transporte rodoviário, sistema de inovação tecnológica, desafios, oportunidades, implementação, União Europeia

## Abstract

Title: Green Hydrogen for the road transportation sector in the European Union  
– A Technological Innovation System Analysis

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Purpose: This thesis aims to identify the key challenges and opportunities associated with implementing green hydrogen (GH<sub>2</sub>) in the European Union (EU) road transportation sector. The research used the Technological Innovation System (TIS) framework as an analytical tool to analyze the implementation of GH<sub>2</sub> and explore its potential for contributing to a decarbonized future.

Design/methodology/approach: A comprehensive literature review was conducted to establish the theoretical foundation of the TIS framework and gather insights into the existing literature on GH<sub>2</sub> technology. Expert interviews were also conducted with stakeholders from the road transportation sector, GH<sub>2</sub> sector, and policy sectors to gain practical insights and support the findings from the literature review.

Findings: Findings underscore the challenges in GH<sub>2</sub> implementation across all TIS functions. These highlighted technological and infrastructural challenges, elevated costs, regulatory limits, and the necessity for increased public acceptance. Specific challenges identified include fundamental financial requirements, lack of awareness about the availability of resources, supplydemand dynamics, and public acceptance. Furthermore, several development opportunities have been identified, including developing safety standards, increased collaboration initiatives, and government support.

Implications: Despite its complexity, the transition to GH<sub>2</sub> was identified as a potential long term alternative, promising cleaner energy, reducing greenhouse gas (GHG) emissions, potential economic growth, and enhanced energy security. The research concludes that a coordinated, multistakeholder effort is crucial to overcome the identified challenges, and the EU can learn from countries with more mature GH<sub>2</sub> sectors to support the transition.

Keywords: Green Hydrogen, Road Transportation, Technological Innovation System, Challenges, Opportunities, Implementation, European Union

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## List of Abbreviations

CBAM	Carbon Border Adjustment Mechanism
CO <sub>2</sub>	Carbon Dioxide
ETS	Emission Trading System
EU	European Union
EV	Electric Vehicles
FCEV	Fuel Cell Electric Vehicles
FCV	Fuel Cell Vehicles
GHG	Greenhouse Gas
GH <sub>2</sub>	Green Hydrogen
GW	Gigawatt
H <sub>2</sub>	Hydrogen
IRA	Inflation Reduction Act
MW	Megawatt
OEMs	Original Equipment Manufacturers
R&D	Research and Development
R&I	Research and Innovation
TIS	Technological Innovation System

## Introduction

As the successful implementation of green hydrogen (GH<sub>2</sub>) for the road transportation sector in the European Union (EU) faces various challenges and requires a comprehensive understanding of the dynamics involved, this thesis will conduct the following research question, which was developed based on the Technological Innovation System (TIS) framework and its seven functions developed by Bergek et al. (2008):

“What are the key challenges in implementing green hydrogen for the road transportation sector in the EU, as perceived through the lens of the Technological Innovation System framework's seven functions?”

## Contextualization

According to the IEA (2021), the COVID19 epidemic rapidly reduced worldwide energy demand, and global CO<sub>2</sub> emissions from various fuel types recorded an extraordinary reduction of approximately 6% in 2020. Oil made up 29% of all fossil fuels that made up the total energy supply in the world, followed by coal (27%) and natural gas (24%). Coal accounted for 45% of all fuel-related emissions globally, followed by oil (32%) and natural gas (22%). The EU is behind the United States and China in third place in total greenhouse gas (GHG) yearly emissions.

While GHG emissions in the EU decreased by 32% between 1990 and 2020 across various industries, including energy and manufacturing, emissions from the transportation sector defied the trend and increased by 7% during that time. Moreover, the EU has pledged to have more than cut half its current greenhouse gas emissions by 2030 with agendas like the EU Green Deal. (Masterson, 2022)

The road transportation sector significantly contributes to GHG, and the urgent need to decarbonize this sector has become an increased priority. One promising solution is the implementation of GH<sub>2</sub> technology, which has the potential to revolutionize the road transportation sector by providing a clean and sustainable energy source. GH<sub>2</sub> is produced through different production types that further define the colorcoding (see Figure 1). At the same time, this thesis will focus on electrolysis using renewable energy sources, such as wind power, solar power, and hydropower. It is considered a clean and sustainable energy carrier that can be used as fuel for various modes of transportation, including road transport. (IEA, 2019)

The EU has set ambitious targets to reduce GHG emissions by 55% by 2030 and achieve netzero emissions by 2050. To achieve these targets, it is crucial to identify and implement sustainable solutions in the transportation sector, responsible for approximately one quarter of the EU's GHG emissions. (Panarello & Gatto, 2023) Therefore, implementing GH<sub>2</sub> in the road transportation sector could be a significant step toward achieving these targets.

The ongoing conflict in Ukraine and the geopolitical tensions between Russia and the EU have highlighted the importance of energy security and reducing dependence on fossil fuel imports. Therefore, GH<sub>2</sub> in the road transportation sector can contribute to energy diversification, enhance energy independence, and strengthen the EU's resilience in such conflicts. (Nerlinger & Utz, 2022) Furthermore, the recent passage of the US Inflation Reduction Act (IRA) has created a competitive investment environment for cleantech subsidies presenting opportunities for collaboration and resource mobilization between the EU and the US in GH<sub>2</sub> technology. (Bilan et al., 2023)

### Research Theme

This research aims to identify the key challenges associated with implementing GH<sub>2</sub> in the road transportation sector in the EU. By analyzing the dynamics through the lens of the TIS framework developed by Bergek et al. (2008), this study aims to provide insights into the factors influencing the adoption and diffusion of GH<sub>2</sub> technology in the EU. Additionally, coming from the results of the conducted Interviews, this thesis will also give some recommendations on overcoming the presented challenges.

### Theoretical Relevance

The TIS framework offers a comprehensive and structured approach to understanding technological innovation and diffusion complexities. By applying the TIS framework to the context of GH<sub>2</sub> implementation in the road transportation sector, this research contributes to the theoretical understanding of how technological transitions develop in the road transportation sector. Furthermore, it presents the specific challenges and opportunities related to GH<sub>2</sub> diffusion.

### Managerial Relevance

The findings of this research will have practical implications for policymakers, stakeholders in the road transportation and GH<sub>2</sub> sector, and researchers involved in the development and deployment of GH<sub>2</sub>.

## Dissertation Structure

This dissertation is structured into several sections. The first section provides an overview of the research context, highlighting the need for GH<sub>2</sub> implementation in the road transportation sector. The second part presents a comprehensive review of the relevant literature, focusing on the TIS framework and the challenges associated with GH<sub>2</sub> implementation. The third section describes the research methodology, including the research design, the data collection, and the data analysis. The fourth section presents the findings from the expert Interviews, identifying the key challenges and opportunities across the TIS functions. In contrast, the fifth section discusses the results of the conducted Interviews with the findings from the literature review. Finally, the conclusion summarizes the main findings and contributions, answers the research questions, and provides future research and action recommendations.

## Literature Review

### The Technological Innovation System (TIS) framework

The success of a sustainability transition in the EU's road transportation industry depends on two critical interconnected mechanisms. First, new transportation technologies must create viable alternatives to traditional fossil fuels. Secondly, the road transportation industry must begin using the latest energy technology of GH<sub>2</sub>. (Guarierio et al., 2022)

As the technology around GH<sub>2</sub> is already developing in the EU and needs to be further implemented, this chapter will present the technology of GH<sub>2</sub> analyzed along the TIS framework. First, the TIS will be structured into a structural analysis of the value chain, the central actors and networks, and the Institutions involved in implementing GH<sub>2</sub>. Following this, the functional analysis will provide an overview of specific categories of the framework first developed by Bergek et al. (2008).

The reason and background for choosing the TIS framework are that for years this framework has been one of the critical methods in the studies of sustainability energy transitions to examine the early stages of new renewable energy technologies, such as GH<sub>2</sub>. (Bergek et al., 2015)

The TIS framework will in this thesis focus on the exchange of knowledge between the public and private sectors, the development of infrastructures and institutions, as well as the diffusion of knowledge. Mapping the players, networks, and institutions will be the first step in TIS framework analysis. The examination will serve as the foundation for the discussion and recommendations in this thesis's conclusion and further help answer the research question. (Bergek et al., 2015)

Such recommendations will be further based on the system's advantages, such as innovative corporate practices or forwardthinking governmental policies, from interviews conducted with experts from different fields. The goal of the TIS analysis is to explore the challenges and opportunities of the technology of GH<sub>2</sub> and ultimately contribute to answering the research question. (Bergek, Jacobsson, et al., 2008)

Table 1 will highlight the functions and categories developed by Bergek et al. (2008) and Bergek et al. (2015). Along these functions, the challenges and upcoming opportunities of the technology will be explored.

Table 1: TIS Framework Functions (Bergek, Jacobsson, et al., 2008) & (Bergek et al., 2015)

Function	Description
Knowledge Development and Diffusion	To develop new technologies, different actors need to illuminate the processes to understand the new technology better. This can be done through research, experimentation, or observation. Once new knowledge is created, sharing it with other actors is essential. This can happen through things like scientific publications, conferences, and workshops.
Influence on the Direction of Search	When actors try to create new technology, they are guided by things like what has worked in the past, what society needs, what businesses want, and what the rules are. These things help actors to decide what kind of new technology to create.
Entrepreneurial Experimentation	This function involves testing out new concepts to evaluate if they are effective. It entails taking chances and putting innovative technology to the test in practical applications. Entrepreneurs are those that do this role, and they frequently find new businesses to create and market cuttingedge technologies.
Market Formation	Once new technology is developed, it is crucial to create a market for it so that actors will buy and use it. This function involves things like marketing, sales, and distribution.
Legitimation	This function ensures that new technology is accepted and recognized by other actors. This can happen through government regulations, industry standards, and public opinion.
Resource Mobilization	Since creating new technology can be expensive, having the necessary tools, personnel, and financial resources is critical. The main goal of this function is to gather the materials required to develop new technology.
Development of positive Externalities	This function aims to create synergies along new technology that can have positive side effects throughout the development of the technology, which finally contributes to the diffusion of the technology

## The TIS analysis for green hydrogen and the road transportation sector in the EU

This part of the literature review will now focus on applying the TIS framework introduced in the previous part of the chapter. First, it is essential to introduce and provide an overview of the road transportation sector, the technology surrounding GH<sub>2</sub>, and its relevance for the energy transition within the sector before delving further into the structural and functional analysis of the new technology for the EU's road transportation sector.

As the road transportation sector is one of the most significant emitters of GHG, with about 16.2% of global total energy carbon emissions, the need to decarbonize and move towards a low or even zerocarbon industry gains more and more attention. (Shi et al., 2022) The road transportation sector within the EU accounts for about 26% of all carbon dioxide (CO<sub>2</sub>) emissions. (Statista, 2023) The thesis will define the range of transport techniques frequently employed in the EU while looking more closely at the road transportation sector inside the EU. In particular, we can distinguish between cars, motorbikes, lightduty trucks, heavyduty trucks, and other forms of road transportation, but mainly between passenger and freight transport. (European Commission, 2022a)

In 2020 cars and heavyduty trucks accounted for the most significant shares of CO<sub>2</sub> emissions within the EU. (European Commission, 2022a)

Hydrogen (H<sub>2</sub>), particularly GH<sub>2</sub>, can be seen as one of the most promising technologies for decarbonizing different industries. It has excellent potential to significantly reduce GHG emissions in various sectors, such as road transportation. (Hosseini & Butler, 2020) In general, H<sub>2</sub> can be a substitute energy source in various applications. Moreover, its applications can be seen as viable sources of fuel for vehicles, either for Fuel Cell Vehicles (FCV) or Fuel Cell Electric Vehicles (FCEV), that offer advantages for both passenger and freight transport. (Salvi & Subramanian, 2015)

Other studies from Oliveira et al. (2021) indicate that FCEVs and FVCs, which only use hydrogen and oxygen from the air and emit just water vapor, can compete with other fuel options like batteryonly vehicles. This study further states that more than 20.000 FCEVs, like cars, buses, or even trucks, are already on the road in the EU.

Almost all hydrogen is produced from natural gas by separating and recombining hydrogen molecules from methane and water in a process called steam methane reforming, especially in the transportation sector. Although wellestablished, this process consumes much energy and releases carbon dioxide into the environment if not caught and stored. With this

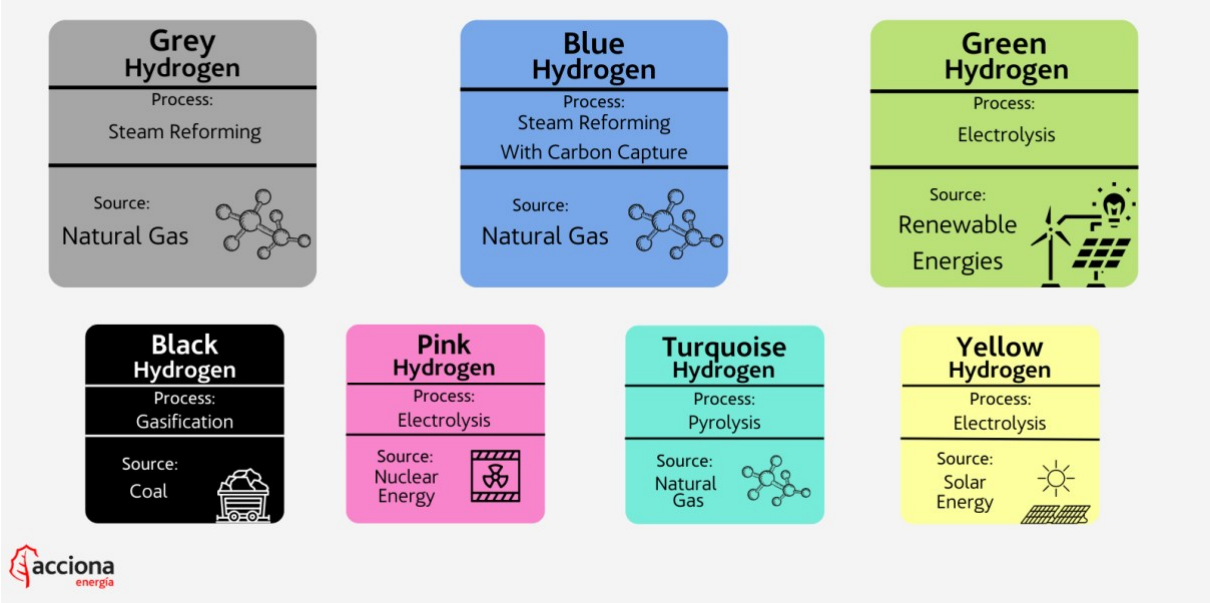
process, H<sub>2</sub> is well known for the colorcoding grey, blue, or even turquoise. Grey and Blue H<sub>2</sub> are both colors of H<sub>2</sub> that follow the production process of steam reforming while using natural gas as a source for creating the H<sub>2</sub>. The main difference between the two colors is that blue H<sub>2</sub> also captures the carbon in the steam reforming process. Black H<sub>2</sub> uses coal as a primary source to produce the H<sub>2</sub> while processing it through gasification. When looking at pink H<sub>2</sub>, which has the same production process as GH<sub>2</sub>, the electrolysis. The difference between GH<sub>2</sub> and pink H<sub>2</sub> can be identified in the source, where GH<sub>2</sub> uses any kind of renewable energy, and pink H<sub>2</sub> uses nuclear energy. (Acconia, 2022)

Additionally, yellow H<sub>2</sub> follows the same process of producing H<sub>2</sub> as pink H<sub>2</sub> or GH<sub>2</sub>, just that the energy source is solely solar energy. The last, turquoise H<sub>2</sub>, is produced through a process method called pyrolysis and uses natural gas as a source. (Acconia, 2022)

However, the essential aspect of classifying and colorcoding H<sub>2</sub> is what kind of electricity produces it. (Salvi & Subramanian, 2015)

The following Figure 1 gives an overview of the colorcoding of H<sub>2</sub>:

Figure 1: Hydrogen colorcoding (Acconia, 2022)



Another suitable method of producing H<sub>2</sub> for transportation is electrolysis, in which water molecules are split into H<sub>2</sub> and Oxygen by electric current. When considering GH<sub>2</sub>, this thesis refers to the production of H<sub>2</sub> that is only produced using renewable energy sources, such as solar, wind, and hydropower. There is much global interest in H<sub>2</sub> as a low or zerocarbon fuel. As H<sub>2</sub> or GH<sub>2</sub> becomes more widely used in the economy, its cost should continue to decline and become more competitive with other energy sources. (Oliveira et al., 2021)

Therefore, this thesis will mainly focus on the production of GH<sub>2</sub> with the method of electrolysis coming from renewable energy sources.

When looking at the current state of GH<sub>2</sub> in the road transportation sector in the EU and how the technology can help to decarbonize the industry, Lagioia et al. (2023) noted that the use of H<sub>2</sub> in Europe still needs time to be fully implemented. However, currently, many barriers occur due to governmental regulations and general volatility. (Lagioia et al., 2023) The authors also claim that because diverse decarbonization techniques utilize most of the electricity generated by renewable energy sources, GH<sub>2</sub> has little chance of overtaking other colors of H<sub>2</sub> soon.

To give a future outlook, Lagioia et al. (2023) forecast that GH<sub>2</sub> will become increasingly a competitive energy fuel source for the transportation sector among the different colors of H<sub>2</sub>, presented in Figure 1. In addition, it can be stated that the demand is increasing much faster than the current supply can cope with. (Hosseini & Butler, 2020) Several factors like the prices for electricity coming from renewables, investment opportunities in the field, as well as the cost for production, play a massive role in the development and diffusion of GH<sub>2</sub> firstly for any sector, but specifically for the road transportation sector – that is finally depending on the central infrastructure. (Reuß et al., 2021)

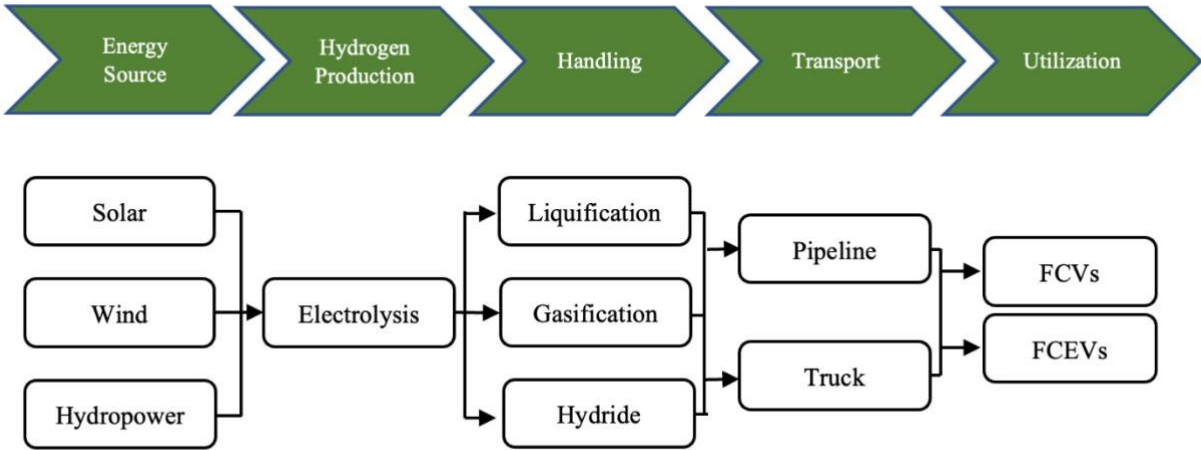
The EU Commission aims to increase the production capacity of GH<sub>2</sub> to at least 40 gigawatts (GW) by 2030 and up to 80 GW by 2035. A new market must be established across various industries for this crucial component of the European Commission's hydrogen strategy and sustainable and intelligent mobility strategy. Additionally, significant infrastructure must be built and developed, and international cooperation must be promoted to foster knowledge exchange and hasten the technology's faster and more extensive implementation. (European Commission, 2020a), (European Commission, 2020b)

Structural Analysis

The structural analysis will start presenting the value chain for GH<sub>2</sub> for the road transportation sector in the EU with the following Figure 2. The first step of the value chain is the Energy Source, where the source comes from one of the three renewable energy sources listed. (Coleman et al., 2020) The thesis' second section will address the generation of GH<sub>2</sub> using only the electrolysis method. When handling the produced GH<sub>2</sub>, there are different ways to continue. GH<sub>2</sub> transports in liquid, gaseous, or hydride form through trucks or pipelines. The hydride form is when GH<sub>2</sub> is saved in gas from specific types of chemicals or metals for storage. (Salvi & Subramanian, 2015)

The utilization of GH<sub>2</sub> for the road transportation sector, especially in the EU, can be through FCVs or FCEVs. (Coleman et al., 2020) It also has to be mentioned that there are several other use cases for GH<sub>2</sub> that this thesis will not bring attention to.

Figure 2: Value Chain of GH<sub>2</sub> for the road transportation sector in the EU. (Salvi & Subramanian, 2015)



To continue the structural analysis as part of the TIS analysis of GH<sub>2</sub>, it is necessary to map out the central actors and networks involved in the technology and the industry. Therefore, this part will also focus on the institutions involved in developing the technology for the industry.

Regarding the central actors involved in the development of GH<sub>2</sub> within the EU, private companies comprise the largest share of stakeholders. Furthermore, networks, associations, or even institutions play a significant role. (Guarieiro et al., 2022)

Schlund et al. (2022) state that the main actors, when explicitly considering the road transportation sector, are producers or manufactures of

Green Hydrogen,  
Fuel Cell System Developers,  
HeavyDuty Transport vehicles and applications,  
Individual Transport vehicles and applications,  
Vehicle manufacturers and original equipment manufacturers (OEMs),  
Infrastructure Providers, like refilling station operators, and  
Other commercial vehicles (for example, garbage trucks, street cleaning vehicles, and construction vehicles)

Furthermore, other stakeholders are national and regional governments that provide policy support, funding, and regulation for GH<sub>2</sub> and fuel cell technology within their respective domestic jurisdictions. The European Commission and the EU are further responsible for establishing the policy framework and funding research and development programs related to GH<sub>2</sub> and fuel cell technology in the EU, while the European Investment Bank finances GH<sub>2</sub> infrastructure projects in Europe for the road transportation sector. (European Commission (A), 2020; SadikZada, 2021)

Several initiatives have been developed within the EU to adopt H<sub>2</sub> or GH<sub>2</sub> in multiple sectors. When looking at the road transportation sector, the most relevant implementations from the governmental side are the EU Green Deal, the EU Hydrogen Strategy, and the Sustainable and Smart Mobility Strategy. (Leonard et al., 2021) These deals and strategies aim to provide governmental support to private companies and other stakeholders to have a better foundation for building an economy around GH<sub>2</sub>. Additionally, these policy foundations show what significant role governmental actors play in the diffusion and development of a specific technology for a specific sector. ;Panarello & Gatto, 2023)

Moreover, research institutions and networks such as universities, research organizations, and think tanks should be considered relevant stakeholders researching hydrogen fuel cell technology and its applications. (Panarello & Gatto, 2023)

## Functional Analysis

This part of the thesis will now provide the second part of the structure of the TIS framework, in which the functional analysis will dive deeper into the presented categories developed by Bergek et al. (2008), which have been adjusted for this thesis. Furthermore, the literature review will give insights into the key challenges and opportunities alongside the categories of the conducted TIS.

### Knowledge Development and Diffusion

As the creation and sharing of knowledge is one of the essential levers for the effective diffusion and application of GH<sub>2</sub>, the European Hydrogen Association „Hydrogen Europe” has to be mentioned as one of the most essential stakeholders in how the knowledge around the technology is spread within the EU. However, several other organizations are not mentioned here for this thesis that also works significantly on the diffusion and development of knowledge around GH<sub>2</sub>. (Mneimneh et al., 2023) These groups significantly advance our understanding of hydrogen generation, storage, and infrastructure development. Therefore, it is essential to consider that knowledge sharing has to happen among all involved stakeholders in this thesis presented in the structural analysis. This might involve publications, conferences, workshops, and cooperation between academic institutions and business partners. The Hydrogen Europe Association's yearly report on the technology's state is a good example. (Allsop & Bortolotti, 2022)

When considering the road transportation sector in the EU, a unique publicprivate partnership supporting research and innovation (R&I) activities in hydrogen technology in Europe is the Clean Hydrogen Joint Undertaking or Clean Hydrogen Partnership. These associations also publish reports and share knowledge through different mediums. (Clean Hydrogen Joint Undertaking, 2022)

As we can see from these examples of associations in combination with the listed actors in the previous chapter, we can identify for this analysis that there are multiple stakeholders within the EU working in the general development of GH<sub>2</sub> as well as more specifically for the industry of the road transportation sector. (Wolf & Zander, 2021) Therefore, the key challenges are the risk of fragmentation due to the involvement of diverse stakeholders from different backgrounds and angles and the communication among these diverse stakeholders. (Van De Graaf et al., 2020)

## Influence on the Direction of Search

As already explained previously, the direction of search refers to how the priorities and objectives of different stakeholders shape the TIS. For example, in the case of GH<sub>2</sub> in the road transportation sector in the EU, the direction of search is influenced mainly by policymakers and industry partners committed to decarbonizing the transportation sector. (Kakoulaki et al., 2021) However, ensuring that the search direction is not too narrowly focused on specific technologies or solutions is essential. This can limit innovation and prevent the emergence of alternative solutions that may be more effective or efficient, ultimately hindering the need for technology openness. (Bergek et al., 2015)

When considering examples of how that is done in practice, the Green Deal in the EU has gained support from many Western nations in the EU as a new set of policy interventions with the primary objective of fostering sustainable development methods focusing on reducing energy emissions and climate change. A "roadmap of important measures for the EU's climate agenda" is what the European Green Deal is intended to be. (Panarello & Gatto, 2023)

As the road transportation sector in the EU is one of the most important sectors with the transportation of passengers and goods, it can be seen from various analyses, such as from Salvi & Subramanian (2015), that the direction of search is not only focused on specific technologies rather than on the sector and therefore on the decarbonization of the road transportation sector. Other technologies, such as the electrification of vehicles, can be used to accomplish this. (Tamba et al., 2022)

A significant opportunity would be a general technology openness within the EU, representing the major challenge in implementing the technology around GH<sub>2</sub>. (Salvi & Subramanian, 2015) & (Glanz & Schönauer, 2021)

## Entrepreneurial experimentation

Investment activities, GH<sub>2</sub>related projects, and government subsidies are the best indicators for entrepreneurial experimentation and activities throughout the EU. This experimentation is critical for driving innovation and improving the performance and efficiency of GH<sub>2</sub> technology. However, it is crucial to ensure that entrepreneurial experimentation is supported by policies and incentives encouraging risktaking and investment in new technologies. (Panarello & Gatto, 2023)

In the case of GH<sub>2</sub> for the road transportation sector in the EU, several companies and start ups are engaged in entrepreneurial experimentation, including automakers, fuel cell

manufacturers, GH<sub>2</sub> infrastructure developers, and manufacturers of OEMs for the production of GH<sub>2</sub>. (Clean Hydrogen Joint Undertaking, 2022)

Throughout the EU, the European Clean Hydrogen Alliance monitors around 840 projects regarding implementing H<sub>2</sub> through different sectors, including the road transportation sector. Additionally, it has to be mentioned that 16 EU member states have already submitted their national Hydrogen Strategy. The European Commission and the EU Parliament also established a European Hydrogen Bank to encourage industry entrepreneurship. (European Commission, 2023)

The European Commission (2023) estimates for the investment needs for the production of GH<sub>2</sub> that critical categories in the production will require investments of between 50 and 75 billion € by 2030 for electrolysis, between 28 and 38 billion € for EU internal infrastructure, and between 6 and 11 billion € for storage.

With these numbers and facts, it can be identified that the critical challenge regarding entrepreneurial experimentation lies in the interaction between the private sector, local governments, and the European Commission. So, naturally, the most important topic is the financial support for entrepreneurship. (Sandström et al., 2022)

## Market Formation

Regarding the market formation for GH<sub>2</sub> for the road transportation sector within the EU, it must be noted that supply and demand play a huge role. Besides the supply and demand side, governmental regulations can be crucial for forming markets. (Tamba et al., 2022) Furthermore, the market type must be identified to evaluate further and analyze the formation and influencing factors. (Bergek, Hekkert, et al., 2008)

To get a good overview of the market within the EU, the European Commission (2023) states that from the current consumption of 8 million tons of H<sub>2</sub>, most of which is made from natural gas, less than 0.3 million tons of H<sub>2</sub> based on electricity and can therefore be considered as GH<sub>2</sub>.

About 160 megawatts (MW) of installed electrolyzer output capacity in the EU, but 80–100 GW would be needed to produce 10 million tons of GH<sub>2</sub>. To make GH<sub>2</sub> competitive with its fossil counterparts, approximately 150210 GW of additional renewable capacity providing energy at a reasonable cost will be needed. (European Commission, 2023)

In the case of the road transportation sector within the EU, it can be identified that the market is already partly existing since it is a working system, which means it has an operational infrastructure that is being used from other technologies like fossil fuelbased vehicles or electric vehicles. There is much competition among different technologies to decarbonize the industry through technological innovations like electric vehicles (EV), FCEVs, or FCVs. (Tamba et al., 2022)

The European Commission (2019) has already anchored the road transportation sector with different strategies and policies. As the sector is responsible for about one-fifth of the total EU GHG emissions, it is set to be one of the highest priorities for climate action and a vital element of the European Green Deal to archive a more decarbonized sector with less GHG. (European Commission, 2019)

As the market around road transportation already partly exists within the EU, the market formation for the technology around GH<sub>2</sub> has significant leverage for the future. For the EU to achieve climate neutrality by 2050, the European Green Deal calls for a 90% reduction in greenhouse gas emissions from transportation. Also, by 2050, almost all new heavy-duty vehicles, vans, buses, and cars will have zero emissions. (European Commission, 2019)

With its Hydrogen Strategy, the EU further tries to set clear targets to leverage the demand side for GH<sub>2</sub>. Additionally, the strategy sets for the road transportation sector to deploy at least 40,000 H<sub>2</sub> FCVs by 2030. From such actions, it can be observed that the sector's most significant challenges are transformation and GHG emission reduction, which are top priorities across the EU, and that laws and policies have already been put in place so that market formation is imminent. (European Commission, 2020a)

## Legitimation

As Bergek, Hekkert, et al. (2008) state, legitimation refers to gaining social acceptance and approval for new technologies; it has to be analyzed how this can be developed. Efforts in this direction can include promoting the technology's environmental and economic benefits and initiatives to address safety and reliability concerns.

In the case of GH<sub>2</sub> in the road transportation sector in the EU, there is a need to build public trust and awareness of the benefits of GH<sub>2</sub>, as the legitimation coming from the governmental side with legislation that supports the diffusion of GH<sub>2</sub> already exists. However, the main problem for that is that the topic of decarbonizing the road transportation sector through technological innovations is complex.

The challenge that GH<sub>2</sub> faces is that it is one of several promising technologies, and the public is engaged in the overarching objective of decarbonization. (Smith et al., 2023; Tamba et al., 2022)

Additionally, it might be said that the road transportation sector heavily depends on societal behavior, namely societal travel, consumption, and related freight transportation and that societal transformation will likely be necessary to support the technical transition. (Hainsch et al., 2022)

### Resource mobilization

Bergek, Jacobsson, et al. (2008) adapted the function of Resource Mobilization, which refers to securing financial instruments to support the development and diffusion of GH<sub>2</sub> for the road transportation sector in the EU, as the EU contains several member states that all have individual strategies to implement technologies within sectors.

When considering resource mobilization and, therefore also, the private and public investment needs, SadikZada (2021) states that there are three categories of potential investments in the technology. First, there needs to be investments in production and infrastructure. Second, there need to be R&D investments to support a better scaleup, and last but not least, there needs to be investments in the deployment.

In the EU, several funding programs and initiatives are aimed at supporting the development of hydrogen technology, including the Fuel Cells and Hydrogen Joint Undertaking and the European Innovation Council. As many GH<sub>2</sub>related investments are still in the planning stages, more demand visibility is required for investments to be unlocked on the production side. Electrolysisgenerated hydrogen is not costcompetitive with conventional hydrogen and is hardly ever produced on a large scale. (European Commission, 2023)

Also, establishing the European Hydrogen Bank aims to bridge the investment gap and link future renewable hydrogen supply with our target demand of 20 million tons of GH<sub>2</sub>. The European Hydrogen Bank will support domestic and imported GH<sub>2</sub>, advancing the goals of RepowerEU and the move toward climate neutrality. (European Commission, 2022b)

By the end of 2022, the EU stated that for the 10 million tones production volume for GH<sub>2</sub>, they are predicted to require expenditures totaling 335–471 billion €, with an extra 200–300 billion € needed to increase the amount of power produced from renewable sources. Investments in storage, pipelines within the EU, and electrolyzers are anticipated to total between 50 and 75 billion €, 28 to 38 billion €, and 6 to 11 billion €, respectively, by 2030. The

expansion of electrolyzers production will require up to 1.2 billion € in investments. Further investments totaling 500 billion € must be made in global value chains to make it possible to import 10 million tons of GH<sub>2</sub>, including derivatives. (European Commission, 2023)

Currently, the EU is already setting up the format for private and public investments in the development and diffusion of GH<sub>2</sub>. Nevertheless, the key challenges are to find and attract investment opportunities related to GH<sub>2</sub> in the EU that can fulfill the presented Investment needs and help the EU to stay competitive against other countries. (Bilan et al., 2023) Additionally, the IRA in the United States represents a significant challenge for European Investment needs in green energy infrastructure (Boehm & Scalamandrè, 2023)

#### Development of positive Externalities

According to Kraciuk et al. (2022), the externalities of the road transportation sector in the EU can be categorized as the following:

##### Social Benefits

- Private benefits of direct and indirect users,
- External benefits outside transport,
- External benefits generated by infrastructure.

##### Social costs of transport

- Private costs of transportation of people and goods,
- Costs of infrastructure,
- Costs related to the creation and maintenance of infrastructure,
- The exploitation of means of transport.

Furthermore, it can be differentiated between positive and negative externalities. In the case of GH<sub>2</sub> in the road transportation sector in the EU, several positive externalities are associated with developing and deploying GH<sub>2</sub> for the road transportation sector. These include improvements in air quality and public health and the potential for job creation and economic growth in the clean energy sector. Additionally, when deploying GH<sub>2</sub>, FCVs can help reduce dependency on fossil fuels, enhance energy security, and reduce GHG emissions drastically. (European Investment Bank, 2022)

Finally, it can be seen that through the development and diffusion of GH<sub>2</sub> for the road transportation sector in the EU, the creation of positive externalities will support the EU

strategies implemented and anchored in the last years. However, as Kraciuk et al. (2022) identified in their categorization of the benefits, the significant challenges in achieving the identified positive externalities lie in building the proper infrastructure.

## Methodology

This section outlines the research design and provides a brief overview of the different methods and approaches used to analyze the implementation of GH<sub>2</sub> for the road transportation sector in the EU to answer the research question further. Additionally, a description of how the literature review was conducted and how the literature was chosen are presented. This is followed by how data was collected through interviews and later how the data was analyzed.

As the aim of the thesis is to analyze the implementation of green hydrogen for the road transportation sector in the EU, along with the literature review and according to the analysis of the TIS framework and its seven functions, the following research question has been derived as the following:

“What are the key challenges in implementing green hydrogen for the road transportation sector in the EU, as perceived through the lens of the Technological Innovation System framework's seven functions?”

## Research Design

The research design is the logical chain that links empirical data to the research question and, in the best situations, to the conclusion. This thesis aims to assess the potential of GH<sub>2</sub> for the EU's road transportation sector and to highlight further the significant challenges encountered along the proposed TIS framework. The TIS framework was chosen for this analysis as it provides a holistic view, focusing on the technology side and the innovation process involving multiple stakeholders, market dynamics, and infrastructure-related aspects. (Bergek, Hekkert, et al., 2008) An inductive method is appropriate since it allows for a more flexible approach to applying theory and frameworks for analyzing the gathered data. (Yin, 2016) This kind of research is an excellent way to learn more about a subject of interest and to comprehend the conducted literature review. A richer theoretical viewpoint than that found in existing literature can also be attained by combining qualitative research with an inductive method. (Saunders et al., 2012)

A qualitative research design is applied in this thesis. Furthermore, the data is gathered by questioning alongside a predefined semistructured questionnaire. Key challenges and

questions building on the framework for this analysis were derived from the literature to answer the presented research question. The questionnaire is orientated along the seven functions of the TIS framework. (Bergek, Hekkert, et al., 2008) (See Appendix A)

### Data Collection

As a first step, primary data is taken into consideration to respond to the presented research question in addition to and to complete the conducted literature evaluation. Interviews are explicitly used in this thesis as a qualitative research method. In general, the study methodology used provides professional expertise and information. (Yin, 2016)

According to Aspers & Corte (2019), individual beliefs, attitudes, patterns of perception, or processes become apparent through the qualitative research methodology. Therefore, qualitative interviews are predestined as a method of data collecting because they allow respondents to reply, share their experiences, and discuss their knowledge and perception of impact measurement techniques. Furthermore, the process of randomly selecting and choosing the Interview expert partners is called purposive sampling, which was used for this qualitative research.

A total of 9 semistructured interviews with experts from various fields were conducted. The semistructured interviews are organized around a series of openended questions that have been predetermined and are based on the main challenges found in the literature. (Yin, 2016)

As the main actors were presented in the previous parts of the thesis, the experts have split into three groups according to Schlund et al. (2022) differentiation of the actors. Interviews will be conducted with individuals who are directly involved in the production of GH<sub>2</sub> (Green Hydrogen) in the first group, specialists in the road transportation sector in the second (Road Transportation), and policy experts in the third (Politics). The interview questions were not provided before the interview to ensure data quality and especially an unbiased opinion of the experts. (Rugg & Petre, 2010)

### Data Analysis

For this part, the data analysis, a thematic analysis, was used as an approach to analyzing qualitative data. (Castleberry & Nolen, 2018) It has to be noted that due to the different locations of the experts, the interviews were held virtually. Additionally, the interviews were recorded and finally transcribed. The transcript (see Appendix C) version allows for further data analysis. The average duration of the interviews was 35.2 min.

Table 2: Conducted Interviews

ID	Date	Type	Category	Role	Duration (min)
A	29/03/2023	Automotive	Road Transportation	Senior Manager	28
B	30/03/2023	Government	Politics	Politician	41
C	05/04/2023	Government	Politics	Lawyer	34
D	05/04/2023	Production	Green Hydrogen	CEO	39
E	06/04/2023	Association	Road Transportation	Senior Executive	43
F	12/04/2023	Production	Green Hydrogen	CEO	30
G	20/04/2023	Logistics	Road Transportation	Senior Executive	22
H	12/04/2023	Production	Green Hydrogen	Advisory Board	37
I	20/04/2023	EU Parliament	Politics	Member of the EU Parliament	29

The experts were chosen randomly based on their expertise and characteristic of their job. For the analysis of this thesis, three experts from each category, “Green Hydrogen,” “Road Transportation,” as well as “Politics,” were chosen randomly to have a broad and differentiated view on the topic. (Miles & Hubermann, 1994) Additionally, an analysis was adopted to get a precise data analysis derived from the conducted interviews and the inductive approach of the constructed questionnaire.

As the data is processed, codes are created in this process. These codes were created to define the material and highlight relevant portions. (Castleberry & Nolen, 2018) In addition, these code patterns were found and categorized into themes (See Appendix B). This made it possible to identify crucial and ambiguous results of the conducted Interviews. Finally, a diagram was created to summarize and visualize the results of the interviews according to the color coding (See Appendix D). (Azungah, 2018)

## Results

After presenting the Methodology of the thesis and the conducted Interviews with the experts from the three different sectors, this section summarizes the findings from the Interviews conducted for this thesis, organized and based on the TIS framework's seven functions. In addition, it includes insights from interviewees in the green hydrogen, road transportation, and politics sectors (see Appendix D)

### Knowledge Development and Diffusion

Interviewees A, E, and G from the road transportation sector stated that implementing GH<sub>2</sub> faces governmental restrictions, cost competitiveness, and a lack of industry standards. Furthermore, Interviewee G mentioned that the increasing market demand and supportive policies are necessary to address these issues. Collaboration, public awareness, and policymaking play crucial roles in promoting GH<sub>2</sub> adoption, according to the statements of both Interviewees A and G. Interviewee E stated additionally that trade shows, conferences, and interactions with specialized engineers facilitate knowledge exchange. When considering the results from Interviewees D, F, and H from the GH<sub>2</sub> sector, collaboration, lobbying, and public affairs consulting are recommended for awareness and policy advancement.

Interviewee D stated that, as a private sector company, they are not interested in sharing too much knowledge as they are competing and bidding against their competitors for governmental funds and support.

Additionally, Interviewees F and H stated that university lectures, conferences, and work with associations foster knowledge development and diffusion for their businesses. As the involvement of politics is crucial, all Interviewees D, F, and H share the common opinion that associations and platforms like Hydrogen Europe provide incentives for sharing knowledge in the hydrogen sector.

From a political background, Interviewees B, C, and I also see associations like Hydrogen Europe as reasonable means to share knowledge. At the same time, Interviewee C stated that the biggest problem in politics could be identified with the knowledge gap and a general technology openness within Europe. This identified problem can additionally lead to slow or wrong decisionmaking from the political side. Additionally, Interviewee I stated that standardization and open innovation discussions could improve knowledge sharing in the road transportation sector.

## Influence on the Direction of Search

The experts from the road transportation sector, Interviewees A, E, and G, mentioned that the influence on the direction of GH<sub>2</sub> research in the road transportation sector is mainly shaped by policymaking, the supplydemand dynamics, as well as certification of the technology. In addition to the mentioned aspects, Interviewees A and G, who both work at a European car or heavyduty vehicle manufacturer, see the requirements of their company and group as limiting factors in the research direction.

Furthermore, the answers of the Interviewees from the GH<sub>2</sub> sector align well with the answers of the Interviewees from the road transportation sector. Interviewees D, F, and H also see that supply and demand is the primary factor influencing the direction of search within their companies. In addition to that, Interviewee D stated that his company is also driven by the requirements of customers and Investors' requirements. Interviewee H added that they, as a company, must also consider cost aspects as influencing when it comes to research.

When considering the answers coming from the experts in the political field, Interviewees B, C, and I also stated that supply and demand and the cost questions for the private sector companies play a significant role when it comes to the influence of the direction of search for GH<sub>2</sub>. Interviewee I also stated that the EU's climate targets are crucial for policymakers' search direction. Furthermore, Interviewee B added that the EU Hydrogen Strategy often pushes private sector actors in specific research directions.

## Entrepreneurial Experimentation

Considering the TIS function of Entrepreneurial Experimentation, it can be seen from the Interviews with the experts in the three fields that the identified challenges differ. Interviewees E and G, from the road transportation sector, see a clear challenge in the knowledge about funding and support opportunities from the EU for Entrepreneurs. To foster Entrepreneurial experimentation, Interviewee A stated that they, as a company, collaborate with universities to get more stakeholders involved. Regarding the experts' answers from the GH<sub>2</sub> sector, Interviewee D stated that the Supply & Demand structure plays a significant role, while the market demand represents a challenge for the function of the TIS. Interviewee F added that technological challenges are crucial in implementing GH<sub>2</sub> solutions to sectors like the road transportation sector.

Additionally, the EU regulations and public access to government subsidies represent the most significant challenges regarding Entrepreneurial Experimentation for them as a private

company. When starting a company operating in the GH<sub>2</sub> field, it is crucial to get access to financial support very early, mentioned Interviewee F as another challenge to consider.

Considering the results from Interviewees B, C, and I, with a political background, it can be seen that the identified challenges differ from those from the other Interviews. While the private sector Interviewees see the challenges regarding the TIS function more on the financial side, Interviewee I stated that “the collaboration and communication between different actors involved in the implementation of GH<sub>2</sub> for road transportation sector represent the greatest challenge.” To overcome any challenges, Interviewee B mentioned that they, as a political organ, have dedicated departments to implement GH<sub>2</sub> for specific sectors, like road transportation, to help Entrepreneurs and private sector actors. Furthermore, Interviewee I stated that policymakers should create the right environment for Entrepreneurs to experiment and therefore support the implementation of the technology.

### Market Formation

Regarding the function of Market Formation, all conducted Interviews share a common sense about the significant challenges and limiting factors that can be identified and pointed to the political landscape. The Interviewees from both the road transportation sector and GH<sub>2</sub> stated that government support is needed to implement new technology throughout a sector. To give a practical example, Interviewee G from the road transportation sector stated that governmental support is crucial to building the proper Infrastructure in the European transportation sector. Interviewee B from the political side agreed that the Infrastructure plays a significant role but added that “within the EU, about 600 H<sub>2</sub> refueling stations are in planning to build the right and needed infrastructure.”

Besides the given examples, Interviewee D mentioned that the price of renewables represents a challenge for the GH<sub>2</sub> sector that could be tackled with governmental subsidies. Interviewee C also stated that one of the most significant challenges for the sector and the market could be identified in reducing GHG emissions. Therefore, governmental subsidies for fossil fuels in the road transportation sector must be limited to support the market formation of GH<sub>2</sub>.

### Legitimation

For Interviewees A, E, and G from the road transportation sector, the challenges regarding the TIS function Legitimation can be identified in a lack of public and internal acceptance within their companies or specific industries. Interviewee A mentioned more in

detail that not many people in the automotive industry count on H<sub>2</sub> as the technology to overcome the overall goal of decarbonizing the industry. Interviewee G sees that the problem is more on public opinion towards mobility. To support that, Interviewee E stated that a significant challenge in legitimation could be identified in the acceptance of the new technology, which ultimately results again in the challenge of a general technology openness in the EU.

The experts from the GH<sub>2</sub> sector mentioned other problems regarding certifications and labels in the EU. Regarding this, Interviewee F stated that the labels in the EU play a significant role but need to be revised by policymakers and decisionmakers. Following this, Interviewee E from the road transportation sector brought up another point regarding the technology's safety that can be handled with EU standards and labels.

Considering the Interviews from the political sector with Interviewees B, C, and I, the significant challenges regarding the legitimation of the technology around GH<sub>2</sub> can be identified in public awareness. There, Interviewee B discussed the role of EU Initiatives as the Hydrogen Strategy that further help the member countries in the EU roll out the technology for multiple sectors furthermore, Interviewee I stated that pilot projects within the EU for GH<sub>2</sub> can boost public awareness.

### Resource Mobilization

Considering the TIS function Resource Mobilization, all three Interviewees from the road transportation sector see similar challenges in implementing GH<sub>2</sub> for the road transportation sector. For Interviewee G, the main problem in the road transportation sector is the research towards mobility, which is dominant compared to GH<sub>2</sub>. In addition, Interviewee G noted that several resources are available to private sector businesses in the EU, but the issue is that more actors cannot access these resources due to a lack of knowledge about them.

The experts from the GH<sub>2</sub> sector shifted the focus of the challenges to a global perspective. Interviewee D mentioned that the competition in resource mobilization comes a lot from the middle east, where the production prices for renewables are way lower than in Europe. Interviewee F changed the geographical focus towards the United States of America as a significant competitor in resource mobilization for GH<sub>2</sub> companies. The challenge comes from the Inflation Reduction Act, which makes it harder for Europeanbased companies to fundraise any money as the terms in the United States are way more attractive for investors. Additionally,

Interviewee H mentioned the same problems with the Inflation Reduction Act and sees that currently as a significant challenge for Europeanbased companies.

Taking the results of the Interviewees from the political sector into consideration, it can be seen that also there is a significant concern about the United States Inflation Reduction Act and the EU's competitiveness in terms of Investor attractiveness. Interviewee I mentioned that although the established Hydrogen Bank in the EU deploys around 800 million € for H<sub>2</sub>related projects, a longterm strategy for foreign investments needs to be established. For that, it should be essential to have good coordination between all involved actors.

#### Development of positive Externalities

For the last TIS function, Development of positive Externalities, the conducted Interviews with the experts from the road transportation sector highlighted that the implementation of GH<sub>2</sub> has potential positive externalities that are further depending on the application, e.g., where GH<sub>2</sub> is used, if it is in cars, in heavyduty transport or public transport. Furthermore, another positive Externality in the deployment of GH<sub>2</sub> for road transportation could be a spillover effect, meaning that other industries and sectors also benefit from the development of GH<sub>2</sub>. Interviewee G mentioned additionally that GH<sub>2</sub> has the potential to reduce GHG emissions for the road transportation sector. Furthermore, Interviewee E stated that current challenges in the EU can be identified in the priority setting of H<sub>2</sub> color coding. The challenge is again the supply & demand topic, as there is insufficient GH<sub>2</sub> within the EU to decarbonize sectors like road transportation.

Considering the results of the Interviews conducted with experts from the GH<sub>2</sub> sector, it can be seen that challenges are price related, as GH<sub>2</sub> is for most of the sectors not visible coming from a premium price for the fuel. Interviewee F further mentioned the aspect of Human Resources as a potential positive externality for the sector. However, the challenge identified is the shift in the European job market.

Interviewee C from the political sector further mentions that the EU has excellent opportunities for longterm learning from other countries like the United States with its Inflation Reduction Act. To come back to the challenges in achieving the development of positive externalities, Interviewee B mentioned that the EU first needs to implement the proper Infrastructure around the technology before benefiting from positive externalities.

## Discussion

This part of the thesis will highlight the findings and challenges from the literature review along the seven TIS functions. Furthermore, this part will compare the findings and results with the nine conducted Interviews with experts from different sectors. Additionally, this part will also highlight some opportunities the Interviewees mentioned on how to overcome or tackle the identified challenges.

### Knowledge Development and Diffusion

In both the literature review and the conducted Interviews, a primary factor in the deployment of GH<sub>2</sub> for the road transportation sector is the function of Knowledge Development and Diffusion, which is facilitated by various stakeholders, particularly associations like Hydrogen Europe and Clean Hydrogen Joint Undertaking. These associations, along with other relevant stakeholders, play an integral role in promoting GH<sub>2</sub> as a technology for the sector by publishing reports and sharing information through different mediums. (Allsop & Bortolotti, 2022) This aligns with the testimonies of interviewees from different backgrounds, who agree on these associations' role in fostering knowledge development and diffusion.

Nevertheless, a challenge Van De Graaf et al. (2020) identified in the literature review is the risk of fragmentation and ineffective communication among the diverse stakeholders, which could negatively impact the implementation of GH<sub>2</sub>. Furthermore, this challenge was also identified by the Interviewees, who mentioned concerns about the challenges posed by governmental restrictions, cost competitiveness, and lack of industry standards in implementing GH<sub>2</sub>. Additionally, Interviewee D highlighted a reluctance from private sector companies to share knowledge due to the competitive nature of bidding for governmental support, which could further support the risk of fragmentation due to the involvement of multiple stakeholders. To overcome these challenges, the literature and interviews identified the importance of increased stakeholder collaboration. The Interviewees from the road transportation and GH<sub>2</sub> sectors suggested lobbying, public affairs consulting, and cooperation with associations to advance policy and foster awareness. These suggestions from the Interviewees align with the opportunities mentioned in the literature review, including publications, conferences, workshops, and partnerships between academic and private entities.

Additionally, the Interviewees emphasized the importance of events like trade shows and conferences, interactions with specialized engineers, and the integration of GH<sub>2</sub> topics in university lectures as effective methods for knowledge exchange. This supports the idea that

engaging with various stakeholders through multiple mediums is essential to the successful diffusion of GH<sub>2</sub> knowledge.

Interviewees from the political sector mentioned concerns, highlighted the knowledge gap and technology openness in Europe, and stated that these challenges might harm decision making. Interviewee I suggested that conversations about standardization and open innovation could enhance information sharing in the road transportation sector, potentially solving this issue.

While there are several challenges presented in this thesis that are associated with the development and diffusion of GH<sub>2</sub> knowledge in the EU, there are also multiple approaches that stakeholders can implement to overcome these challenges.

### Influence on the Direction of Search

Considering the results from the literature review and the conducted Interviews, it can be identified that policymaking, industry demands, and market dynamics primarily determine this function.

The literature review highlighted the European Green Deal as a significant policy intervention shaping the direction of the search toward reducing GHG emissions in the road transportation sector (Panarello & Gatto, 2023). This policy agenda aligns with the climate goals of the EU, demonstrating how political actors can influence the direction of search toward specific objectives, such as decarbonizing the transportation sector (Kakoulaki et al., 2021). However, an overly narrow focus on specific technologies could hinder innovation and the emergence of potentially more sustainable alternatives (Bergek et al., 2015). This reflects the challenge in the literature about the need for technology openness within the EU (Salvi & Subramanian, 2015; Glanz & Schönauer, 2021).

These insights align with the findings from the Interviews, where Interviewees from both the road transportation and GH<sub>2</sub> sectors identified that policymaking and supplydemand dynamics influence the direction of search within their companies. Furthermore, the influence of customer and investor requirements was also noted as a negative factor.

The interviewees from the political field also identified the critical role of supply and demand, cost considerations, and climate targets in influencing the direction of the search for GH<sub>2</sub>. They also mentioned the crucial role of policy documents, such as the EU Hydrogen Strategy, in directing the search directions of private sector actors.

While the political sector, as identified in initiatives like the European Green Deal and the EU Hydrogen Strategy, set broad goals for decarbonization, the specific targets are influenced by supply and demand dynamics and financial considerations at the company and investor levels.

The need for technology openness appears to be a crucial aspect of future policymaking guiding industry research. (Salvi & Subramanian, 2015) & (Glanz & Schönauer, 2021) This could promote innovation and the development of effective and efficient solutions for GH<sub>2</sub> in the road transportation sector.

### Entrepreneurial Experimentation

The conducted literature review identified the significance of Entrepreneurial Experimentation, giving importance to its role in fostering innovation and enhancing the development and efficiency of GH<sub>2</sub> technology for the road transportation sector (Panarello & Gatto, 2023).

The European Clean Hydrogen Alliance monitored approximately 840 GH<sub>2</sub>related projects across various sectors, including road transportation projects, highlighting the EU's proactive engagement in this area. Furthermore, the formation of a European Hydrogen Bank by the European Commission and the EU Parliament showed commitment and governmental support for the implementation of GH<sub>2</sub> (European Commission, 2023).

However, the financial investment needs regarding entrepreneurial experimentation present a crucial challenge and the interactions between the private sector, local governments, and the European Commission. (Sandström et al., 2022)

The challenges found in the existing literature align with the insights identified from the conducted Interviews. Interviewees from different sectors mentioned various financial challenges, including a knowledge gap about funding and support opportunities in the EU. Interviewees also mentioned the market demand, technological barriers for GH<sub>2</sub> solutions, and access to government subsidies as essential factors in enhancing entrepreneurial experimentation.

Furthermore, the political sector Interviewees presented a different viewpoint. While acknowledging financial challenges, they highlighted the importance of efficient collaboration and communication among involved actors in implementing GH<sub>2</sub> for the road transportation sector.

The findings from the literature review and the Interviews highlighted the importance of entrepreneurial experimentation in driving innovation and advancing GH<sub>2</sub> technology in the EU. Collaboration, financial support, and policies are crucial for creating an environment that helps Entrepreneurs and ultimately leads to the implementation of GH<sub>2</sub>. By supporting entrepreneurial activities, the road transportation sector in the EU can achieve its goal of reducing GHG emissions with the adoption of GH<sub>2</sub> (Sandström et al., 2022)

### Market Formation

Tamba et al. (2022) identified that the market formation regarding the implementation of GH<sub>2</sub> in the EU depends on supply & demand dynamics, with governmental regulations having a crucial influence on the success. Furthermore, understanding the market type becomes essential to identifying its formation and associated factors (Bergek, Hekkert et al., 2008).

The road transportation sector, and especially the market for GH<sub>2</sub> in the EU is partially existing, as the literature review identified, and policies and strategies from the European Commission have been developed to reduce GHG emissions from the sector, bringing it to a high priority in the European Green Deal (European Commission, 2019). Furthermore, it can be identified from the literature review that with the EU Hydrogen Strategy, market formation is rising in the EU. Specifically, it can be seen by the number of FCVs estimated to be on the streets in the EU by 2023. (European Commission, 2020a).

Findings from the conducted Interviews align with the literature review, highlighting the need for governmental support to develop market formation. In addition, interviewees across sectors mentioned the importance of infrastructure development and renewable energy price management. For example, Interviewee G, from the road transportation sector, identified the need for governmental support in building the necessary infrastructure for the successful implementation of GH<sub>2</sub>. This perspective was shared by Interviewee B from the political sector, who added information about the plans to build 600 H<sub>2</sub> refueling stations within the EU.

Interviewees D and C highlighted two other critical challenges: the cost of renewables, which governmental subsidies could mitigate, and the reduction of GHG emissions, which demands a reorientation of subsidies away from fossil fuels towards fuels coming from renewable energy sources, like GH<sub>2</sub>. Improving governmental support, infrastructure development, and favorable policies can furthermore play a crucial role in enhancing market dynamics in terms of supply & demand and driving the development of GH<sub>2</sub>. By fostering

market formation in the road transportation sector in the EU, the transition to a more sustainable and decarbonized future can be accelerated.

## Legitimation

As presented in the literature review, the TIS function of Legitimation regarding the GH<sub>2</sub> technology is quite complex. The complexity comes from a mixture of several factors, including the development of public awareness about the benefits of GH<sub>2</sub>, the competition GH<sub>2</sub> faces from other promising technologies for decarbonization, and the dependence of the transportation sector on societal transformation involving travel and consumption habits (Smith et al., 2023; Hainsch et al., 2022). These factors present the primary challenges faced by GH<sub>2</sub> technology within the EU regarding the Legitimation function.

The Interview findings present a more differentiated perspective on these challenges, highlighting sectorspecific and broader difficulties. For instance, Interviewees from the road transportation sector identified a lack of acceptance, both publicly and internally, within their industries. Furthermore, this is also represented in the literature review with the importance of public awareness and the competition GH<sub>2</sub> faces in the decarbonization space in the sector. As mentioned by Interviewee A, the challenges identified within the industry and the public's leanings towards emobility, as identified by Interviewee G, represent the challenges GH<sub>2</sub> has to overcome for public acceptance.

Regarding regulation and certification, the GH<sub>2</sub> sector Interviewees highlighted the importance of revising EU standards and labels, which they consider a significant challenge. These concerns equally apply to the road transportation sector, where Interviewee E identified the role of safety standards and certifications in developing general legitimation.

Finally, the Interviewees from the political sector identified the lack of public awareness as a significant challenge to the technology's legitimation. They argue for the critical role of EU initiatives, such as the Hydrogen Strategy, in providing member countries to roll out GH<sub>2</sub> technology across different sectors smoothly. They also mentioned the potential of pilot projects within the EU to improve public awareness about the benefits of GH<sub>2</sub> technology.

The connection between the findings from the literature and the Interviews showcased the challenges involved in the legitimation process GH<sub>2</sub> faces in the road transportation sector. Therefore, it is critical to view legitimation as a process that needs combined efforts at multiple levels to ensure the successful implementation of GH<sub>2</sub>. Building public awareness, addressing safety concerns, and showcasing the benefits of GH<sub>2</sub> are all crucial for its legitimation. By

actively promoting the advantages of GH<sub>2</sub> and engaging stakeholders through collaborative efforts, the road transportation sector in the EU can succeed in implementing GH<sub>2</sub>.

### Resource mobilization

Securing financial resources is, as identified by Bergek, Jacobsson, et al. (2008), very complex due to the involvement of different member states in the EU, which has its individual technology implementation strategies.

According to the literature review, SadikZada (2021) categorized potential investments in GH<sub>2</sub> technology into three different sectors: production, infrastructure, R&D, and deployment. Furthermore, as the EU has several funding programs designed to support GH<sub>2</sub> technology development, including the Fuel Cells and Hydrogen Joint Undertaking and the European Innovation Council, the establishment of the European Hydrogen Bank aims to bridge the investment gap and link GH<sub>2</sub> supply with a target demand of 20 million tons of GH<sub>2</sub> (European Commission, 2022; 2023).

Besides these funding initiatives, challenges could be identified in attracting investment to fulfill the essential financial requirements associated with GH<sub>2</sub>. For example, the EU estimated total expenses ranging from 335–471 billion € for a production volume of 10 million tons of GH<sub>2</sub>, along with an additional 200–300 billion € required for increasing renewable power production. Furthermore, investments in storage, pipelines, electrolyzers, and global value chains also require a significant capital raise (European Commission, 2023). These figures highlight the need for substantial private and public investments, both from within the EU and abroad.

The findings from the Interviews support understanding the resource mobilization challenges. For example, Interviewees from the road transportation sector, such as Interviewee G, identified a significant challenge in the dominant focus on mobility research and a lack of knowledge about accessing available resources. In addition, the GH<sub>2</sub> sector's Interview experts highlighted the global competitive pressure, with the Middle East's lower renewable production costs and the United States Inflation Reduction Act offering more attractive investment terms (Interviewees D, F, and H).

Moreover, political sector Interviewees supported the challenges of the United States Inflation Reduction Act's impact on global investment competitiveness. Despite the EU Hydrogen Bank's commitment of 800 million € for H<sub>2</sub>related projects, Interviewee I

mentioned the need for a longterm strategy for foreign investments, highlighting the importance of coordination between all involved actors.

These findings collectively demonstrate that significant challenges remain while the EU has established funding mechanisms for GH<sub>2</sub> implementation. Developing a coordinated long term strategy that improves investor attractiveness and better communicates available resources could improve the EU's GH<sub>2</sub> ambitions in road transportation and help private sector actors with resource mobilization.

#### Development of positive Externalities

The last function within the TIS framework, the Development of positive Externalities, involves the broader benefits and costs both social and economic resulting from implementing technology, in this case, GH<sub>2</sub>, for road transportation in the EU.

According to the literature review, positive externalities within the road transportation sector can generally be categorized as social benefits and transport costs. (Kraciuk et al., 2022). The positive externalities associated with GH<sub>2</sub> deployment in road transport include improved air quality and public health, job creation and economic growth in the clean energy sector, and reduced dependency on fossil fuels, thus enhancing energy security (European Investment Bank, 2022). More importantly, these externalities align with and support several EU strategies for sustainable development and carbon neutrality throughout different sectors. Furthermore, it could be identified that achieving these positive externalities can only be granted with the proper infrastructure in place. (Kraciuk et al., 2022)

The Interview results highlighted several other challenges that may hinder the development of these positive externalities. For example, experts from the road transportation sector, like Interviewee G, highlighted that these positive externalities' development highly depends on where and how GH<sub>2</sub> is used. Further, there may be spillover benefits for other industries and sectors from GH<sub>2</sub> deployment, although this would also require a substantial increase in GH<sub>2</sub> supply within the EU, a current challenge, as noted by Interviewee E.

Another challenge mentioned is the premium pricing of GH<sub>2</sub>, a point raised by experts from the GH<sub>2</sub> sector. Additionally, there is a potential shift in the job market, which needs to be managed, as identified by Interviewee F.

Lastly, Interviewees from the political sector, like Interviewee C, mentioned that the EU could leverage learning opportunities from countries like the United States, specifically its

Inflation Reduction Act. Furthermore, Interviewee B identified that substantial infrastructure must be in place before the EU can develop these positive externalities.

In conclusion, while implementing GH<sub>2</sub> in the EU road transportation sector promises several positive externalities, there are still challenges to overcome. Addressing cost barriers, creating supportive policies, and increasing public awareness are crucial steps toward realizing the full potential of GH<sub>2</sub> and its positive externalities. By aligning the efforts of policymakers, industry actors, and the public, the road transportation sector in the EU can leverage GH<sub>2</sub> technology to create these positive externalities.

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The following table 3 summarizes the challenges coming from both the literature review and the conducted Interviews. The table also summarizes the potential solutions coming from the Interviewees' answers.

Table 3: Summary of Challenges and Opportunities

TIS Function	Challenges Literature	Challengers Interviews	Potential Solutions
Knowledge Development & Diffusion	Risk of fragmentation (Van De Graaf et al., 2020)	Governmental restrictions, Cost competitiveness, and a lack of industry standards	Standardization & Open Innovation
Influence on the Direction of Search	Technology Openness ((Salvi & Subramanian, 2015) & (Glanz & Schönauer, 2021))	Supply and Demand Dynamics	Technology Openness
Entrepreneurial Experimentation	The most important topic is the financial support for entrepreneurship. (Sandström et al., 2022)	Knowledge gap over EU funding opportunities, Interaction between Stakeholders	Collaboration, financial support, and policies
Market Formation	Transformation and GHG emission reduction (European Commission, 2020a)	Infrastructure	Improving governmental support, infrastructure development, and favorable policies
Legitimation	Public Acceptance for GH <sub>2</sub> as one out of several potential Technologies (Smith et al., 2023)	Public Awareness/ Acceptance	Building public awareness, addressing safety concerns, and showcasing the benefits of GH <sub>2</sub>
Resource Mobilization	Find and attract investment opportunities related to GH <sub>2</sub> in the EU. (Bilan et al., 2023)	Investment attraction in the EU and competition from IRA	Coordination between all involved stakeholders, a longterm strategy similar to IRA
Development of positive Externalities	Building the proper Infrastructure, that leads to the achievement of positive externalities (Kraciuk et al., 2022)	Application of GH <sub>2</sub> + Infrastructure	Leverage learning opportunities from countries like the United States

## Conclusion

The thesis aims to identify the critical challenges in implementing GH<sub>2</sub> for the road transportation sector in the EU by applying the TIS framework with its seven functions. To achieve this, a comprehensive analysis of the literature review was conducted. Furthermore, Interviews with experts provided valuable insights into the challenges and opportunities regarding GH<sub>2</sub> implementation in the road transportation sector in the EU. The following research question,

"What are the key challenges in implementing green hydrogen for the road transportation sector in the EU, as perceived through the lens of the Technological Innovation System (TIS) framework's seven functions?"

has been addressed and explored. Furthermore, this part will answer the research question along with each of the seven TIS functions. The findings highlight several significant challenges that must be overcome for successful GH<sub>2</sub> implementation in the road transportation sector. These challenges cut across all TIS functions, identifying the complexity of the implementation process. However, each challenge can also be seen as an improvement opportunity for all stakeholders from different sectors.

Knowledge Development and Diffusion was identified as a critical function that requires enhanced collaboration, knowledge exchange, and policy support. Overcoming governmental restrictions, promoting cost competitiveness, and establishing industry standards are crucial for knowledge development and diffusion within the sector. Stakeholders from the GH<sub>2</sub>, road transportation, and political sectors must actively share knowledge through platforms such as trade shows, conferences, and interactions with specialized engineers. Furthermore, policymakers should incentivize knowledge sharing and foster collaboration through funding programs and universityindustry partnerships.

The Influence on the Direction of the Search function identified that regulations and policymaking significantly shape the research direction for a potential GH<sub>2</sub> implementation. It is crucial to align political decisions with the development of GH<sub>2</sub> technology, considering factors such as wind power utilization, private sector technology push, and supplydemand dynamics. Standardizing certification processes, legislation, and policy instruments could potentially positively influence the adoption of GH<sub>2</sub> in the road transportation sector.

For Entrepreneurial Experimentation, considerable challenges were identified, specifically the high costs linked to GH<sub>2</sub> technologies, hindering newcomers from engaging

with this field. These expenses limit innovation and slow the development and especially the diffusion of technology in the transportation sector. In addition, safety and reliability concerns about GH<sub>2</sub> further limit entrepreneurial participation and adoption by potential stakeholders. The interviewees suggested collaborative initiatives, safety guidelines, reliability standards, and innovative business models as potential solutions to these issues. These solutions could promote a safer operational environment, encourage GH<sub>2</sub> technology adoption, and potentially decrease the financial barrier encouraging more entrepreneurial experimentation.

Regarding Market Formation, key challenges were identified in the supply and demand dynamics of the markets and the required governmental regulations that must be in place to facilitate the growth and development of the technology. Besides the fact that market conditions for GH<sub>2</sub> were identified as partly existing with some infrastructure already in place, the needed infrastructural and cost barriers can still be identified as significant challenges for forming the market around GH<sub>2</sub> within the function of the TIS. These challenges prevent the effective growth and diffusion of GH<sub>2</sub>, limiting its potential impact. Experts interviewed identified that the role of government is crucial in overcoming these challenges, emphasizing the need for comprehensive support in infrastructure development and energy price regulation. They suggested that government subsidies and implementing supportive policies could be critical drivers for the successful and accelerated development of GH<sub>2</sub>.

Moving on to the function of Legitimation, a multifaceted range of challenges was identified. Public acceptance of GH<sub>2</sub> and compliance with regulatory and safety standards can be seen as significant challenges that must be overcome. Results from the expert interviews highlighted the crucial role of public awareness and the development of comprehensive safety standards. They further mentioned the need to focus on the advantages of GH<sub>2</sub> more effectively to gain wider acceptance and promote legitimacy for the technology in public.

Regarding Resource Mobilization, the implementation of GH<sub>2</sub> depends on initial investments, which can be seen as crucial for technological development and infrastructure setup, representing a significant challenge. Additionally, the current level of public awareness regarding potential investment opportunities in the EU is identified as low, representing a further challenge to the mobilization of resources. Experts from different fields argued in the Interviews for creating a longterm strategic framework for attracting and managing investments in GH<sub>2</sub>. Such a strategy could highlight the potential of GH<sub>2</sub> for good returns in the medium to long term, thus making it an attractive prospect for private investors from within the EU as well as from outside of the EU. The experts also highlighted the importance of clear,

transparent communication regarding the available resources. They suggested that a comprehensive, easy-to-navigate information system detailing potential funding opportunities and incentives could encourage more stakeholders to invest in GH<sub>2</sub>. Ultimately, the EU needs to set a long-term strategy to stay competitive with other countries' regulations like the United States IRA.

When considering the last function, the Development of Positive Externalities, the potential benefits of GH<sub>2</sub> were identified, including job creation, energy security, and improved air quality. However, these benefits are currently hindered by crucial challenges such as high costs, lack of supportive policies, and insufficient public awareness about the potential of GH<sub>2</sub>. The expert interviews highlighted that the EU could glean valuable lessons from countries with a more developed GH<sub>2</sub> industry, such as the United States, where policy instruments and strategies have successfully addressed some of these challenges. Furthermore, to fully benefit from the positive externalities of GH<sub>2</sub>, a significant restructuring of the current infrastructure is needed. This would mean the physical infrastructure for the production, storage, and distribution of GH<sub>2</sub> and the policy and institutional framework guiding and regulating these development processes until now. The potential of GH<sub>2</sub> in transforming the transportation sector should not be understated, as it holds opportunities in the form of cleaner energy, reduction in GHG emissions, and ultimately possible economic growth by creating new jobs and industries.

According to the Interviews' findings, a coordinated and collaborative effort including all stakeholders must take advantage of these opportunities. For the challenges to be overcome, cooperation is essential. While the path to implementing GH<sub>2</sub> in the transportation sector in the EU still has some challenges identified in this thesis through the functions of the TIS, this thesis concludes that these challenges, though significant, are not impossible. The development of this technology would not only provide a potential solution to the challenges currently facing the transportation sector in the EU but also significantly contribute to the broader goal of environmental sustainability and ultimately decarbonizing the sector.

This research hopes to act as a roadmap, guiding the direction of future research overcoming the challenges of GH<sub>2</sub> implementation in the EU. Furthermore, it highlights that the transition to GH<sub>2</sub>, despite being difficult and complex, is a feasible and long-term option for the road transportation sector in the EU.

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## Appendices

### Appendix A: Interview Questionnaire

Green Hydrogen Production Experts (G)

Road Transportation Sector Experts (R)

Policy Experts (P)

Knowledge Development and Diffusion:

(G) + (R) + (P): How is knowledge shared in the hydrogen sector? What are the primary means of knowledge sharing?

In your opinion, what factors influence knowledge sharing among the different actors that ultimately limit the diffusion of the technology throughout different sectors?

Influence on the direction of search

(G): What factors influence the direction of any speed of research and development in the green hydrogen production/transportation/political industry?

How do you decide which areas of research and development to focus on?

(R): How can the road transportation sector influence the direction of research and development toward green hydrogen technology?

(P): What factors influence the direction of policymaking related to green hydrogen technology for the road transportation sector?

Entrepreneurial Experimentation:

(G): What are the main opportunities and barriers to entrepreneurship and innovation in the green hydrogen production industry?

(R): What are the main opportunities and barriers to entrepreneurship and innovation in the road transportation sector?

(P): What can policymakers do to improve the support of entrepreneurial experimentation in the field of green hydrogen?

What are the main opportunities and barriers to entrepreneurship and innovation in policymaking related to green hydrogen technology for the road transportation sector?

### Market Formation:

What significant factors influence the market formation for green hydrogen in the EU?

(G) + (R): How is market formation developed in the hydrogen sector? What can you, as a private sector company, do to support or enhance the market formation?

(R): What are the main opportunities and barriers in the road transportation sector that hinder the diffusion of green hydrogen as a fuel?

(P): How do you think policymakers and other stakeholders can support the market formation of green hydrogen in the transportation sector?

What needs to happen from the political side to adapt green hydrogen for any sector as a significant fuel?

### Legitimation:

(G): What are the main opportunities and barriers to gaining public acceptance for green hydrogen to fight climate change?

(R): What are the main opportunities and barriers to gaining public acceptance for green hydrogen as a viable fuel source for transportation to fight climate change?

(P): What policy measures are needed to increase public acceptance and understanding of green hydrogen as a viable fuel source for transportation?

### Resource mobilization:

(G) + (R): How is mobilizing (financial) resources that support the development and diffusion of green hydrogen happening?

What are, in your opinion, the most significant challenges when mobilizing (financial) resources that support the development and diffusion of green hydrogen?

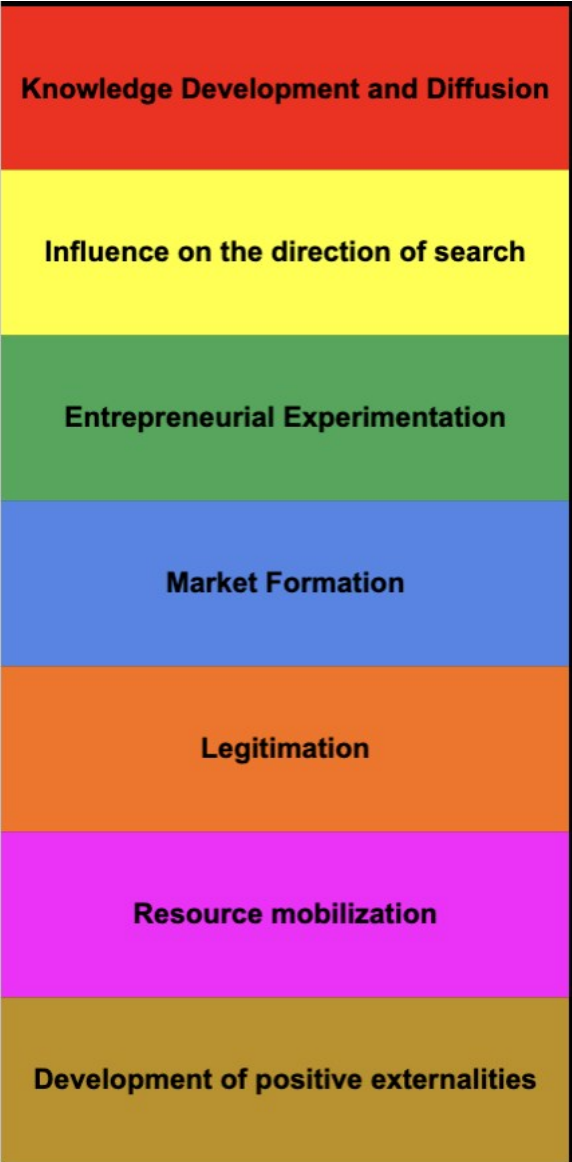
(P): What challenges do policymakers face to encourage investment in green hydrogen production and infrastructure for the transportation sector?

### Development of positive externalities:

(G) + (R): What positive externalities could arise from the increased use of green hydrogen in the transportation sector?

(P) What policy measures are needed to maximize positive externalities from the increased use of green hydrogen in the transportation sector?

Appendix B: Color Coding for Data Analysis of Interviews



## Appendix C: Example of Interview Transcript (Interview A Road Transportation)

Johannes

I am happy to give you a short intro right away on how we best proceed because I do not want to be too much on your schedule when you have heavy weeks anyway, and yes, well, for me, it is like I am exploring with my master's thesis the introduction of green hydrogen for the road transportation sector in the EU. That means everything on the street, from trucks to buses to cars, i.e., passenger transport to goods transport. Moreover, as in such academic works courses, it must be very theoretical. Furthermore, I have found a framework, a kind of analysis tool, with which I analyze this work. Using this tool, there are seven functions that I will also hang on to in my questions, which I then answer individually and will explain. Based on these seven functions, it will then be checked, so to speak, to what extent the new technology is ready for the respective sector or to what extent there are still weaknesses in the system. So now it is not like us. Moreover, as it is in such literary and academic work, it all has to be very theoretical, of course, and accordingly, I have found a framework, an analysis tool, with which I analyze this work. Using this tool, there are seven functions, which I will also grapple with in my questions, which I will then explain individually based on these seven functions, it will then be checked, so to speak, to what extent the new technology is ready for the respective sector or to what extent there are still weaknesses in the system. Above all, if it is not prescribed, nobody will do it, but I can; I would be happy to give you a short intro on how we best proceed because I do not want to be too late when you are going through heavy weeks anyway, and yes, that is how it is for me. I am researching the introduction of green hydrogen with my master's thesis, i.e., green hydrogen for the road transportation sector. That means everything on the street, from trucks to buses to cars, i.e., passenger transport to goods transport. Transport the transportation sector. Then it is a bit about to what extent knowledge is developed and how widespread is knowledge? That means that if we now look at green hydrogen for trucks or for buses or something like that for commercial vehicles at your place, to what extent would you say, can one assume that if knowledge is developed, so to speak, it will also be disseminated? Do you mean internally at VW, in the industry, in the entire sector, or with green hydrogen? Are there publications that VW makes or that your group makes? Are there trade fairs people visit to learn about new topics?

To what extent is this done, so to speak, and what factors influence it?

Interviewee

So yes. I will be informed about it. I would even go a step further. Concepts for this are in the drawer. Technology is possible. So, there is the whole EFuels topic as a headline. **The limiting factor is current politics. That simply pretends and says we do one way, which means there is nothing else but electromobility without being open to any form of technology.** You see that in the press too, but there is much to it. That means it depends on tonnage and volume in the commercial vehicle sector. **Yes, and now when I pick up the E Focus, then E Focus, no matter what technology, I always take a certain amount of space for the battery and a certain weight, which is all to the envy of the tonnage. Yes, and regarding loading volume, especially in the transport sector, it is only the quantity of the goods you handle.** The money brings. So that means you must do many tours to get some money in. However, when you have this one technology, it becomes problematic. That means it is challenging economically. So that means going back a bit. I get. It was over, but what is essential from my point of view in order to understand the overall context.

Johannes

Definitely, I find that to be briefly interrupted. I think that is good because I can then simply skip other questions, for example, and skip other questions. After all, they go hand in hand; there is also a category just for your info, for example, which means what kind of influence does it have on the search or the research in the sense? Moreover, if you already say that, then it is simply politics, for example, in the sense that spends the influences in total or, for example, in the commercial vehicle sector, the tonnages just like to count further. That helps is very good.

Interviewee

Let us look at a few examples of where I would say that efuels would be the better alternative for the commercial vehicle sector namely, trucks. Let us take a classic 40ton truck that drives 800 kilometers, and everything is roughly the same size, and so on. If you now assume a suitable battery, that would be around three and a half tons just for the battery. The system Weight goes away, so volume reoccurs, but the tonnage is more critical. Or shall we take another example? A light commercial vehicle takes a VW Bus t 6 yes trailer load, which means classic. I attach it in the horse trailer, and I attach a mini excavator for garden landscaping. I can attach more than 2 tons to it, two and a half tons, and everything is fine if I take the latest model today, a so called ID bus. Great car drives excellent, no question maybe you have seen it, that is me? Has an attachment load of a ton? That means it is just in terms of the relationship. You can see it;

that means these user concepts are entirely different. If I just go straight down this oneway street and the lack of openness to technology is not because the concepts do not exist. It is simply ideological principles that are being dictated by green politics. Other countries do not do it with the EU. Then he said a little bit about it, and I hope that if that catches on, it is supposed to be yes, do you want to file an objection from Germany, yes against the E judgment that you have to be open to technology, what from my would also be correct. So set a goal and let the engineers decide how to get there, and then the topic of efuels would, in my view, come out of the drawer again because it would make much more sense for the application example just mentioned because you could. If I continue to use these combustion engines with minor adjustments, I will use the engines and the infrastructure in this sector. That means this whole gas station system, et cetera, you could use all of that? Contrary to all this electromobility, you must redesign the infrastructure and all these components. Others, that is, the concepts from my point of view, are there.

Johannes

Ok, and if we look at it now, especially if you are talking about emobility and the infrastructure, it is already clear that they come from the last few years, for example. Hydrogen has not just been around since yesterday; the technologies are already relatively mature. To what extent would you say that new technologies, in that sense they are not new technologies, green hydrogen in that sense, are now gaining more and more ground, above all simply because of the energy transition, which is happening in Europe right now takes place, in that sense? There is not much yet when we come to sustainable energy sources from wind and solar in Europe. However, Bio Hydro Power also comes from water; how far would you say the topic will simply gain more and more ground and become more and more the focus of politics or now, for example, especially in your sector in the transport sector, in the sense that this debate is swinging right now. Green hydrogen is becoming more and more feasible, for example, due to production prices falling constantly.

Interviewee

Yes, with us, as I said, above all, there is simply the requirement of politics, and if you are honest, this whole emissions scandal means that the automotive industry is very defensive. Usually, you could also say you are the better technology and just get up, but simply because of the other things, you are now very careful with what you say, but again politics, if you pretend that they? The economy could, and yes, I think that ratio will, so in terms of price, it will

improve because this technology is aligning. The more critical point is that the German industry or the industrial environmental policy relies heavily on wind power. If you take the wind power now and look at the plans, how much will it cost there? Wind turbines should be built to produce electricity. Then that is a considerable amount, and now I can come on; you can only store electricity to a limited extent. What do you do with the energy? From the windmills at night, when you do not need electricity, they keep turning, and you cannot store the energy properly. That means I have energy over, and this energy that is over. Could Green e Fuels be used for the production of hydrogen? Yes, that means the more wind turbines you build, which RE is planning anyway, the cheaper or, the more energy you have for producing efuels and thus also a price. Scaling, yes, that means over there it will also get massively better from my point of view the topic plus of course you continue to develop with the technologies to become more efficient. Yes, and one advantage, perhaps briefly mentioned again. We would have the infrastructure for these things, and from my point of view, a factor that is rarely mentioned is the unemployed Klimatec. Alternatively, regarding the employment issue, one assumes that in the VW Group alone over the next few years, if everything continues as it is if one simply buys electromobility simply because there are fewer components and the components are preferably bought from abroad, 80,000 places or jobs are only in the VW Group per se, because they have less vertical integration. You just build motors for emobility and that motors you bought, and you have all these foundries that do not cast the motors, parts, et cetera out anymore. That means we will have an incredible number of jobs. Of course, you can now say that we have new technologies, wind turbines, e things. There are new ones. Yes, jobs will hopefully be absorbed, but never to the same extent. So maybe you have to keep that in the back of your head.

Johannes

I think so too, and I think that is an excellent transition to the next topic, in the sense that I know that from the automotive industry, so that is quite a lot. However, things are bought, and quite a lot is external. Now we are going to look at VW, for example, in battery production, then they are starting to take over this vertical, so to speak, in the appreciation of heads, which means that battery production is now more or less at VW in Salzgitter. If we now look at the whole issue of green hydrogen, to what extent would you say that there are entrepreneurial experiments in the transport sector, which is operated, for example, by a large corporation like VW Research and, therefore, R&D Research and Development? Or is that more outsourced? As with other

components, you say hey, we will look at what is on the market, either by use for the technology or then try to develop something ourselves, so how far are these experiments going?

Interviewee

So both. It is still in the drawer, I say. They also sponsor universities. I mean the LU in Munich. For example, MAN Nutzfahrzeuge has set up a hydrogen center in Nuremberg, also in engine production, so there are a few things. But very slow and very defensive. This again goes hand in hand with the topic just discussed, that politicians simply do not want it, and of course, you always have a specific budget available. Yes, you invest in research and development, and that, of course, you invest in the sectors a, which order it currently gives, if the legislature is simply open to technology now. Once published and lived that way, I firmly assume that the NG budgets will be redistributed again and that concepts will be pulled out of the drawer.

Johannes

Yes, and then for a company like Volkswagen, it is an entirely new stream because you can develop new research there. Sure, they are all fully focused on electromobility now, but if they change the legislature or the legislation like that, they have to go along with it, which is happening in the EU right now. Germany is the only country that is suing against the combustion engine. I believe that is 35 and or 3530, yes. It is wild because I do not get it here; you must work your way into it to get a sense of European news here in South America. However, it makes sense that politics is just the deciding factor. It is remarkable because I got it right after our call. In 2 hours of an interview with the head of the digital and transport ministries' hydrogen and fuel cell departments, I am inquisitive about what he says from his side because I am trying to look at politics a bit. I am trying to look at the hydrogen and transportation sectors, and I have only got two or yes, in a sense, 2 to 3 small categories that I would like to discuss. The first is probably set off relatively short in how far you would say it involves legitimation in public hands. So, I think the topic is relatively exciting in the public sector. Everyone is on the trip, mainly driven by politics. Hey, emobility is the solution E mobility is good. However, most people do not have the technical expertise and cannot assess it, even if they do not deal with the topic now. To what extent is it to say Greens have green hydrogen, which is gaining ground primarily through the Ukraine war, and somehow have legitimacy among the population to say, " Hey, that is the miracle cure or excellent? We know that a few years ago when emobility was somehow very popular. It is now the white knight on

horseback who could somehow save, but after a few years, everyone thinks maybe we need something else, so a bit in the legitimization direction.

Interviewee

Well, I think the ones are the advocates for it, so first of all, they are not very many because, from my point of view, the reporting tends to be so, yes, that means you feel what is predetermined in Brussels. And then one argues like that, that is partly, there it is tendentious, my subjective ones. So, you say that is a solution. I think there are two categories of people. First, people who deal with it technically have some kind of well founded knowledge. They are the second category of people who simply have something against green in general, without delving deeper into it to work, so not technically wellfounded, yes, but rather a bit of a flat rate, no, so they do not help that much, but these two categories, people who justify it technically, yes and just that different. Forward and forget some people who say I am not what is new.

Johannes

Yes, I see it that way too, so it is also interesting because I am working on the topic a bit from the literature and trying to get answers from the literature first and then compare the exact experts like you from the field, and I say you of course not before, but that is about what the literature gives. It is just that the measures are not yet so pronounced that people have something. Do you have a call directly afterward or somehow 5 minutes longer?

Can we do more afterward so the next category, the penultimate, would also be in the extent to which mobile sources are mobilized? So how far would you go now in a car? Can you say yes? Do you see that money is being put into research on the subject? Green Hydrogen Spread of Fuel Sales.

Interviewee

Highly profitable brands can afford it because they have a VW that counts. Yes, they only put that into secure technology, that is, security, if they can get rid of it later. That means electric mobility parts of a group like Porsche that are profitable. They can, for example, support universities such as LMU or do something themselves. Spend BS to have such concepts in the drawer. However, that is reserved for the companies that make many profits.

Johannes

So at the end of the day, it is always the same game. There has to be a push from the government

or the legislature so that something happens. If that is the case, then it is implemented. Firstly, on the one hand, you have to. Secondly, on the one hand, then more can make money, just like e-mobility. Moreover, otherwise, the horse just does not move because.

Interviewee

I have to. Now it is easy for me. So with a date like this from 35, that is simple. We must not forget Co 2 penalties, so if you do not have a specific fleet consumption, yes, approvals are sometimes pushed over the year, so you only ever have a fleet consumption. Yes, it is not explicitly stated that what the customers want is also manufactured, but you have to be tactical here, too, so that you only allow certain cars with specific engines. Suppose you know only the I know v eight, the g class. Yeah, so you can say they sold out in January last year; why? If it is such a great model, where so much money was involved, why isn't production ramped up? Now, of course, you can say yes, that would be OK, but the real reason is simply the bestselling model has almost 600 hp, eight cylinders, 100 from the truck well the end that you would only build or would build even more if you were to increase the fleet consumption a lot. So, you do not do bad things either. You use tactics and do not give the market exactly what you want, so you create a scarcity caused by restrictions, which take precedence over politics.

Johannes

I find that very interesting, especially when it comes to market formation. So the market formation then simply depends entirely on political specifications, which means the market would not form if you did not say hey now.

Interviewee

If you were technology open, then it would be shared. Then you would have the small cars, for example, the ones in the city, more electromobility, would become enemies, and the large transport sector would be opened up with more hydrogen or longdistance cars. Yes, then you would have somehow a transition like the small VWA purely electric, then you would have you would get the Passat in combustion engines with efuels and electric motors, and then you have the big ones, which I have bullies and trucks, which you would then have in. If it were open to technology, you could only do that with efuels or something like that from the transition.

Johannes

It is fascinating that then, like in energies, there would be a sustainable energy mix that people

say, hey, we will find a bestcase solution for energy sources, electric from Heidin, and then just something that's specifically tailored to the respective industry fits best and what is then also best for the environment in that sense, that is very exciting. We still have a single question unanswered, which is okay. However, again, this is a very theoretical thing. Positive externalities that is, to what extent, if you now look at green hydrogen, for example, to what extent are there positive versus negative effects alongside or with the effects of, that is, if you develop such a technology now? You just mentioned, I think, a very positive one. It would be that we already have an example of the infrastructure compared to the electrics. Another point would be, for example, that you can transport it more cheaply on heavy duty. This means that you can do better than e over long distances. Are there also negative things? Would you say if you look at green hydrogen now, without perhaps being an expert in the field? What predominates?

Interviewee

That, in turn, depends on the particular vehicle. The solution, and so I would look at it in a differentiated way, if you now retake the example, you have a small car, the motor may be heavier than the battery, so yes, there might then be a disadvantage in some way, also about the costs of electric power, because electric power is cheaper than it is now, for example with commercial vehicles, where you poorly make more money because you can take more with you. Tonnage plus you do not have to load as often, and waste time, which means the business case is better again, so I would look at it differently from the user's point of view, from the production point of view, i.e., manufacture the vehicles. It is real. Yes, a combustion engine is cheaper because we purchase all these ecomponents and have limited control over the prices. Yes, because it is simply cheaper. Regarding raw materials, we are highly dependent on other countries because we do not have them. Russia is now with China, a complex country, and people are going extreme to Canada and getting many things there. She always comes up.

Johannes

Please, Brazil is also increasingly coming into focus as a very neutral country.

Interviewee

Yes, that means we make ourselves highly dependent on it. We would have the other technologies ourselves, so that is perhaps another point to consider that you cannot convert directly into money, but depending on how the price dumping is afterward if you are dependent,

then the money can come in, money goes. There you are with e Fuels, then you have your hand no, and it would be a bit of a waste product, especially if this topic with the wind turbines comes up again. No, so you have to. It is always better and worse regarding costs related to the respective things. So it is the one who is the user of the respective vehicle. The producer of the respective subject and depending on the segment, you can do that on the respective vehicle. Then do a little bit, so there is not a blanket answer. I mean, for everything, but you have to look at it differently. Of course, it is a mix of everything.

Johannes

Yes, that is a good point, and above all, for the logistics transport area, the cost factor is simply the decisive factor. Ultimately, the powerful lever to decide yes or no makes total sense, but I am curious what the others will say about it. I am inquisitive about the political direction and what they will say about it, especially from the Federal Ministry. I have next week again from the European Parliament. The one with hydrogen and the further development of the whole thing, which will report on the whole sector, but a super good interview from your side. I think I have mine

Appendix D1: Interview Summaries road transportation sector

	Interviewee A	Interviewee E	Interviewee G
Knowledge Development & Diffusion	<p>Politics just say EMobility is the key                      Hydrogen is not in focus                      Politics is a limiting factor                      Differentiation between heavyduty and person transport                      Limiting factors: Politics and Openness towards new technologies                      more interaction with engineers etc.                      positive: infrastructure is already existing e mobility needs a new one</p>	<p>Trade fairs                      Advocacy                      Tech Knowledge</p> <p>Challenges:                      Costs competition</p>	<p>Challenges:                      Demand from market requirements for production legislation and allowances                      no excellent industry standards for industry regarding new technologies</p>
Influence on the Direction of Search	<p>Politics and Rules direct the direction of the search                      potential use of wind power from the night for hydrogen etc.</p>	<p>Technology push of the private sector                      Supply &amp; Demand</p> <p>Challenges:                      Social Media reluctance                      Policy Making influences the Direction of search (super slow)                      Certification                      Legislation</p>	<p>Challenges:                      group requirements                      exciting knowhow                      governmental regulations</p> <p>GH2:                      customer requirements                      smaller badges</p>
Entrepreneurial Experimentation	<p>Collaborations with universities, for example but very defensive</p>	<p>Challenges:                      Knowledge gap over EU funding opportunities</p> <p>Challenges:</p>	<p>the biggest problem in the financing need</p>
Market Formation	<p>Politics need to build and do without legislation, the automotive industry would not make the push itself. Its need incentives                      Openness to new technologies</p>	<p>Governmental Support in funding                      EU communication                      Access to information                      EU Standards for individual countries (27 member states every country has different obstacles)</p>	<p>political instances, the ay role the the private sector does not push                      customer plays a significant role                      hydrogen needs infrastructure                      Market formation comes from the market push</p>

Legitimation	not many persons within the automotive production industry in Europe call on hydrogen	Challenges: Acceptance of Technology Competition of EMobility People are not aware and do not know enough Safety of Technology (look at EU standards)	Governments don't subsidy technology open public opinion is more on battery heavy duty truck industry is. Better than the private sector  Technology openness is a crucial problem
Resource Mobilization	example, VW Group. only highly profitable brands can invest resources in R&D for green hydrogen	Challenges: Lack of Knowledge There is a pool of money for the tech but it is not taken from the companies  Opp: Technical roundtables funding support with EU funding help build networks	EMobility gets all the funding
Development of positive Externalities	depending on the angle (small cars, heavy duty, etc.)	Challenges: Enabling commissions are not there now Order of Priority in terms of colors of Hydrogen only green hydrogen is currently not visible (not enough) look at other sectors as well Zero emissions are to be achieved by all means Opp: general decarbonization Spillover effect through different industries Bridging solutions	chances of reducing CO2 taxes in the EU reducing CO2 emissions in general EURO7 norm

Appendix D2: Interview Summaries GH<sub>2</sub> sector

	Interviewee D	Interviewee F	Interviewee H
Knowledge Development & Diffusion	<p>do not care about sharing developments mainly (internal focus)</p> <p>actively involved with governmental groups to participate in policy making</p> <p>public affairs consulting</p> <p>building a GH<sub>2</sub> collaboration group to funnel all requirements from the private companies</p> <p>partnering with universities and so to bidding for governmental funds</p> <p>universities research, etc.</p>	<p>Challenges:</p> <p>work with associations</p> <p>lobbyism</p> <p>public affairs</p> <p>hydrogen working groups</p> <p>conferences</p> <p>awareness work in public unis schools, interviews</p> <p>Lecturer at University</p>	<p>private sector companies want to keep their knowledge</p> <p>public awareness</p>
Influence on the Direction of Search	<p>What are Investors looking for (grid connection etc.)</p> <p>off take</p> <p>supply and demand for GH<sub>2</sub></p> <p>demand is the main factor to influence</p>	<p>Challenges:</p> <p>Regulations of governments</p> <p>first of all, applications will be considered from the private sector</p> <p>market demand</p> <p>Willingness to pay off customers</p> <p>Market analysis + Market models</p> <p>Political Regulations decide in what direction the R&amp;D is focused</p> <p>technological visibility</p>	<p>EU Legislations</p> <p>demand</p> <p>public opinion</p>
Entrepreneurial Experimentation	<p>What are Investors looking for (grid connection etc.)</p> <p>off take</p> <p>supply and demand for GH<sub>2</sub></p> <p>demand the main factor to influence</p>	<p>Challenges:</p> <p>Technological Challenges are crucial</p> <p>EU Legislations</p> <p>Access to Subventions</p> <p>general costs at the beginning</p>	<p>Investors play a role</p> <p>supply &amp; demand</p>

Market Formation	<p><b>BARRIERS:</b>  money  economics  access to governmental support  the price of renewables &gt; governmental subsidies</p>	<p>Associations, like Hydrogen Europe, etc.  Regulations on the EU level  political work for the regulatory framework</p>	<p>government  infrastructure to use the produced GH2</p>
Legitimation	<p>Challenge:  the economics of mobility (cars)  depending on the application (long distance vs. short distance)  manufacturing problem (production costs)  acceleration from tech push, demand side</p>	<p>Challenges:  Labelling in the EU is essential but needs revision (only green products should be labeled as green)  EU Taxonomy  Infrastructure with refueling stations are too expensive currently</p>	<p>certifications &amp; labels  knowledge gap</p>
Resource Mobilization	<p>Challenges:  access to grid connection of electricity  investors see this as a positive sign  governmental subsidies technologies  competition from the middle east (low production costs)</p>	<p>Challenges:  regulatory + subvention support from the EU is crucial  Europe used to be the leading market for Hydrogen (Problem of Technology Openness)  Inflation Reduction Act is crazy  competition  it is hard for European companies to get significant funding (global markets, US investors)  a big problem of resources in the EU (steel, electricity, etc.) disadvantage  Opp.:  global market is a positive development for accessibility to financial resources  subventions are good in the EU  employees in Germany are great (human</p>	<p>complex process to get money from governments  IRA is way better than EU legislation</p>

		capital is good)	
Development of positive Externalities	costs are crucial premium for nongrey hydrogen driven by economics	employees in Germany are great (human capital is good) shift from the automotive sector to green Hydrogen in terms of employees	green hydrogen is still too expensive

Appendix D3: Interview Summaries political sector

	Interviewee B	Interviewee C	Interviewee I
Knowledge Development & Diffusion	NOW GmbH from the German ministry Think thank for knowledge development and diffusion Roadshows Publications on the Homepage Mandatory Information about grants	biggest prob: knowledge gap in politics chicken/egg problem Technology openness is missing in Europe leads to wrong or slow decision making  personnel talks/interviews with experts to gain knowledge conferences publications	Hydrogen knowledge shared like other industries Factors affecting knowledge sharing: politics, IP, commercial interests, trust, culture Improve sharing through open innovation, standard protocols, collaboration EU institutions supporting hydrogen knowledge: FCH JU, DG Energy, EHA Platforms like Hydrogen Europe incentivize funding and partnerships for hydrogen technology advancement.
Influence on the Direction of Search	Supply and Demand different colors of hydrogen EU hydrogen strategy makes the push and national hydrogen strategies execute (nothing mandatory)	political decisions are years behind and set the direction for the search public opinion	MEPs need to stay informed about the latest technology advancements and cooperate with industry and research organizations to address crucial points of technological progress. MEPs should pay attention to meeting climate targets and considering market demand and supply, as well as policy instruments to stimulate demand or increase the supply of (green) hydrogen. Cost considerations of green hydrogen technology, including production, storage, and transportation costs, play an essential role in exploring financing options for its development.
Entrepreneurial Experimentation	Support the scaleup dedication to single departments for each sector	depends on political institutions and laws (incentives etc.)	Policymakers need to create a regulatory environment for green hydrogen. Collaboration among stakeholders is crucial. Regulation creates trust and benefits companies. Internal market can create green hydrogen infrastructure.

			The transport sector can benefit from green hydrogen.
Market Formation	Europe 2030, around 20% FCEVs or FCVs (with more to come) Infrastructure around the technology is a limiting factor for the market formation (600 hydrogen gas stations in planning in the EU) 7585% of green hydrogen will be imported into the EU (the reason is to get it as cheap as possible)	depends on political institutions and laws (incentives etc.) cut fossil fuel subventions	Invest in hydrogen infrastructure Avoid the chickenandegg problem Explore hydrogen applications in other sectors
Legitimation	Differentiation when it comes to awareness between private and corporate private, mainly electric corporate (logistics etc.), mainly hydrogen private sector needs more attention Implementation of the Hydrogen Strategy gave an enormous push public awareness also corresponds to the provision of human resources within the federal government.	Investment Size more risks subventions	Firsthand experience with hydrogen tech Pilot projects can boost confidence Financial incentives for early adopters
Resource Mobilization	Europe EU legislations have a really strong and sometimes also can be a limiting factor	Hydrogen Bank Innovation Fund Subsidies IPCEIs	EU's Hydrogen bank provides 800M Euro for hydrogen projects Concerns about IRA's investment attraction EU needs a comprehensive approach and collaboration on financial incentives Clear, longterm strategies for investment needed Coordination between the EU, national governments, and industry players crucial

<p>Development of positive Externalities</p>	<p>Infrastructure  Implementation of reasonable regulations and legislation for other technologies to arise at another point  competitiveness internationally  new production sides for electrolysis  in the long term, only green hydrogen helps fight climate change  Europe aims to be the first continent to be climate neutral</p>	<p>Infrastructure  Long time learning from the USA (inflation reduction act)</p>	<p>Emission Trading System (ETS) and Carbon Border Adjustment Mechanism (CBAM) create financial incentives for companies to reduce emissions and invest in cleaner technologies like green hydrogen.  ETS is a capandtrade system with emission allowances that will apply to road transport and buildings from 2027.  CBAM imposes a carbon price on imported goods based on their embedded emissions to prevent "carbon leakage" and promote a global shift towards cleaner energy sources and technologies  Social Climate Fund will subsidize national social climate plans to cushion the adverse effects of higher gas and petrol prices.</p>
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