Østfold University College
Department of Engineering

Business Prospects for Energy Enterprises in Norway's Flourishing Green Hydrogen Industry

Vinod Rani

Masters in Green Energy Technology (Smart Energy)

Department of Engineering

Supervisor: Gunnar Andersson

August 15, 2023

Abstract

The increasing need for environmentally friendly solutions is compelling Norwegian energy firms to embrace green technologies and fuels, aligning them with their sustainability objectives. However, these companies face a dilemma due to the strong presence of the oil and gas industry and electric vehicles in Norway. A continual debate among politicians and corporate actors revolves around the feasibility of implementing green hydrogen in the nation. This master thesis highlights the significance of considering multiple factors, including market opportunities, national development strategies, policies and regulations, political support, infrastructure, and social acceptance, within the hydrogen sector. Political support and infrastructure development are identified as key drivers for the adoption of hydrogen technology in Norway, with the potential to replace the natural gas trade and contribute to a sustainable economy. While hydrogen stands as a high-cost fuel demanding judicious utilization in the green transition, its suitability is most pronounced in sectors that are hard to abate. Notably, hydrogen demonstrates feasibility in sectors such as maritime, aviation, industry, and long-haul transportation, whereas technologies like electric cars and heat pumps are more pragmatic alternatives for short-haul transportation and home heating, respectively. Hence, it becomes crucial to demonstrate resolute political determination and conduct a thorough evaluation of energy efficiency to fully capitalize on the potential of hydrogen.

Acknowledgements

I would like to express my heartfelt gratitude to several individuals who have played a significant role in the completion of this thesis.

First and foremost, I would like to extend my deepest appreciation to Dr Gunnar Andersson for his exceptional guidance, unwavering support, and valuable insights throughout the entire thesis process. His expertise and encouragement have been invaluable in shaping the direction of this research. I am grateful for his acknowledgement of the iterative nature of design thinking and his efforts in arranging meetings with other professors and industrial players to provide a practical perspective to the thesis. I would also like to thank Dr Nand for his valuable contributions and vision on the use of hydrogen in the power sector. His insights and expertise have added depth and clarity to the thesis.

I would like to acknowledge the assistance and cooperation of the Østfold University and the individuals who generously shared their insights and expertise during interviews and data collection. Their valuable contributions have greatly enriched the quality and depth of this study. A special thanks go to my former colleague, Mr Hemal Sanghvi, whose industry knowledge and expert guidance have been invaluable throughout my master's journey. His support and mentorship have helped me extract the utmost value from this program.

Finally, I would like to express my sincere gratitude to my mother and brother for their unwavering support, encouragement, and belief in my abilities. Their presence and encouragement have been the driving force behind my success in reaching this important milestone in my career.

Although it is not possible to mention everyone individually, I extend my deepest thanks to all those who have contributed to the completion of this thesis in various ways. Thank you all for your invaluable support and contributions.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Background and Motivation

Climate change speaks of the dire and potentially irreversible threat to humankind and the planet. Based on various studies, it has been observed that climate change will not only imbalance industrial and economic processes but also jeopardize the physical and mental health of human beings (Ebi et al., 2021; Liu et al., 2015). In acceptance of this, countries around the world adopted the Paris Agreement in December 2015 with the motive of devising a plan to limit global temperature rise to 1.5°C (IPCC, 2019). To keep the global warming limit to 1.5°C, emissions must be reduced by 45% by 2030 and reach net zero by 2050 with the help of zero-emission fuels.

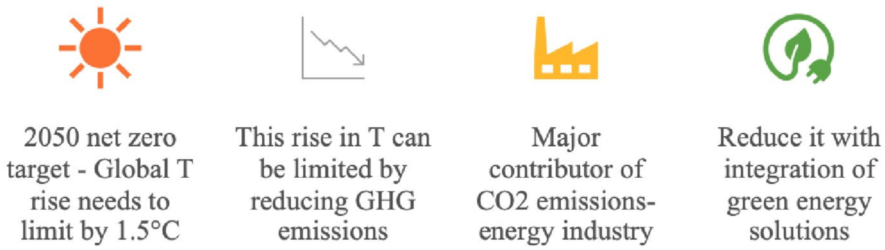


Figure 1.1: Green transition

Green hydrogen is among the different green alternatives to reduce CO2 emissions. Produced through the electrolysis of water using electricity generated from renewable energy sources, green H_2 is a vital component of the energy transition. It serves as a clean and sustainable fuel, offering zero CO2 emissions compared to grey hydrogen derived from fossil fuels which is used in industries like refineries, fertilizer plants, and the chemical industry. Green hydrogen stands out for several reasons. Firstly, it produces only water as a by-product and utilizes renewable resources that are not depleted. Stored hydrogen can be converted back to electricity, and used as a feedstock for industry, heating and fuel for vehicles as represented in Figure 1.2 (Schrotenboer et al., 2022).

However, the integration of hydrogen into the system raises several concerns in terms of

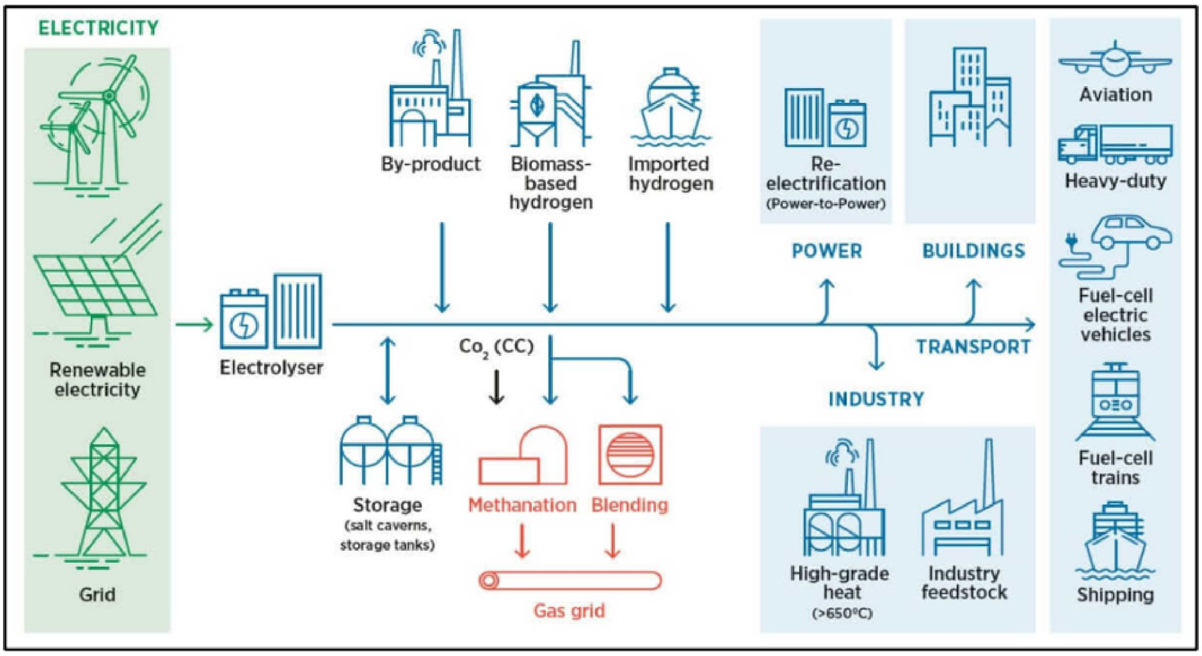


Figure 1.2: Different hydrogen sources and potential hydrogen applications (Store, 2020)

technology and business. Some technical challenges are of concern, including cost-inefficient hydrogen production, low energy density storage, safety, and limited hydrogen storage and transportation infrastructure (Massaro et al., 2023). Whereas, economic or business challenges such as regulations, market demand, risk, policies, and integration among different stakeholders, need detailed attention to pursue profit maximization while addressing environmental concerns simultaneously (Söderholm, 2020).

Even though green hydrogen is currently perceived as an expensive solution, the market for it is not yet fully matured. There is significant discussion and interest surrounding hydrogen's potential to replace fossil fuels in various sectors that are difficult to decarbonize. Energy companies in Norway are interested in green hydrogen due to its potential as a sustainable solution that contributes to achieving net-zero targets and their commitment to sustainability. However, these companies are uncertain about whether to promote green hydrogen over direct electricity, despite its lower energy efficiency. Moreover, these energy companies are determined to generate profits from green hydrogen while also recognizing its societal value. They aim to achieve this by establishing a robust customer base, leveraging government funding, and capitalizing on synergistic opportunities. Norway presents a favourable environment to produce green hydrogen by utilizing excess renewable energy instead of curtailing it. Furthermore, the surplus green hydrogen can be exported to countries with limited access to RE sources, thereby facilitating their transition to a greener energy landscape.

1.2 Problem Statement

According to discussions with the energy company, it has been revealed that companies are facing a dilemma when it comes to investing in the hydrogen business in Norway, this is particularly due to factors such as the country's abundant gas reserves, and the increasing adoption of electric vehicles and ferries. One of the significant challenges they face in their hydrogen business is the lack of comprehensive market research. The immature market and the unavailability of potential customers led to a lack of confidence in initiating hydrogen business operations. The uncertainty lies in determining which sectors will have the greatest need for hydrogen and prove to be profitable for businesses. Companies are unsure about the potential customer base and who would be willing to purchase hydrogen despite its relatively high cost. This uncertainty poses challenges for decision-making and investment strategies in the hydrogen sector.

It is essential to consider that hydrogen is not a one-size-fits-all solution and how green hydrogen can compete economically against other green solutions. Its application must be carefully assessed to identify suitable areas of use.

1.3 Research Question

This research aims to contribute to understanding the potential of green hydrogen within the Norwegian context. It offers valuable insights to an energy company in Norway that seeks to align with Sustainable Development Goals (SDGs) by promoting green solutions within the green hydrogen sector.

This thesis will focus on addressing the following research questions:

- How do external factors influence the green hydrogen business within the Norwegian framework?
- In which specific sectors should green hydrogen be prioritized over other green solutions in Norway?
- Identification of potential customer segments that could be targeted by an energy company in Norway

1.4 Report Outline

In section 2, an extensive literature review is performed to identify crucial factors that significantly impact the commercialization of green hydrogen energy. Section 3 provides a detailed explanation of the various methodologies employed in this thesis to analyze the feasibility of the hydrogen business in Norway. Following this, Section 4 presents the findings on the hydrogen business, which are then followed by the conclusion and discussion.

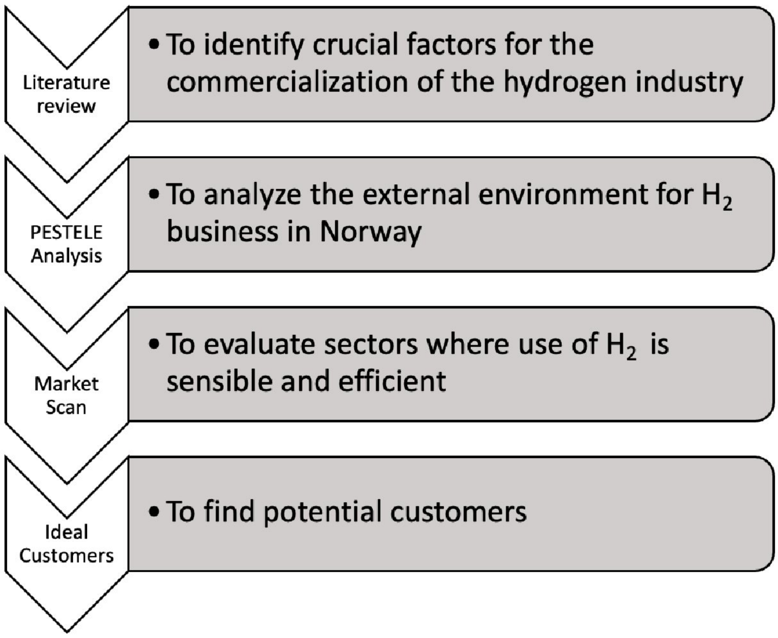


Figure 1.3: Thesis outline

Chapter 2

Literature Review

In recent years, several studies have been conducted to explore the feasibility of hydrogen production by utilizing renewables (known as Green Hydrogen) and to assess the potential of new business models for the advancement of the hydrogen energy industry. The primary objective of this literature review is to identify key factors relevant to the hydrogen business that have been researched. Furthermore, in the next chapters, this thesis aims to investigate these factors in a structured manner using optimal methodologies to evaluate the scope of hydrogen business in Norway.

2.1 Review Methodology

In this section, I describe how I conducted the review to determine the feasibility of a hydrogen economy. For identifying relevant scientific literature, I searched academic databases including Google Scholar, IEEE Xplore, Web of Science, and Science Direct.

As part of the search strategy, I used the following search terms in the databases mentioned above: "Hydrogen", "Storage system", "Utility applications", "Business model", "Hydrogen economy", "Renewable", and "Water electrolysis". After performing searches using the keywords mentioned above, I further excluded some irrelevant literature by using the following criteria:

- Papers that were considered irrelevant based on the initial screening of the title and abstract were excluded
- Research papers without a business perspective were eliminated
- Papers written in languages other than English weren't accepted

2.2 Analysis of the literature

The 2011 paper *"Economic Analysis of large-scale hydrogen storage for renewable utility applications"* uses a system where wind energy is used to produce hydrogen. The cost analysis (economic analysis) on different hydrogen storage systems is performed based on capital cost, number of hours of stored energy for full power discharge, annual life cycle cost including O&M cost, charging electricity and replacement costs. It has been mentioned that underground hydrogen storage offers opportunities at a large scale and competitive cost as shown in Figure 2.1. The report performs a sensitivity analysis by varying the hydrogen system costs, economic and operational parameters such as days of operation per year, capital charge rate, and replacing target geologic storage costs with cryo tank gas storage costs and evaluates the economic feasibility of hydrogen storage for business decision-making. The business case of utilizing excess wind energy for 6 hours is established for benefit/cost analysis. It is highlighted that H_2 storage cost is competitive with other energy storage systems when excess wind power is utilized for charging storage at no cost shown in Figure 2.2. This paper concludes that H_2 energy storage is a good fit for renewable energy at large scale, especially wind energy. The major disadvantage of the H_2 storage system is its relative inefficiency of energy conversion and the advantage is lower storage cost and higher mass-energy density. The stored H_2 is used during peak periods of demand to fuel utility-scale fuel cells while its use in other sectors is not explored. The recommendations for future work are to consider scaling in the business model, create opportunities for non-utility (third party) into the business model and consider different value propositions a business model can offer to its customer at a large scale and smaller scale of storage. It is recommended to consider the location to benefit/cost analysis. The importance of developing market opportunities is emphasized. It suggests exploring those opportunities where the relative inefficiency of energy conversion becomes less significant in comparison to relatively cheap storage, and where storage is indispensable to counter inconsistent electricity production (Schoenung, 2011).

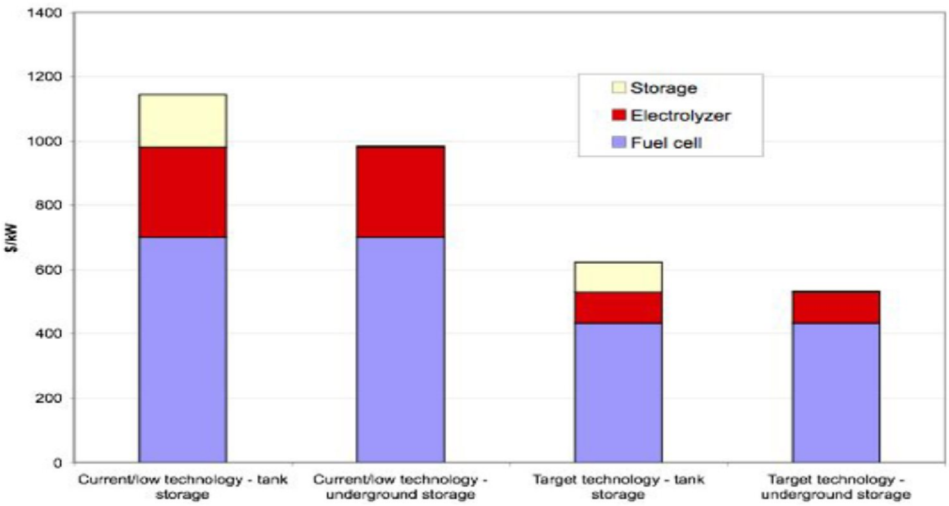


Figure 2.1: Capital cost components for 6-hr hydrogen energy storage systems(Schoenung, 2011)

The 2018 paper *"Potential of new business models for grid-integrated water electrolysis"* coupling electric power systems with a high share of renewable energy in the H_2 demand market. It investigated the business potential of grid-integrated water electrolysis systems (Green Hydrogen) in cross-commodity arbitrage trading by using complex power market simulation

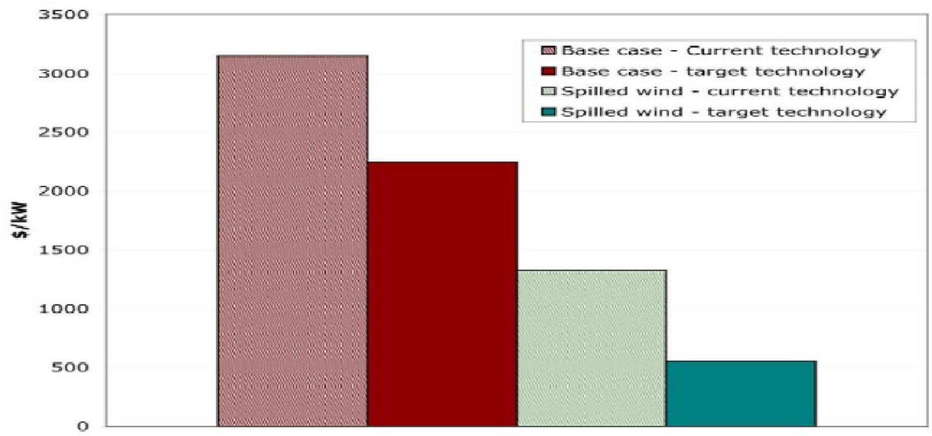


Figure 2.2: Present value of hydrogen system costs - 6 hours of storage(Schoenung, 2011)

methods for future scenarios shown in Figure 2.3. The maximum revenue can be achieved by optimizing electrolyser operation based on electricity price and hydrogen price. The different sectors of H_2 demand and uncertain H_2 prices are analyzed through sensitivities of different H_2 sales prices. It has been observed that cross-commodity trading is profitable for the transportation sector compared to industry and natural gas systems. Therefore, additional provision of services towards grid operators can increase the utilization ratio of electrolyser thus increasing its profitability during low hydrogen prices. Full load hours of electrolyser in terms of grid service highly depend on the point of grid connection. It is analyzed that the efficiency of a business model and electrolyser utilization ratio depends on H_2 price. While existing business models focus on hydrogen demand, new business models need to consider the fluctuating nature of RES feed-in. The integration of renewables into the power system is decreasing the prices at the spot market, thus promoting cross-commodity trading. The increasing share of RES and decreasing investment cost for electrolysers will result in more profitable business models in future. The importance of new business models, potential markets, electrolysers with dynamic operation capability and exemption from charges is crucial for economically sustainable operation. Moreover, the dependency of new business models on trading between the electricity market and hydrogen market demand during low prices of electricity is important for the economic feasibility of a business model (Larscheid et al., 2018).

The 2021 paper *"Assessment of technological path of hydrogen energy industry development: A Review"* considers hydrogen as one of the most promising energy sources due to its high energy density, no carbon emissions, and cleanliness. The present research status and development prospects of various technologies such as electrolysers, storage tanks, hydrogen refuelling machines, and surface treatment of the bipolar plate in the fuel cell, in the hydrogen value chain, are analyzed shown in Figure 2.4. Integrated energy service parks with heating networks, gas networks (power to gas conversion), power grids (power to power conversion), transportation networks (power to fuel conversion) and industry networks (power to feed conversion) are proposed. The demand for H_2 in the transportation sector results in hydrogen energy development. The specific technical path to develop renewable energy such as the combination of wind/ H_2 production by electrolysis of water, off-grid H_2 production with fuel cell power generation, hydrogen refuelling station supply, natural gas hydrogen mixing technology and methanol production would tackle the uneconomical production and transportation difficulties of hydrogen. The demand for national development strategies, relevant power market regulations and policies, large-scale scientific research programs, synergies, new export

Input data	Relevant output data
European spot market simulation	
• Generation units in all coupled market areas	• Hourly spot market price time series
• Dispatch constraints for generation units (gradients, minimum operation and down times)	
• Technical parameters and limited availabilities per unit due to power plant outages	• Dispatch and location for each generation unit
• Time series per market area (demand, RES, combined heat and power)	
• Exchange capacities between market areas	
• Primary energy and emission certificate prices	
• Reserve demand	
Simulation of transmission grid operation	
• Dispatch and location for each generation unit	• Time series and location of curtailment
• Time series and location of demand and RES	
• Transmission grid topology	
• Operating limits of transmission grid	
• Network related remedial measures including relevant constraints	
Simulation of electrolyser operation	
• Hourly spot market price time series	• Dispatch of electrolyser
• Time series and location of curtailment	• Costs of electricity demand
• Electrolyser key performance indicators (KPI)	• Hydrogen production
	• Revenues from hydrogen sales

Figure 2.3: Overview of simulation input and output data(Larscheid et al., 2018)

opportunities and commitment of the countries towards a sustainable future are vital factors to boost the hydrogen economy. Research areas include the exploration of the business models to integrate renewable energy and hydrogen energy and their applications in integrated energy service parks involving multiple types of energy networks, including power grids, heating networks, gas networks, and transportation networks (Norouzi, 2021).

The 2022 paper *"Moving toward the low-carbon hydrogen economy: Experiences and key learnings from national case studies"* considers the H_2 zero carbon energy vector to complement electrification which can be used in transport, commercial and residential, power sector and industry in a cost-efficient manner. The factors such as technological development, policies, safety, legal, environmental, and societal aspect, business models with risk mitigation measures, sectors where hydrogen demand is marginal, stakeholders, public-private collaboration, and national opportunities need to be addressed to stimulate the commercialization of green hydrogen. The use of hydrogen fuel cells in the transport sector can scale up the hydrogen demand significantly. The social acceptance of infrastructure and technologies is necessary for their large-scale deployment. The mathematical models are used to assess the potential of hydrogen in integrated hydrogen systems, gas and power market dynamics, different end-user sectors and environmental impact. However, the importance of financial and legal barriers and risks must be understood to develop a business model for H_2. In this paper for the development of a business model, first defined the scope of the project, followed by reviewing market and policy structures, analysing gaps, then identifying and mitigating business and investment risks, and finally developing the business model itself shown in Figure 2.5. The challenges are the development of cost-efficient infrastructure, technical assessment of H_2 potential, financial risks, lack of practical overview to define scope, analyze gaps, identify risks and mitigation for successful business models. The incentivization of a large-scale hydrogen value chain, significant public support to ensure coordinated planning, governance, and the establishment of supportive regulatory frameworks are required to foster the growth of hydrogen markets and infrastructure. It is necessary to conduct further research for a comprehensive techno-economic assessment of the hydrogen economy that can facilitate its development. Ad-

Compare items	Alkaline water electrolysis	SPEpure water electrolysis	Solid oxide electrolysis
Electrolyte	20%~30% KOH	SPE film	Y_2O_3 /ZrO_2
Working temperature/°C	70~90	70~80	700~1 000
Current density/($A\cdot cm^{-2}$)	0.2~0.4	1~2	1~10
Electrolysis efficiency/%	60~75	70~90	85~100
Energy consumption/[($kW\cdot h$)$\cdot m^{-3}$]	4.5~5.5	3.8~5.0	2.6~3.6
Operating characteristics	Start and stop faster	Start and stop fast	Inconvenient start and stop
Dynamic response capability	Stronger	Strong	—
Power quality requirements	Stable power supply	Stable or fluctuating	Stable power supply
System operation and maintenance	Corrosive liquid, complicated operation and maintenance in later stage, high cost	Simple operation and maintenance, low cost	Currently focusing on technical research, no operation, and maintenance requirements yet
Stack life/h	120 000	100 000	—
Technology maturity	Commercialize	Commercialization abroad	Development phase
Whether there is pollution	Lye pollution, asbestos carcinogenic	No pollution	No pollution

Figure 2.4: Comparison of water electrolysis technologies(Norouzi, 2021)

ditionally, there is a need for successful collaboration across international borders and efficient integration of hydrogen into the overall energy system (Reigstad et al., 2022).

The 2022 paper *"Perspective on the hydrogen economy as a pathway to reach net-zero CO2 emissions in Europe"* considers hydrogen as a versatile energy carrier that can be used as a replacement in sectors like industry and transportation where fossil fuels are in use. It emphasizes the need for strong political support and robust infrastructure to materialize the hydrogen economy. The technology development for hydrogen production and conversion, market design with vast demand, infrastructure co-creation, international trading, social acceptance, and business model development is required for hydrogen deployment at a large scale. The readiness of the entire H_2 value chain is lower than standalone technologies. The end-use technologies need to be improved from a cost and technical perspective. Hydrogen storage enables more stable H_2 production and full exploitation of the potential of RES during low demand. Power-to-H_2 can be cost-efficient compared to batteries for large-scale hydrogen production and conversion. Scaling production volume of hydrogen, and the development of transportation and distribution infrastructure is required to reach the cost parity of fossil-fueled counterparts in the transportation sector. Moreover, the rising oil prices and carbon taxes would also play a significant role. The large-scale storage and transport infrastructure is important to balance the variable hydrogen supply with variable power demand and heat demand which complicate the design of the corresponding hydrogen supply chains. To support market deployment, hydrogen infrastructure can be integrated with available gas networks with adjustments to the pipe materials. Renewable energy in the North Sea can support 40 GW of low-carbon hydrogen production by 2030. For short distances, trucks are suitable over pipelines and for long-distance ships may be cheaper than pipelines for hydrogen transport. To meet peak demands of electricity instead of oversizing the hydrogen storage infrastructure,

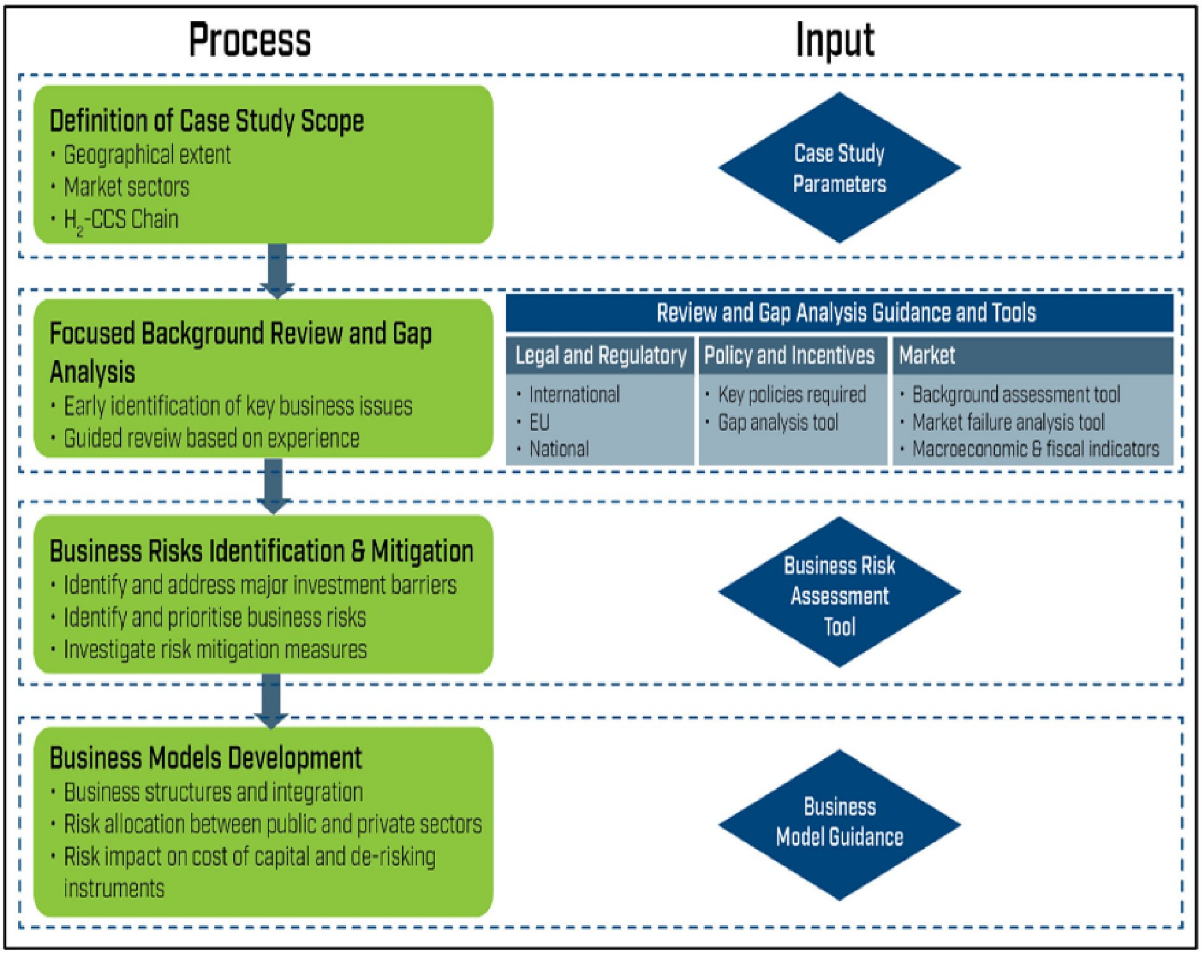


Figure 2.5: Business Model Development Methodology adopted(Reigstad et al., 2022)

steam reformers can be combined with it. The cost of hydrogen storage plays a crucial role in the economic viability of hydrogen networks. The need for a streamlined permitting process at the national and EU level to execute hydrogen projects without delay and in a cost-effective manner. This will result in increased acceptance of hydrogen activities and public support in the hydrogen supply chain. Government intervention can be helpful to overcome investment barriers. A business model is important to organize, and structure all the investments, market development, and asset operation and to deploy large-scale infrastructure serving multiple sectors of the economy to deliver the value and combined objectives of the public and private stakeholders as shown in Figure 2.6. This paper suggests that (1) system thinking is important to remove investment barriers to deliver optimal outcomes for multiple sectors (2) project decisions and investments need to be broadened away from standard cost-benefit analysis to consider the greater value for society with sustainable growth and circular economy with less dependency on fossil-fuels (3) The first investment should meet three outcomes- initial revenue from medium to long term anchor users, both government and private stakeholders are ready to invest with low or no regret, flexibility to adapt future evolution of technology and market (4) initial market development for end-use must be led by government or public bodies (5) collaboration between stakeholders, regions, projects or industries for cost effectiveness and government support and to avoid barriers for expansion (6) risk assessment and allocation to structure collaborative business model for a successful business model based on research in two pan-European projects. It states that a combination of commercial, legal, financial and policy constraints need to be overcome by developing business models with economic sustainability. The main difficulty is the efficient integration of production, infrastructure, and markets into a functioning system across regions and market sectors for an effective business model (van der Spek et al., 2022).

	Example System Business Model	Asset & Rights Ownership	Capital Sourcing	Market Development		Physical Delivery	
				Responsibility	Remuneration	Responsibility	Business Structure
H_2 INFRASTRUCTURE	H_2 Production with Integrated CO_2 Capture	PRIVATE	PRIVATE	PUBLIC	Targeted Revenue Support	PRIVATE	Free Market Enterprise
	H_2 Transmission	PRIVATE	PRIVATE	PUBLIC	Price Regulated Revenue + Construction Support	PRIVATE	Regulated Asset Base (New)
	H_2 Distribution	PRIVATE	PRIVATE	PUBLIC	Price Regulated Revenue	PRIVATE	Regulated Asset Base (Existing)
	H_2 Storage	PUBLIC	PRIVATE	PUBLIC	Performance Based Revenue	PRIVATE	Public Concession (Design-Build-Finance-Operate)
H_2 END USE MARKETS	Industry	PRIVATE	PRIVATE	PUBLIC	Targeted Revenue Support	PRIVATE	Free Market Enterprise
	Centralised Heat & Power	PRIVATE	PRIVATE	JOINT	Targeted Revenue Support	PRIVATE	Free Market Enterprise

Figure 2.6: Example of H_2 system business model with component segment(van der Spek et al., 2022)

The 2022 paper *"Structural Model of Power Grid Stabilization in the Green Hydrogen Supply Chain System—Conceptual Assumptions"* and the 2023 paper *"Functional Model of Power Grid Stabilization in the Green Hydrogen Supply Chain System—Conceptual Assumptions"* developed a conceptual framework for the structural model that includes the conceptualization of 49 variables assigned to a two-dimensional system (first dimension-supply chain, procurement, production, distribution, & second dimension-interdisciplinary approach) architecture covering the three phases of the hydrogen supply chain (feedstock, production with storage, and distribution) in four groups of factors (technical, economic–logistical, locational, and formal– legal factors) taking into account the four hydrogen utilities (conversion of electricity to hydrogen, fuel cells converting hydrogen to electricity, hydrogen storage, and hydrogen utility application). The developed model is recommended for use due to its multidimensional approach as shown in Figure 2.7. The factors such as legal regime, spatial development plan, permits and environmental safety are based on an analysis of national and EU regulations (Frankowska et al., 2022) (Frankowska et al., 2023).

The 2023 paper *"How a Grid Company Could Enter the Hydrogen Industry through a New Business Model: A Case Study in China"* emphasizes that even though renewables and distributed resources are increasing rapidly, traditional grid utilities are not fully benefiting from this transition and have not yet achieved financial success due to unavailability of a business model with financial feasibility. This paper proposed an economically sustainable business model for the grid company as shown in Figure 2.8. The challenges such as high grid management costs, lower electricity prices, fewer customers due to decentralization of electricity, and upgradation of local substation capacities for better access to distributed resources create economic pressure on grid utilities. SWOT analysis based on the value chain model and PEST

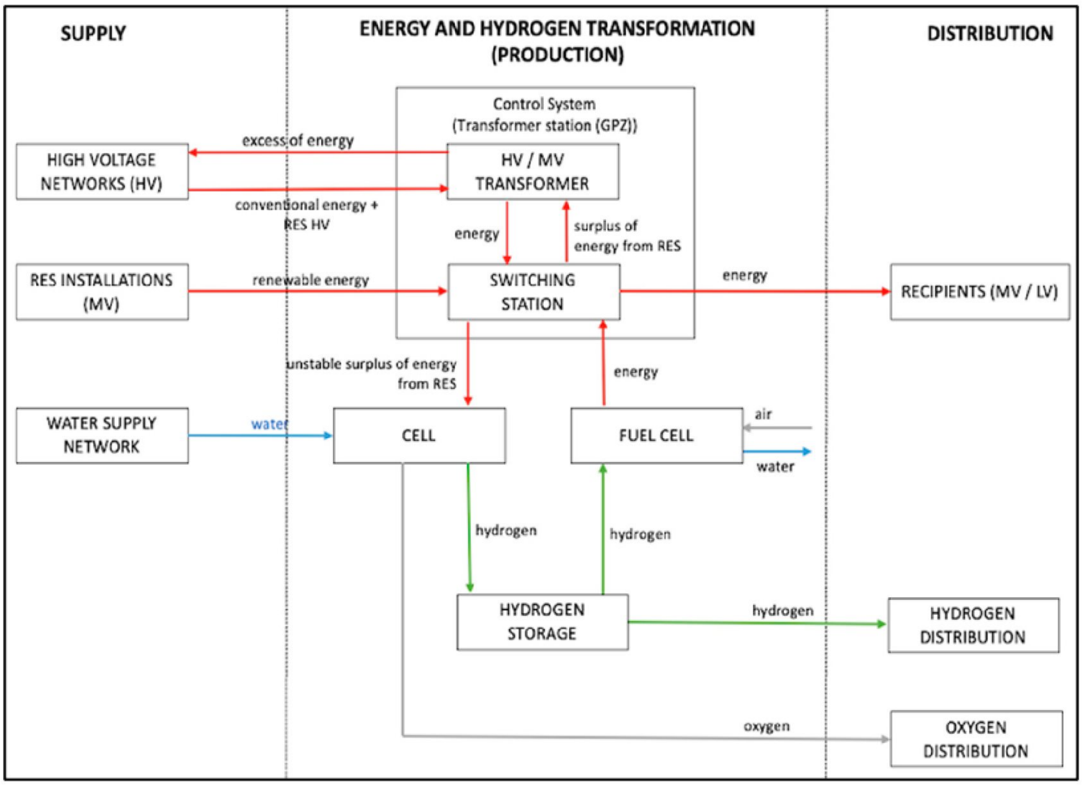


Figure 2.7: The concept of stabilizing the operation of power grids in the phase system of the supply(Frankowska et al., 2023)

framework is used to identify factors which further subjected to receiving insightful feedback from experts from the grid sector, hydrogen-related industries, and academia. The strengths of a grid company that wants to engage in the hydrogen market can be their ultrahigh-voltage transmission technology that can be utilized to construct hydrogen pipelines, technical proficiency in smart grids which will be useful in hydrogen integration, robust R&D, solid monetary foundation to consider new business development options, strong position in the financial market, determination to reduce carbon emissions, good reputation and connection with national administrations to influence hydrogen policies and strategies in the country. The weaknesses are a conservative way of handling a fast-evolving industry, a lack of technical solutions in the H_2 value chain and the impact of policy factors on financial performance. The opportunities like support from the government, demand due to the decarbonization goal of the country, profitability in the market due to the advantage in hydrogen production costs and companies which are first movers will gain more market shares by leveraging their technical and leadership strengths gained over time. The threats are (1) geopolitical uncertainty such as increased tariffs, and trade bans which can be challenging for supply chain stability (2) emerging technologies can treat existing market share, revenue, and survival of the projects (3) Lump-sum capital investment. The strategies such as new pilot projects to get hands-on project credentials, a reliable network of both vendors and partners, quick integration of hydrogen into a full-service menu by using an energy-as-a-service model, policies, and regulations at the domestic and global level in the hydrogen supply chain to commercialize hydrogen economy. The strategic analysis is used to recommend business strategies for transmission and distribution companies to enter the hydrogen economy in a more timely and less risky manner by considering hydrogen as a raw material than as energy. The quantitative aspects of the business model are not assessed to check its economic feasibility. The greater involvement from different stakeholders or market participants like small grid companies, pipeline companies, governments, generation companies, transmission grid operators and distribution operators in the grid utility ecosystem to present a comprehensive strategy for joint ventures is crucial (Xu et al., 2023).

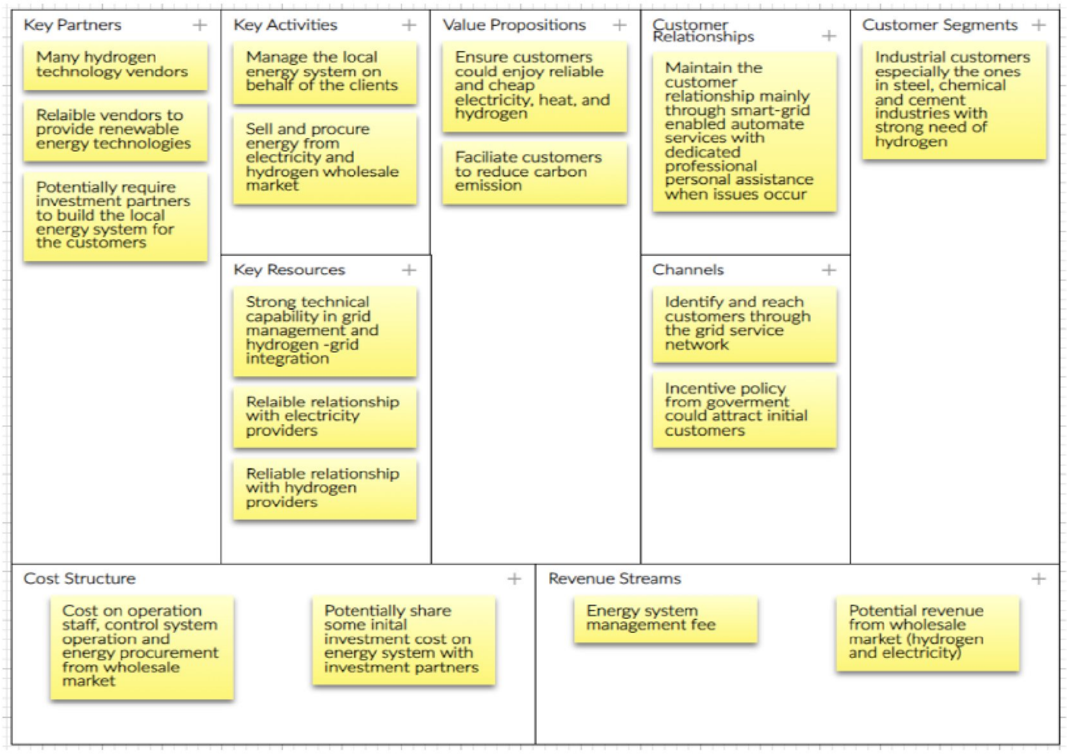


Figure 2.8: Summary of one potential business model for the grid company(Xu et al., 2023)

2.3 Results of Literature Review

In conclusion, this literature review highlights the importance of considering different factors as outlined in Table 2.1, that impact the feasibility of hydrogen and address the obstacles hindering the realization of a sustainable hydrogen business or economy. The assessment of various factors and potential markets is vital for the formulation of successful business opportunities in this domain. It is important to foster improved business opportunities for hydrogen that are economically viable and efficient, minimizing energy conversion losses. Therefore, different methodologies discussed in next chapter 3 are used to analyze these crucial factors for hydrogen business in Norway and results based on these methodologies are presented in chapter 4.

Table 2.1: Summary of literature review

Year	Title	Key Factors
2011	Economic analysis of large-scale hydrogen storage for renewable utility applications	Scaling, integrate non-utility users, different value propositions for customers, **develop market opportunities**
2018	Potential of new business models for grid integrated water electrolysis	Couple electric power systems with sectors of H_2 demand, increase utilization ratio of electrolyser, trading between hydrogen and electricity market, consider fluctuating nature of RES feed-in, **potential markets**
2021	Assessment of Technological Path of Hydrogen Energy Industry Development: A Review	Integrated energy service parks (with heating, gas, fuel services), **national development strategies, power market regulations & policies, large-scale scientific research program,** synergies, new export opportunities, **the commitment of the nation**
2022	Moving toward the low-carbon hydrogen economy: Experiences and key learnings from national case studies	Technology development, public-private collaboration, **national opportunities, policies,** stakeholders, **social acceptance**, address financial and **legal barriers and risks**, practical knowledge, **research for techno-economic assessment**, collaboration across international borders, large-scale value chains
2022	Perspective on the hydrogen economy as a pathway to reach net-zero CO2 emissions in Europe	**Political support, robust infrastructure, technology development, market with demand**, international trading, **social acceptance, regulations, streamlined permit process, government support**, collaboration between stakeholders, risk assessment and allocation
2023	How a Grid Company Could Enter the Hydrogen Industry through a New Business Model: A Case Study in China	Technical proficiency, technology development, **R&D, financial support, commitment towards the environment, market demand**, reliable network of both vendors and partners, use H_2 as energy-as-a-service, **policies & regulations**, joint ventures
2022	Structural Model of Power Grid Stabilization in the Green Hydrogen Supply Chain System—Conceptual Assumptions	Investment, safety, technology development, access to utilities and land, **infrastructure development and costs**, system efficiency, **social acceptance, market demand**
2023	Functional Model of Power Grid Stabilization in the Green Hydrogen Supply Chain System—Conceptual Assumptions	

Chapter 3

Methodology

Based on the literature review, it is evident that the evaluation of various factors impacting business is crucial for the success of a business idea. To assess these factors, several methodologies and frameworks are available. In this thesis, the roles of these factors in the hydrogen business are summarized and presented with PESTELE analysis and Market feasibility analysis. This information is utilized in the later stages of the project work to identify potential customers. Within the scope of this thesis, the objective is to propose appropriate customers for conducting business in green hydrogen. The identification of suitable sectors and customers is of utmost importance for businesses aiming to capitalize on opportunities in the hydrogen sector and ensure profitability. The following methodologies are employed in this thesis to evaluate the factors relevant to the hydrogen business in Norway.

3.1 PESTELE analysis

The top management in companies needs to scan external environmental factors very carefully to create a competitive advantage. Organizations use various tools to evaluate the business environment and to create effective business strategies for new ventures. There are different analysis tools such as McKinsey 7S Framework, Porter's Five Forces Framework, SWOT (Strength, Weakness, Opportunities, Threats), PESTELE (Political, Economic, Social, Technological, Environmental, Legal, Ethical), POCC (Potential, Opportunities, Challenges, Constraints) and SOAR (Strength, Opportunities, Aspirations, Results).

In this thesis, PESTELE has been used based on a comprehensive understanding gained about it within the master's curriculum. PESTELE is a tool used to assess what is happening in the broader economic and business environment and to investigate all macroeconomic factors which can affect the future development of the business. These factors are part of the larger society which impacts business performance and are not directly under the control of the organization. It depends on the corporation, country, and industrial sector within which it operates and plays a crucial role in strategic decisions to ensure the development and sustainability of the business. PESTELE analysis is a method that allows companies to predict the situation to adapt to new situations and develop competitiveness by providing data and information. It is a

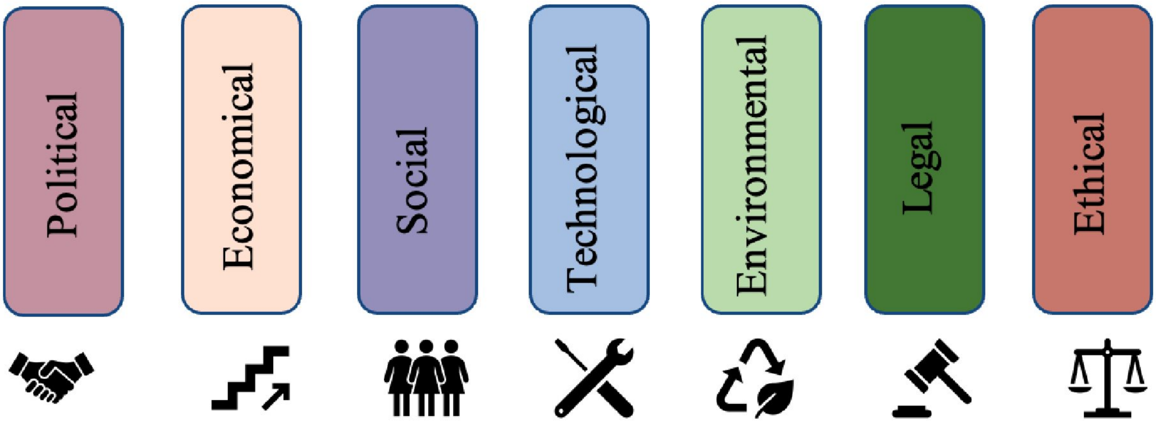


Figure 3.1: PESTELE analysis

key element in designing future businesses (Sugatri et al., 2018).

Before we proceed with evaluating and mapping customers, it is essential to understand the position of the hydrogen business in the country. Considering the dominant forces of oil, EV vehicles (Cars and ferries), and hydropower in Norway, it is essential to assess how the external environment will support the adoption and growth of hydrogen in Norway.

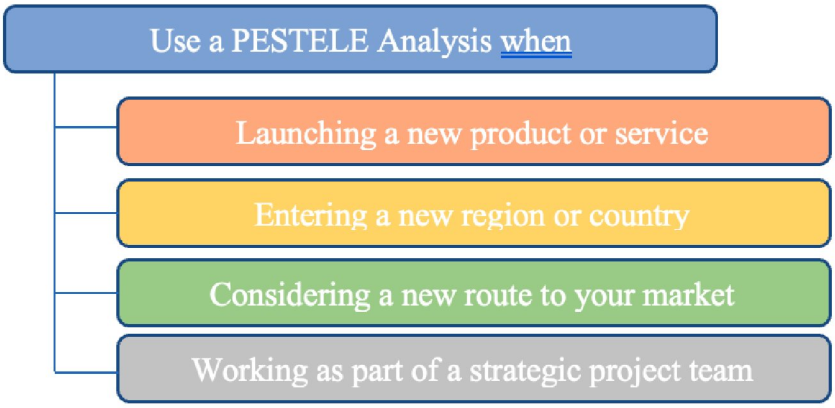


Figure 3.2: Use of PESTELE analysis

While conducting a PESTELE analysis, valuable insights are drawn from reports concerning energy transition and the hydrogen economy. These reports, authored by research institutes and analytical companies, are specifically indicated and conveniently located in Appendix A for easy reference.

In the process of performing a PESTELE analysis, specific assumptions are established as outlined in the following section.

- Hydrogen is a part of the energy transition scenario, therefore many factors of net zero target are correlated or used in terms of hydrogen
- The hydrogen value chain will be cost-effective, and efficient with technology development

- It is assumed that hydrogen is a part of the green transition and consumer behavior is assessed based on the green transition
- The hydrogen means green hydrogen in this report, the colour is mentioned explicitly if it is blue and grey hydrogen

Based on these reports and assumptions, a PESTELE analysis is conducted to assess the impact of external factors on the hydrogen business in Norway, and the results are discussed in Chapter 4.

3.2 Feasibility Analysis (Market Scan)

PESTELE provides an extensive overview of the external environmental factors that impact the business, but a feasibility study is important to assess the practicality and viability of a new business venture. The purpose of the feasibility study is to evaluate the likelihood of success and identify potential risks and challenges before committing resources. A feasibility study involves assessing economic, technical, legal, operational, and time-related factors to determine the practicality of a plan or method. As the name implies, you simply ask a question during evaluation “Is this feasible?” The feasibility analysis is a process of determining the viability of an idea to create a successful business. The purpose is to determine whether the business idea is worth pursuing. If the idea passes the feasibility analysis, the next step is to build a comprehensive business plan to capitalize on the idea. The valuable time, energy, money, and other resources should not be wasted to create a full-blown business plan or launch a business plan that is destined to fail as it is based on a flawed concept. Although a feasibility study does not guarantee an idea’s success, it reduces the likelihood of spending excessive time on futile business ventures. It provides an assessment of the positive and negative sides of business ventures (McLeod, 2021).

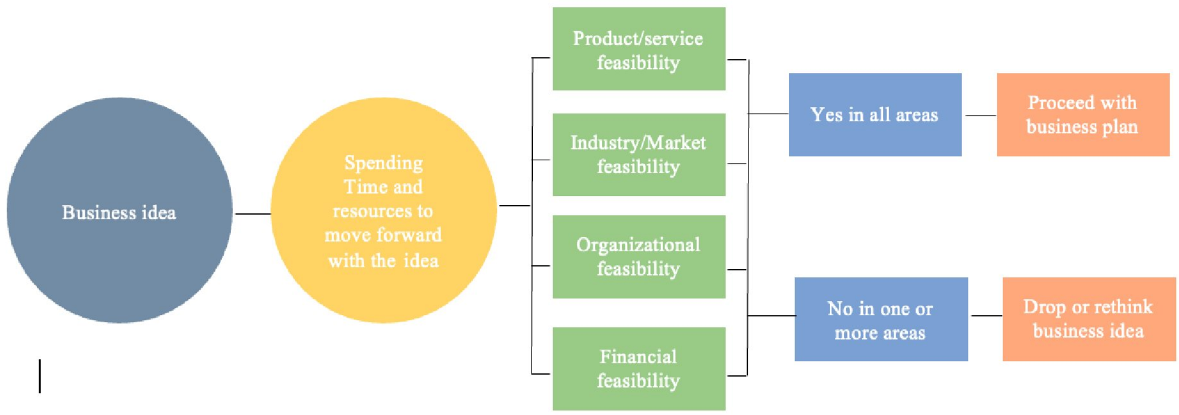


Figure 3.3: Feasibility analysis process

A feasibility analysis has four components: industry and market feasibility analysis, product or service feasibility analysis, organizational feasibility analysis, and financial feasibility analysis as shown in Figure 3.3. As feasibility studies are complex and in the scope of this thesis, only market feasibility analysis is performed to identify how attractive an industry is overall as a home for a new business opportunity in hydrogen. During the feasibility study of the market, the focus is on the threat of new entrants or substitutes in the industry considering green transition the focus of the century. Market analysis provides the aggregated demand for the product or service in future and captures the expected market share.

Hydrogen is an energy carrier with potential applications in multiple sectors such as transport, industry, power, and buildings. The evaluation of a market where the use of hydrogen is sensible before mapping customers is important for a successful business plan (Mukherjee & Roy, 2017).

In Chapter 4, the sectors are evaluated based on market feasibility to narrow down the sectors where customers will be mapped.

3.3 Customer Identification

Conducting a feasibility analysis helps identify the target sectors for hydrogen as the use of green hydrogen is not feasible everywhere due to the challenges associated with the availability of renewable energy and infrastructure. It is essential to strategically promote the use of hydrogen where it makes the most sense and is economically viable. Once the market feasibility has been assessed, the next step is to identify potential customers within those sectors who are likely to purchase the company's products or services. This process enables the company to set realistic goals, determine their desired direction and establish financial prerequisites. Targeting potential customers is crucial for building a profitable business. The identification of potential customers is crucial for the success of the business and to drive any business forward.

There are several methods available for identifying target customers for a company, such as the Ideal customer profile (ICP), customer segmentation, buyer persona, customer profiling, and customer surveys and feedback. In this thesis, to identify and target specific customers, Ideal Customer Profile (ICP) framework is used. ICP defines the type of company that would benefit the most from a product or service, have a budget to pay for the product or service, is part of the market, and have pain points that will be solved with the product. The task is to determine the main challenge the customer is facing and how the product or service will solve the issue. The hydrogen company will use the market opportunity where customers are in urgent need to reduce their emissions to comply with EU regulations and are ready to pay to solve the global warming problem (Gartner, 2019).

Companies that fit ICP are most likely to buy and continue to use the product and contribute to business growth. For B2B businesses, it considers the factors such as industry, company size, location, and revenue. To create an ICP, templates can be used but a simple table can be created to organize the gathered data. The experts have recommended the inclusion of the most important factors in a B2B customer profile, as depicted in Figure 3.4.

In this thesis, the focus will be on identifying and summarizing customers rather than developing comprehensive Ideal Customer Profiles. The purpose is to determine how green hydrogen can align with the market and differentiate itself to benefit customers. A simple template, as shown below, is utilized for collecting and presenting customer data, which will

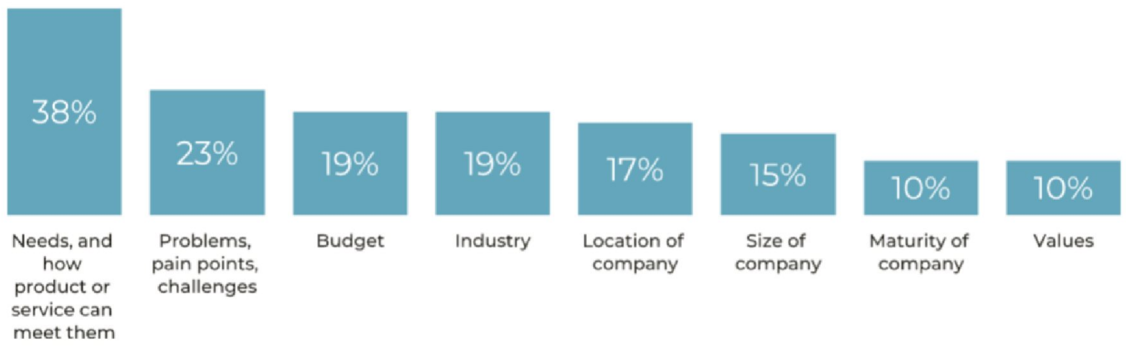


Figure 3.4: Most Important factors to include in a B2B customer profile, to assist in qualifying leads(Memon, 2022)

be discussed in Chapter 4.

Table 3.1: Ideal Customers Profile

Ideal Customer	Location	Challenge/Issue	When is customer ready for purchase

Chapter 4

Results

By utilizing the methodologies discussed in Chapter 3, we have obtained a comprehensive understanding of the role of hydrogen in Norway. Hydrogen has been validated as a crucial energy vector by the country and the future of hydrogen in Norway appears promising. Our analysis acknowledges the urgent need for efficient energy utilization. To present an impartial viewpoint on hydrogen, we have consolidated findings from multiple reports. We advocate for the implementation of hydrogen in situations where it provides a practical solution and there are no better alternatives available. Conversely, we discourage the promotion of hydrogen in areas where its utilization proves to be highly inefficient. It's interesting to observe hydrogen's growing presence in the market despite the significant economical investment required. The results, which indicate Norway's stance on hydrogen, sectors where hydrogen usage is sensible, and potential customers, are presented below.

4.1 PESTELE analysis

The role of various external factors specific to Norway in the hydrogen business is summarized and presented through a PESTELE analysis, providing insights into the impact of these factors on the industry.

4.1.1 Political Factors

Norway participates in European Union's internal energy market and cooperates with the EU on energy and climate matters due to Norway's agreement with the European Economic Area (EEA). Norway has committed to reducing GHG emissions to 50 % or 55% by 2030 compared to 1990 levels through its nationally determined contribution (NDC) under the Paris Agreement. Norwegian Parliament adopted the Climate Change Act in June 2017, to reduce emissions to 90% or 95% from 1990 levels by 2050. Norway shares the European Commission's European Green Deal vision of transformation to a sustainable, low-carbon economy. The Norwegian 2021 climate plan targets a green transition aligned with economic development with renewable energy playing a key role.

Table 4.1: Norway's commitment to climate change regardless of ruling political party

Agreement on the European Economic Area	Cooperates with the European Union (EU) on energy and climate matters.
Nationally Determined Contribution (NDC) under the Paris Agreement	Norway aims to reduce its greenhouse gas (GHG) emissions to 50% or 55% by 2030 and 90% or 95% by 2050 compared to 1990 levels.

A new government was formed in Norway in 2021 and hydrogen is mentioned several times in their political platform (Hurdalsplattformen) as compared to any platform previously. Generally, all political parties are supporters of green transition in the country and support the development of hydrogen technologies. However, the pathways to support the hydrogen economy can be different. In the history of Norwegian politics, there is no such occurrence where a change in political party refused the technology supported by a former government on climate change. The focus of the 2023 budget is to reduce emissions for sustainable and inclusive growth in the country. As per the national budget for 2022, the Norwegian government increases funding for R&D in H_2 and NH3 by founding its own research centre (Research Council of Norway). For up to eight years, the Ministry of Petroleum and Energy will allocate the centre NOK 30 million per year, totalling NOK 240 million. A research centre was established in early 2022 to develop innovative solutions for hydrogen and ammonia. The establishment is carried out under the FME scheme (Research Centers for Environmentally Friendly Energy) of the Research Council of Norway (FINANCE, 2021).

Currently, the hydrogen (grey hydrogen) used in industrial processes is 225000 tonnes which is produced from natural gas, and it costs only one-third of the green hydrogen in Norway. The cost of green hydrogen is more expensive than the production of hydrogen from natural gas without carbon capture and storage. It is estimated that the cost of green hydrogen will decrease if demand increases and is produced on a large scale. The goal of the government is to strengthen the R&D development of green hydrogen. There are sectors like transport and industry where solutions are developed for hydrogen as an energy carrier and several projects are under testing. The projected hydrogen demand as an energy carrier by sector in Norway is shown in Figure 4.1.

The Norwegian government released the H_2 strategy in June 2020 followed by a white paper in 2021 to assess the entire energy sector and road map for hydrogen. In June 2021, Norway presented a white paper on energy policies and long-term value creation from Norwegian energy sources such as hydrogen and offshore wind energy. This includes signposts for the production and use of hydrogen in 2025,2030 and 2050. It is focusing to develop the whole value chain of hydrogen including production, distribution, and use. The national assembly has asked the government to introduce a plan for the introduction of Contracts of Difference in 2023 which will reduce risk and accelerate investments in H_2 production and use in Norway (IEA, 2022a).

Norwegian Hydrogen Forum (NHF) established in 1996 is a non-profit member organization to promote the advantage of hydrogen and ammonia as energy carriers. It wants to develop competency and experience within hydrogen technologies in Norway. NHF is the secretariat of the county network which is a cooperation between counties and municipalities in

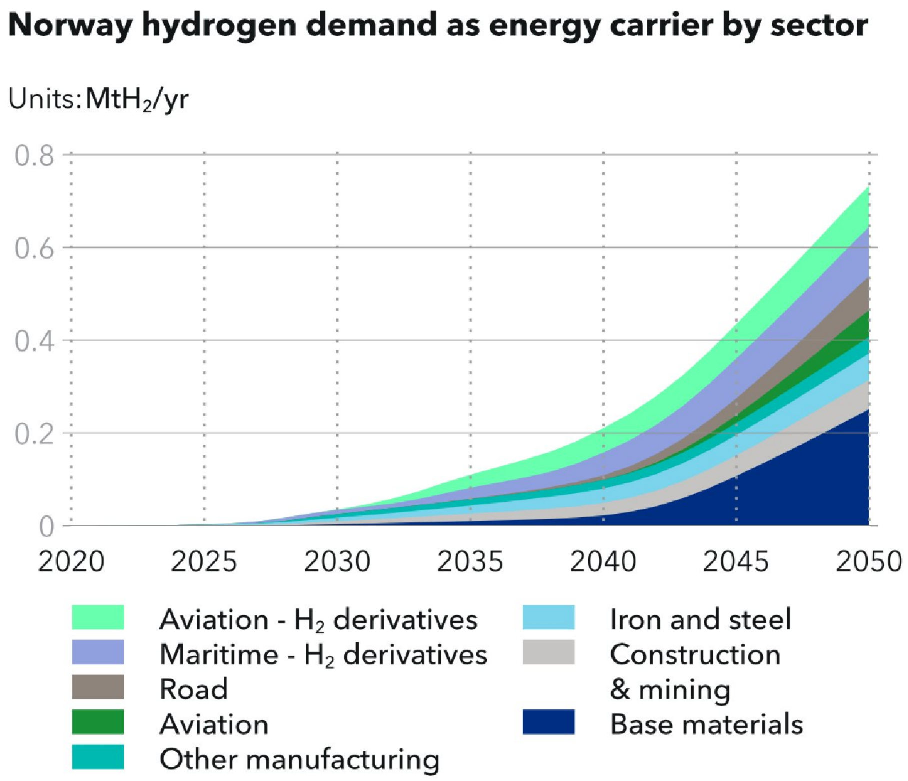


Figure 4.1: Norway hydrogen demand as energy carrier by sector(DNV, 2022)

Norway to create value chains for hydrogen throughout the country. The nationwide deployment of H_2 solutions, infrastructure, public awareness and scaling up are the areas in the H_2 value chain which are targeted by the Norwegian government. Norway wants that Norwegian stakeholders can take their pioneering role and adequate share in the global market for H_2 and NH3 solutions. Ministry of Petroleum & Energy and Transport & Communications released its first National H_2 strategy in 2005.

Nordic Hydrogen Partnership (NHP,2006) is a collaboration between the Nordic hydrogen associations such as Norsk Hydrogen Forum in Norway, Vätgass Sverige in Sweden, Brintbranchen in Denmark, VTT Technical Research Center of Finland and Icelandic New Energy in Iceland. The target is to boost the cross-sector implementation of H_2, fuel cell technologies in the Nordics, and promote H_2 companies to establish the world's first expansion of H_2 infrastructure for large vehicles. Enova is an entity supported by the Ministry of Climate and Environment which drives innovation in terms of new technologies in Norway. Enova (2021) granted public funding to three hydrogen and ammonia projects for more than one billion NOK. In 2021, a total of 1,6 billion NOK was granted to different hydrogen and ammonia projects by Enova, Innovation Norway, the Research Council of Norway and Gassnova (Norsk Hydrogen Forum).

Green Platform Program is an initiative of five ministries - The Ministry of Petroleum and Energy, The Ministry of Trade, Industry and Fisheries, The Ministry of Climate and Environment, The Ministry of Transport and Communication, and The Ministry of Agriculture and Food. The motive is to provide funding for organizations and research institutes engaged in green growth and restructuring driven by research and innovation. This program provides funding of 1 billion NOK over three years for a green transition of the industrial sector. Innovation Norway is supported by the Norwegian Government which provides funding to organizations developing new technologies. It provides monetary help for hydrogen-related R&D projects. European Union Funding also provides grants and loans to Norwegian companies for R&D as Norway is a member of the European Economic Area.

4.1.2 Economic Factors

Norway is one of the countries with the highest GDP per capita. The main components of GDP are O&G, hydropower, seafood, and products from energy-intensive industries. To mitigate climate risk, demand and initiatives based on O&G are anticipated to reduce. Green hydrogen tends to bring a sustainable economy to the country. Several factors, including renewable energy availability, the EU's energy dependency on Norway, and high investment in R&D bolster the transition towards green hydrogen in Norway.

Renewable Energy - Norway's significant share of electricity is produced by hydroelectric power whereas other energy sources are also emerging in the mix mainly wind and solar as shown in Figure 4.2 & Figure 4.3. Thus, the projected share of renewable energy provides good support for the development of a green hydrogen economy. It will remove the country's dependency on fossil fuels and drive sustainable economic growth in the country. The availability of a significant proportion of renewable electricity in the country facilitates the adoption of green H_2 without the need for substantial investments in renewable energy infrastructure specifically for hydrogen production (IEA, 2022b).

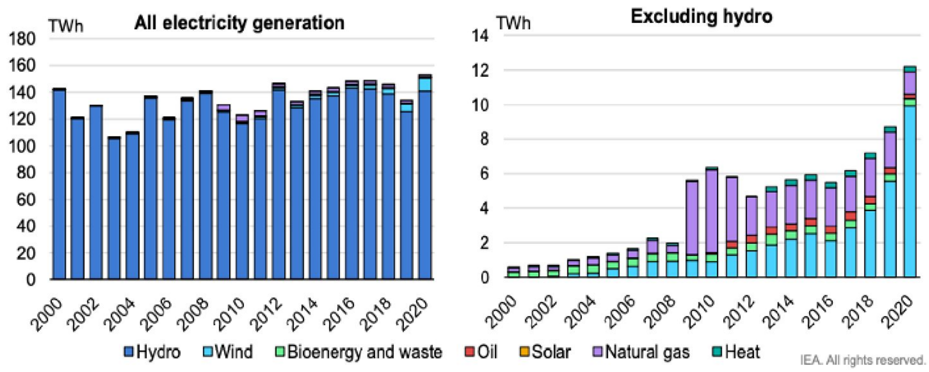


Figure 4.2: Renewable energy in electricity generation in Norway, 2000-2020(IEA, 2022b)

Trade opportunities–The Confederation of Norwegian Enterprise (NHO) and partners in the 'Green electrical value chains' project (NHO, 2020) outlined export-oriented industry development in 6 priority areas - renewable energy, offshore wind, batteries, hydrogen, maritime transport, power system optimization incl. smart charging infrastructure, with an estimated revenue potential of €32bn/year in 2030 and at least €76bn/year by 2050. Green hydrogen can be exported to other countries due to the abundance of hydropower in Norway. It is estimated that the hydrogen export will reach 1 Mt/yr in 2040 and 3.4 Mt/yr in 2050, while the export of ammonia will be 1.2 Mt/yr in 2050 as shown in Figure 4.4 (DNV, 2022).

Norway produces hydrogen mainly from natural gas or coal for its domestic feedstock

	2021	2025	2030
Hydro	33 269	34 092	34 701
Wind	4 929	5 041	5 019
Solar PV	300	699	1 796
Thermal	315	315	315

Source: Norwegian Water Resources and Energy Dirrerctorate, based on the Norwegian government's response to the IEA questionnaire.

Figure 4.3: Electricity generation capacity growth projections in Norway (MW), 2021-2030(IEA, 2022b)

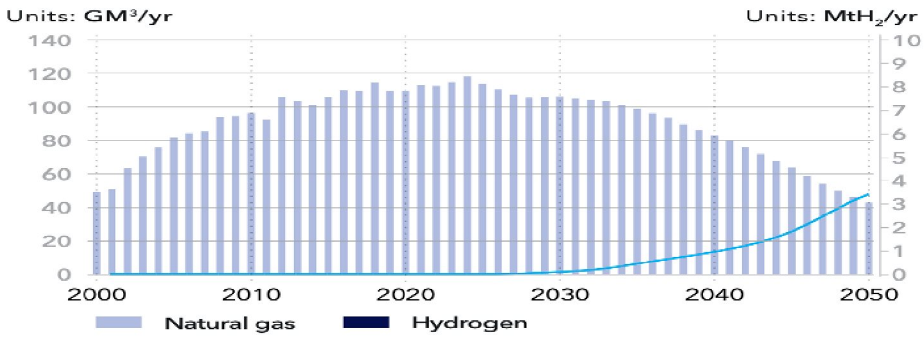


Figure 4.4: Pipeline gas trade to Europe(DNV, 2022)

market. By 2050, 2/3rd of hydrogen produced will be green and 1/3rd will be produced from natural gas with carbon capture. It is estimated that by 2050, hydrogen demand in Norway will triple but production will increase by a factor of 10. This creates possibilities for Norway to export hydrogen to the market. There are installed and future pipelines to Europe and UK to transport the hydrogen from Norway to Europe. Moreover, Norway plays a crucial role in the overall energy situation of Europe, due to Europe's dependency on gas imports from Norway. The Russia-Ukraine war has increased the export of Norwegian gas for the short term, but it will be declined in the long term as shown in Fig. 22. Europe tends to lead the global hydrogen market with 11% hydrogen and its derivate in 2050 energy mix with its strong hydrogen policies. It will consume two-thirds of the global hydrogen demand for energy purposes mainly for maritime and aviation energy. While hydrogen export to Europe will be through pipelines, ammonia will be exported on keels from Norway. In the 2040s, 1.2Mt/year of low-carbon ammonia will be exported from Norway to European (80%), British (15%) ports and to other ports (5%) (DNV, 2022).

Foreign Investment–Research and infrastructure development in the green hydrogen value chain will attract foreign investors which will drive economic growth in the country. As per the IEA report, Norway spends the largest share of GDP on energy-related public RD&D as compared to other IEA countries as shown in Figure 4.5. The investment in the hydrogen value chain will create new jobs that will stimulate GDP growth.

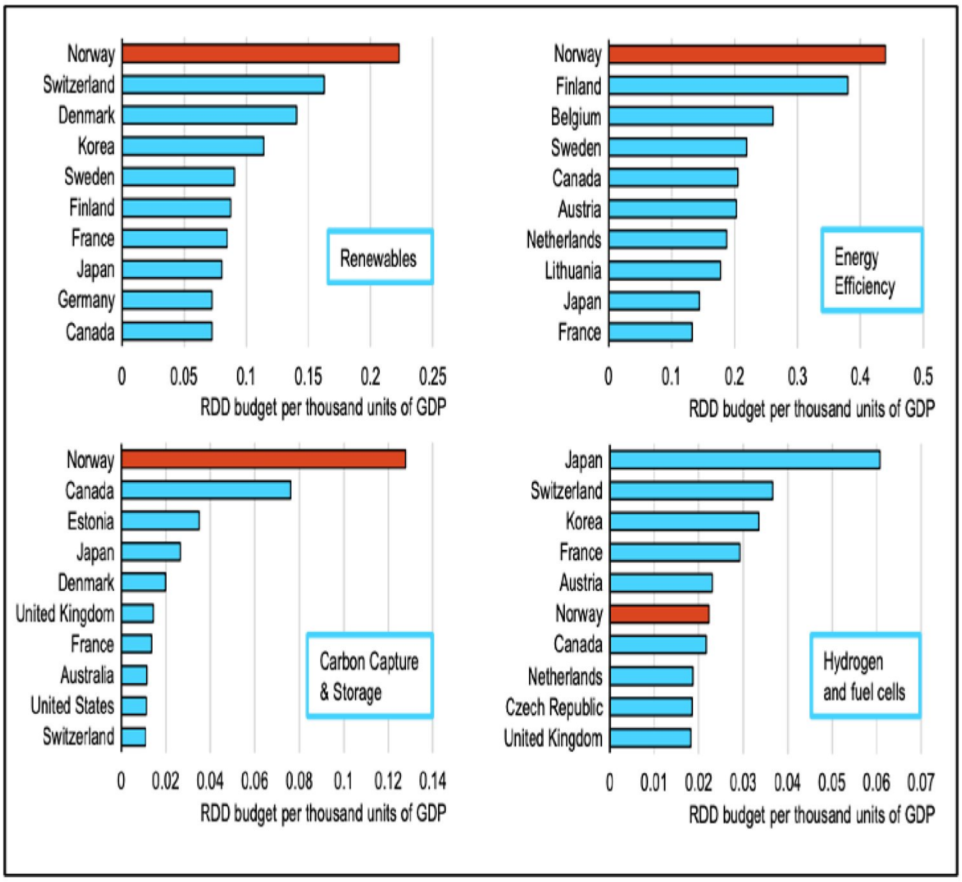


Figure 4.5: Top 10 countries for selected technologies in RD&D budget per thousand units of GDP,2020(IEA, 2022b)

4.1.3 Social Factors

Social acceptance: These days the acceptance of technology by end users decides its success. To promote a green hydrogen economy, it is important to make the public aware of the different uses of hydrogen. The fear or uncertainty about the hydrogen future in the country raises the importance of communication to reduce risks for end users. Moreover, to check the awareness and perspective of the public, researchers and corporate people on green hydrogen, responses from them are collected in the form of a questionnaire as shown in Appendix B.

In Norway, political support in terms of policies and incentives tends to bring change in customer behaviour and push the technology for adoption in the country. The breakthroughs have been made in Norway through advanced research, public awareness campaigns and financial incentives, especially in terms of EVs. The number of incentives for users such as lower taxes, exemptions from road tolls, free charging ports, incentives for buildings and businesses with charging points, and free fast infrastructure development for charging points boosted the EV model in the country as shown in Figure 4.6.

Job creation: The use of green hydrogen will create many jobs in different areas such as engineering, construction, and maintenance. Green hydrogen is in its early stages and further deployment of the technology will create a job market. The labour transition and competence transfer from the O&G sector into green industry ventures can be a challenge. The digital and

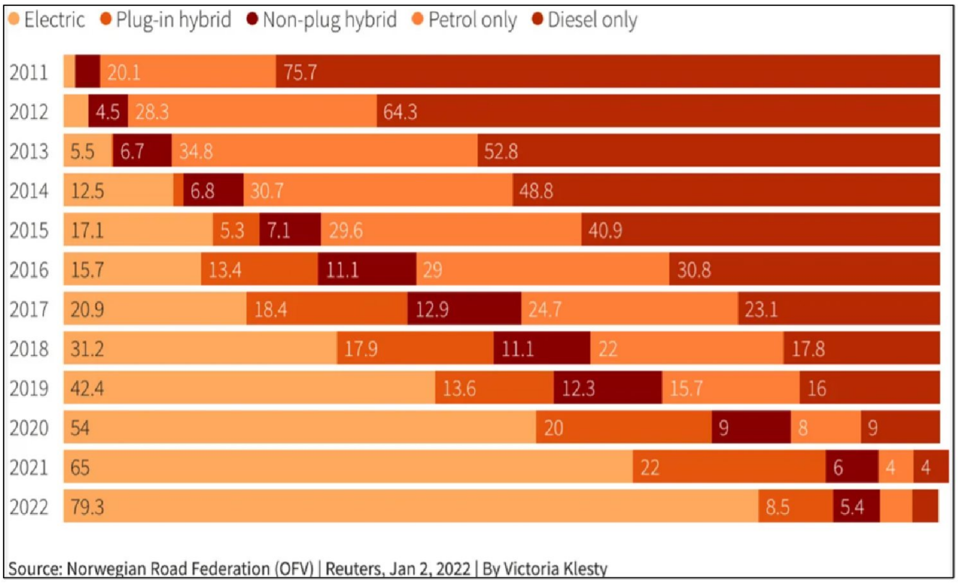


Figure 4.6: Years 2011-2012 in the percentage of market per car type(Klesty, 2023)

green transitions are likely to threaten the existence of some businesses. The young generation is declining work if it entails O&G projects. Improvements to education and training help individuals to transition to new occupations such as digital as well as green transition. Therefore, insolvency prevention arrangements using enhanced tools such as restructuring, light penalties for failed entrepreneurs and smooth reallocation of resources need to be adopted.

Energy security: The use of hydrogen will provide energy security in the country by diversifying its energy mix, reducing reliance on oil and gas which is under geopolitical risk. The Norwegian government has set a target to become a leading supplier of hydrogen to Europe by 2030. It will help the country to reduce its reliance on fossil fuels for energy and can enhance the country's energy security. While the Middle East, the world's largest oil exporter, is determined to become the largest exporter of hydrogen, Norway can also devise a plan to show the world that it is not just an exporter of crude oil but can also export clean energy. It is a good opportunity for Norway to diversify its economy, and resources, and distance itself from oil by opting green energy economy.

4.1.4 Technological Factors

The viability of green hydrogen depends upon the feasibility, efficiency, and economics throughout its supply technologies as shown in Figure 4.7. The technologies are at a different level in the hydrogen value chain as depicted in Figure 4.8. The efforts are required to push critical technologies at a commercial level which are not fully developed and not available commercially. However, hydrogen infrastructure technologies are more developed as compared to production technologies.

In the future, the production of green hydrogen from wind energy will be more cost-efficient than exporting electricity. Green hydrogen production requires expensive electrolysis equipment and undergoes energy losses during conversion. When production from variable

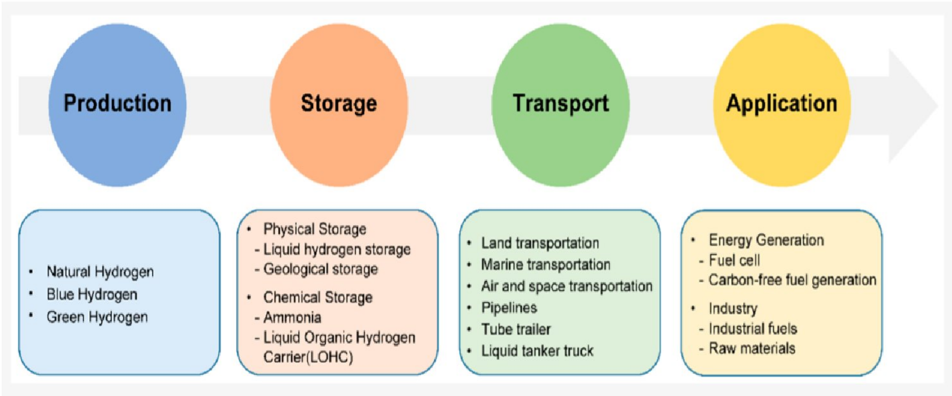


Figure 4.7: Hydrogen value chain's distinct technologies(Shin, 2022)

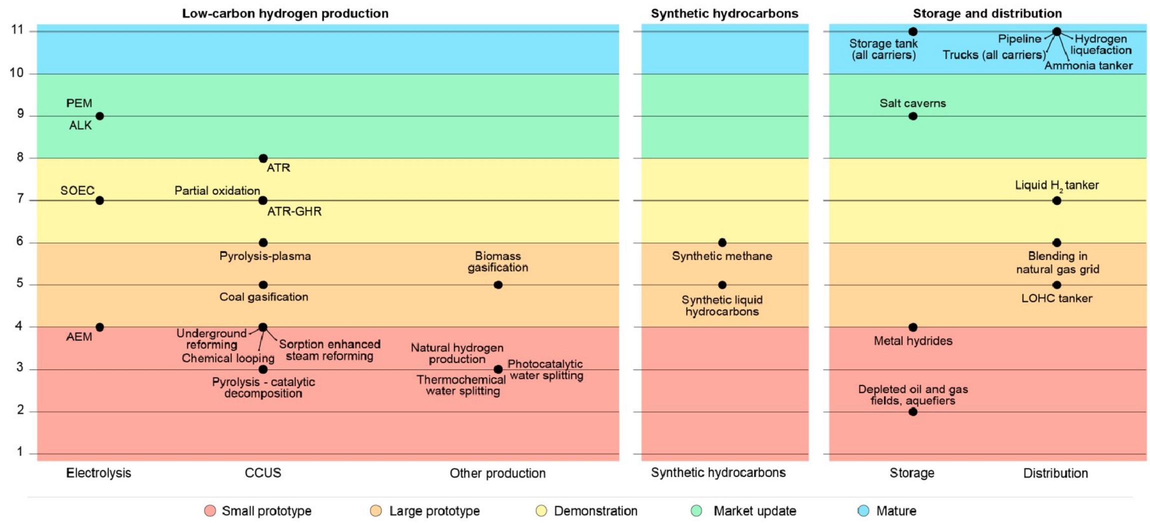


Figure 4.8: Technology readiness levels of low emission hydrogen production and infrastructure(IEA, 2021)

renewable energy sources is in excess and demand is less, low-price electricity can be used to produce hydrogen. However, there are many options like demand response, battery-electric vehicles, pumped hydro, and utility-scale batteries available in the market to use this cheap electricity. Therefore, till 2030 major hydrogen will be produced with steam methane reforming with or without carbon capture. With more penetration of renewable energy or wind energy in Norway's power system, electrolysis will gain momentum in 2040 and will supply 80% of hydrogen by 2050 as shown in Figure 4.9 (DNV, 2022).

Additionally, Norway is home to several renowned companies that excel in various aspects of the green hydrogen value chain. Nel, a Norwegian company, holds the distinction of being the world's largest manufacturer of electrolyzers, crucial devices for hydrogen production. Hexagon Purus and Umoe Advanced Composites are prominent suppliers of composite tanks, storage containers, and transport solutions designed specifically for hydrogen. Statkraft, the largest producer of renewable energy in Europe, has made significant investments in the field of hydrogen. There are other examples of Norwegian companies positioning themselves in hydrogen-related early markets: Raufoss Fuel Systems and Hystorsys are active within hydrogen storage, Nordic Power Systems is developing fuel cells, ZEG 'Power, GasPlas, RotoBoost

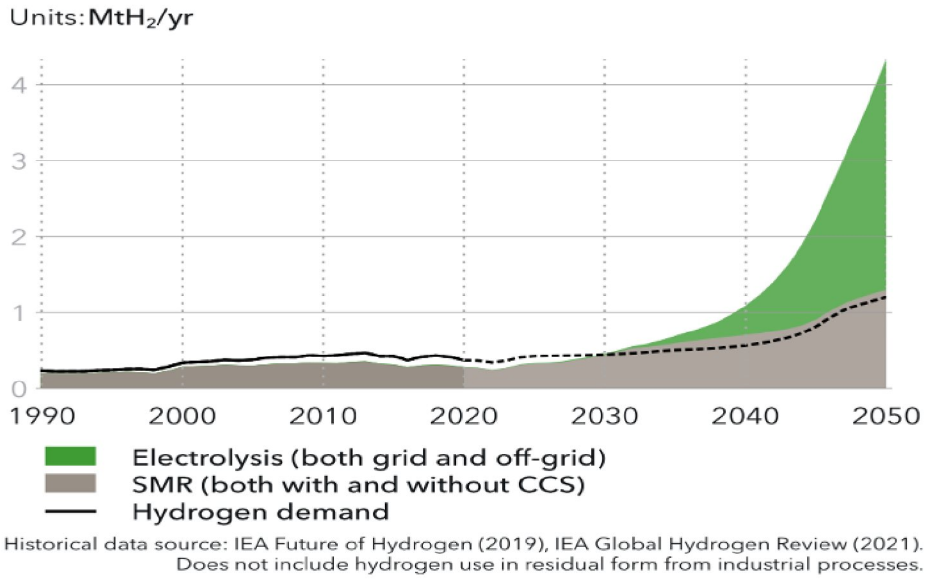


Figure 4.9: Norway's hydrogen production by production route(DNV, 2022)

and others are active within technologies to improve hydrogen production. Other notable Norwegian companies involved in green hydrogen are Greenstat, Gen2 Energy, Viken H_2, Gasnor, and Hyon AS, among others.

4.1.5 Environmental Factors

Zero GHG emissions: Green hydrogen is a sustainable fuel which emits zero GHG during production and combustion. Green Hydrogen is produced using renewable energy sources like wind and solar. The combustion of hydrogen produces tremendous heat and water as compared to other fuels. The use of hydrogen fuel cell vehicles helps to reduce air pollution in urban areas. When hydrogen burns in an atmosphere containing nitrogen and oxygen, it doesn't produce CO2 but produces NOx.

Health and Environment risk: Hydrogen is a flammable and volatile gas. The handling of hydrogen needs proper safety measures to avoid fire and explosions in the environment. However, there is a debate regarding the volatility of hydrogen it's lighter than air so tends to disperse quickly in the air and reduces the risk of explosion. But in the case of enclosed spaces tends to displace oxygen that can make people suffocate and be deprived of oxygen in that confined area (Asphyxiation). However, the release of large quantities of hydrogen into the atmosphere can increase other greenhouse gases like methane, ozone and water vapour causing indirect warming. Hydrogen is a tiny molecule easy to leak into the atmosphere from production to end-use and causes a threat to its surroundings. In 2019, an explosion occurred in Oslo, Norway due to a gas leakage in one of the hydrogen fuel filling stations. The leaked gas caught fire and created a pressure wave which harmed three people.

High demand for electricity, water, and rare materials: The use of electricity to produce hydrogen put pressure on the electricity grid and is an inefficient use of renewable energy for the areas where direct electricity can be used. However, the use of hydrogen storage with renewables is helpful to reduce peak load and to store excess energy instead of curtailment of renewable energy sources. The use of water in green hydrogen has raised concerns about water scarcity, but Norway can excel in the green hydrogen industry due to its plenty of water resources. The major share of electricity is coming from hydropower in Norway which is raising concerns among environmentalists for the water ecosystem. The construction of dams disrupts the natural flow of rivers resulting in a change in temperature and disrupting fish populations. The IEA raised concerns about a shortage of raw materials such as iridium and platinum required to produce electrolysers. The demand for green hydrogen will increase the demand for these rare materials.

Even though there are negative impacts of green hydrogen on the environment, long-term use of hydrogen with safety measures and in areas where direct electrification is not feasible will help to reduce GHG emissions.

4.1.6 Legal Factors

The legal and regulatory framework for hydrogen projects in various sectors is not well defined in Norway, as in many other countries. It can be challenging to navigate the hydrogen value chain since there is no complete framework covering it.

Regulations: There is a specific statute governing the Norwegian energy market (the "Energy Act") that governs the generation, conversion, transmission, trading, distribution, and use of energy. Hydrogen production, storage, and transportation are not covered by the Energy Act, according to its legislative history. Nevertheless, hydrogen production facilities must comply with the Energy Act and its regulations just like other industrial plants, as outlet customers in the grid. All types of activities related to real estate are covered under the Planning and Building Act. The construction can only be done if it is not in conflict with the municipal area and zoning plan and act and associated regulations. A permit is required to produce hydrogen by electrolysis under the Pollution Control Regulations even though it does not cause any pollution. Further, the production of electricity from fuel cells or gas turbines with hydrogen as an input factor requires a plant license as per Energy Act if the plant is over the threshold for a licensing obligation. A facility doesn't need a separate permit under the Building and planning act if the plant receives a such license.

The trade-in electrical energy requires a license from the regulatory authority as per the Energy Act. Hydrogen is considered a type of flammable gas that belongs to the category 1 classification. As a result, it falls under the scope of the Act concerning the prevention of fire, explosions, and accidents caused by hazardous substances and the fire service. Hydrogen is handled under the Regulations on the Handling of Dangerous Substances. As per regulations, risk assessment is a must for hydrogen plants, and they must be built and assessed based on the recognized norm. The handling of hydrogen should be at a safe distance from the surroundings for the safety of third parties. As per regulations, companies need to document the requirement of spatial measures and restrictions on hydrogen handling facilities.

The equipment used in hydrogen handling should comply with the requirement of the Regulations on Pressure Equipment. The storage of 5 tons or more hydrogen is covered by the Regulation on major accidents. Moreover, compliance with the Regulation on Health and Safety in Explosive Atmosphere is required for the protection of workers and other persons. The transport must be following the Regulation on Carriage of Dangerous Goods by Road. It sets general requirements for transport persons, to clear safety marking, packaging, equipment, and materials required to transport dangerous goods. There are regulatory bodies in Norway which issue permits in the hydrogen value chain as shown in Figure 4.10 (CMS-Law.Tax.Future, 2023).

Regulatory Body	Role
The Directorate for Civil Protection (DSB)	• The authority for regulation of dealings with flammable, reactive, pressurised, and explosive substances, including hydrogen. • The authority for regulation of transport of dangerous goods. • The administrative authority with regards to regulation of electrical safety, i.e., requirements for safe execution and use of supply networks and electrical installations, including installations for production of hydrogen.
Local Authority/ Town and County Authority	• Regulates the use of land. • The authority enforcing pollution regulations in their respective town/county.
Ministry of Climate and Environment and the Norwegian Environment Directorate	Superior authority on pollution regulations.
Ministry of Petroleum and Energy	Regulates generation, conversion, transmission, trading, distribution, and use of energy.

Figure 4.10: Regulation of hydrogen(CMS-Law.Tax.Future, 2023)

Policies: In Norway, the tax on the non-emission trading system will increase by 21%. Norway was the first country to impose a carbon tax in 1991 to cover the combustion of fossil fuels and the petroleum sector. The national CO2 tax is 766 NOK/ton of CO2 equivalent for emissions outside the EU ETS. The white paper submitted by the former government announced an increased carbon tax rate to 2000 NOK/ton of CO2 equivalent in 2030. Although increased carbon prices will help to achieve emission reductions in Norway, the main intention is to motivate technological shifts and to consider incentives and support for the sectors that may need them. Moreover, the manufacturing and petroleum industries are part of the European Emission Trading System (EU ETS) which also decides the profitability of the business. The reduction of the EU ETS allowance will drive the use of green hydrogen in the industrial energy mix.

To promote the production of green hydrogen, electricity used for electrolysis is exempted from consumer tax (consumer tax NOK 0.1541/kWh in 2022). It will help to reduce green hydrogen production costs and to make it cost-competitive compared to other energy carriers.

4.1.7 Ethical Factors

There is a quote by Nobel Prize-winning Dutch economist, Jan Tinbergen, “Equal distribution, and fairness, creates profits, not the other way around”. Organizations should align ESG and sustainability in their company agenda. It has been proved in many studies that companies with sustainable business models, sustainable financial models and sustainable business practices can generate good returns for investors or shareholders. It will help to create a more sustainable and resilient society.

Companies should prioritize corporate social responsibility (CSR) as a core aspect of their business for the betterment of the environment and society. The business should be creating some value for society and the environment rather than degrading it. This vision of the company motivates the employees and raises their morale. Companies need to conduct business in a transparent, ethical, and responsible manner. The business actors should respect the culture, dignity and rights of individuals and entities in the regions where they operate.

4.2 Market Scan

Fossil fuels are deeply rooted in the global economy and society, from the cars we drive to the energy that heats our homes. So, the challenge is how to phase out fossil fuels with new technologies efficiently and economically. The idea of this market mapping is to promote the use of green hydrogen in sectors where it makes sense over other green solutions available in the market. Due to the high cost of green hydrogen, there is ongoing debate about which sectors should prioritize using hydrogen, and which should consider alternative solutions. The sectors like steel, cement and refineries are hard to electrify due to technological reasons and other sectors like marine, aviation, rail, or mining consume energy that exceeds the capacity of batteries. Some people argue that the use of green hydrogen for cars, heating, electricity, and storage will only be a distraction over other green alternatives and hydrogen is not a silver bullet to all our problems. The sectors where hydrogen can be used will be discussed and customers will be mapped accordingly later in the mapping section. Before mapping customers, all the feasible sectors will be accessed for hydrogen use in terms of energy efficiency and economic benefits and compared with other better alternatives in the market.

4.2.1 Hydrogen in Home Heating

The efficiency and carbon emissions of the heat pump were compared with green hydrogen for domestic heating during one study in the UK and the results are shown in Figure 4.11 and Figure 4.12. The analysis in Table 4.2 show heat pump is a clear winner over H_2.

Due to their high efficiency and adaptability in various weather conditions, the heat pump market is growing in cold European countries like Norway, Sweden, and Finland as shown in Figure 4.13 and Figure 4.14. Customers for this sector are not mapped as the use of hydrogen is not efficient and economical for household heating based on research and analysis.

Table 4.2: Hydrogen in Home Heating

Supporting factors for Green H_2	**Arguments against Green H_2**
Avoid replacement of existing gas boiler infrastructure	Less efficient (five times more electricity) and more expensive (two or three times) than alternatives such as district heating, heat pumps, and solar thermal
The heat pump will not be suitable in some places due to lack of space, financial constraints, and electricity supply	Heating homes with green hydrogen requires five or six times more renewable energy than required for heat pumps

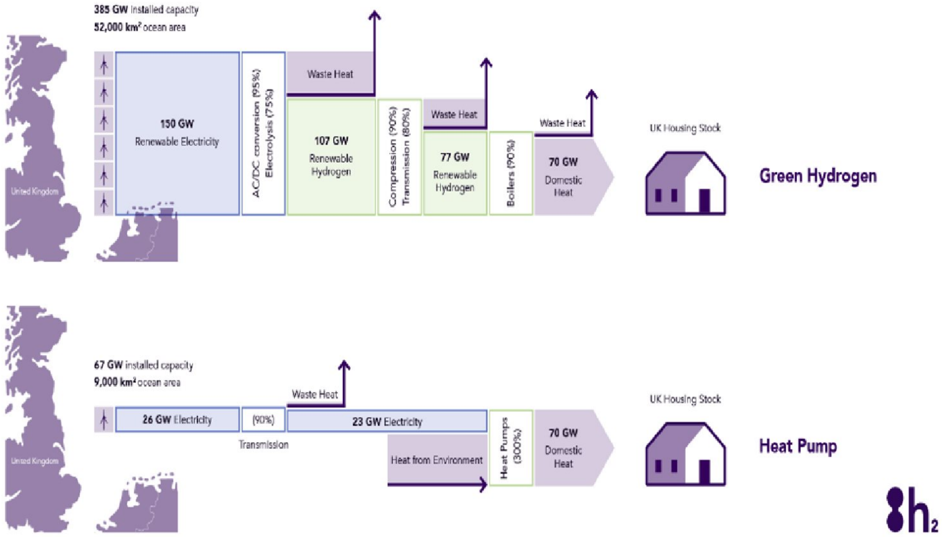


Figure 4.11: Energy use by Green Hydrogen and Heat Pumps for domestic heating(Cebon, 2022)

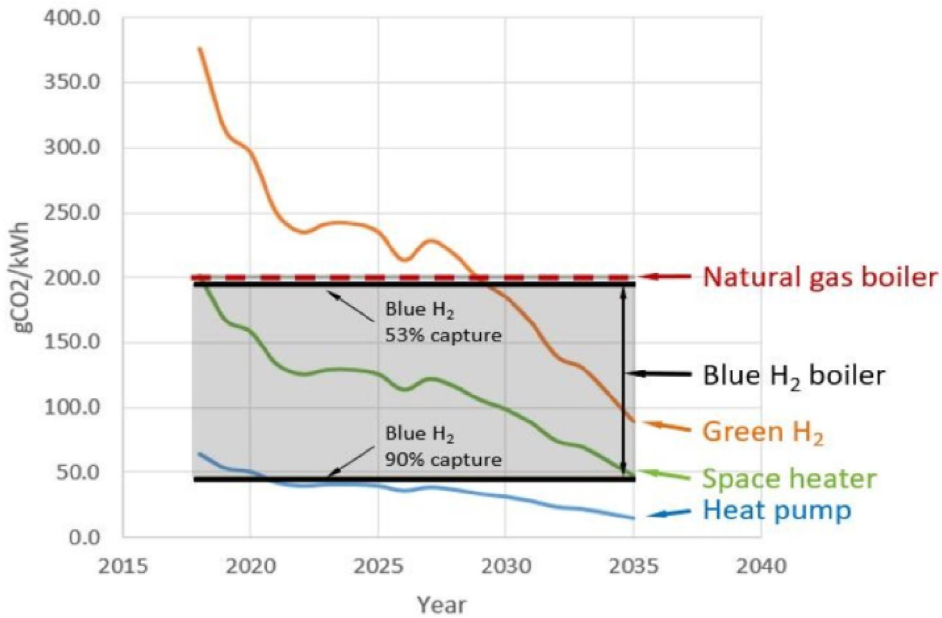


Figure 4.12: Carbon emissions by Green Hydrogen and Heat Pumps for domestic heating(Cebon, 2022)

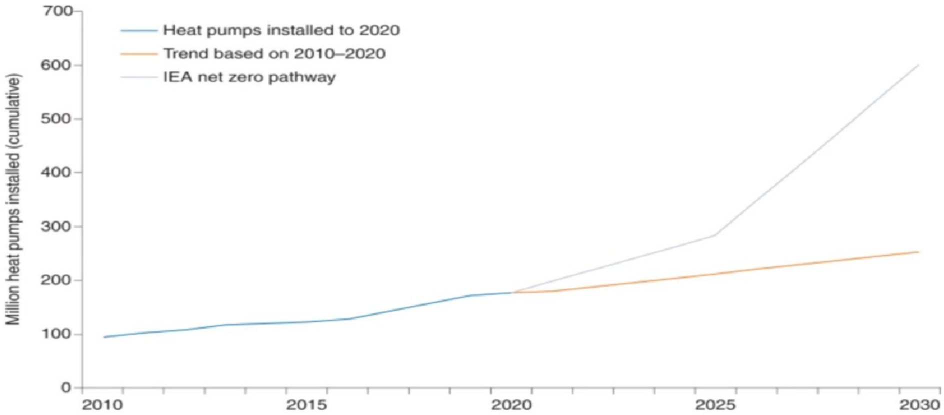


Figure 4.13: Global historic heat pump sales and IEA Net Zero 2050 pathway(Rosenow et al., 2022)

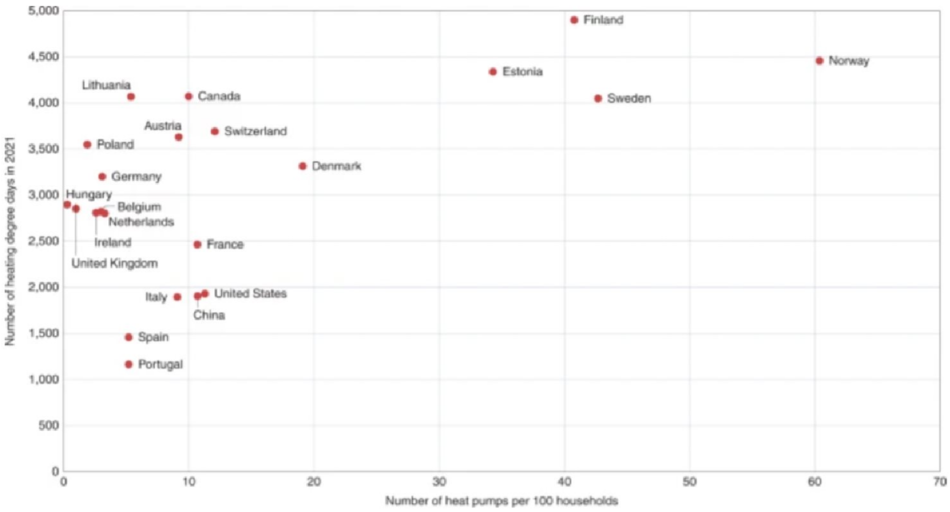


Figure 4.14: Heat Pump penetration and number of heating degree days in 2021 in selected countries(Rosenow et al., 2022)

4.2.2 Hydrogen in Road Transportation

In the next few decades, transportation will undergo major changes by abandoning fossil fuels-based technologies and fuels. The whole sector will be dominated by zero-emission vehicles and fuels. Governments, ruling bodies like the EU and customers want to reduce their carbon footprint and look for eco-friendly solutions. The scope of hydrogen in different transportation segments is shown below.

Hydrogen in Cars: In the near future, customers will replace their fossil fuel vehicles with zero emissions vehicles. There is a big rivalry between EVs and hydrogen cars that will take over the market in future. The well-to-wheel analysis by Volkswagen shows that a considerable amount of energy is lost in running a hydrogen car than in operating a BEV as shown in Figure 4.15.

Figure 4.15: Hydrogen and Electric Drive (Efficiency rate in comparison using Eco-friendly Energy(Volkswagen, 2020)

As mentioned in Table 4.3, there are significant obstacles to the mass adoption of H_2 cars in the near future. The EVs are more prevalent in the market and make sense to use for short or medium-haul (300-500 miles). But H_2 vehicles could have a bright future in long-haul trucking, maritime, rail and freight industries that will provide a good platform for the growth of H_2 technology.

Table 4.3: Hydrogen in Short-Haul Transportation

Supporting factors for Green H_2	**Arguments against Green H_2**
H_2 cars are better in terms of weight (H_2 is stored in gaseous form), refuelling time (5 mins to refill the full tank), and driving range compared to BEV	Inefficiency of FCEV compared to BEV due to the high energy losses
In cold conditions, the range for EVs drops significantly compared to H_2-powered cars	H_2 refuelling infrastructure is not widely available (and complex process) and is highly expensive compared to BEV
Big automakers like Hyundai, Toyota, BMW, Stellantis, and Honda invest heavily into hydrogen car technology	H_2 cars are more expensive and costly to refuel than BEVs. There are only two models available in the market (Hyundai Nexo SUV and Toyota Mirai)
Recycling of battery components and mining of raw materials (nickel, lithium, and cobalt) raises both environmental and ethical issues, while fuel cells can last through the lifetime of the vehicle	Automobile giants such as Tesla, Volkswagen, and Mercedes oppose the idea of hydrogen cars
Batteries can cause injuries if overcharged and overheated	H_2 is flammable and can be dangerous if not handled properly

Hydrogen in Heavy-Duty Vehicles (HDV): Though EVs are prevalent and seem promising solutions for short-distance transportation, hydrogen will win over EVs in long-haul trucking. "Time is Money" is applicable in the long-haul freight business, where labour is the second costliest part after fuel. Therefore, it is crucial not to select one energy source for the whole transportation sector. For long-haul trucking, the high energy density of hydrogen than batteries makes it a more practically viable option to travel long distances without recurring refuelling and recharging. Table 4.4 presents a comparison between hydrogen trucks and battery trucks.

Table 4.4: Hydrogen in Long-haul Trucking

Supporting factors for Green H_2	**Arguments against Green H_2**
Battery-powered trucks will take approximately six hours for charging while H_2-powered trucks will take only 15 mins to refuel completely which improves the cross-country drive times	The vehicles are double the cost of EV
The biggest downside of EV trucks is the increased weight of batteries which will eventually reduce the size of cargo by 20% compared to diesel trucks where H_2 trucks barely lose any capacity as shown in figure 4.16. The cargo capacity of a 40t truck for 800 km is compared	Three times more electricity is required to drive H_2 trucks for 1 km than EV due to their low efficiency
Fuel cell trucks have a longer range (require fewer stops on long hauls) and can fuel much faster which provides operational flexibility	Currently, infrastructure (limited refueling stations) is the hindrance for long distances
Companies like Hyundai Motor, Daimler Truck and Volvo Trucks are supporting H_2 trucks due to longer range and uptime via faster refuelling and heavier payloads	Companies like Volkswagen and Tesla promoting EV trucks due to their lower cost and more developed infrastructure
The total cost of ownership (TCO) of H_2 trucks is lower due to lower maintenance costs and high ranges as shown in figure 4.17	Charging multiple EV trucks at the same time and location would be challenging for the grid

As per the study, drivers of long-haul freight are legally bounded to take a break after a maximum of four and a half hour's journey and the distance covered during this time at a speed of 70km/h will be approximately 300km. While the EV trucks available in the market can go up to 800 km (Tesla Semi) on a single charge, an EV truck can go approximately 700-800 km without charge during one shift. But under the 'Two-Driver Rule' a truck can drive for 18hrs on a single charge which requires an EV truck with a 1200-1300km range, which is not available in the market. The hydrogen stored in liquid form will have more energy density which significantly improves the range and gives a comparable performance of a H_2 truck with that of a conventional diesel truck. However, if the same platform such as developed infrastructure is provided for hydrogen, it will be a more viable and economical option for long-haul trucking than electric trucks. Therefore, this thesis supports the idea of using hydrogen for long-haul trucking and promotes the development of infrastructure to

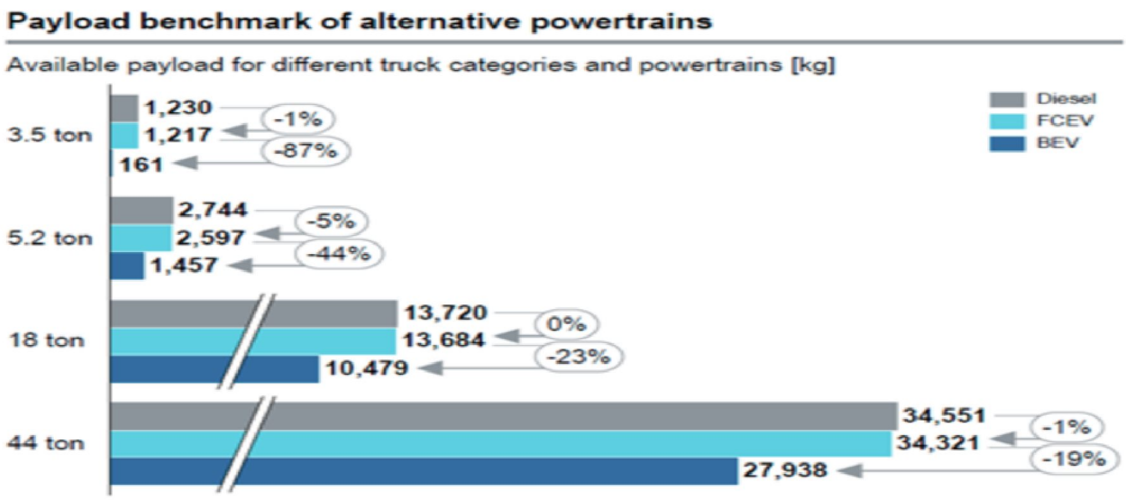


Figure 4.16: Heavy-Duty Trucks(Experts, 2022)

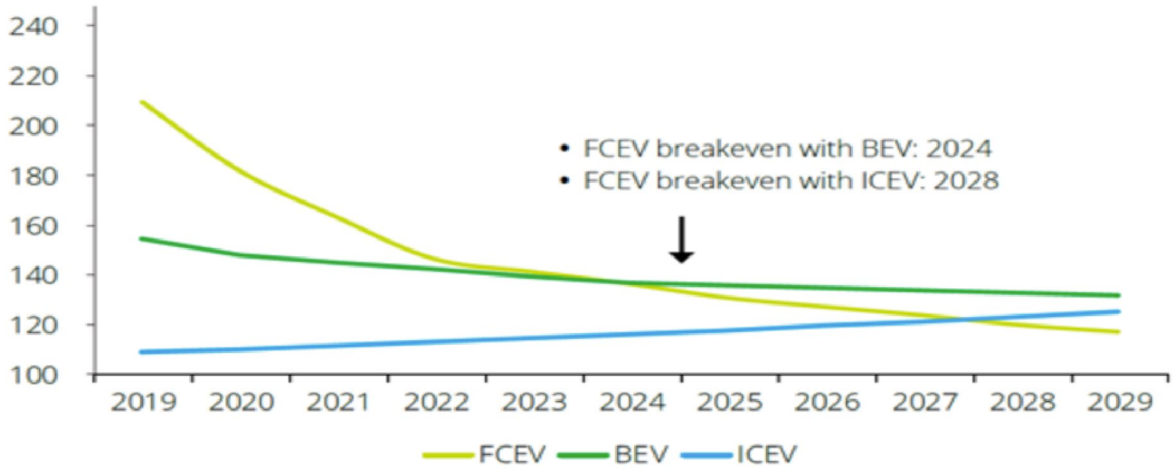


Figure 4.17: Total Cost of Ownership/USD per 100 km comparison of Diesel, Battery, and Fuel Cell Trucks(Experts, 2022)

support hydrogen technology.

Hydrogen in Rail (Hydrail): The trains are the lowest emitting transport mode and diesel trains need to be phased out to reach net zero by 2050. The selection of zero-emission fuel for trains depends upon the distance between interstation, demand on the route and how fast the trains need to be refilled. The electric train, hydrogen fuel cells and hybrid trains will play a key role to decarbonize the rail industry. Table 4.5 presents a comparison between hydrogen and electric trains.

In Europe, 60% main lines are already electrified and 80% traffic is running on these lines. The electrification of low-density routes is not economical; thus, hydrogen can be an alternative in freight and passenger trains in isolated islands which are difficult to electrify.

Table 4.5: Hydrogen in Rail Transportation

Supporting factors for Green H_2	**Arguments against Green H_2**
The existing non-electrified railway lines can be turned into zero-emission lines with hydrogen without investing in long-range electrification infrastructure	Battery powered trains are 35% cheaper than hydrogen
H_2 is more economical for routes which are less utilized and in regions with limited grid capacity	Electric trains are more efficient (3 times) than hydrogen trains
H_2 trains offer greater flexibility due to their longer range	Due to the low volumetric energy density of H_2 (4.6 Mj/Litre) compared to diesel (35.8 Mj/Litre), it requires 8 times the size of a fuel tank of a diesel train
H_2 trains can go up to 1000 km without refuelling, which is 10 times further than electric trains	

4.2.3 Hydrogen in Maritime

Hydrogen will play a crucial role to decarbonize the maritime industry from well to wake. Shipping consists of different segments which operate under different conditions where hydrogen can be part of hybrid solutions in combination with battery solutions or other zero-emission fuels. A Global Maritime Forum examined 106 projects looking at zero emissions in maritime shipping in March 2021 study and found that half of the projects are focused on hydrogen. Hydrogen is an important component of electro fuels among three categories of non-fossil fuels (produced from renewable or zero-carbon energy sources) for the maritime industry as shown in Figure 4.18.

- Blue fuels – Reformed natural gas with CCS
- Biofuels – Sustainable bioenergy sources (Biogas, biodiesel)
- Electrofuels (Synthetic fuels) – Renewable electricity (e-ammonia, e-methanol, e-LNG)

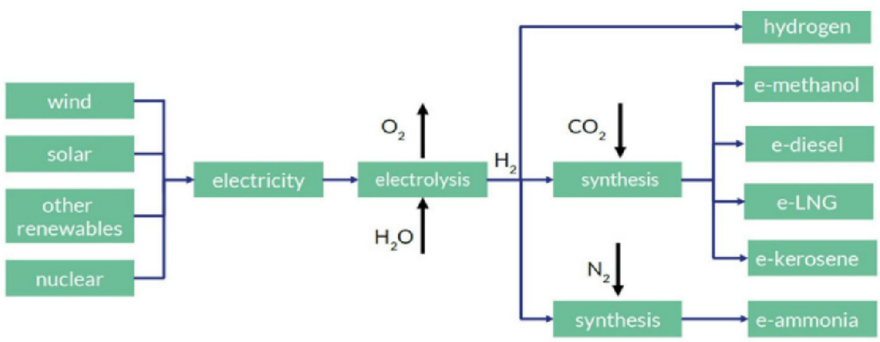


Figure 4.18: Schematic representation on the role of hydrogen and relevant E-fuels (source TNO)(Europe, 2021)

Hydrogen in Shipping: As per the DNV report, ammonia is one of the promising carbon-neutral fuels for the shipping industry and pure hydrogen will not be suitable due to its lower energy density by volume. It is easier to store ammonia than hydrogen or LNG and it's cheaper than batteries. As per IEA, shipping hydrogen derivate ammonia instead of hydrogen makes economic sense. But ammonia is toxic, corrosive and releases nitrous oxide (N2O) on combustion. As per DNV's 'Maritime Forecast to 2050 report', pure hydrogen will be losing out to biofuels and hydrogen derivates in the 2050 fuel mix. The projected use of zero-emission fuels in the shipping industry by IRENA to meet the decarbonization goals of the industry is shown in Figure 4.19. Table 4.6 presents the pros and cons of using green hydrogen in shipping.

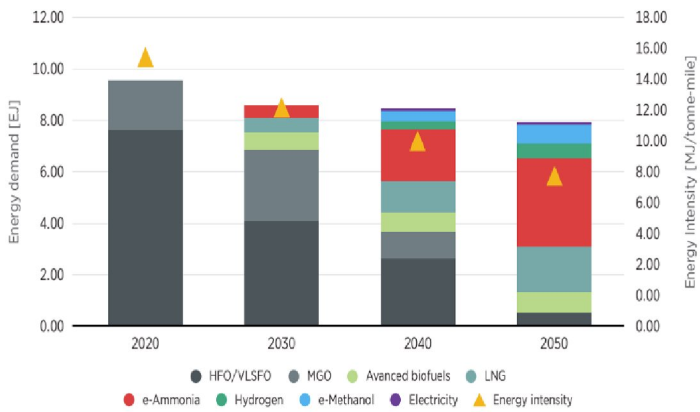


Figure 4.19: 1.5°C Scenario Energy Pathway, 2018-2050(IRENA, 2021)

Table 4.6: Hydrogen in Shipping

Supporting factors for Green H_2	**Arguments against Green H_2**
H_2 is a range extender and a supplement for coastal and short-sea shipping where EV is not a solution due to lack of grid capacity	Huge storage tanks are required in a setting where space is a premium as compressed (1.2 kWh/l) and liquid H_2 (2.4 kWh/l) have poor volumetric energy density. H_2 storage requires 6 to 10 times more space compared to conventional fuel oils
Hydrogen can be stored for long periods of time in large amounts	Liquid hydrogen storage at -253°C (cryogenic temperatures) makes it difficult to handle and store at sea
Fuel cells are quiet, without moving parts and scalable for larger ships (individual cells can be stacked)	
Most of the ships can be retrofitted with hydrogen fuel cells	
Green hydrogen can be used directly in internal combustion engines, in fuel cells, and as a building block for a range of fuels such as e-ammonia and e-methanol	

Hydrogen in Ferries: The shipping segment with the highest potential for pure hydrogen are ferries, passenger boats, fishing vessels and offshore vessels. Ferries are modes of transport in coastal or island communities and transit multiple times in a day between one route and several routes. Besides battery-electric ferries, a promising option for the ferry segment is the adoption of green hydrogen and green hydrogen-based fuels such as ammonia, methanol, and liquid organic hydrogen carriers (LOHC). Electric ferries are emission-free, but the availability of charging stations and available charging time is crucial for their operation. Therefore, engines burning green fuel mix such as hydrogen or fuel cells combined with batteries can be considered. The ferry operator DFDS conducted a poll to evaluate the movement of zero emissions fuels among ferry operators and 80% confirmed that they are working on projects to evaluate alternate green fuels. Table 4.7 presents the pros and cons of using green hydrogen in ferries.

Table 4.7: Hydrogen in Ferries

Supporting factors for Green H_2	**Arguments against Green H_2**
Electric ferries with sailing time over 60 minutes and without a charging station need a green fuel mix (batteries, fuel cells, and hydrogen)	Electric and hybrid ferries will have higher capital expenditures than a normal ferry but operational expenditures depend on fuels and electricity prices
Current battery technology doesn't have enough capacity to support long distances due to its weight and volume. H_2 ferries can sail long distances and at higher speeds	

Thus, green hydrogen will support the production of zero-emission fuels like e-ammonia and e-methanol for the shipping industry. As per DNV, pure green hydrogen will be suitable to use for short-sea shipping as a part of the green fuel mix due to storage difficulties, when vessels don't travel long distances and stay close to shore.

4.2.4 Hydrogen in Aviation

The IATA (International Air Transport Association) sees H_2 as a key element in achieving net-zero carbon emissions for the airline industry by 2050. There is an estimation that hydrogen planes can enter the market by 2035 and H_2 has the potential to reduce the aviation industry's CO2 emissions by up to 50%. Another fuel type which is in the race for the aviation industry is Sustainable Aviation Fuels. These SAF fuels such as biofuels and synfuels have hydrocarbons from sustainable sources and possess similar properties as conventional jet fuel with a smaller carbon footprint. The comparison of hydrogen with different zero-emission fuels in the aviation industry is shown in Figure 4.20. Table 4.8 presents the pros and cons of using green hydrogen in aviation.

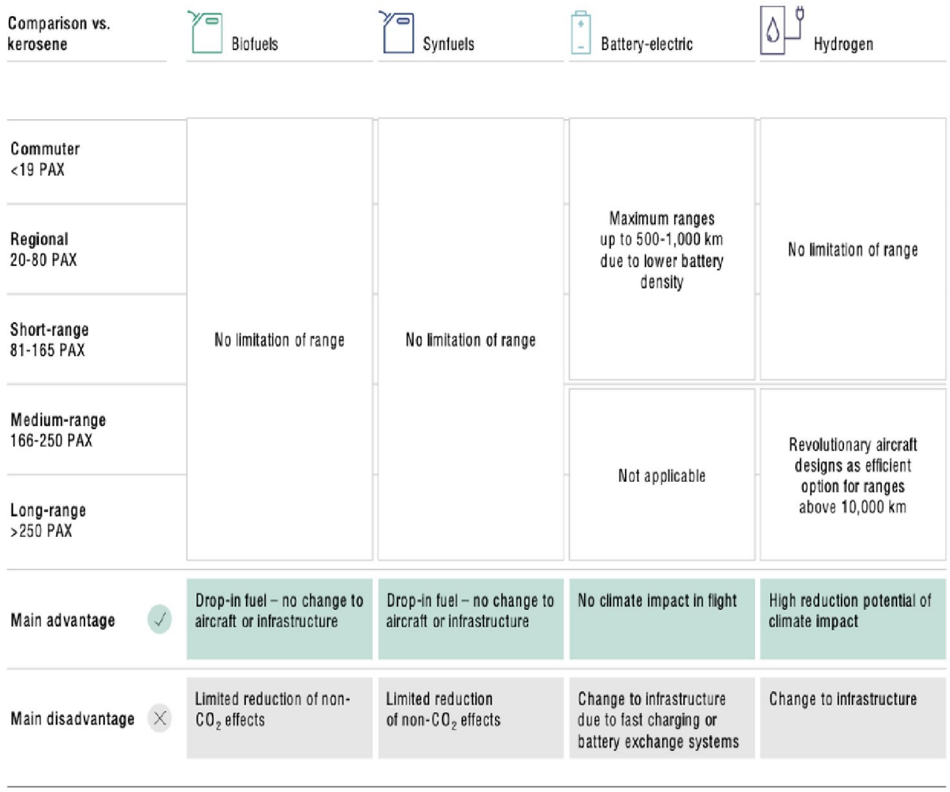
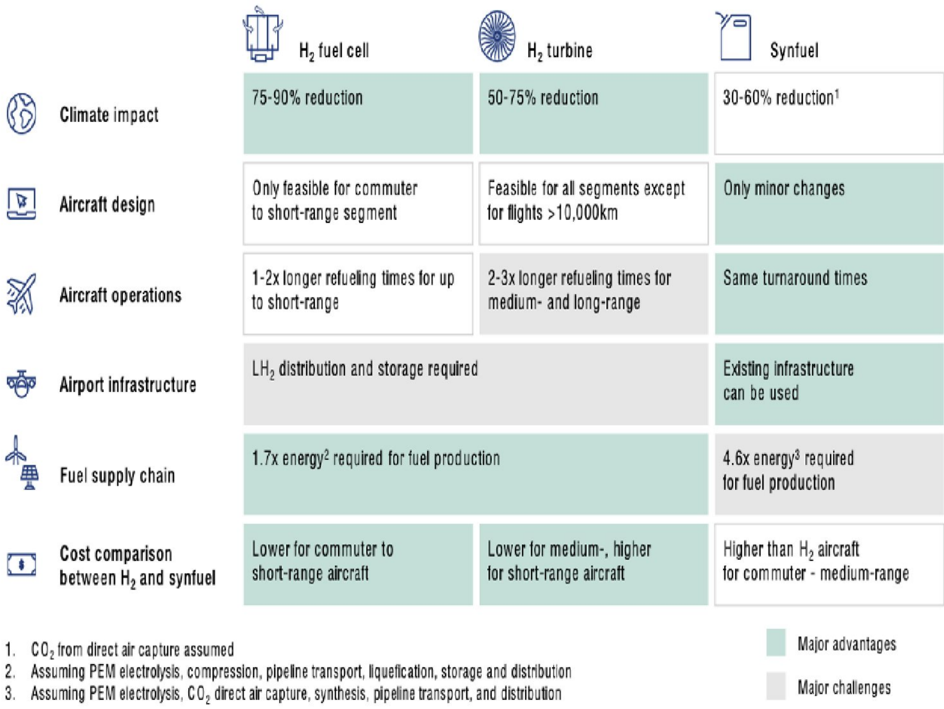


Figure 4.20: Comparison of Sustainable Aviation Fuels and new technologies(Union, 2020)

Table 4.8: Hydrogen in Aviation

Supporting factors for Green H_2	**Arguments against Green H_2**
Hydrogen's mass-energy density is three times more than traditional jet fuel	Accommodating H_2 storage will be bulkier (4 times) than existing jet fuel storage tanks
Biofuels rely on feedstock, changes in land use, high water use, and production of a single crop, resulting in conflicts of interest between aviation and other industries	Hydrogen costs four times compared to jet fuel on a flight-mile basis
Hydrogen propulsion is projected to be two to three times more effective than synthetic fuels in reducing aviation's climate impact as shown in Figure 4.21	Sustainable aviation fuels (Biofuels and Synfuels) don't require changes in aircraft and fuel infrastructure and are applicable for all aircraft segments
The FlyZero research program by the UK government to check the feasibility of hydrogen-powered aircraft confirmed that an aircraft carrying 280 passengers can travel anywhere in the world with one refuelling stop	Biofuels are commercially available - e.g., HEFA fuels

The ambitious scenario is that 40% of the (European aviation) fleet would be powered by H_2 by 2050. In the current scenario, the use of hydrogen in regional, short-range, and medium-range routes should be targeted first to make use of H_2 as aviation fuel. The use of H_2



	H_2 fuel cell	H_2 turbine	Synfuel
Climate impact	75-90% reduction	50-75% reduction	30-60% reduction[1]
Aircraft design	Only feasible for commuter to short-range segment	Feasible for all segments except for flights >10,000km	Only minor changes
Aircraft operations	1-2x longer refueling times for up to short-range	2-3x longer refueling times for medium- and long-range	Same turnaround times
Airport infrastructure	LH_2 distribution and storage required		Existing infrastructure can be used
Fuel supply chain	1.7x energy[2] required for fuel production		4.6x energy[3] required for fuel production
Cost comparison between H_2 and synfuel	Lower for commuter to short-range aircraft	Lower for medium-, higher for short-range aircraft	Higher than H_2 aircraft for commuter - medium-range

1. CO_2 from direct air capture assumed
2. Assuming PEM electrolysis, compression, pipeline transport, liquefication, storage and distribution
3. Assuming PEM electrolysis, CO_2 direct air capture, synthesis, pipeline transport, and distribution

Figure 4.21: Comparison of H_2 technology and Synfuel(Union, 2020)

in larger passenger planes requires considerable change in aircraft design and a huge volume of hydrogen which could be envisaged in the longer term.

4.2.5 Hydrogen in Chemical Industry

Hydrogen will play a vital role to decarbonize energy-intensive industries such as iron and steel, chemicals & petrochemicals, cement & lime, and aluminium which are the hardest to decarbonize and electrify. Hydrogen is used in industrial processes in three ways-as a chemical feedstock, as an energy carrier and in the process itself. Currently, hydrogen has been used mainly as a feedstock in oil refining, ammonia production & methanol production as shown in Figure 4.22. There is considerable focus to explore the potential use of H_2 as a replacement for coal and NG for heating in the industry with the new need to reduce GHG emissions. The high-grade heat from H_2 combustion can meet the heat requirement of all heavy industries as shown in Figure 4.23.

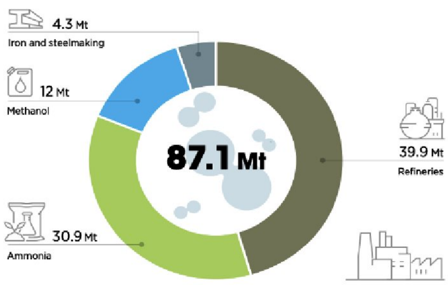


Figure 4.22: Pure hydrogen demand in industry, Global 2020(International Renewable Energy Agency, 2022)

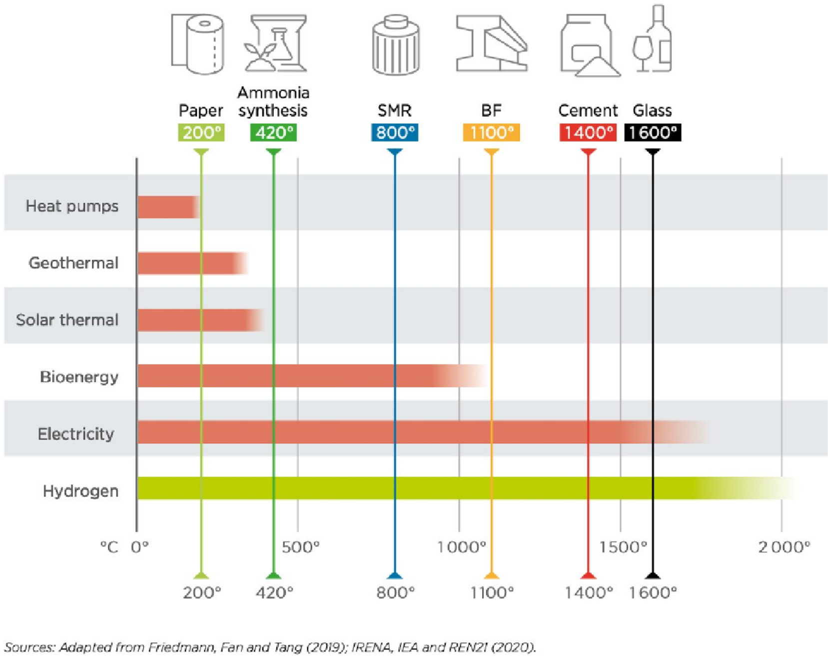


Figure 4.23: Working temperatures for selected renewable heat technologies and temperature requirement of selected industries(International Renewable Energy Agency, 2022)

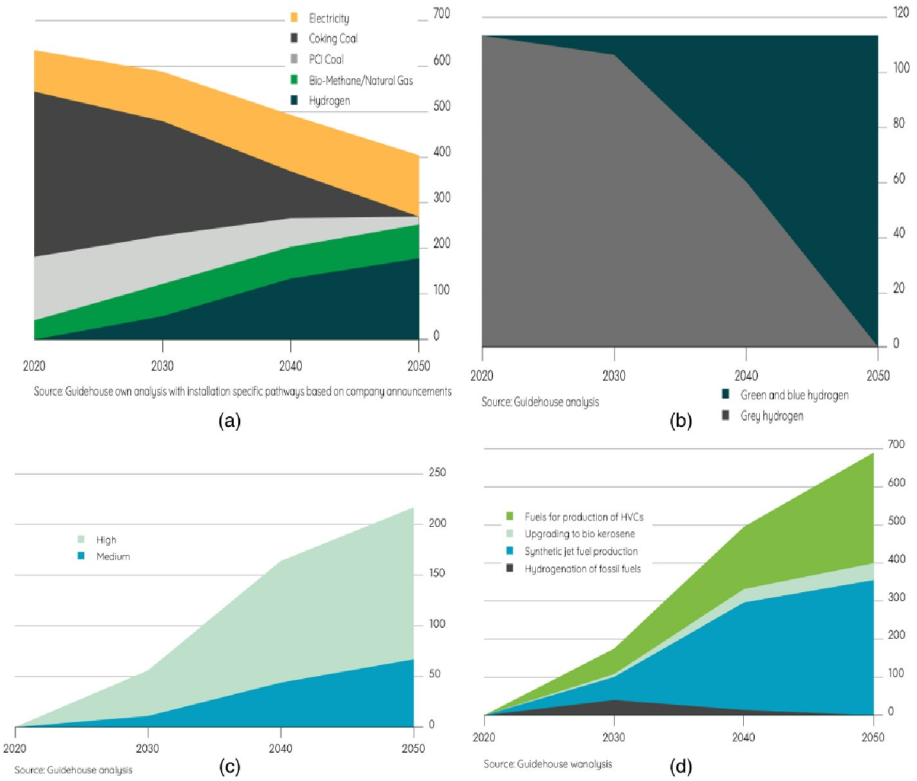


Figure 4.24: (a) Expected development of annual energy demand in steelmaking from 2020-2050 (b) Development of the European annual hydrogen demand (TWh) in ammonia production from 2020-2050 (c) Expected annual green and blue hydrogen demand (TWh/Year) for industrial process heat based on current production (d) Expected development of annual green and blue hydrogen demand (TWh) for fuel production between 2020-2050(Anthony Wang, 2021)

The forecasted demand for hydrogen in steelmaking, ammonia production, industrial heating and fuel production is shown in Figure 4.24, which provides a positive outlook for green hydrogen in industrial use. However, except hydrogen, alternative solutions such as biomass & synthetic feedstocks, recycling of products, carbon capture and digital transformation will also play an important role to reduce chemical-industry emissions. Table 4.9 presents the pros and cons of using green hydrogen in the chemical industry.

Table 4.9: Hydrogen in Chemical Industry

Supporting factors for Green H_2	**Arguments against Green H_2**
Industries have the infrastructure (NG pipelines) that can be reused for the use of hydrogen	The materials produced using green processes cost more than the default fossil fuel-based processes
H_2 is useful in processes with high temperature (more than 1000 degrees Celsius) requirements which can't be achieved with electricity	Currently, green goods are driven only by climate ambition or speculation on their demand rather than immediate economic gain
Major steel makers such as SSAB, Voestalpine, ThyssenKrupp steel, Salzgitter, and library steel are considering direct reduction of iron (DRI) with H_2 as a primary solution to decarbonize primary steel-making	Industrial processes have limited experience with continuous load adjustment for supply variation. So, hydrogen storage is required for a steady supply which will further increase the cost of green hydrogen
The use of green hydrogen as a fuel will make processes emission-free and sustainable	

4.2.6 Hydrogen in Power Industry

H_2 is one of the leading options for storing RE and as an energy carrier to generate electrical power with H_2 (or NH3) combustion engines and H_2 fuel cells to balance loads in electricity networks. The variable output from VREs sometimes requires curtailment due to low demand which is expensive. Long-term storage is required to harness this excess energy which will also reduce system costs. This excess energy can be utilized to produce green H_2 (known as brilliantly green H_2) that can be blended with NG turbines (or NH3 blending in coal-fired plants), burnt directly in power plants, and used in fuel cells. Table 4.10 presents the pros and cons of using green hydrogen in the power industry.

The electricity is produced mainly from hydro in Norway, which is stable, low-emission and stores energy in water reservoirs. As per the Norwegian Government's hydrogen strategy report due to the flexibility of hydropower and significantly more efficiency than electrolysis, the value of H_2 (Power-to-Power) is less in the Norwegian power system than in Europe. Thema has studied the potential of using H_2 compared to upgrading a transformer to back-up Norwegian Grid. It has been found that upgrading transformers is an economical solution than batteries or hydrogen to tackle overloads of several hours each year. However, hydrogen has the potential to power construction sites as a reliable energy source compared to weather-dependent green energy sources such as wind and solar. It can be used for heavy machinery such as bulldozers, cranes, and excavators instead of diesel engines or as a backup power gen-

Table 4.10: Hydrogen in Power Industry

Supporting factors for Green H_2	**Arguments against Green H_2**
H_2 fuel cells can be used as backup power, peak-shaving, and grid stabilization	High conversion losses. Using H_2 is 20-40% less efficient than using renewable energy directly
The existing infrastructure of gas-fired power plants can transition from natural gas to H_2	Storage and delivery of H_2 is a challenge
In the short term, H_2 can be blended with natural gas in gas-fired turbines	
Companies like Equinor, SSE, Siemens, and GE are investing in hydrogen-fired power plants	
H_2 storage is efficient and cost-effective compared to batteries and demand response	

erator. Some companies like Siemens Energy & GeoPura, Implenia, Generac Power Systems, and EODev are already testing H_2-powered equipment at construction sites.

Thus, green hydrogen is a suitable solution only for hard-to-abate sectors which cannot directly rely on clean electricity. This thesis evaluation is that it will make sense to use green hydrogen in long haul trucking, maritime shipping, aviation, high heat industrial processes, as a feedstock in some industrial processes and to store excess renewable energy. Based on these evaluations, the market (Customers) is mapped in the next section for a business.

4.3 Customer Identification

The sectors that should be targeted for the green hydrogen business have been identified in section 4.2. Within these sectors, the following customers with the potential to utilize green hydrogen have been identified.

1. Ferry connection between Lofoten and Bodø: Torghatten Nord will operate hydrogen ferries and is one of the world's largest marine hydrogen fuel cell projects. The target is to replace LNG ferries with hydrogen. PowerCell will deliver the fuel cell solution with 6MW for each ferry and Norwegian Ship Design is entitled for the design. Norwegian company SEAM specialising in Zero-emission alternatives for the maritime industry will deliver propulsion, control, and safety systems.

2. H_2 Truck project: It's a joint venture of transport users, the developers of stations and production facilities and public authorities to roll out 100 hydrogen trucks. The project is funded by the partners, Oslo Municipality and Viken County Municipality at the Climate and Energy Fund. The objective is to promote sustainable mobility including people, goods, or services. DB Schenker, Rema, DnB, Posten and Bring are among the transport users who want to reduce CO2 emissions from their operations.

3. SeaShuttle: The collaboration between transportation and logistics group Samskip and marine robotics company Ocean Infinity to serve a route between Rotterdam and Oslo

> Fjord. The objective is to decarbonize and transform maritime operations using two hydrogen-powered containerships. The combination of fuel, technology and operational best practice will lead to emissions-free shortsea shipping costs competitive with existing solutions.

Moreover, the energy-demanding and longer connections such as Hordaland and Nordland which are part of Norwegian highways ('Riksveg') have a high interest in hydrogen ferries (Torvanger, 2021). Collaboration with fertilizer, aviation, and logistics companies to provide on-demand green fuel. Establish green hydrogen and green ammonia facilities and invest in bunker barges. The potential customers that have been identified are listed in Table 4.11.

Table 4.11: Potential Customers for Green Hydrogen Solutions

Potential Customer	**Location**	**Challenge/Issue**	**When is Customer Ready for Purchase**
Torghatten Nord	Norway – Ferry connection between Lofoten and Bodø	The Norwegian government stipulated that new ferries across the Vestfjord to Lofoten must be emission-free and run predominantly on hydrogen. From 2024, the maritime sector will be included in the EU ETS.	2025
Evig Grønn AS	Oslo Region	To reduce emissions from heavy vehicles	2025
Samskip & Ocean Infinity	Oslo Fjord - Rotterdam	To make container shipping emissions-free	2025

Chapter 5

Discussion

Initially, the focus of the thesis was on developing a business model for utilizing hydrogen in grid stability. However, it was discovered that hydrogen storage for grid stability is not a feasible option for Norway. According to the Norwegian Government's hydrogen strategy report, due to the flexibility of hydropower and its significantly higher efficiency compared to electrolysis, the value of H_2 (Power-to-Power) in the Norwegian power system is lower than in Europe. As the thesis progressed, the research scope was adjusted to evaluate the factors noticed in the PESTELE literature review, rather than incorporating these factors into a business model. The literature review emphasized the importance of considering multiple factors when venturing into the hydrogen business, including market opportunities, national development strategies, policies and regulations, the commitment of the country, legal barriers and risks, political support, infrastructure, and social acceptance. It was noted that the hydrogen business is complex, and influenced by multiple actors and factors.

A systematic PESTELE framework is employed to address the research question of how external factors impact the green hydrogen business within the Norwegian context.

The analysis indicated that political support, including incentives and infrastructure development, will play a crucial role in driving hydrogen technology adoption in Norway. Like the success of electric vehicles in the country, this political support is expected to enhance public acceptance of hydrogen as a viable alternative. Though social acceptance could present a hurdle for hydrogen adoption in Norway due to a previous incident involving an explosion at a hydrogen station. Consequently, the hydrogen economy has the potential to replace the trade of natural gas in Norway, contributing to a more sustainable economy and providing energy security to the nation. Additionally, Norway's abundance of renewable electricity positions it as an ideal location for green hydrogen production without significant limitations on electricity supply. Undoubtedly, Norway's esteemed reputation as a global sustainability leader draws foreign investments and organizations seeking to assess solution feasibility. This agile and adaptable approach distinctly underscores the nation's unwavering commitment to innovation. Notably, the country hosts prominent companies within the hydrogen value chain, such as Nel, Hexagon Purus, Umoe Advanced Composites, Raufoss Fuel Systems, Hystorsys, ZEG Power, GasPlas, Greenstat, and Gen2Energy, further promoting the growth of the hydrogen economy. The Norwegian industry possesses the resources and expertise to drive hydrogen initiatives, and attractive projects. However, despite these favourable conditions, it's worth noting that the regulatory framework for hydrogen in Norway is not well-defined, potentially posing challenges to the industry's development. The high water demand for green hydrogen raises environmental concerns within the water ecosystem.

A market feasibility study aimed to address the research question of identifying which specific sectors should prioritize hydrogen, even when other green alternatives are available.

The market scan highlighted that in certain sectors, such as short-haul transportation and home heating, alternative technologies like electric cars and heat pumps are more energy-efficient and practical than hydrogen. However, hydrogen derivatives like e-ammonia and e-methanol are anticipated to play a dominant role in the maritime industry by 2050, surpassing hydrogen. Additionally, hydrogen fuel cells are expected to have significant applications in long-haul trucking. Projections indicate that hydrogen-powered aircraft will be introduced to the market by 2035. The simultaneous availability of commercial biofuels and Sustainable Aviation Fuels, without necessitating aircraft or fuel infrastructure modifications, presents a challenge to the growth of hydrogen in aviation. Nonetheless, the predominant advantage of utilizing hydrogen remains its substantial potential for reducing climate impact significantly. In contrast, other fuels have limited capacity to mitigate non-CO2 effects due to their carbon content. The use of green hydrogen in industrial processes presents an opportunity to replace the utilization of grey hydrogen, effectively reducing emissions and promoting sustainability. Hydrogen stands as a unique solution that adeptly meets the high-temperature requirements of industries like steel, glass, and refineries, outperforming the capabilities of most other considered alternative fuels, including electricity. Green hydrogen has the potential to render industrial processes emission-free and sustainable. Collaboration among companies within the hydrogen value chain is encouraged to leverage synergies and provide comprehensive green solutions.

Moreover, the uncertainty surrounding potential customers can often perplex companies. Therefore, customer identification has been undertaken to assess the actual market situation in Norway. It has been observed that hydrogen is widely adopted in maritime and long-haul trucking projects in Norway. For instance, under the world's largest marine hydrogen fuel cell project, ferries will operate between Lofoten and Bodø. A joint venture involving transport users, station and production facility developers, and public authorities aims to introduce 100 hydrogen trucks. The collaboration between transportation and logistics group Samskip and marine robotics company Ocean Infinity aims to serve a route between Rotterdam and Oslo Fjord using hydrogen-powered SeaShuttle.

However, it is important to acknowledge that hydrogen is a rapidly evolving technology. At the beginning of this thesis, no direct hydrogen combustion cars were available in the market. Within a span of six months, Toyota launched a hydrogen combustion engine, highlighting the dynamic nature of the industry. This development is considered groundbreaking for the automobile industry, showcasing the potential for significant advancements in the field. Throughout the evaluation process, the thesis has considered the latest updates from companies and reports. However, it should be noted that any updates released after the evaluation timeline are not included in the analysis, as the focus is on information available at the time of the thesis. Nevertheless, it is crucial to recognize that technology is advancing rapidly, and decisions should be based on the most up-to-date information to ensure accuracy and relevance.

Chapter 6

Conclusion and Future Work

In conclusion, this master thesis has highlighted the significant potential of hydrogen as a key element in Norway's transition towards a sustainable and zero-emission future. The use of hydrogen and its derivates will be diversified by pushing sectors that are hard to electrify such as the maritime sector and industries (with the use of ammonia and e-fuels). The most of demand will come from industrial heat, e-fuel, ammonia and methanol for shipping and aviation. Hydrogen is an energy-storage medium that is competing with battery storage in zero-emissions usage and replacing O&G in the transport sector. Batteries are not suitable for main storage in long-haul and heavy road transport like passenger vehicles due to their low energy density, infrastructure to recharge batteries and longer charging time. Therefore, fuel-cell solutions are suitable despite being only half as energy efficient as batteries and more complex and costly. The use of hydrogen in transport will pick up from 2035 onwards and in the maritime industry, zero-emission fuels like hydrogen and ammonia will be used in a hybrid configuration with gas-fueled propulsion and diesel. In the aviation sector, battery electric flights are suitable for short-haul distances, while synthetic fuels and hydrogen will be used for the long-haul to decarbonize the sector.

However, political support plays a crucial role in driving the hydrogen economy in the country. The development of infrastructure and the establishment of supportive regulations will further accelerate market demand for hydrogen. Norway's alleged "climate hypocrisy" and the resistance to the green transition within the country have been topics of discussion. While the industry seems supportive of the shift towards sustainability, there appears to be a lack of political determination to steer away from oil and gas in Norway.

The thesis emphasizes the importance of adopting a neutral stance when promoting technologies and prioritizing energy-efficient and feasible solutions. Efficient energy usage is essential in combating climate change and facilitating the global green transition. Although hydrogen is generating significant interest among large companies, political agendas, and environmental advocates due to its diverse applications and potential as a sustainable solution, it also faces opposition on political, environmental, and corporate fronts. Questions are raised regarding the use of renewable energy for hydrogen production and the ability to produce enough to meet global demand. Furthermore, it is crucial to evaluate Norway's renewable energy resources to determine if they are sufficient to support large-scale hydrogen production. If an excess of hydrogen is produced, Norway can explore the opportunity to export it to other countries striving to achieve their own net-zero targets, thus contributing to the global effort in combating climate change.

While hydrogen holds the potential to replace fossil fuels, it is essential to use it sensibly due to its costliness as an energy source. Direct electricity should be prioritized over hydrogen in cases where it is feasible, such as in heating and short-haul transportation. The gas companies are overselling the idea of running gas infrastructure on hydrogen. The distraction from better and cheaper options delays actual progress on climate change. The efficiency of green hydrogen must be carefully considered when assessing its viability as an energy source.

In conclusion, while hydrogen offers promising prospects, a comprehensive and strategic approach is necessary to fully harness its potential while considering its limitations and energy efficiency during the process. By doing so, Norway can position itself as a leader in the global green transition and contribute to a more sustainable and environmentally conscious future.

Appendices

PESTELE Analysis Report List

- Energy Transition Norway 2022-A National Forecast To 2050-DNV,2022 (DNV, 2022)
- External Factors Analysis- OG21,2020 (OG21, 2020)
- Green Transition – Damvad,2021 (Mikkel Skjoldager, 2021)
- The Norwegian Government's Hydrogen Strategy- Norwegian Ministry Of Petroleum And Energy,2020 (ENERGY, 2020)
- Largescale Hydrogen Production In Norway - Possible Transition Pathways Towards 2050 -Sintef,2020 (SINTEF, 2020)
- Long-Term Perspectives On The Norwegian Economy 2021 - Norwegian Ministry Of Finance,2021 (FINANCE, 2021)
- Hydrogen Applications And Business Models- Going Blue And Green – Kearney, Energy Transition Institute, 2020 (KEARNEY, 2020)
- Low Carbon Hydrogen Business Model: Consultation On A Business Model For Low Carbon Hydrogen – Department For Business, Energy & Industrial Strategy,2021 (DEPARTMENT FOR BUSINESS, 2021)
- The Norwegian Hydrogen Guide – Norwegian Hydrogen Forum, 2023 (Forum, 2023)
- Norway 2022 Energy Policy Review- IEA,2022 (IEA, 2022b)
- Norway's Climate Action Plan for 2021-2030 - Ministry of Climate and Environment,2020 (Environment, 2020)
- Green Hydrogen For Industry – IRENA,2022 (International Renewable Energy Agency, 2022)

Survey Report

Hydrogen

37 responses

Which of the following describes your background the best?

37 out of 37 answered

Academia 14 resp. 37.8%

Student 12 resp. 32.4%

Other 7 resp. 18.9%

Business 4 resp. 10.8%

Which of the following types of carbon offset projects are you most interested in supporting?

37 out of 37 answered

Green Hydrogen 24 resp. 64.9%

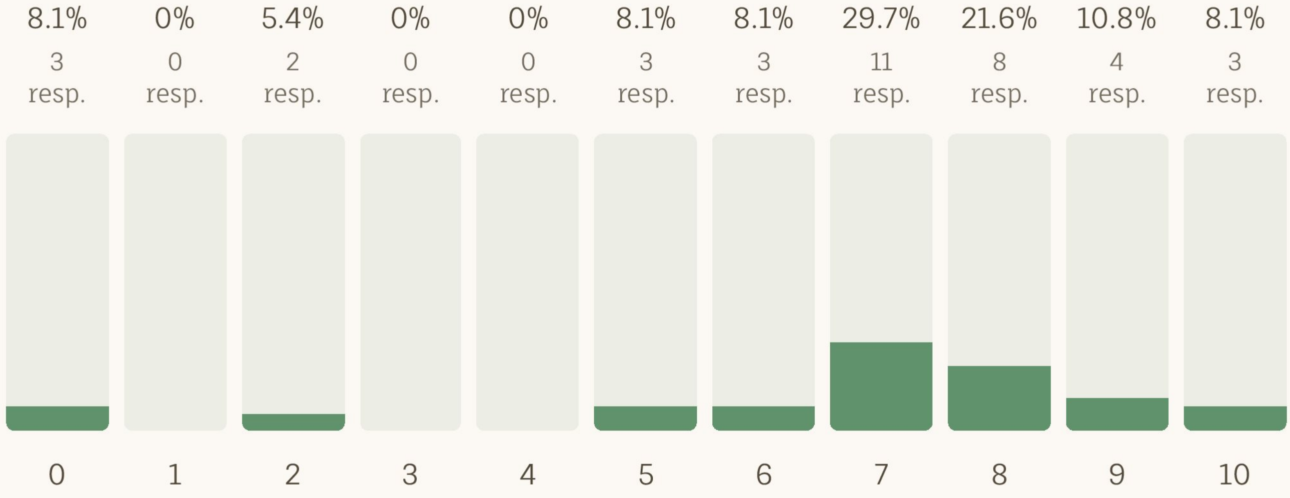
Electrification 17 resp. 45.9%

Carbon capture and storage 15 resp. 40.5%

How enthusiastic do you become when you hear the words "Green Hydrogen" and "Fuel"?

37 out of 37 answered

6.6 Average rating



Do you believe that green hydrogen has the potential to replace traditional fossil fuels in the future?

37 out of 37 answered

Agree 14 resp. 37.8%

Neutral 11 resp. 29.7%

Strongly disagree 6 resp. 16.2%

Strongly agree 4 resp. 10.8%

Disagree 2 resp. 5.4%

Which sector do you think will benefit the most from the use of green hydrogen?

35 out of 37 answered

Transportation (cars, trucks, buses, etc.) 22 resp. 62.9%

Industry (manufacturing, agriculture, etc.) 18 resp. 51.4%

Energy (power generation, heating, etc.) 13 resp. 37.1%

Other (Please specify) 1 resp. 2.9%

What is your opinion on the current state of the Green Hydrogen Market?

37 out of 37 answered

Slow Progress 17 resp. 45.9%

Uncertain future 10 resp. 27%

Rapid growth — 8 resp. — 21.6%

Limited Potential — 2 resp. — 5.4%

Do you think that green hydrogen will be a viable fuel source for transportation (including shipping and aviation) and industry in Norway?

36 out of 37 answered

Yes — 20 resp. — 55.6%

Too early — 11 resp. — 30.6%

No — 5 resp. — 13.9%

Are regulatory initiatives in place to promote the utilization of green hydrogen in Norway, in your opinion?

37 out of 37 answered

I'm not sure — 19 resp. — 51.4%

No — 12 resp. — 32.4%

Yes 6 resp. 16.2%

In the long run, is it possible for green hydrogen to surpass blue hydrogen (hydrogen produced from fossil fuels with carbon capture) in terms of viability?

37 out of 37 answered

Yes 17 resp. 45.9%

Too early to say 16 resp. 43.2%

No 4 resp. 10.8%

What do you think is the biggest challenge to widespread adoption of green hydrogen technology?

37 out of 37 answered

Lack of infrastructure for storage and transport 20 resp. 54.1%

High production costs 18 resp. 48.6%

Technical difficulties in producing green hydrogen at scale 14 resp. 37.8%

Competition from other clean energy sources 9 resp. 24.3%

Other 5 resp. 13.5%

In your opinion, what are the major advantages of using green hydrogen as a fuel source?

37 out of 37 answered

Reduced carbon emissions 29 resp. 78.4%

Reduced reliance on fossil fuels 22 resp. 59.5%

Increased energy security 7 resp. 18.9%

Increased energy efficiency 4 resp. 10.8%

Other 1 resp. 2.7%

What actions do you think individuals and businesses can take to promote the adoption of green hydrogen as a fuel source?

37 out of 37 answered

Invest in green hydrogen technologies 13 resp. 35.1%

Educate themselves and others about the benefits of green hydrogen 12 resp. 32.4%

Pressure governments and companies to adopt green hydrogen 10 resp. 27%

Other 2 resp. 5.4%

Bibliography

Anthony Wang, D. M., Jaro Jens. (2021). *Analysing future demand, supply, and transport of hydrogen* (Report). https://gasforclimate2050.eu/wp-content/uploads/2021/06/EHB_Analysing-the-future-demand-supply-and-transport-of-hydrogen_June-2021.pdf

Cebon, D. (2022). Hydrogen for heating. https://h2sciencecoalition.com/blog/hydrogen-for-heating-a-comparison-with-heat-pumps-part-1/

CMS-Law.Tax.Future. (2023). Hydrogen law, regulations strategy in norway. https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/norway

DEPARTMENT FOR BUSINESS, E. I. S. (2021). Low carbon hydrogen business model: Consultation on a business model for low carbon hydrogen. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011469/Consultation_on_a_business_model_for_low_carbon_hydrogen.pdf

DNV. (2022). *Energy transition norway 2022-a national forecast to 2050* (Report). https://www.norskindustri.no/siteassets/dokumenter/rapporter-og-brosjyrer/energy-transition-norway/2022/energy-transition-norway-2022_web.pdf

Ebi, K. L., Vanos, J., Baldwin, J. W., Bell, J. E., Hondula, D. M., Errett, N. A., Hayes, K., Reid, C. E., Saha, S., Spector, J., & Berry, P. (2021). Extreme weather and climate change: Population health and health system implications [doi: 10.1146/annurev-publhealth-012420-105026]. *Annual Review of Public Health*, *42*(1), 293–315. https://doi.org/10.1146/annurev-publhealth-012420-105026

ENERGY, N. M. O. P. A. (2020). *The norwegian government's hydrogen strategy - towards a low emission society* (Report). https://www.regjeringen.no/contentassets/8ffd54808d7e42e8bce81340 hydrogenstrategien-engelsk.pdf

Environment, N. M. o. C. a. (2020). *Norway's climate action plan for 2021-2030* (Report). https://www.regjeringen.no/contentassets/a78ecf5ad2344fa5ae4a394412ef8975/en-gb/pdfs/stm202020210013000engpdfs.pdf

Europe, H. (2021). *How hydrogen can help decarbonise the maritime sector* (Report). https://hydrogeneurope.eu/wp-content/uploads/2021/11/How-hydrogen-can-help-decarbonise-the-maritime-sector_final.pdf

Experts, S.-H. (2022). Fuel cells vs. batteries – how will truck fleets decarbonise. https://synerhy.com/en/2022/03/fuel-cells-vs-batteries-how-will-truck-fleets-decarbonise/

FINANCE, N. M. O. (2021). *Long-term perspectives on the norwegian economy 2021* (Report). https://www.regjeringen.no/contentassets/91bdfca9231d45408e8107a703fee790/en-gb/pdfs/stm202020210014000engpdfs.pdf

Forum, N. H. (2023). *The norwegian hydrogen guide* (Report). https://www.hydrogen.no/files/documents/nhf-hydrogenguiden2023.pdf

Frankowska, M., Mańkowska, M., Rabe, M., Rzeczycki, A., & Szaruga, E. (2022). Structural model of power grid stabilization in the green hydrogen supply chain system—conceptual assumptions. *Energies*, *15*(2), 664. https://www.mdpi.com/1996-1073/15/2/664

Frankowska, M., Rzeczycki, A., Sowa, M., & Drożdż, W. (2023). Functional model of power grid stabilization in the green hydrogen supply chain system—conceptual assumptions. *Energies*, *16*(1), 154. https://www.mdpi.com/1996-1073/16/1/154

Gartner. (2019). The framework for ideal customer profile development. https://www.gartner.com/en/articles/the-framework-for-ideal-customer-profile-development

IEA. (2021). Research gaps towards hydrogen commercialization. https://iea.blob.core.windows.net/assets/787357a0-ce67-4c03-aa99-d4018aa67698/20211124-IEA-EGRD_JBermudez.pdf

IEA. (2022a). *Executive summary* (Report). https://www.iea.org/reports/norway-2022/executive-summary

IEA. (2022b). *Norway 2022-energy policy review* (Report). https://iea.blob.core.windows.net/assets/de28c6a6-8240-41d9-9082-a5dd65d9f3eb/NORWAY2022.pdf

International Renewable Energy Agency, A. D. (2022). *Green hydrogen for industry: A guide to policy making,* (Report). https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Mar/IRENA_Green_Hydrogen_Industry_2022_.pdf?rev=720f138dbfc44e30a2224l

IPCC. (2019). *Global warming of 1.5°c* (Report). https://www.ipcc.ch/site/assets/uploads/sites/2/2022/06/SR15_Summary_Volume_HR.pdf

IRENA. (2021). *A pathway to decarbonise the shipping sector by 2050* (Report). https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_Decarbonising_Shipping_2021.pdf

KEARNEY, E. T. I. (2020). *Hydrogen applications and business models- going blue and green?* (Report). https://www.kearney.com/documents/17779499/18269679/Hydrogen+applications+and+business+models_single_page.pdf/c72700b3-e66a-6338-82bb-46ca8031e86d?t=1594994670000

Klesty, V. (2023). Tesla in pole position in norway's race to ev goal. https://www.reuters.com/business/autos-transportation/hitting-record-electric-cars-sales-norway-near-80-2022-2023-01-02/

Larscheid, P., Lück, L., & Moser, A. (2018). Potential of new business models for grid integrated water electrolysis. *Renewable Energy*, *125*, 599–608. https://doi.org/https://doi.org/10.1016/j.renene.2018.02.074

Liu, J., Hertel, T. W., Diffenbaugh, N. S., Delgado, M. S., & Ashfaq, M. (2015). Future property damage from flooding: Sensitivities to economy and climate change. *Climatic Change*, *132*(4), 741–749. https://doi.org/10.1007/s10584-015-1478-z

Massaro, M. C., Biga, R., Kolisnichenko, A., Marocco, P., Monteverde, A. H. A., & Santarelli, M. (2023). Potential and technical challenges of on-board hydrogen storage technologies coupled with fuel cell systems for aircraft electrification. *Journal of Power Sources*, *555*, 232397. https://doi.org/https://doi.org/10.1016/j.jpowsour.2022.232397

McLeod, S. (2021). Feasibility studies for novel and complex projects: Principles synthesised through an integrative review. *Project Leadership and Society*, *2*, 100022. https://doi.org/https://doi.org/10.1016/j.plas.2021.100022

Memon, M. (2022). 8 ways to identify your ideal customer profile: Qualify better b2b leads [from the experts]. https://referralrock.com/blog/identify-your-ideal-customer-profile-b2b-experts/

Mikkel Skjoldager, T. B. V., Andrea Skjold Frøshaug. (2021). *Green transition-an analysis of trends, future directions and potential missions to address societal challenges in norway* (Report). https://www.forskningsradet.no/siteassets/om-forskningsradet/foresight-report-green-transition.pdf

Mukherjee, M., & Roy, S. (2017). Feasibility studies and important aspect of project management. *INTERNATIONAL JOURNAL OF ADVANCED ENGINEERING AND MANAGEMENT*, *2*, 98. https://doi.org/10.24999/IJOAEM/02040025

Norouzi, N. (2021). Assessment of technological path of hydrogen energy industry development: A review. *Iranian (Iranica) Journal of Energy & Environment*, *12*(4), 273–284. https://doi.org/10.5829/ijee.2021.12.04.01

OG21. (2020). External factor analysis report. https://www.og21.no/contentassets/f826df43db324d79b148a14 omgivelsesanalyse-2020_endelig-02-07-2020.pdf

Reigstad, G. A., Roussanaly, S., Straus, J., Anantharaman, R., de Kler, R., Akhurst, M., Sunny, N., Goldthorpe, W., Avignon, L., Pearce, J., Flamme, S., Guidati, G., Panos, E., & Bauer, C. (2022). Moving toward the low-carbon hydrogen economy: Experiences and key learnings from national case studies. *Advances in Applied Energy*, *8*, 100108. https://doi.org/https://doi.org/10.1016/j.adapen.2022.100108

Rosenow, J., Gibb, D., Nowak, T., & Lowes, R. (2022). Heating up the global heat pump market. *Nature Energy*, *7*(10), 901–904. https://doi.org/10.1038/s41560-022-01104-8

Schoenung, S. M. (2011, August 1). *Economic analysis of large-scale hydrogen storage for renewable utility applications* (Report). https://doi.org/10.2172/1029796

Schrotenboer, A. H., Veenstra, A. A. T., uit het Broek, M. A. J., & Ursavas, E. (2022). A green hydrogen energy system: Optimal control strategies for integrated hydrogen storage and power generation with wind energy. *Renewable and Sustainable Energy Reviews*, *168*, 112744. https://doi.org/https://doi.org/10.1016/j.rser.2022.112744

Shin, J.-E. (2022). Hydrogen technology development and policy status by value chain in south korea. https://doi.org/10.3390/en15238983

SINTEF. (2020). *Largescale hydrogen production in norway - possible transition pathways towards 2050* (Report). https://ife.brage.unit.no/ife-xmlui/bitstream/handle/11250/2650236/Final%2breport%2b2020-00179.pdf?sequence=2&isAllowed=y

Söderholm, P. (2020). The green economy transition: The challenges of technological change for sustainability. *Sustainable Earth*, *3*(1), 6. https://doi.org/10.1186/s42055-020-00029-y

Store, F. C. (2020). The use of hydrogen as an energy storage system. https://www.fuelcellstore.com/blog-section/use-of-hydrogen-as-an-energy-storage-system

Sugatri, R. I., Wirasadewa, Y. C., Saputro, K. E., Muslih, E. Y., Ikono, R., & Nasir, M. (2018). Recycled carbon black from waste of tire industry: Thermal study. *Microsystem Technologies*, *24*(1), 749–755. https://doi.org/10.1007/s00542-017-3397-6

Union, E. (2020). *Hydrogen-powered aviation:a fact-based study of hydrogen technology, economics, and climate impact by 2050* (Report). https://www.euractiv.com/wp-content/uploads/sites/2/2020/06/20200507_Hydrogen-Powered-Aviation-report_FINAL-web-ID-8706035.pdf

van der Spek, M., Banet, C., Bauer, C., Gabrielli, P., Goldthorpe, W., Mazzotti, M., Munkejord, S. T., Røkke, N. A., Shah, N., Sunny, N., Sutter, D., Trusler, J. M., & Gazzani, M. (2022). Perspective on the hydrogen economy as a pathway to reach net-zero co2 emissions in europe. *Energy & Environmental Science*, *15*(3), 1034–1077. https://doi.org/10.1039/D1EE02118D

Volkswagen. (2020). The efficiency of pure battery-electric vehicles is much higher. https://www.volkswagen-newsroom.com/en/stories/the-efficiency-of-pure-battery-electric-vehicles-is-much-higher-frank-welsch-5545

Xu, D., Liu, Z., Shan, R., Weng, H., & Zhang, H. (2023). How a grid company could enter the hydrogen industry through a new business model: A case study in china. https://doi.org/10.3390/su15054417