A service design to enhance regional hydrogen market through increasing social participation

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Design For Interaction

Executive Summary

This project explores the integration of hydrogen within the Dutch energy system, using the gigamapping method to define hydrogen's role in energy transition across key sectors such as transportation, heating, industry, and power. Recognizing hydrogen as a green energy carrier, the Dutch government prioritizes its development to replace natural gas for deep decarbonization. However, the growing trend of electrification may pose challenges to hydrogen's wider application. Research into the hydrogen supply chain and national energy strategies revealed that the Dutch government and businesses prioritize green hydrogen, aligning the hydrogen economy with sustainable development goals.

The project's investigation highlighted hydrogen's current applications in industrial heating, refueling stations, fuel cell electric vehicles (FCEVs), and space heating. However, expert interviews identified significant challenges, including insufficient legislation, infrastructure, and green hydrogen supply. While the FCEV market for passenger vehicles appears limited, industry efforts are now focused on heavy-duty and long-haul transportation.

Through systemic design approaches, including Causal Loop Diagrams (CLD) and Three Horizons workshop, the project identified three leverage points and generated four intervention ideas. The final design direction focuses on a service enabling households to convert excess solar electricity into hydrogen, contributing to grid congestion management and promoting hydrogen use.

Prototype testing of the "Particles" app showed positive feedback, with users expressing openness to the concept. However, improvements were needed, such as automating the conversion process, providing clearer instructions, and offering financial incentives. After iteration, the app allows users to choose subscription plans based on electricity generation, adjust supply timings, and use hydrogen points for a variety of energy services, with enhanced information clarity and user experience.

Special Thanks

I want to give my special thanks to my mentor, Mahshid, and my chair, Sine. Your support made me able to complete this project. This project can not be completed without your guidance. Your patience gave me enough space to keep working during my hard time. I also want to thank other participants who were involved in this project, thanks for your time to help me finish the project.

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Chapter 1

Introduction

With the signing of the Paris Agreement on climate change, the vision of sustainable development has become a shared value globally. The European Union is the backbone to push the trend of sustainable development in multiple areas, such as innovations, politics and technology. Energy transition toward a cleaner energy system is one of the crucial factors in decarbonization and development of a sustainable economy(EU Strategy on Energy System Integration, n.d.). With the 2030 goal to reduce 55% of greenhouse gas, it raises the priority to accelerate the process of energy transition. Thus, developing a global hydrogen market is urgent under the international energy inertia of climate action and pressure on energy security(NWP, n.d). The Netherlands is able and willing to play a critical role in the global hydrogen market with the country's large-scale rollout of offshore renewable energy.

The current Dutch hydrogen market heavily relies on industry usage and grey hydrogen. In 2020, 8400 PJ of hydrogen were produced annually all over the world, and 74% were used for industrial purposes. The electrolysis hydrogen only took about 2% of the total hydrogen production(IEA,2019). The distribution of hydrogen use is similar in the Netherlands(Detz, et al., 2020). But, the energy consumption of industry in the Netherlands is only 24.1% of total energy consumption(IEA, 2024).

The development of hydrogen market in other energy sectors only takes a minor percentage of hydrogen consumption. The Dutch hydrogen strategy aims to have a 500MW green hydrogen electrolysis capacity in 2025. However, this number was only 3MW in 2021 according to IPHE(2024), and recently announced a 998 million

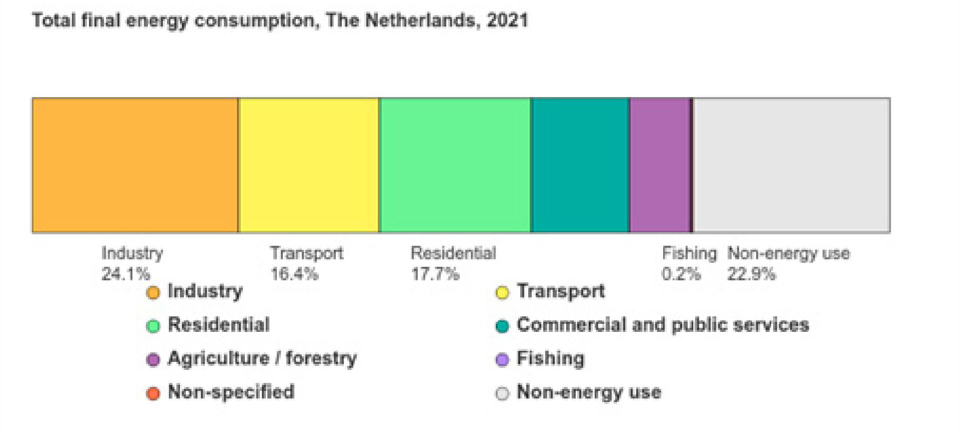


Image 1.1 Total final energy consumption in the Netherlands(IEA, 2024)

euros scheme to enlarge 200MW electrolysis capacity in the Netherlands. But, the goal of having 500MW green hydrogen capacity still have not yet been approached with about one and half year left. From these perspective, the ambition of using Green hydrogen to achieve energy transition still has a long way to go.

1.1 Research objectives & research questions

This study sees opportunities in the current scenario of the Dutch energy system and the ultimate goal is to generate a design intervention that is able to foster the development hydrogen market in other energy sectors. The research objectives refer to these points, (1) reviewing the current scenarios of the Dutch energy system as well as its hydrogen development strategy. (2) identifying the barriers and opportunities of hydrogen application in other energy sectors. (3) identifying the intervention method & impact(in what context).

The following research questions regarding these research objectives can be defined as:

Main research questions:

How to design a system intervention to facilitate the development of hydrogen market during Dutch energy transition?

Sub-research question 1: What hydrogen strategies have the Netherlands implemented to facilitate its energy transition?

Sub-research question 2: What are the barriers and opportunities that have been encountered and foreseen in the Dutch energy scenario and how do they invoke the intervention space?

Sub-research question 3: What specific energy scenarios that the system intervention occur in?

Sub-research question 4: How does the design intervention impact the system?

1.2 Project Approach

The project approach(image 1.2) follows the classic double-diamond diagram which consists of two main parts. The first part focuses on establishing an understanding regarding the Dutch hydrogen strategy in the Dutch energy context and defining opportunities and barriers that will be addressed by this project. The second part focuses on defining the design context and design goal, sequentially, creating a design intervention, and validating its impact on the system.

This master thesis consists of 8 chapters. In the first part, the notion of Dutch energy transition and review the hydrogen development strategy under the context of energy transition will be provided in Chapter 2. Chapter 3 will first discuss the barriers and opportunities identified from the results of expert interviews. Then, using them to reveal the intervention space under the system dynamic. Chapter 4 decides which intervention method will be used to generate design intervention.

In the second part, the specific energy scenario of design intervention will be defined in Chapter 5. Chapter 6 and Chapter 7 will focus on conceptualizing the design and explain how the design intervention can positively impact the system. The master thesis will be concluded and discussed in Chapter 8.

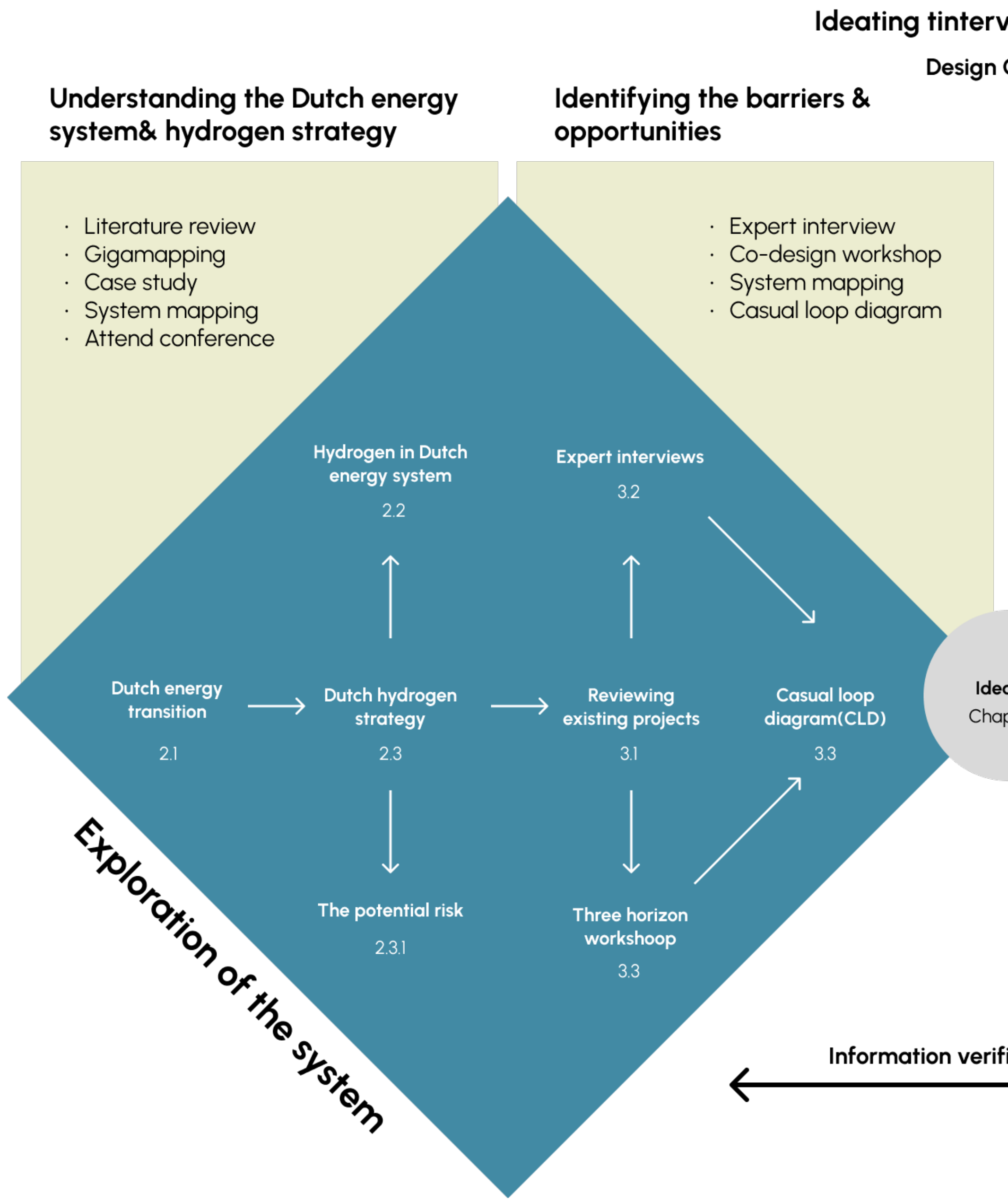
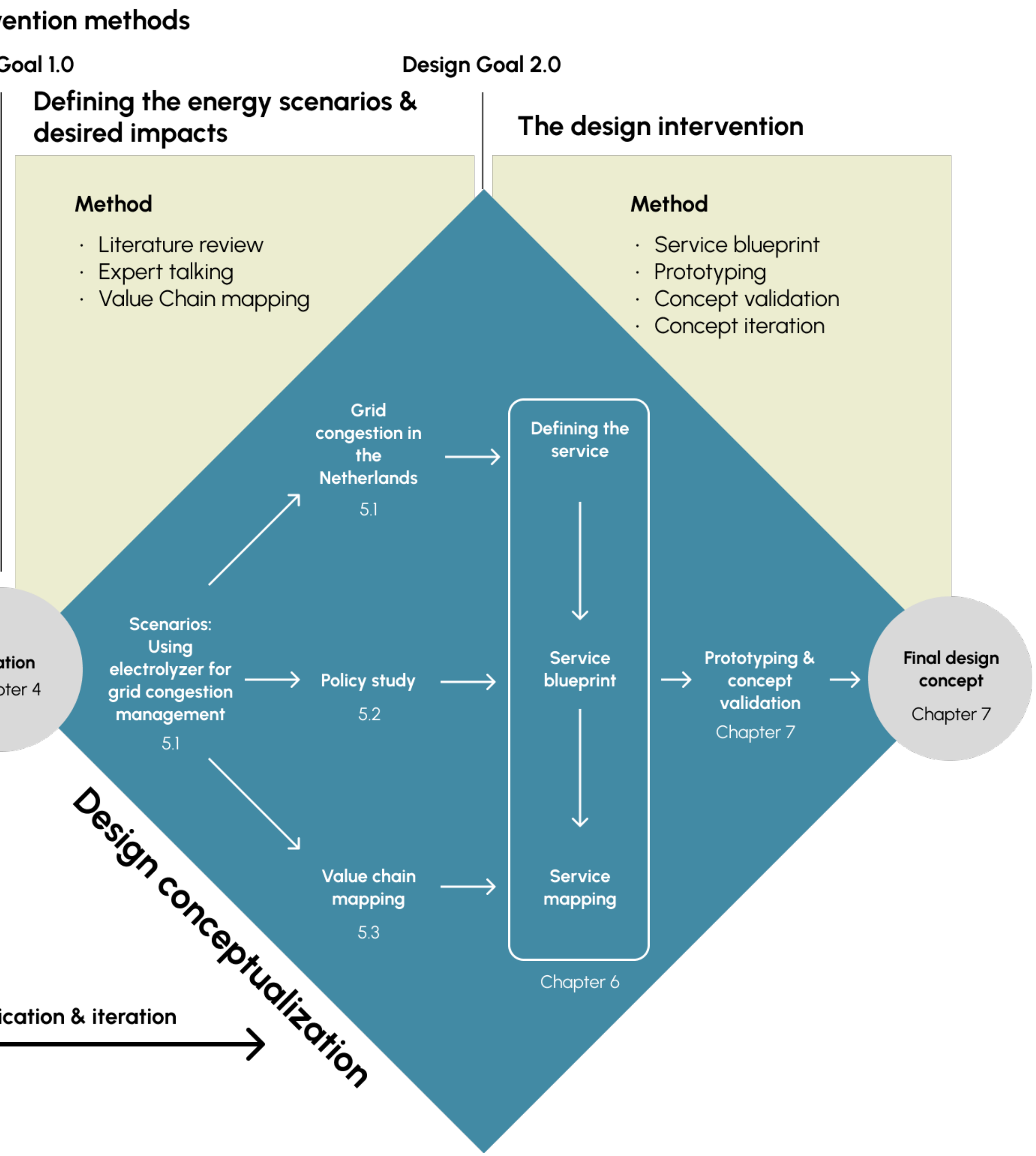


Image 1.2 Project appr



oach of this thesis

Chapter 2

Understanding Dutch energy system & hydrogen strategy

The research began with a broad context, which is extensive and complex. It can turn into endless research of the existing system. Thus, the Gigamapping method is applied in the early research phase to formulate a starting point of exploration and a way of storytelling.

Gigamapping is a system mapping technique often used in the research phase of system-oriented design. It contains seemingly separate, extensive information across multiple layers and scales, and the goal is to identify their relations. This technique allows the designer to frame the boundary of research and investigation to the system(Sevaldson, 2022). Gigamapping helps designers grasp the complexity of the system and move from descriptive to generative(Sevaldson, 2018). Those features of Gigamapping make it a valuable technique to conduct design research without losing the focus of the study. The use of Gigamapping aims to answer research question 1 'What hydrogen strategies have the Netherlands implemented for its energy transition?'. Thus, the storytelling will centered around two major components in the question, the Dutch energy transition and the Dutch hydrogen strategies under the context of energy transition.

This section will first introduce the broader context of hydrogen energy application within the framework of the Netherlands' energy transition strategy. Next, it will discuss the role that hydrogen energy plays in the Dutch energy transition and provide an overview of relevant technical details. Finally, the development plans for hydrogen energy will be reviewed and highlighting the risks faced by the hydrogen economy in the context of energy transition.

2.1 Dutch energy transition

2.1.1 Energy sectors

Dutch government set up a goal to realize carbon neutrality at 2050(Ministerie van Algemene Zaken, 2023b). This goal requires the Dutch energy system to achieve a high level of decarbonization and move toward of using sustainable energy resources. Based on the way of energy consumption, the energy system can be categorized into four energy sectors(Transition to Sustainable Energy, 2016), the realization of transition in these energy sectors requires different technology breakthroughs and supports:

1. Industrial Process Heat

Industry requires energy for its production process to generate high temperatures. The high temperature is acquired normally from natural gas. The state-of-art at present does not allow for large-scale energy conservation. But, the industry is actively looking forward of using zero-emission gas or low-emission gas to replace natural gas during the production process. Hydrogen is one of the alternatives to replace the position of natural gas.

2. Transport

Transport by road, rail & air has a very important role in the Dutch economic, but heavily relies on fossil fuels. The current strategy for energy transition in the transport sector follows two paths, electrification and alternative fuels(biofuels or biogeses). Moreover, innovative solutions are still needed to facilitate the large-scale development of alternative fuels.

3. Spacing Heating

Natural gas is a primary energy resource for house heating, water heating, and stoves for cooking. It requires drastically use reduction of natural gas to achieve deep decarbonization and make the energy system more sustainable. According to European agreements, the Member States must ensure that all new buildings are practically energy-neutral by the end of 2020. This pushes building constructor to make their heating system more sustainable, such as using thermal insulation and solar panels. Upgrading old building's heating system is also part of the energy transition strategy by upgrading the local infrastructure or subsidy the installation of sustainable technologies(for example, solar panels and electric boilers).

(4)Power & light

European electricity generation for power and lighting will need to significantly reduce its carbon footprint. This involves making devices and lighting systems more energy-efficient to lower overall electricity demand. The shift toward renewable energy sources such as solar, wind, and hydropower will play a crucial role in this transition. However, because these sources are dependent on weather conditions and thus intermittent, both energy consumption and generation will need to become more adaptable and flexible to ensure a stable energy supply.

2.1.2 Dutch Energy Transition Strategy

The Dutch energy transition strategy facilitates energy consumption to enhance the efficiency, affordability, reliability, and sustainability of the Dutch energy supply system. Based on this vision, the cabinet has defined three main principles of achieving the vision(Transition to Sustainable Energy, 2016) which are:

Principle 1: Focus on CO2 reduction

This principle emphasizes the cruciality of reducing greenhouse gas emissions. The existing Dutch energy supply system depends on fossil fuels(95%), and the key is to reduce their reliability. This can be approached in various ways, such as building a profitable relationship with other EU members for sustainable energy supply, encouraging the use of alternative green fuels, incentivizing innovations and technologies that reduce emissions, and punishing the pollutive sectors.

Principle 2: Making the most of the economic opportunities

The energy transition should foster the development of the Dutch economy and earning potential. The cabinet wants to enable economic opportunities by developing and implementing innovations and contributing to the global energy transition. The Dutch energy market should maintain its high competence in the future low-emission energy market.

Principle 3: Energy will become an integral part of the public space

The transition process requires the collaboration of all kinds of parties in society from large-scale production to individual initiatives. The involvement of different stakeholders should happen in the early stages when identifying the energy production, transportation and storage. The competent authority should support the relevant initiatives.

2.2 Hydrogen in the energy system

After understanding the energy transition strategy of the Netherlands, it is necessary to further analyze the role of hydrogen energy in this transition. This section will review the contributions of hydrogen energy to the Dutch energy transition and examine related technologies, such as the hydrogen supply chain and production methods

2.2.1 Hydrogen spectrum

Hydrogen can be produced through various methods, each using different feedstorcks and resulting in varying levels of carbon emissions and economic effectiveness. The hydrogen spectrum reflects the relationship between production methods and sustainability. In the Dutch energy system, green hydrogen, blue hydrogen, and gray hydrogen make up the main hydrogen supply chains.

Green hydrogen

Green hydrogen is the most sustainable hydrogen. It is produced through the electrolysis process with water(using electricity to electrolyze water and the result is oxygen and hydrogen). Green hydrogen normally refers to the use of renewable electricity(wind farms and solar farms) or other types of green feedstock, for instance, bio-waste, for steam methane reformation(SMR).

However, the economic effectiveness of green hydrogen varies depending on the local renewable energy resource. For those regions that have rich renewable energy resources, the economic effectiveness can be as competitive as other colors of hydrogen. Therefore, the feasibility of using green hydrogen has a strong regional favorability.

Blue hydrogen

Blue hydrogen refers to hydrogen that is produced from fossil fuels, such as coal and natural gas but with the captured emissions. The common production methods are gasification for coals as feedstock and steam methane reformation for natural gas as feedstock. Although the emissions from the production process were captured but the use of unrenewable feedstocks makes it less sustainable. However, due to the mature production methods and cheap feedstocks, blue hydrogen has a greater economic effectiveness compared with green hydrogen.

Grey hydrogen

Grey hydrogen and blue hydrogen are fundamentally the same, the only difference is that the emissions during the production were not captured. Therefore, grey hydrogen is the least sustainable compared with other colours of hydrogen. However, the mature production methods and no need of additional cost to capture the emissions make grey hydrogen the most economically competitive. The production cost of grey hydrogen is about half of green hydrogen(Mulder et al., 2019b).

2.2.2 Hydrogen Supply Chain

The hydrogen supply chain normally consists of the upper stream, middle stream, and downstream. Image 2.1 elaborates a whole hydrogen supply chain by sectors from upper stream to downstream. Please note that this image demonstrates all the possible methods that can exist in the supply chain. Hydrogen-based projects should optimize their hydrogen supply for cost reduction. In the upper stream of the supply chain where hydrogen is produced(sectors 1 to 3), the production methods determine the color of hydrogen. Hydrogen will be transported to the middle stream(sectors 4 to 6) where hydrogen is stored and reallocated to downstream. Downstream includes hydrogen retailers(such as HRS) and end users,

The hydrogen supply chain is structured in 4 four categories generally, production, transportation, storage and end users. The production of hydrogen has been discussed previously(see 2.2.1). Hydrogen transportation methods can be classified into two categories, transportation through infrastructure(e.g. pipeline) and transportation through vehicles(e.g. trucks or vessels). Hydrogen can be stored in gaseous form or liquid form. Gaseous hydrogen storage is relatively cheap but in a low energy density. Storing liquified hydrogen requires extra energy to maintain its pressure and temperature as well as stronger containers, but the energy density is much greater than gaseous hydrogen. Liquified hydrogen is ideal for long-distance transportation and gaseous hydrogen is more cost-effective for short and middle-distance transportation. The last one is end-users who consume hydrogen or retail hydrogen. These end users are from the four energy sectors mentioned in 2.1.

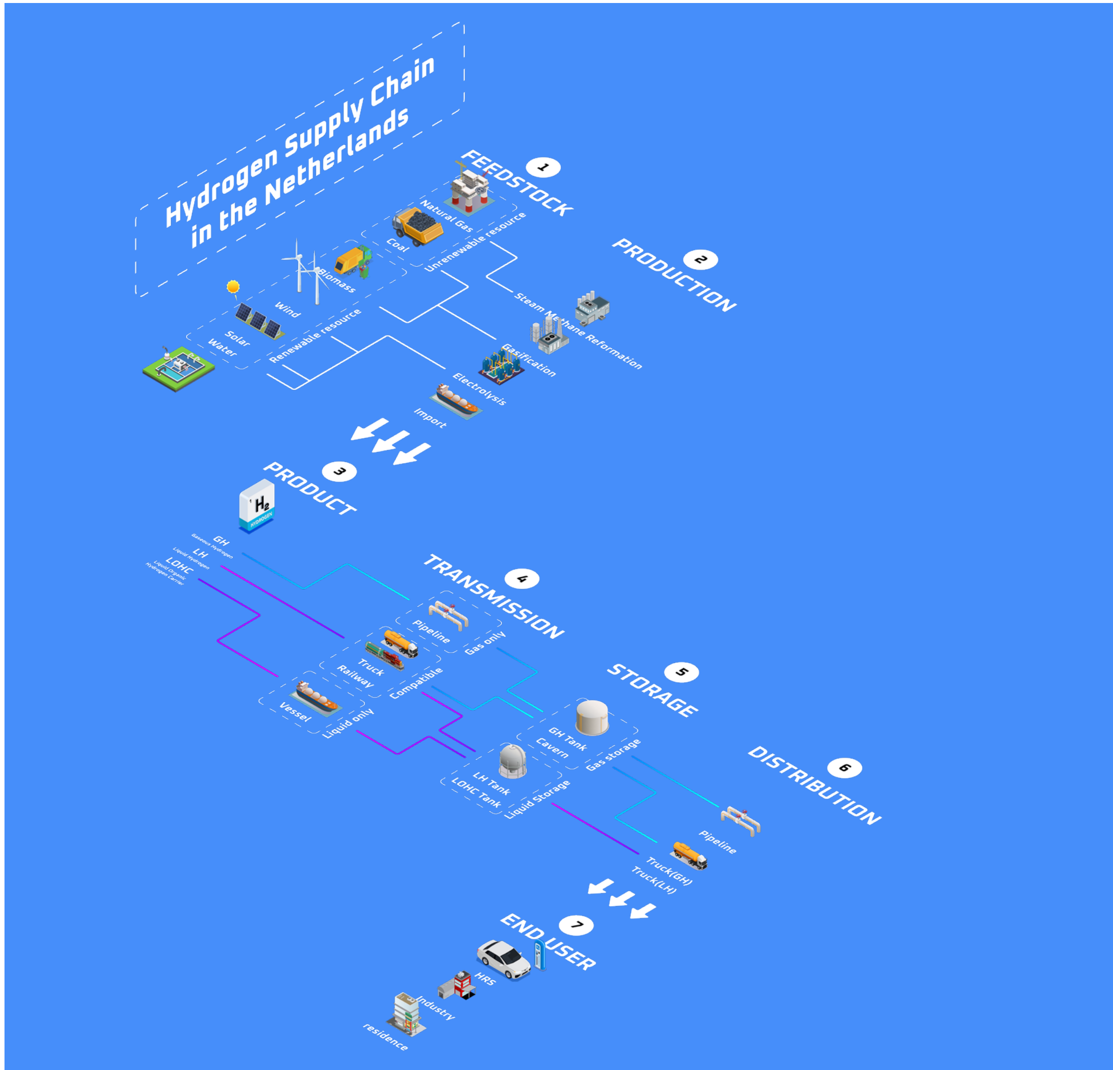


Image 2.1: Hydrogen supply chain in the Netherlands

2.2.3 The Responsibility of Hydrogen

Hydrogen contributes to the Dutch energy system in three aspects. Firstly, hydrogen as a type of green gas, provides a sustainable energy solution for decarbonisation. Secondly, hydrogen as an energy carrier, can contribute to energy integration. Lastly, hydrogen is able to store seasonal energy that facilitates the development of renewable energy in the Netherlands.

Hydrogen for decarbonization

Hydrogen does not emit any greenhouse gas during the usage. The only product from its consumption is water. Thus, hydrogen can significantly contribute to decarbonization in the applied area. According to IEA(2021), the energy sectors mentioned previously contribute to the major carbon emissions(image 2.2).

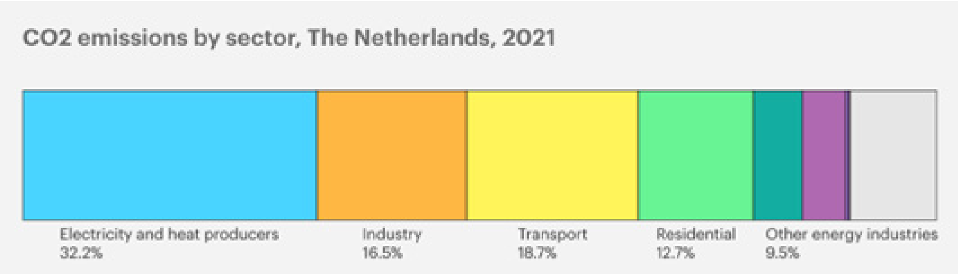


Image 2.2: Carbon emission by sectors(IEA, 2021)

Hydrogen can become alternative energy in both these sectors, for example, hydrogen can be used in power generation to provide flexible electricity to maintain the stability of the grid; The development of fell-cell technology allows vehicles(so-called, FCEV) to fuel hydrogen as a power resource with a longer drive range and short refueling time compare with battery electric vehicles; The industry can use hydrogen to replace natural gas for high-temperature generation; and in the residential domain, hydrogen boilers can use hydrogen boiler to heat up the house. Image 2.3 concludes the major application of hydrogen in different energy sectors.

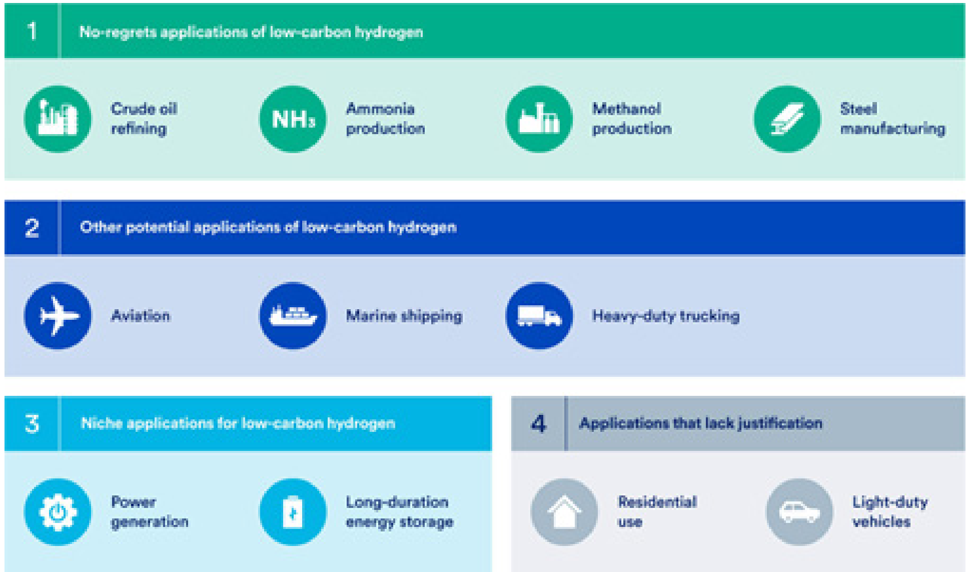


Image 2.3: Hydrogen enabling decarbonisation in areas(Virone, 2024)

Hydrogen for energy integration

The European Commission(n.d) proposed the strategy for energy system integration as a part of energy transition process. In this proposal, there will be linkages between different sectors with the various energy carriers. The energy furnish will no longer be providing specific types of energy for particular sectors but being converted to energy carriers flowing through different segments(see Image 2.4). Hydrogen as a energy carrier, is able to carrier energy from differen energy resource and extensive application enable it to connect interfaces between different sectors. Energy system integration will allow evaluation and optimisation of the energy system as a whole rather than examining the efficiency gains in each different sector separately. Expanding the interfaces between energy sectors is the key.

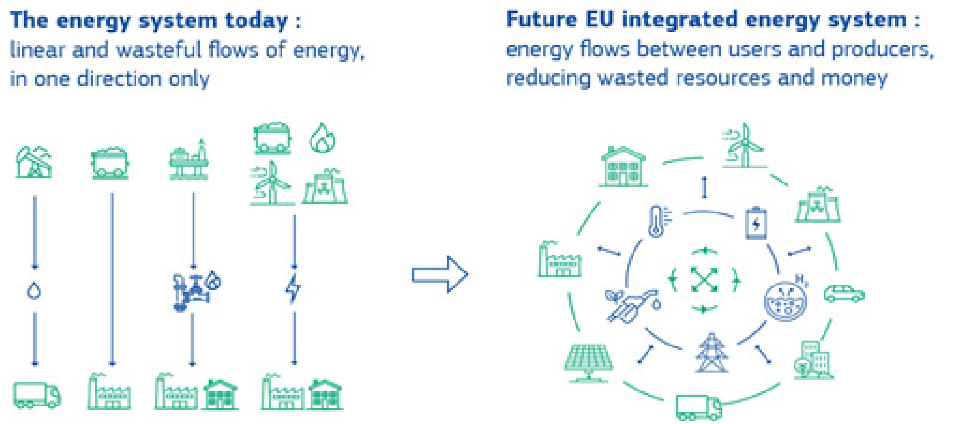


Image 2.4: EU energy integration vision(EU Strategy on Energy System Integration, n.d.)

Hydrogen to store seasonal energy

The Dutch government will increase the share of renewable electricity in the energy system, and hydrogen can cooperate with this strategy by providing solutions for energy storage. The production of green hydrogen will be linked with offshore wind energy to store renewable energy and reduce the congestion of the electric grid(Government Strategy on Hydrogen, n.d). The electrolyzer for green hydrogen production will cope with the off-shore wind farm program located on the North Sea for centralized production(Image 2.5). Meanwhile, electrolysis hydrogen production fosters the development of decentralized renewable energy production for the regions that have rich renewable energy resources.. Due to the unpredictability of production, the generated electricity needs to be consumed immediately; otherwise, it will be wasted. Hydrogen can be produced through the electrolysis process which provides a feasible solution for storage and transportation.

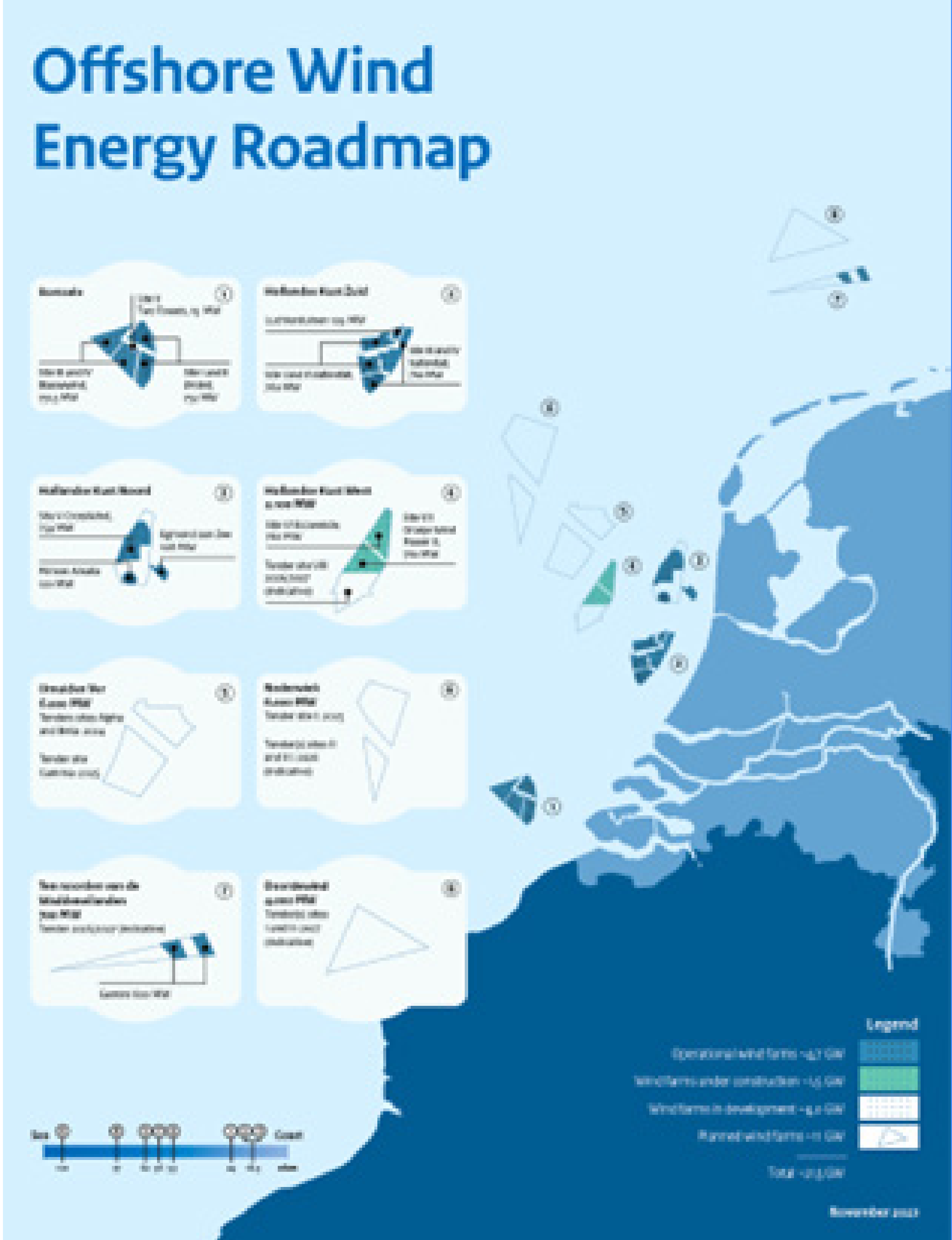


Image 2.5: Dutch offshore wind energy roadmap(Netherlands Enterprise Agency, 2021)

2.3 The Dutch Hydrogen Strategy

The Dutch hydrogen strategy is structured around four key pillars which are: (1) Legislation and Regulation. (2) Cost reduction and scaling up green hydrogen (3) Sustainability of final consumption (4) Supporting and Flanking Policy. These four key pillars aim to develop a comprehensive hydrogen economy(Ghaemi et al., 2023):

Legislation and Regulation

This pillar focuses on establishing the legal framework necessary for hydrogen infrastructure and market development. It highlights the potential for repurposing parts of the existing natural gas grid for hydrogen transport. This approach leverages existing infrastructure to reduce costs and accelerate the deployment of hydrogen networks. The government, alongside national and regional network operators, such as Gasunie and TenneT, will assess the feasibility and conditions for using these gas networks for hydrogen distribution. Coordination between the electricity grid and the future hydrogen network is essential for efficient energy management. The government, through the Main Energy Infrastructure Programme, will work with industrial clusters to determine optimal locations for electrolysers and necessary infrastructure. This ensures the integration of hydrogen into the broader energy strategy, particularly in synergy with offshore wind energy.

Cost Reduction and Scaling Up Green Hydrogen

To make hydrogen a competitive energy source, the strategy emphasizes reducing production costs and scaling up green hydrogen production. The Dutch government aims to significantly increase green hydrogen production capacity from the current levels to 500 MW by 2025 and 3-4 GW by 2030. This scaling up will involve developing large electrolysis plants and integrating hydrogen production with offshore wind energy projects, leveraging the Netherlands' existing infrastructure and expertise in renewable energy. A major focus is on reducing the cost of producing green hydrogen through technological advancements and economies of scale. The strategy anticipates a 50-60% cost reduction over the next decade, making green hydrogen competitive with fossil-based hydrogen (gray and blue hydrogen).

The strategy also emphasizes the integration of hydrogen production with offshore wind energy projects. By converting electricity from offshore wind farms into hydrogen, the Netherlands can reduce grid congestion, lower the costs of landing renewable energy, and create a flexible, scalable energy carrier that complements the country's renewable energy ambitions.

Sustainability of Final Consumption

This pillar aims to promote the use of zero-carbon hydrogen across various sectors, including industry, transportation, and the built environment. Green hydrogen is positioned as a key solution for achieving zero-emission targets in the transport sector, especially for heavy-duty vehicles, public transport, and maritime applications. The strategy outlines ambitious goals, including 50 hydrogen refueling stations, 15,000 fuel cell vehicles, and 3,000 heavy-duty vehicles by 2025. It also envisions 300,000 fuel cell vehicles by 2030, supported by subsidies and cooperation agreements with stakeholders in the transport industry. Hydrogen is also seen as a potential solution for decarbonizing the heating of buildings, particularly in areas where electrification is not feasible or cost-effective. The strategy includes plans for pilot projects in the built environment to test hydrogen's viability for heating and its integration with other renewable energy sources like hybrid heat pumps and heat grids.

Supporting and Flanking Policy

The final pillar involves creating a supportive policy environment to facilitate the hydrogen economy. This includes international cooperation, particularly within Europe, to align standards, regulations, and market incentives. The strategy also emphasizes regional policy development to foster local hydrogen clusters and support research and innovation to advance hydrogen technologies.

2.3.1 The risk of hydrogen economy under the context of energy transition

Mulder et al. (2019b) illustrate four scenarios(Table 2.1) based on two dimensions. The x-axis is the stringency of EU/NL climate policy; the representative is the carbon tax enterprises have to pay for their emissions. The y-axis is the tightness of the international market of natural gas which represents the price of natural gas.

These two dimensions formulate four future scenarios in which different types of energy are mainstream in the energy system and where the economy is based. The Dutch authority has a strong tendency to establish radical(above the EU average) climate policies to reduce carbon emissions by raising the carbon levy(Ministerie van Algemene Zaken, 2024b). Thus, the Green economy and the Blue hydrogen economy are most likely the future development trends.

In the Green Economy, high natural gas prices and carbon tax will foster investment in the use of green energy which result in a low electricity price. Electricity will become the mainstream energy for space heating and transport due to the low electricity prices. The application of hydrogen concentrates on the industry for replacing natural gas and other energy sectors will be dominate by electricity.

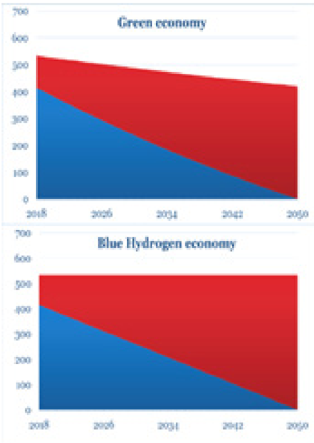
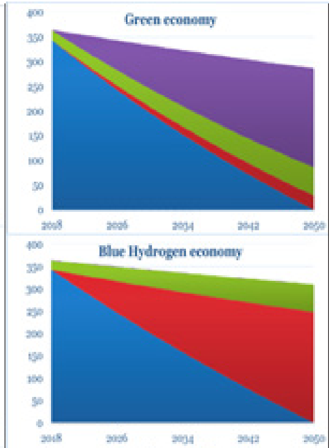
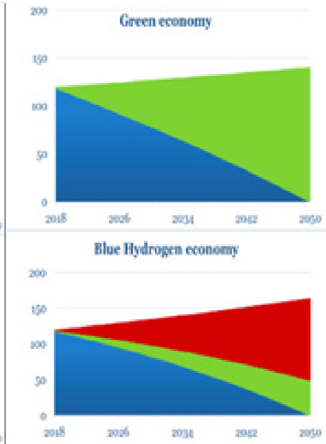
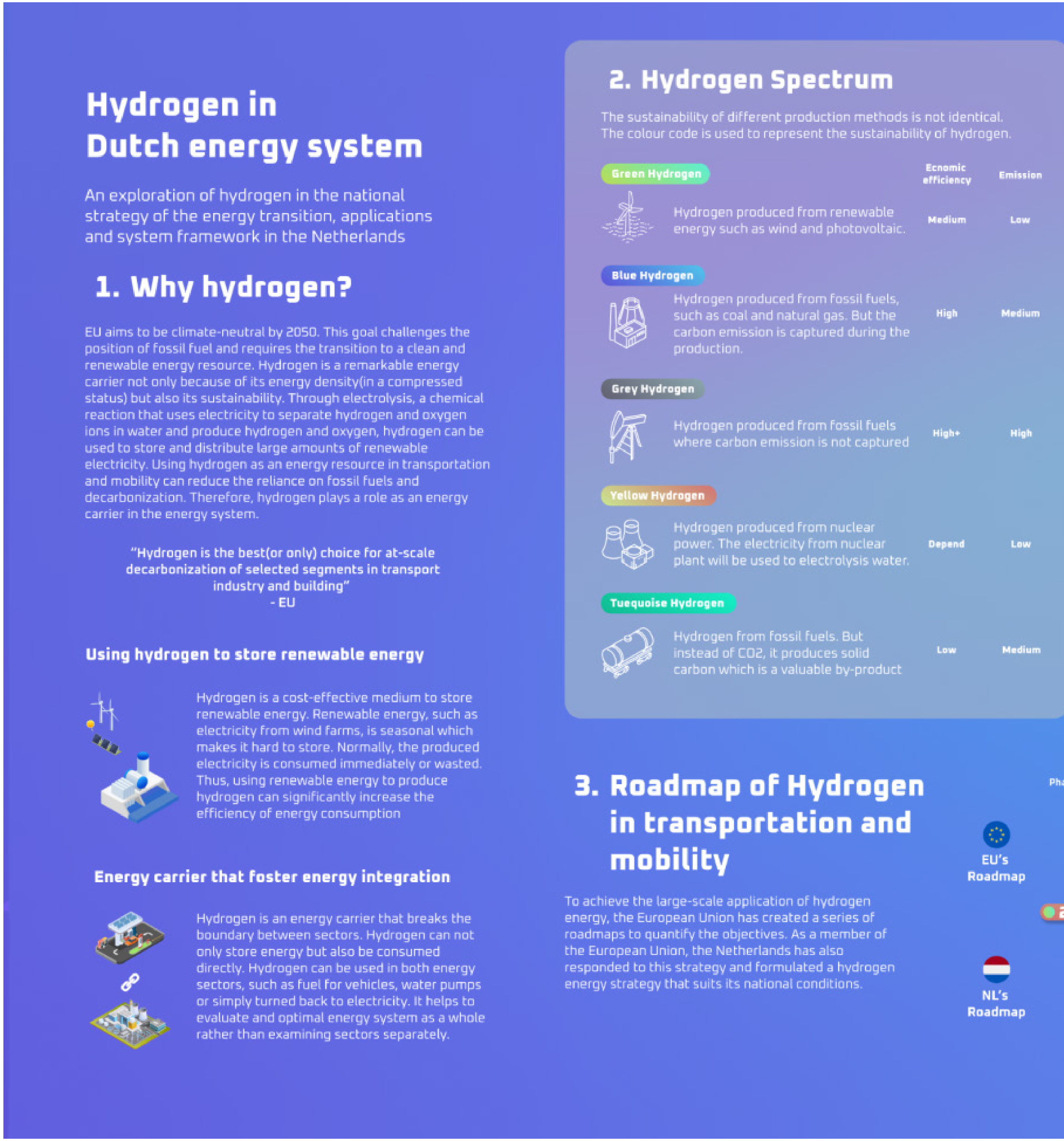
		
Red - Hydrogen Blue - Natural gas	Red - Hydrogen Blue - Natural gas Purple - Electrification Green - District heat	Red - Hydrogen Blue - Natural gas Green - Electricity
Use of natural gas and hydrogen in the industry, per scenario, 2018-2050	Energy use for heating by households per type of energy carrier, per scenario, 2018-2050	Energy use in road transport, measured in distance covered by various types of cars, per scenario, 2018-2050

Table 2.1: Energy use in different social context by energy types(Mulder et al., 2019)

In the Blue Hydrogen economy scenario, the high carbon tax also fosters investment in renewable energy, but the energy system will be a combination of renewable energy farms and gas-fired power planets due to the low natural gas price. Therefore, green hydrogen lost its favourability, and using natural gas to produce hydrogen is more cost-effective in this case. Blue hydrogen will become the mainstream energy for both sectors due to its competitive price. Therefore, there will be a greater hydrogen market in both sectors.

Conclusion & Gigamap

The chapter inspects the hydrogen strategy under the context of the Dutch energy transition. Dutch government has created an ambitious roadmap for developing a hydrogen economy. In the strategy vision, hydrogen has an irreplaceable role in achieving deep decarbonization in different energy sectors and fostering the development of renewable energy. Hydrogen should be an energy carrier that is able to store energy and be used in different energy sectors instead of becoming an energy resource. However, hydrogen and electricity are competitors in some energy scenarios, such as transport. In the future Dutch energy scenarios where the society will rely on green electricity, hydrogen may have the risk of losing the market in some energy sectors due to the low electricity price. These research outcomes are concluded in the form of Gigmap which will be used for the next design activities for the purpose of proofing research outcomes with experts and matching the knowledge level regarding hydrogen with the participants of design activities.



4. Dutch hydrogen strategy

Economic first

The energy transition should foster the development of the Dutch economy and earning potential. The cabinet wants to enable economic opportunities by developing and implementing innovations and contributing to the global energy transition. The Dutch energy market should maintain its high competence in the future low-emission energy market.

Investing hydrogen infrastructure

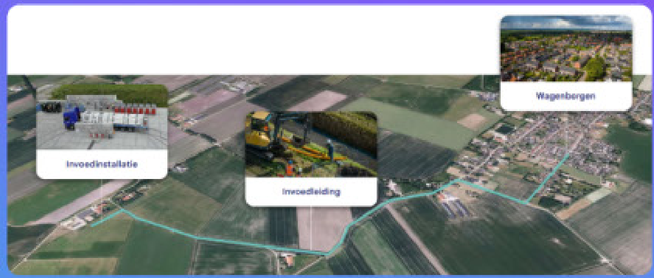
The energy transition should foster the development of the Dutch economy and earning potential. The cabinet wants to enable economic opportunities by developing and implementing innovations and contributing to the global energy transition. The Dutch energy market should maintain its high competence in the future low-emission energy market.

Green hydrogen is favourable

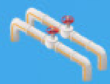
The energy transition should foster the development of the Dutch economy and earning potential. The cabinet wants to enable economic opportunities by developing and implementing innovations and contributing to the global energy transition. The Dutch energy market should maintain its high competence in the future low-emission energy market.

5. Pioneer projects

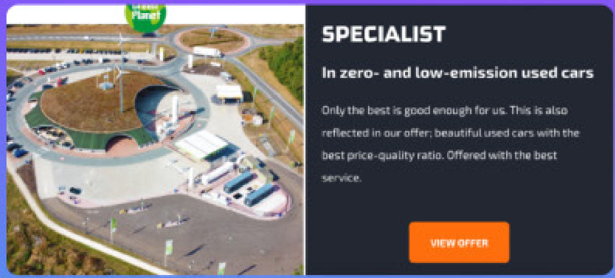
Project Wagenborgen



Project Wagenborgen replaces the existing natural gas network at a 1970s residential area located at Wagenborgen with hydrogen for house heating to make the community more sustainable. Due to the aging infrastructure and urban planning, the community can not afford full electrification. Thus, hydrogen is selected to replace natural gas. The natural gas heat pump in the house is replaced by a hydrogen heat pump. The natural gas pipeline is reused for hydrogen distribution.

Main customer	Hydrogen delivered by	Hydrogen type
		
Householders	Pipeline	Green hydrogen

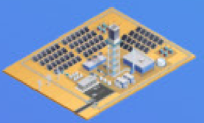
Green Planet - energy hub for mobility



Green Planet is an energy hub that offers numerous types of fuel for mobility and extra services such as restaurants, meeting rooms, and car rentals for a better customer experience. Green Planet integrates hydrogen as part of its product line. Hydrogen is served in 350 bar for heavy-duty vehicles and 700 bar for passenger vehicles. It also provides services that are relevant to mobility and drivers. These services include restaurants for drivers, meeting room rentals, second-hand car retail, and truck rentals.

Main customer	Hydrogen delivered by	Hydrogen type
		
Mobilities	Truck	Green hydrogen

ase 1: Investment in infrastructure



Investment in FC(fuel cell) development, hydrogen industries and projects. Construct **200 HRS**(hydrogen refuelling station) in Europe in 2023 and **more than 750 HRS** in 2025. Build **6GW of renewable hydrogen** electrolysers, **1 million tons of renewable hydrogen**.

Phase 2: Enlarge the market

By 2030, 1/22 of passenger cars and 1/12 of light commercial vehicles are expected to be Fuel Cell Electric Vehicles (FCEVs), amounting to **3.7 million passenger cars and 500,000 light commercial vehicles**. Additionally, there will be **4,500 FC trucks and buses**, with **570** diesel trains being replaced by fuel cell trains. In the region where renewable electricity is cheap, electrolysers are expected to be able to **compare with fossil-based hydrogen**.

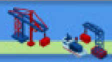
Phase 3: Energy transition

2250 terawatt hours of hydrogen production(ambitiously) which can fill **42 million large cars, 1.7 million trucks, a quarter million buses and 5500 trains.**

2020 — **2025** — **2030** — **2050**

Import:

First imports of hydrogen as ammonia



Development of large-scale imports

Large scale imports, the Netherlands become a part of the EU market.

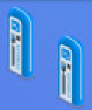
Production:

600 MW electrolysis capacity

80 PJ hydrogen production

Complete renewable offshore hydrogen production

Application:



50 HRS and corresponding FCEV. Finalization of the policy framework for the hydrogen market.

Before 2025

A national network of hydrogen filling stations for different mobilities. **15 - 58 PJ hydrogen** for all transportation.

Before 2030

Hydrogen is a **fully-fledged option** for road transportation and fossil-free flights.

Before 2050

Chapter 3

Identifying the inter-vention spaces

This section focuses on identifying the barriers that negatively impact the development of the hydrogen market and the opportunities foreseen. First, two hydrogen-based projects will be reviewed and analyzed to understand how such projects are implemented under the Dutch hydrogen strategy to grasp the mechanism behind the project execution. This study will serve as probes to identify critical actors within the system. Then, by interviewing these critical actors, expert perspectives on the barriers and opportunities within the system can be formulated. However, those results only reflect the point of view from certain perspectives which lack comprehensivity. Through a Three Horizon workshop, the previous research and interview results will be used as input to generate the intervention space that can involve multi-stakeholders' interests and use Casual Loop Diagram to visualise the internal dynamic of the identified intervention spaces.

3.1 Reviewing existing hydrogen project

3.1.1 Project Wagenborgen - Hydrogen for space heating(Waterstofwijk Wagenborgen, 2024b)

Project Wagenborgen replaces the existing natural gas network at a 1970s residential area located at Wagenborgen with hydrogen for house heating to make the community more sustainable. Due to the aging infrastructure and urban planning, the community can not afford full electrification. Thus, hydrogen is selected to replace natural gas. The natural gas heat pump in the house is replaced by a hydrogen heat pump. The natural gas pipeline is reused for hydrogen distribution.

Image 3.1 Project Wagenborgen(Waterstofwijk Wagenboren, 2024b)

Supply chain & actor

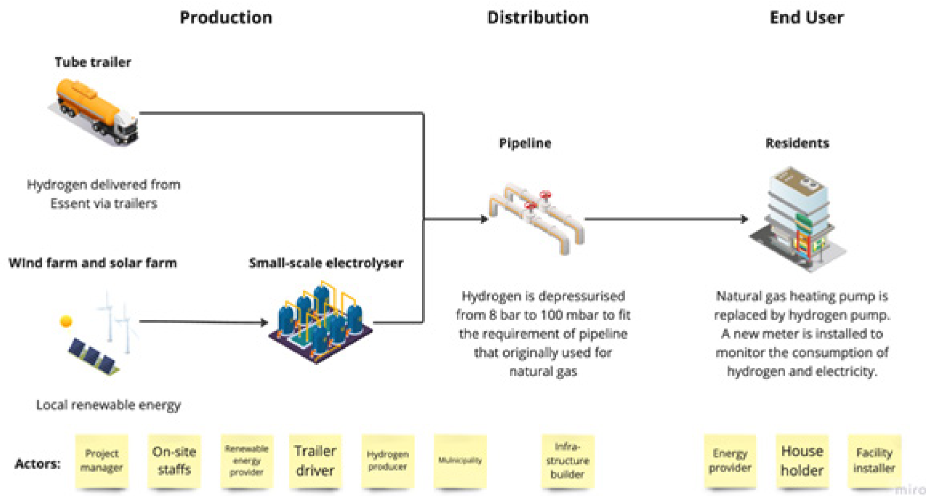


Image 3.2: Supply chain & involved actors in project Wagenborgen

The production of hydrogen combines self-produced hydrogen and buying hydrogen from the hydrogen producer delivered by tube trailers. Hydrogen will be depressurized from 200 bar to 8 bar and fed into the pipeline on the site after necessary processes(e.g., add odor agent). The pipeline was used for natural gas transportation and is now used for hydrogen. The residential building has been upgraded to fit the new system. A hydrogen heat pump replaced the natural gas pump and a new meter is installed to monitor the consumption of hydrogen and electricity. Relevant actors in different sectors are identified.

3.1.2 Green Planet - energy hub for mobility

Green Planet is an energy hub that offers numerous types of fuel for mobility and extra services such as restaurants, meeting rooms, and car rentals for a better customer experience. Green Planet integrates hydrogen as part of its product line. Hydrogen is served in 350 bar for heavy-duty vehicles and 700 bar for passenger vehicles. It also provides services that are relevant to mobility and drivers. These services include restaurants for drivers, meeting room rentals, second-hand car retail, and truck rentals. Green Planet is also a part of and subsidized by HEAVENN programme(H2 Energy Applications in Valley Environments for Northern Netherlands). HEAVENN aims to build an entire green hydrogen supply chain from production to local end-user of hydrogen in the Northern Netherlands.

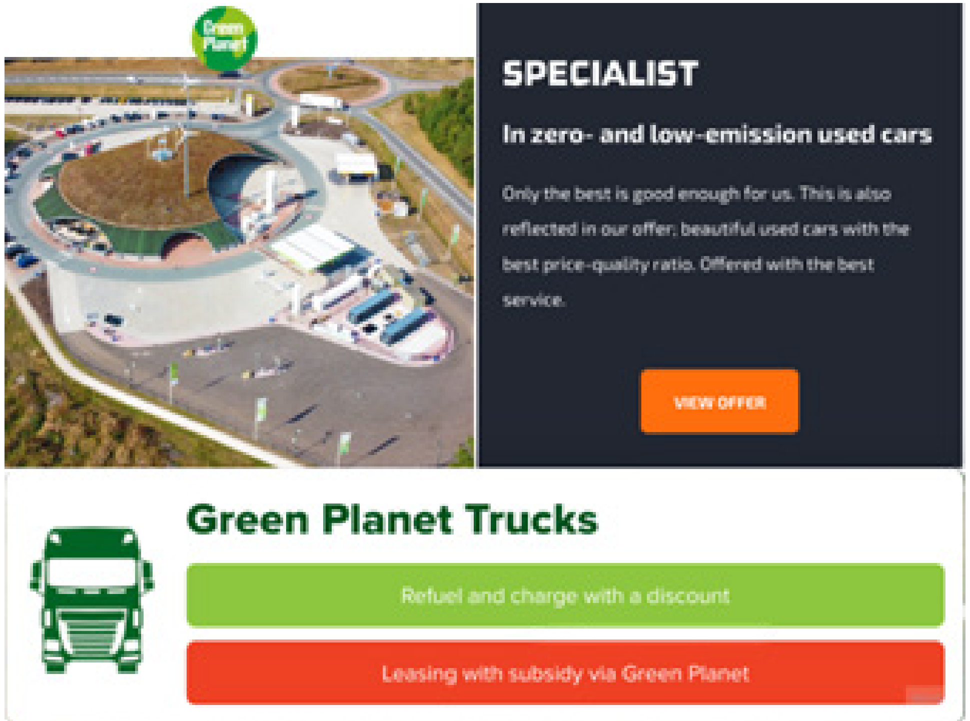


Image 3.3: Services provided by Green Planet(Multifuel Tankstation Green Planet in Pesse: Best of Both Worlds, 2023)

3.1.2 Green Planet - energy hub for mobilityGreen

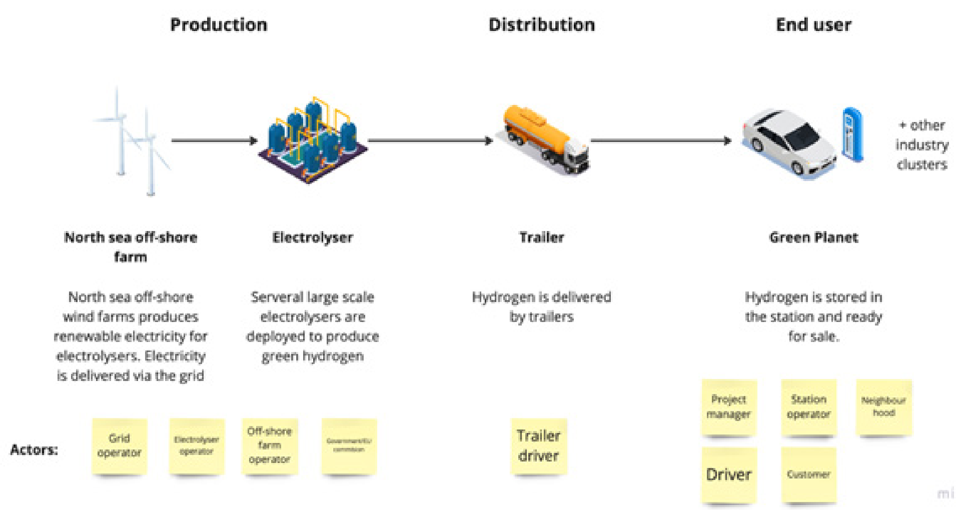


Image 3.4: Hydrogen supply chain of Green Planet

Planet is an energy hub that offers numerous types of fuel for mobility and extra services such as restaurants, meeting rooms, and car rentals for a better customer experience. Green Planet integrates hydrogen as part of its product line. Hydrogen is served in 350 bar for heavy-duty vehicles and 700 bar for passenger vehicles. It also provides services that are relevant to mobility and drivers. These services include restaurants for drivers, meeting room rentals, second-hand car retail, and truck rentals. Green Planet is also a part of and subsidized by HEAVENN programme(H2 Energy Applications in Valley Environments for Northern Netherlands). HEAVENN aims to build an entire green hydrogen supply chain from production to local end-user of hydrogen in the Northern Netherlands.

3.1.3 Discussion of project reviews

From those two case studies, a system map() of Dutch hydrogen supplies was created. There are few insights that can be concluded:

Flexibility of hydrogen

These two projects use distinctive hydrogen supply chains which reflect the flexibility of the hydrogen supply chain. Green Plane chooses to purchase hydrogen from large production and Project Wagenborgen utilizes the local renewable energy resource to produce hydrogen. This flexibility allows hydrogen can adapt to different kinds of business models or energy scenarios.

High initial investment

Integrating hydrogen in the business case requires a high initial investment which may exclude small business owners. The initial investment in these two example projects can be imaginably high, for Project Wagenborgen, a hydrogen supply station was built that requires maintenance and operation. Green Planet has to purchase hydrogen dispensers and storage containers only for providing hydrogen in the station, The effort of integrating in their product line could be considerably higher than other types of fuels. Thus, these high initial investments might exclude the participation of small or middle businesses, especially with an uncertain return(aka, high risk).

Low impact on energy integration

The ability of energy integration is not well reflected in these projects. In the last chapter, one of the features of applying hydrogen to the energy system is the ability to foster energy integration. However, the use of hydrogen is still limited within the domain of the project and does not connect to other energy sectors or energy interfaces which is quite a pity.

Critical actors

Different actors represent different positions within the supply chain. The energy provider represents the upstream part of the supply chain, directly producing or importing hydrogen and selling it to the downstream. HRS managers, Site operators, and the government represent the downstream part of the supply chain, with extensive experience in integrating resources to provide solutions to consumers. Householders or FCEV owners represent the consumers who can point out whether the existing solutions meet their needs.They both play an irreplaceable role in the system and their values align with the system values which facilitates the application of hydrogen. Empathy with critical actors can help to discover barriers and opportunities in the system on the next.

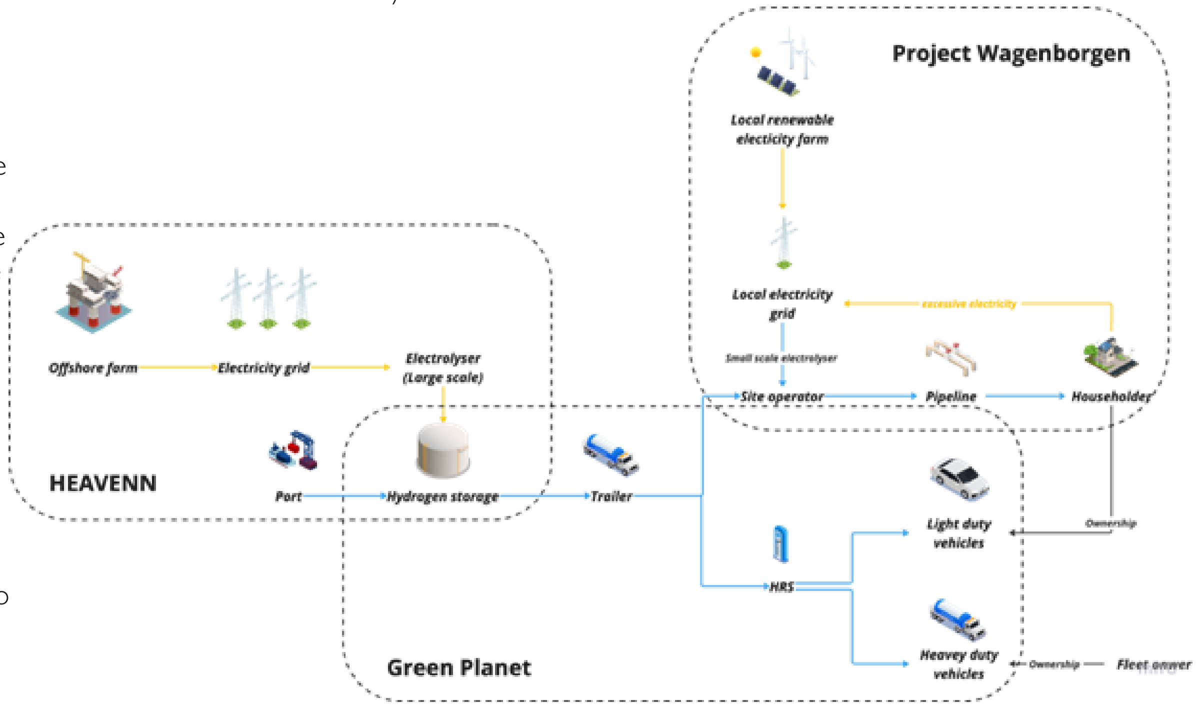


Image 3.5

3.2 Interview Critical Actors

Desktop research provides a holistic understanding of the system. It is time to zoom in on the internal relationships between different actors by conducting expert interviews with the actors in the system. Critical actors were identified in the last chapter which prioritizes who should be interviewed from numerous actors in the system.

3.2.1 Method

The method of theory-generating expert interviews was used for conducting interviews. This is a qualitative research method to refine existing theories and develop new theoretical insights based on the knowledge and perspectives of experts in the system(Döringer, 2020). In the project, this interview method is useful to prove the previous research result and gain an in-depth understanding of intricate issues through the lens of those critical actors.

Interview goal

- Validate the research findings, discuss the findings with the participants and collect feedback
- Formulate a sense of tensions between actors within the system in reality
- Empathy with participants, and discover the deeper mechanisms behind their action/commercial decisions.
- Gain a comprehensive understanding of existing issues, underlying mechanisms and contextual factors.

Participant recruitment

The goal is to interview eight experts and two participants each for one critical actor group. However, due to the limitation of time, reaching that much participants is inviable. Finally, only four participants participated in the interviews and were not able to find participants who represented householders. One participant does not belong to the critical actor but is still directly relevant to the research topic and capable of providing useful insight for quantitive analysis. The characteristics of participants are given on table 3.1:

Participant No	Domain	Expert background	Role of actor
1	Fueling station business	Technical manager at the company(fuel station business), also responsible for building new fuel stations within Europe	HRS manager
2	Fueling station business	Project manager of the company's hydrogen project(hydrogen in the fuel station), mainly focuses on the work that outside of display.	HRS manager
3	Province Zuid Holland	Responsible for public tendering and implementation of public transport concessions, also been involved in a deployment of zero-emission buses	Government
4	Hydromotion Team at TU Delft	Responsible for partnerships and acquisition. Exposure department in promotion of own story	FCEV developer

Table 3.1: Participants list

Process

The interview structure is semi-structured and involves open-ended questions with the flexibility to explore emerging themes in depth. A list of probing questions was provided to interviewees in advance. The interview process will not strictly follow the order of questions, but provide a flow of topic. The probing questions are used to delve deeper into interviewees' expert knowledge and reveal the underlying issue from their perspective. The probing questions cover these domains: 1) enterprise/organisation values. 2) strategies related to hydrogen 3)current barriers and future vision regarding hydrogen.

The gigamap was shared and discussed during the interviews and they are encouraged to point out any information they think is incorrect. The goal of doing this is to prove the previous research result and create a common understanding of the discussed topic.

3.2.2 Data process

The records of interview were transcribed and reviewed. After that, a combination of deductive coding and inductive coding methods is used to process the data. The first round of the data process uses deductive coding. This method can preliminarily categorize data according to different themes based on the interview goals. Content related to the theme will be marked in different colours. The codebook that includes five themes based on interview gaols was developed to determine the theme. These notions are:

Action - current business/project strategy cope with hydrogen

Barrier - factors they encountered that have a negative impact on the business or project

Opportunities - factors that may positively impact the project now or in the future

Wish/demand - factors that can positively impact their project at the current stage

Mission/goal - The social value they bear

The second and third rounds of the data process use inductive coding which is useful to capture and generate narratives. This is the ground-up approach that does not create preconceived notions of what the narrative should be but discovers narratives or notions from the data. The data was filtered and categorised into themes by deductive coding. The first round of data process focuses on emerging narratives under the different themes from the individual perspectives of experts. The third round of data process reviewed all captured narratives. These narratives were re-categorised based on their theme. In the end, new narratives from a system's perspective were generated.

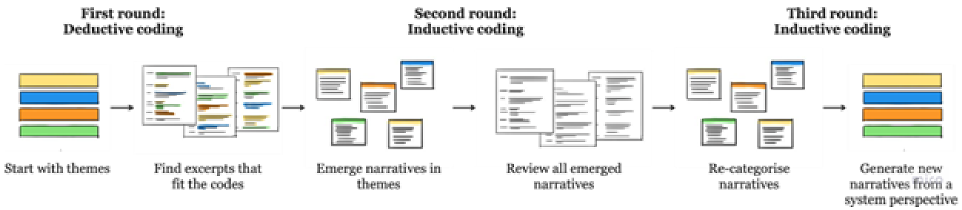


Image 3.6 analysis method for the interview data

3.2.3 Result/Discovered narratives

Recognition of the Advantages of Hydrogen in Applications

Participants 1, 2, and 4 recognize the advantages of hydrogen in applications, noting that hydrogen can offer better performance while reducing carbon emissions. For example, hydrogen can provide greater driving range and shorter refueling times compared to batteries, which can significantly cut costs for the maritime and transportation industries. Additionally, more hydrogen vehicles can alleviate pressure on the electrical grid, as the current prevalence of battery electric vehicles is causing power shortages, especially when they charge simultaneously. Participant 3 maintains a neutral stance towards hydrogen. In the hydrogen bus project he is involved in, the primary factor for using hydrogen buses is local policy favorability for hydrogen, while the longer range and shorter refueling time offered by hydrogen are secondary considerations.

'The distance that we can do, we would have to have like three times the size of our boats, if we wanted to do it on battery.'

- FCEV Developer

Because of network congestion problems with the grid, too much too much electricity is asked from the from the grid.

- HRS Manager

Lack of Infrastructure & Legislation

Participants 1, 2, and 4 criticized the government's sluggish efforts in legislating and promoting infrastructure related to hydrogen. For instance, providing hydrogen at refueling stations still requires going through cumbersome procedures and facing stringent regulations, which severely hinders their project progress. Participant 4 noted that this is due to government officials' lack of recognition and their instinctive belief that hydrogen is a dangerous energy source. In summary, they all expressed that the government's efforts to promote the hydrogen economy are insufficient. To achieve large-scale hydrogen application, the government needs to invest more in infrastructure, such as the construction of hydrogen pipelines and relevant legislation. offered by hydrogen are secondary considerations.

> *we don't need trucks, we need to get it in the pipeline. In Holland, in the Netherlands, we have a gas network everywhere in the Netherlands. So we don't have to, don't have to transport it by the expensive truck anymore*
>
> *- HRS Manager*
>
> *BWell, what we encounter every year regarding hydrogen is that you're not allowed, or we are not allowed at least to transport hydrogen without it being attached to a motor*
>
> *- FCEV Developer*

Low profitability due to insufficient demand & expensive hydrogen

Participants 1 and 2, though in the same industry, use entirely different supply chains. Participant 1 stated that they collaborate with local energy providers to produce green hydrogen, covering almost all production costs themselves, such as electricity and electrolyzer expenses. They chose this model to better control the company's assets. On the other hand, Participant 2's company opts to purchase green hydrogen from suppliers and store it at their stations to reduce costs. Both participants acknowledged that even when selling at near-cost prices, hydrogen is currently too expensive for consumers, not to mention the difficulty of refueling due to the lack of widespread hydrogen stations. All participants agreed that it is challenging to achieve profitability at this stage, relying heavily on government subsidies for sustenance. Expanding the production scale of green hydrogen to lower its price could effectively address this issue. When asked why they do not use the cheaper blue hydrogen, they stated that it contradicts their corporate values, and they are unwilling to compromise on the sustainability of their products or services.

> *Almost not. Oh my goodness, we have we have to do the conversion cost ... It's not really profitable today because not a lot of cars are are refilling with a fueling with with hydrogen. It's expensive. The market is not lapping big, not big no, it's really small.*
>
> *- HRS manager*

Insufficient hydrogen demand as well as green hydrogen

Currently, almost all hydrogen projects are conducted under government subsidies. The insufficient demand for hydrogen has led to a market downturn. Even when hydrogen is available at refueling stations, there isn't enough sales volume. Participant 2 suggested that this might be due to the current lack of widespread adoption of FCEVs. The market downturn has also led to a lack of confidence among companies in the entire hydrogen economy. Participant 1 mentioned that they plan to reduce the scale of hydrogen station expansion and try to diversify and upgrade their business to increase profits and reduce costs. Although Participant 2 remains optimistic about the hydrogen economy, they also indicated that they would not expand their scale in the short term. The government is aware of the market downturn for hydrogen, which is why they provide subsidies to keep these projects afloat. Making these projects profitable from this is not within their scope of concern

> *Because there are a couple of hundreds of hydrogen cars in the complete Netherlands, if you build on hydrogen station only without any fossil fuels only on hydrogen, you will get bankrupt.*
>
> *- HRS manager*
>
> *So that means that there is less demand, less hydrogen stations will be built and that also has influence.*
>
> *- Government*

Alignment of values

All participants demonstrated a strong commitment to sustainability, prioritizing it even above profitability in their business plans. For example, participants 1&2 mentioned their desire to showcase the potential of refueling stations in sustainable development. Participant 4 also stated that their project is built on the premise of making the maritime industry more sustainable. These shared values have driven them to adopt more aggressive business strategies. Participant 4 claimed they were the only ones using hydrogen-powered ships in last year's competition and achieved first place. For them, using hydrogen is not the goal but a means to achieve a more sustainable future. These values are shaped by policy pressures and societal norms. Politically, the government is gradually increasing carbon taxes, forcing companies to use cleaner energy. People also expect enterprises to take on more social responsibility, and companies are eager to meet this expectation to gain more market share. These two reasons align different companies with the goal of sustainable development.

> *We only do clean fuels*
>
> *- HRS manager*
>
> *We need hydrogen because we want to say that we have all the fuels you can think of.*
>
> *-HRS manager*
>
> *We need hydrogen because we want to say that we have all the fuels you can think of.*
>
> *- FCEV developer*

Insufficient Collaboration

The lack of experience has led to lower-than-expected collaboration. Organizations lack experience in operating hydrogen-related services and products, resulting in reduced collaboration efficiency, which is often a mutual issue. For example, the government believes its role is limited to regulation and subsidies, while businesses think the government should provide additional resources, such as faster approval processes and broader platforms. Despite having a common shared value, they differ in their approaches to collaboration, leading to lower-than-expected operational efficiency for the entire system. Participant 2 provided an example: due to the absence of communication channels with customers, they cannot predict hydrogen demand accurately, causing hydrogen to be consumed too quickly and failing to meet customer needs at times, while at other times, it is consumed too slowly, leading to inventory build-up.

> *We have problems getting permits from the local governments because they don't. They're not familiar with hydrogen*
>
> *- HRS manager*
>
> *The actually implementation and then the first phase of the Operation show a lot of setbacks because the refueling station from every fuel was made to be off the shelf.*
>
> *-Government*

Lack of social recognition

Multiple interviewees mentioned that lack of social recognition is one of the main barriers they encountered during the execution of the project. People and staff from regulation organizations hold a stereotype that hydrogen is a dangerous energy. This stereotype causes hydrogen-relevant projects to deal with longer and stricter regulations and monitoring. This increases the effort in project execution and decreases the efficiency to push the project.

> *People can sometimes have an idea that hydrogen is dangerous, because they don't really know what it is.*
>
> *- FCEV developer*
>
> *when they went putting the hydrogen inside, they invite all people, all kinds of experts from a former hydrogen world. ... the possibilities of hydrogen and they concluded it's not that dangerous*
>
> *- HRS manager*

Future opportunity of hydrogen in long-haul transportation

Participants expressed that hydrogen is expected to gain favor in the heavy-duty and long-haul transportation markets in the future, and they are adjusting their businesses to align with this trend. For example, Participant 2 mentioned that they are building more hydrogen refueling stations specifically for trucks. Participant 1 also expressed anticipation for the government's plan to implement hydrogen-powered trucks on a large scale by 2028. Participant 4 agreed, stating that showcasing the advantages of hydrogen will attract more investment in the transportation sector and accelerate the construction of infrastructure. However, in the passenger vehicle market, Participants 1 and 2 noted that due to policy reasons and the advancement of BEVs, FCEVs currently cannot compete with BEVs and are unlikely to do so in the future. Therefore, their business focus will gradually shift towards long-haul transportation.

> *we believe that hydrogen, especially for the maritime industry, is a very good option*
>
> *- FCEV developer*
>
> *It's not possible to charge those trucks at all sites in the Netherlands. We don't have the the electricity for that. We need hydrogen for that*
>
> *- HRS manager*

3.3 Identifying intervention space & Exploring the system dynamic

Through interviews, the current difficulties and future vision of hydrogen application from different professional perspectives can be identified. However, these findings often emphasize the interests of a single stakeholder. Design intervention should balance the interests of multi-stakeholders and enhance the value of the entire system. Therefore, it is necessary to integrate existing findings and transfer them to the intervention space that reflects values from the system perspective. These intervention spaces can also reveal the internal system dynamic between different system sectors.

3.3.1 Identifying Intervention Space though Three-horizons methodology

The three-horizons methodology provides a framework to systematically review how entities act in the current system and how the future looks under different circumstances. This approach allows systematically reassessing the barriers encountered by different stakeholders and their expectations for the future. Consequently, transforms the storytelling about insufficiency and the desired future from the angle of individual stakeholders to a system perspective. Thus, it reveals the opportunities where the design intervention can engage.

Set-up

Two participants with design backgrounds are invited to the workshop and formulate a design team to co-create the three horizon mapping(the workshop is online on the Miro platform). The workshop started with 10 minutes of sense-making which the Gigamap and previous research were introduced to participants to align the understanding of context.

The map's(Image 3.7) initial setup consists of three horizons(red, H1; green, H3; grey, H2.) and is divided into 12 themes based on their curvature. These themes are modified from the explanatory video Three Horizon Framework by Doughnut Economics Action Lab(2018) and the book Three Horizons: The Patterning of Hope by Sharpe (2020b). This framework has two dimensions: Dominance and Time. Dominance describes the system's impacts on society; greater dominance means a greater force of impact. The author divided Time into three timescales: Now, Transition, and Future. An added timescale, called Past, was found after the co-create workshop while reviewing the result. This extra timescale justifies the action of the current system and provides clues for its development direction. This set of timescales describes a process of change, what is happening in the system, what changes the system will encounter, and how the system will be in the future.

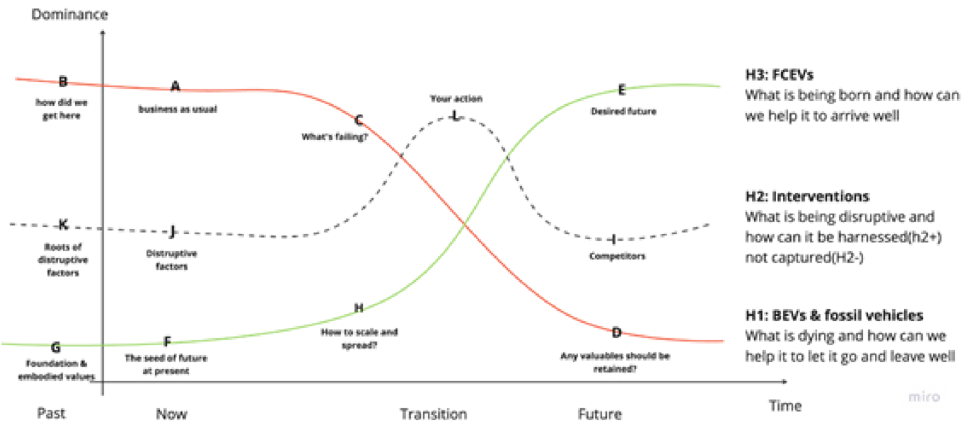


Image 3.7: Three horizon workshop sheet

The main workshop theme was primarily focused on the transport sector(discussion on the development of Fell-cell vehicles and hydrogen refueling stations) since the interviewees are mainly from this energy sector and enabled more in-depth discussion. But they are welcome to extend the discussions to other energy sectors that have relevance. 12 sub-themes were assigned corresponding to its position in the diagram(based on their dominance and time), these sub-themes refers Table 3.2. Participants will discuss in alphabetical order. They will first be encouraged to write their ideas on Post-it notes and explain the origins of their thoughts to the other participants. New ideas will be generated during the discussion and then displayed for further discussion, which constitutes the process for a single session.

H1	H2	H3
A: Business as usual What are the key characteristics of BEV and its infrastructures in the social context? Why is it prevailing?	E: Desired future How does the future look and feel with FCEV's existence? What are the key characteristics that will make this future desirable?	I: Competitors Are there any competing visions? Can we collaborate with them, or are they inherently competitors?
B: How did we get here? How do those key characteristics originate? What values, laws, technologies etc, are embodied?	F: The seed of future at present Are there any seeds of those key characteristics that are visible at present? Giving examples.	J: Disruptive factors What is being disruptive to H1? (Cultural, technological, political, etc.)
C: What's failing? What makes the BEV system fail? Why do we believe it does not fit the purpose of society? How fast will it collapse?	G: Foundation & embodied values Whose work are these possibilities built upon? What values, cultures and laws are embodied?	K: Roots of disruptive factors How did they originate? Would they be captured(H2-) or harnessed(H2+)?
D: Any valuables? Is there anything valuable to retain? This can include aspects such as values, laws, infrastructures, etc.	H: Scale and spread How can those seeds be cultivated? How can they be spread and scaled? Give examples of actors who have already worked on that.	L: Your action If you were the disruptive actors, how would you disrupt H1 and harness H3? Consider different factors such as political, technological, design, service, etc.

Image 3.2: Three horizon themes

Method

In the Three Horizons workshop, we analyzed the current state, transition, and future of BEVs and FCEVs, and described their development in the previous chapter, completing an exploration and definition of the system. By further categorizing and analyzing the post-its generated by participants, we can understand the multifaceted impacts of hydrogen applications in the transportation industry. Given the inclusion of different timelines, we can infer both the current state and the anticipated future of hydrogen energy applications.

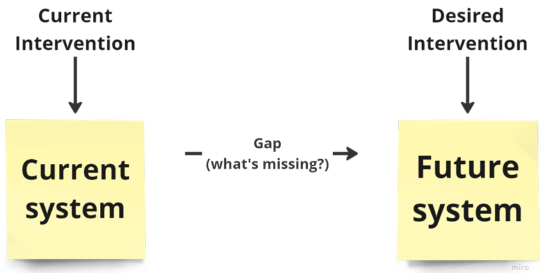


Image 3.8

By comparing the present with the future, we can identify how the system needs to be guided to ensure that the desired future is realized. The gaps between the defined present and future can be seen as converging points of research and will be used to continue generating design goals.

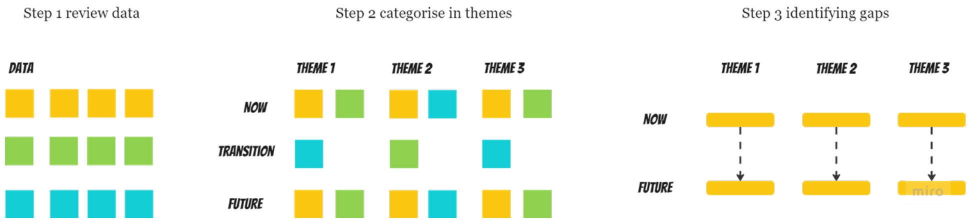


Image 3.9: the method of identifying the gaps

The analysis employed an inductive method, as detailed in 3.2.2. First, all data were reviewed and distinguished using different colors. In the second step, this data was categorized by time and theme, with time categories including present, transition, and future, and thematic categories encompassing technology, politics, culture, society, environment, and economy(see image 3.10). Finally, these post-its were used to generate narratives about the current state and the future, and these narratives were compared and analyzed to identify the gaps between them(Image 3.11).

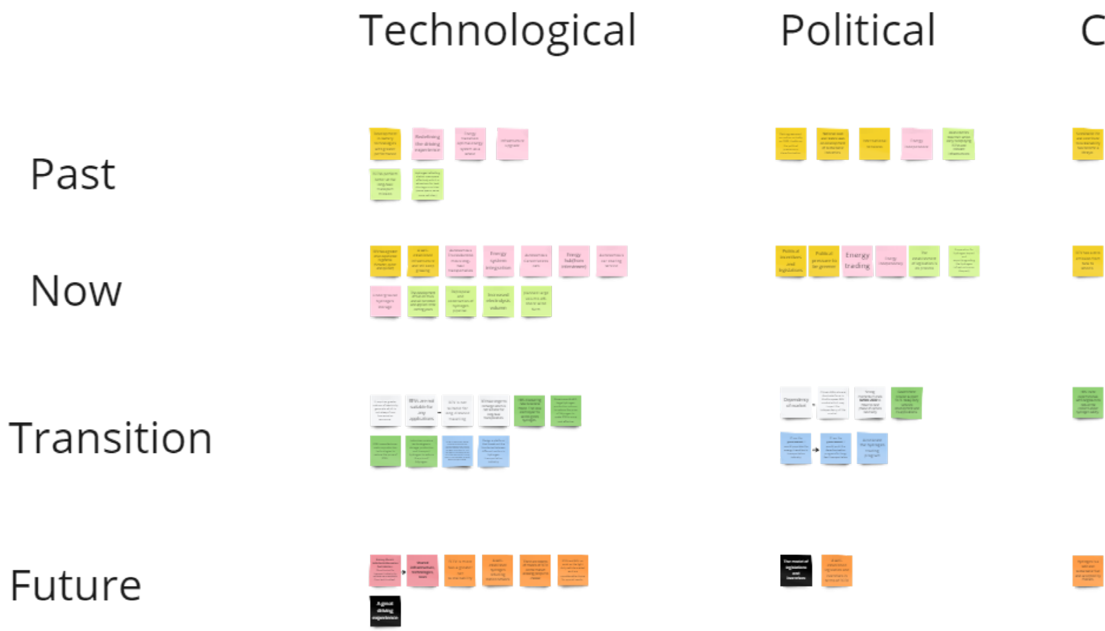


Image 3.10: the result of categorized po

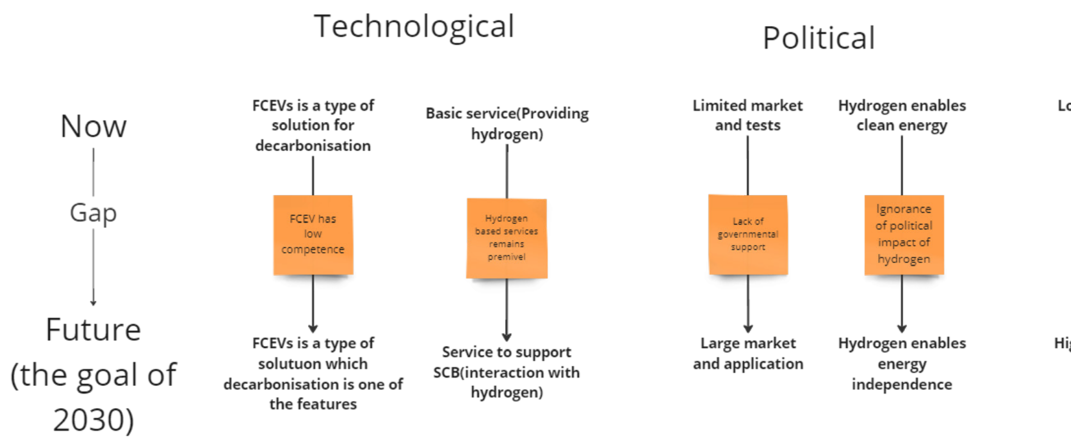
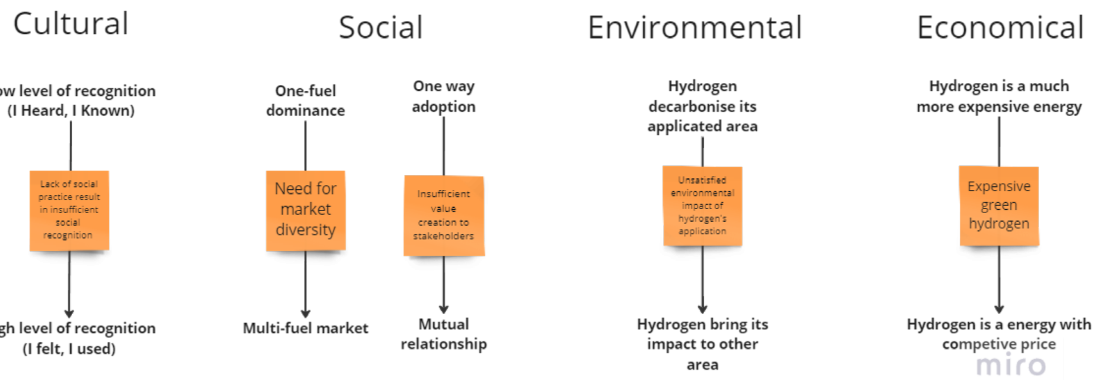


Image 3.11: Identified

ost-its from the Three Horizon workshop



gaps(intervention space

3.3.2 Identified space for interventions

Developing products & services to cope with sustainable consumer behavior:

Services based on hydrogen remain quite primeval. Typical hydrogen projects in the Netherlands focus on building more hydrogen refueling stations and selling hydrogen. Interview 4 from PZH shows an example of deploying hydrogen buses for public transportation. However, in this case, the initiatives from consumers are very low because they passively interact with the service. These shortcomings also appear in projects such as using hydrogen for house heating, cooking, or other applications. These basic services do not offer a significant added value to users. Consumers require advancer service models to increase their initiatives and support sustainable consumer behavior.

Educating the public:

Because of the small-scale application of hydrogen. It creates a bubble that blocks contact from the public. They might have images of hydrogen for instance 'I think it is very dangerous' or 'I think it is very clean and sustainable'. However, the majority of public maintains a sallow recognition of hydrogen because they never contact with hydrogen before. They perceive hydrogen as a concept that floats on air. A higher level of recognition is required by allowing them to do practices that are relevant to hydrogen. In this way, they can express their authentic feelings, ideas and desires regarding hydrogen, and join the process of improving the whole system.

Facilitate market diversity

Society is showing radical growth in the BEVs market and a trend to abandon fossil fuel passenger vehicles. BEVs might dominate the transportation market in the future. However, this will harm market diversity as well as the whole country's economy. In the worst case, the market can be monopolized by other countries' BEVs with more advanced solutions, China, as an example, has been investigated for unfair market competition by the EU. The market should offer diverse solutions to customers to maintain economic growth healthily.

Increase the availability and accessibility of green hydrogen:

At present, hydrogen remains an expensive energy carrier. The economic benefits of using hydrogen as an energy source are currently limited. For hydrogen to become a widely adopted energy solution, its price needs to be significantly reduced to a more accessible level. Making hydrogen a cost-effective energy option would greatly accelerate its adoption and integration into various sectors.

3.4 Explore the system's dynamic though Casual Loop Diagram

A Causal Loop Diagram (CLD) is a visual representation used to illustrate the relationships and feedback loops within a system. This tool is used to discover dynamic connections between factors in a complex system. CLDs commonly consist of three factors: Factors, Arrows, and Feedback Loops(Lannon, 2016). Factors are the elements that can change, such as hydrogen price and user experience, etc. Arrows present causal relationships between variables, indicating how one variable affects another. In this CLD, there are two types of connections, black arrows mean positive linkage where an increase in one variable leads to an increase in another, and red arrows mean negative linkage where an increase in one variable leads to a decrease in another. For instance, the increasing market share of FCEV has a positive impact on attracting more investment and revenue. Feedback Loop is formed when a series of cause-and-effect relationships circle back to the starting variable, creating a loop and revealing potential leverage points that can intervene in the system with significant impact. There are two types of loops, reinforcing loop and balancing loop. Reinforce loops amplify changes and impacts. A leverage point in a reinforcing loop could be a way to enhance a positive outcome or mitigate a negative one. Balancing loops seek to stabilize the system. Balancing processes generate the forces of resistance, which eventually limit growth, maintain stability, and achieve equilibrium Identifying leverage points in balancing loops can help in achieving desired stability or preventing undesirable stabilization.

3.4.1 The Casual Loop Diagram of hydrogen in transport sector

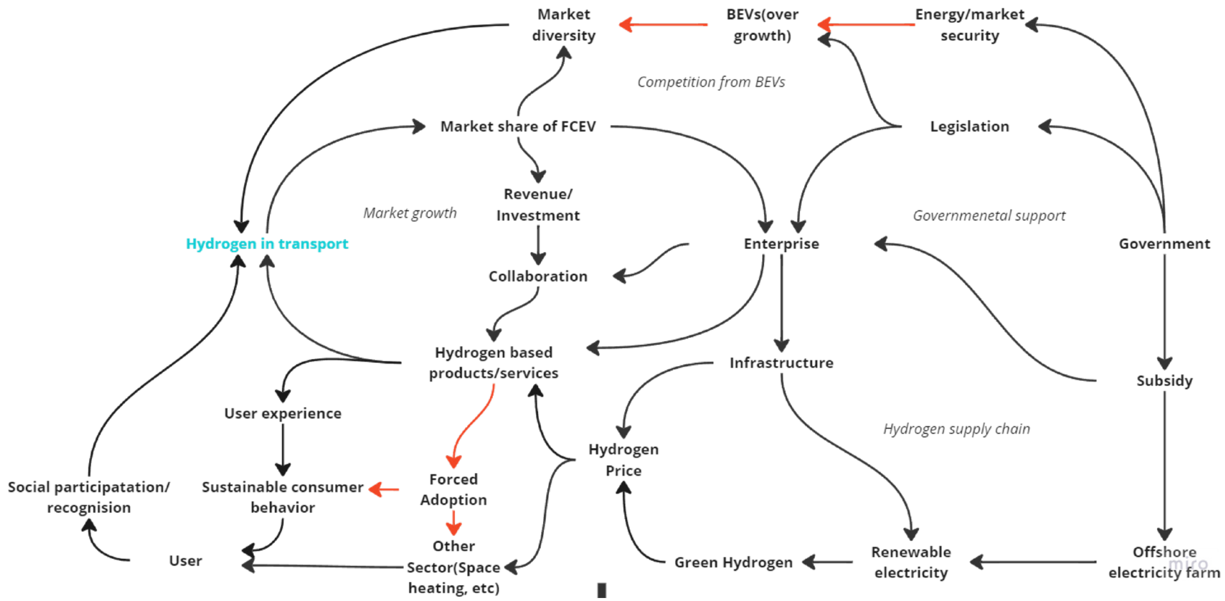


Image 3.12: The generated CLD

Loop of market growth

The starting point of this CLD is hydrogen in transport, this factor refers to the scale of application of hydrogen in the Dutch transport sector. It has a positive impact on the market share of FCEV. The high market share of FCEV can attract more investment and more enterprises would be involved. These further facilitate the collaboration between enterprises to create more hydrogen-based products and services which increase the scale of hydrogen application in the transport sector. This is a reinforcing loop that respresents the market growth of hydrogen. This diagram emphasizes the importance of aligning the interests of different organizations. If a project fails to provide sufficient benefits to companies (not limited to economic gains), the efficiency of collaboration between companies will decrease. Moreover, companies may be reluctant to participate in the industry because it poses a burden to them.

Loop of governmental support and hydrogen supply chain

The Dutch government plays an important role in the system. The government is responsible for the establishment of hydrogen-relevant legislation that can significantly facilitate the involvement of enterprises. It also subsidy the enterprise to ensure the business won't collapse. This increases the willingness of enterprises to start projects that build hydrogen-related infrastructure such as storage and transportation. For example, in case study 1, the repropose of pipeline and site construction are built by different enterprises. The government also subsidy offshore electricity farms in the North Sea which will enable more renewable electricity and larger green hydrogen production. It will decrease the price of green hydrogen and further to make the product or service operation cost lower. This loop is also a reinforcing loop that emphasizes the impact of governmental support. The government can attract more companies to participate by promoting relevant legislation and subsidies. These companies not only create more hydrogen-related products and services but also contribute significantly to infrastructure development. Additionally, government incentives for sustainable energy and infrastructure development can reduce the cost of green hydrogen, making hydrogen-related services and products more commercially viable.

Loop of Competition from BEVs

The legislation also contributes to the BEVs market. It offers incentives to car buyers and encourages enterprises to build more charging points. However, the government also wish to control the market security of BEVs and limit the import of BEVs from other countries. Eventually, the overgrowth BEV market could harm the market diversity which will limit the application of hydrogen in the transport sector. This is a balancing loop that explains the competition between FCEVs and BEVs. Politically, hydrogen has the potential to enhance national energy security and establish a more reliable energy system with other countries, reducing dependence on Russian natural gas. Integrating hydrogen into the energy system can also curb the growth of BEVs, limiting foreign influence on the Dutch BEV market and promoting greater market diversity.

Loop of user engagement

Service and product innovation can enhance user experience, making products and services better support sustainable consumer behavior. For example, leasing services for FCEVs may encourage consumers to choose lower-cost, lower-emission FCEVs over their own fossil-fuel vehicles. Quality products and services can attract more users, and as the user base grows, it can change public attitudes toward hydrogen at the societal level and increase public participation. Effective products and services often extend their impact to other sectors, promoting greater sustainability and encouraging more users to get involved. Increased social participation translates into a larger market and a greater scale of hydrogen-based applications. This is the reinforcing loop of user engagement.

However, it could turn into a balancing loop. If the products and services are forced to be adopted into the system. It will harm sustainable consumer behavior. For instance, if using hydrogen for water heating is not as effective as natural gas, it will result in longer shower time and increase water consumption. This negative impact can potentially bring to other sectors such as a decreased willingness to upgrade the existing natural gas system to hydrogen. This also highlights the relationship between products/services, society, and users. Currently, if existing products or services cannot provide an excellent experience, it becomes challenging to influence consumer habits. This limitation hinders the project's ability to expand its audience and restricts public awareness and participation. Furthermore, if the impact of products/services is confined to their own domain, it may reduce interest in using hydrogen as a decarbonization solution in other sectors, further decreasing user engagement.

3.4.2 System dynamic between intervention space

The intervention spaces are assigned to the place in the CLD(Image 3.3.2 - 2) and their interconnections can be concluded as Image 3.3.2 -3. Facilitate market diversity is interrelated with Require radical adoption efforts and Increase the availability and accessibility of green hydrogen through the development of market and infrastructure respectively. A well-developed market fosters more collaboration opportunities between companies and enables better resource allocation, which in turn reduces development and operational costs for businesses. The positive market response also makes companies more optimistic about the expected returns on their investments, thereby increasing their willingness to enter the market and commit more resources. Furthermore, developing infrastructure, such as renewable energy and hydrogen pipelines, can increase green hydrogen production capacity, leading to low-

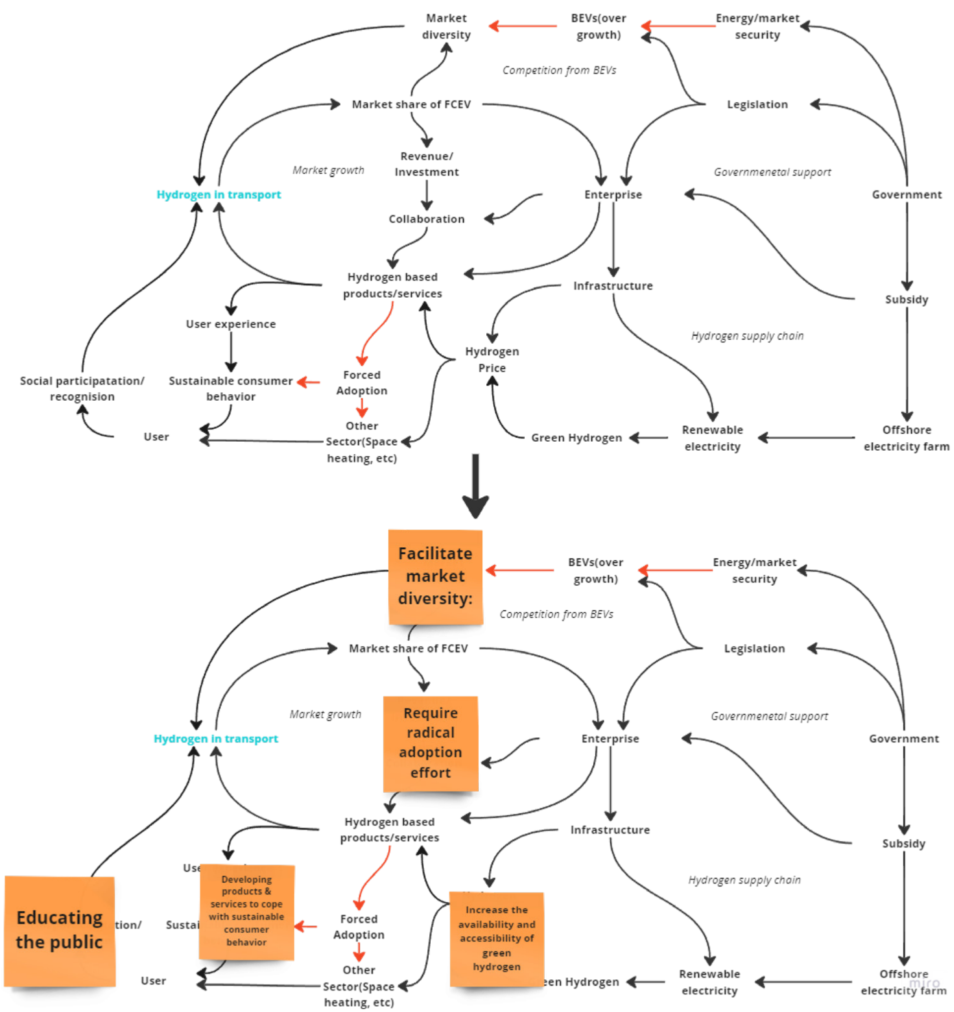


image 3.14 Using CLD to reflect interrelationships between intervention space

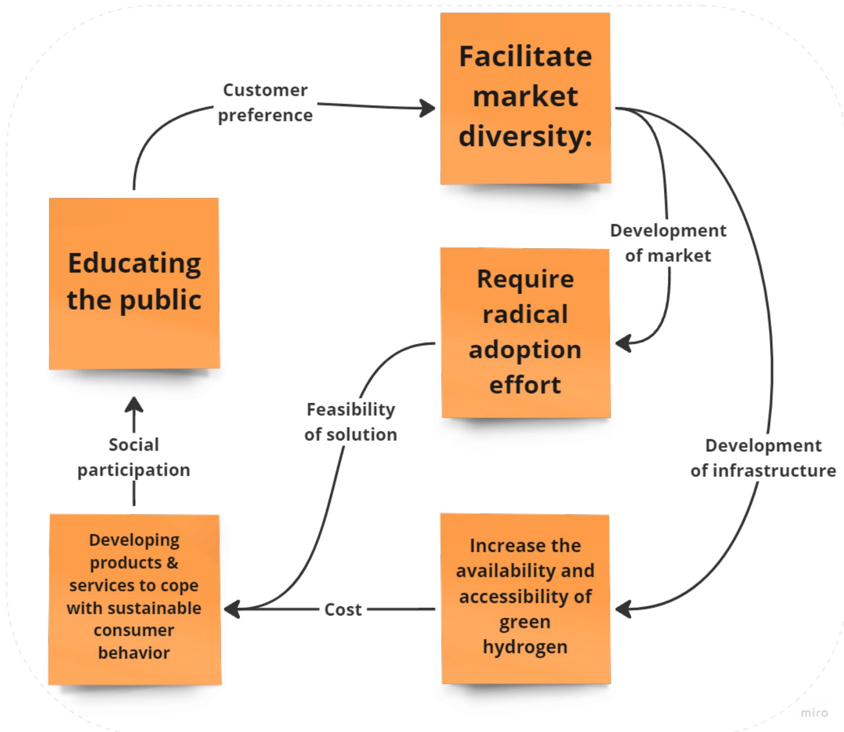


Image 3.15 How intervention spaces are interrelated to each other

er production costs. Building hydrogen pipelines also allows for a wider transportation range and lower transportation costs to increase the availability and accessibility of green hydrogen.

Greater involvement of companies means there will be more solutions for consumers to choose and cheaper green hydrogen to reduce the cost. They can choose the solution that fulfills their needs, in the meantime support their sustainable consumer behavior. These elements will attract more consumers to choose hydrogen and increase social participation of using hydrogen for energy solutions. A higher level of public engagement can influence public perception of hydrogen, educating them to build a positive image of hydrogen. Making them more likely to prefer using products and services that are based on hydrogen.

Chapter 4

Ideation for intervention methods

In the previous chapter, the interrelationships between intervention spaces are identified. This helped us establish a framework for understanding the interactions within the system and the influences at play, providing guidance on narrowing the scope of design. In this chapter, we will discuss leverage points based on the CLD and generate specific ideations grounded in these leverage points to effectively intervene in the system.

4.1 Leverage point 1: Intervention through Effort Reduction by facilitating a better collaboration

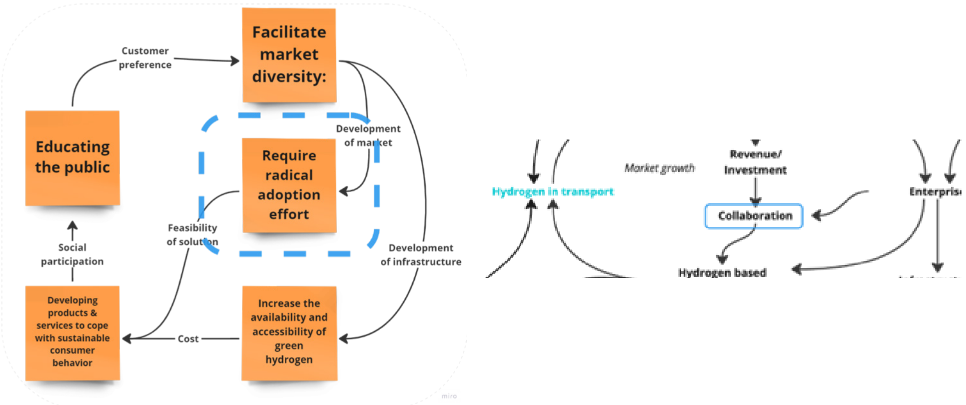


Image 4.1: Leverage point 1: fostering communication

The first intervention method sees opportunities in reducing the effort of adoption by facilitating better collaboration within the system. Good partnership and effective collaboration between enterprises and organizations are the keys to creating excellent products and services. Each company's business strategy is unique, but face implementation challenges due to insufficient collaboration. By enhancing cooperation among companies, they can more efficiently execute their business plans and achieve their objectives which can directly reduce the cost of allocating the required resources. Thus, a design goal for this intervention method can be formulated

Design goal for intervention 1

How can the design enable effective communications between different organizations to allow them to communicate their needs and demands?

4.1.1 Ideation 1: Guidebook to enable the collaboration

Image 4.2: Ideaton 1: Guidebook for enabling a better communication

A guidebook that supports project managers' decision-making process in taking the initiatives in hydrogen-related business(Image 4.2). This ideation focuses on companies that have ambitions to enter the hydrogen industry. This guidebook provides tools, suggestions, and knowledge that can be used as a reference or starting point for researching and finding relevant resources. This guidebook can also be used to make sense to colleagues or superiors. Thus, by reducing the effort of communication, the guidebook promotes the company and inter-organizational collaboration.

4.1.2 Ideation 2: A product-service system that communicates the need between the fleet manager and HRS owner

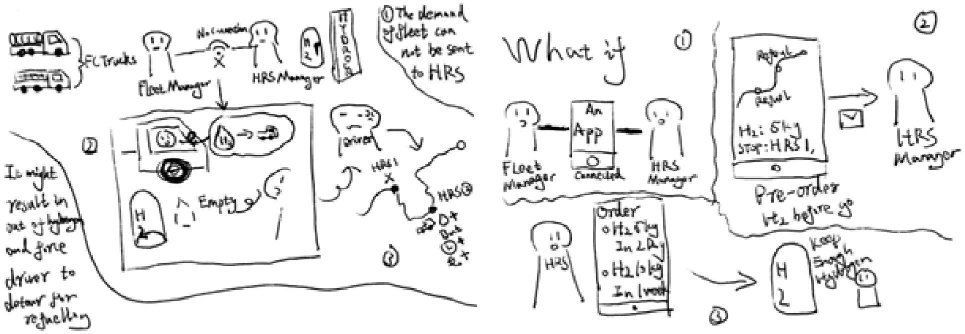


Image 4.3: : Ideation 2, the problem left, the solution right

This ideation follows the same design goal as ideation 1 and focuses on more concrete issues that already exist in the industry. It highlights the communication gap between fleet managers and HRS managers mentioned in the interview.

Currently, there is a lack of communication channels between hydrogen refueling stations and fleet operators(with FC trucks). This disconnect creates operational challenges for station managers due to unpredictable hydrogen consumption and demand. At times, hydrogen is consumed rapidly, necessitating more frequent restocking, while at other times, slow consumption leads to excess inventory, increasing storage and management costs. For fleet operators, this inconsistency poses the risk of refueling stations running out of hydrogen, which could increase the risk of delays and as they search for alternative stations.

To address the communication gap and improve efficiency between hydrogen refueling stations and FC Truck fleet operators, the ideation focuses on developing a platform(potentially in the form of an app) to facilitate real-time communication and planning. This platform would allow refueling station operators to upload their hydrogen inventory levels and maintenance schedules (as stations require regular maintenance). Fleet operators could use the platform to reserve hydrogen refueling amounts and schedule specific times, ensuring that drivers can reliably refuel at the stations. Such a system would enable refueling station operators to better anticipate hydrogen consumption patterns and manage their inventory accordingly, potentially attracting more customers due to improved service reliability. For fleet operators, this platform would provide the benefit of establishing consistent and dependable partnerships with refueling stations, reducing the risk of delays or detours due to fuel shortages. This solution would enhance overall efficiency and reliability in the hydrogen fuel supply chain for the transportation sector.

4.2 Leverage point 2: Invention through educating the public and increase the social recognition

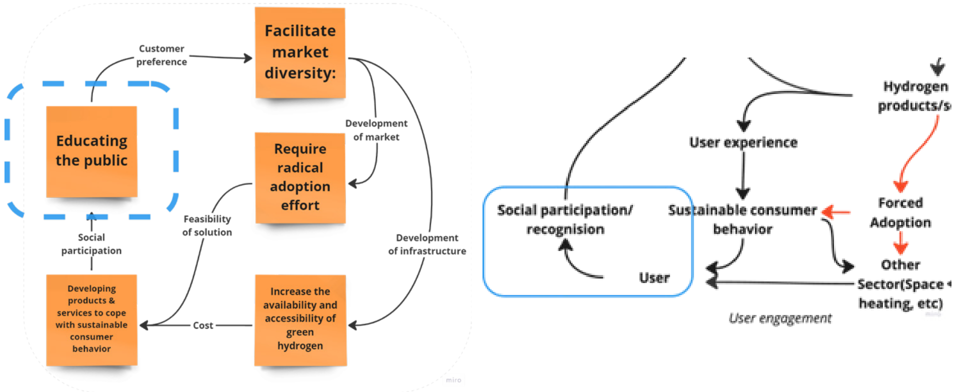


Image 4.4: Leverage point 2: increase social participation

The second intervention method highlights the importance of public recognition regarding the hydrogen economy. Currently, hydrogen is still not an energy that is well-accepted by the public. There are stereotypes toward this new energy, such as the belief that hydrogen is a dangerous energy source. This leads to hydrogen being dismissed as a viable option by consumers, even if it may be the right energy solution for them. By fostering a correct understanding of hydrogen among the public, the intervention should enable people to evaluate hydrogen more accurately and consider it as a suitable option for their energy needs. In this way, it reinforces the positive loop of user engagement. Thus, the design goal for this intervention method could be

Design goal for Leverage point 2

How to design an educational game that helps people develop an understanding of the Dutch energy system?

This design goal aims to enhance users' recognition of the energy system through practical engagement. Educational games are an excellent option for this purpose, as they can offer users a different perspective on the energy system and encourage reflection. Such games can also serve as a practical alternative, providing experiential learning opportunities in place of direct access to hydrogen-related products or services, which may otherwise be rare to encounter in reality.

4.2.1 Ideation 3: Educational game that emphasizes energy transition in transport

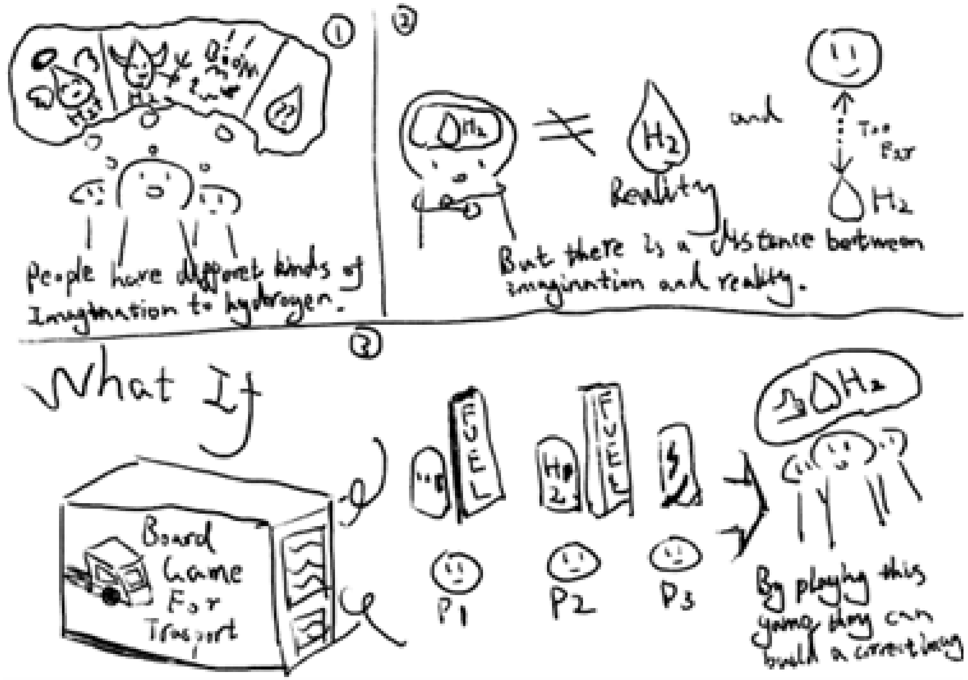


Image 4.5 Ideation 3: A educational game to increase the recognition of players regarding to energy transition

This board game embodies the challenges and opportunities of the energy transition process in transportation. It aims to match players' recognition to real paradigms that happened in reality and populate the concept of energy transition in transportation.

In this board game, participants will assume roles representing different segments of the transportation industry, such as fleet operators, fueling station managers, and government officials. Through a mix of competition and cooperation, players aim to achieve game objectives and build their own business empires. This setup not only provides an engaging way to explore the complexities of the energy system but also helps players understand the interplay between various stakeholders and the strategic considerations involved in the adoption of hydrogen technologies.

4.3 Levarge point 3: Intervention through coping with sustainable consumer behavior

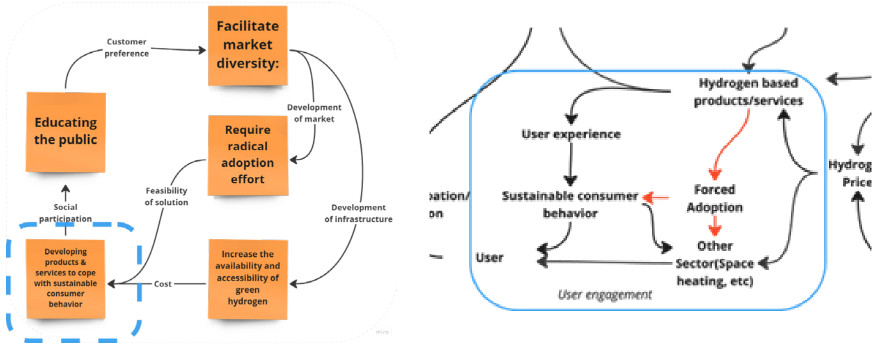


Image 4.4: Leverage point 3: coping with SCB

This intervention method notices opportunities to design an intervention that can cope with users' sustainable consumer behavior. User behavior is influenced by the products and services they use. A well-designed product or service can meet user needs while also changing their consumption behavior through interaction, making it more sustainable. Currently, hydrogen-based products and services tend to emphasize decarbonization during application, lacking features that engage users and encourage their sustainable consumer behaviors. Therefore, the design goal for this intervention method could be:

Design goal for Leverage point 3

'How can hydrogen empower the public, practically support their sustainable consumer behaviours and encourage them to join the process of energy integration?'

This design goal emphasizes consumers' autonomy in actively participating in energy integration and how hydrogen can better serve this purpose.

4.3.1 Ideation 4: Turn self-generated electricity into hydrogen and use it for public service

Image 4.7: Ideation 4: A service that convert eccessive electricity from householders to hydrogen

This ideation targets households that can produce energy independently, typically those with solar panels. These households often generate more electricity than they consume or face challenges in storing the electricity they produce. Under this concept, they would sign agreements whereby their excess electricity is supplied to local electrolyzers to produce hydrogen. In return, they would receive a certain number of hydrogen tokens. These tokens can be used for various services, such as discounts on heating if the community uses hydrogen for heating or at hydrogen refueling stations to get discounts when refueling their vehicles. This service-plus-product model spreads the impact to other sectors.

4.4 Ideation evaluation&selection

These ideations represent different design directions and methods of intervention in the system. Therefore, a scoring system is needed to evaluate these ideations and select the final design direction. However, this poses a challenge where my desired method of intervention as a designer may conflict with objective standards. This means that the intervention approach I prefer might not be the most effective in impacting the system. Thus, I expect the scoring system will balance personal preferences and objective criteria to support the decision-making. In the end, based on the matrix of evaluation, **ideation 4** is selected as the design direction for the next design process.

Ideation	1	2	3	4
Impact(1-10)	4	4	6	8
Commercial viability(1-10)	8 (It's pretty viable commercially since it a only a 'product')	7 (Not sure how many fleets use FC trucks for delivery)	8 (It's pretty viable commercially since it a only a 'product')	7 (There are a lot of uncertainties, the interests of stakeholders are not clear)
Policy resistance(1-10)	10 (No policy concerns)	9 (Not really see any policy concerns)	10 (No policy concerns)	8 (Use of infrastructure, agreement of use electricity, etc)
Personal preference(1-10)*0.5	5	7	7	10
Total	25	23.5	27.5	28

Impact:
The impact of the design to the system, the magnitude of impact depends on the level of leverage points explained in Appendix 1.

Commercial Viability:
Determine if the ideation can be executed feasibly from a business perspective.

Policy resistance:
Policy feassibility of ideation, it means will the policy resist the intervention or not.

Personal Preference:
Assign an additional value to the ideation based on personal preference. To maintain relative fairness, this value will be multiplied by 0.5.

Chapter 5

Further defining the energy scenarios & Design goals

In the previous chapter, we discussed multiple possible leverage points based on the CLD and generated a series of design goals and ideations that could intervene the system. Finally, Ideation 4 was chosen as the final design direction. At this stage, the ideation has only outlined the general concept of the service. Key components such as the involved stakeholders, value exchange, service processes, front-end and back-end systems have not yet been defined. This chapter will further dive into the context that grounds the design direction and evolute the design goal that address the conflicts in the context.

5.1 Viability of using electrolyzers in the grid congestion management

Dowling and Jansen(2023) discuss the potential of using electrolyzers to reduce grid congestion in the Netherlands. Currently, grid congestion exists in two forms: demand congestion and supply congestion. Demand congestion occurs when the grid simultaneously needs to supply excessive amounts of electricity, while supply congestion refers to the situation where electricity production exceeds consumption, causing congestion. Thus, congestion management is crucial to ensure the stability of the grid. Demand-side flexibility technologies refer to those technologies that can adjust their power demand to shift the demand and supply peak, further avoiding or postponing congestion. Electrolyzers are a type of technology that addresses these issues. Ghaemi et al. (2023) claimed that using an electrolyzer for congestion management in a medium-voltage distribution grid has great economic feasibility.

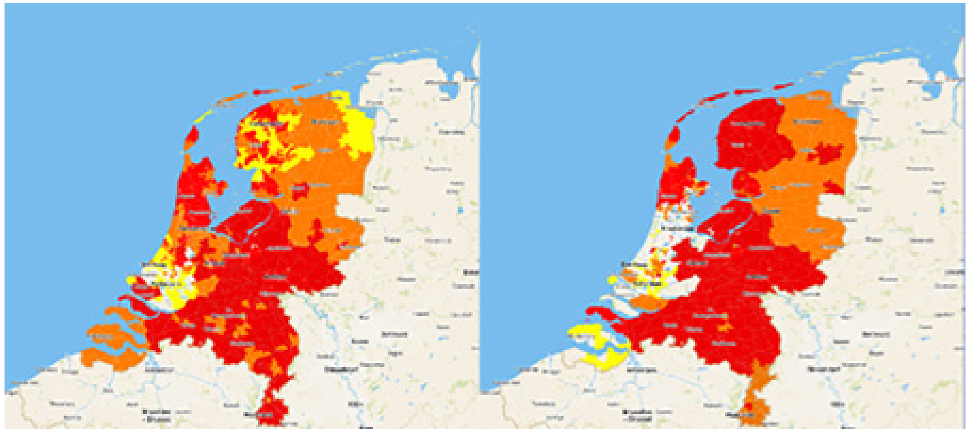


Image 5.1A visual representation of grid congestion by Netbeheer Nederland, on the left is demand congestion map and on the right is the demand congestion map, the deeper colour means lesser transportation capacity in the grid(Dowling & Jansen, 2023)

In the report(Dowling & Jansen, 2023), the author discusses four scenarios for using electrolyzers to reduce grid congestion: 1.) Electrolyser in combination with renewable generation. 2.) Electrolyser in combination with an industrial end-user 3.) Electrolyser in combination with local energy hub. 4.) Electrolyser operated by grid operator for congestion management.

Electrolyzers in combination with local energy hubs(scenario 3) demonstrate greater advantages compared to other scenarios. In this context, an electrolyzer converts renewable energy resources to hydrogen when supply congestion occurs in the grid. The hydrogen produced will be, for example, supplied to nearby industrial clusters, used for refueling and space heating, etc. The energy hub is a unique concept born out of the Dutch energy system. In this system, agreements between an energy user, the grid operator, and an energy supplier were separate. Energy hubs are a local collaboration between users and energy producers. In an energy hub, various energy and energy carriers are produced, transported, managed and used. An energy hub may specialised in a specific function; for example, a mobility hub is more focused on providing various energy solutions for mobilities. Energy hub plays a crucial role in integrating and improving the efficiency of the local energy energy system.

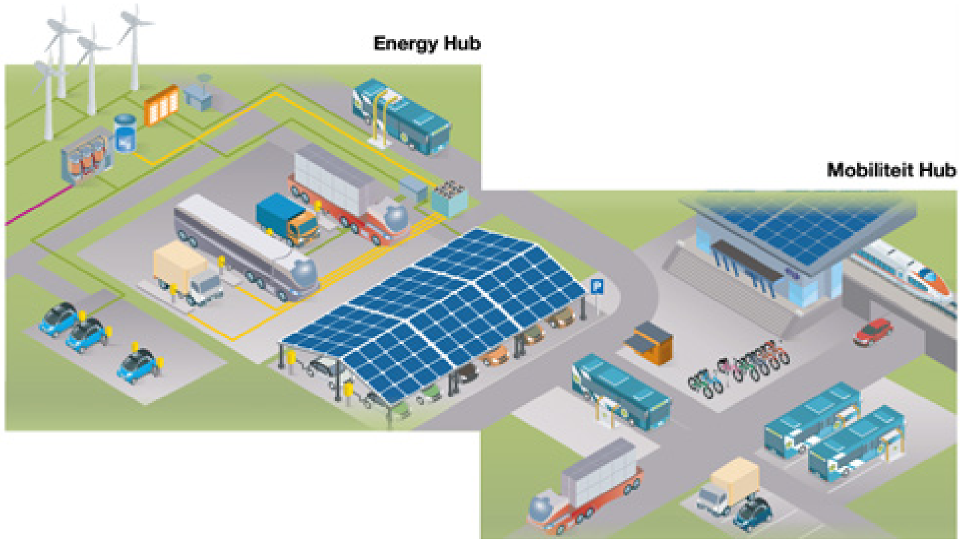


Image 5.2: An example of mobility energy hub("Energy Hubs: Vitale Knooppunten in Een Energiesysteem," 2021)

Using electrolyzer combining with an energy hub has several advantages. Firstly, the readiness of technologies is high. Secondly, there are no legal concerns for operating electrolyzers in energy hubs. Lastly, energy hubs have already connected with the hydrogen market such as the industry clusters nearby or service providers who want to integrate hydrogen into their solutions.

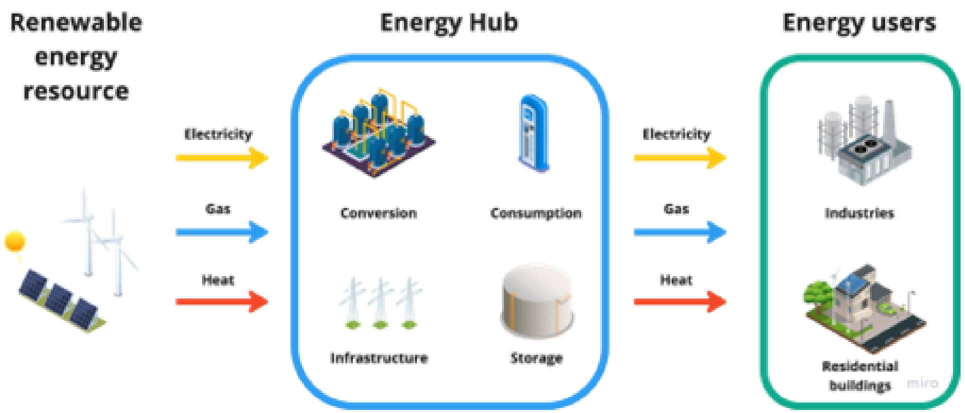


Image 5.3: the function of energy hub in the energy scenario

Using electrolyzer combining with an energy hub has several advantages. Firstly, the readiness of technologies is high. Secondly, there are no legal concerns for operating electrolyzers in energy hubs. Lastly, energy hubs have already connected with the hydrogen market such as the industry clusters nearby or service providers who want to integrate hydrogen into their solutions.

However, economic feasibility is the biggest concern in this scenario. It relies strongly on the presence of a local hydrogen user(size of the market). The business case is only feasible if there is sufficient local demand for hydrogen combined with an adequate willingness to pay(Dowling & Jansen, 2023). From an electrolyzer operator's perspective, cost-efficiency is crucial for their business case. The hydrogen price, the number of full load hours, the electricity cost, and the production volume of hydrogen are key factors that influence an electrolyzer's cost-efficiency. If an electrolyzer only operates when supply congestion occurs, the number of full load hours may be insufficient(electricity price is low during the supply congestion). If the electrolyzer operates outside the times of grid congestion, the electricity price becomes another important factor.

5.1.1 Policy in the way: Salderingsregeling voor zonnepanelen(Netting scheme for solar panels)

Salderingsregeling allows solar panel users to feed excess electricity back into the grid and use the same amount of electricity for free at other times. For instance, if they feed 1000 kWh of electricity into the grid during the summer, they can receive 1000 kWh of electricity for free in the winter. However, there are certain limitations to this policy, such as not being able to feed more electricity than they consume. Additionally, depending on the grid operator, households may have to pay corresponding electricity transportation fees. This policy encourages households to install solar panels to make their homes more sustainable. This policy was planned to be canceled by the government but was vetoed by the Senate. According to Van Gastel (2024), the policy now has a negative impact on energy transition. Households consume only 30-40% of the electricity they produce, with the rest fed back into the grid. This policy exacerbates grid congestion and forces energy providers to curtail renewable electricity production at times. It also hinders the implementation of renewable energy projects due to grid capacity limits. This situation forces the government to subsidize grid reinforcement, but as more households choose to install solar panels, their electricity production grows faster than the grid can be reinforced. Therefore, this service aims to explore a new way to alleviate the negative impacts brought by this policy and to continue encouraging users to install solar panels in the future, even if the policy is abolished.

5.3 Value conflicts in the system & Design Goal 2.0

Based on previous research, a value chain mapping between the main stakeholders can be formulated. Householders install solar panels to save energy expenses and wish to recover the cost of solar panels as quickly as possible. This creates conflicts with the grid operator's value in reducing the cost of congestion management because a large amount of self-generated electricity causes serious supply congestion. It delay the development of renewable energy resource due to the lack of electricity transport capacity and results in the curtailment of renewable energy production by energy providers because they wish to produce as much energy as possible. For the electrolyzer operator, they wish to maximize the cost-efficiency of the electrolyzer which means they want to run their electrolyzer 24 times 7 hours at a low electricity price. However, running an electrolyzer during supply congestion can offer a low electricity price, but during noe-congestion time, the cost efficiency of operating the electrolyzer is questionable. Do not even mention that the electrolyzer may need to be closed during the demand congestion period. From the energy hub perspective, their value aims to facilitate collaboration between different energy sectors. It facilitates the integration of the local energy system which benefits both stakeholders.

The desired value chain illustrates how, with the design's presence, householders can build positive, mutually beneficial relationships with other stakeholders. Householders should be able to join the congestion management process and get rewarded. The reward can be given in other forms of energy instead of 'electricity out, electricity back'. In this way, householders build a partnership with electrolyzer operator. Electrolysers use their electricity to generate hydrogen, and householders are rewarded with hydrogen-related services or products.

Therefore, the previous design goal should be redefined to fit the new context we have defined. Thus, the new version of design gaol is

Design goal 2.0

How to design a service that enables households to actively participate in local grid congestion management and incentivize the use of hydrogen-based products and services?

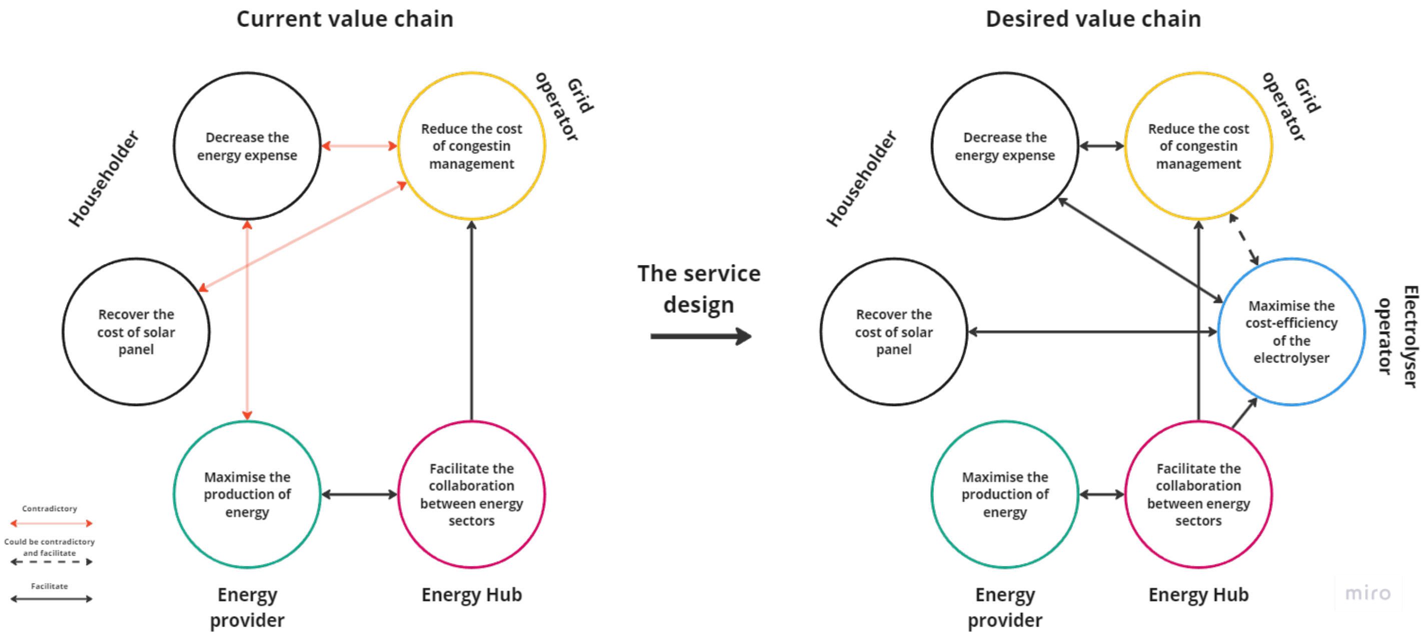


image 5.4:from current value chain to the desired value chain with the presence of the design

Chapter 6

Development of intervention method

The new design goal has addressed the conflicts that exist in the context of ideation. It provides support and direction for the conceptualization of ideation. This chapter will define the service and generate an interactive prototype allowing for demonstrating the invention method and validating the effectiveness of the design intervention.

6.1 Defining the service

6.1.1 Defining Customer Journey

Before generating a service blueprint, a customer journey needs to be identified. A customer journey is a series of events that a user may encounter when interacting with a service, and a touchpoint represents an interaction between a customer and an organization. It involves, for instance, the used facilities, the interaction channels, and specific tasks being completed. Therefore, a customer journey is made up by a series of touchpoints. The customer journey of interacting with the service is as follows(Image 6.1):

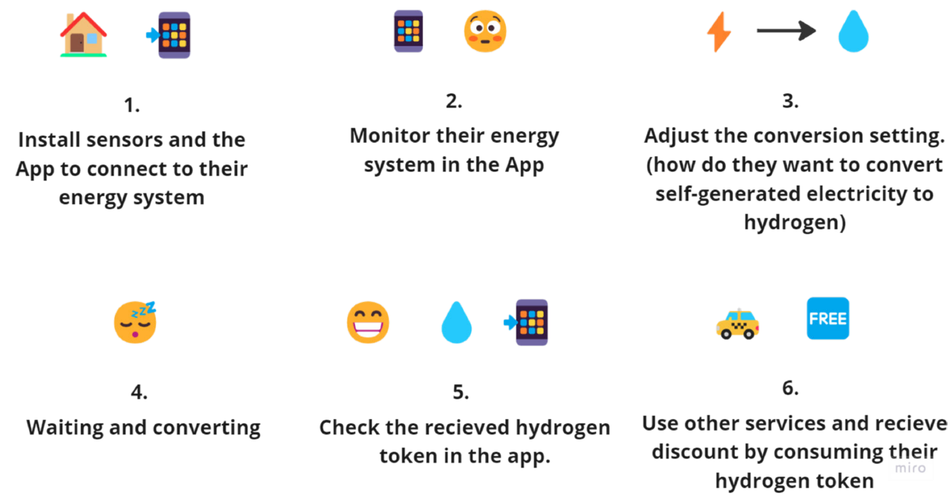


Image 6.1: Customer Journey of the concept

First, necessary sensors and applications are installed to monitor the home's energy system(touchpoint 1). For homes equipped with smart meters, installing additional sensors may not be necessary. Second, the home's energy system (specifically the part that generates energy, such as the solar panels) is connected to the app. Householders can then monitor the efficiency of their solar panels in real-time on the app(touchpoint 2) and adjust how they want to convert excess electricity into hydrogen tokens(touchpoint 3). Subsequently, they simply wait for the system to utilize their electricity to power the local electrolyzer to produce hydrogen(touchpoint 4). They can confirm the hydrogen tokens they receive and view the history of converted electricity on their phones(touchpoint 5). Finally, they can use third-party services that collaborate with this service, such as ride-sharing, paying for home heating, and refueling hydrogen cars, and earn discounts by consuming the hydrogen tokens they have earned(touchpoint 6).

6.1.2 Service Blueprint

A service blueprint(image 6.2) is a visualization of the relationships between different service components that are directly tied to touchpoints in a specific customer journey. The primary interaction between users and the service is through an app. Initially, during installation and registration, staff will install sensors that enable the app to monitor the solar panels' power generation. In the backstage, users will be added to a list for supplying power to the electrolyzers, with their excess electricity prioritized for this purpose. When users decide how much of their excess power to convert into hydrogen tokens, the system's algorithm will suggest a reasonable amount based on their past electricity production, ensuring they have enough electricity for daily use while maximizing the power supplied to the electrolyzers.

In the backstage, the system will determine how much electricity will be transported priorily for the electrolyzers based on the users' settings. During the waiting & converting, the electricity supplied by the users will be used to produce hydrogen. The electrolyzer operators will pay for the electricity provided by the service, at a lower rate compared to other energy suppliers. The system will then compensate users with hydrogen tokens according to the amount of electricity they contributed.

Users can access other third-party services via the app or generate a QR code to use these services. The system will partner with these service providers to enable users to receive discounts by spending their hydrogen tokens. Service providers should pay a fee to join this service, gaining access to a stable customer base.

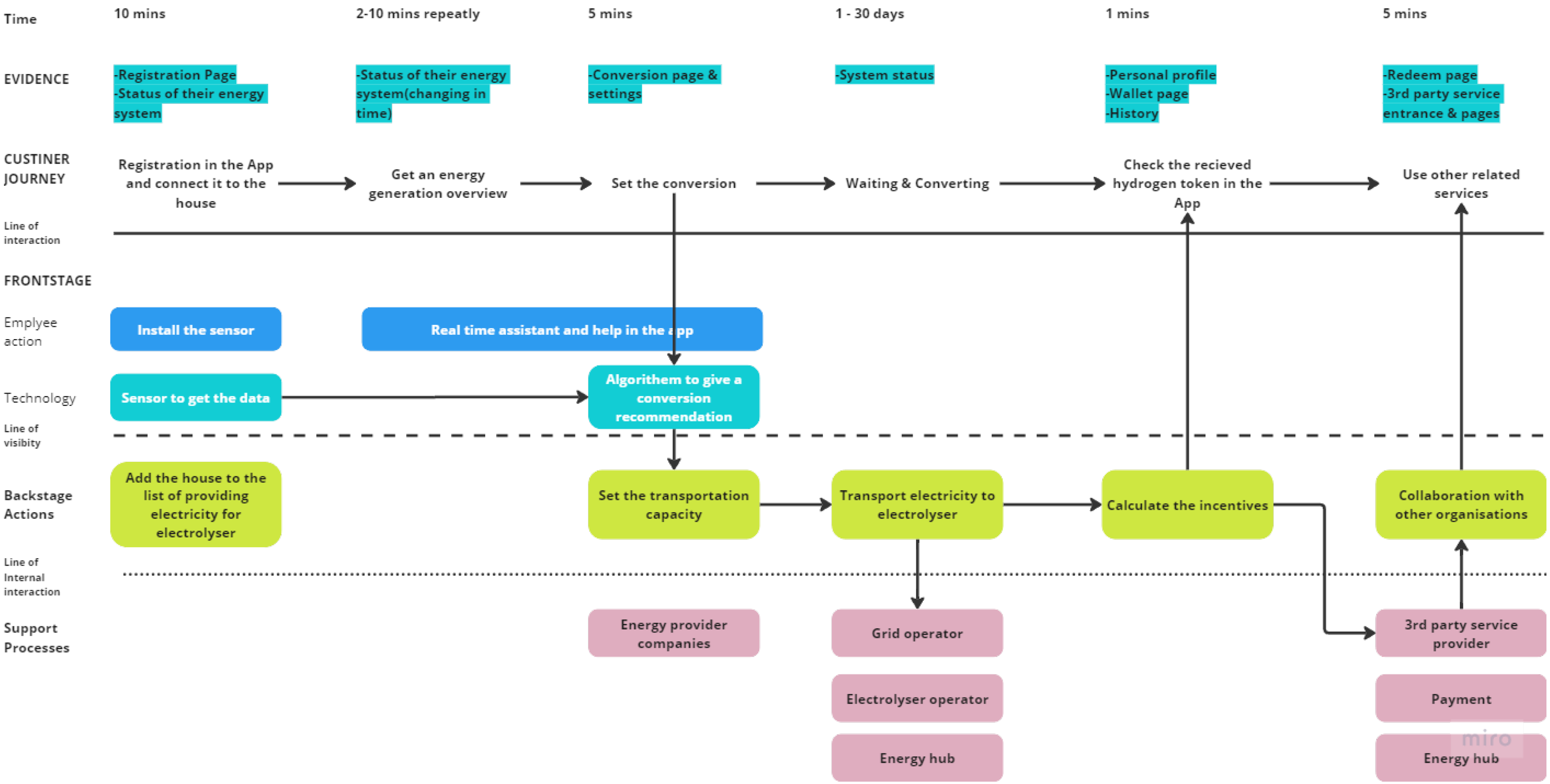
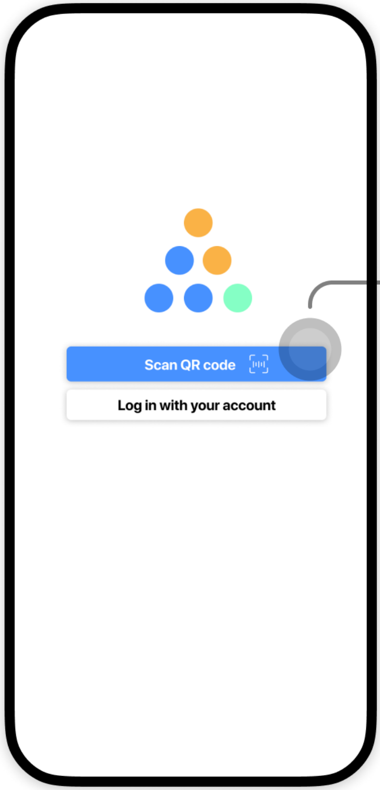


Image 6.2: Service blueprint of the concept

6.3 Concept prototyping

On the main page, users can interact with various information and features. They can monitor the real-time status of their energy systems. The entrance to third-party services is also integrated into this page, making it easier for users to access them. The system suggests a conversion value based on users' past energy generation, allowing users to complete the converting operation quickly. In the management section, the grid status and corresponding additional bonuses are displayed, encourage users to supply power during grid congestion (or when the electrolyzer needs more power) to earn extra hydrogen tokens. Finally, the trace function provides detailed information to ensure users can track every activity of the system.

1. Registration in the App and connect it to the house



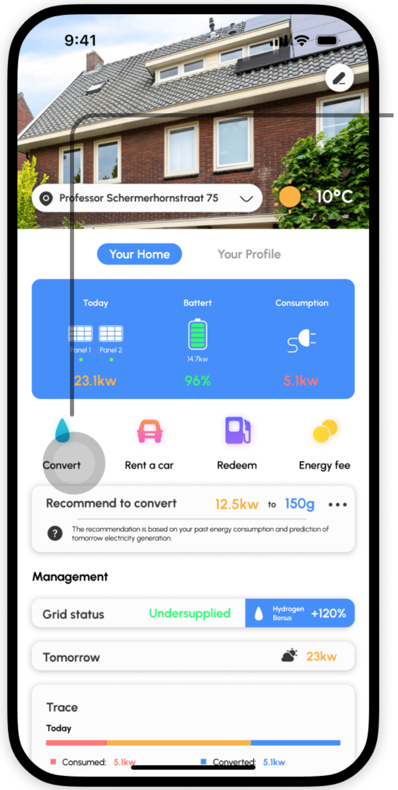
Log in page

Step 2

They can log in via the QR code on the device or with their personal account.

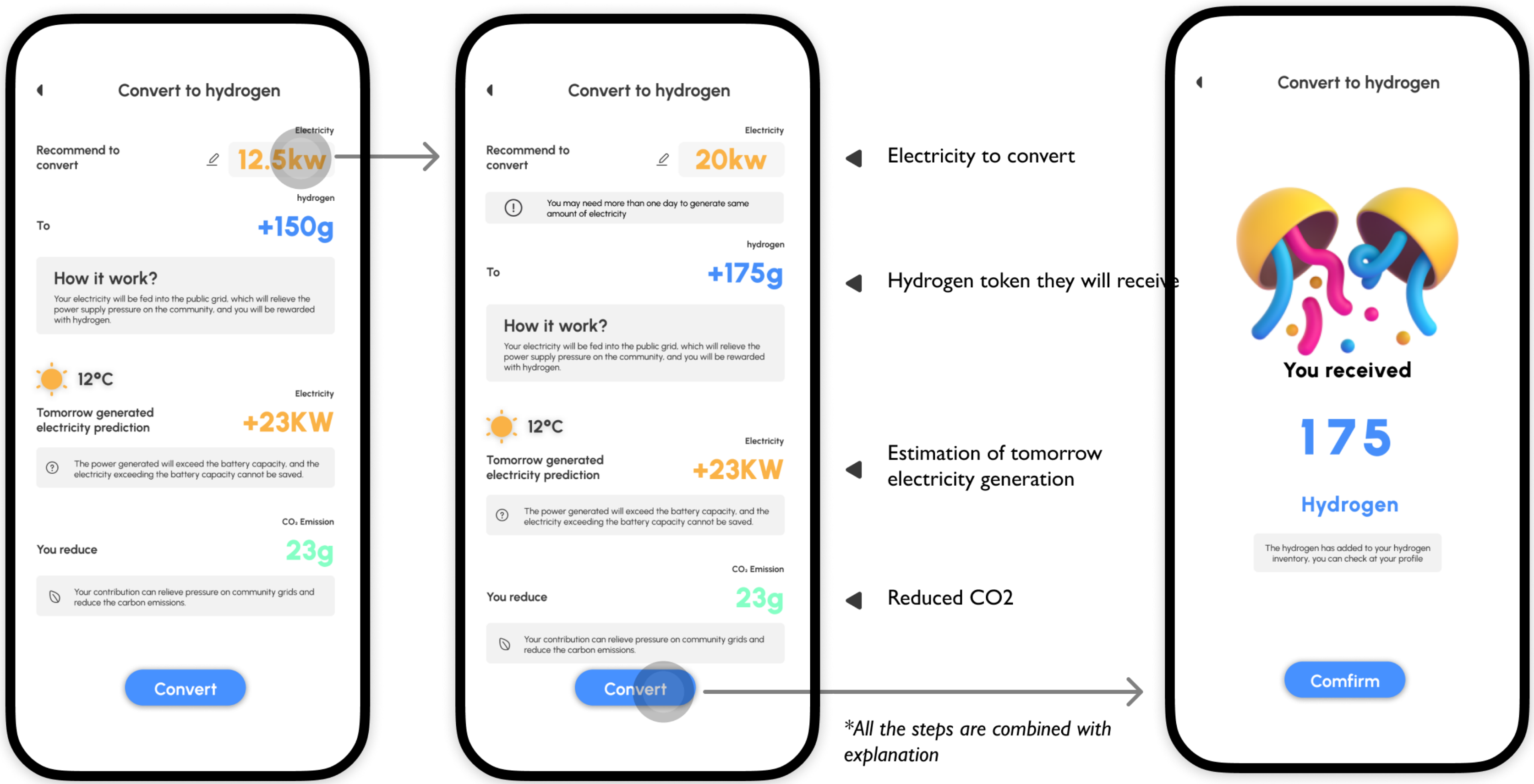
**The QR code is given when they install the sensor*

2. Get an energy generation overview



Main page

3. Set the conversion



Convert page

Users allow to set the amount of electricity for conversion

Success of their conserting

Users can set the amount of electricity they want to convert on the convert page. Based on the amount set, the number of hydrogen tokens they receive will vary (the conversion has limits and diminishing returns, encouraging users to set a reasonable value to help maintain grid stability). A forecast of the next day's energy production is also provided to enhance users' confidence, ensuring sufficient electricity for their daily activities.

4. Waiting & Converting

5. Check the recieved hydrogen token in the App

Users can repeat previous actions to accumulate their hydrogen tokens.

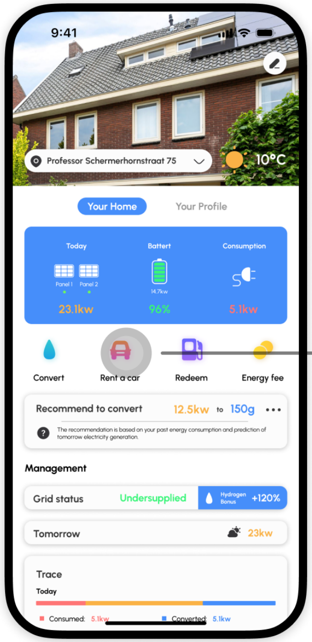
User profile page

On the user profile page, they can quickly view their balance and other statistics. User support (online chat or phone service) and more detailed explanations about this service can also be found on this page.

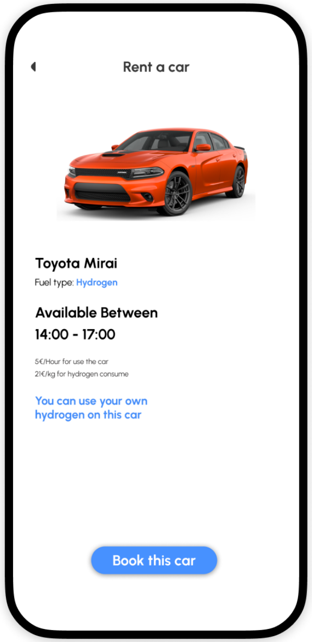
Balance Page

They can view their balance history with more detailed information and corresponding action.

6. Use other related services



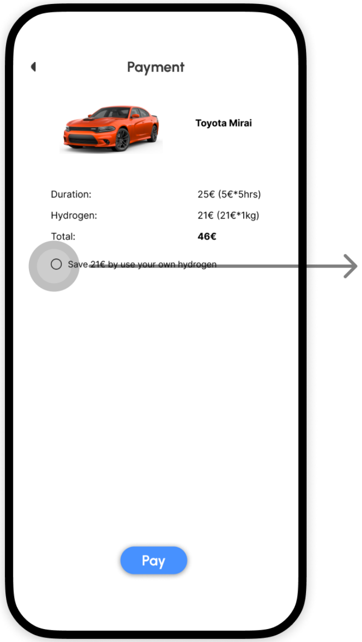
They can use their hydrogen token in the 3rd party service. Let's use rent a car as an example

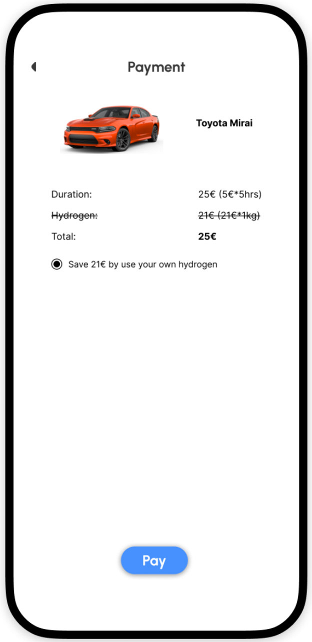


Car rental(3rd service)

They can book a car at the local energy hub.

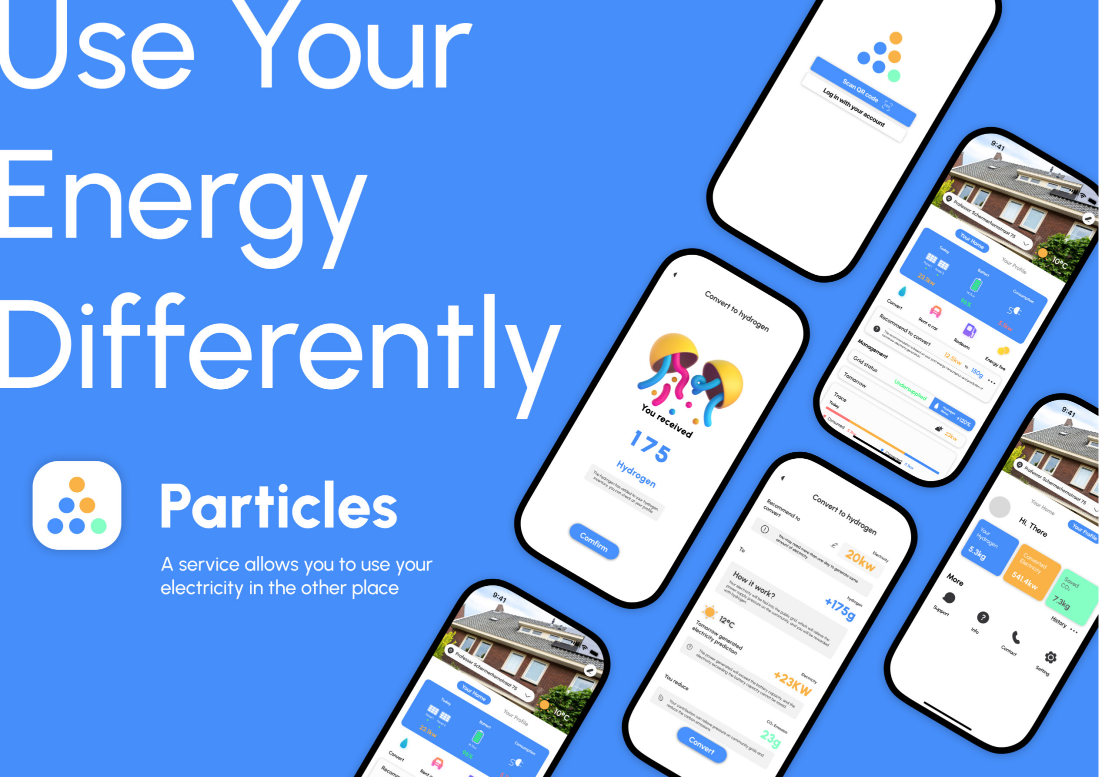
Take the car at the local energy hub and use it.

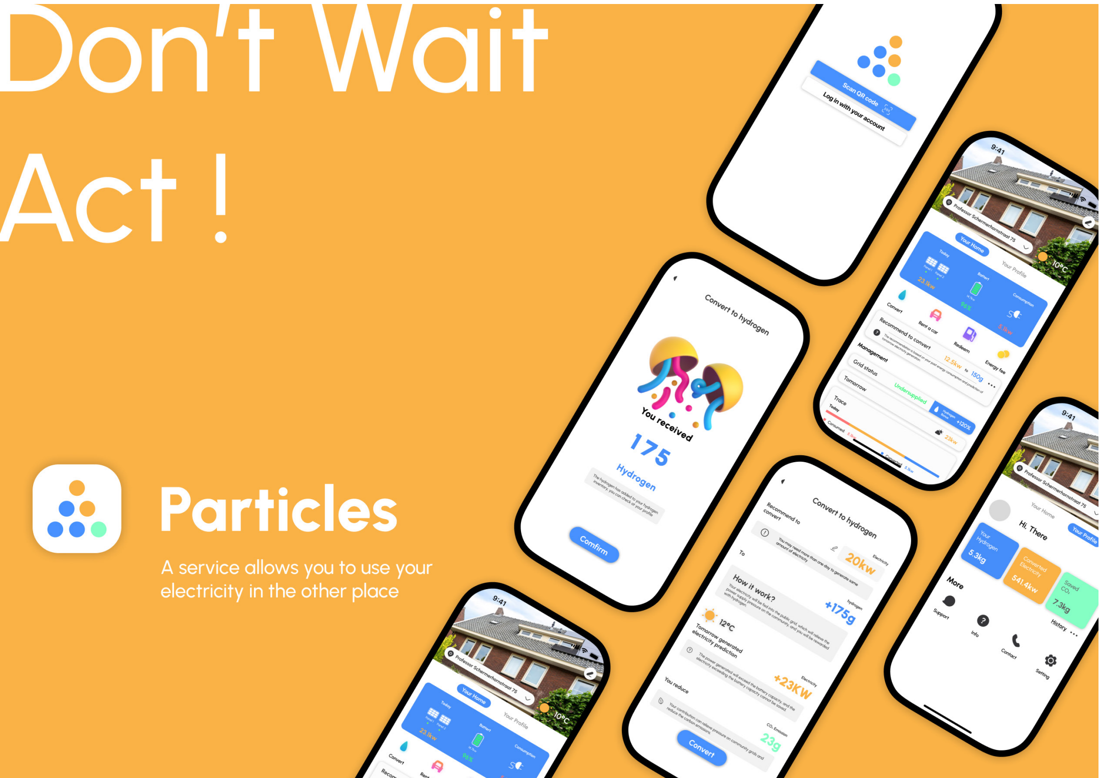




After use and payment

When they finish the rental, they can select 'use my own hydrogen' to get a discount.





6.4 Intervention impacts

A system mapping(Image 6.3) is generated to elaborate the service mechanism that improves the efficiency of the energy system as well as how the service design approach to the value conflicts between the stakeholders that addressed in the identified energy scenario. The main changes occur through the engagement of the service during the process of transferring electricity back to the system and use of other hydrogen-based services(where the phone icons are located). This system indicates three positive impacts brought by the invention.

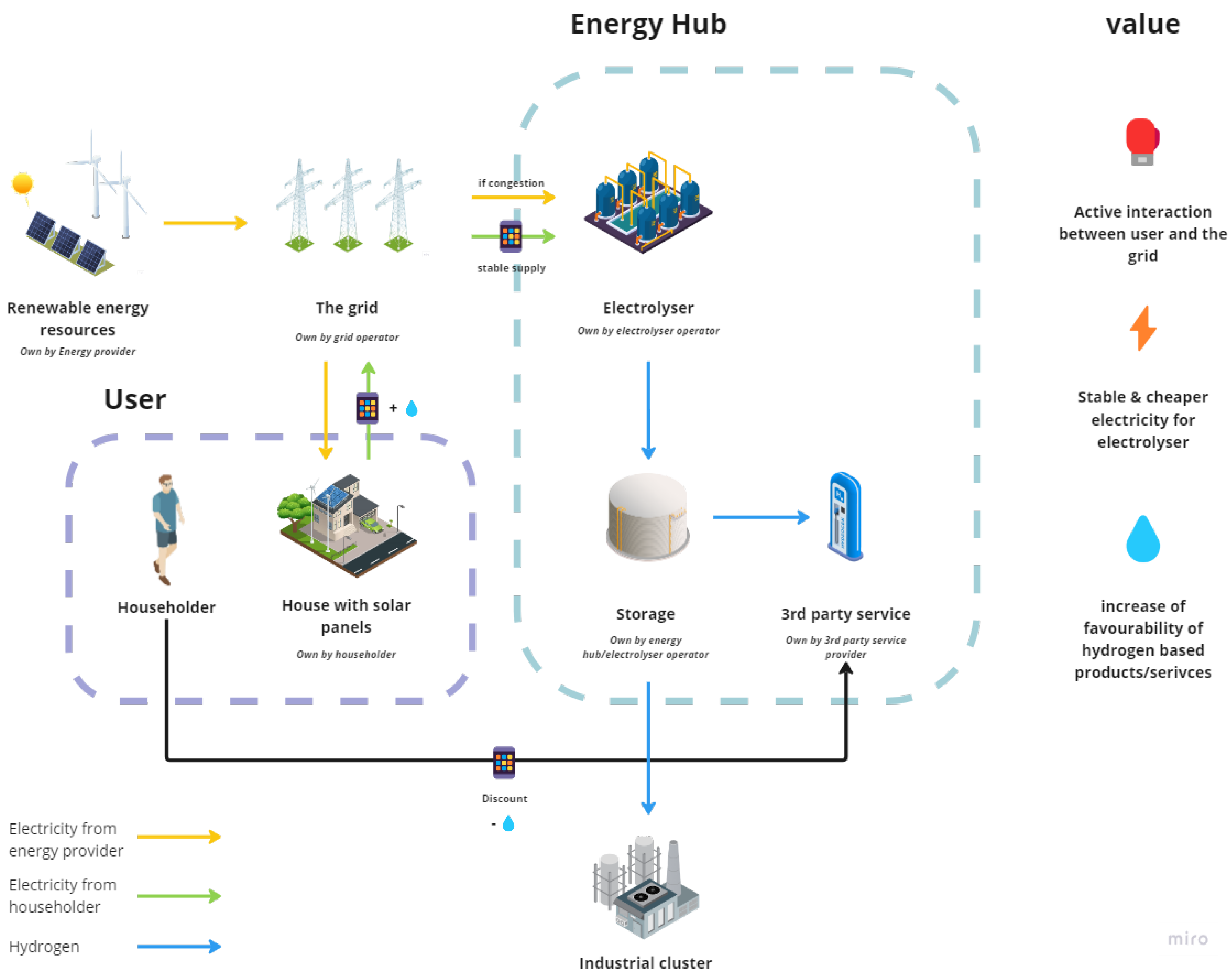


Image 6.3 system mapping with the intervention concept

Inviting householders to participate through creating a positive mutual relationship between householders and the grid

Although users can benefit by supplying electricity back to the grid, but this behaviour increases the cost of congestion management for the grid operators. It harms the interests of the grid operator and increases challenges for them in maintaining grid stability. This service uses electrolyzers to convert excess electricity from the grid into hydrogen, which helps alleviate grid congestion while reducing the cost of hydrogen production. By distributing a portion of the earnings to users as hydrogen points and adjusting rewards in real-time based on the grid's status, this service allows users to interact actively with the grid and their individual energy system(within the house) and encourage them to consume their energy more sustainably.

Transferring the burden to incentives and enlarging the hydrogen demand

The service model transfers the burden to incentives by decentralizing the electricity supply. Electricity supply for hydrogen production is not limited to a single energy provider but also includes renewable energy produced by local communities. In the past, these energy assets were considered a burden, but through this service, they are effectively utilized. The electricity provided by the service users to the electrolyzer will extend its peak operating time. Even during off-peak periods, the electrolyzer can still receive a relatively stable power supply at a lower price, enabling it to produce hydrogen at a reduced cost and decrease the price of hydrogen. This model can enhance the competitiveness of hydrogen in the energy market and increase hydrogen favourability in the local energy market. Also, this service can act as a platform, attracting more hydrogen-based products and services to be involved. The service users will need to use the received hydrogen points and formulate a stable demand of hydrogen. The profitability of the business case will likely to increase due to a lower hydrogen price and stable demand for hydrogen.

A new interface for energy integration and stimulating the development of renewable resource in the future

The service provides a new interface that connects individual energy generation and hydrogen production. This service is also seen as a better alternative solution if the policy of Netting scheme for solar panels is disabled in the future. It provides a flexible and effective way to use self-generated energy. From this perspective, Moreover, as mentioned before, this service can cope with local renewable energy development strategy by unlocking more electricity transport capacity and creating the demand.

Chapter 7

Concept validation&It-eration

This chapter will focus on validating the performance of the design intervention regarding its impact and collecting valuable feedback from participants to further improve the design.

7.1 Concept validation

Concept validation will involve inviting groups who might be interested in this service to participate in testing. The primary participants include four homeowners who have installed solar panels and a representative from a grid operator. The goal of the test is to gauge their willingness to use this service and to determine if using it would lead them to adopt more hydrogen-based services and products.

It is important to note that since the context in which this service is set has no real-world examples, the test participants may lack relevant knowledge and experience. Therefore, the test will include an introduction to the service's features to help participants build a basic understanding of it. These introductions will inevitably favor the service and may introduce biases among the participants. The test will likely collect inaccurate data. Evaluating the commercial feasibility of this service design concept is not the primary goal of this test, but to assess whether this service could achieve the design goal set before. Therefore, the participants' subjective expressions (preferences) toward this service will be the main data collected and inform the subsequent design iterations.

7.1.1 Validation Method

Objectives

The objective of the session is to identify the acceptance of the potential service user regarding this service concept and to assess whether their energy consumption behavior would change due to the intervention of this service, in order to determine if the design meets the initially established design objectives.

Thus, the objectives of validation are to identify if the service:

- motivate householders to actively monitor the energy consumption of their house
- enable mutual interaction between individuals and public energy system
- create a positive mutual impact between the electric grid and the hydrogen system.
- increase the participants' favorability of hydrogen-based services and products.

Participants

A total of five people were invited to participate in the test. Among them, three were householders with installed solar panels, one lived in a rental apartment equipped with solar panels, and another was from the grid operator Stedin, responsible for grid management and hydrogen pipeline management in the Project Stad aan 't Haringvliet.

Procedures

The test starts with an introduction of the service to establish a basic understanding of the service design and background. A series of questions will be asked before and after they walkthrough the design. These questions aim to create a profile about the participants' energy-consuming behavior and measure how the design changes their energy-consuming behavior. Two tasks(see Appendix xxx) will be given to the participants during the design walkthrough that highlights the core features of the service. One task asks participants to monitor their energy system and convert excessive electricity to hydrogen tokens. The other task focuses on using received hydrogen tokens on integrated third-party services. In the end, they will be asked to give their feedback regarding the service.

7.1.2 Result

After going through five rounds of validation sessions, the feedback from participants on this service can be summarized into the following points:

Will to use the service and try hydrogen-base products/services

All participants hold an open attitude towards this service and are interested in using the electricity they generate in other areas. Two participants indicated that if they used this service, they would prefer to prioritize hydrogen-based services. Another two participants mentioned that they value the contributions made to the community (such as jointly maintaining the community grid) more than the rewards (hydrogen tokens), which are seen as optional to them. Participants from grid operators stated that the communities they manage are highly enthusiastic about hydrogen energy systems and might become users of this service. In summary, they are interested in the value provided by this service but have significant concerns about various aspects and look forward to improvements(will be talked at next).

Good usability but requires more explanatory information to ensure that users can fully understand the outcomes of their actions and their associated benefits

The app's user interface is user-friendly but has some usability issues. Participants indicated that more explanations and information are needed to make it clear what results their actions will produce. For example, when using the conversion feature, they want to understand the details of the conversion process, such as where their electricity will be delivered and how long the entire process will take.

Automatic conversion rather than click for every conversion

All participants expressed a desire for the app to automatically convert excess electricity into hydrogen tokens. Currently, they need to manually perform each conversion, which significantly increases the time cost for users and reduces their willingness to use the service due to the perceived inconvenience.

Inclusivity of different types of services and householders

Participants expressed that the app should include more than just hydrogen-based services and consider users with different levels of electricity generation. Currently, the service only includes third-party hydrogen-based services, which forces users to use their generated electricity exclusively for such services. This limits the service's appeal to householders who are conservative about hydrogen or prefer other energy types. It somewhat undermines energy integration, as it means electricity can only be used if converted into hydrogen. Third-party services should offer multiple energy options to cater to user preferences.

Additionally, the service should accommodate homeowners with varying levels of electricity generation. Some householders, such as farmers, produce significantly more electricity than average householders. These users are clearly more interested in how to utilize their excess electricity. Therefore, the service should take into account the different electricity generation levels of each householder and consider alternative ways to use their energy.

Wish for more interaction with other users in the community

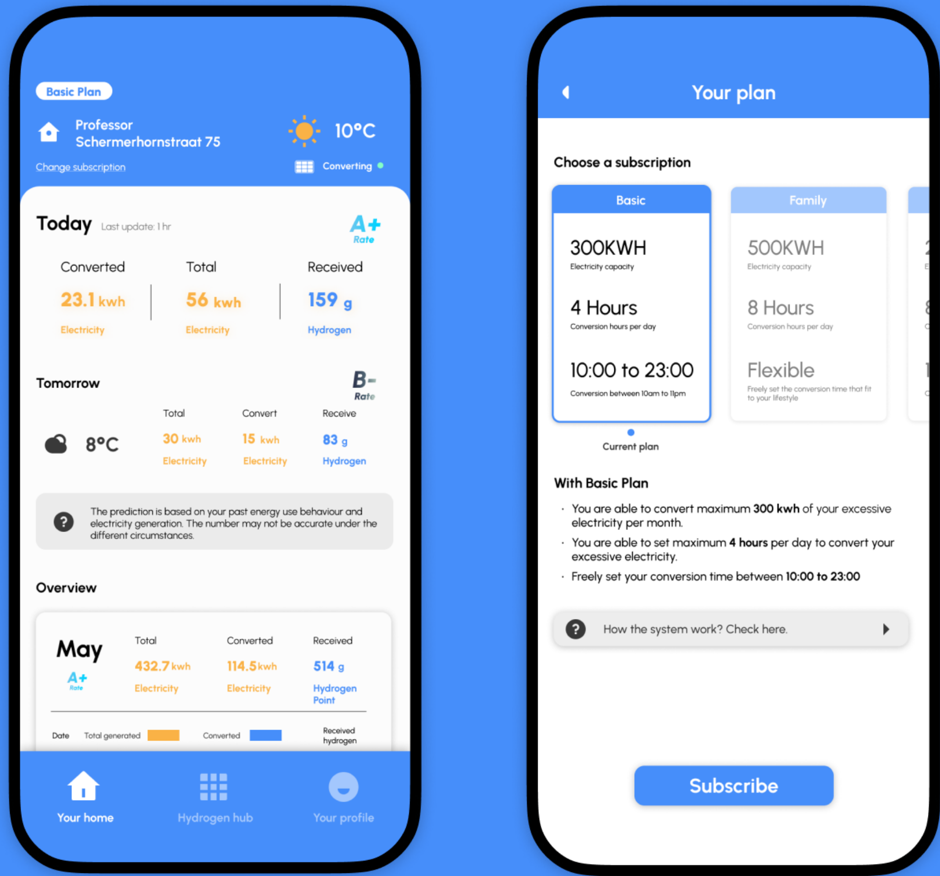
Two participants expressed a desire for the service to facilitate interactions within the community. They want to understand the community's electricity needs and contribute their power during those times. Currently, the service only provides the grid's status, which does not enable them to determine whether to convert their electricity to help alleviate congestion in the community grid.

Concerning the financial benefits offered by the service

Four participants expressed concern about the economic returns this service could actually provide. For them, the service needs to offer at least a better economic return than the Salderingsregeling policy to make it worthwhile. Additionally, since the rewards are given in the form of hydrogen tokens, users are unable to determine their actual value. They hope to quantify the value of the hydrogen tokens, for instance, knowing that 100 hydrogen tokens could allow them to drive 300 km, which would help them understand the economic benefits of using this service.

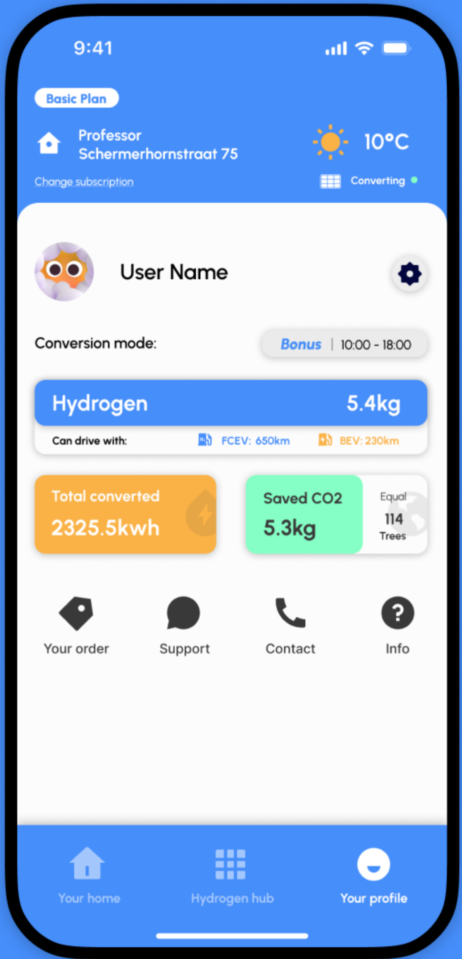
Participants from grid operators also questioned whether this service could reduce the cost of hydrogen production. They noted that the hydrogen they provide is imported from Belgium, which halves their purchase costs. While the cost of hydrogen production under this service model might decrease, it's unclear if it can match the cost of imported hydrogen. This uncertainty could result in electrolyzer operators being unable to sell their hydrogen, potentially undermining the viability of the entire service.

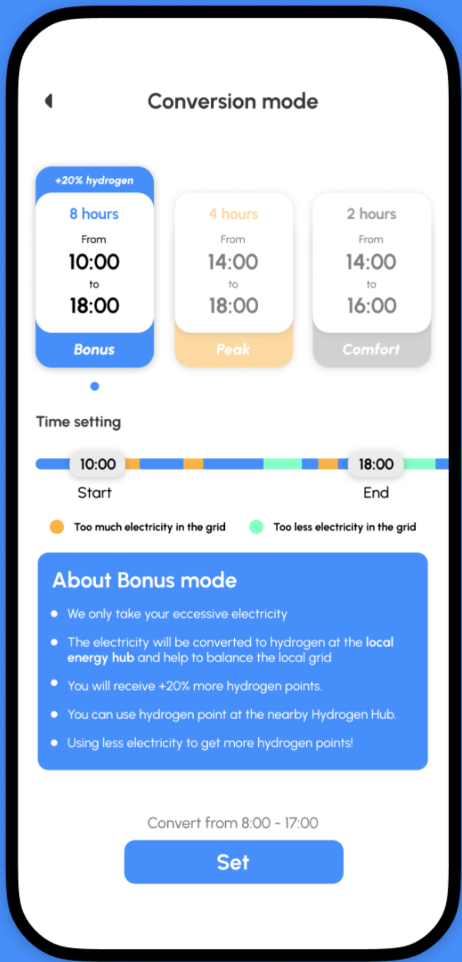
7.2 Concept Iteration/ Final Concept



Subscription plans

The new subscription plans replaces the need for users to manually set each conversion. Users can choose different subscription plans based on the amount of their excess electricity to maximize their benefits.The system will automatically use excess electricity for electrolysis and alleviating grid congestion.

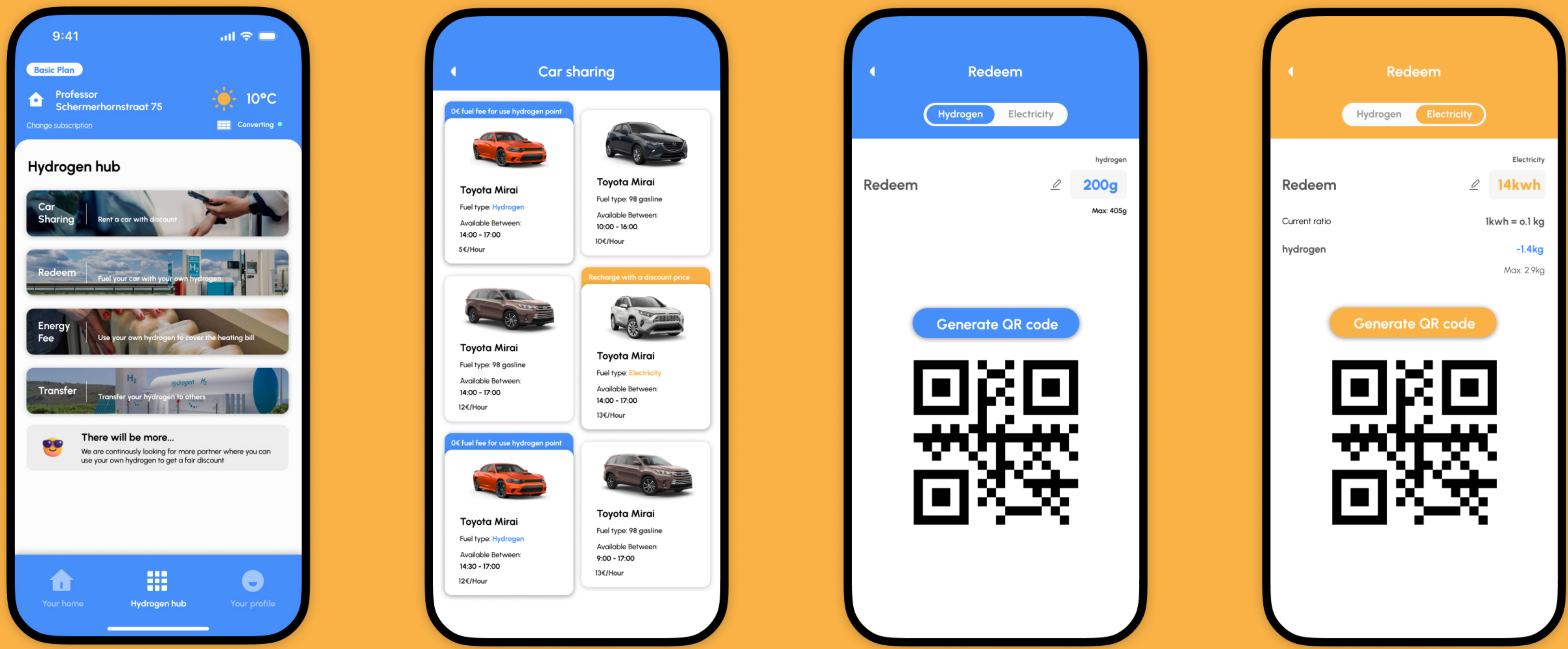




Flexible conversion mode

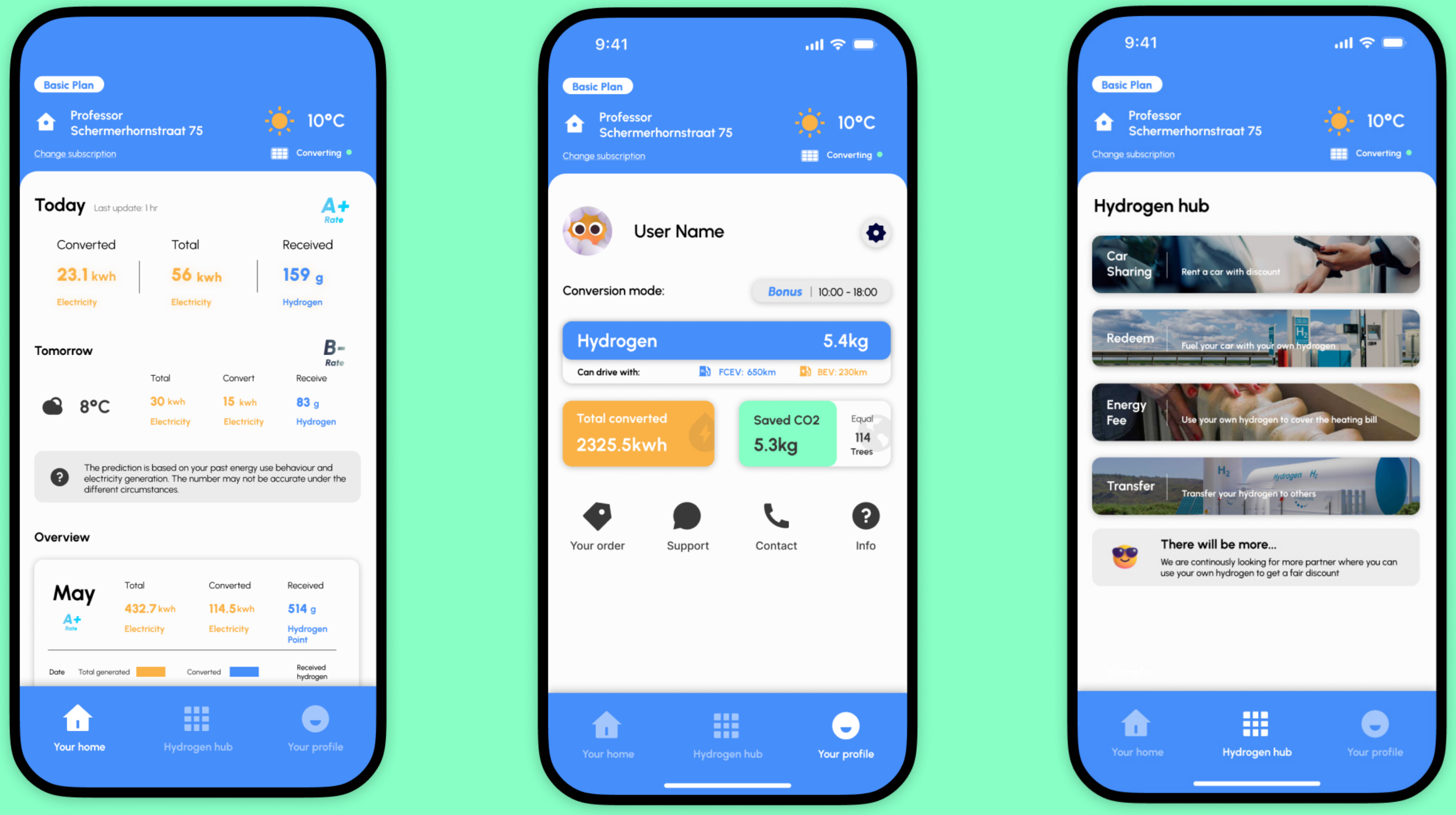
Along with the subscription model, users can now freely set the time periods for conversions. They can choose which time periods to send electricity back to the grid based on the local grid's historical status and their lifestyle.

Depending on the time periods they set, their returns can vary (for the same amount of electricity). Under normal conditions (when the grid is not congested), they will receive the usual returns. During demand congestion, the electricity they supply will earn additional hydrogen points. However, during supply peaks, they will not receive any rewards. Electrolyzer operators can also collaborate with this service to encourage users to supply electricity at specific times for extra rewards.



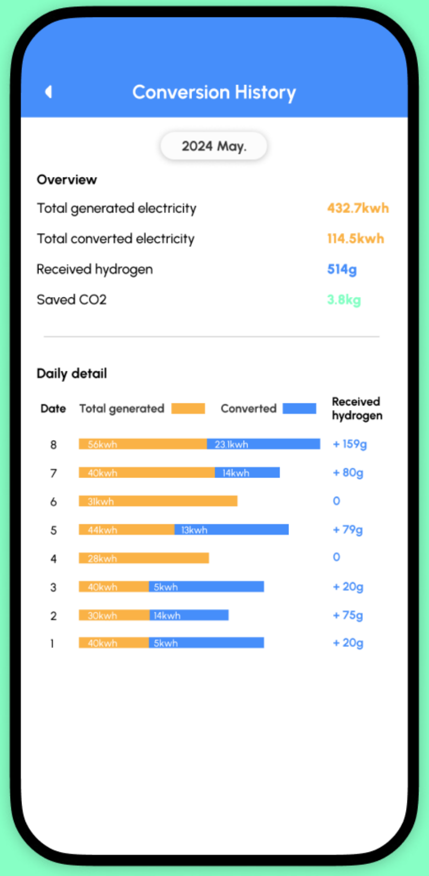
More ways of using hydrogen points

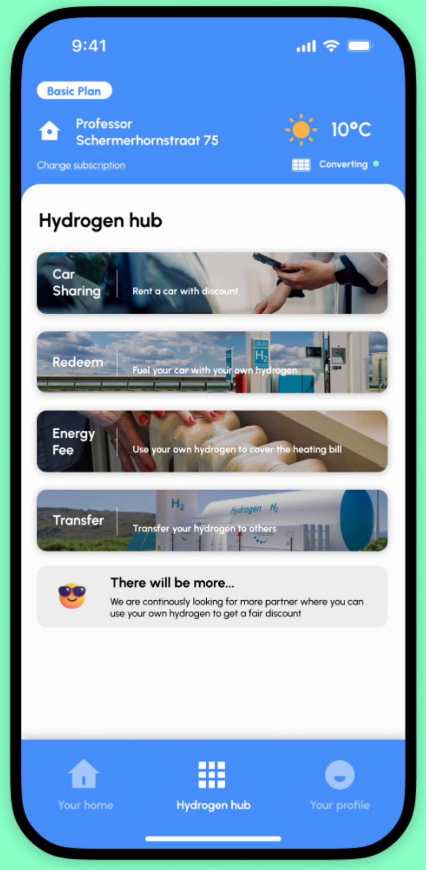
Users can use hydrogen points on third-party services based on different energy types. They can charge their electric vehicles or refuel their FCEVs using hydrogen points. Broader uses include renting electric vehicles or even transferring hydrogen points to others. However, since this service encourages users to utilize hydrogen-based services more, using hydrogen-related services will yield more significant benefits compared to other energy types.

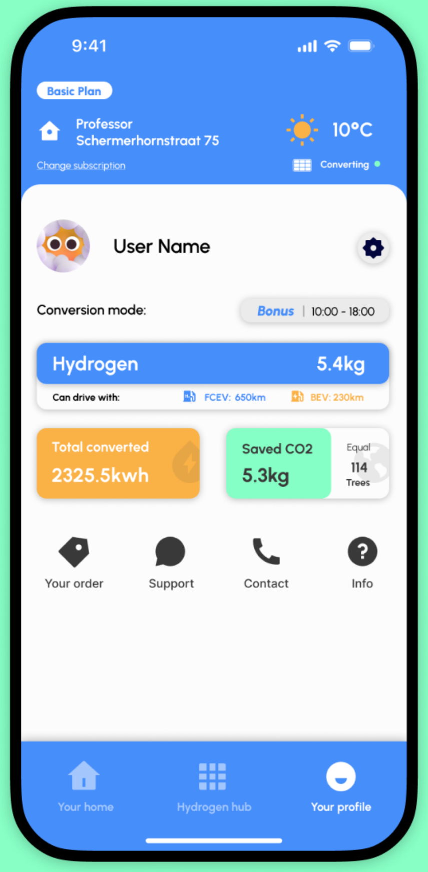


Re-arrangement of information hierarchy

The iteration also reorganized the information hierarchy within the app. Features and information were redistributed according to their type, making the app more intuitive and simpler to use. Additionally, more annotations were added to explain the operation principles and precautions of each feature.







More update

The iteration also drew significant inspiration from the testing phase. For instance, a dedicated page was added to explain how the entire service operates; more detailed energy usage history was provided; and hydrogen points were quantified into driving mileage to help users better understand the value of hydrogen points.

Try the design here

Chapter 8

Conclusion & Recommendation

Conclusion

This project initially used gigamapping to define hydrogen's role within the Dutch energy system, recognizing hydrogen as a key element in the country's energy transition. Hydrogen, as a green gas and energy carrier, has the potential to replace natural gas in transportation, heating, industry, and power sectors for deep decarbonization. However, the rise of electrification could hinder hydrogen's broader application. Research on the hydrogen supply chain and Dutch energy strategy revealed that the government and businesses prioritize green hydrogen development, emphasizing economic growth and sustainability. Currently, hydrogen is mainly applied in industrial heating, refueling stations, FCEVs, and space heating.

Expert interviews highlighted hydrogen's potential in transportation but identified challenges, including a lack of legislation, infrastructure, and green hydrogen supply. While the FCEV market for passenger vehicles appears limited, there is growing focus on long-haul and heavy-duty transport. Using CLD, system dynamics were analyzed, leading to three leverage points and four intervention ideas. The final design chosen allows residents to convert excess solar electricity into hydrogen for other uses.

The continued development envisions electrolyzers easing grid congestion and promoting hydrogen use. Initial prototype testing revealed openness to the service but highlighted areas for improvement, such as automating processes and enhancing community interaction. Post-iteration, users can select subscription plans, adjust electricity supply times, and use hydrogen points across various services, with improved clarity on service operations and potential financial benefits.

Recommendation

Due to time and resource constraints, the data sources in this project only covered a subset of industries, which may result in conclusions that are somewhat one-sided. Additionally, due to limitations in capability, the implementation of the final design is primarily focused on the user interface. While the project defines the overall service framework, certain technical aspects beyond the user interface and service model need further specification, such as determining the appropriate capacity of the electrolyzer and its compatibility with the energy hub. The proposed solution in this project suggests that hydrogen can play a crucial and irreplaceable role in grid interaction. Furthermore, the project assumes that the Salderingsregeling voor zonnepanelen policy will be discontinued in the future, introducing a certain degree of opportunism.

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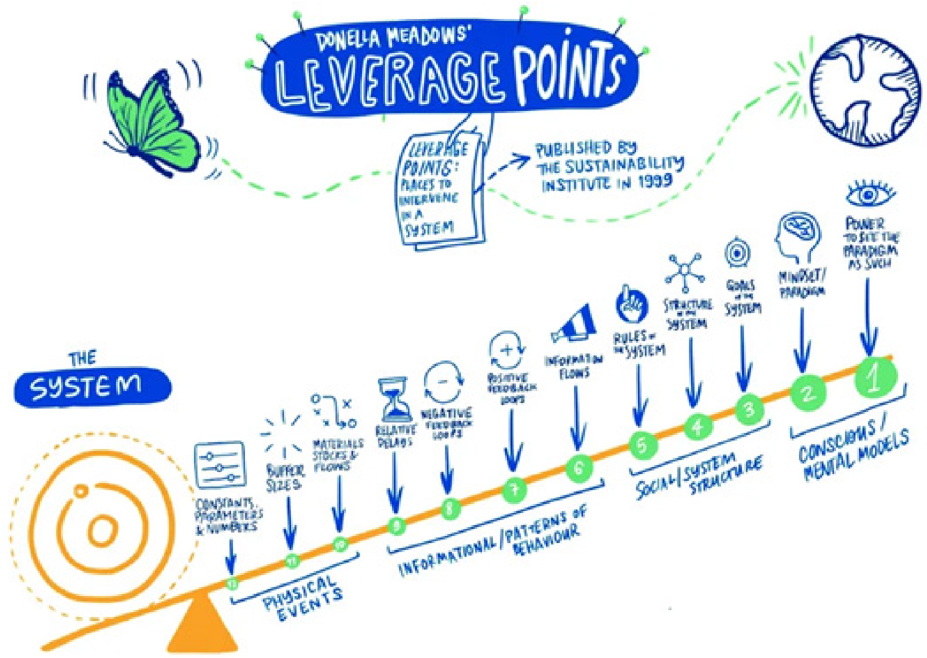
Appendix

Appendix 1: Leverage point theory



Meadows(2008) classifies interventions into twelve classes based on their impact. These categories are the leverage points(Image 5.1 - 1). The concept of leverage points highlights how interventions impact the system and the effectiveness of the impact. Imagine there is a weight on a lever. The greater the effectiveness of the impact, the greater the torque you have. In extreme cases, only a little force is needed to lift the weight. Meadows(2008) rank the leverage points from its effectiveness from high to low:

12. Constants, parameters, and numbers (such as subsidies, taxes, standards).

11. The sizes of buffers and other stabilizing stocks, relative to their flows.

10. The structure of material stocks and flows (such as transport networks, population age structures).

9. The lengths of delays, relative to the rate of system change.

8. The strength of negative feedback loops, relative to the impacts they are trying to correct against.

7. The gain around driving positive feedback loops.

6. The structure of information flows (who does and does not have access to information).

5. The rules of the system (such as incentives, punishments, constraints).

4. The power to add, change, evolve, or self-organize system structure.

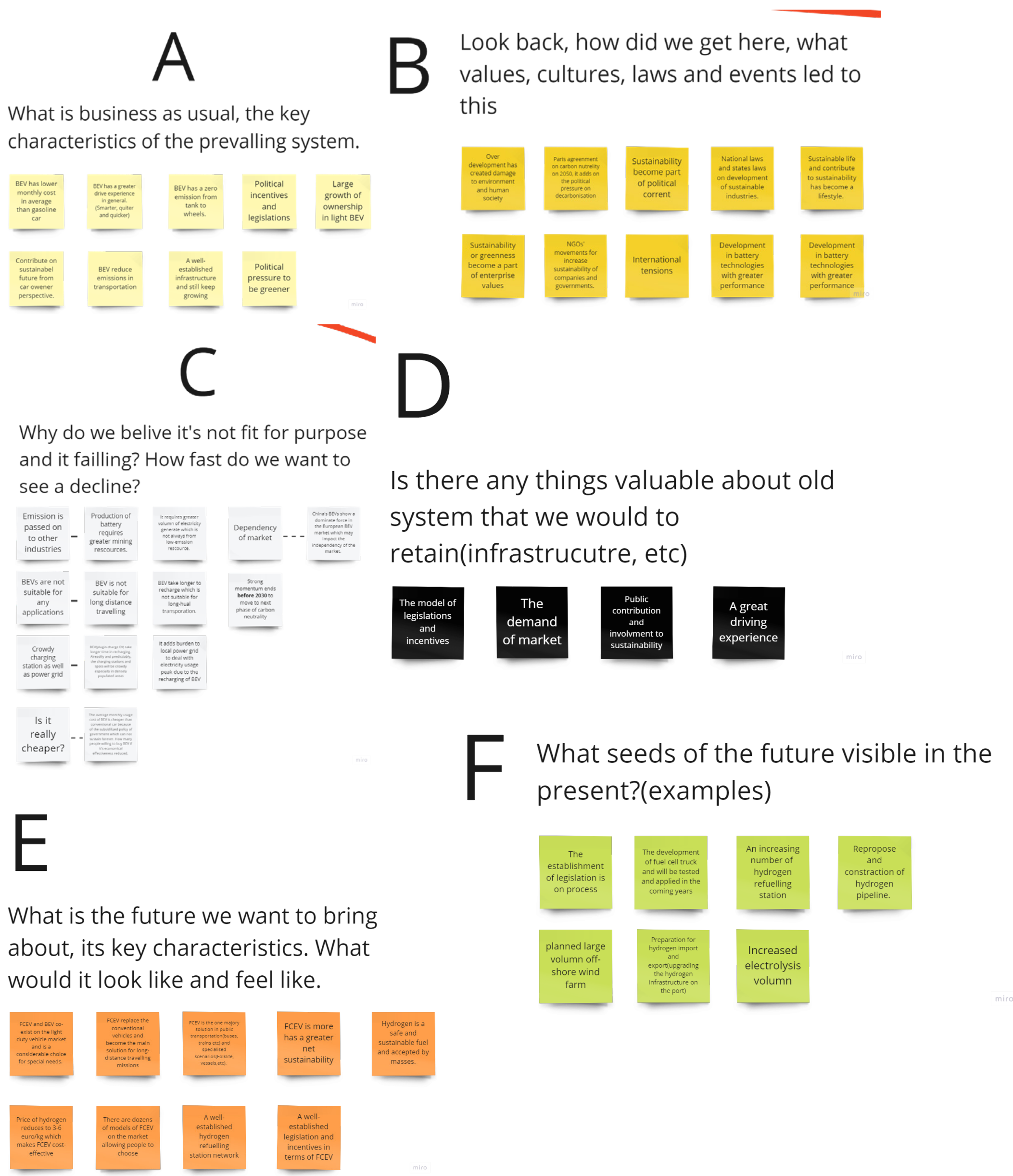
3. The goals of the system.

2. The mindset or paradigm out of which the system — its goals, structure, rules, delays, parameters — arises.

1. The power to transcend paradigms.

That would be too wordy to explain every leverage point in detail. Generally speaking, the leverage points with greater impact effectiveness bring a border perspective. However, that does not mean the lower leverage points are worse than those at higher levels. It is a matter of perspective and spreading the impact from bottom to top or from top to bottom.

Appendix 2: Result of Three horizons



G

Whose work are these present posibilites build upon? What history, values and culture are embedded within.

- The price of fuel cell has decreased due to the mature production method
- Hydrogen reflects the company's radical strategy in sustainable development
- Hydrogen as an energy carrier to break the boundary of different sectors
- Hydrogen has potential to achieve deep decarbonisation
- The raised awareness for climate crisis and urgent for energy transition
- FCEVs perform better at the long-haul transport mission
- Asian coutries took their action early in deploying FCEVs and relevant infrastructures
- Hydrogen refuelling station uses space effectively which is advantous for land shortage countries. (same space, serve more vehicles.)

H

How can they being scaled and spread? Giving examples of actors who are already working on it.

- Government sectors: collaborate with enterprises for hydrogen public transportation.
- HRS: discovering new bussiness model. Find local electrolyser to access green hydrogen.
- HRS: invite experts to talk with neigbours to reduce the concern about hydrogen safety.
- FCEV builder: Participate events, conference and matches to demostrate the greate performance of FCEV
- Government: provide support to FC heavy duty vehicles development and its applications.
- Government&HRS: large hydrogen production volumn to reduce the price of hdyrogen to make FCEVs more cost effective
- Government&HRS: Investment in Hydrogen infrastructure
- Enterprises: Interenterprise collaboration
- FCEV manufacturer: mature production technologies to reduce the price of FCEV.
- Industries: mature technologies in storage, production and transport hydrogen to reduce the price of hdyrogen.

I

What are competing vsisions by others, being pursued by others, could we collaborate or it is inherently competing

- **Battery Electric Vehicles & Alternative fuel Vehicles::** Decarbonise the transport industry by achieve zero emission from tank to wheel.
  → **Shared infrastructure, technologies, laws**
- **Zero emission transportation**: Choose transportation method has a net zero-emission

J

What is being disruptive(different factors, tech, political, cultural, ecological, etc)

- Autonomous Trucks/Autonomous long-haul transportation
- Energy system integration
- Autonomous Cars/driveless cars
- Supply chain carbon-footprint & track
- Cheap electricity
- Door to door public transportation
- Energy hub(from interviewee)
- Carbon footprint to individuals
- Autonomous car sharing service
- Underground hydrogen storage
- Energy trading
- Energy independency
- Raise of awareness of being more sustainable

K

What are the roots of them, would it being captured or harnessed, how to ensure they are harnessed.

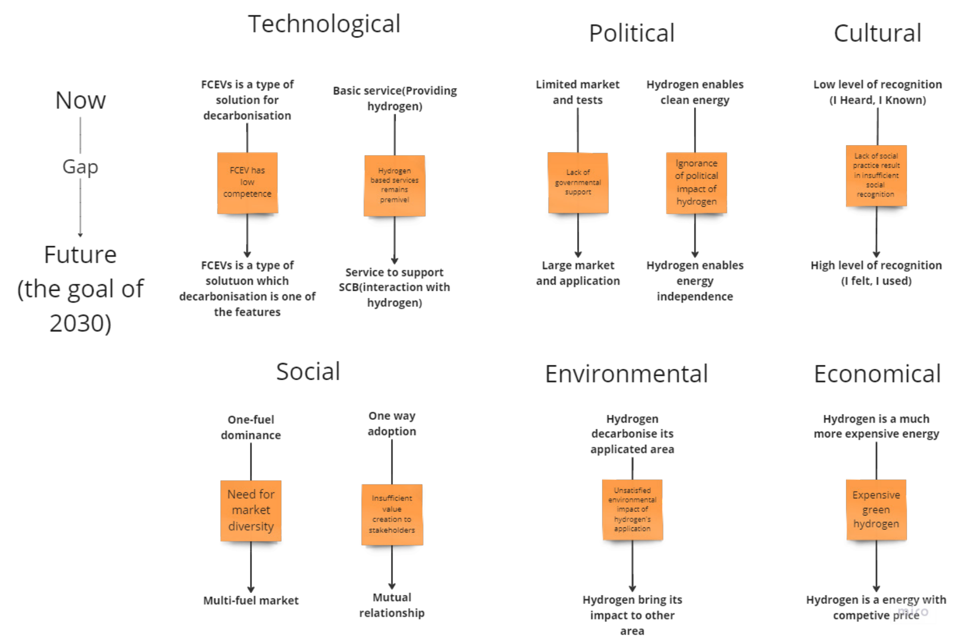
- Redefining the driving experience
- Energy transition: optimal energy system as a whole
- Sustainable consumer behaviour/ strategy → New service model and way of consumption
- Infrastructure upgrade
- Energy independecе

L

If you are a disruptive actors, how can I disrupt H1 and harness H3.

- **If i am a HRS owner**, I would build the infrastructure to support different types of zero emission vehicles, not just only for BEV or FCEV. Such as, use hydrogen as the energy carrier to provide electricity for charing point, in the meantime, FCEV can refuel hydrogen directly.
- If i am the **government**, I would populate the energy transition in transportation industry → If i am the **government**, I would push the decarbonisation progress for long-haul transportation
- Collaborate with other country to import hydrogen
- Incentives for products delivered by zero-emission transportation
- Design a platform that break out the boudaries between different section in hydrogen transportation industry
- Expand the volumn of renewable electricity generation

Appendix 3: All identified intervention space



Appendix 4: Intervention spaces assigned to the CLD