X. P. Szadkowski

Crossing the "Valley of Death"

Transitioning from green hydrogen production pilots to full-scale commercial production using transition management theories in order to realise energy transition ambitions

TU Delft

DNV

Front page picture: (Arquitecturaviva, 2021)

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Transitioning from green hydrogen production pilots to full-scale commercial production using transition management theories in order to realise energy transition ambitions

By

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in partial fulfilment of the requirements for the degree of

Master of Science
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'There are risks and costs to a program of action. But they are far less than the long-range risk and costs of comfortable inaction.'

John F. Kennedy

Preface

In this Master thesis, I present the results of my research on an analysis of the applicability of Strategic Niche Management concepts during the 'take-off- and acceleration phase' of green hydrogen production pilots, as performed in the period between September 2020 and May 2021, conducted in order to obtain my Master's degree in Construction Management and Engineering at the Delft University of Technology at the faculty of Civil Engineering and Geosciences.

To this end, it is a current topic of research, directed by researchers from the Transition Management field, as well as professionals that are involved in the development of green hydrogen production pilots in the Netherlands. Due to the fact that the Dutch government, the European Commission and the UNFCCC (United Nations Framework Convention on Climate Change) have stressed the need for decarbonisation solutions, there is a both societal and corporate feeling of urgency. I am therefore proud to say that I have had the opportunity to contribute to the awareness and understanding of a multitude of factors that manifest themselves during the 'take-off- and acceleration phases'. Factors that potentially might cause procrastination with regard to decarbonisation investments for the Energy Transition.

The front-page picture of this report reflects the Valley of Death. The fog underneath the bridge displaying the valley, and the crossing of this valley by the bridge that connects starting point 'A' with vantage point 'B'. I believe that crossing the valley of death can be realised by proverbially building bridges across industry, government and academia. It is a time where the necessity for an alternative is widely expressed and where the vantage point 'B' should be a shared target which can be realised by multi-disciplinary collaboration. The Millau bridge also reflects my origin in Civil Engineering (being one of the most beautiful artworks out there) and additionally reflects my masters in CME, which is all about collaboration and multi-disciplinary and multi-cultural work. The picture is therefore fit for purpose!

I would like to thank Martijn Duvoort for his guidance and for understanding the importance of doing research on this intriguing and challenging topic. The starting point of this thesis, an episode of the television program 'Tegenlicht' (Van Hattum, 2019) on the 'Deltaplan waterstof'. It was a source of motivation, continuously making me think about improvements and awareness on the policy and management side with regard to stimulating- and impeding factors that can be found in decarbonisation investment decisions that are carried out in the face of the Energy Transition. Ultimately preparing my graduation on the topic, I stumbled across the TIKI report, which brought us (me and M. Duvoort) into contact.

The contributions of all members of the graduation committee are gratefully acknowledged. The comments and dedication of all members are highly appreciated. I would like to thank Martijn Leijten for our valuable bi-weekly meetings and his broad knowledge and his passion and enthusiasm during the entire project. In particular, I thank Daan Schraven for the times you advised me on my course of action. Furthermore, I would like to thank Martijn Duvoort from DNV once more for sharing his expertise, the countless times gave concise feedback. Also, I thank Prof. Kornelis Blok for his coordinating role and for completing the graduation committee.
Finally, I would like to thank my family and friends for their understanding and support throughout this intensive time of research.

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Executive summary

Urgency

Ambitious decarbonisation targets that have been set by both the Dutch government and corporations alike can be achieved. However, this requires the current approach to fulfilling the energy supply and demand to be drastically changed over the next decade. Failure to do so will result in a prolonged energy transition which ultimately results in the failure of realising decarbonisation targets by 2030. This is particularly important because the development of alternative energy sources that is partly-necessary for the realisation of the energy transition, tend to have long lead times and are not straightforward to implement.

Purpose and scope of this report

Practical relevance

This report assesses development cycle of Dutch green hydrogen pilot projects. Green hydrogen production by means of electrolysis has been named as an indispensable alternative in the energy transition mix, because it can make an important contribution to the decarbonisation of energy-intensive industries, amongst others. Its development has gained traction across European companies, and manifests itself in a recent rise of feasibility studies and a significant portfolio of projects to be realised by 2040. However, it is not self-evident that these projects will be developed without hick-ups or friction.

Pilot projects – that are at the basis of this movement – require high investments, take high risks and require the formulation of joint visions across all involved parties. These high investments are needed to generate information on the performance and behaviour of the future products and product lines, and to get a better understanding of the market. But due to the fact that high investments must be made before uncertainties are reduced, the investment and the reduction of uncertainty are out of sync. Additionally, a variety of failure mechanisms may lead important investments to end up in the 'Valley of Death'.

Theoretical relevance

Transition management in general is in line with developments and changes that are currently observed in the energy transition. Nevertheless, a major challenge lies ahead of us in order to empirically validate the partly descriptive and partly prescriptive components of transition management. Strategic Niche Management (SNM) – as part of transition management theories – has proven useful for the analysis of success and failure of experiments with a range of sustainable radical innovations.

The theory advocates the creation of socio-technical experiments in which the various innovation stakeholders are encouraged to collaborate and exchange information, knowledge and experience, thus embarking on an interactive learning process that will facilitate the incubation of the new technology. Furthermore, SNM helps to provide insights into the nature of obstacles that potentially impede the development of market niches (i.e. pilot projects that need to be scaled-up in order to generate transition). Ever since green hydrogen pilots manifest the theoretical preconditions of a niche, SNM literature will be used to realise the objective of this research, which is:

⇒ *To further **elaborate, generalize** and **verify** the barriers that lead to procrastination during the pilot- and scale-up phases of green hydrogen pilots. And additionally capture the influence of Strategic Niche Management on these barriers in order to realise energy transition ambitions.*

The research question that follows from the research objective, and ultimately is the basis of this research:

⇒ **How can Strategic Niche Management (SNM) concepts be applied to aid the pilot- and acceleration stage of green hydrogen production pilots?**

Method & Analysis

The objective of this research has been realised by reviewing both theory and practice on the influence – of both corporate-internal and -external obstacles – during the pilot- and scale-up phase of green hydrogen technology. Additionally, the link between these obstacles and SNM theories and solutions has been assessed. In order to review and empirically validate the state-of-the-art literature, a qualitative research has been performed by means of single-case methodology. The theoretical data was verified by performing a case study in which a series of interviews with industry was performed. Based upon category, capacity, project phase and number of project-partners, five green hydrogen pilot projects were selected for this single-case study (e.g. PosHYdon, NorthH2, H2.50, H-vision, Oosterwolde electrolyser). From these pilots, a total of 19 parties were interviewed, mostly consisting of corporate entities. The results were analysed and consecutively validated by performing a second round of interviews and an exploratory survey.

Findings

Conclusions about SNM literature

Even though the theory is over two decades old, the niche development concept stands at the basis of transitions. The niche concept is widely adopted in transition management theory and is therefore still valuable in today's literature, as it is for the green hydrogen case. However, the description of the acceleration-, or scale-up phase of niche development is limited and provides little to know significant guidance for practitioners to use.

SNM introduces the notion of barriers that can impede the development of niches. The barriers in SNM are based upon ex-post research and are focused on a policy-based perspective. Moreover, limited to no empirical studies in the green hydrogen sector were conducted using SNM literature. As a result, the collection of barriers is limited and does not fully reflect the failure mechanisms that have been identified in this study. Governance- or policy-based barriers were complemented by the failure framework by Weber and Rohracher (advocates of transition management literature that aimed to summarise the scattered knowledge on failure mechanisms). Corporate internal factors were however not named at all – where it became clear that these also play an important role.

Conclusions about the Green hydrogen case

The development of green hydrogen technology in the Netherlands is currently based upon outspoken initiatives, feasibility studies and pilot projects and has not yet reached the scale-up phase. Therefore, the green hydrogen case is in line with the studied transitional phases of "take-off- and acceleration phases", which share similar characteristics. Furthermore, SNM advocates the creation of socio-technical experiments in which the various innovation stakeholders are encouraged to collaborate and exchange information, knowledge and experience, thus embarking on an interactive learning process that will facilitate the incubation of the new technology. This notion is in line with the philosophy of professionals that are currently involved in the development of green hydrogen.

Additionally, a collection of failure mechanisms has been identified in the interviews that are in line with, or can be explained by SNM theory. The top five of barriers that was identified as factors that potentially impede the development of green hydrogen technology consists of; lack of legislation and regulations, directionality failure, corporate-internal factors, lack of market supply and demand, lack of subsidy. Corporate-internal factors were however not mentioned in SNM literature, but it became clear that this failure mechanism plays a significant role nonetheless.

Recommendations

The first recommendations for further research are in line with the concluded lack of profundity that was observed for the description of the SNM framework with regard to the acceleration phase. This phase is crucial for the success of a niche to enter into the current market. It is therefore recommended to conduct further research on the acceleration and scale-up phase in order to provide a more in-depth explanation for this phase.

Secondly, the list of barriers that is provided in SNM literature should be complemented by the notion of corporate internal factors, as this is not momentarily the case. Furthermore, the list of barriers that is mentioned in SNM literature is incomplete for the green hydrogen case. This research concluded that a multitude of failure mechanisms leads to potential procrastination during the development of niche technologies. In order to tackle these failure mechanisms, a holistic approach would be preferred by professionals. SNM could play a role in providing sufficient information upon the failure mechanisms.
It is therefore recommended that SNM theory is updated in to a version that also reflects corporate-internal- and other factors in a holistic approach. This newly (to be renamed) iteration of SNM could also follow up on the knowledge gap that still remains with regard to the correlation, causality and time-dependents of barriers. Literature outside the direct realm of SNM should therefore be consulted.

Lastly, but most importantly, this research showed that corporate-internal factors play a significant role in potentially slowing down nice developments. This study resulted in the strong presumption that practitioners understand the dynamics of niche development and transitions, but do not act accordingly, i.e. penalising green investments by the fact that they continue to be seen through the same KPI's as for the 'traditional' regular investments. The evaluation of business cases for these decarbonisation technologies is predominantly focused upon the financial aspects, instead of corporate- or even sectoral risk. KPI's that are commonly used for the assessment of regular investment decisions are directly applied on pilot- and scale-up investment propositions. Scale-up investments specifically suffer from unprofitable outcomes due to insufficient input, vast unknowns, and rough assumptions.

It is therefore recommended that a new sort of decision framework should be developed, for especially the scale-up phase where its abundance of uncertainty, vast unknowns and rough assumptions are considered accordingly. For example, lower return requirements could be set for the future, alternative financing options could be investigated and a fit consideration of its uncertainties should be accounted for, i.e. an investment decision framework that is designed especially for scale-up project investments.

Limitations

The beforementioned projects differ in approach, goal, and technology. Therefore it may be difficult to draw conclusions about the hydrogen transition in general. Additionally, government perspectives were only based on state owned enterprises or companies (i.e. InvestNL, EBN and Nexstep) and literature. A perspective from the Ministry of Economic and Climate Affairs was not obtained. Therefore the cause of corporate-external barriers could not be determined from the governmental perspective. Lastly, one can argue about the validity of the case-study research in regard to the SNM framework since it is designed over two decades ago. Recent empirical studies of SNM in the hydrogen sector lack, which could make the validation of this reports' results difficult.

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1 Introduction

This chapter gives an introduction on this thesis – 'Crossing the valley of death' – by describing both the background of the subject as well as the motivation for performing this research. Thereafter, the research goals are defined, together with the scope of this research in Section 2.2. Lastly, the thesis approach and outline are briefly touched upon in Section 1.3.

1.1 Context

The energy sector is currently undergoing major systemic changes, popularly referred to as the energy transition. One of the most eye-catching parts is the transition from fossil to renewable energy. This transition crosses the borders of individual systems, market supply and demand, legislation, and corporate strategies amongst others. Transitioning from fossil to renewable energy has gained momentum both nationally and internationally in the past decade due to the Paris Climate Agreement, which aims to limit the effects of climate change by large scale decarbonisation efforts (United Nations, 2015). Moreover, the Dutch Government aims for a fossil-carbon-free, sustainable and circular economy by 2050 (Ministry of Economic Affairs and Climate Policy, 2020).

Such a far-reaching transition to a fossil-carbon-free, sustainable and circular economy requires a multitude of green energy solutions in order to decarbonise the energy supply- and demand chain that touches upon many industries. The current conventional energy market is highly demand driven. When there is a high demand for electricity, power plants increase their production and in cold periods we tap into gas storage. But the production of solar and wind power is much less easy to regulate. In the future, on cloudy or quiet days, we will not be able to make the wind and solar power plants run any faster. This requires a change in the way the energy market is managed. Alternative policy models and market mechanisms for back-up plants and energy storage must provide an answer (TNO, n.d.-d). Thus, the current approach to fulfilling the energy supply and demand must drastically change. One of the more prominent alternatives (for reaching decarbonisation goals) that has gained traction across many industries (as raw material within the chemical industry, as fuel within the mobility sector, as a solution to the flexibilization of the energy sector) and is adopted as a promising alternative by many governments is green hydrogen. Other sorts of hydrogen are elaborated in Appendix A.

(Green) Hydrogen is indispensable in the energy transition mix, because it can make an important contribution to reducing the CO_2 emissions of energy-intensive industries, among others (TNO, n.d.-a). Currently hydrogen is mainly used as a raw material for the production of fertilisers and the desulphurisation of fuels. Current hydrogen production is now based on natural gas and is associated with high CO_2 emissions. Much remains to be done to stimulate the production and use of green hydrogen, derived entirely from solar and wind energy. Electrolysis, splitting water into oxygen and hydrogen, using electricity from wind and sun is the main option (TNO, n.d.-b).

Momentarily, the capacity of the electrolysers, which are currently being deployed in subsidised pilots, does not exceed 1 to 10 megawatts (TNO, n.d.-b). In order to supply the Netherlands with CO_2-free hydrogen, electrolysers should produce at gigawatt level (Bellona, 2020). That means scaling up by a factor of a thousand. In the Netherlands, a multitude of pilot projects aim to be built before 2030 in order to show their potential (De Laat, 2020). A number of promising pilot projects will be elaborated upon later in this report.

The above-mentioned pilot projects, will help realising the envisioned energy transition (Rijksoverheid, 2019). It reflects the ambitions to produce a minimum of 27% of used energy from sustainable sources (Ministry of Economic Affairs and Climate Policy, 2020). In order to realise these energy transition ambitions, the development of hydrogen production technologies undergo a transition from R&D (Research and Development) into new products and services. According to a report from the European Commission (European Commission, 2015) this transition consists of the three steps. First R&D is translated into product development, next product development translates into competitive manufacturing.

However, the translation from product development, such as pilot production and demonstration projects, to industrial applications (named 'competitive manufacturing' in Figure 1) are found at the heart of the 'Valley of Death', where both costs and risks are very high (European Commission, 2015).

Many pilot projects never reach the market and thus the societal and economic impact of scarce public and private resources is suboptimal. Figure 1 is a graphical representation of the steps that 'key enabling technologies (KET)' – such as green hydrogen production – go through on their way to competitive production, i.e. KET's cross the valley of death.

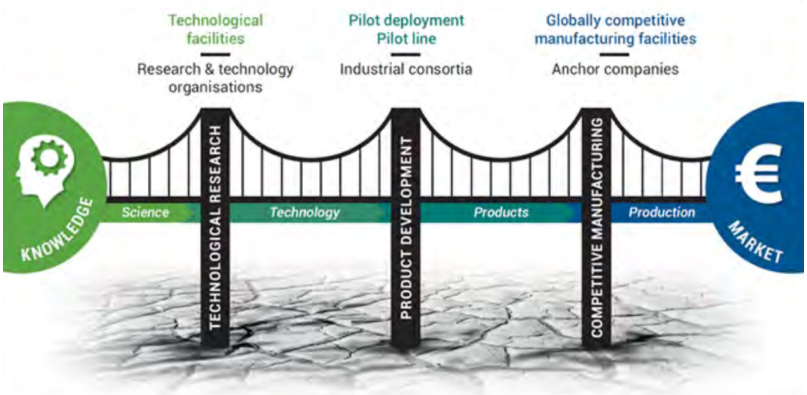

Figure 1 - Crossing the 'Valley of Death' (European Commission, 2015)

1.2 Problem statement

The envisioned energy transition ambitions seem to be difficult to realise. Last year, the used energy from sustainable resources amounted to 8,6% from the total amount of energy used. In 2018, this was 7,4% (CBS, 2020). An on EU-level agreed amount of sustainable resources used by 2020, is set on 14%, which most likely will not be realised by the Netherlands. Hydrogen technologies, being one of the solutions for the realisation of decarbonisation goals, first came into the spotlight in the second half of last century. Since then, it did not however catch onto the energy market as a true contender of fossil fuels. It is therefore not evident that green hydrogen will be incorporated into existing market structures. In order to further elaborate on this notion, the practical problem will be discussed next. Thereafter, the link with transition literature will be made and explained.

1.2.1 Practical problem

Ideas of what might be more sustainable technologies exist, but their development is prone to lock-in situations and procrastination during development and acceleration stages. Reasons like long development times, uncertainty about the market demand, the need for change at different levels – in organisations, technologies, infrastructure and the wider social and institutional context – might work as barriers for the development of emerging technologies (Kemp et al., 1998). Hydrogen has the potential to play an important cross-cutting role in a future low carbon economy, with applications across the industrial, transport and power sectors (Hall et al., 2020). However, a full electrification of our current energy systems could be prohibitively expensive and technologically challenging, given the important storage, flexibility, chemical, and heating attributes of current fossil fuels (Hall et al., 2020). Nonetheless, low carbon hydrogen could mimic these attributes without the associated emissions, providing significant value across many sectors.

Most of the proposed 'green hydrogen' ambitions are planned to be realised by 2030. However, prior to the realisation of these ambitions, pilot projects need to be realised and finalised successfully in order to show the potential of green hydrogen production in general, as well as the scalability of the technology. Pilot projects in general require high investments, take high risks and require the formulation of joint visions across all involved parties (Kemp et al., 2007). These high investments are needed to generate information on the performance and behaviour of the future products and product lines, and to get a better understanding of the market (European Commission, 2015). But due to the fact that high investments must be made before uncertainties are reduced, the investment and the reduction of uncertainty are out of sync.

This can lead to economic risks for private investors and enterprises and often leads companies to decide not to invest in pilot production (European Commission, 2015). The sum of all these individual decisions creates the Valley of Death.

Apart from the risk that is apparent during the pilot- and scale-up stage, as well as limited governmental stimulation in the past decades, the development of hydrogen technologies was procrastinated upon (Hall et al., 2020). Hydrogen technologies have gone through several periods of hype over the past few decades. Initially stimulated by the oil crisis in 1973 (Figure 2), countries started exploring alternative sources of energy to reduce import dependency. During the 2000s, the drive towards hydrogen technologies was aimed at rapidly expanding their role in the transportation sector. Due to high costs of hydrogen technologies, along with a lack of sustained policy support at the time, there was no major uptake two decades ago. As governments and businesses discounted hydrogen on the basis of past failures, a 'trough of disillusionment' then followed (Figure 2). However, this time there are three major factors that drive change for the 2020s, including (Hall et al., 2020):

1. Rapid cost reduction renewable electricity;
2. Strong cost reduction and performance improvements of electrolysers;
3. Deep de-carbonisation is needed to tackle climate change.

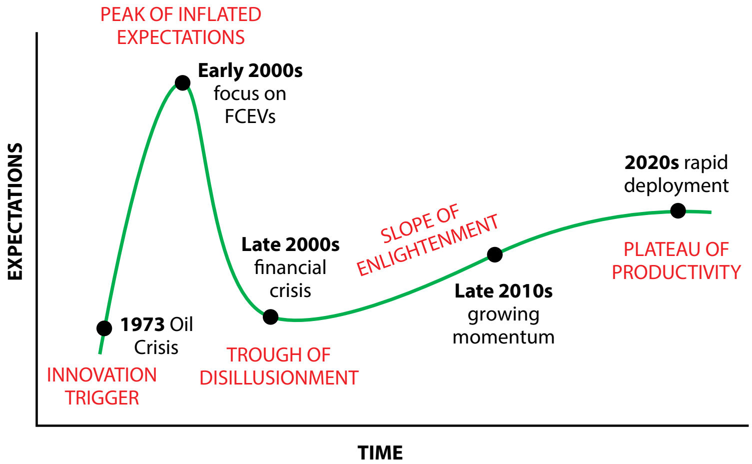

Figure 2 – The hydrogen hype cycle (Hall et al., 2020)

1.2.2 Practical problem – National perspective regarding the importance of hydrogen

A significant number of policy changes is required to meet the ambitious plans for hydrogen development in the Netherlands and to mitigate the risk of the Valley of Death. However, in the Netherlands Climate and Energy Outlook (Marian Abels-van Overveld et al., 2020), it is clear that the Netherlands is lagging behind other European countries in achieving overall CO_2 reduction targets (Lambert & Schulte, 2021). The report suggests that climate policy in the Netherlands will focus initially on the promotion of renewable power generation (Marian Abels-van Overveld et al., 2020), so it is less clear to which extent hydrogen will be a priority for policymakers. This has also become apparent by the limited financial stimulation that has been proposed by the Dutch Government, in comparison to multi-billon euro programs in other European countries (Lambert & Schulte, 2021).
After Germany, the Netherlands has the highest demand in excess of 50TWh of hydrogen per year. Nearly all this production is currently grey hydrogen that will need to be decarbonised or eliminated on the journey to net-zero (Lambert & Schulte, 2021). Moreover, on European scale, the Dutch Government will subsidise only €338 million into R&D of green hydrogen production only (Ministry of Economic Affairs and Climate Policy, 2021), which is relatively small in comparison to multi-billion euro schemes (> €5 billion) that have been proposed by Germany, France, UK and Italy (Lambert & Schulte, 2021).

The making- and understanding of a (energy) transition seems to be causing political struggle, destabilisation and uncertainty (European Commission, 2015). Due to these pressures, a transition can get stuck in a lock-in or even break down (i.e. the 'Valley of Death'). Pilot production however, is a significant step in the development stages of a KET (Key Enabling Technology). Only after pilot projects have been realised, the 'valley of death' can be crossed in order to create a market for green hydrogen (i.e. the acceleration or scale-up of a KET) (European Commission, 2015). Green hydrogen can play a significant role in reaching decarbonisation goals, as part of the energy transition.

But only can it do so when it's technological potential has been proven, and the technology of electrolysis is scaled-up to market scale.

Thus, there are many factors at play that do not make it apparent that current green hydrogen projects will become a success. On the one hand the time-factor is at play (with ambitious decarbonisation targets set for 2030 and 2050). On the other hand, strategic-factors that manifest themselves in policymaker prioritisation and investment decisions by private investors and enterprises into pilot production require attention. By failing to respond to these factors, that are of both internal- and external nature (read: internal corporate barriers, and external corporate barriers) (Vermunt, 2016), the scale-up- or acceleration phase (the translation of the product development step into competitive manufacturing) might slow down further or even stop (Vandevyvere & Nevens, 2015).

Pilot production needs 'fertile soil' in which inventions can grow into successful businesses (European Commission, 2015). Finding partners, establishing trust and creating a long-term, agile innovation ecosystem is difficult and requires commitment. The above-mentioned factors and barriers raise the question of why new technologies are not introduced into the marketplace when their benefits to society are so evident? How will the Netherlands reach her decarbonisation efforts by 2030 if it's currently not actively promoted by the government? Will the private sector be able to realise these ambitions by themselves?

1.2.3 Theoretical problem – Transition management in general

In order to realise energy transition objectives, pilot projects need to be accelerated out of the 'Valley of Death' in order to realise this transition. Transition Management concepts seem to be more applicable then ever (Loorbach et al., 2015) and might be used to aid the scale-up phase of green hydrogen production technologies to transition into full-scale commercial production in order to realise energy transition ambitions.

Transition management is generally in line with developments and changes that are currently observed in the energy transition – like it was when thinking about public administration in recent decades, such as network and process management, interactive and participatory policy, multi-level approaches and management focused on learning and adaptivity. However, where these approaches are mainly process-oriented and often originate from the analysis of control problems in practice, transition management offers a conceptual framework that makes it possible to arrive at a targeted mix of control forms (Loorbach et al., 2015).

Momentarily, a major challenge still lies ahead of us in empirically validating the partly descriptive and partly prescriptive components of transition management in such a way that a scientifically well-founded concept and steering framework can also be applied and further developed in a broader social context, certainly also internationally (Rotmans et al., 2005). Consequently, questions that remain unanswered in transition management research are:

- What type of transition management do we need for other stages of transition, especially the acceleration stage (Loorbach & Rotmans, 2010)?
- How can basic ideas and principles underlying transition management be translated into specific operational models that would tune in with the acceleration stage (Loorbach, 2010; Van den Bosch & Rotmans, 2008)?
- Which bottlenecks for anchoring and accelerating initiatives within the energy sector can be identified and classified – especially for the green hydrogen efforts currently undertaken in the Netherlands (Hekkert et al., 2007)?

1.2.4 Theoretical problem – A brief introduction into Strategic Niche Management and procrastination

Strategic Niche Management (SNM) – a branch within transition management theory – might help provide insight into the nature of bottlenecks or obstacles that are at the base of slowing down the acceleration stage. SNM advocates the creation of socio-technical experiments in which the various innovation stakeholders are encouraged to collaborate and exchange information, knowledge and experience, thus embarking on an interactive learning process that will facilitate the incubation of the new technology (Caniëls & Romijn, 2008). This is in line with the development stages that were previously mentioned for KET's (European Commission, 2015).

Furthermore, SNM has proven useful for the analysis of success and failure of experiments with a range of sustainable radical innovations, such as wind energy, biogas, public transport systems, electric vehicle transport and eco-friendly food production (Caniëls & Romijn, 2008). It might therefore provide pointers as to how to overcome obstacles that ultimately lead to inertia within the acceleration stage.

However, SNM was developed in the first decade of this century, and its writers have indicated the need for improvement and expansion. In particular, SNM has been seen to be useful to some extent for managing pilot projects, but with few exceptions these have remained isolated technological experiments that did not evolve into actual niches (emerging markets); And where niche status was attained, this constituted mainly limited technological niches that did not evolve further into market niches (Caniëls & Romijn, 2008). Stated more generally, there is still a lack of understanding in SNM about the processes by which experiments can ultimately culminate in viable market niches that ultimately will contribute to a transition. Until now, SNM has mainly been used as a research tool and policy claims that have been made by SNM researchers still remain a promise.

Additionally, SNM as proposed by its writers has not been developed and tested for the green hydrogen niche yet. Still, there is little expertise, knowledge and experience in defining these ‘obstacles’ (that will be distinguished in this report by external- and internal barriers) during the acceleration phase of a transition, or more specifically, during the acceleration phase of green hydrogen electrolyses projects as part of the hydrogen transition. These barriers might lead to procrastination of the overall energy transition (in which the hydrogen transition plays its part) as well as slow down needed developments that fuel the transition. The study of SNM dates back over two decades, but may be more actual than ever before.

The theory so desperately needs real-life experimentation in society (Caniëls & Romijn, 2008). In contrast, Dutch green hydrogen pilot developments and its acceleration into the energy market might bring along various hick-ups as became apparent from past experiences (Duvoort, 2020; European Commission, 2015; Hall et al., 2020; Kemp et al., 1998). There is a strong indication that the acceleration stage of green hydrogen technologies might therefore benefit from a framework that is based upon the lessons learned during the development of niches in the past century, consequently aiding the realisation of energy transition ambitions. Therefore, this research will focus on the application of SNM, that finds its application within the acceleration stage and is used to both analyse and research market niches. The niche that will be used as a case-study for this research is a combination of green hydrogen production pilots in the Netherlands. Specific cross-sectoral applications and related technologies will not be discussed in this report.

1.2.5 Summarising the problem statement

In summary, it has been shown from the review on both the theoretical- and practical problem of the hydrogen transition that a smooth adoption of green hydrogen into the market is not self-evident. There are many reasons causing a delay of important developments of green hydrogen production. In order to achieve the targets in the Dutch Climate Agreement, it is required that the hydrogen transition accelerates at a significant rate (Ministry of Economic Affairs and Climate Policy, 2020). This claim therefore stresses the significance of this research and can be summarised by the following reasons:

- ‘Trough of disillusionment’ as described in the past;
- Relatively small investment into the development of green hydrogen pilots by the Dutch Government;
- A multitude of factors that can lead to procrastination during pilot- and acceleration stages;
- A validation of theoretically found barriers that lead to procrastination have not been empirically substantiated for the hydrogen transition;
- A lack of case studies into Strategic Niche Management;
- And the role of SNM for the green hydrogen niche has not yet been defined,

To illustrate the uncertainties in the future potential of hydrogen in the Netherlands, as well as exploring potential reasons that might lead to procrastination of the transition, this research aims to look into theories that might remedy factors leading to procrastination.

1.3 Thesis outline

The contents of this thesis are built up by the following sequence. Chapter 1 introduced the context of the research concerning the relevance of the topic as well as the problem statement upon which this research will be based. In chapter 2 the research scope, research objective and research questions will be given. Subsequently, the methodology is described in Chapter 3. Chapter 4 elaborates upon the literature study is performed on Transition Management theories in general – in order to understand the background of transition management before diving into the SNM theory. Thereafter, Chapter 5 discusses the practitioners' perspectives as part of the empirical study. Next, both theoretical- and empirical results are analysed and validated by a second round of interviews and with the aid of a specifically designed explorative survey in Chapter 0. Thereafter, Chapter 7 summarises the conclusions of this research. The final chapter of this report, Chapter 0, will list recommendations for further research.

2 Research objective

As a result of the previous section, the main goal of this Master's thesis is defined as follows:

⇒ *To further* ***elaborate, generalize*** *and* ***verify*** *the barriers that lead to procrastination during the acceleration stage of the hydrogen transition (as part of the energy transition). And additionally capture the influence of Strategic Niche Management – as part of Transition Management theories – on these barriers in order to realise energy transition ambitions.*

The objective of this research is to give insight into the application of SNM concepts during the acceleration stage of green hydrogen production projects. This research aims to investigate which barriers cause corporate decarbonisation efforts to be procrastinated upon and assess how SNM theories can aid in overcoming these barriers. Consequently, this research aimed to achieve both a theoretical and practical purpose by the following objectives:

1. Gather and provide academic and empirical data on the causal relationship between internal- and external barriers and procrastination during the acceleration stage of emerging technologies (specifically green hydrogen electrolysis) as part of the energy transition. In doing so, this study aims to capture the cause-effect mechanisms between these barriers and the procrastination with regard to investment decisions in the industry;
2. Find practical reasons for these barriers within the case study and propose solutions for overcoming the vulnerabilities during the acceleration stage;
3. Propose DNV with a conceptual framework (mentioned in point 1 and 2) that will stand at the base of understanding and predicting where and why inertia is caused within companies with regard to investment decisions into emerging technologies. Moreover, DNV will be provided with an advice on how to alter these barriers, as well as advice on further research that can be performed within the field of internal corporate barriers that lead to procrastination with regard to investment decisions in innovative technologies.

This will be done by reviewing the theories and practice on the influence of both external- and internal corporate barriers on the development of green hydrogen projects during the acceleration stage. The link of these barriers with SNM theories and solutions will be assessed in this research. For this purpose, the focus of the research will lie on corporate parties that are currently involved in the development of green hydrogen pilots in the Netherlands. Further analysis on transition management literature is however required in order to grasp the idea behind the resulting research question that will be mentioned in Section 2.1.

2.1 Research questions

Now that the problem statement (Section 1.2) and research objectives have been stated and performed, this section introduces the research questions. To achieve the objectives and close the gap of knowledge and practice, the following research question has been formulated in order to be answered during the thesis research:

⇒ **How can Strategic Niche Management (SNM) concepts be applied to aid the pilot- and acceleration stage of green hydrogen production pilots?**

The research question has been divided into several sub questions. This helps to make the research comprehensible and structured. The sub questions will contribute to the understanding of the subject and analyse the theoretical and practical elaboration in support of the main research question.

1. What is the role of Strategic Niche Management (SNM) within the pilot- and acceleration phase?
2. What are the obstacles that create inertia during the pilot- and acceleration stage and lead to the procrastination of decarbonisation investment decisions?
3. What SNM instrument can be proposed to overcome the obstacles (mentioned in sub question 2) during the pilot- and acceleration stage?

2.2 Scope

Since transition management and specifically SNM are broad topics, this report is limited in scope to ensure that the research is finalized within the given time frame. The boundaries of the research (scope of this research) are shown in Table 1. Firstly, the chosen sector of analysis consists of 'green hydrogen production' projects that are currently tendered or realized within the Netherlands. To be more specific: projects that are demonstrating the technology of electrolysis on the basis of R&D and laboratory findings.

Furthermore, the research focuses on the pilot- and acceleration (scale-up) phase of green hydrogen production projects. This phase encompasses pilot projects that are found between the R&D phase of technological development and the competitive manufacturing phase (European Commission, 2015). In transition management terminology the pilot projects within the acceleration phase, entails the phase in between the 'take-off phase' and the 'institutionalization phase', as will be later explained in Figure 5 from Section 4.1.

Table 1 - Scope of the research

	In scope	**Out of the scope**
	Theoretical part	
Transition management theory	Strategic Niche Management, 'Failures framework'	Multi-level perspective, Technical innovation management
Project- / transition phase	Pilot- and acceleration phase	Predevelopment- (R&D), and stabilization phase
	Empirical part	
Sector	Green hydrogen production (electrolysis)	Other emerging technologies
Perspective	Corporate perspective	Governmental-, consultants' perspective
Project objective	Investment decisions into pilot and scale-up production applications	Investment decisions into R&D or regular market applications

The chosen research methodology (Chapter 3) has provided the ability to gain a large amount of knowledge on the applicability of SNM in the hydrogen transition and vice versa. However, this study has some limitations that are highlighted below.

2.3 Theoretical-, practical and societal relevance

The following sub-sections will summarise and briefly explain the theoretical-, practical- and societal relevance of this research.

2.3.1 Theoretical relevance

In terms of scientific relevance, transition management literature forms the basis for the experimental development of a range of new instruments, strategies and actions to influence the speed and development of sustainability transitions (Loorbach et al., 2015). Of the four phases (predevelopment, take-off, acceleration and stabilisation) in the S-Curve model of J. Rotmans (Rotmans et al., 2001), predevelopment and take-off phases have received the most interest (Gorissen et al., 2018). The acceleration phase however, has thus far been under-conceptualised in the literature (Gorissen et al., 2018). By gathering new empirical data and combining theory with practice, this research contributes to a better understanding of the internal- and external barriers that might cause procrastination. Furthermore, the applicability of SNM for both the hydrogen case and the acceleration stage specifically, will be determined. This is particularly beneficial, since the results of this research might lead to insights regarding the solvability of the barriers using SNM.

2.3.2 Practical relevance

The European Union, the Dutch Government (Rijksoverheid, 2019) and numerous companies have set out long-term visions in order to express their energy transition ambitions. These entities have different backgrounds, varying objectives and varied interests. With promising hydrogen pilot projects on the horizon, the industry appears to be optimistic about the acceleration stage (the translation from demonstration projects, to industrial applications).

Most of the proposed 'green hydrogen' ambitions have been envisioned to be realised by 2030. However, prior to the realisation of these ambitions, pilot projects need to be realised and finalised successfully. Pilot projects in general require high investments, take high risks and require the formulation of joint visions across all involved parties (Kemp et al., 2007). But due to the fact that investments, the reduction of uncertainty and a common vision are out of sync during the acceleration stage, many of these pilots never reach the market (European Commission, 2015). Historically, the development of hydrogen technologies was procrastinated upon (Hall et al., 2020). This time however, the stakes are higher due to pressure from the Paris Agreement as well as society in the race for decarbonisation efforts. This research sets out to map the different reasons (later on referred to as: barriers) that might cause disappointing investments, unsuccessful reduction of uncertainty and a common vision to be out of sync, and might ultimately lead to procrastination in regard to decarbonisation efforts.

Thus, value will be added by creating awareness of the complexity of the hydrogen transition (or any transition for that matter) by mapping possible causes for procrastination. A rise in awareness might help safeguard the ambitions of the involved entities. Furthermore, the results of this research might help overcome procrastination due to internal and external pressures (Vermunt, 2016) in order to escape the 'Valley of Death' in the fastest reasonable time.

2.3.3 Societal relevance

As a result of climate change reports and forecasts that potentially endanger various places throughout the world, the need for solutions is apparent. Furthermore, the solutions that are 'out there' should be realised as quickly as possible in order to push back the consequences of climate change. The energy transition plays an important role, as has become apparent during the Paris agreement in 2015.

Furthermore, during the State of the Union in 2020 by the President of the European Commission, far-reaching reforms and an optimistic view was set in order to reduce emissions by at least 55% by 2030. These reforms and goals were set in the European Green Deal that urges the continent to become climate neutral by 2050 and thus meeting its Paris Agreement obligations. Apart from a vast revision of the EU's climate and energy legislation to make the continent 'fit for 55', the President further announced that 37% of the €750 billion #NextGenerationEU budget will be invested in European Green Deal objectives, including European hydrogen projects (European Commission, 2020).

2.4 Professional collaboration for this research

This research was executed as an independent TU Delft study, in collaboration with the international consultant firm of DNV. DNV primarily provided professional advice and supervision from Dr. M. Duvoort concerning the scope and methodology regarding the empirical part of this thesis. Moreover, DNV provided the opportunity to contact people from their professional network. Interviews that were carried out for this research were carried out independently of DNV in order to guarantee the unbiasedness of the respondents as well as ensure that the conclusions of this research are of general relevance and significance.

The decision to perform this study in collaboration with DNV was made because of its positive attitude towards the further justification of factors that might lead to procrastination with regard to investment decisions into decarbonization technologies. Furthermore, the company is actively involved in various researches regarding the framing of scenarios that concern the course of action within the energy transition, both nationally as internationally (e.g. TIKI report (Duvoort, 2020), and does so independently of market dynamics. This makes DNV the perfect partner for this study.

3 Methodology

In this section a description of all methodologies used in this research will be given. In other words: it describes in which way the research questions will be addressed. A distinction will be made between the theoretical- and qualitative research that will be performed. The theoretical context of the research, which effectively encompasses the literature study and is essentially the backbone of this research, will be discussed in Chapter 4. In order to review and validate findings from literature, an empirical study will be performed thereafter, followed by the analysis of the final results. The latter will lead up to the conclusions of this research. This chapter will discuss the methodology used for the literature study, empirical study, validation and discussion of the results consecutively.

3.1 Research methodology

This study sought to answer these research questions through both a theoretical framework and an empirical research. The research design of Figure 3is set up, consisting of three parts to answer the main research questions.

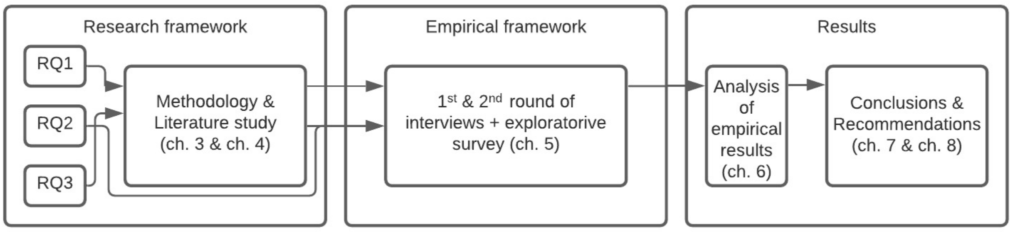

Figure 3 - Flow diagram of the research design

This section further elaborates on the method by first discussing the theoretical context of the research, consisting of the literature study. Thereafter elaborating upon the empirical framework, that is the qualitative case-study. Concluding with the results, that are made up by the analysis, validation, conclusions and recommendations for this study.

3.1.1 Literature study

The goal of the first part is to establish a theoretical context of how SNM fits in the pilot- and acceleration stage during transitions and which barriers are found within these stages. The collection of relevant literature will be obtained by consulting Google Scholar, ResearchGate, Scopus and in the Repository of the Delft University of Technology. Keywords as: 'Strategic Niche Management', 'Transition Management', 'Failure framework', 'Barriers and enablers', '(Green hydrogen) pilot production', 'Innovation dilemma' and 'Technical regime' will be used to search for reports and papers regarding the subject of this research. The reports and papers that will be used for this research will be selected based on their relevance to the scope of the study, the year of publication, the number of times cited and recommendations from articles or committee members and fellow students.

The literature study concerns the three sub questions. By reviewing the state-of-the-art literature, knowledge on the topic of SNM, barriers in the pilot- and acceleration stage have been obtained. The beforementioned topics will be reviewed and studied in respective order. According to the problem statement, pilot projects tend to be susceptible to procrastination. Procrastination may occur during the development of pilot projects because of a variation of both external- and internal barriers.

The barriers that have been found from theory will not be compared or assessed upon there (in)dependence, instead they will be summarised and categorised during the analysis of the data obtained from literature. The barriers and theories found during the theoretical research will be used as a basis for the empirical study.

Answering sub-questions two and three, about obstacles, opportunities and the role that SNM might play within the pilot- and acceleration stages will not merely rely on a literature study focussed on SNM. In addition to the barriers that were mentioned in SNM, the 'failures framework (Weber & Rohracher, 2012) and obstacles that have been found in professional literature have also been reviewed in Chapter 4.

3.1.2 Qualitative research

In order to review and empirically validate literatures' findings, a qualitative research will be performed. In order to find the (missing) link between theory and practice, the theoretical data will be verified by performing a case study. This case study, as part of this overall qualitative research, will be done by performing a series of interviews with industry professionals that are currently involved in the development of green hydrogen project in the Netherlands. Analysis of the data found will be performed through a second round of interviews and an exploratory survey.

3.1.2.1 Single-case study on Green Hydrogen pilots

The scope of the research concerns the pilot- and acceleration stage that a selection of green hydrogen production projects in the Netherlands undergo momentarily in order to stimulate the hydrogen transition eventually play part in the envisioned energy transition. This study will be of a qualitative nature and concerns the applicability of SNM within the pilot- and acceleration stage. For this purpose, a single case study approach was adopted for the intent of building and extending SNM as part of Transition Management theories (Eisenhardt, 1989) and better understand issues that invole the acceleration stage of green hydrogen projects in their real world settings (Yin, 2014). In Yin's classification of case studies, the 'Type 1' case study was selected: a single-case study with embedded units.
A single-case study approach is considered applicable due to the fact that the focus of the study is to answer a 'how' question, the behaviour of involved parties cannot be manipulated (Baxter & Jack, 2015).

With regards to the generalizing potential of observations as well as the risk to deductive theory confirmation, potential limitations of a single case study are acknowledged (Yin, 2014). However, at the same time and in this particular context, a 'limited number of cases' is not quintessential, since we are not dealing with mere 'comparison', 'representativeness' and establishing statistically underpinned 'evidence' (Vandevyvere & Nevens, 2015). Rather, this study aims to cover contextual conditions because they are believed to be relevant for the hydrogen transition (Baxter & Jack, 2015). Furthermore, qualitative research is limited by the fact that it is often the victim of the question: "How do I know that you know (what you are claiming)?" (Gioia et al., 2012), which can lead to scientific scepticism. Additionally, in performing case studies, the generalizability of the study is often questioned (Jensen & Rodgers, 2001). However, this type of research is also essential for the development of social science, where the case study is required in order to build upon the body of cases that is needed future in depth research (Flyvbjerg, 2006).

3.1.2.2 Sub-case selection

A selection of green hydrogen pilot projects currently tendered or realised within the Netherlands, will be used and reviewed. Green hydrogen pilots are currently a niche (IRENA, 2020) and therefore fit the requirements for SNM to be applied. The data is collected by conducting semi-structured interviews with professionals related to green hydrogen pilot projects or decarbonisation efforts in general in the Netherlands (primary data). Verification of current practice in regard to theoretical findings will be performed by examining the viewpoints and company practices of professionals during these interviews. Theory that is reviewed for this research in Chapter 0, will be greatly generic in nature, but can be compared and reflected upon with practical knowledge and experiences as a result from the interviews.

First, a selection was made of leading pilots that are currently tendered or realised in the Netherlands (e.g. PosHYdon (TNO, n.d.-e)). The overview of Hydrogen projects in the Netherlands by TKI (De Laat, 2020) will be used for this purpose. This selection is based upon:

- Category: Green hydrogen production, by means of electrolysis;
- Capacity: measured in MW, with ambitions for >GW scale in 2030;
- Process phase: concept, feasibility study (first design), FEED-study (business case), FID (investment decision), execution (implementation, building);
- Link of project partners with consulted parties in the TIKI report.

Secondly, a selection of companies and professionals has been made by making an inventory of the list of consulted parties for the TIKI report (Duvoort, 2020). The TIKI report was used for this purpose, since the professionals that were approached for their research, are part of the DNV professional network.

These professionals could therefore be approached for this research through DNV as part of our collaboration. By approaching these professionals through DNV, the likelihood of a positive response was enlarged.

A minimum of twelve actors will be interviewed to acquire sufficient data and be able to compare the outcomes (Guest et al., 2006). The parties were chosen based on the condition that they are involved in green hydrogen pilots or in general decarbonisation efforts as a result of the energy transition. In order to combine the views and answers from diverse types of entities (Adams, 2015), respondents will be focused on private enterprises where energy usage is high and will be varying in:

- Nationality;
- Type of enterprise (over 18 different identified types (Duvoort, 2020);
- Financial clout (ranging revenues from several millions of euros, to several hundred of billions of euros).

By embedding different green hydrogen projects, and their involved actors, it allows this research to engage in a rich analysis in order to better illuminate the single-case (green hydrogen production projects in the pilot- and acceleration stage) (Yin, 2014).
Moreover, due to the fact that this research was performed in collaboration with DNV, it was possible to approach Semi-structured interviews. The aim of the interviews is to:

- Verify in which state the pilot currently finds itself;
- Explore obstacles that have been and will be encountered during the pilot;
- Validate theoretically found barriers;
- Find which KPI's are used in regard to decarbonisation investment decisions (i.e. investing in the green hydrogen pilot);
- Uncover independent thoughts of the professionals on the transitional process of their pilot;
- Possibly examine unchartered territory with unknown but potential findings in regard to internal barriers. The results from these interviews will be regarded as primary research data for this study.

3.1.2.3 Semi-structured interviews
Semi-structured interviews were used to gather the main results for this study. It gives the flexibility needed in an interview to anticipate on the answers of the respondents, while retaining structure through pre-set questions (Adams, 2015). A semi-structured interview provides a level of detail needed to answer the sub-questions as their outcome is largely based on experience within current state of the pilot projects. The disadvantage is the possibility of the actor being biased (Adams, 2015).

For this purpose, the interview will be conducted with the representation of myself as a independent TU Delft researcher. My temporary employer and partner DNV will not be mentioned, nor will the results of the interview be biased towards a consultancy advise that could be used for corporate purposes. DNV will however aid in laying the contact with the respondents and advise on the questions and results from these interviews.
Answers on the sub-questions, based on interviews and on the literature review will be evaluated and compared. This evaluation will give insight as to whether theory and practice are in, or out of sync.

The questionnaire that was set-up for these interviews was based upon the failure framework by Weber and Rohracher (Weber & Rohracher, 2012). A review of the barriers that were mentioned in literature resulted in the conclusion that their failure framework gives a complete summation with a general description per failure type. A general description of the failure mechanism would prove to be enough information to potentially share with the respondent, without framing him / her in a certain direction. The risk of biased answers could be avoided in this way. This conclusion was reached in consultation with the graduation committee. Furthermore, the barriers (types of failure) that were mentioned in the failure framework have been labeled. Thus making it relatively easy to introduce the topic for the interview and remaining on the level of abstraction required for this study. Prior to the discussion of the failure framework however, the interview was always introduced with some small talk, which was followed by a question on the current 'state of affairs' of the pilot. A phased plan of how the interview was conducted can be found in Appendix C.

3.1.2.4 Transcription and Verification

The interviews have been transcribed in summary. This method was chosen because of the following reasons:

- The interviewees that were approached and interviewed for this study are high-level professionals. In order to give each interviewee the opportunity of reviewing and validating the summarised transcriptions, summaries of 2, max. 3 pages were made – leading to a verification and validation of all interviews;
- Semi-structured interviews were performed on the basis of general themes. Based on expert judgement and depending on the background and their role in a specific case-study project of the interviewee, a selection was made of the themes that were most in line with the expertise and interest of an interviewee. Furthermore, the results of these interviews cover mostly a general discussion about the transitional aspects that a case is going through;
- Transition management and SNM theories are rather abstract concepts which are of a qualitative nature, and are difficult to quantify. Departing this research with the focus on SNM, the choice was made to qualitatively describe the results of the case-study. Therefore, there is no added value in alternative transcription methods that might describe the findings from the interviews qualitatively.

After the summarisation of an interview, the transcriptions were sent to the interviewee for verification. In the case of necessary changes of the results, the transcription would be amended, and hereafter resend to the interviewee for a final verification. Only after the transcription of an interview as validated by the interviewee, the results would be interpreted as true and relevant for this research. Thus, the summarised transcriptions will be used as final results for analysis and conclusion. Some of the summarised transcriptions might include quotes. The usage of these quotes in this report will be duly noted if their notion is deemed necessary.

3.1.2.5 Analysis and conclusions

The 3rd sub-question will act as an introduction for the main research question. This question will be answered by combining the body of literature on SNM in combination outcomes from the interviews.
Combining findings from the interviews as part of the single case study may help to investigate the conditions within the entities that are involved in the acceleration stage, but also help to identify opportunities in the SNM theory.
For the purpose of analysing and verifying the results from the first round of interviews, a second round of interviews will be conducted as part of the analysis. The purpose of these interviews will be to verify the categorisation and ranking of the barriers that have been found in this research as part of the SNM and 'Failures framework' study. Furthermore, it will be possible to propose coping mechanisms linked to these barriers that has been proposed in relevant literature.

After evaluating the answer to the final sub-question, a conceptual framework (regarding categorisation and relation between barrieres, as well as a placement of these barrieres within the S-Curve as part of the discussion) can be designed and proposed. The resulting framework will ultimately be the conclusion of this research on how SNM concepts be applied to aid the acceleration stage of green hydrogen production pilots. Furthermore, by uncovering the barriers that lead to procrastination during the pilot- and acceleration stage, future causes of procrastination can be predicted and altered. Additionally, the aim of this framework will be to act as the basis for further research with regard to rational decision-making for emerging technologies in the future.

3.1.3 Exploratory survey in the form of a poll

This exploratory survey was set up in order to assess the generalizability of theoretical- and empirical barriers that were found in literature and during the first empirical study (interviews). Investments that are made for the purpose of reaching decarbonization goals of companies, are reflected in this research by the single case study of 'green hydrogen pilot projects. However, decarbonization goals can be reached not only by investing in innovative technologies. In fact, the majority of decarbonization goals can be met with replacement. The objective of this explorative survey is to collect data on the current trend regarding the way in which corporate decarbonization investments are taken in order to reach a deeper layer of meaning with regard to internal barriers.
Specifically, the survey will be aimed at ranking the most common key performance indicators (KPI's) in regard to decarbonization investment decisions. Furthermore, the survey will aim to elaborate on which layer within a firm (i.e. international- or national level board, or project management) is responsible for an investment decision.

The outcome of the survey will allow for a pinpoint of the location within a company where procrastination in regard to decarbonization investments might occur by investigating:

- the current market tendencies with regard to the choice of technology when faced with a replacement investment decision;
- the ranking of KPI's for such an investment decision in order of importance;
- which management layer makes this investment decision;
- targeting the short- or long-term preference of companies

Due to the fact that the poll is anonymized and is compiled out of 5 questions, even though an international audience will be ought to reached, findings from this survey will be considered as an explorative trial. The results will be elaborated upon as an informative note to the results that were obtained previously. Information regarding the methodology of the explorative poll, and the resulting poll-questionnaire, can be found in Appendix D.

3.2 Limitations of the research methodology

3.2.1 Single case study

In conventional case study methodology literature, it is stated that a case study cannot provide reliable information about the broader class that is investigated. For this case study practitioners were consulted from five green hydrogen pilot projects in the Netherlands. These pilots differed however in approach, goal, and technology. Therefore it may be difficult to draw conclusions about the hydrogen transition in general, whereas this study sought to generalise the results that were found for decarbonisation projects, as part of the energy transition. Moreover, these results will be based on a relatively small number of pilot projects currently undertaken in the Netherlands. This may either bias or create deficiencies in the conclusions of this research.

However, Flyvbjerg states (Flyvbjerg, 2006), a case study may be useful in the preliminary stages of an investigation since it provides hypotheses, which may be tested in the future. Added to that, this study is one of the few currently available in the body of knowledge, in conducting an empirical study upon SNM theory for the green hydrogen case. In addition, the case study is a necessary and sufficient method for certain important research tasks in the social sciences (Flyvbjerg, 2006), as which the transition management theories can be considered.

3.2.2 Green hydrogen pilots, a disruptive technology causing transition of a regime or not?

In addition, one can argue about the validity of the case-study research in regard to the SNM framework. The SNM theory is designed to facilitate the introduction and diffusion of new sustainable technologies through protected societal experiments in fields such as wind energy, biogas, public transport systems. It discusses the processes by which such experiments can evolve into viable market niches and ultimately contribute to a broader shift towards sustainable development.

A green hydrogen production case would not be fit for purpose, due to the fact that it does not concern a new sustainable technology. As a matter of fact, the technology has been around for over half a century (Hall et al., 2020). Therefore, the technology itself is not disruptive to the energy sector (regime). As a result, one might argue that transitional theories are therefore not applicable to the hydrogen case.

It has however become clear that even though the hydrogen case does not concern a disruptive technology as such, the scalability of it has never been realised. Furthermore, the multitude of applications that can be developed from a scaled-up version (i.e. a commercialised version) of hydrogen production (that is in its decarbonised form), might result in a disruptive trend within the energy sector. The energy-regime is momentarily heavily focused upon carbon-emitting solutions (Energy Agency - Clingendael International Energy Programme, n.d.). An application of a carbon neutral, or decarbonised application – as green hydrogen can be – will however require a transformational change across sectors, from supply to demand, as well as require transformational change within government policy. From this broad perspective, the application of transformational theory, such as SNM, can be validated.

3.2.3 The practitioners’ perspectives

For this case study a number of company representatives were interviewed. The respondents represented a number of companies that are involved in five pilot projects in the Netherlands and differed in backgrounds, financial clouts, positions within partnerships, mandates. As a result, empirical data of this study cannot be easily generalised for decarbonisation initiatives in general. The results of this study may be biased towards the green hydrogen case, and as a result not necessarily represent the challenges found in other emerging or contributing technologies. In essence, the case study contains a bias towards the verification of SNM theory with regard to the green hydrogen case.

Added to that, government perspectives were only based on state owned enterprises or companies (i.e. InvestNL, EBN and Nexstep). A perspective from the Ministry of Economic and Climate Affairs has not been obtained. The cause of corporate-external barriers (i.e. Legislation and regulations, subsidy support, directionality failure) could not be determined from the governmental perspective.

3.2.4 Bias of results

This study aimed to *elaborate, generalise* and *verify* barriers that led to potential procrastination of decarbonisation investments. It therefore did not assess the correlation and causality between barriers. Therefore, the resulting conclusions are biased towards the green hydrogen case and cannot necessarily be generalised for other decarbonisation investment decisions that are performed in the light of the energy transition.

However, as a result of the 2nd round of interviews (which was performed in order to validate the results of this study), it became clear that practitioners agreed upon the suggested failure framework as a useful tool that gives insight in the potential bottlenecks of pilot development (pilots with regard to decarbonisation targets and thus the energy transition that is). Barriers, in this framework, have been described in a general sense – as was proposed in literature – occasionally adding case-specific barriers. Case specific barriers (for other cases) can however be retrieved by a case-study of another decarbonisation application in the industry, ultimately making the framework broadly applicable.

3.2.5 Critique on SNM as main theory for this research

Raven (van der Laak et al., 2007) criticizes that the use of SNM as a practical policy tool (as opposed to a research instrument) is an important issue that deserves more attention: “SNM can be used for improving the design of experiments, for evaluating policies in the past, or for using SNM as part of scenario development, or for designing future policies on niche management. However, SNM has not been used as such in practice, but mainly as a research tool. The policy claims that are often made by SNM researchers still remain a promise; SNM needs real-life experimentation in society”. Moreover, it has mainly been used as a tool that contributes to the formulation of governmental policies for the development of emerging niches. It has however not yet been tested for applications that reflect upon private stakeholders.

Without this, its usefulness will remain essentially limited to a research tool for historical (rather descriptive) analysis of cases, and as a management tool for isolated learning experiments. Therefore, SNM needs real-life experimentation in society, as will be performed for this research. The theory may however not fully cover the anticipated research objective.

4 Literature study – Transition management in theory

In this Chapter the background information on transition management literature will be addressed. In doing so, the concept of a transition landscapes, regimes and niches will be clarified. Hereafter, the SNM literature will be further elaborated upon and the bridge will be made to various failure frameworks or barriers that were listed in adjacent theories. The last section will summarise the barriers that occur during niches and that were found in literature. But first, the research scope will be set.

4.1 Technological Transitions – basic principles

Prior to the elaboration of Strategic Niche Management (SNM), as part of the transition management stream 'Technological transitions', and partly based on the Multi-Level Perspective (MLP) theory, the general notion of transition management will be touched upon. The identification of these theories and consecutive selection of SNM with regard to the research question is important for the general understanding of this research and the theory it is based upon. MLP and SNM both explain a transition, or a part of it. These theories mainly differ in context (regarding the phase of the transition), the level of abstraction that is assessed, their timeframe (historical-, or present time analysis), or specific events and elements that can be observed within transitions.

4.1.1 Transition management in general

The context of these theories, as well as their application within literature and practice, can be best described by the transition path following the 'S-curve' by J. Rotmans and the addition of a 'breakdown' cycle by Loorbach in the principle of the 'X-curve'. These curves, as part of transition management literature, can be considered as the basis of transition management. Both Rotmans and Loorbach can be seen as the founding fathers of transition management theory. Rotmans et al. first introduced the term in 2000 (Rotmans et al., 2000) in his case-study about low-emission energy supply in the Netherlands. Following the next two decades, Rotmans and Loorbach have studied transition management in theoretical and practical sense, mainly in the Netherlands, as novel mode of governance for sustainable development. Both Rotmans and Loorbach describe the essence of transition management as theory and method by four important principles, which are (Competentiecentrum Transities, 2009):

- Transitions or system innovations require changes at different levels of society;
- Innovation is driven mainly by front runners inside and outside the regime;
- Change is brought about by stakeholders formulating a common definition of the problem and a long-term vision;
- The fundamental uncertainty of transitions due to complex processes and discontinuities calls for a process of learning by doing and doing by learning.

These principles describe the basis of a transition, regardless of its point in time, its transition stage and the technology that subject to transition. In essence, it is but a very general explanation of transition management. Rotmans et al. (Rotmans et al., 2000) examined these principles and summarised them into a framework comprising four elements, 'the transition management cycle'. The weight of each of these elements may differ from one round to another, from project to project, or from application to application (Competentiecentrum Transities, 2009). According to Rotmans et al. (Rotmans et al., 2001), these elements can be found in a transition (of any sort and in any sector) and can be described and illustrated by the 'Transition management cycle' (Figure 4). The elements described in the transition management cycle are:

- Problem structuring in combination with the creation of a vision in a participatory process and the organisation of a transition arena;
- Development of a transition agenda, transition paths and experiments with broader coalitions and networks;
- Planning and execution of transition experiments and mobilisation of existing transition networks;
- Monitoring, evaluating and learning from transition experiments, using the conclusions to adjust the vision, agenda and coalitions.

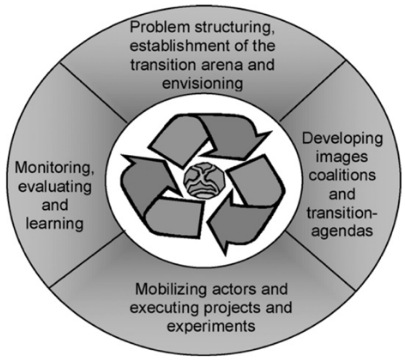

Figure 4 - Transition management cycle (Loorbach & Rotmans, 2010)

NB. The suggestion in the figure that the steps in the transition management cycle occur successively is deceptive. In practice, some activities occur sequentially, some take place separately but simultaneously and some overlap.

4.1.2 S- and X-Curve further explained

As explained earlier, the principles that describe the basis of a transition – regardless of its point in time, its transition stage and the technology that subject to transition – are described by the transition management cycle. However, the hypothesis states that the dynamics of transitions happen in time can be described by the multi-phase concept. It provides a framework concerning the direction, speed and magnitude of a transition (Rotmans et al., 2000). This framework describes four distinct phases placed in time and are often described in the form of an S-curve (Figure 5):

- Pre-development phase, the status quo of a system is changing on the background, but a transition is not yet visible;
- Take-off, actual starting or ignition moment at which time a structural changing- and transitioning process are triggered;
- Acceleration, structural changing- and transitioning process becomes visible;
- Stabilisation, a new dynamic balance is constituted.

Thus, a multi-phase perspective on systemic transitions, where an effective paradigm change leads towards stabilization in the form of a new sustainable system configuration — can be described by a transition path following the “S-curve”. A graphical representation of the S-curve, including the 4 phases of transitional progress are shown in the figure below. The importance for the development of a transition – characterised by specialized applications or niche development – lies in the early phase of technology development. In the early phase of a radically new technology there is usually little or no economic advantage of the technology; however, existing technologies tend to improve during the acceleration phase (Kemp et al., 1998).

Alternatively, this figure includes the terms backlash and system breakdown which are characterised by systems that can get stuck in a lock-in or even break down by failing to respond to the external and internal pressures that threaten them (Vandevyvere & Nevens, 2015). One can observe this backlash and system breakdown as a downward trend that manifests itself after either the take-off- or acceleration phases. External and internal pressures that threaten transition, result in destabilisation and uncertainty for the KET (Key Enabling Technology) that is developed (European Commission, 2015). Moreover, these pressures are described by a lock-in or even break down, i.e. the ‘Valley of Death’. The transition from the take-off phase towards the acceleration phase (as described in the S-Curve), or the transition from product development to competitive manufacturing (as described by the Valley of Death), might result in a downward trend due to high costs and risks (European Commission, 2015). As a result, pilot projects (being part of a transition) never reach the market causing a suboptimal societal and economic impact.

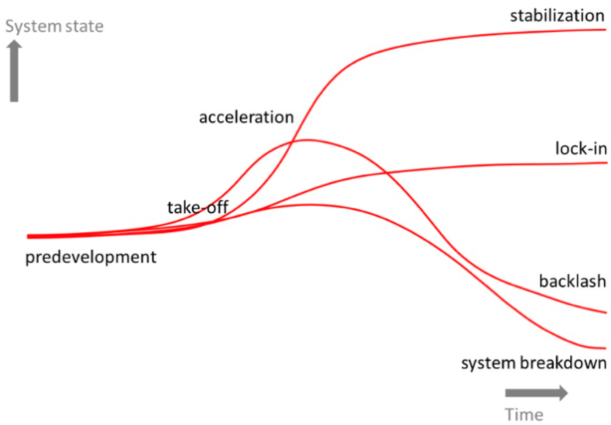

Figure 5 - Transition path following the 'S-Curve' (Vandevyvere & Nevens, 2015)

In addition to the S-curve, Loorbach (Lodder et al., 2017) debates whether the S-curve fully covers the dynamics of a transition. It righteously focusses on the development of a transition, showing an upward trend of development. However, transitions take place in a currently present reality which can be distinguished by a society, a specific market or a technological application. *These places are called 'landscapes' within the transition management theory, which will be further explained in section 4.1.3.* During a transition, something that is present at the moment, will change to something else in the future. But for this to happen, the current set of boundary conditions needs to change, or even breakdown in order to make room for a new technological application for example.

Loorbach's X-curve (Figure 6) of transitions adds a pattern of demolition to the pattern of construction and argues that these patterns reinforce or counteract each other. The x-curve is a complementary depiction of the path which a transition follows to the s-curve. In the report 'Staat van Transitie' (Lodder et al., 2017).

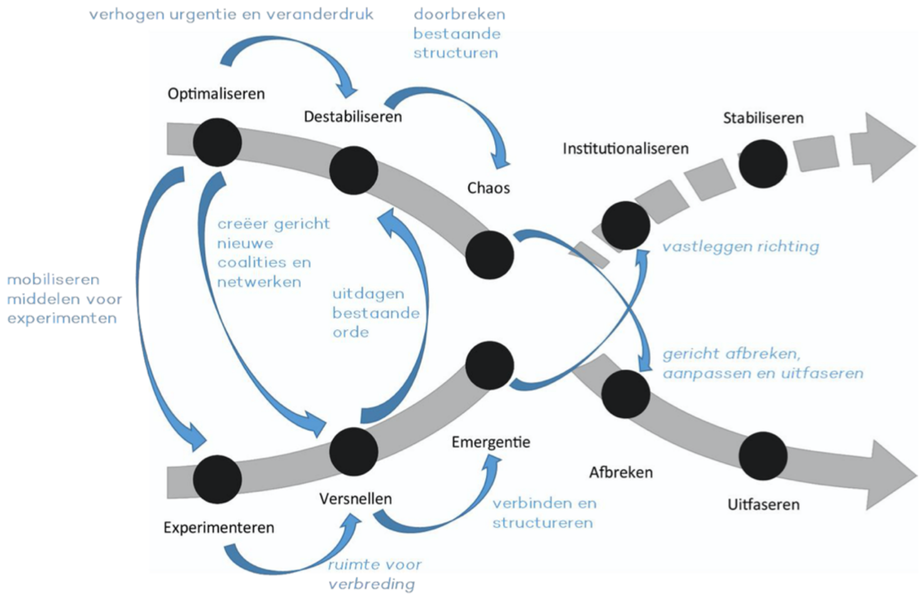

Figure 6 - Guidance recommendations (Lodder et al., 2017)

So far, this section has focused on patterns of transition that happen in time and can be described by the multi-phase concept. The X-curve is shown in order to grasp the general trend that a transition goes through according to state-of-the-art literature. One can visualise the phase that the green hydrogen transition – as part of the energy transition – finds itself in momentarily. Furthermore, the phase between the stages of experiments towards emergence (as can be seen in Figure 6), is characterised by the risk of the Valley of Death. For that reason, This research, focusses on the constructive pattern of a transition and more specifically on the phase between experimenting and emergence ('Experimenteren' – ruimte voor verbreding – 'emergentie' respectively). These phases are described in the S-curve by the transition from the take-off phase towards the acceleration phase. The following section will discuss transitions in terms of interferences from a multi layered systems perspective.

4.1.3 Multi-level perspective

Geels (Rotmans et al., 2000) states in his dissertation that although there is no specific literature in the field of system innovations or transitions, there is a broad literature available which pays attention to aspects of system innovations or transitions. Geels has tried to bring together elements from that literature and link them together in his multi-level perspective (MLP).

The MLP is the result of an attempt to gain more insight into large-scale socio-technological processes of change ('regime shifts') and how and why these come about (ten Pierick & van Mil, 2009). This attempt arose from the dissatisfaction of a group of researchers (Kemp, Rip and Schot) with the prevailing theories at the time concerning technological innovation and its impact on the fulfilment of social needs. They took the evolutionary theory of technological change – as developed by Nelson and Winter (Rip & Kemp, 1998) and Dosi (Kemp et al., 1998) – as their starting point and enriched it with insights from sociology and the history of technology. With the MLP, Geels builds upon the ideas that were introduced by Rip and Kemp (Rip & Kemp, 1998). They were the first to discuss the three scale nodes – landscape, regime and niche – in relation to each other. In order to deal with a number of shortcomings of Rip and Kemp's version, Geels developed the MLP – with the help of the insights mentioned above – into a dynamic MLP model (Rotmans et al., 2000).

The term multi-level perspective (MLP) refers to the distinction that is made within this perspective between multiple levels of scale. The MLP distinguishes three levels: the niche level (micro), the regime level (meso) and the landscape level (macro). The interdependent of these levels together contribute to the success of new technology (Rotmans et al., 2005). According to Rotmans and Loorbach (Loorbach & Rotmans, 2010) transitions are always the result of developments and events on a large scale (megatrends) and on a small scale (niche developments). Transitions will only be realized if developments at the three different levels link together and reinforce each other in one and the same direction (modulation) (see Figure 7).

The MLP framework (Figure 7) thus provides a multi-level explanation to the phases concerning the direction, speed and magnitude of a transition as proposed by Rotmans (Rotmans et al., 2000). The MLP framework focusses on the development of niche-innovations as basis for the development of a transition cycle. Here the pattern of construction of the niche – and ultimately the transition – is characterised by the following four phases:

- Small networks of actors support novelties on the basis of expectations and visions. Learning processes take place on multiple dimensions (co-construction). Efforts to link different elements in a seamless web;
- Elements become aligned, and stabilise in a dominant design. Internal momentum increases;
- New configuration breaks through, taking advantage of 'window of opportunity'. Adjustments occur in socio-technical regime;
- New regime influences landscape.

Alternatively, this Figure 7 includes the term 'failed innovations', which reflect upon a backlash and system breakdown which are characterised by systems that can get stuck in a lock-in or even break down by failing to respond to the external and internal pressures that threaten them (Vandevyvere & Nevens, 2015). For further information a precise explanation of the MLP levels is given in Appendix G.1.

Ten Pierick and Van Mil (ten Pierick & van Mil, 2009) summarised the possibilities and limitations of the MLP as follows:

- the MLP is a thought model; in practice it has proved less suitable as an analytical instrument in the empirical sense;
- the MLP appears better suited to ex-post descriptions than to ex-ante investigations;
- the MLP offers a vocabulary to interpret problems of transition;
- applying the MLP demands a deep understanding of the subject matter and knowledge of the underlying principles and assumptions of this perspective.

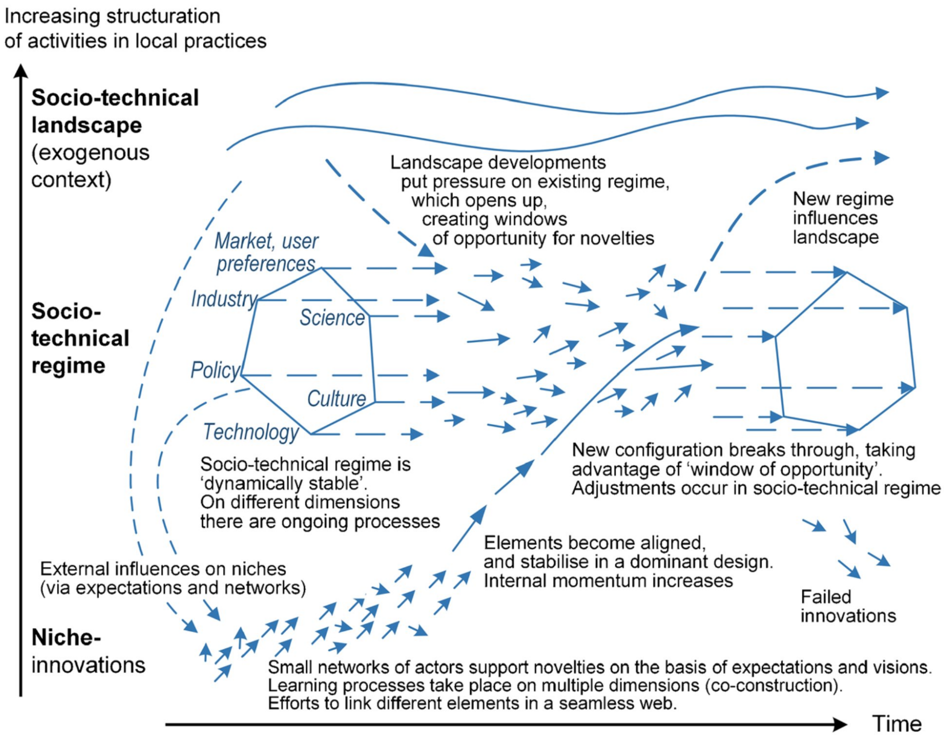

Figure 7 - Multi-level perspective on transitions (Geels, 2012)

Geels' multi-level perspective (Geels, 2012) is therefore a specific interpretation of transition thinking, focusing on complex long-term socio-technical processes of change at the level of societal needs (such as transportation, nutrition, energy). It offers a useful vocabulary for discussing such processes in addition to the previously discussed patterns of transition. However, it appears less well suited to describing and analysing a contemporary transition such as the one taking place in the energy sector (e.g. the emergence of green hydrogen fuel and green energy sources to replace fossil fuels in various applications). System innovations do not only reflect technological advancements, but also impact social environment and current markets. System innovations should be approached within a multi-layered systems perspective, i.e. the Multi-Level Perspective (MLP).

Having defined what is meant by the multi-level perspective approach to transitions, the relevance and position of niches and niche-innovations as part of a transition and system innovations has become apparent. The explanation of the MLP is important in order to understand the position of niche developments, which is in line with this research topic: the development of the green hydrogen niche as part of the energy transition. Strategic Niche Management (SNM), as developed by Kemp and Schot – that on their part also contributed to MLP theory – emphasises its scope on niche-development. Combined with the S- and X-curves that were explained in the previous sub-section, one can understand thorough which phases of 'construction' a niche would go in order to cause a transition. Therefore, the next section will now move on to discuss SNM.

4.2 Strategic Niche Management

As explained in the previous section, niches, or niche-innovations, are a level in which small networks of actors support novelties on the basis of expectations and visions. In niche innovations, learning processes take place on multiple dimensions. The pivotal role of niches as part of transitions is further strengthened by SNM theory that elaborates upon niche innovations and processes that happen within the niche-level.

As the introduction described the essence of crossing the valley of death for the hydrogen application, this section will elaborate upon the notion of niche innovations and aims to require an understanding on the pitfalls and solutions that are provided by state-of-the-art literature. This section will therefore elaborate upon SNM.

4.2.1 Origin of SNM

The first time Strategic Niche Management has been mentioned by (Kemp et al., 1998) is by describing it as a way to manage the transition into another technological regime. Kemp *et al.* (Kemp et al., 1998) proposes the following definition for SNM: "Strategic niche management is the creation, development and controlled phase-out of protected spaces for the development and use of promising technologies by means of experimentation, with the aim of learning about the desirability of the new technology and enhancing the further development and the rate of application of the new technology" (Kemp et al., 1998).

Strategic niche management is a concentrated effort to develop protected spaces for certain applications of a new technology. It differs from the "technology-push" approach that underlies most of today's technology promotion policies, by bringing in knowledge and expertise of users and other actors into the technology development process and to generate interactive learning processes and institutional adaptation. The focus upon learning is an important aspect of SNM. A second aim of SNM is to foster institutional connections and adaptations, to align technology and user environment. More specifically the aims of strategic niche management are:

- to articulate the changes in technology and in the institutional framework that are necessary for the economic success of the new technology;
- to learn more about the technical and economic feasibility and environmental gains of different technology options – that is, to learn more about the social desirability of the options;
- to stimulate the further development of these technologies, to achieve cost efficiencies in mass production, promote the development of complementary technologies and skills, and stimulate changes in social organization that are important to the wider diffusion of the new technology;
- to build a constituency behind a product – of firms, researchers, public authorities – whose semi-coordinated actions are necessary to bring about a substantial shift in interconnected technologies and practices.

4.2.2 SNM method further explained

Strategic niche management (SNM) is a method which was developed in the first decade of this century and is designed specifically to facilitate the introduction and diffusion of new sustainable technologies through societal experiments. Its ultimate aim is to contribute to a broad shift to more sustainable economic development, through an integral combination of technological progress and system-wide social-institutional transformation (Caniëls & Romijn, 2008).

Initiating a broad societal movement in this direction is highly challenging. Potentially useful sustainable technologies often fail to be fully developed, or to catch on in the market, even though they promise superior performance compared to incumbent technologies. SNM can help to provide insight into the nature of these obstacles, and provide pointers as to how to overcome them. It suggests that as a result of obstacles that are found in niche innovations create the phenomenon of inertia that can be derived from the fact that technologies are part of a broad and complex system, a 'socio-technological regime'. Meaning: "the whole complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, established user needs, regulatory requirements, institutions and infrastructures" (Hoogma et al., 2005).

In order to address this complexity, SNM advocates the creation of socio-technical experiments in which the various innovation stakeholders are encouraged to collaborate and exchange information, knowledge and experience, thus embarking on an interactive learning process that will facilitate the incubation of the new technology. This occurs in a protected space called a niche, a specific application domain for the new technology. In the initial phase a niche is still only technological in nature. The new technology has promising characteristics but these are not yet supported through actual market sales. Experiments thus create 'proto-markets', in which connections with market parties are made even though the technology is still in a laboratory phase. This is called the co-construction of technologies and markets, or the linking of evolutionary variation and selection processes. When incubation goes well, a technological niche will evolve into an actual market niche, in which the innovation can sustain itself commercially in a specific market segment (Caniëls & Romijn, 2008).

Practical experimentation is the essence of SNM and the SNM framework. Experiments should be carried out in so-called (partly) 'protected niches', where actual users can benefit from experimentation without pressures from the meso- and macro-levels, i.e. the market, as mentioned earlier. The development of a niche in a protected surrounding is the result of numerous 'niche internal processes' in combination with external developments. Schot, and Weber identified three internal niche processes that are at the basis of SNM (Kemp et al., 1998; Weber & Rohracher, 2012):

- Learning processes;
- (actor) Network building;
- Articulating visions and expectations.

These processes are measured by underlying criteria on their level of effectiveness in innovation pathways. In addition to the SNM framework is the 'feedback loop', as proposed by Raven (van der Laak et al., 2007). It highlights the interconnectedness of the 'niche internal processes'. The feedback loop can be seen in Figure 8.

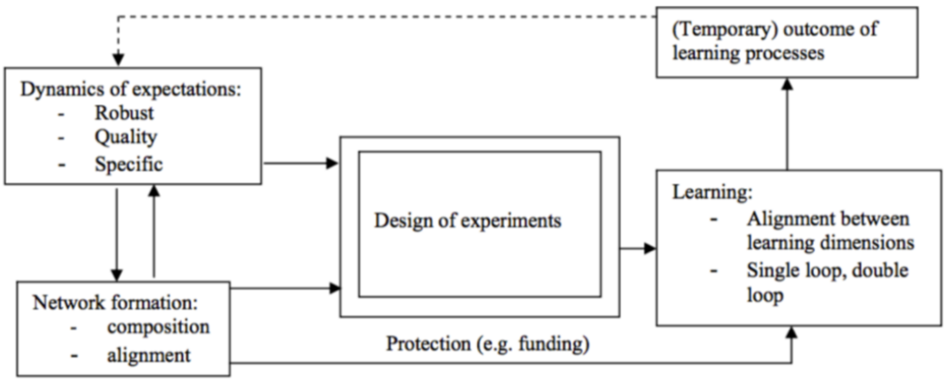

Figure 8 - Feedback Loop for SNM (van der Laak et al., 2007)

If expectations from actors (manufacturers, governmental agencies, private corporations, etc.) are expressed, an actor can choose to become involved in the development of a niche. Once an actor becomes involved, the learning process can be experienced in numerous ways. An actor might alter his/her view and expectations about the technology he is involved in developing. Based on new expectations, new actors can be involved with the experimentation phase, which in sequence might alter the network interactions and potentially lead to new partnerships. Due to potential changing of expectations, or changing network interactions, an experiment within the niche might be revised, ended, or lead to new experiments.

4.2.3 SNM framework

According to Kemp *et al.* (Kemp et al., 1998) niches are platforms for interaction; they emerge out of a process of interaction shaped by many actors and cannot be controlled. Governments could try to contribute to these processes of niche formation by setting up a set of successive experiments with a number of new technologies; this is strategic niche management. This policy of SNM consists of five consecutive steps which are described in Table 2:

Table 2 - SNM framework (Kemp et al., 1998)

Step	Explanation
The choice of technology	A choice must be made as to which technology will be supported and must comply to the following preconditions: • A technology that is appropriate for support through SNM is outside the existing regime or paradigm, but may greatly alleviate a social problem (like climate change) at a cost that is prohibitively high (societal precondition); • Major technological opportunities should be embedded in it (technological-scientific precondition); • Clearly manifest increasing returns or learning economies throughout time (economic precondition); • Consistence with actual or feasible forms of organisation and control and computability with important user needs and values (managerial and institutional precondition); • Already being attractive to use for certain applications in which the disadvantages of the new technology countless and the advantages are highly valued.
The selection of an experiment	The selection of an appropriate setting in which the new technology is to be used where the advantages of the technology are valued highly and the disadvantages countless.
The set-up of the experiment	A balance must be struck between protection and selection pressure. Protection should not be too generous but force developers to take care of user requirements and impelled to eliminate negative side-effects connected with the wide-scale application of a new technology. On the other hand, the selection pressures should not be too strong, putting development work under time pressures and making companies opt for conventional solutions that offer short-term benefits at the expense of long-term benefits.
Scaling up the experiment	The next step concerns scaling up the experiment by means of policy. Even a highly successful experiment may require some kind of support from public policy-makers in the form of a preferential treatment. But this again raises the question of *how far government s should go in support of a particular technology*
The breakdown of protection	The final step is the phased breakdown of protection. Support for the new technology may no longer be necessary or desirable when the results are disappointing and prospects are dim.

4.2.4 SNM's explanation of barriers

While the steps that are described in the SNM framework are the final proposition of Schot and Kemp's their research (Kemp et al., 1998) – adding a useful framework to the spectrum of policy instruments – the researchers actually stress the importance of dealing with different barriers that can be observed during niche developments prior to their proposed framework. They show that there are many factors that impede the development and use of new technologies, especially systemic technologies that require changes in the outside world. These factors (barriers) are interrelated and often reinforce each other (Rip & Kemp, 1998). Schot and Kemp (Rotmans et al., 2000) mention for example that in the early phase of a radically new technology there is usually little or no economic advantage of the technology; however, existing technologies tend to improve during the acceleration phase (Kemp et al., 1998).

What they found is not a set of factors that act separately as a containment force, but a structure of interrelated factors that feed back upon one another, the combined influence of which gives rise to inertia and specific patterns in the direction of technological change. Schot and Kemp (Kemp et al., 1998) explain that the barriers should not be considered individually, lest we lose sight of the coherence and interaction between the different factors.

Kemp and Schot (Kemp et al., 1998) provide insight into the nature of these obstacles in their paper on SNM. The obstacles that are discussed by Kemp and Schot were responsible for the slow transition to more sustainable transport technologies. However, these barriers were identified for the sustainable transport case and their occurrence in other regimes – or sectors – has not yet been verified empirically. The individually discussed barriers however, have been described in a general sense, which makes their validation in another transition totally feasible. A summation of the barriers that have been proposed in the first SNM paper (Kemp et al., 1998) is given in Table 3.

Table 3 - Reasons for under-utilization of more sustainable technologies

Barrier	**Explanation**
Technological factors	A newly proposed technology does not fit into the existing system and may require complementary technologies that are perhaps not available or expensive to use.
Government policy and regulatory framework	Governments are on the one hand committed to environmental protection and other social goals, but they are often not expressing a clear message with the need for a specific new technology. Due to the lack of technology policy based on a clear view of the future, manufacturers remain uncertain about market developments and will be reluctant to invest in often precarious and risky alternatives.
Cultural and psychological factors	The current industry may have an idea of what the industry should look like and be able to do. The unfamiliarity with alternatives may lead to scepticism in regard to the adoption of a new alternative or technology because the actors in an industry will judge the new technology on the basis of characteristics of the dominant technology.
Demand factors	Since new technologies have not proven what they are worth, customers are not sure what to expect, causing risk aversion and troubling the willingness to pay. Apart from an uncertain expectation for a new technology, an important demand factor is the price of the product. New technologies are often expensive as a result from high unit costs of production. Manufactures think that consumer demands cannot be changed and are therefore the most important barrier, arguing that products cannot be manufactured without a clear consumer demand.
Production factors	As mentioned before, the development of a new technology is a risky process that evolves from prototype to mass production. This process is quite a long and cumbersome process and which is aggravated by an uncertainty of consumer interest or due to a lack of external factors such as legislation that require companies to offer a certain product to consumers. Moreover, existing companies do not want to risk their core competencies to become unnecessary. Big manufactures tend to be interested in alternative technologies only when these can be produced for a big market.
Infrastructure and maintenance	In order to introduce new technologies, an adaptation of infrastructure may be required. For a new sustainable technology, a new distribution system may have to be established or special provisions may have to be made. The threshold value being a key characteristic that states: only with a relatively high number of consumers does it become profitable to create a new infrastructure, although the consumers may require such an infrastructure from the very beginning. Furthermore, groups in charge of current infrastructure may form a strong lobby for their own interests.
Undesirable societal and environmental effect on new technologies	New technologies may be able to solve some problems, but they may also introduce new ones. Newly produced problems, which cannot be foreseen beforehand (during the development of a new technology) may affect the image and performance of the new technology.

Only a brief explanation of possible ways to solve the above-mentioned barriers that is given in SNM literature. It reflects upon the notion to bring together different parties (firms, universities, research institutes) to work on a problem, providing financial assistance, and manipulating technological and economic expectations – for example, by securing a (future) market for a new product.

In the case of technological controversies, they could arrange discussions between proponents and opponents to generate better understanding of the issues, and by doing so guide technology developers in their decisions. As noted, learning and institutional adaptation should be an important focus of policies. Policies should also be aimed not just at changing the structure of incentives and constraints but far more at learning and coordination.

4.2.5 SNM critique

SNM literature primarily focusses on governmental and policy related barriers that are described as processes, whereas the explanation of barriers that manifest themselves within-, or due to other actors (e.g. corporations, investors) and case specific barriers are not explained. A transitional process, indeed can be stimulated by policy and regulations, but in the end, the investments needed for the realisation and development of hydrogen niches are realised by private companies. As quoted from the paper ‘Regime shifts to sustainability through processes of niche formation’ (Kemp et al., 1998):

> *“Historical evidence suggests that entrepreneurs / system builders and niches play an important role in the transition process. Niches were instrumental in the take-off of a new regime and the further development of a new technology. It may be clear that the shift into a new, more sustainable technological regime presents a huge problem for both public policy-makers and anyone else. The task is no longer to control or promote a single technology but to change an integrated system of technologies and social practices. The problem is to manage the change process to another regime without creating transition problems. This is the problem that public policy-makers face and must try to resolve. But how do they do this?”*

Furthermore, it is not yet clear from SNM if entrepreneurs / system builders also might impede the development of niches, i.e. what corporate-external barriers – or internal factors –might lead to a cautious attitude towards investing in niches within the valley of death. As stated earlier by SNM’s advocates, it is the combined occurrence of barriers that might cause procrastination in regard to required investments. However, the theory does not argue about the combined occurrence of mainly governmental- and policy related barriers and corporate internal factors.

Lastly, SNM research is solely based upon ex-post research, meaning that cases from the past are being analysed in order to describe the transitional process of niches. The body of SNM literature is also relatively limited in regard to the cases that have been studied in the past. Therefore the question remains whether the ex-post nature of the theory is applicable for ex-ante studies and if the theoretical framework that resulted from past-studies is applicable for problems found in present transitions.

4.3 Barriers identified in transitional theory

The explanation given by Dosi, as adapted by Kemp and Schot (Kemp et al., 1998), gives a brief insight in causal factors that play a key role in the exclusion of certain technological alternatives. There is however a multitude of factors that have been identified and described in literature. Therefore, we take a closer look at the different factors that affect the development and use of new technologies in this section. In particular how they impede a shift to more sustainable technologies in general as mentioned in the state-of-the-art transition management literature. Thereafter, section 4.4 will review professional literature in order to find case-specific barriers. The definition for the summary of the various factors and obstacles that have been mentioned in literature – that are the reason for procrastination or inertia within the scale-up phase of transitions – we will from now on use is 'internal- and external barriers'. The resulting summary will form the basis for the case study that is to be performed in this research.

4.3.1 External barriers found in SNM and MLP

External issues concerning the Landscape or Regimes, significantly impact the niche processes that take place in the immediate environment of the experiment. If not addressed, these issues could result in a failure of aligning elements and stabilising a dominant design and ultimately result in the failure of an innovation. Raven et al. (van der Laak et al., 2007) points out that shifts in visions and expectations can largely be explained by external factors. Additionally, Hoogma et al. point out that initiating a broad societal movement is highly challenging. Potentially useful sustainable technologies often fail to be fully developed, or to catch on in the market, because of external barriers, even though they promise superior performance compared to incumbent technologies (Hoogma et al., 2005).

The previous section briefly introduced the notion of obstacles or barriers that impede the transitional process of niches. In short, SNM theory identifies seven factors that might lead to procrastination during niche development. Kemp and Schot (Kemp et al., 1998) sum up the following factors (an elaboration of which can be found in Table 3):

- Technological factors;
- Government policy and regulatory framework;
- Cultural and psychological factors;
- Demand factors;
- Production factors;
- Infrastructure and maintenance factors;
- Undesirable societal and environmental effect on new technologies.

This is in line with the barriers that are proposed in the adjacent MLP theory. Ten Pierick and Van Mil (ten Pierick & van Mil, 2009), that follow up on MLP in their paper, provide insight into the opportunities and barriers to the large-scale use of biofuels in road vehicles in the Netherlands in their research. Building on this, their study aims to contribute to the development of policy at national and European level to prevent or (partially) remove the barriers and exploit the opportunities (ten Pierick & van Mil, 2009). Their study is based upon the building blocks and starting points on which MLP is based (Rotmans et al., 2000). In their study, an assessment was made of the usefulness of the MLP perspective, particularly in relation to issues in the bio-based economy.

Their study gave insight into barriers and the actors that can play a role in this. The definition for barriers in technological regimes that is proposed is: 'Reasons that cause technology to get stuck in a paradigm, thought only in known risks' (ten Pierick & van Mil, 2009). Where it is easier for small or medium companies to break out of a paradigm, but they have a too small capital to make it happen. A summary of the barriers that were identified by Geels (ten Pierick & van Mil, 2009), and were used in the research with the bio based economy as case-study are given in Table 4.

A critique to the findings in the light of SNM and MLP theory is that their frameworks seem to be more suitable for ex-post descriptions and analyses than for ex-ante explorations. In short, the capabilities and limitations of the MLP can be summarised as follows (ten Pierick & van Mil, 2009):

- MLP is a thinking model; in practice it is less suitable as an analytical tool in the empirical sense;
- MLP seems to be more suitable for ex post descriptions than for ex ante verifications;
- The MLP offers a vocabulary for interpreting transition problems.

Table 4 - Examples of potential barriers for the breakthrough of a new technology

Barrier	**Explanation**
Actors and markets	• Poorly articulated demand; • Established technology characterised by increasing returns; • Local search processes; • Market control by incumbents.
Networks	• Poor connectivity; • Wrong guidance with respect to future markets.
Institutions	• Legislative failure; • Failures in the educational system; • Skewed capital market; • Underdeveloped organisational and political power of new entrants.

4.3.2 External barriers summarised in the 'Failure Framework' (Weber & Rohracher, 2012)

Transition management literature, along with the streams of SNM and MLP, all discuss technological- or systemic transitions. They differ however from perspective, discussed time frame and focus on transitional phase. But all of the previously discussed theories agree on the fact that during a transition, regardless of the discussed transitional phase, time frame or perspective, there are factors that impede the development of a transition. However, due the fact that these theories individually discuss factors that might impede a transition, there is still lack of a table of framework that summarises these barriers and links them to a specific transitional phase. Such a table is required in order not to overlook barriers that have been discussed in adjacent theories. The theory that comes closest is the 'failure framework' by Weber and Rohracher (Weber & Rohracher, 2012) as will be introduced in this subsection.

The framework has been developed on the basis of the existing literature on innovation systems and multi-level transition research. Its advocates have tried to reconcile structure-oriented innovation system approaches with the MLP of socio-technical transitions. Their aim was to propose a broader approach to innovation policy that is geared towards inducing and realizing long-term processes of transformative change towards sustainability. As a result, the 'failure framework' reformulates transformational system failures and adds well-established market- and structural system failure arguments in order to provide a comprehensive framework for legitimising research, technology and innovation policies for transformative change (Weber & Rohracher, 2012).

This extended framework of failures provides the necessary underpinning of transformational failures for strategic innovation policies that are geared towards stimulating and enabling transformative change in innovation, production and consumption. However, as both Weber and Rohracher stress in their paper (Weber & Rohracher, 2012), their framework still needs to be tested in practice as a support instrument for policy development. As Weber and Rohracher explain: "The importance of the different types of barriers suggested may differ from area to area, and it may well be that some failures have still been overlooked. Moreover, thorough methods and criteria need to be devised to assess whether in particular the four novel types of failures really represent a problem or not" (Weber & Rohracher, 2012). Therefore, a series of empirical studies, aiming to study the occurrence and magnitude of such barriers should be performed with the precondition that empirical work should go hand in hand with a refinement of the concepts and definition suggested of what constitutes a failure in the context of long-term transformative change.

The 'Failure framework' by Weber and Rohracher (Weber & Rohracher, 2012) will be introduced due to the fact that the niche development phase and its scale-up tent to encompass an abundance of impeding factors. The failure framework does not necessarily lie at the basis of transitional literature; however, it aims to build upon its cornerstones by introducing a comprehensive summation of the various failure mechanisms that have been mentioned in transitional literature. It will be used in order to give structure to the experienced barriers within the hydrogen case that will be discussed in the next chapter. In order to promote comprehensiveness to the terminology used in their failure framework, Table 5 will give an overview of failures from the failure framework with an explanation of each failure mechanism.

Table 5 - Overview of failures in the context of transformative change (Weber & Rohracher, 2012)

	Type of failure	Failure mechanism
Market Failures	Information asymmetries	Uncertainty about outcomes and short time horizon of private investors lead to undersupply of funding for R&D.
	Knowledge spill over	Public good character of knowledge and leakage of knowledge lead to socially sub-optimal investment in (basic) research and development.
	Externalisation of costs	The possibility to externalize costs leads to innovations that can damage the environment or other social agents.
	Overexploitation of commons	Public resources are over-used in the absence of institutional rules that limit their exploitation (tragedy of the commons).
Structural system failures	Infrastructural failure	Lack of physical and knowledge infrastructures due to large scale, long time horizon of operation and ultimately too low return on investment for private investors.
	Institutional failure	Hard institutional failure: Absence, excess or shortcomings of formal institutions such as laws, regulations, and standards (in particular regarding IPR and investment) create unfavourable environment for innovation. Soft institutional failure: Informal institutions (e.g. social norms and values, culture, entrepreneurial spirit, trust, risk-taking) that hinder innovation.
	Interaction or network failure	Strong network failure: Intensive cooperation in closely tied networks leads to lock-in into established trajectories and lack of infusion of new ideas, due to too inward-looking behaviour, lack of weak ties to third actors and dependence on dominant partners. Weak network failure: too limited interaction and knowledge exchange with other actors inhibits exploitation of complementary sources of knowledge and processes of interactive learning.
	Capabilities failure	Lack of appropriate competencies and resources at actor and firm level prevent access to new knowledge, leading to an inability to adapt to changing circumstances, to open up novel opportunities, and to switch from an old to a new technological trajectory.
Trans-formational failures	Directionality failure	Lack of shared vision regarding the goal and direction of the transformation process; Inability of collective coordination of distributed agents involved in shaping systemic change; Insufficient regulation or standards to guide and consolidate the direction of change; Lack of targeted funding for research, development and demonstration projects and infrastructures to establish corridors of acceptable development paths.
	Demand articulation failure	Insufficient spaces for anticipating and learning about user needs to enable the uptake of innovations by users. Absence of orienting and stimulating signals from public demand Lack of demand-articulating competencies.
	Policy coordination failure	Lack of multi-level policy coordination across different systemic levels (e.g. regional–national–European or between technological and sectoral systems; Lack of horizontal coordination between research, technology and innovation policies on the one hand and sectoral policies (e.g. transport, energy, agriculture) on the other; Lack of vertical coordination between ministries and implementing agencies leads to a deviation between strategic intentions and operational implementation of policies; No coherence between public policies and private sector institutions; No temporal coordination resulting in mismatches related to the timing of interventions by different actors.
	Reflexivity failure	Insufficient ability of the system to monitor, anticipate and involve actors in processes of self-governance; Lack of distributed reflexive arrangements to connect different discursive spheres, provide spaces for experimentation and learning; No adaptive policy portfolios to keep options open and deal with uncertainty.

4.4 Barriers identified in the hydrogen case

Now that barriers from transition management literature have been summarised in the Section 4.3, prominent professional literature will be consulted to give an insight into barriers that have been observed in the hydrogen case until today. Most of the obstacles that were mentioned in transition management literature were identified as a result of ex-post research. The energy transition, as well as the hydrogen niche however, find itself momentarily in the midst of the proverbial 'battle'. In opposition to ex-post research, ex-ante research and analysis is also required in order to grasp the whole picture. In addition, Chapter 1 made clear that green hydrogen pilots will be assessed in a case study which will be introduced later on in this report.

Additionally, the barriers that have been identified in literature thus far have not however assessed the hydrogen case specifically, but are however based on other examples of technological transitions. Professional literature will make it possible for theoretical research to be complemented by empirical research and vice versa. Section 4.4.1 through 4.4.3 will therefore discuss limitations that might impede the hydrogen transition found in recent professional literature. The reports that are discussed below have been written by- or commissioned by governmental bodies. Incomplete- or results that are biased by the view of private enterprises are consequentially excluded.

4.4.1 External barriers as identified in professional literature – Pilot production in KET's

During pilot production, high investments are needed to generate information on the performance and behaviour of the future products and production lines, and to get a better understanding of the market. This is necessary for estimating the expected profits from new products (based on expected production costs and sales). In other words, high investments must be made before uncertainties are reduced, which means the investment and the reduction of uncertainty are out of sync, leading to high economic risks for private investors and enterprises (European Commission, 2015). This phenomenon can be visualised in Figure 9:

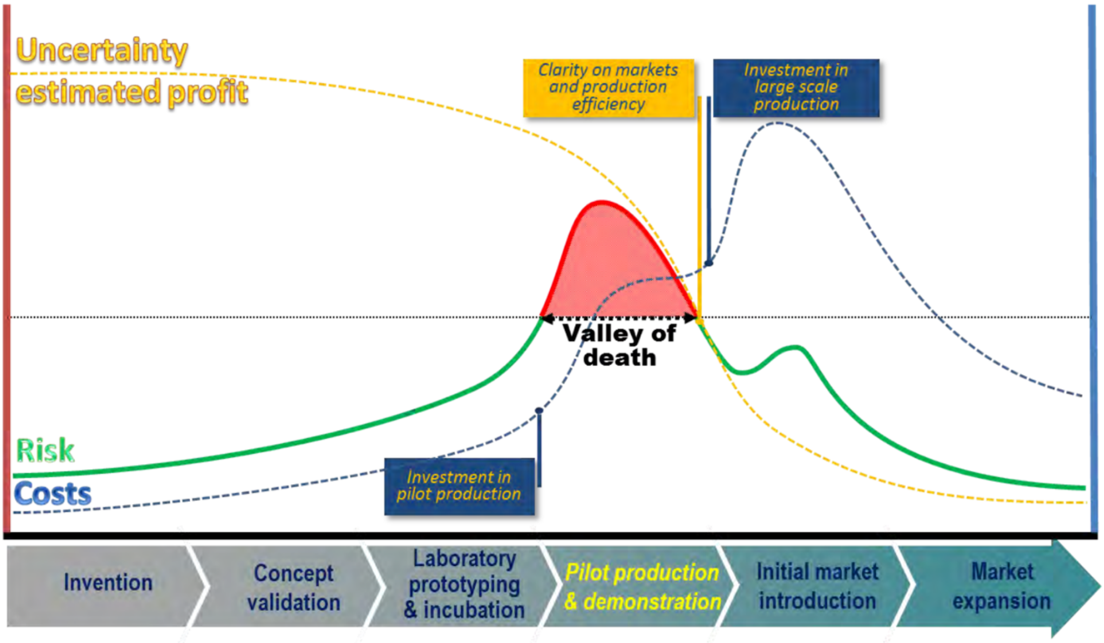

Figure 9 - The Valley of Death, uncertainty reduction versus required investment (European Commission, 2015)

While KETs are definitely on the radar of many governments around the world, pilot production has only recently attracted the interest of governments. This trend is seen globally, but only a limited number of countries already have systematic support in place for pilot production, despite demonstrated market failures. Without adequate support, there is a risk that innovative solutions to societal challenges will not be deployed and technological developments will be sub-optimally used for job creation and economic growth. Public R&D expenditures will not be used efficiently and Europe will lose opportunities to maintain or (re)gain industrial leadership in strategic sectors (European Commission, 2015).

The European Commission focusses on business and policy practices concerning pilot production activities in 21 countries for their report. Business practices are primarily market oriented.
Finance, skills, intellectual property rights and time to market are therefore the main attributes that are assessed, whereas limited attention is given to the building of the ecosystem.

Policy practices show an emerging focus on pilot production, with a wide variety of instruments. But a systematic approach towards supporting pilot production within the broader innovation policy is almost always missing (European Commission, 2015). Therefore, the European Commission (European Commission, 2015) formulates four main barriers which are crucial for policy to address, and attribute to the high economic risk of pilot production are summarised in Table 6.

Table 6 - Main barriers attributing to the high economic risk of pilot production (European Commission, 2015)

Barrier	**Explanation**
Access to finance	The cost of pilot lines/plants is high, and external investment is often needed. There is relatively limited capital available and private investors are reluctant to invest due to economic risk. Single investors often cannot individually bear the high risk.
Limited market articulation	To lower economic risks, it is crucial to reduce the uncertainty about demand. Having a customer that explicitly places an order will boost pilot production.
Quality of the industrial ecosystem	Pilot production requires cooperation in the industrial value chain. Suppliers of input materials as well as suppliers of equipment need to synchronize their activities—along with complementary producers and end-users. These relationships are difficult to create.
Available human capital	Core to successful pilot production activities are, for example, the technical, managerial, organisational, and marketing skills of personnel. These skills are not always available.

The report also gives recommendations for policy actions on ‘pilot production in key enabling technologies. These recommendations will however not be summed up in this chapter, since the aim of this section was to summarise potential barriers during pilot- and scale-up of innovative technologies.

4.4.2 External barriers as identified in professional literature – TIKI report

The report by the Taskforce Infrastructure Climate Agreement Industry (TIKI) (Duvoort, 2020) identifies scheduled industrial decarbonisation projects and the associated infrastructural needs. The Dutch Climate Agreement prescribes that infrastructure must not impede the industrial energy transition. Thus, a comparison between the current infrastructure and the projects scheduled for the period up to 2030 is made which identifies potential infrastructure-related limitations. Limitations that have been identified for this report focus on four different commodities: H_2, CO_2, electricity and heat/steam. This report is therefore a relevant source for the identification of barriers for the H_2 commodity in the light of the energy transition.

However, the report not only focusses on technical limitations which have been identified in the existing infrastructure, but also shares its recommendations in order to solve these limitations. Appropriate solution paths have been designed, based on consultations and expert meetings with representatives of the Ministries of Economic Affairs and Climate Policy, Interior and Kingdom Relations, the Provinces, academia, infrastructure operators and industry. Instead of discussing these solutions, only the barriers will be summed up for the purpose of this section. Technical limitations are often caused by non-technical obstacles (Duvoort, 2020). In this report, these obstacles have been subdivided into four categories:

- Regulatory obstacles;
- Economic obstacles;
- Administrative obstacles;
- Public support obstacles.

A more in-depth explanation of these categories can be found in Appendix G.2.

4.4.3 External barriers as identified in professional literature – Contrasting European Hydrogen Pathways

This paper has looked in some detail at the prospects for hydrogen demand and supply, together with the associated policy developments for France, Germany, Italy, Netherlands, Spain, and the UK. Key conclusions with regard to factors that impede the large-scale roll-out of low carbon hydrogen are summed up as follows and will be elaborated upon thereafter:

- Insufficient clarity on precise policy mechanisms of low-carbon hydrogen production;
- Cross-country varying assumptions regarding the significance of hydrogen across sectors;
- Cross-country varying approaches with varying rationales;
- Limited investment into project funding by Dutch Government;
- Long term capacity of renewable electricity may be constraint for the Netherlands.

One of the key conclusions is that government policy remains the key driver in the growth of low-carbon hydrogen production. While the aspiration of each country is becoming clearer, there is as yet little clarity on the precise policy mechanisms which will be put in place to enable the required investments leading to significant low- carbon hydrogen production (Lambert & Schulte, 2021).

Furthermore, there is a very wide range of hydrogen demand forecasts in each of the countries being considered. This broad spectrum is largely based on widely varying assumptions of the extent to which different sectors will become significant for hydrogen consumption. In particular, space heating and transport show large variations depending on assumptions on the extent to which consumers will adopt electric solutions (heat pumps and BEVs respectively). A larger uptake of electrical solutions, which, where they are possible, typically have a higher efficiency, will lead to a smaller role for low-carbon hydrogen. The use of hydrogen to decarbonise industry is a common theme in projections for all countries and provides a solid baseline for potential hydrogen demand, until at least 2030. Longer term, there is a possibility that heavy industry may relocate to those regions, both within and outside Europe, with large and low- cost renewable energy potential, but that should not constrain initial development of low-carbon hydrogen supply within Europe (Lambert & Schulte, 2021).

Alternatively, on the supply side, there is a wide variety of different approaches being considered with different rationales across the studied countries. There is an apparent lack of strategy geared towards unifying the various hydrogen initiatives. A division between advocates of blue hydrogen (that is preferred in the north-western part of Europe) verses green hydrogen (that is preferred in the southern European countries) manifests itself due to a difference in public and government opinion, or perhaps the role of with higher incidence of solar irradiation and lower cost of solar PV electricity.

4.4.3.1 External barriers as identified in professional literature – The Dutch perspective

Compared to five other European countries, a significant limitation in investment support is apparent in the Netherlands. The Netherlands' investment support policies are mostly aimed at research funding rather than investment project funding. Put into perspective, the Dutch Government recently announced a €338 million investment support scheme (Ministry of Economic Affairs and Climate Policy, 2021) for hydrogen projects, whereas Germany and France both announced multi-billion schemes, rising up to a total of €9 billion in Germany and €5-10 billion in France (Lambert & Schulte, 2021). Moreover, current hydrogen demand, which is predominantly in the refining and ammonia industries, is highest in Germany and the Netherlands – each in excess of 50TWh hydrogen per year. Nearly all this production is currently grey hydrogen, so will need to be decarbonised or eliminated on the journey to net-zero. In order to decarbonise the grey hydrogen by green hydrogen, a rise in capacity of renewable electricity is required. However, in the longer term, the available capacity for renewable electricity production may become a constraint for the Netherlands.

The writers (Lambert & Schulte, 2021) remain unconvinced of the logic for significant investment in hydrogen from electrolysis as long as marginal incremental power generation is provided by fossil fuels. It would be more logical to focus on blue hydrogen initially, until around 2030 when there should be sufficient large-scale renewable power generation to justify significant investment in electrolysis.

Comparing supply and demand projections, it is clear that at least until 2030 total low-carbon hydrogen supply (both blue and green) will be lower than the existing industrial use of grey hydrogen. Thus, there is scope for the production of low-carbon hydrogen to be accelerated, without any limitation on demand. That statement, however, ignores pricing considerations, since without clear policy drivers, existing users of grey hydrogen will have little incentive to switch to higher cost low-carbon hydrogen (Lambert & Schulte, 2021).

4.4.4 External barriers as identified in professional literature – The potential role of hydrogen in India

In the report on the potential role of hydrogen in India, barriers are established in four applications within the industry – Ammonia, Methanol, Refineries, Iron and Steel respectively – that concentrate on the technological application of hydrogen rather than policy- or governance related factors that were mentioned in previous sections. As the industry is the largest consumer of hydrogen today and will continue to be so as demand for hydrogen grows across industrial sub-sectors out of 2050 (Hall et al., 2020) (this is not only the case in India, but practically in every country (Maltais et al., 2020)). As with all green hydrogen production, large quantities of low carbon electricity will be required (Lambert & Schulte, 2021). The steel sector is the highest energy-consuming industrial sub-sector, which reflects the energy-intensive processes required to reduce iron ore and make steel. Given this high energy intensity, procuring sufficient low carbon electricity from nearby could be a challenge.

The report focusses on technical reasons as a reason for impeding the development of low-carbon hydrogen as an alternative to fossil energy sources. These reasons vary from low-cost existing options that make a transition towards high-cost hydrogen unnecessary, to the lack of policy incentives. The barriers for the development of low-cost hydrogen will be summarised in Appendix G.3.

Apart from the barrier story, it is clear that there is significant potential for hydrogen to continue to play a role in India's – and others countries – industrial sectors. Switching existing emissions-intensive hydrogen production to low carbon alternatives should be a priority, where it is cost-effective (Hall et al., 2020). Nonetheless, without significant policy support in the near-term, hydrogen direct reduction is unlikely to be competitive with smelting reduction with CCUS, or the other incumbent fossil fuel technologies.

4.5 Summarising the literature study

The energy transition is an ongoing topic that has gained traction in recent years. Hydrogen – green hydrogen particularly – has been denoted as a key alternative in order to reach decarbonisation targets in the next decade across many sectors (European Commission, 2020). It is however not obvious that these targets will be met (European Commission, 2015; Hall et al., 2020; Weber & Rohracher, 2012). Green hydrogen technology finds itself in the preliminary phase momentarily and its development needs to be accelerated still in order to make a significant impact as a decarbonisation alternative (De Laat, 2020).

Transition management literature introduces a variety of directions and focus points that describe various phases, time frames or aspects of a technology that ultimately causes a transition to take place in a given regime. SNM advocates the creation of socio-technical experiments in which the various innovation stakeholders are encouraged to collaborate and exchange information, knowledge and experience, thus embarking on an interactive learning process that will facilitate the incubation of the new technology. This occurs in a protected space called a niche, a specific application domain for the new technology.

In essence, the theory stands at the basis of a transition that is caused by innovative technologies – when seen from a multi-level perspective. It assumes that in order to cause large-scale socio-technological processes of change, niche-formations play a pivotal role and is the very basic ingredient that is required in order to promote change in the socio-technical regime (Rotmans et al., 2000, 2005), and afterwards result in a transition in the socio-technical landscape (see Figure 7). This notion is strengthened by the main principles of transition management: transitions or system innovations require changes at different levels of society. Moreover, niche-formation can be seen as the basic ingredient of the S-curve that is promoted by Loorbach and Rotmans (Loorbach, 2010), where the pre-development-, take-off- and acceleration phases stand at the basis for structural change and transitioning processes to become visible.

Put into perspective, SNM developed individually of – and prior to transition management. Moreover, it triggered advocates of MLP to make their framework. Regardless of its rather dated iterations, the basis of SNM remains a cornerstone within transition management literature, as well as for future transition management iterations. The link to MLP and the S- and X- curves from transition management that were mentioned at the beginning of this chapter can be best visualised in Figure 10. Here, Markard et al. (Markard et al., 2012) aim to understand and structure sustainability transition literature with all its complexities (due to the large number and variety of actors and interests involved in transformation processes). As mentioned in Section 2.2, Technological innovation systems will not be assessed for this research.

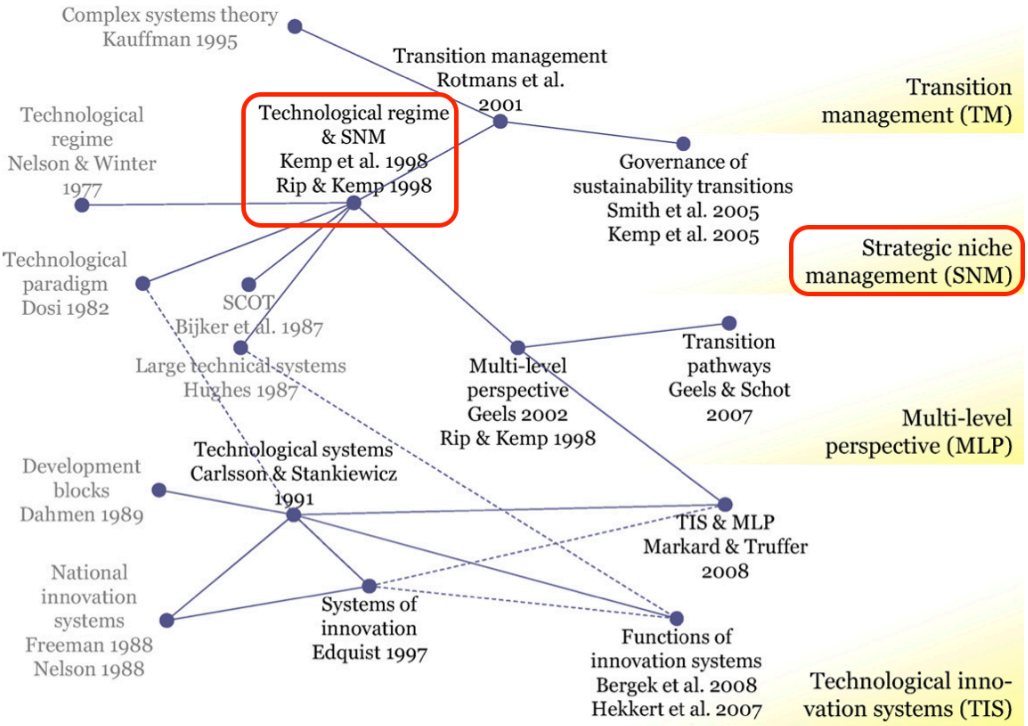

Figure 10 - Map of key contributions in the field of sustainability transition studies (Markard et al., 2012)

4.5.1 Barriers that impede the development of a niche (from a theoretical- and professional perspective)

Pilot development and scale-up are both known and important phases through which the development of a transformative technology must go in order to realise a transition. However, the phases of pilot development and acceleration are prone to the Valley of Death (alternatively referred to as procrastination of development resulting in inertia of the transitional process) due to a multitude of factors (European Commission, 2015; Rip & Kemp, 1998; Vandevyvere & Nevens, 2015). Transition management theory has verified and validated various obstacles that lead to procrastination in these phases. Some of these obstacles have proven to cause breakdown of the technology that was to be developed, ultimately leading to a delay or stop of a transition. Apart from that, the hydrogen case presents itself as an interesting case-study that could benefit transition management literature and vice versa.

Kemp and Schot (Rip & Kemp, 1998), stress the importance of dealing with different barriers that can be observed during niche developments in their final proposition of SNM. Potentially useful sustainable technologies often fail to be fully developed, or to catch on in the market, even though they promise superior performance compared to incumbent technologies. SNM, in combination with adjacent theories, provides insight into the nature of these obstacles, and provide pointers as to how to overcome them. Table 7 summarises barriers that were found across adjacent theories (Geels, 2012; Rip & Kemp, 1998; Rotmans et al., 2000; ten Pierick & van Mil, 2009; Weber & Rohracher, 2012) as well as lists barriers that were found in professional literature (Duvoort, 2020; European Commission, 2015; Hall et al., 2020; Lambert & Schulte, 2021). An elaboration of the barriers that are listed in Table 7 can be found in Appendix G. The summed-up barriers, or obstacles that are mentioned in Table 7will act as the parameters on which the empirical study will be based. Most barriers in Table 7 reflect 'external' barriers. However, the question remains which role (if at all) corporate-internal factors play in causing inertia within a transition.

Table 7 - Summary of barriers within the take-off- and acceleration phases of a developing niche

Kemp & Schot (Rip & Kemp, 1998)	**Geels** (Geels, 2012; ten Pierick & van Mil, 2009)	**Weber & Rohracher** (Weber & Rohracher, 2012)	**European Commission (KET)** (European Commission, 2015)	**TIKI report** (Duvoort, 2020)	**Hall et al.** (Hall et al., 2020)	**Contrasting European Hydrogen Pathways** (Lambert & Schulte, 2021)
Technological factors	Actors and markets	Market Failures	Access to finance	Regulatory obstacles	Existing stock of natural gas plants	Little clarity on policy mechanisms
Government policy and regulatory framework	Network barriers	Structural system failures	Limited market articulation	Economic obstacles	Low cost methanol imports	Widely varying assumptions leading to wide range of demand forecasts
Cultural and psychological factors	Institutional barriers	Transformational failures	Quality of the industrial ecosystem	Administrative obstacles	Availability of low carbon electricity	Varying approaches across countries
Demand factors			Available human capital	Public support obstacles	Lack of external- / policy incentives	Lack of policy drivers
Undesirable societal and environmental effect on new technologies				Industry specifics		Low governmental investment support scheme in comparison to neighbouring countries
Infrastructure and maintenance						
Production factors						

5 Empirical study – Identification of industry barriers

From Chapter 4, it became clear that there are many barriers, both of internal- and external nature, that have been mentioned in current SNM theories and related literature. However, none of these theories have been tested for the green hydrogen niche, which plays a role in the energy transition today. Moreover, most of the barriers that have been mentioned in literature, reflect only external-corporate barriers that potentially lead to inertia of the development of a niche and thus impeding the rate at which a transition unfolds. Therefore, including an analysis of present barriers that affect the development of the green hydrogen niche may have potential to enhance the SNM procedure. Furthermore, it may enhance the awareness of causes leading up to inertia.

Empirical research was therefore conducted in order to verify, classify and organise the practical perception on internal- and external barriers causing inertia within the green hydrogen niche. In doing so, the second and third sub-questions of this research were answered. This chapter presents the findings of this empirical research. Firstly, results from the empirical study will be given in the following sections. Thereafter, a summary of empirical results will be given in Section 5.4.

5.1 Case study selection

First, a selection was made of leading pilots that are currently tendered or realised in the Netherlands. The overview of Hydrogen projects in the Netherlands by TKI (De Laat, 2020), was used for this purpose. Pilot projects were based upon:

- Category: Green hydrogen production, by means of electrolysis;
- Capacity: measured in MW, with ambitions for >GW scale in 2030;
- Process phase: concept, feasibility study (first design), FEED-study (business case), FID (investment decision), execution (implementation, building);
- Link of project partners with consulted parties in the TIKI report.

Table 8 summarises the pilot projects that were selected for this case study. In column 'partners' from Table 8, the project partners that were interviewed for this research have been higlighted in bold. A more detailed elaboration can be found in Appendix B.

Table 8 - Hydrogen projects selection for the case study

Name	**Capacity**	**Process phase**	**Project period**	**Partners**
H2.50	250 MW	FEED-study	2019 – 2022 (FID)	BP, **PoR**, Nouryon
H-vision	Several installations	FEED-study	2020 – 2026	**Air Liquide**, BP, Deltalinqs, **Gasunie**, **PoR**, Power Plant Rotterdam, **Shell**, Uniper, Vopak
PosHYdon	1 MW	FEED-study	2019 – 2021	**Neptune Energy**, **Nexstep**, **EBN**, **TNO**, Nogat, DEME, NGT, Eneco
NorthH2	3 – 4 GW wind – 0,8 Mt H_2/y	Feasibility study	2020 – 2040	**Gasunie**, **GSP**, Provincie Groningen, **Shell**, Equinor, RWE
Oosterwolde electrolyser	1.4 MW	Under construction	Present – mid 2021	**Alliander,** Green Hydrogen Systems (GHS), GroenLeven

Figure 11 shows when and where the need for main infrastructure for H_2 and CO_2 transportation can be expected to arise in the Netherlands (Duvoort, 2020). In it, the location of the green hydrogen pilot projects from Table 8 are shown with a green star. This picture is relevant due to the fact that the layout of the main infrastructure becomes clear after reviewing the location of these pilot projects. It appears that the main harbours (PoR and GSP) in the Netherlands are popular locations amongst green hydrogen pilot production. A heavy industry area, that is Chemelot in the province of Limburg, has also got great interest in the development of green hydrogen. Some of the enterprises that want to decarbonise on the long term (Sabic, AirLiquide) and made this clear in their interviews.

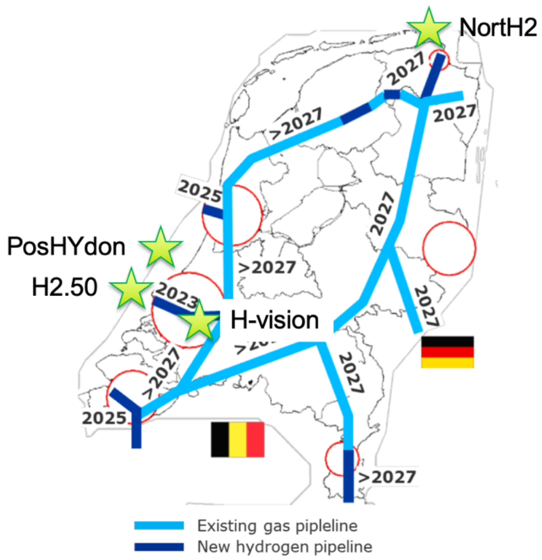

Figure 11 - Location of hydrogen projects for the case study

5.2 Decision framework

Before an analysis of present barriers that affect the development of the green hydrogen niche can be made, it is important to understand at which stage during the development of a low-carbon hydrogen technology these barriers occur. Based upon the steps that are taken by stakeholders during the take-off- and acceleration stages, one might ask the question of how these steps follow upon each other consecutively. Stated more precisely, how do parties that are involved in the development of green hydrogen technology weigh their decisions when moving from one stage to the next? What is the decision framework that is used in order to decide if the developed technology is viable for another investment round in order to move into the acceleration stage? In essence, which decision framework – consisting of what KPI's – is used to decide upon pilot- and scale-up investment decisions for hydrogen technology?

It is important to understand the steps that are taken by practitioners in order to form the basis for the verification, classification and organisation of the internal- and external barriers that might cause inertia within the green hydrogen niche. When one understands the process that is momentarily used for the making of investment decisions, a comparison can be made with the SNM framework that was proposed in the previous section. Furthermore, one might be able to pinpoint the time and step in the decisions process where barriers might occur and ultimately analyse if these barriers can be altered by applying the SNM framework. This analysis however, will be performed in the next chapter.

The next sub-section will first explain at which level in the company investment decisions are taken. Thereafter, A summation of KPI's will be given that form the basis of the currently applied decision framework for pilot- and scale-up investments. Then, various processes that are used in order to come to an investment decision will be named. Lastly, the key take-aways of the decision framework will be named. The following subsections will elaborate upon these points by paraphrasing or citing the respondents. The transcriptions will however not be shared in this report in accordance with the General Data Protection Law from the EU.

5.2.1 Organisational level decision

From the interviews that were performed for this research, it became clear that investment decisions for green hydrogen pilots and their scale-up involve a substantial amount of financing and are therefore mostly taken on:

- Senior management level;
- Executive board level;
- or by the Ministry of Economic Affairs (this applies to state-owned companies that were interviewed for this research and include: EBN and InvestNL).

In order to follow-up on these results the example of HyTrucks will be given. AirLiquide and the Port of Rotterdam have realised their shared ambitions in the name of HyTrucks which is a platform in which hydrogen suppliers and customers collaborate in order to realise trucks powered by hydrogen. This platform was created in order to create a market-push. A combination of consensus amongst involved parties and the connected business case, may convince senior-management in taking an investment decision. Another respondent explained: *'The investment decision of large-scale pilots is taken by the CEO'* (Shell).

Furthermore, when respondents were asked in which level within the company an investment decision would be taken regarding an explicit choice between short-term and long-term objectives, 14 out of 15 respondents of the explorative survey replied that these investment decisions are made at either national level or international level within their company.

However, it has not become clear from the interviews if senior-management (e.g. CEO's) are influenced by corporate-external or internal factors with regard to their investment decisions. This could not be determined, since only three of the total 17 respondents, senior management (CEO of GSP, CFO of Aldel, Director of Nexstep) was consulted. In the other cases, respondents were part of the operational and organizational team that reports.

5.2.2 KPI's for the pilot- and scale-up phases

The realisation of pilot projects relies on the one hand on very basic indicators (e.g. location, connection with grid, size, technology) and on the other hand typical KPI's that are used in order to determine the feasibility of a business case. Basic indicators that have been mentioned by respondents are summed up in the following table. Their position in the table, or position within an investment decision are not linked to their importance during an investment decision as this has not become clear from this research.

Table 9 - KPI's for pilot and scale-up phases

Performance Indicator	**Explanation**	**Named by respondent**
Likelihood of market supply & demand	Forecasts are made for potential market demand ('Outlook for potential customers' – PoR);	PoR, Neptune Energy, Shell, Alliander, GSP
Legislation and regulations	Without which a project can simply not be realised	All respondents
Technological	Technological feasibility (*TRL (Technology Readiness Level) 7 to 9 are required for InvestNL to fund pilots'* – InvestNL). As another interviewee added: (*'Projects are assessed on their TRL. On the basis of this level, contenders receive more or less subsidy'* – Gasunie), power supply as precondition for electrolysis, physical space (*'… needed for the realisation of the wind farm'* – GSP)	Nexstep, PoR, Gasunie, TNO, EBN, InvestNL
Infrastructural availability	Transport of power from- and to project location, transport of H2 from supply side to demand side, deck space on repurposed gas-platform (*'Deck space to store 20ft container-sized electrolyser'* – Nexstep)	Other respondents involved in PosHYdon
Corporate strategy	The same goes for corporate strategy. Whenever available, this can be aligned with partners in order to invest in the development of a common project (*'… by sharing a* CO_2 *reduction strategy with the shareholders, shareholders promise (financial) commitment and corporate activities can be executed and checked'* – AirLiquide);	All corporate respondents
Pay-back period	A specific pay-back period was not mentioned during the interviews. Respondents did however explain that regular (relatively short) pay-back periods were commonly used for investment decisions with regard to pilots and scale-up.	All respondents

	However, the explorative survey showed that when faced with a replacement decision, 7 respondents chose standard technologies with standard payback times and 8 respondents chose low carbon technologies with payback periods of 15 years that rely on subsidisation	
Financial	Availability of subsidy, risk-sharing in joint venture, alternative finance options	All respondents
Costs vs Benefits	risk mitigation, risk sharing with joint venture parties, risk of lacking market supply or demand	All respondents
Quality control	All respondents require a certain degree of quality from the project that will be invested in	All respondents
Governmental strategy	Clear strategy with shared vision and direction is required in order to focus investments in projects that are in line with national strategy, without it, the solution space with regard to green hydrogen initiatives becomes diffuse	All respondents

The importance of the most mentioned KPI's in order of most important to least important was however retrieved from the explorative survey. 15 respondents placed these KPI's in order of most influence to an investment decision, where 1 is of most influence and 6 is of least influence to an investment decision. The results show the following ranking:

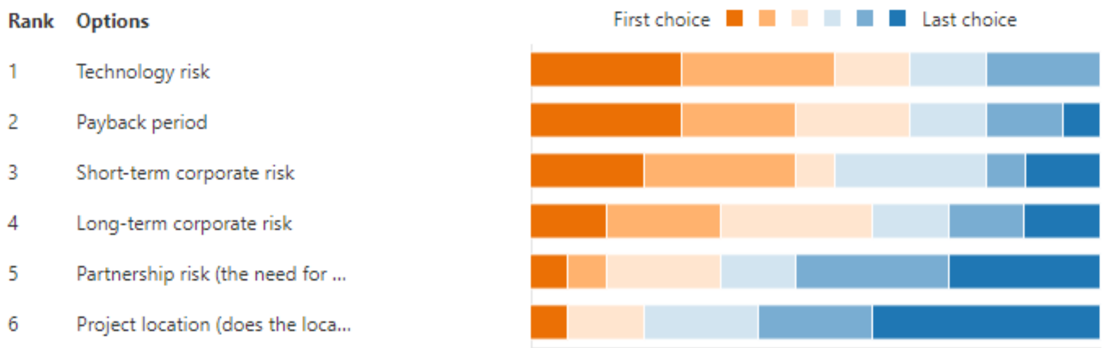

Figure 12 – Explorative survey: KPI's top 6 for FID

Interviewees additionally stressed that the KPI's that are mentioned in Table 9 form the basis of investment decisions for both pilot- and scale-up projects. Regarding pilot- and scalability investments for green hydrogen technology, business cases are by definition negative at the time of writing. This is due to the fact that for most of the KPI's mentioned above, uncertainties are proportionally bigger in comparison to regular investments. Furthermore, interviewees state that there in order to assess business cases for the green hydrogen technology, regular business case models are used. There is thus no special 'transition' or 'acceleration stage' business case that might be more fit for purpose.

However, respondents mention a difference between pilot- and scale-up investment decisions. The interviewees state that investment decisions for pilot projects are more mildly approached by executives than scale-up investments. When a pilot project is in line with corporate strategy, and when most of the KPI's perform within the risk-boundaries of a given corporation, a pilot project might be invested in. It is in essence but a demonstrator project with the aim of clarifying uncertainties and assessing future scalability and return on investment. Financial risks for pilot projects are deemed manageable in comparison to financial risks that are involved with scale-ups. Thus, one could say that a clear distinction is apparent between investment decisions between pilot projects and scale-up projects, where the KPI's that were mentioned earlier are 'softly' applied by the parties that were interviewed for investment decisions for pilots, but 'hard KPI's' are governing for scale-ups.

Figure 13 clearly sums up the difference that was observed by practitioners between the availability of information for the first six performance indicators that were introduced in Table 9. The availability of information for performance indicators that are used in order assess the business case for regular investments is deemed quite obvious. As is the availability of information that is regarded for scale-up investment decisions (as mentioned by multiple respondents). From the figure below, it is clear that there is a difference in available information and risks. However, as mentioned earlier, and as became clear from the interviews, the investment decisions that are made for scale-up projects and regular projects are the same (i.e. a business case based upon 'knowns' as shown in the regular investment column, is also used for scale-up investments). More specifically, this holds for the way investment decisions are made for the scale-up of green hydrogen technologies.

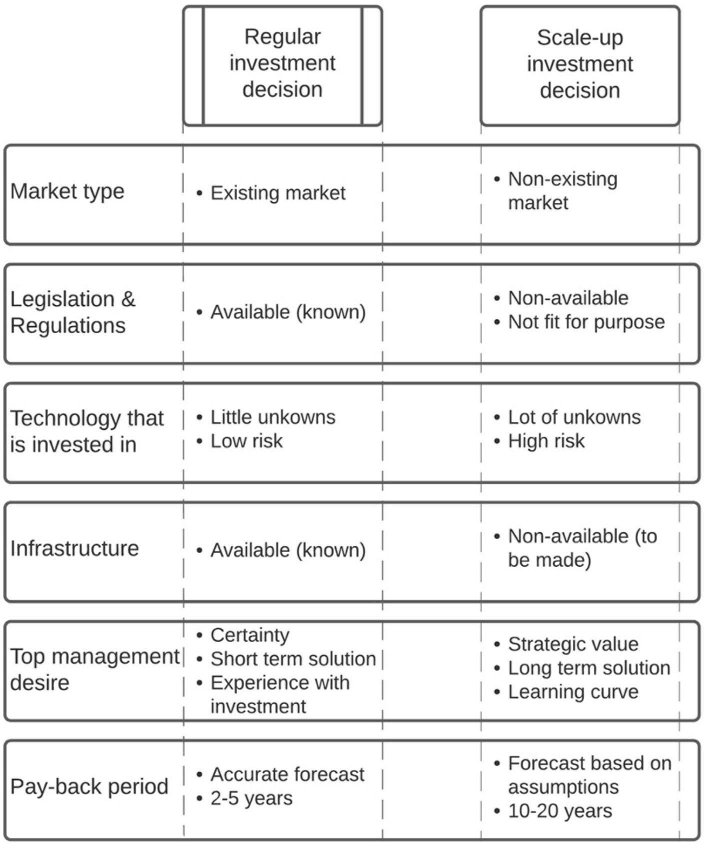

Figure 13 - Regular- vs scale-up investment decision

In addition to this notion, respondents mentioned that in order to determine the viability of business cases for the scale-up phase the following base-requirements should be in place:

- Clear strategy with shared vision and direction (from both governmental as corporate perspective);
- Security of supply (*'The supply of green hydrogen must be secured before it can play a role in the hydrogen-economy'* – PoR);
- Security of demand (*'Prior to the investment decision of a bank, the supply-demand issue needs to be resolved'* – ING);
- Understanding major uncertainties for the business case (*'Scale-up needs to be realised for something for which the market supply and demand, and technological viability are not yet known'* – Gasunie);

Apart from the KPI's that were mentioned in Table 9, respondents also mentioned factors that they deemed as stimulating for investment decisions to be taken for green hydrogen projects. These responses came about as a result of an open discussion upon possible ways in which the development of green hydrogen projects could be accelerated.

Stimulating factors that were mentioned during the interviews can be summed up as follows:

- External pressure: CO_2 emissions on heavy transport result in necessity of action (AirLiquide);
- External pressure: The Paris agreement stimulates corporations to decarbonise (Shell);
- Clear strategy: '*Which position does my company want to fulfil on the long term'* (Sabic);
- Appropriate scaling (*'… be the 'big elephant' in the room in order to create momentum.'* – AirLiquide);
- Motivators: '… transitions require people that are the driving force behind a project' – Stedin.

5.2.3 KPI's for the pilot- and scale-up phases – State owned entities' perspective

Two of the respondents (EBN and Nexstep) are state-owned enterprises. InvestNL is a special purpose vehicle from the Ministry of Economic Affairs in order to stimulate investments for the sake of the energy transition. Other than the KPI's that were mentioned above, the decision framework of these parties is bound by the following perquisites:

- Is the market not disturbed?
- Is the partnership of EBN not unauthorised state aid?
- How and for what is government finance used?
- Are potential CO_2 reduction, creation of job opportunity and additionality to market being realised?

5.2.4 Process of investment decision making

Respondents were also asked about the process or protocol that is used in order to assess the viability of a business case, i.e. meaning the process towards taking an investment decision. The most noteworthy decision-making processes of which are summarised below:

- TECOP-model (Technical, Environmental, Commercial, Operational, Political) according to corporate-specific requirements (PoR);
- 5 go, no-go moments are taken during prior to the approval of a business case. The board of executives ultimately makes the Go or No-go decision. Furthermore, the FID that is made applies the same set of requirements that is used for regular- and 'transformative' investments alike (Gasunie);
- Regular FID (final investment decision) process is used for both regular and 'transformative' investments (Sabic);

Whenever an investment decision is made for a pilot, or scale-up project in which multiple stakeholders collaborate, the division of the shares amongst the stakeholders is decisive for an investment decision. Whenever a party has a small stake, the partner that has a larger stake in the project has more decisive power.
However, the above-mentioned decision framework and associated KPI's apparently result in negative business cases and thus slow down needed investments into the development of green hydrogen production projects. However, as we saw from the Chapter 4, there are a multitude of obstacles and factors that also lead to procrastination. The next section will therefore discuss the obstacles that were observed in the case study.

5.3 Observed barriers during pilot- and scale-up of green hydrogen technology

Respondents were asked to elaborate upon the obstacles they experienced during the feasibility-, FEED-, and FID phases. Moreover, respondents were asked to suggest which obstacles they foresaw for the scale-up phases of their projects, as well as the development of the hydrogen niche in general. In response to the questions: 'What are reasons that impede the development of your pilot now?' and 'What are the reasons that may impede the scale-up of (your) green hydrogen technology in general?', a range of responses was elicited. These responses have been gathered in a first impression in Figure 14.

Figure 14 is a word cloud that consists of words, or word combinations that describe barriers or obstacles that either cite or summarise the answers that were given by the respondents. In the occasion where a summarised word or word combination was used, the terminology from barriers in the failure framework (Weber & Rohracher, 2012) were used.

Many specific reasons could be summed up by the general failure mechanism that was described in this failure framework. The amount of occurrence per word or word combination that have been extracted from the interviews, result in a larger font size – thus stressing the apparent presence of the barrier. A table showing the input values and their frequency – that were used as the basis for this word cloud – has been added to Appendix E. The colour combination in Figure 14 has been chosen randomly and have no meaning.

Figure 14 - Word cloud containing most mentioned causes for procrastination (generated by worditout.com)

Over half of those surveyed reported that the barriers captured by: Legislation and regulations, directionality failures, various corporate-internal factors, lack of subsidy and lack of market demand and supply, played a significant role in (potentially) impeding the development of pilots and hindering their scale-up. These barriers were each named in 7 or more interviews. Words with smaller font size were mentioned less than 7 times – most of which only once. However, respondents stated that it is not the individual occurrence of the barrier that is responsible for a slow transition, but rather their combined occurrence.

In order to briefly introduce obstacles that were mentioned most, the top 5 (in order of occurrence from high frequency to low frequency) will be named cited by responses from the interviewees. The transcriptions of the interviews will however not be added as an Appendix in this report in accordance with the General Data Protection Regulation from the EU.

5.3.1 Legislation and Regulations

Governments are on the one hand committed to environmental protection and other social goals, but they are often not expressing a clear message with the need for a specific new technology. Due to the lack of technology policy based on a clear view of the future, manufacturers remain uncertain about market developments and will be reluctant to invest in often precarious and risky alternatives (Rip & Kemp, 1998).

One interviewee argued that the development of hydrogen pilots strongly depends on government legislation and regulations (TNO). As another interviewee said: *'The existing licensing, legislation and regulations are not fit for the repurposing of offshore assets into green hydrogen production units'* (Nexstep). Another interviewee alluded to the notion of the: *'… difficulty in defining risks (during the feasibility study or an FID) due to lack of laws and regulations'* (Shell). In one case, the participant mentioned a concrete example: *'Lack of licensing, legislation and regulations delays the development of a pilot project, e.g. the Green Village in Delft'* (Alliander). This argument was confirmed by the following comment: *'Legislation and regulation are important barriers: The Gas Act does not currently include hydrogen as a gas, so hydrogen distribution is not legal at present'* (Stedin). This was further strengthened by the account of Neptune Energy: *'Legislation and regulations need to be developed for the production and distribution of (green) hydrogen'.*

A concrete example was given by GSP: *'Methanol based on H_2 and CO_2 is at least as sustainable as bio methanol (as long as it is green H2), but it cannot be sold as bio methanol. So it has to compete with grey methanol and that is not possible'.*

5.3.2 Directionality failure

Directionality failure is defined in Weber and Rohrachers' paper (Weber & Rohracher, 2012) as follows: Lack of shared vision regarding the goal and direction of the transformation process; Inability of collective coordination of distributed agents involved in shaping systemic change; Insufficient regulation or standards to guide and consolidate the direction of change; Lack of targeted funding for research, development and demonstration projects and infrastructures to establish corridors of acceptable development paths. In their accounts of the events surrounding green hydrogen pilots, the interviewees gave slightly different answers that eventually all distilled into the manifestation of the directionality failure.

As one interviewee said: *'A proper trade-off should be made as to what kind of energy transition is required. An adaptive or transformative transition (where either blue- or green hydrogen respectively become viable'* (TNO). Another participant commented: *'Blue hydrogen is deemed necessary for the energy transition and ultimately for the development of green hydrogen initiatives. Security of supply of hydrogen must first be guaranteed before green hydrogen can play a role in the development of the hydrogen economy'* (PoR). One of the interviewees argued that there are constantly changing opinions among a multitude of parties involved in these kinds of development paths, e.g. the chicken-and-egg story regarding transport of hydrogen or the lack of business case regarding storage of hydrogen (ING). Another interviewee, when asked about the directionality failure, said: *'With a multitude of options, it seems as if parties are spending time downplaying other people's options instead of developing their own. Parties also tend to link a multitude of options to each other with regard to the development of green hydrogen initiatives, as a result of which too many things want to be tackled at once and there is a lack of time to work out the details of individual components'.* This respondent also said: *'It is important to make a clear distinction between the purpose of pilots. Is the investment made for 'now' or to achieve goals 'for later'? The total vision must remain the same in order to implement change'* (Alliander). Another respondent strengthened this reply, arguing that there is a lack of focus or direction by the government on a particular industry (InvestNL). Lastly, a participant specified the previous remarks saying: *'There is a lack of innovation programmes mentioning: Type of innovations; Focus of the innovation; Demand from the market; Objectives of pilot projects; Duration of a pilot'* (Stedin).

5.3.3 Corporate-internal factors

Corporate-internal factors are not specifically explained or named in transition management theory. However there are multiple suggestions following the impact that (corporate) internal factors may have on the development of pilot projects on the one hand and the generally envisioned transition on the other. Interestingly internal factors were observed multiple times, varying in specific forms in which this barrier manifests itself. Internal factors reflect the dynamics within a corporation, e.g. capability failure, board-level decision making, shareholder pressure amongst others.

One of the interviewees mentioned that being stuck by myopia may cause inertia with regard to the development of an innovative market (AirLiquide). As EBN put it: *'Operators will have to consider smaller margins than they are used to in, for example, the oil and gas industry. The cost structure of operators will have to adapt to a new situation where there is a 'limit in the sky'* (EBN). In another case, a respondent reflected: *'A constraining mindset eliminates the necessity of investments in decarbonization or hydrogen projects'* (Stedin). In another case, Stedin reflected on the lack of structure, saying: *'Lack of structure, with regard to how a strategy is implemented, leads to procrastination with regard to investment decisions'.* This argument was further strengthened by AirLiquide, saying: *'A lack of transparency with regard to market developments in the hydrogen sector lead to fragmented developments'.* This respondent further argued that: *'Shareholder pressure leads to inertia in the development of hydrogen fuel for heavy transport'* (AirLiquide). But it also appears that: *'The board of management is critical of investment decisions'* (Shell). Further strengthening this remark by saying: *'When oil prices are low, less can be invested in pilot projects related to the production of green forms of energy because these projects already have little or no return on investment. Furthermore, the willingness to take risks is limited'.* (Shell).

5.3.4 Lack of subsidy

This barrier reflects an economic obstacle that is in fact a low-hanging fruit. But, it seems that it indeed does play a role in procrastinating the development of pilots. Projects involving relatively new or rarely used technology may incur high costs while the benefits are highly uncertain. In many cases this can be attributed to specific technical and/or organisational risks. A technical risk arises when a relatively new technology is implemented which has not been applied extensively before. These risks result in uncertainty, which makes it harder to secure funding for a project. Ultimately hindering the development of (pilot) projects due to a lack of resources such as funding. An argument that is often put forward is that the development of hydrogen pilots or niches, are currently found in the unprofitable top. As a result, business cases often have a financial gap that needs to be filled in order to make FID's.

One interviewee argued that there is a necessity of subsidy for pilot project in order to stimulate private investments into innovative technology (Nexstep). Another respondent suggested that: *'Innovation subsidies should be allocated for the purpose of risk mitigation, thus enabling a learning curve in pilot projects'* (TNO). Moreover, the PoR said: *'Subsidy is required to get out of the unprofitable top*'. As another respondent put it: *'There is a lack of subsidy, which is needed to motivate investing partners in the pilot to invest into green hydrogen production*' (Nexstep). Another suggestion was given by Tennet, saying: *'The price difference between grey hydrogen and green hydrogen is too big for the occurrence of a competitive edge'* (Tennet). Moreover, projects require a proper project proposal in order to get subsidised. However, as one respondent righteously comments: *' Uncertainty of scaling-up costs of the pilot, leads to undersupply of funding*' (Nexstep). It appears, that subsidy does work as a stimulating factor for the development of projects (European Hydrogen subsidy has worked as a duplicator of value over the past seven years with a factor of 2.24 (*Www.Fch.Europa.Eu*, n.d.)).

However, subsidy is not the only financial obstacle leading to procrastination. Lack of 'corporate-external' financial incentives also impede this process. As one participant commented: *'A financial incentive could be to assign a value to plastic waste and CO_2 that makes it worthwhile to carefully design the production and recycling process for decarbonisation purposes'* (Sabic). Another participant commented: *'Uncertainty of green hydrogen 'kg-prices' in the future leads to uncertainties in business cases*' (EBN). As an alternative to subsidy, credits for the usage of green hydrogen products could be awarded as a positive financial incentive. However: *'Credits than can be earned by using green hydrogen fuel in the refinery are not strengthened in reward, thus causing the business case of green hydrogen investments to be inconclusive'* (Shell).

5.3.5 Lack of market demand & supply

The failure framework from Weber and Rohracher (Weber & Rohracher, 2012) elaborates upon their demand articulation failure. The connected failure mechanism is determined as: Insufficient spaces for anticipating and learning about user needs to enable the uptake of innovations by users, absence of orienting and stimulating signals from public demand and lack of demand-articulating competencies. Since new technologies have not proven what they are worth, customers are not sure what to expect, causing risk aversion and troubling the willingness to pay. Apart from an uncertain expectation for a new technology, an important demand factor is the price of the product. New technologies are often expensive as a result from high unit costs of production. Manufacturers think that consumer demands cannot be changed and are therefore the most important barrier, arguing that products cannot be manufactured without a clear consumer demand (Rip & Kemp, 1998).

This argument is observed in many of the interviews. As one interviewee explained: *'Electrolysers are made on project level and by hand, more manufacturers are required for the development of green hydrogen technology'*, adding to that: *'Electrolyser manufactures are protective of their data, thus inhibiting market supply growth'* (TNO). Another respondent said: *'The supply chain side of electrolyser production should be developed'* (Shell).
Nexstep for example urges: *'The need for more pilot projects is high in order to develop the market supply side of electrolysers'.* A potential future investor reports: *'Due to the lack of a supply- and selling market, the scale-up risk is still substantial. This lack can be described as the typical chicken-and-egg story'* (ING). As another respondent argues, a prerequisite for the development of the hydrogen economy is the security of supply of hydrogen (PoR). The lack of a market makes scale-up difficult. As one respondent argues: *'Scaling up must take place for something for which you do not yet know whether there is a market and whether it is technically feasible'* (Gasunie).

5.4 Summarising the empirical study

Empirical research was conducted in order to verify, classify and organise the practical perception of internal- and external barriers causing inertia within the green hydrogen niche. A selection of leading pilots in the Netherlands was made based on category, capacity, process phase and link to TIKI. A session of semi-structured interviews was conducted with partners from pilot projects: H-vision, H2.50, PosHYdon, NorthH2 and Oosterwolde electrolyser. The respondents consisted of senior-level professionals that were interviewed about obstacles during pilot- and acceleration phases. As a result of the interviews it became clear what kind of decision framework is used in order to determine the viability of business cases related to green hydrogen projects. Another key-stone result reflected on KPI's that are used for decarbonisation investments. Their order, and the organisational-level in which business cases are assessed – across the energy sector – was further explored in an explorative poll.

Additionally, the five most mentioned obstacles that can be encountered during these investment decisions were: Legislation and regulations, directionality failure, lack of subsidy and lack of market supply and demand. Figure 15 summarises the corporate external barriers that were identified during the interviews. The orange coloured factors consist of terms that were mentioned in both SNM and failure framework literature. The yellow coloured factors are case specific barriers. In Figure 15, the size of the sphere does not depict its importance, however, the larger spheres were mentioned more often than the smaller spheres. Interestingly, the third most mentioned cause were corporate-internal factors as a reason for potential procrastination.

Figure 15 - External barriers as identified in the green hydrogen case

Furthermore, all respondents agree that pilots have negative business cases. An investment decision is most likely to be taken senior-level management within a company and is only taken whenever a given project is in line with corporate strategy. Investments however, are taken in the same way for pilot- and scale-up projects of innovative technologies and for regular technologies alike – i.e. no distinction is made for the decision framework regarding transformative technologies or regular technologies.
It is however obvious – as multiple respondents agree – that pilot projects and scale-up projects from upcoming technologies have longer lead- and pay-back periods as regular technologies. Most of the interviewees agreed that they normally are not more lenient with regard to decarbonisation investments. Furthermore, long lead-times are not common in the banking world, nor are they for corporations that are stock-market listed.

Regarding the ‘technological’ PI (performance indicator), GSP is optimistic about the development of technology that is required for green hydrogen production. In the view of this respondent, other PI’s play a larger role in slowing down the transition. However, as one of the respondents states, corporations that are involved in the development of green hydrogen technology, and ultimately need to take investment decisions with regard to linked projects, require the understanding of major uncertainties for the business case (*‘… assumption on electricity price in 10y, hydrogen/kg price, potential market demand…’* – EBN). This is however not possible and often leads to a business case being rejected due to the vastness of uncertainties involved.

6 Analysis, validation and verification

So far, this study has reviewed literature on SNM, and it's application within transitions and transition management. Upon this literature study, a case-study was performed in the Dutch hydrogen case (i.e. reviewing the dynamics that are currently experienced within the hydrogen pilots). However, before the research questions of this study can be answered, the results of this case-study need to be evaluated. Therefore, this chapter will analyse the results that were found during this study.

First, an elaboration will be given upon the choice of SNM for the Dutch green hydrogen case. Thereafter, the framework that is proposed by SNM literature will be compared to the investment decision framework that is currently used by practitioners. In the last section of this chapter, the barriers that impede the development of the green hydrogen technology in the Netherlands is analysed.

6.1 Strategic Niche Management and Dutch Green hydrogen production

6.1.1 Is the green hydrogen technology a niche?

The niche is in fact a longstanding theme in relation to the diffusion of innovations and technological change (Rip & Kemp, 1998). Kemp and Schot ((Rip & Kemp, 1998) present the theoretical framework in which niche markets are more simply defined as small, focused and targetable portions of a larger market, comprising a group of actors whose needs for products or services to perform particular functions are not being addressed by mainstream providers. Small networks of actors support novelties on the basis of expectations and visions. By learning processes, the niche develops itself into a certain course of action (i.e. elements become aligned, a dominant design is established). Ultimately awaiting a window of opportunity in order to enter a socio-technical landscape.

The claim that SNM is an appropriate theory to assess the developments within the hydrogen niche can be verified by assessing the aims of strategic niche management, which are:

- to articulate the changes in technology and in the institutional framework that are necessary for the economic success of the new technology;
- to learn more about the technical and economic feasibility and environmental gains of different technology options – that is, to learn more about the social desirability of the options;
- to stimulate the further development of these technologies, to achieve cost efficiencies in mass production, promote the development of complementary technologies and skills, and stimulate changes in social organization that are important to the wider diffusion of the new technology;
- to build a constituency behind a product – of firms, researchers, public authorities – whose semi-coordinated actions are necessary to bring about a substantial shift in interconnected technologies and practices.

The above-mentioned aims are analysed with results from the interviews consecutively. From the results it became apparent that:

- the articulation of changes in the institutional framework are indeed necessary for the success of a new technology. An often-mentioned barrier reflects upon the lack, or incompleteness of legislation and regulations.
  However, the articulations of changes in technology mainly reflect the scalability of electrolysers. The technology for the production green hydrogen is already there, it is not however ever been scaled to industrial size;
- Due to the fact that the technology has not been scaled to industrial proportions as of yet, much needs to be learned about the technical and economic feasibility and environmental gains of green hydrogen production technologies;
- The case-study related interviews resulted in an almost unanimous claim that stated all parties are interested in the stimulation of further development of these technologies.

Almost all of the respondents agreed on the need of achieving cost-efficiencies in mass production in order to ultimately stimulate the wider diffusion of the new technology (where technology means – scaled up electrolysis);

- The results also made clear that due to the social- and governmental pressure, corporations that are involved as partners in the case-studied pilots, are all keen to build a constituency behind a product. This however, has only really manifested itself few ex-governmental agencies that are involved in research upon the hydrogen niche (e.g. Fuel Cell Hydrogen Undertaking).

Furthermore, the applicability of SNM for the hydrogen niche can be confirmed by comparing conditional factors to the use of SNM studies, and the case-study pilot projects as such. Prominently emphasised boundary conditions have were adopted from a report by Caniëls and Romijn (Caniëls & Romijn, 2008). Table 10 summarises boundary conditions for SNM and reflects upon comparison of the case-studies that have been reviewed for this study.

Table 10 - Comparing SNM and Hydrogen case

Conditional factor SNM	**(Green) Hydrogen case study (as decarbonisation technology)**
The creation of sheltered spaces for incubation (Rip & Kemp, 1998)	Pilot projects originate from the need for the creation of an initial setting within which the new technology can be used experimentally, without immediate pressure for adequate technical and market performance. In this setting, the potential benefits of the new technology are valued highly by the stakeholders. This is the case for all sub-cases used in this study.
Possibility for continuous evaluation and incremental improvement by means of broad stakeholder interaction processes (Geels, 2012)	The green hydrogen pilots that have been set up and used in for this case-study research, have all been realised for the sake of learning and evaluation of their potential application. All respondents stress the fact that mutual learning is the main purpose for pilots and that partners prefer to broaden partnerships with other companies in order to broaden their development potential.
The new technology must … exhibit temporal increasing returns or learning economies (Rip & Kemp, 1998)	As mentioned by all respondents, pilot projects are only realised once the feasibility study concludes a positive financial forecast in the future. Most business cases tend to be negative, requiring preferably external financial aid, or positive (mostly short-term) financial prospects.
'… new technology should still be open to development in different direction' (Rip & Kemp, 1998)	Experimentation is conducted in a range of application domains simultaneously. Cross-fertilisation across niches can occur, contributing to critical mass in the learning process. This does not necessarily happen momentarily due to an apparent directionality failure.
'… already attractive to use for certain applications in which the disadvantages of the new technology count less and the advantages are highly valued' (Rip & Kemp, 1998)	Decarbonisation properties of green hydrogen production are attractive for a range of applications in various industries. Due to the urgency of decarbonising industry because of the Paris agreement, Dutch Government policy and the European Green deal, companies are eager to explore the upside of green hydrogen. However, production costs and market competitiveness with carbon-emissive sources slow down the acceleration of the technology momentarily.

On the basis of the beforementioned comparison of conditional factors for SNM and the similarities with the properties of the Dutch green hydrogen case, one can conclude that the state of green hydrogen in the Netherlands can indeed be perceived as being a niche that is part of the energy transition.

6.1.2 SNM framework compared to proceedings in the green hydrogen sector

Kemp and Schot (Kemp et al., 1998) provide a 5-step framework as part of SNM literature. Similarities can be drawn between the current state of affairs within (green) hydrogen production developments and the first three steps in the SNM framework (Table 2). The choice of an application, being the feasibility study or FEED-study. None of the respondents however were consciously applying this framework for the development of green hydrogen technology. The first three steps that are proposed by Kemp and Schot appear to come naturally. As a company chooses a technology it wants to explore, sets up a combination of like-minded industry-peers and executes the pilot that is required in the first stage of niche development.

Only after the pilot has been developed, forecasts can be drawn as to whether scale-up is deemed feasible for the involved party. Step 4 and 5 in the SNM framework, concerning the scaling up of the experiment and the breakdown of protection, have not however been reached at this stage. It can therefore be assumed that the application of SNM for the case study of green hydrogen in the Netherlands is fit.

6.1.3 Relevance of SNM literature in regard to the green hydrogen developments

The development of a niche within transitions is positioned predominantly in the three levels of Geels' multi-level perspective. However, the most important presence of relevance of this theory can be distilled from its similarities with the vary basis of transition management theories (the S-Curve by Rotmans in Figure 5). One can observe the hypothesised dynamics of a transition in the form of an S-curve when put into perspective within the MLP framework (Figure 16).

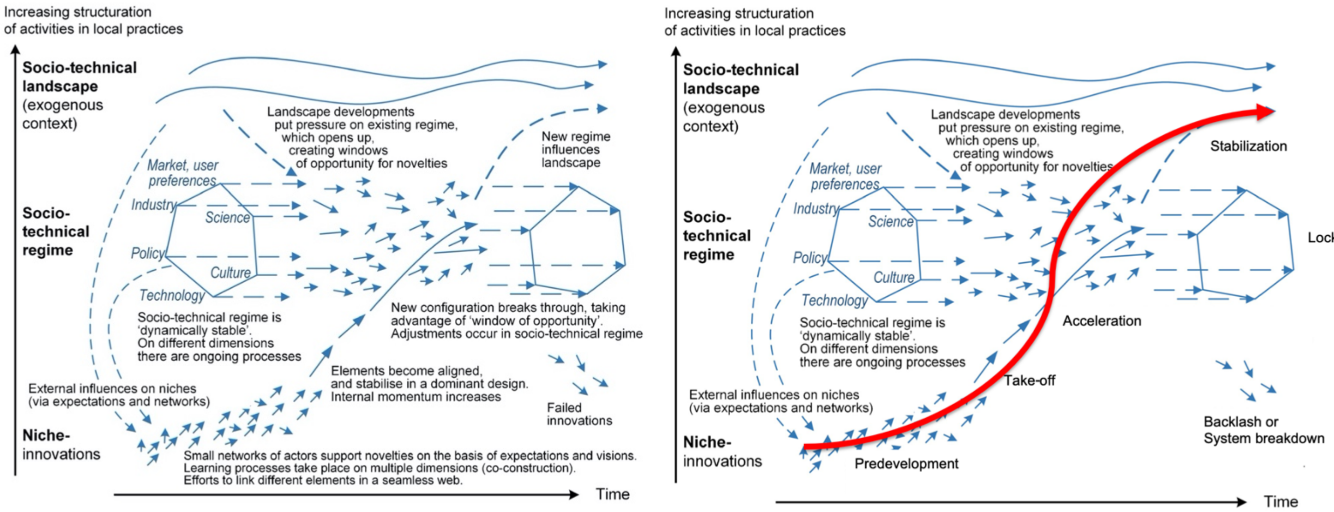

Figure 16 - Multi-level perspective on transitions (Geels, 2012)

Figure 16 shows the MLP framework of transitions on the left, and incorporates the S-curve in the same framework on the right. The S-curve describes four distinct phases of development of which: Predevelopment, take-off, and acceleration, are further elaborated upon in SNM. The S-curve also includes the terms backlash and system breakdown which are characterised by systems that can get stuck in a lock-in or even break down by failing to respond to the external and internal pressures that threaten them. These pressures are essentially both phases that are explained in SNM in the 5th step in the SNM framework which states: 'Support for the new technology may no longer be necessary or desirable when the results are disappointing and prospects are dim'. Disappointing results and prospects however, are further specified within the SNM theory as barriers.

The hydrogen case shows similarities with the terms that are introduced on the S-curve (on the right-hand side of Figure 16). The similarities between the phases of pre-development, take-off and acceleration and the green hydrogen case shows are shown in

Table 11.

Table 11 - Transitional phases and green hydrogen case

S-curve phase	(Green) Hydrogen case study (as decarbonisation technology)
Pre-development phase: *the status quo does not visibly change*	When pilot or demonstrator projects, the status quo does not visibly change. In this phase new collaborations are set-up in order to explore and learn possibilities with regard to green hydrogen production
Take-off phase: *in which the change process is initiated as the state of the system begins to shift*	The realisation of demonstrator projects initiates momentum within the existing regime (energy sector). Locations where change is required become apparent and developments take place to pursue the adaptation of the existing sector in order to prepare itself for a potential introduction of green hydrogen
Acceleration phase: *in which visible structural changes take place due to an accumulation of interacting socio-cultural, economic, ecological and institutional changes*	The acceleration phase is the desired outcome of all respondents and is reflected by goals that are formulated in corporate strategy. Pilots are realised in order to acquire information about the scalability of the technology in order to ultimately forecast the risks of scale-up

6.1.4 Critique

Neither of the theories offer at this moment an operational, fully founded and empirically verified policy tool, although transition management is much further in terms of operational application and establishment as regular policy practice. SNM can be seen as a relatively conservative approach in which on the basis of solid empirical research, recommendations are being made for limited, demarcated aspects of regime shifts or transition. There is elegance in its simplicity and analytical strength (Loorbach & Van Raak, 2006). Moreover, SNM is mostly based on traditional ex-post empirical research and focusses on description that leads to recommendations on specific issues. The lack of involvement throughout the last decade withheld the theory from developing into a usable policy tool. It is therefore more useful as a research model.

In the analysis on the iterations of SNM literature, it has become apparent that there is still a lack of understanding about the processes by which learning experiments can ultimately culminate in viable market niches, which will successively widen and finally contribute to regime shift (Caniëls & Romijn, 2008). Furthermore, a cross-cutting review of the main SNM studies yields more comprehensive insights into the niche creation process than any of the individual SNM studies are able to provide on their own. Additionally, due to a lack of evolution in the last decade, the theory has not developed into a usable policy tool (Markard et al., 2012). It is therefore too limited for practitioners to be really used as such.

Furthermore, the most important phase of niche development – the acceleration stage – is underexposed. It merely explains the necessity of niche formation and knowledge sharing. Practically seen however, professionals that are involved in hydrogen niche formation want to have practical framework that they can work with instead of general explanations upon niche formation as a solution to barriers during that same process (Caniëls & Romijn, 2008).

6.2 (Investment) decision framework in the pilot- and scale-up phase

The empirical study has shown that practitioners make a distinction between investment decisions for pilot projects and regular projects. There does not appear to be a specific decision framework for the acceleration stage. This section will elaborate upon these findings and compare SNM literature to the case-study results. First the investment decision framework that is used by practitioners will be assessed by comparing it to the SNM framework. Next, the decision framework that is currently used for investment decisions for the green hydrogen pilot- and scale-up phases is analysed. The last subsection will discuss points of critique from both the case-study- and literature perspective.

6.2.1 Does SNM provide a fit for purpose decision framework?

From the empirical study, it became clear that investment decisions – which lie at the basis of realising a green hydrogen technology pilot or scale-up – are taken on senior management level. This is due to the fact that pilot and scale-up projects require significant financial investments that are in line with corporate strategy. But these investment decisions are also based upon a multitude of unknowns (as seen in Figure 13).

Even though there is a clear distinction between pilot-, scale-up-, and regular investments (Chapter 5), let alone the transitional phases (as described in SNM literature), respondents made clear that no distinctive (investment) decision framework is used in order to assess the viability of scale-up projects. In fact, the decision framework – and line of reasoning – that is used in order to determine the viability of scale-up projects is the framework that is normally used for regular investment decisions. Due to the many unknowns that appear during the pilot- and scale-up phases ((European Commission, 2015), it becomes rather difficult to substantiate a promising business case based upon the KPI's that are used by practitioners (Table 9). As a result, green hydrogen pilot- and scale-up projects are realistically prone to the Valley of Death.

Could SNM literature then aid in shaping a fit for purpose decision framework, that practitioners may adopt? As a matter of fact, the 5 steps that are at the basis of the SNM framework provide guidelines for the choice of a technology (see step 1 in Table 2). These guidelines are in line with the reasoning from practitioners in the field of green hydrogen technology developments. Their description is spot on and in line with the technology assessment that are performed in the form of the feasibility study, conceptual design phase and ultimately FEED (Front End Engineering Design, i.e. phases prior to the FID. These guidelines are rather descriptive, which makes it generalisable for firms with varying outlooks and targets.

Step 2 of the SNM framework elaborates upon the selection of a specific experiment, i.e. meaning the selection of a pilot. Kemp and Schot explain that "the selection of an appropriate setting in which the new technology is to be used where the advantages of the technology are valued highly and the disadvantages count less" (Kemp et al., 1998). Again, this step is described in a general manner and can therefore be interpreted as fit for any party. It does however suggest that the disadvantages of a technology should count less. This notion is fundamental to any decision framework that should be applied for both pilot- and scale-up phases, where the disadvantages (reflected by the unprofitable top) are evident. Despite this important statement, SNM literature does not provide guidelines, nor a specific decision framework that could be used by practitioners. The theory remains rather descriptive and provides no explanation with regard to practical interpretation.

6.2.2 Practitioners do not recognise the scale-up phase as part of niche development

Transition management literature, as well as SNM theory, clearly distinguishes four phases during a transition. The predevelopment-, take-off-, acceleration- and stabilisation phases. Each of these phases is based upon specific characteristics as explained in Chapter 4. Differentiation between the phases gives a strong indication that each phase should be approached accordingly. SNM literature goes on to explain the difference of the take-off and acceleration stages in its five-step framework. In spite of that, it does not give specific guidance that could be of use for the green hydrogen case. Rather, it is descriptive in nature and based upon ex-ante research.

The case study made clear that practitioners are aware of the different stages that the development of a technology goes through. Using sometimes alternative theories or explanations to for example the S-curve, the reasoning of the respondents is in line with transition management literature. Surprisingly though, practitioners do not use a specific (investment) decision framework for a specific stage. Business case assessments that are used for regular investment decisions are also used for the assessment of pilot- and scale-up projects – even though these require a different approach due to their different characteristics (amongst which, pilot- and scale-up projects have far more unknowns compared to regular existing technologies). This notion was validated in the second round of interviews as well as confirmed in the explorative survey (Appendix F).

A difference in approach is observed between pilot and scale-up projects. Respondents agreed on the fact that KPI's that are used for the assessment of business cases of pilots are interpreted less strictly then KPI's for scale-up or regular investment decisions. The way in which these KPI's are interpreted is also dependent of the corporations' characteristics (large- or small company size, state-owned or stock market listed, to name a few). A reason that was often named is that pilots tend to receive subsidy more easily than scale-up projects. Pilot projects are also short-term undertakings in comparison to scale-up projects, which makes the corporate risk manageable. Furthermore, respondents noted that the positive societal impact of being involved in pilot projects is substantial. Pilot projects, are but the beginning of developing a transitional technology.

The scale-up or acceleration phase has to contend with extended assumptions on the long-term implications of the scale up. Respondents agree upon the fact that it is difficult to determine market related prices, on both the supply- and demand side, for the green hydrogen case. This is, amongst others, due to the fact of the directionality failure which neglects long term strategy for green hydrogen production. Moreover, scale-up projects do not qualify as easily for subsidy programs as pilot projects. As a matter of fact, the Dutch government mainly focusses her attention on the financing of R&D and pilots (Ministry of Economic Affairs and Climate Policy, 2021). As a result, the often named 'unprofitable top' is a logical result of assessing scale-up technologies (with an abundance of uncertainties) with regular (investment) decision frameworks.

Professional literature points out that in order to reach decarbonisation targets for 2030 and beyond, specific roadmaps need to be designed and orchestrated by governments in collaboration with the industry (Lambert & Schulte, 2021). A cross-country analysis of roadmaps that were presented in North-Western European countries showed a variation in the quality of analysis on which they are based . Some draw on strong analysis, with well-established methods and transparent assumptions. However, there are also many roadmaps that appear to be based on weak analysis or that lack sufficient transparency to judge the robustness of the conclusions on which the roadmaps are based (Lambert & Schulte, 2021). This is potentially damaging: poor quality and opaque analysis results in unrealistic expectations, and can exacerbate hype-cycles, undermining the development of the innovation system (McDowall, 2012).

In order to summarise above mentioned analysis, Figure 17 depicts the take-off (pilot), acceleration (scale-up) and stabilisation (regular technology) phases and puts them along the vertically displayed decision characteristics. In the columns the difference between the three stages becomes apparent. The S-curve has been depicted above the columns in order to stress the difference in required system state during these transitional stages.

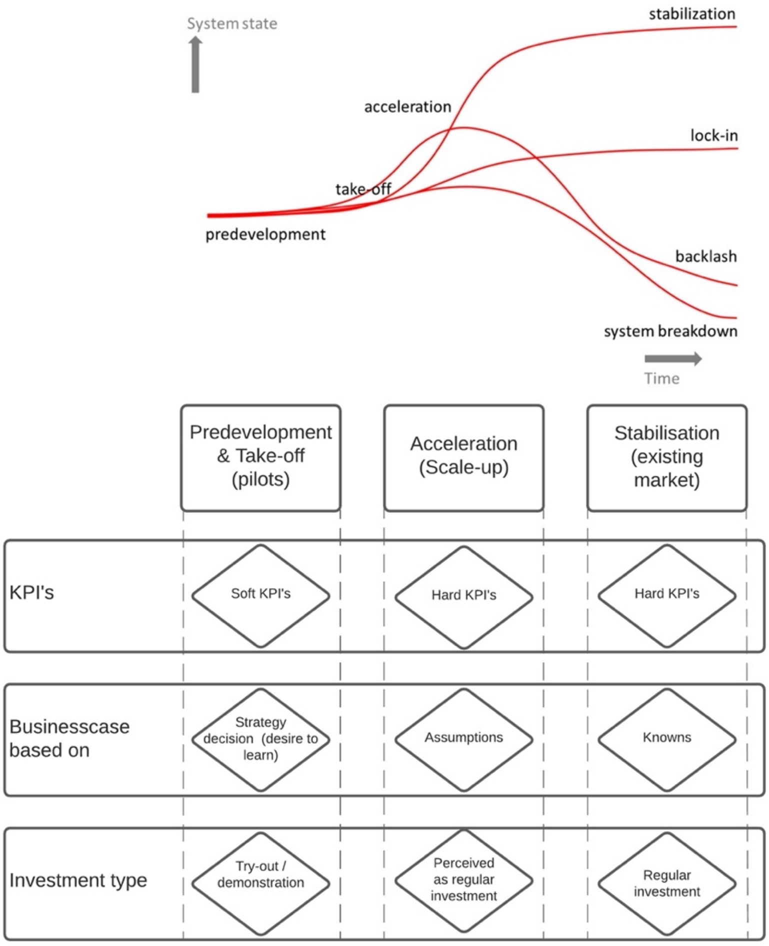

Figure 17 - Investment decisions across transition phases

6.3 Obstacles leading to procrastination

The title of this master thesis names the concept of 'Valley of Death'. It reflects upon the phase in between product development (such as pilot production) and industrial applications (referred to as competitive manufacturing) where both costs and risks are very high. The term is dramatized by using the word 'death', which Is appropriate, due to the fact that many pilot projects never actually reach the market. As one respondent explains in the second round of interviews: *'There are concrete barriers that might result pilots to reach the valley of death. Amongst others: green hydrogen is dependent of a competitive energy price and green hydrogen supply is too low to play a significant role, electrolysis will only be viable at €20/MWh'* (VNPI). Additionally, as mentioned in the previous sections of this chapter, transition management theories and SNM also mention the occurrence of barriers during the development of niches on their way to change regimes. The occurrence of these barriers, their similarities and differences between theory and practice, will be discussed in the subsections below.

6.3.1 Barriers in theory compared to barriers in the green hydrogen case

A niche (as described in both SNM and MLP), is prone to failure. SNM identifies and categorises barriers that may lead to procrastination of the development of a niche, or it's breakdown altogether, mostly focussing on corporate-external barriers. As SNM focusses solely on niche formation, and proposes a limited set of impeding factors. Therefore the failure framework (Weber & Rohracher, 2012) was introduced additionally, as explained in Chapter 4. A summation of barriers as shown in Table 7 was thereafter used as a basis for the interviews with practitioners.

The interviews were set-up on the basis of Table 7, due to the fact that it was considered as a useful summation of barriers that are found during pilot phases. A multitude of responses was given and therefore a multitude of barriers were mentioned. Questions were always asked in a general sense, resulting in an unbiased specific or general answer. In a second round of interviews, the barriers that were found were validated. Therefore it is possible to discuss the factual findings hereafter. Verification and comparison of the results with Table 7 resulted in the following insights:

- The categorised barriers as proposed in SNM fall short with regard to barriers that are experience in practice;
- The general classification of the failure framework by Weber and Rohracher can and does in some cases complement the barriers of SNM;
- Not all failure types from the failure framework by Weber and Rohracher are expressed in the hydrogen case-study (i.e. the take-off and acceleration phase);
- Respondents mentioned Corporate-internal barriers as an important reason for procrastination. This category is however not mentioned in SNM or transition management related literature (see subsection 6.5.4);
- The time-specific occurrence of barriers is not given within literature (see subsection 0).

As a result from the interviews a mould of both SNM barriers and failure framework factors that manifest themselves in the take-off and scale-up phases of green hydrogen technology became apparent. Whereas the SNM framework is based upon ex-post research on different case-studies (therefore not having discussed green hydrogen technology), the failure framework tried to give a complete overview of failure factors that were found across different studies. Figure 15 introduced the corporate-external barriers as a collection of both SNM and failure framework factors that were mentioned by the respondents in this case-study. Occasionally, this figure was complemented by case-specific failure mechanisms from which they consist (yellow spheres). The case-specific failure types that were adopted from the failure framework by Weber and Rohracher are (the definition is explained in Table 5):

- Infrastructural failure;
- Directionality failure;
- Institutional failure;
    - Policy coordination failure;
- Market failure (specifically adopting the failure mechanism of Information asymmetries).

Case-specific failure types that were adopted from the SNM framework also happen to be at the top five barriers that have been identified in this case-study. These failure types were not mentioned specifically in the failure framework by Weber and Rohracher, but they were mentioned by the interviewees.
These failure types are mentioned below (their definition is given in Table 3):

- Technology factors;
- Societal effect;
- Demand factors (specifying the uncertainty of supply and demand).

Weber and Rohracher (Weber & Rohracher, 2012), as well as Kemp and Schot (Kemp et al., 1998), agree that within their theories it may well be that some failures mechanisms have still been overlooked. Moreover, both agree that a series of empirical studies, aiming to study the occurrence and magnitude of such failures should be launched – keeping in mind that this empirical work should go hand in hand with a refinement of the concepts and definition suggested of what constitutes a failure in the context of long-term transformative change. This last sentence is important, as it embodies the spirit of this research. Deficiencies within theory are apparent with regard to the green hydrogen case, however, this is logical ever since empirical ex-ante studies on this topic are limited.

6.4 Barrier top 5 analysed

In Chapter 5, a practitioners perspective is given upon barriers that cause procrastination with regard to pilot- and scale-up investments. The top 5 that is discussed in the previous chapter will hereunder be briefly analysed and compared to SNM literature.

6.4.1 Legislation and regulations

SNM literature introduces the 'government policy and regulatory framework barrier'. Kemp and Schot elaborate as follows: "Governments are on the one hand committed to environmental protection and other social goals, but they are often not expressing a clear message with the need for a specific new technology. Due to the lack of technology policy based on a clear view of the future, manufacturers remain uncertain about market developments and will be reluctant to invest in often precarious and risky alternatives" (Kemp et al., 1998). This notion is strengthened by Weber and Rohracher with the failure mechanism of 'Hard institutional failure'.

Surprisingly, the over two-decade old SNM framework is strikingly accurate with regard to this barrier. During the case-study interviews it became apparent that this is the most named barrier that causes the development of the green hydrogen niche to be procrastinated upon. Momentarily, there is indeed a lack of legislation and regulations, in combination with existing legislation that is not fit for purpose, that hamper pilot- and scale-up investments. From the interviews it became clear that a reason for this disconnect between policymakers and corporate investors, is the chicken-and-egg discussion. One awaits action from the other and vice versa, resulting in a lock-in situation.

6.4.2 Directionality failure

The term 'directionality failure' reflects the lack of shared vision regarding the goal and direction of the transformation process (Weber & Rohracher, 2012). This failure mechanism pinpoints the lack of technology policy-based view of the future that is also mentioned in the SNM framework. This barrier reflects the inability of collective coordination of distributed agents involved in shaping systemic change. Due to insufficient regulation or standards, guidance and consolidation of the direction of change is not hampered. Furthermore, lack of targeted funding for research, development and demonstration projects and infrastructures impedes the establishment of corridors of acceptable development paths.

This last notion is almost directly related to recent professional literature that was mentioned in Chapter 4. As Lambert and Schulte explain: Investment support policies are mostly aimed at research funding rather than investment project funding (Lambert & Schulte, 2021). Furthermore, the Dutch government invests a fraction of what neighbouring countries invest in hydrogen projects (Ministry of Economic Affairs and Climate Policy, 2021). These statements from professional literature are strengthened by the views from respondents of this case-study. It can be concluded that SNM and the failure framework are spot-on regarding this failure mechanism.

6.4.3 Corporate internal factors

Corporate internal factors were amongst the 3rd most mentioned reasons for procrastination of investment decisions with regard to decarbonization projects. However, neither SNM nor the failure framework mention corporate internal factors as a reason for procrastination. This is however understandable due to the fact that both SNM and the failure framework are policy-oriented studies. Governmental and policy related factors are assessed within this literature. Due to the fact that respondents stress the role of corporate internal factors within the take-off and acceleration phases, we need to complement the failure mechanisms with this factor. Subsection 5.3.3 will therefore discuss the reasons why corporate internal factors may cause procrastination by briefly touching upon alternative theories.

6.4.4 Lack of subsidy

An often-mentioned reason for procrastination was the lack of subsidy. This however has not as such been specifically mentioned in theory. A recent study of Maltais *et al*. concludes that the real barrier to decarbonizing heavy industry is not financial but linked to policies, regulations and technological development. Again, uncertainty and unclear long-term policies make investments in transitioning very risky (Maltais et al., 2020). Maltais et al may be right in his statement, however, the financial part of pilot projects plays a large role in the viability of the project as has become apparent in the interview sessions.

Subsidy can be regarded as a financial incentive. Subsidisation is regarded as a positive incentive; however, businesses can also be incentivised with negative incentives such as CO_2 tax. As one respondent mentioned in the validation interview: *"The end-of-life and CO2 consequences of existing assets are not sufficiently highlighted and considered with regard to the decarbonisation issue"* – SABIC. Lack of subsidy thus does not solely reflect a positive financial incentive, but also a negative one. In accordance with replies in the validation session, the 'lack of subsidy' factor will be renamed to 'Cost & Benefit barrier' – which better fits the meaning of the term.

6.4.5 Lack of demand and supply

SNM literature explains that the demand barrier causes risk aversion, troubling the willingness to pay, due to the fact that customers are not sure what to expect since new technologies have not proven what they are worth. Apart from an uncertain expectation for a new technology, an important demand factor is the price of the product. As Kemp and Schot elaborate: "New technologies are often expensive as a result from high unit costs of production. Manufactures think that consumer demands cannot be changed and are therefore the most important barrier, arguing that products cannot be manufactured without a clear consumer demand" (Kemp et al., 1998). This notion is strengthened by the failure mechanism of 'Information asymmetries' by Weber and Rohracher – stating that uncertainty about outcomes and short time horizon of private investors lead to undersupply of funding for R&D.

The definition of the lack of demand and supply barrier that is proposed by SNM literature is again spot on when compared to answers from respondents. It appears that the definition that is proposed in SNM literature – that is mostly based upon ex-ante research of previous century case-studies – remains as accurate with the green hydrogen case-study. As can be recited from the interviews: "*Due to the lack of a supply- and selling market, the scale-up risk is still substantial. This lack can be described as the typical chicken-and-egg story"* (ING). Another respondent argues, that a prerequisite for the development of the hydrogen economy is the security of supply of hydrogen (PoR). The lack of a market makes scale-up difficult. "*Scaling up must take place for something for which you do not yet know whether there is a market and whether it is technically feasible"* (Gasunie).

6.5 Critique

SNM sheds light upon the failure of sustainable technologies to catch on in the market. SNM can help to provide insight into the nature of obstacles that are observed during niche formation, and provides an introduction into a number of barriers (see Table 3) that can manifest themselves during niche formation as well as cause potential procrastination of the niche development. However, the SNM framework does not provide concrete solutions for the barriers that are identified in SNM literature and related literature. It remains unclear what (practical) solutions can be applied in order to mitigate the risk of the barriers named across SNM related literature. SNM provides insight into the nature of obstacles that result in inertia and provides pointers as to how to overcome them. However these pointers lack in-depth solutions in how specific barriers can be tackled (Caniëls & Romijn, 2008).

6.5.1 Incompleteness of failure mechanisms

Researchers in the field of SNM and related transition management literature (Geels, 2012; Rip & Kemp, 1998; Rotmans et al., 2005; Weber & Rohracher, 2012) have widely contributed to the identification and elaboration upon the various barriers and failure mechanisms that potentially impede niche development. All of the theories summarise and ultimately categorise the barriers according to their specific case-studies or research directions. As a result, there remains a gap with regard to a generalisable summary of failure mechanisms that encompasses the totality of barriers. The list of barriers in SNM literature is limited and does not shed a light on for example corporate internal factors, that appear to be of great importance. The failure framework by Weber and Rohracher comes closest to providing a complete list of impeding factors. However, due to their policy-based focus, corporate barriers are left out of the picture.

The fact that different theories develop to display varying sets of impeding factors can be attributed to the scattered development of transition management theories as shown in Figure 10. Scholars that are involved in the various iterations of these theories tend to collaborate occasionally, this does not lead however to a complete and 'multi-disciplinary' collection of barriers.

6.5.2 Lack of corporate-internal barriers

An often-mentioned barrier, within this case study, that may cause the procrastination of niche developments, are corporate-internal barriers. These barriers manifest themselves in different forms: lack of senior-management urgency, lack of decarbonisation investment decisions, lack of corporate strategy, lack of human-capital that drive transitions within the company, to name a few. The reasons of human capital can even be strengthened by recent management changes within the Shell company:

> *'People are really questioning if there will be any change at all', said one of the people familiar with the internal tensions. The mindset isn't there among senior leaders for anything radical'*

The importance of this barrier comes forth from the interviews with practitioners in developing green hydrogen pilots. Subsection 6.5.4, showing alternative theories that specifically study corporate internal factors, confirms the different failure mechanisms that were explained by the respondents. SNM literature however, does not mention corporate internal factors. It does so, due to its governmental-policy oriented line of research. However, as the advocates from SNM suggest that deep interrelations between technological progress and the social and managerial environment in which they are put to use are common elements in technological regime shifts (Kemp et al., 1998). This suggests that SNM literature will try to explain the totality of perspectives and users of a transition, which it nonetheless does not.

6.5.3 Lack of time-based occurrence of barriers

In addition to the previous sub-section, SNM and related theories summarise barriers and consequently explain the fashion in which failure mechanisms may manifest themselves. However, it remains unclear in which stage of niche development, or in which stage along the S-curve barriers occur. Professionals that were interviewed explain the necessity for a time-linked failure framework. As one respondent suggested: *'Corporate-internal factors mostly play a role in the take-off phase (i.e. before accelerating and scale-up), thereafter, external barriers play a big role'* – Neptune Energy. Additionally, the investment decisions during the acceleration phase heavily rely on the well-known notion of risk mitigation and financial risk level of a project. Many uncertainties remain unidentified during the take-off- and acceleration phase and can therefore not be mitigated (European Commission, 2015). Consequently senior management, will most likely choose for the alternative with least risk (This argument was made by some of the respondents, and strengthened by the results from the explorative poll where 8 out of 15 respondents – Q1 in Appendix F). Such knowledge would ultimately enable practitioners to predict during what stage a barrier might occur and therefore be able to adequately prepare, assess and mitigate potential risks for procrastination. However, this is not made clear in SNM literature

6.5.4 Proposition for the incorporation of adjacent literature about corporate internal factors

Transition management literature does not explicitly explain corporate-internal barriers – even though these play a role in disruptive technologies. Lack of corporate-internal barriers can however be complemented by theory that is found outside the realm of SNM. Literature that reflects the corporate-internal dynamics that are experienced during the development of disruptive technologies can be found in the body of knowledge about radical innovation management at firm level. Prominent scholars in this field – Christensen (Christensen, 1999) and Rumelt (Rumelt, 1995) will be briefly introduced. Christensen was chosen due to the fact that there are similarities between the hydrogen case and his study where disruptive technologies are assessed.
The hydrogen case conforms the conditions of a disruptive term: an innovation that results in *worse* product performance, at least in the near-term – as opposed to a *sustaining* technology: an improved product performance of new technologies. With his theory he builds upon the friction framework by Rumelt, which explains corporate-internal dynamics that lead to procrastination. His framework consists of the terms: distorted perception, dulled motivation, failed creative response, political deadlocks and action disconnects – which are elaborated upon in Appendix G.4.

Recap: From the case-study it became clear that multiple internal barriers might lead to inertia within the hydrogen case. A recap of corporate internal barriers related to human capital – that were mentioned in the interviews were:

- Senior-management preference of less risky alternatives;
- Lack of people that are the driving force within a firm;
- Lack of strategy that is supported by concrete targets connected to time-scale;
- Risk-aversiveness with regard to the assessment of business cases.

Reflecting upon the first notion. One respondent mentioned: *'Large parties like Shell (with relatively large financial clout) should help develop green hydrogen initiatives. If large parties succeed in developing electrolysers, the market may be motivated to develop electrolysers as well, as the feasibility of the machine would then be proven'* (Shell). There seems to be a common belief that established firms in the energy sector – mostly related to carbon-emitting firms – are the ones to lead the energy transition. Indeed these firms have large financial clouts, therefore potentially having enough financial power to lead the energy transition. However, large firms will not be likely to invest heavily in disruptive technologies like the green hydrogen production. First of all, risks are too high, but second of all, small markets cannot satisfy the near-term growth requirements of big organisations (Christensen, 1999).

Regarding the second notion, one interviewee said: *'Lack of people with a vision will lead to a delay in decarbonization investments*' (Stedin). Indeed, Rumelt explains that a combination of the frictions: distorted perception, failed creative response, political deadlocks or action disconnects all reflect reasons that might result in corporate-internal inertia with regard to deciding upon decarbonisation investments (Rumelt, 1995).

Only the first two notions from the recap were touched upon in order to briefly elaborate upon the corporate-internal barriers that were mentioned by respondents. A more thorough explanation that uses the notions by Christensen and Rumelt will not be given, as this is out of the scope of this research. However, surprisingly, Christensen and Rumelt indeed elaborate upon internal barriers. Even though their studies are relatively dated pieces of literature, the frictions found in their literature reflects the barriers that were mentioned in this case-study. SNM literature can therefore be enriched by reflecting upon corporate internal barriers and moulding with the body of knowledge about radical innovation management at firm level.

6.5.5 Proposition for a case-specific update of the failure framework

A new classification could be proposed by making a clear distinction between corporate external and -internal factors, as this has not been done yet in SNM literature. In one of the validation interviewees, a respondent commented: *'Due to the lack of policy coordination, finance options, lack of negative incentives, technical developments and corporate-internal developments, scale-up is difficult at the moment'* – (TNO). It becomes clear, that there are distinct themes within the hydrogen case with connected case-specific failure mechanisms.

As a result of case-specific, corporate external barriers – where both SNM and the failure framework complement each other in order to reflect the specifics of the green hydrogen case – a new overview of corporate-external barriers was given in Figure 15. Likewise, a proposition will be made for a visualisation of corporate internal barriers that were identified in this study. This structure consists of four corner stones (technology, human capital, governance and finance) that are based in part on Christensen's and Rumelt's theories. These cornerstones are demarcated in dark blue. Hanging of the corner stones, a combination of barrier demarcations by Christensen, Rumelt and the case-study have been mentioned. The outside spheres are all resulting barriers that were found in the interview sessions. The resulting corporate internal failure framework is shown in the following figure.

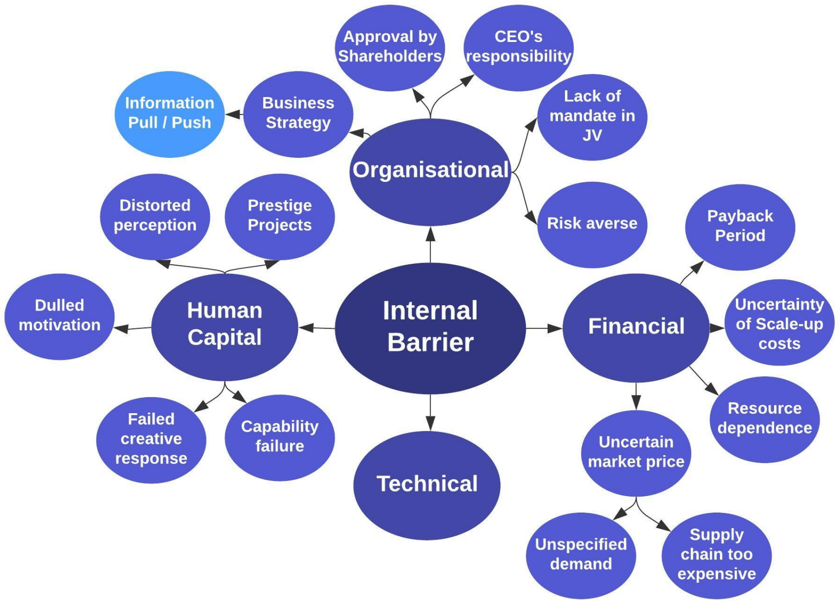

Figure 18 - Corporate-internal barriers

Figure 18 can be seen as an addition or even update to the SNM framework, in the way that it complements the theory by naming and explaining relevant corporate-internal barriers. Furthermore, both Figure 15 and Figure 18 aim to update SNM literature with green hydrogen case-specific failure mechanisms. However, as advocates of SNM theory, but also respondents of the green hydrogen case have confirmed, it is the combined occurrence of both corporate-internal and external barriers that should be assessed in future research in order to give a more complete analysis of developing niches. As a result, the final proposition of this analysis will mould both figures into one case-specific failure framework and is shown in Figure 19.

Furthermore, the second round of interviews that was conducted for verification purposes resulted in an approval of this framework by practitioners. Respondents noted that the framework clearly depicts the complexity of a transitional process – specifically the development of niches. Interviewees also said that the framework was depicted in such a way that the inner-spheres (orange-coloured for external barriers and dark-blue for internal barriers) consisted of generalised terms that could be used for other case-studies. However, all respondents stressed the value that could still be gained by placing the failure mechanisms on a time-line like the S-curve. By doing so, practitioners could forecast when to act with regard to counter specific failure mechanisms.

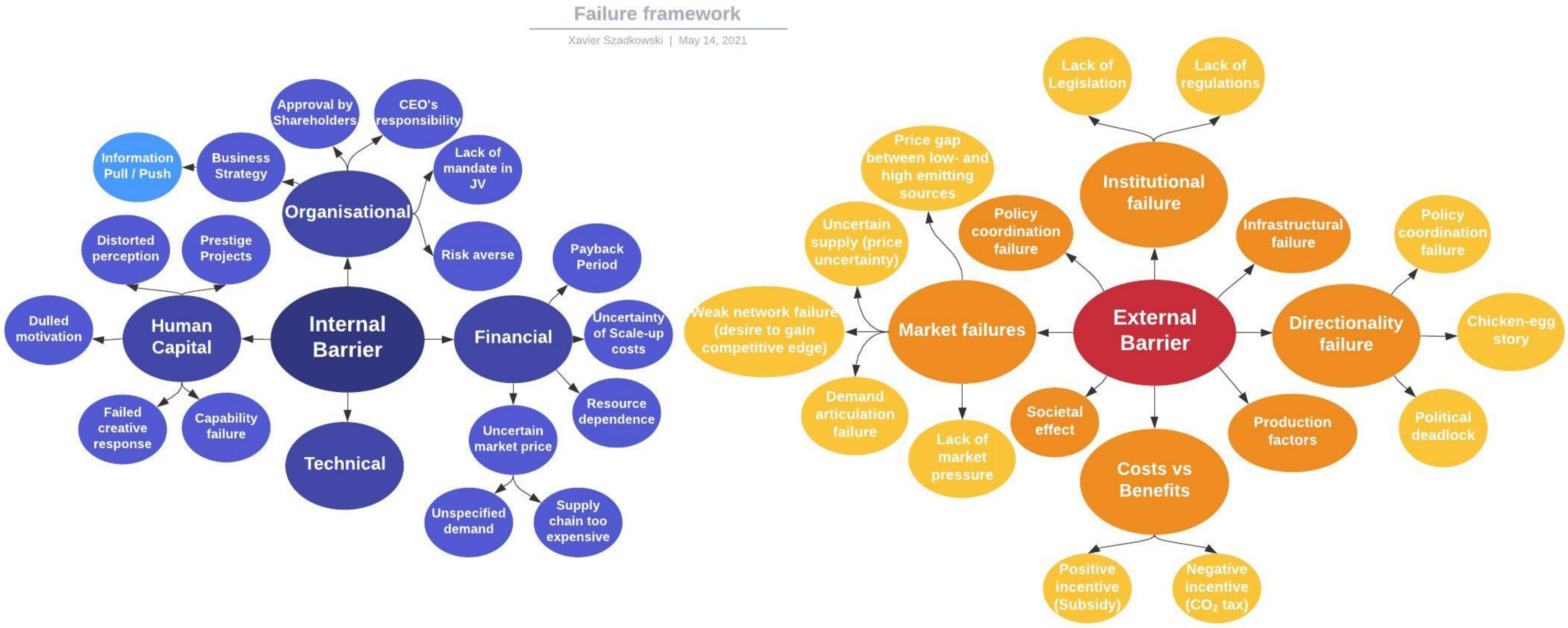

Figure 19 - Proposed failure framework for the development of green hydrogen niche

7 Conclusions

In this study, the usability of strategic niche management framework was assessed with regard to the green hydrogen technology niche. It aims to contribute to the field of SNM by performing a case-study for a technology that currently undergoes a transition and that specifically finds itself in the take-off- and acceleration phases. Two phases that are at the core of SNM literature. Additionally, adjacent literature was consulted in order to assess its real-world application in practice. For the sake of completeness, the objective of this Master's thesis is repeated:

> *The objective of this research is to* ***give insight*** *into the application of SNM concepts during the acceleration stage of green hydrogen production projects. Furthermore, this research aims to* ***investigate*** *which barriers cause corporate decarbonisation efforts to be procrastinated upon and* ***assess*** *how SNM theories can aid in overcoming these barriers.*

This Chapter substantiates the core findings and formulates the conclusions for this research. First, conclusions will be drawn on the studied SNM literature in section 7.1. Next, the conclusions on the green hydrogen case are elaborated in section 7.2. Section 7.3 answers the main research question.

7.1 Conclusions about SNM literature

7.1.1 The value of Strategic Niche Management within the acceleration phase

Strategic niche management (SNM) is an approach that has been developed in the first decade of this century and is based on the multi-level conceptualisation of socio-technical regimes, embedded in a slowly changing landscape and influenced by emerging niches. It aims to help induce a broad socio-technical transition towards more sustainable development by focussing on the 'predevelopment', 'take-off' and 'acceleration' phases. The SNM framework is designed to facilitate the introduction and diffusion of new sustainable technologies through protected societal experiments in different fields. According to adjacent transition management literature, niche-formation are at the basis of transitions, which confirms the importance of this theory about niche formation and development. However, the SNM framework is mostly based upon solid empirical ex-post research of historically observed transitions and has therefore not (yet) been operationalised into a verified policy tool.

7.1.2 Impeding factors during niche development

Based on its ex-post research, SNM advocates can shed a light on the failure of sustainable technologies to catch on in the market, and consequently helps to provide insight into the nature of obstacles that are observed during niche formation. The theory righteously suggests that the phenomenon of inertia derives from the fact that technologies are part of a broad and complex system and summarises the obstacles as a list of barriers that can impede the development of niches.

Their validity and completeness was assessed in this case study. The case study found that the hydrogen niche follows this line of thought and shares part of the barriers that were named in SNM theory (e.g. demand-, technological-, infrastructural and Government policy and regulatory framework related factors). However, the list of barriers appears to be incomplete and was supplemented with the failure framework (Weber & Rohracher, 2012). The failure framework is a useful addition to the barrier collection of SNM due to the fact that it builds upon the notion of barriers that have been mentioned in adjacent theories (Figure 10). Some of the failure mechanisms that are mentioned in the failure framework overlap with SNM (e.g. Institutional failure is in conjunction with government policy and regulatory related factors). However, the case study results also roots out some barriers and failure mechanisms that do not play a role in the development of green hydrogen pilots momentarily. Nonetheless, the general description of SNM literature, makes the list of barriers applicable to any technology that can be seen as a niche.

7.1.3 Critique

First, SNM literature is based upon ex-post research and focusses on policy-intervention perspective. It therefore does not offer an analysis of the (private) corporations' perspective. And even though it is a rather dated theory, basic concepts are mostly in line with the present-day case-study.

Unfortunately, SNM can be seen as a relatively conservative approach in which on the basis of solid empirical research, recommendations are being made for limited, demarcated aspects of regime shifts or transition. It offers no operational guidelines that are more than welcome by practitioners. A reason for this may be a lack of evolution in the last decade. Therefore, the theory has not developed into a usable policy tool (Markard et al., 2012) and is more useful as a research model.

Secondly, SNM literature does not specifically name, or address, corporate-internal barriers. Whereas it became clear from the empirical study that corporate-internal barriers play a large role, especially during the pilot- and scale-up phases. Literature outside the realm of SNM needs to be consulted in order to fill this underexposed barrier. Kemp and Schot nota bene suggest that possible ways to incentivize learning and coordination – by bringing together different parties (firms, universities, research institutes) – to work on a problem, providing financial assistance, and manipulating technological and economic expectations. However, they do not discuss the perspective of firms, which are as important as governments due to their interaction within niche development. Nonetheless, SNM does not offer an analysis of this view.

Third, the generalised description of barriers is spot on and is still accurate for today's green hydrogen case. The description of the 5-step framework is also concise, but accurate according to the interviewees. Unfortunately, the theory lacks profundity in order to really prescribe or practically aid the transitional process. The most important phase of niche development – the acceleration stage – is very much underexposed. It merely explains the necessity of niche formation and knowledge sharing. Furthermore, a cross-cutting review of the main SNM studies yields more comprehensive insights into the niche creation process than any of the individual SNM studies are able to provide on their own, which may be a reason for its limitations. Practitioners will however benefit from a practical framework that they can work with (Caniëls & Romijn, 2008). It is therefore too limited for practitioners to be really used as such.

7.2 Conclusions about the green hydrogen case-study

7.2.1 Can present day green hydrogen developments be regarded as a niche?

Green hydrogen can be perceived as a niche, the technology is not disruptive, however, the transition of the energy sector that is caused by the upstream of hydrogen technologies in recent years has a disruptive nature. As explained in Table 10, the green hydrogen case shows striking similarities with SNM literature. Not only does the case compare to niche characteristics that are mentioned in SNM literature, it also became clear from the results of the case study that the hydrogen case is prone to the valley of death due to a multitude of barriers. These barriers can be verified and analysed by combining the lists of barriers that are mentioned in SNM with the failure framework (as shown in Figure 19).

7.2.2 Impeding factors for investment decisions

Green hydrogen seems to be a promising alternative for decarbonising various applications within the energy sector. From energy storage to fuelling cars and even ships. From decarbonising the hydrogen guzzling heavy industry to stabilising the energy grid. Green hydrogen technology is however still in its pilot phase. In order to play a significant role, sale-up of the technology still needs to be realised. Both the pilot- and scale-up phases are prone to the Valley of Death due to a variety of reasons that became clear from SNM literature as well as practitioners' views on present day challenges. A top 5 of failure mechanisms that could cause procrastination consists of: legislation and regulations, directionality failure, corporate-internal factors, lack of market demand and supply and lack of subsidy. The latter can be perceived as a failure mechanism that reflects lack of positive- and negative financial incentives. In fact, there is no limitation of hydrogen demand, and therefore low-carbon hydrogen demand within the industry. Lack of Pricing considerations that are linked to policy drivers results in lack of incentive to switch to higher cost low-carbon hydrogen initially (Energy Agency - Clingendael International Energy Programme, n.d.).

Surprisingly, corporate-internal factors also play a large role in potentially impeding the development of green hydrogen technology in the Netherlands. This failure mechanism manifests itself in the lack of motivators, lack of knowledge and lack of a practical roadmap in line with corporate strategy amongst others. It is surprising, since SNM literature does not mention corporate internal factors explicitly.

Alternative literature needs to be consulted in order to analyse corporate-internal failure mechanisms.

7.2.3 Critique

First, as explained in literature, the legislation and regulations failure is expressed by the lack of technology policy based on a clear view of the future. Added to that, the failure framework explains the institutional failure as the absence, or shortcomings of formal institutions such as laws, regulations, and standards (in particular regarding IPR and investment). This failure mechanism creates an unfavourable environment for innovation and impedes the speed at which technology can be developed. The definitions from the failure framework are almost a decade old, but are based upon failure mechanisms from adjacent literature (SNM amongst others) that is over two decades old. This notion is important due to the fact that institutional failure is a known concept from which practitioners have obviously not learned. Respondents approved, that this failure mechanism indeed plays a large role in slowing down the development of the green hydrogen niche. The reason why this institutional failure also manifests itself in this case-study has not been uncovered.

Secondly, when asked about barriers, practitioners often started by naming corporate-external factors – that is, the factors that have been mentioned in SNM literature and in the failure framework. Corporations easily identify policy- or governmental related issues that result in procrastination. However, only after specifically questioning if corporate-internal processes might contribute to a slowing down of the development of green hydrogen technology, it becomes clear that corporate-internal factors indeed play a significant role. Corporations often await a clear message with the need for a specific new technology that is expressed by the government – leading to a lock-in situation. A typical chicken-and-egg story. However, respondents agree that corporations could do more themselves, if only everyone in the organisation understands the urgency of action.

Thirdly and most importantly, practitioners do not perceive green hydrogen projects as niches. Practitioners know that green hydrogen is a solution for the energy transition, and that the pilot- and scale-up phases bring along specific characteristics like long lead times, unprofitable top, vast unknowns, an abundance of assumptions. Furthermore, respondents agree upon the need of creating a space for interactive learning and a limited focus on the down sides of the pilot- and scale-up phases – which is in line with SNM theory. Nonetheless, (investment) decision frameworks for pilot- and scale-up projects are not different from regular decision frameworks. KPI's that are used for regular technology investments, are also used in order to assess the viability of scale-ups, i.e. scale-up projects are not perceived as part of the acceleration stage. By using a framework for regular investments the often-mentioned unprofitable top, or negative business cases will logically follow. Therefore using a decision framework for regular investment decisions for scale-up projects is not fit for purpose. The 'unknowns' of pilot- and scale-up investment decisions can never compete with the 'knowns' from regular investments. Unfortunately, SNM does not provide solutions for this problem.

7.3 Answering the research question

This research set out to answer the main research question, which will be recited for the sake of clarity:

⇒ **How can Strategic Niche Management (SNM) concepts be applied to aid the pilot- and acceleration stage of green hydrogen production pilots?**

The answer to this question consists of multiple parts, and can be summed up as follows:

- SNM identifies and names the characteristics of a niche based on ex-post research. These characteristics are however in line with the green hydrogen case. Practitioners can therefore identify if the development of a technology is a niche and act accordingly. SNM then goes on to propose that a niche should be developed in a closed setting where the learning curve is more important than negative characteristics;
- Failure mechanisms within the pilot- and acceleration stage can be identified, characterised and mapped, therefore creating awareness with regard to the multitude of failure mechanisms that hamper the development of the green hydrogen technology. By doing so, awareness can be created amongst involved entities. The failure framework is however incomplete and is supplemented by adjacent theories;

However, this study has been unable to demonstrate that SNM can be used as a specific tool to overcome the obstacles that create inertia during the acceleration stage. Limited information is available about the stages of scale-up and acceleration, where a clear technological niche has been developed and the main task is shifting to the creation of a viable niche market and beyond. Kemp and Schot seem to suggest that the preceding niche development steps have created the necessary conditions for the subsequent successful commercialization of the innovation. However, the fulfilment of these conditions will be not sufficient to ensure the acceleration of a technology. This stage has its own dynamics and pitfalls and require the multitude of identified barriers to be solved in order to happen.

The most likely reason for SNM literature's limited discussion of these issues, is that few SNM experiments have actually managed to get this far (Caniëls & Romijn, 2008). The experiences and case-study research with SNM as a policy tool is still too limited. Moreover, SNM was initially developed as an ex-post policy related research tool, descriptive in nature, rather than a prescriptive practical tool to guide practitioners through the development of a niche. In essence, step 4 and 5 of the SNM framework need to be reviewed and complemented.

Furthermore, the list of failure mechanisms proposed in the SNM framework is incomplete and falls short of naming corporate-internal factors. SNM (in combination with the failure framework (Weber & Rohracher, 2012)) can help to provide insight into the nature of obstacles that are observed during niche formation, and provide pointers as to how to overcome them, but these pointers remain largely generalised ideas. This case study concluded that professionals that are currently involved in hydrogen niche formation, highly value insight into obstacles during the take-off and scale-up phases. As SNM does not propose concrete solutions in order to overcome these barriers, important lessons can be drawn from (policy) experiments outside the direct realm of SNM. Insights from studies about radical innovation management at firm level, in combination with important lessons from the infant industry protection policies literature can complement SNM and will hopefully bring SNM one step closer towards a more operational tool for developing successful sustainable innovations with a broad societal impact.

8 Recommendations

The first recommendations for further research are directly related to the points of critique on SNM literature of Section 7.1.3. Recommendations on SNM literature will be discussed in Section 8.1. Next, the recommendations with regard to the green hydrogen case will be discussed in Section 8.2. In the light of the conclusions of this report, the state and future potential of green hydrogen will be briefly put into perspective in Section 8.3.

8.1 Recommendations for SNM literature

Especially the basic ideas upon which SNM is based are very encouraging. Momentarily, SNM concepts offer limited information in order to aid the acceleration stage of green hydrogen technology. The basis of SNM has potential, but an iteration of the theory is necessary in order to be usable in practice. The SNM framework and list of barriers that are based upon ex-post research remain accurate for the green hydrogen case. However, the description of the framework is too limited to be used by practitioners and therefore, further empirical research is required in order to specify and concretise the needs and requirements of involved practitioners.

In the second place, the list of barriers that impede the development of niches remains incomplete and is scattered across the various iterations of SNM literature. Specifically, corporate-internal factors that have been stated to play a significant role in creating procrastination are not at all mentioned. A holistic approach seems to be the most logical way for a transition that is urgent for the world, but is complex due to its multitude of potentially impeding factors and multitude of involved sectors and actors. Therefore, in order to promote SNM as a useful theory, it is recommended that SNM to transform SNM into a more holistic theory rather than only policy-based. This can be done by complementing SNM with important lessons from policy experiments outside the direct realm of SNM, such as literature on disruptive technologies or insights from studies about radical innovation management at firm level. Both literature on disruptive technologies or insights from studies about radical innovation management at firm level discuss the development of disruptive technologies which shares similar characteristics to niches. Key advocates of these studies, Christensen and Rumelt, have both successfully studied and mapped corporate-internal barriers. On top of that, their findings can be used to strengthen the SNM framework. The result of this holistic approach might lead to an updated version of SNM, or to a newly to be named theory altogether.

Lastly, in this thesis, it has been concluded that the identification and mapping of failure mechanisms is useful for practitioners. It creates consciousness across sectors with regard to the complexity of developing green hydrogen as part of the energy transition. SNM theory was complemented in this thesis by the bodies of knowledge in the fields of the failure framework and radical innovation management with regard to the mapping of barriers that occur during the pilot- and scale-up phases. However, cross-barrier correlations, or causalities were not discussed, nor became clear from this study. But, all of the respondents did comment on the importance of understanding the cross-barrier correlations. Only then can barriers be efficiently tackled. For that reason, it is recommended to perform capture the effects that barriers (both corporate-internal and -external) have on each other. The collection of failure mechanisms proposed in Figure 19 can be used as a basis for further research.
Additionally, practitioners demand practical and 'transition-phase' specific solutions. The development of a niche evolves across various stages, from the take-off phase, to the acceleration phase, in order to ultimately stabilise. It became clear from this study that parties that are involved in the development of the green hydrogen niche want to know when certain barriers occur in time – i.e. with which transitional phase barriers are linked. Therefore, it is recommended to study the time-related occurrence of barriers during niche-development.

8.2 Recommendations for the green hydrogen case

The first recommendations for parties that are involved in the development of green hydrogen technology are related to the perception of urgency with regard to developing this technology as a promising alternative within the energy transition. The sector seems to propose many initiatives; however a flow of required investments comes about slowly or even not at all. The barriers that have been identified in this research are at the basis of lacking investments and momentum. Not all barriers however work as motivators for the sector. On the other hand, some barriers need to be in place as enablers, or else these may result in demotivation.

For example: lack of legislation and regulations functions as a disabler – it takes away the foundation that is needed for practitioners to come into action. Alternatively, government strategy or corporate strategy results in motivation. Additional research should be performed in this line of thought, i.e. subdivide the failure mechanisms in two groups: motivators and hygiene factors, or enablers. By doing so, practitioners can easily distinguish the nature of barriers and decide upon the effort that is required in order to solve a barrier. Whereas motivators are fundamental factors that create a driving force within a company, enablers are the basic elements that are required in order to realise any project, i.e. can be defined as sine qua non. One advocate of this division is Herzberg, that distinguishes both groups in his motivation theory. He defines motivators as factors that encourage employees to work harder and explains enablers, or hygiene factors as factors that will not encourage employees to work harder but they will cause them to become unmotivated if these are not present. His theory is based upon the root of motivation in the workplace. It may however well be suited to distinguish the barriers from this study. Research in this direction should reveal if that would be the case. One respondent gave an example for an important enabler: subsidy. "Instead of using innovation subsidies for risk hedging, subsidies should have incentive conditions attached to them (e.g. data sharing on subsidised projects" (TNO).

Secondly, but most importantly, corporations often blame the government for absence of legal frameworks and subsidies that make these projects financially possible. However, corporations are just as important in developing technology, infrastructure by investing in decarbonisation solutions. This research showed that corporate-internal factors play a significant role in potentially slowing down nice developments. A concrete example that was discussed in Section 6.2, is the (investment) decision framework that is used by corporations for pilot-, and more specifically scale-up projects. The evaluation of business cases for these decarbonisation technologies is predominantly focused upon the financial aspects, instead of corporate- or even sectoral risk. KPI's that are commonly used for the assessment of regular investment decisions are directly applied on pilot- and scale-up investment propositions. Scale-up investments specifically suffer from unprofitable outcomes due to insufficient input, vast unknowns, and rough assumptions. Additionally, this study results in strong presumption that practitioners understand the dynamics of niche development and transitions, but do not act accordingly, i.e. penalising green investments by the fact that they continue to be seen through the same KPI's as for the 'traditional' regular investments.

It is therefore recommended that a new sort of decision framework should be developed, for especially the scale-up phase where its abundance of uncertainty, vast unknowns and rough assumptions are considered accordingly. For example, lower return requirements could be set for the future, alternative financing options could be investigated and a fit consideration of its uncertainties should be accounted for, i.e. an investment decision framework that is designed especially for scale-up project investments.

8.3 Discussion

8.3.1 Is it as bad as it seems?

Until now, this study has predominantly focused upon reasons for procrastination during niche development. A multitude of barriers has been identified that potentially result in inertia during green hydrogen production pilots. Furthermore, Section 7.1.3 stressed the deficiencies that have been identified in SNM literature. It draws the intention that the hydrogen case is indeed in a very bad shape and it seems as if prospects are dim. Due to the scope of this research, the reader might be drawn into a state of despair. Therefore, a brief analysis has been performed of the current state of affairs within the hydrogen sector in order to determine if the situation is indeed as bad as it seems.

8.3.2 Yes there are some challenges

As mentioned in this report, SNM literature has got limitations with regard to this case study. There are limitations with regard to the failure framework, as there are with the general SNM framework for niche development. Moreover, a report of the European Commission (European Commission, 2015) stresses the presence of a Valley of Death (Muñoz & Bunn, 2013) during pilot development, which is exactly the phase in which green hydrogen technology finds itself momentarily. Additionally, hydrogen developments, have gained and lost traction historically (Hall et al., 2020), therefore its success is not guaranteed. The existing 'chicken-egg' story also makes it difficult for hydrogen to gain traction across all energy sectors.

8.3.3 But, there is indeed progress

A counter-argument to the difficulties and risks of procrastination with regard to hydrogen technology might be the cross-sectoral optimism that arises as a result of ambitious decarbonisation prospective as part of the energy transition. Additionally, professional literature has shown a multitude of feasibility studies an initiative that aim to realise pilot projects totalling 213.5 GW for delivery by 2040 – of which 85% of projects are in Europe (*Hydrogen Market Attractiveness Report (HyMAR)*, 2021). Moreover, in the maritime sector investments are already being made (*Getting to Zero Coalition*, n.d.; *Major FCH JU Funded Project Will Install the World's First Ammonia-Powered Fuel Cell on a Vessel | Www.Fch.Europa.Eu*, n.d.; The Explorer, 2020). Hydrogen demand could grow by a third by 2030 driven by new industrial applications (primarily in iron and steel), mobility, grid injection or power generation (Energy Agency - Clingendael International Energy Programme, n.d.)

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Appendix A Types of hydrogen

The scope of this thesis focusses on the application of pilot projects concerning 'Green hydrogen production'. In order to understand the various other sorts of hydrogen that exist in common language when relating to hydrogen topics, a summation of four sorts of hydrogen has been given below. The explanation is a direct copy from the TNO website to promote a clear understanding of these term (TNO, n.d.-c).

A.1 Green hydrogen

Green hydrogen, also known as 'renewable hydrogen', is hydrogen that is produced with sustainable energy. The best known is electrolysis, in which water (H_2O) is split into hydrogen (H_2) and oxygen (O_2) via green electricity. A large number of parties in the Netherlands are experimenting with these megawatt-scale electrolysers. Hydrogen is also released during high-temperature gasification of biomass.

A.2 Grey hydrogen

Almost all of the hydrogen currently produces worldwide is so-called 'grey hydrogen'. Production currently takes place via Steam Methane Reforming (SMR). Here high-pressure steam (H_2O) reacts with natural gas (CH_4) resulting in hydrogen (H_2) and the greenhouse gas CO_2. In the Netherlands, approximately 0.8 million tonnes of H_2 are produced in this way, using four billion cubic meters of natural gas and generating CO_2 emissions of 12.5 million tonnes.

A.3 Blue hydrogen

The term 'blue hydrogen' or 'low carbon hydrogen' is used when the CO_2 released in the process of grey hydrogen production is largely (80-90%) captured and stored. This is also called CCS: Carbon Capture & Storage. This could happen in empty gas fields under the North Sea. Nowhere else in the world is blue hydrogen produced on a large scale.

A.4 Turquoise hydrogen

Hydrogen produced from natural gas using the so-called molten metal pyrolysis technology is called 'turquoise hydrogen' or 'low carbon hydrogen'. Natural gas is passed through a molten metal that releases hydrogen gas as well as solid carbon. The latter can find a useful application in, for example, car tyres. This technology is still in the laboratory phase and it will take at least ten years for the first pilot plant to be realised.

Appendix B List of interviewees

No.	Company name	Type of company	Interviewee name and function
1	Air Liquide	Industrial gas supplier	Steve Sol – Director Strategic Partnership
2	Alliander	Energy network operator	Elbert Huijzer – Senior Strategist
3	Sabic Chemelot	Chemicals manufacturer	Bert Bosman – Senior Specialist Climate & Energy
4	EBN (Energie Beheer Nederland)	Independent state-owned enterprise	Barthold Schroot – Programme Manager Advice & Innovation
5	Ministerie van EZK	Government	Paul Boeding – Sustainable Finance Expert
6	Gasunie	Energy network operator	Rene Schutte – Programme Manager Hydrogen, board member Hydrogen Europe
7	Groningen Seaports	Economic operator and port authority	Cas König - CEO
8	ING	Bank	Bert van der Toorn – Managing Director Energy Sector
9	InvestNL	Independent state-owned investor	Stephan Falcao Ferreira – Business Development Analyst
10	Neptune Energy	E&P company	Renee van der Meer – Development Manager
11	Nexstep	Branch organisation	Jacqueline Vaessen – General Manager
12	Port of Rotterdam	Economic operator and port authority	Randolf Weterings – Program Manager Electrification and Hydrogen
13	Shell	Oil & Gas	Ruben van Grinsven – Strategy Manager
14	Stedin	Energy network operator	Henri Bontebal – Senior Strategy Consultant
15	TNO	R&D institute	Lennart van der Burg – Hydrogen expert
16	Tennet	Network operator	Alan Croes – Energy System Planning

B.1 H2.50

BP, Nouryon and the Port of Rotterdam Authority are jointly investigating the feasibility of a water electrolysis plant. They are considering a capacity of 250 MW. The plant could then produce up to 45,000 tonnes of green hydrogen a year, that is destined for BP's refinery in Rotterdam. The partners want to take a final investment decision on the project in 2022.

B.2 H-Vision

H-Vision focusses on the production of blue hydrogen using natural gas and refinery fuel gas in the Port of Rotterdam. Decarbonisation goals are reached by capturing CO_2 during production and safely storing it under the North Sea in depleted gas fields, or ultimately using it as a building block for basic chemicals. Furthermore, even though H-Vision will not produce nor participate in a pilot for the production of green hydrogen.
It anticipates in the arrival of it by co-developing the Port of Rotterdam into a major hub for the production, uptake and trading of hydrogen, whilst significantly contributing to the achievement of climate objectives. H-Vision is currently a feasibility study of a hydrogen backbone within the Rotterdam Port area (*H-Vision (EN)*, n.d.).

B.3 PosHYdon

PosHYdon is the world's first offshore green hydrogen production plant. It aims to integrate three energy systems in the North Sea: offshore wind, offshore gas and offshore hydrogen by producing hydrogen from seawater on the Q13-

a platform from Neptune Energy in the North Sea. Nexstep, the Dutch association for decommissioning and reuse, and TNO, the Dutch organisation for applied scientific research, are the initiators of the pilot. At the time of writing, PosHYdon is awaiting approval from RVO for the allocation of subsidy for the project (Neptune Energy, n.d.).

B.4 NortH2

NortH2 is set up for large-scale green hydrogen production using offshore wind power. Instead of setting up a pilot, the consortium has the ambition to fulfil one of the goals that was set by the Dutch Climate Agreement by producing 4 GW's by 2030. Moreover, the consortium has formulated ambitions for the year 2040 in which it wants to upscale the production of green hydrogen to 10 GW. Gasunie, being partner of this project, is tasked with a feasibility study into the repurposing of their gas grid for the storage and transmission of hydrogen. Backed by the Groningen province, NortH2 plans to realise decarbonisation goals of the industry by cutting carbon emissions by eight to ten megatons a year (*About NortH2 - NortH2 | Kickstarting the Green Hydrogen Economy*, n.d.). NortH2 is in the initiation phase, where the financial viability of the project is investigated.

B.5 Electrolyser in Oosterwolde

The pilot project in Oosterwolde gives the consortium of the pilot the opportunity to gain experience with the application of an electrolyser in areas such as control, regulation and safety. Dutch network companies, like Alliander, is therefore conducting this pilot, amongst others, with hydrogen as a storage medium and a replacement for natural gas. The knowledge is shared among them so that each pilot takes us a step further. Dutch network companies want to investigate how the entire hydrogen chain works, which agreements must be made with stakeholders and which legislation and regulations are necessary. The plant is expected to come on stream in mid-2021 (Alliander, n.d.).

B.6 Indirect involvement in green hydrogen pilot production or decarbonisation targets in general

Parties that are not tied to a specific pilot project for the production of green hydrogen – but play a role in the financing, research or legislation that is required for the realization of these pilot projects, or also need to realise decarbonisation targets – are governmental institutions, or government owned companies, banks, grid operators and chemical companies. The following institutions or companies that play a large role in the financing- and legislative side of green hydrogen projects or decarbonisation projects in general were interviewed for this study:

- Sabic Chemelot;
- Ministry of Economic Affairs;
- ING;
- InvestNL;
- Stedin.

From Table 8 it becomes clear that all the green hydrogen pilot projects that have been selected for this study are multi MW projects and are amongst the pilots with the highest capacity ambitions in the Netherlands (De Laat, 2020). NortH2 even has ambitions to produce 3 to 4 GW of wind energy which can be used for electrolyses.

Three out of 5 pilots are in the Front-end engineering design (FEED) phase in which the most cost-efficient concept is to be selected. Only after a FEED analysis, different concepts can be identified and reviewed, focusing on what is optimal for a particular site. FEED studies cover relevant factors including: Support structures design, Operations & maintenance (O&M), (electrolyses) technology, Electrical Grid connection and Logistics to name a few. Thus, these pilots are not yet in the realisation phase. NortH2 is still one step behind FEED analysis – a feasibility study needs to be finalised. The Oosterwolde electrolyser however, will be commissioned mid 2021.

Furthermore, it becomes clear from Table 8 that all projects have been started around the end of the last decade and will be realised over the course of the first half of the 2020s. This is typical for most (green) hydrogen pilots currently planned in the Netherlands (De Laat, 2020).

Figure 20 shows when and where the need for main infrastructure for H_2 and CO_2 transportation can be expected to arise in the Netherlands (Duvoort, 2020). In it, the location of the green hydrogen pilot projects from Table 8 are shown with a green star. This picture is relevant due to the fact that the layout of the main infrastructure becomes clear after reviewing the location of these pilot projects. Furthermore, it provides the opportunity to put the location of these pilots' location into perspective.

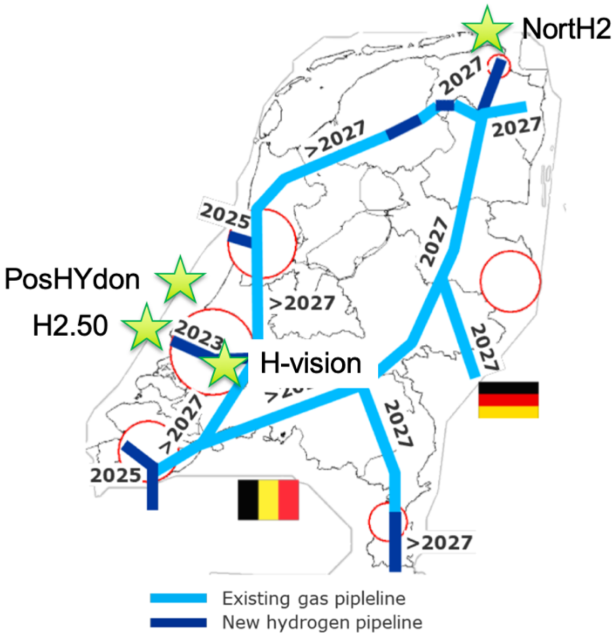


Figure 20 - Location of hydrogen projects for the case study

A selection of professionals that are active in companies – that are involved in the beforementioned green hydrogen pilot projects, currently tendered or realised within the Netherlands – have been interviewed. Most of the interviewees were 'high-level' high-ranking professionals (e.g. CEO, COO, project director and project manager), that were involved in strategic thinking and decision-making within these hydrogen projects. A list of people that were interviewed, can be found in Appendix B. A graphical representation of the companies that were selected and interviewed for this research is shown in Figure 21.

Figure 21 - Graphical representation of interviewed companies

Respondents

The pilot projects, and the entities that encompass the joint venture for the pilot project, will be briefly introduced hereunder. Most, but not all entities that have been involved in these pilots have ultimately also been interviewed for this research. The list of respondents, including their specifics (e.g. type of entity, interviewee, nationality, revenue) is shown in the table above.

A selection was made of practitioners, professionals and companies, that are currently involved in five pilot projects in the Netherlands. The selection of the pilot projects was made based on:

- Ambitions set for 2030 and 2050 (to be realised MW or GW scale);
- Pilot project in procurement phase or in realization phase;
- Start realization phase in the period 2020 – 2025;
- Variability of partners within the pilot (combining both governmental and private entities);
- If the entity was consulted for the TIKI report (Duvoort, 2020) (for the ability of consulting DNV GL's professional network).

Furthermore, the selection of these pilot projects was ought to reflect different approaches to the green hydrogen developments in recent years, as well as reflect varying off-set markets and market ideas. A result of this selection was a list of 15 respondents that were identified and that were willing to participate in this interview.

Thus, a minimum of 12 respondents that is required for a single-case study was reached (Guest et al., 2006). The goal of this research was also to reflect a broad spectrum of entities, varying in nationality, being listed on the stock market or not, and their revenue.

PosHYdon;
PosHYdon is the world's first offshore green hydrogen production plant. It aims to integrate three energy systems in the North Sea: offshore wind, offshore gas and offshore hydrogen by producing hydrogen from seawater on the Q13-a platform from Neptune Energy in the North Sea. Gaining experience of integrating working energy systems at sea, as well as the production hydrogen in offshore environments, are the main aims of this project. Nexstep, the Dutch association for decommissioning and reuse, and TNO, the Dutch organisation for applied scientific research, are the initiators of the pilot. Partners in the Q13-a platform are: EBN B.V. (40%), TAQA Offshore B.V. (10%) and Neptune Energy (50%). At the time of writing, PosHYdon is awaiting approval from RVO for the allocation of subsidy for the project. The joint venture for this pilot project encompasses the following entities **(Neptune Energy, n.d.)**:

- Nexstep;
- TNO;
- TAQA;
- EBN;
- NAM;
- Neptune Energy;
- Gasunie;
- Eneco;
- DEME;
- Nogat;
- Noordgastransport.

H-Vision:
H-Vision focusses on the production of blue hydrogen using natural gas and refinery fuel gas in the Port of Rotterdam. This allows the Port to substantially decarbonise before 2030. Decarbonisation goals are reached by capturing CO_2 during production and safely storing it under the North Sea in depleted gas fields, or ultimately using it as a building block for basic chemicals such as methanol for example. Furthermore, even though H-Vision will not produce nor participate in a pilot for the production of green hydrogen, it anticipates in the arrival of it by co-developing the Port of Rotterdam into a major hub for the production, uptake and trading of hydrogen, whilst significantly contributing to the achievement of climate objectives. H-vision encompasses mainly parties from the Rotterdam harbour and industrial region that represent the hydrogen value chain, from production to end-users. H-Vision is currently a feasibility study of a hydrogen backbone within the Rotterdam Port area. Parties in the H-Vision partnership are (*H-Vision (EN)*, n.d.):

- Air Liquide;
- BP;
- Deltalinqs;
- Gasunie;
- Havenbedrijf Rotterdam;
- Power Plant Rotterdam (Onyx Power);
- Shell;
- Uniper;
- Vopak;
- ExxonMobil;
- Provincie Zuid-Holland;
- Gemeente Rotterdam.

NortH2;
The objective of the NortH2 project is to set up large-scale green hydrogen production using offshore wind power. Instead of setting up a pilot, the consortium has the ambition to fulfil one of the goals that was set by the Dutch Climate Agreement by producing 4 GW's by 2030. Moreover, the consortium has formulated ambitions for the year 2040 in which it wants to upscale the production of green hydrogen to 10 GW. Initially, the production of green hydrogen is planned to take place in the Eemshaven. First, a large windfarm is to be build offshore, that will be able to accommodate green hydrogen production in the year 2027. Gasunie, being partner of this project, is tasked with a feasibility study into the repurposing of their gas grid for the storage and transmission of hydrogen. Backed by the Groningen province, NortH2 plans to realise decarbonisation goals of the industry by cutting carbon emissions by eight to ten megatons a year (*About NortH2 - NortH2 | Kickstarting the Green Hydrogen Economy*, n.d.). NortH2 is in the initiation phase, where the financial viability of the project is investigated. The consortium is made up of the following parties:

- Groningen Seaports;
- Shell;
- Gasunie;
- Equinor;
- RWE;
- Royalhaskoning DHV.

Electrolyser in Oosterwolde;
The pilot project in Oosterwolde gives the consortium of the pilot the opportunity to gain experience with the application of an electrolyser in areas such as control, regulation and safety. Dutch network companies, like Alliander, are therefore conducting various pilots with hydrogen as a storage medium and a replacement for natural gas. The knowledge is shared among them so that each pilot takes us a step further. Dutch network companies want to investigate how the entire hydrogen chain works, which agreements must be made with stakeholders and which legislation and regulations are necessary. The plant is expected to come on stream in mid-2021 (Alliander, n.d.). The joint venture for this pilot project encompasses the following entities:

- Alliander;
- GroenLeven (grootschalige zonne-energie ontwikkelaar);
- Ecomunitypark (Ecologisch werklandschap);
- Gemeente Ooststellingwerf;
- Holthausen;
- Energy Points;
- New Energy Coalition.

Indirect involvement in green hydrogen pilot production.
Parties that are not tied to a specific pilot project for the production of green hydrogen, but play a role in the financing, research or legislation that is required for the realization of these pilot projects, are governmental institutions, or government owned companies, banks, grid operators and chemical companies. The institutions of companies that play a large role in the financing- and legislative side of these project, and were interviewed for this research are:

- Sabic Chemelot;
- Ministry of Economic Affairs;
- ING;
- InvestNL;
- Stedin.

Appendix C Semi – structured interview questions

1. Start out with warm-up questions;
   - Use purposeful small talk, create warm and friendly environment,
   - Observe the participants for seating arrangements
2. Snappy introduction of the topic and the reason for the interview
   - Welcome;
   - Overview of topic;
   - Ground rules
     i. May I record this interview?
     ii. May I quote you in my research if I presume this necessary (probably not.)
     iii. Do you mind in checking the transcript of the interview + results conclusions that I take out of it (1 A4 with key points of the interview)?
     iv. The interview will be strictly confidential if so demanded by the interviewee.
3. First question (see focus area and questions in the table below):

Focus area: Barrier that causes procrastination during technological transitions

General:

- Could you explain in which phase the pilot (project) currently finds itself and what the long-term goals are?
- In what way are you involved in the project?
- Can you describe or state who was the 'first mover' for this project? What party (actor) should take the initiative for a pilot project of a new technology according to you?

Market related barriers:
Pilot projects are usually costly due to (unknown) development risks.

- How do you monitor of the success rate of a (pilot) project?
  - On what occasions do you go forward with the development of a pilot, regardless of market dynamics?
  - Which drivers and who defines project success?
  - Who, or which function within the organisation determines the KPI's for the pilot?
  - How do you decide on the amount of money that is invested in the pilot? When is this too much, when is this too little?
- *If a company is listed,* how do you guarantee the long-term goals of the pilot when a listed company might be mostly focused on short term results?
  - If true, could this statement lead to inertia in regard to investments for the pilot?

System barriers:

- *If a company has shareholders or is owned by (local)government,* What happens to a pilot project if the political spectrum changes after elections or if shareholders change of vision?
  - Is there currently legislation which could lead the project to be procrastinated upon?
- How do you ensure thinking 'out of the box', and overcome myopia within a company?
- Do you pull or push information to parties that you collaborate with?
- Which infrastructural barriers would lead to inertia in the development of this pilot?
  - What is the importance of infrastructural barriers in comparison to the above mentioned?

Transformative barriers (*focusing on market-, infrastructure-, policy-, politically-, financially related barriers):*

- What is the most important of the above-mentioned barriers in creating procrastination?
  - Is there a distinction on the appearance of above-mentioned factors with regard to regular project versus pilot projects?
- Project management is a dominant approach to realise and monitor (pilot) projects. KPI's including time, cost, scope and quality are prioritized. The development of green-hydrogen technology is part of the energy transition.
  - How and when do you decide if a pilot does or doesn't get funding? i.e. how do you prioritise the importance of pilot projects? (which of the M – Must have, S – Should have, C – Could have, W- Won't have, drivers does the decision reflect)
- Lack of strategy and market demand from the industry can be a barrier, similarly as the fact that demand and supply are not in sync.
  - What are momentarily your biggest concerns concerning the development of this pilot?
  - Who is responsible for altering these concerns?
  - How could the development process be improved?

4. Pauses and Probes:
   - Wow, tell me more about that!
   - That is really interesting. Could you elaborate on that?
   - Repeat the answer and emphasize in the part that you want to dive into.
   - Would you explain further?
   - Would you give an example?
   - I don't understand.

5. Three Step Conclusion
   - Summarize with confirmation,
   - Review purpose and ask if anything has been missed,
   - Thanks and dismissal.
     i. Thank you for all that valuable information, is there anything else you would like to add before we end?
     ii. Do you have any questions?

Appendix D Survey questions

D.1 Methodology

Data collection and verification

The chosen survey approach was chosen for its advantages (i.e. the gathered data is more objective in comparison to a (semi-)structured interview, the actual data collection is less time-consuming and a survey is an easy way to target respondents and collect a substantial amount of information (Baarda, 2006). Despite the odds, thorough preparation of the survey is required in order for it to be self-evident. Participants should be able to contribute to the survey with written instructions only.

The questionnaire was developed based on the literary findings of the literature study performed in Chapter 0 and the results of the semi-structured interviews that were performed as part of the empirical study in Chapter **Error! Reference source not found.**.

In order to guarantee the validity of the exploratory survey method (Lopez-Fernandez & Molina-Azorin, n.d.), the draft of the survey was formulated and tested in cooperation with DNV and Dr. Leijten. Based on their feedback, the terminology used for the questions was clarified and the number of questions was reduced to 5. Due to the exploratory nature of the survey, the aim was to compose a survey that was both understandable as generalizable across various sectors. Furthermore, the goal of the survey was to reach as many people as possible within the energy sector and make sure that due to the short nature of the survey people would be willing to invest only 2 minutes of their time. Furthermore, respondents were able to fill in a remark voluntarily in the last question, adding whatever they deemed important or relevant for the topic.

Questionnaire

The first question was posed as an introduction to the survey and set the boundary condition for the following questions. In this question, the respondent is asked about a generic replacement investment within his/her firm. A distinction is made between an investment choice for a standard technology with known (regular) pay-back times, concerning a technology that is settled in the market, and a low-carbon technology with a pay-back time of 15 years that relies on subsidy (the pay-back time is based on the SDE++ subsidy (RVO, 2020)). The second question states 6 common KPI's that are used in order to assess an investment decision. The respondent is asked to rank these KPI's in order of importance. Subsequently, the third question has been set up in order to determine in which managerial level of the firm an investment decision is taken (on international-, national board level, or project management level respectively). With companies that are listed on the stock market, it may be the case that shareholders or external parties are involved in the approval of a replacement investment decision. Question four, therefore raises this question. Finally, if ever the respondent would want to add a remark to the survey, the fifth point has been set-up in order to state any remark.

Respondents

For this exploratory survey, practitioners and professionals that were approached ranged from professional contacts from DNV GL to LinkedIn group members that are all linked to the energy transition. Respondents that were approached consisted of:

- 2000 DNV GL contacts, in the decarbonization mailing list;
- The DNV GL corporate LinkedIn account;
- 150 attendees of the DNV GL Webinar: Decarbonization: Managing your carbon footprint, 10-12-2020;
- On 11 LinkedIn groups that included the keywords: "Sustainability", "Green Hydrogen", "Energy transition" and varying in number of members from 260 to 230,110 professionals.

Data collection

Literature describes guidelines that vary from thirty to one hundred respondents (Baarda, 2006) as the number of respondents needed for the validity analysis. Thus, any number of respondents between thirty and one hundred is sufficient.

The survey was shared through the platform of 'Microsoft Forms'. The results of the survey are translated by the 'Microsoft Forms' program into data points in Microsoft Excel. All data was gathered between the 10th of December 2020 and April 30th 2021. A reminder was sent to the LinkedIn groups on two occasions. A recent article or findings from research within the field of Green Hydrogen projects was summarized for this reminder message. Hereafter, respondents were asked friendly for their participation in the survey in order to increase the response rate and create commitment amongst the potential respondents (Porter & Whitcomb, 2007).

Data treatment

For the analysis of the results, a comparison of literature findings is made with the results from the survey, in order to strengthen the conclusions. Furthermore, due to the exploratory nature of the survey, the results will enable more complete recommendations for further research within this field. A validation of the results will be explored in a second round of interviews as mentioned earlier. In this validation round, the results will be shared and an expert opinion will be sought.
Results are presented in an Excel spreadsheet, therefore understandable figures and tables could be produced. Due anonymized results, potential misunderstandings or biases cannot be excluded. It may be possible that respondents tried to complete the survey with lack of true understanding of the topic.

D.2 Questionnaire

Rather than providing only technical advice to corporates on their decarbonization journey, DNV GL aims to provide real added value to its customers by creating theoretically optimal roadmaps and ensuring practical implementation. In practice, internal factors are a key element in fuelling decarbonization trajectories. To understand how these internal factors either facilitate or penalize green investments, DNV GL has started a research project with the Technical University Delft. In these five questions, we'd like to ask your quick input on the matter.

1. You are faced with a replacement investment. Which option would you choose?
   - Standard technology with a standard payback period;
   - Low carbon technology with a payback period of 15 years that relies on subsidisation.

2. Please rank the following in order of importance from 1 to 6 where 1 is most important to you and 6 is least important to you:
   - Payback period;
   - Short-term corporate risk;
   - Long-term corporate risk;
   - Project location (does the location fit in the corporate strategy);
   - Technology risk;
   - Partnership risk (the need for a complex collaboration for the realisation of a project).

3. An investment decision (discussed in question 2) is an explicit choice between short-term and long-term objectives. At which level within your organisation is this investment decision taken? objectives.
   - Plan- or Operations manager level;
   - Country level;
   - International- or board level;

4. Does an investment decision (discussed in question 2) require approval from shareholders or external parties?
   - Yes;
   - No.

5. Any other comment you would like to make in this respect?

Appendix E Word cloud input data

Text	Frequency
Legislation & Regulations	10
Directionality failure	9
Corporate-internal factors	9
Lack of subsidy	7
Lack of market demand	7
Technological vulnerability & feasibility	6
Weak network failure	6
Lack of market supply	6
Lack of financial incentives	4
Grey- vs Green hydrogen price gap	3
Negative business case	3
Myopia	3
Information asymmetries	2
Infrastructural failure	2
Low gas price	2
Uncertain future green hydrogen price	2
High production costs	1
Lack of mandate	1
Difference in buy-in & selling price	1
Availability of low carbon electricity	1
Unkown unknowns	1
Limited hydrogen capacity record over past decade	1
Low oil price	1
Chicken-egg story	1
Absence of acceleration phase	1
Institutional failure	1
Short pilot duration time	1

Appendix F Survey results

Decarbonization roadmaps

15	03:33	Active
Responses	Average time to complete	Status

View results

Open in Excel

1. You are faced with a replacement investment. Which option would you choose?

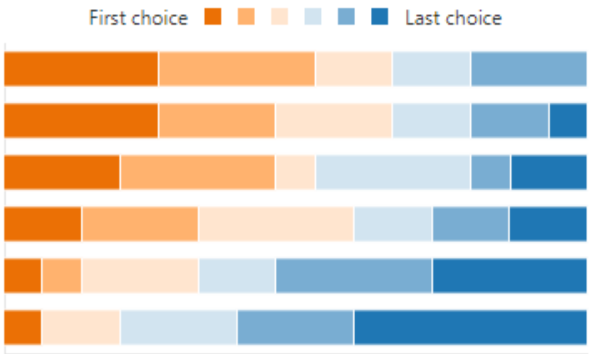
More Details

- Standard technology with a st... 7
- Low carbon technology with a... 8

2. Please rank the following in order of importance; 1 is of most influence to an investment decision and 6 is of least influence.

More Details

Rank	Options
1	Technology risk
2	Payback period
3	Short-term corporate risk
4	Long-term corporate risk
5	Partnership risk (the need for ...
6	Project location (does the loca...



3. An investment decision (discussed in question 2) is an explicit choice between short-term and long-term objectives. At which level within your company is this investment decision taken?

More Details

- Plant or Operations manager l... 1
- Country level 8
- International or board level 6

4. Does an investment decision (discussed in question 2) require approval from shareholders or external parties?

More Details

- Yes 7
- No 8

5. Any other comment you'd like to make in this respect?

More Details

View all responses for question 5

5

Responses

Latest Responses

"Sovereign risk such as volatile of exchange rates "

"I think that what mostly penzalzied green investments is that they co...

3 Responses

ID↑	Name	Responses
1	anonymous	Shareholders expect stable returns, not the uncertainty of subsidies. Low carbon investments produce lower returns.
2	anonymous	I think that what mostly penzalzied green investments is that they continue to be seen through the same KPOs as for the "tradiitonal" Oil&Gas investments, somehow magically expecting that the busiens model is transposable. Even if an organziation decides to make a New Energy division, to have that beign tolerated next to the "money making" divisions takes a lot of long term leadership and changes in business models! And since gievrnance polviies on artnerships/subventions are nto always very clear, most companies just don't dare to take the step of really investing in low carbon technology.
3	anonymous	Sovereign risk such as volatile of exchange rates

Appendix G Literature study

G.1 Hierarchy levels in MLP

Hierarchy level in MLP	Explanation
Macro-level (Landscape)	Landscape changes play a role at the macro level, for example in the areas of politics, culture, worldviews, paradigms and macroeconomic aspects. At this scale level, trends and developments form an undercurrent and are relatively slow. Developments at the macro level are external to the regimes and niches, but do influence them.
Meso-level (Regime)	Regimes are the established systems here that are intended to perform a certain social function. There is a lot of resistance to innovation at this level, because existing organizations, institutions and networks maintain existing rules, methods and interests (Kemp et al., 2007). Socio technical regimes provide an explanation for the embeddedness of certain technical systems, such as fossil- based energy supply, which makes the introduction of (cleaner) alternatives hard.
Micro-level (Niche)	At the micro level, niches develop, often formed by individuals or groups of actors who are open to innovation. At this level there is room for learning processes about innovations, new practices or behaviour and the first steps towards a transition are often taken (Rotmans et al., 2000). The concept of niches plays a crucial role in transition theory (Rotmans et al., 2000, 2005); niches are spaces where deviating practices take place, such as niches for alternative technology (Green Hydrogen production), but also in the form of new initiatives and new forms of culture and governance (Rotmans et al., 2005)These deviating practices are made possible by the heterogeneity of the selection environment (prices, preferences, standards, protection of sponsors). Alternatively, the aspects that make up the selection environment might also manifest themselves as potential barriers causing procrastination within the transition process (these barriers will be elaborated upon in Section **Error! Reference source not found.**. Within this micro level radical new technological developments – including Hydrogen technologies – reside and are protected (Bakhuis, 2020).

G.2 Barriers from the TIKI report

Barrier	Explanation
Regulatory obstacles	Uncertainty with regard to regulatory aspects often impedes the realisation of infrastructure. This is relevant for projects relating to CO_2, H_2 and heat. E.g. current legislation governing carbon accounting (EU-ETS, Scope 1, 2, 3 method) is obstructing decarbonisation of industry. For many projects, the legal framework is either incomplete, non-existent or preventive of crucial exchange of information and lacks: • the appointment of grid operators for H_2, CO_2 and heat networks; • clear rules on third-party access; • statutory regulations governing the storage of CO_2; • quality requirements for H_2 and CO_2. • the Dutch Competition Act, banns competing businesses from exchanging sensitive business information, even when such exchange is necessary for the success of joint ventures in which timelines are crucial.
Economic obstacles	Demand risk involves uncertainty regarding the utilisation and number of users of the new infrastructure, and has a direct impact on the project's business case and is hard to bear for individual parties. Due to high costs that may be incurred on projects involving relatively new or rarely used technologies, whenever the benefits are highly uncertain. In many cases this can be attributed to: • specific technical risks (a relatively new technology which has not yet been applied extensively before, results in less experience with the technology and therefore less understanding of the risk involved); • specific organisational risks (often caused by the lack of a proper project organisation, meaning that there is no clear understanding of the various parties' duties and interests). These risks result in uncertainty, which makes it harder to secure funding for a project. Furthermore, a lack of resources such as: suitable manpower; funding; physical space, can result in the situation where not everything can be executed everywhere, which impedes the realisation of infrastructure projects.
Administrative obstacles	There is a lack of direction from the government's various administrative levels and ministries with regard to infrastructure plans. Government direction is required for projects of significant societal importance that cannot be realised on their own due to market conditions or other impediments. Inadequate governance, selection and prioritisation in the allocation of land for infrastructure projects constitutes an obstacle in the present and will continue to do so in the future. This applies to both private land in clusters and public land designated for national infrastructure.
Public support obstacles	The energy transition is having a significant effect on society. Transition means change, which by definition results in friction, uncertainty and resistance in the form of: • Main focus of climate debate is on the costs of measures, rather than on their potential benefits and the new economic opportunities presented by the energy transition; • Lack of sufficient explanation and emphasis by national government and industry on the societal importance of the energy transition and the opportunities it entails; • Lack of commitment to infrastructure at the administrative level; • Limited public support at the local level, resulting in limited support from local authorities.

G.3 Barriers to low carbon transition (in Indian industry)

Industrial application for hydrogen	Barrier to a low carbon transition
Ammonia	**CO_2 requirements for fertilisers**: The production of urea – a popular Indian fertiliser – (CH_4N_2O) requires the addition of one carbon dioxide molecule to two ammonia molecules, which means an external carbon source is required. For the natural gas route, CO_2 is recovered from the reformation process and recycled for urea production. However, for a switch to green ammonia, an additional CO_2 source would be required. In the short to medium term, a solution could be to add electrolysers to existing natural gas plants, to expand capacity and make use of the waste CO_2. In future, plants could shift to using biomass or direct air capture for a CO_2 source to ensure low carbon production. Over time, the shift away from urea would reduce the requirement for CO_2. **Existing Stock of Natural Gas Plants***:* There is a large existing stock of natural gas plants, with long lifetimes. Whilst the stock is fairly old, many of these plants will still be able to produce cost-effective fertilizer products for many years to come, thereby slowing the rate of transition from fossil fuel-based production to low carbon production. As a result, many natural gas plants are expected to produce fertilizer products in 2050. It is possible that alternative methods of emissions reduction could be explored for these plans, such as retrofitting CCUS (Carbon Capture Utilisation and Storage), technology or replacing a part of the hydrogen requirement with green hydrogen.
Methanol	**Low Cost of Methanol Imports***:* The Middle East region has some of the lowest costs of natural gas production in the world, allowing highly cost – effective production of key products, such as methanol. The relatively low cost of transporting methanol to India – and most European countries – means that this will likely remain a part of India's energy mix for years to come, even as domestic production scales up. **Low Cost of Domestic Coal***:* The recent announcements by the government, aimed at expanding coal to methanol plant capacity, will make it more challenging for green hydrogen to compete in the domestic production of methanol. Out to 2050, it is expected that coal to methanol will be a lower cost route for methanol production versus the electric route. This is primarily driven by the cheap and plentiful domestic coal supplies as well as the cost-effective conversion process. Without additional policy to incentivize an accelerated shift towards green hydrogen for methanol production, coal gasification will continue to be the most cost-effective route. This is different for coal to ammonia, where the extra steps to process the coal gas make it less cost-competitive than coal to methanol. In the European case, LPG, rather than coal, will make it more challenging for green hydrogen to compete in the European production of methanol. **CO_2 Requirements for Methanol***:* As with urea, an external source of CO_2 would be required to produce methanol, if green hydrogen is being used. In the near- to medium-term, CO_2 could be sourced from nearby industrial units, recycling captured CO_2. However, this does not reduce CO_2 to zero, as it would still be emitted. To reduce emissions from the process to zero would require a CO_2 source from biomass or from direct air capture, which may be restrictive due to availability or cost.

Refineries	**Supply of Cost-effective Low Carbon Heat**: The refining process also requires some heat, which is largely supplied by fuel oil, natural gas, or petroleum coke today. Moving to a low carbon refinery would require this heat demand to also be met with low carbon sources. The main issue with this is that hydrogen is unlikely to compete with fossil fuels as a means of heat delivery (Hall et al., 2020). Whilst it is able to compete as a chemical feedstock, as a result of the additional costs of processing fossil fuels, it will be more challenging to compete with directly combusted fossil fuels. Further work is required to understand the extent to which these heat demands could be electrified.
Iron and Steel	**Low-cost Coal:** Without significant policy support in the near-term, hydrogen direct reduction is unlikely to be competitive with smelting reduction with CCUS, or the other incumbent fossil fuel technologies. **Availability of Low Carbon Electricity:** As with all green hydrogen production, large quantities of low carbon electricity will be required. The steel sector is the highest energy-consuming industrial sub-sector, which reflects the energy-intensive processes required to reduce iron ore and make steel. Given this high energy intensity, procuring sufficient low carbon electricity from nearby could be a challenge. Hall et al. (Hall et al., 2020) identified that local, standalone renewables are the most cost-effective option, although this could be limited in industrial areas where many plants are located near one another. In the Low Carbon scenario that is assessed, over 700 TWh of additional electricity would be required to produce 16 Mt of green hydrogen, which could be a significant challenge for industrial users looking to situate renewable plants nearby.

G.4 Five frictions by Rumelt

Table 12 - Five frictions by Rumelt

Barrier	**Explanation**
Distorted Perception	• Myopia (senior management rationally disbelieves statements of 'myopic' subordinates; • Hubris and denial: rejection of information that is contrary to what is desired – overweening pride in past accomplishments; • Grooved thinking: i.e. groupthink
Dulled motivation	The need is not felt with sufficient sharpness. The most important motivational dampers are: direct costs of change, cannibalisation of costs, cross-subsidy comforts
Failed Creative response	Categories as: speed and complexity, reactive mind-set, inadequate strategic vision, may make it difficult for the organisation to choose a direction
Political deadlocks	Tying up time and energy in wrangling. Change in organisations of any size involves more than just commanding change. The commitment and endorsement of powerful figures must be obtained if change is to effectively move forward. Expected categories: departmental politics, incommensurable beliefs, vested values
Action Disconnects	Expected categories; leadership inaction, embedded routines, collective action problems, capability gaps.