

The market introduction of Superwind in the Netherlands

A strategy based on the potential role of Superwind in a future energy scenario



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“ Je hebt je studie en je hebt budo. Dat is alles! “



ABSTRACT

This report discusses the potential role of the Superwind innovation in the Dutch energy production mix. The end goal of this report is to provide an innovation development strategy for Superwind based on the role it could play in the future. The Superwind concept is the flexible tri-generation of electricity, hydrogen and heat with an internal reforming high temperature fuel cell. It can be used to compensate power fluctuations of intermittent power sources. The fuel cell's input can be natural gas or biogas and by adjusting the fuel cell fuel utilisation, gas flow and voltage it is possible to change the electricity/hydrogen-output ratio. This will give the system the ability to adjust to the market demand without having to stand idle. The use of a fuel cell in combination with a biogas is what makes this technology a sustainable hydrogen and power generator. It taps into a renewable power source and due to the fuel cell's high efficiency it produces less greenhouse gas emissions than the present methods of compensating wind power fluctuations. The hydrogen production could be used to stimulate the transition from an oil-based infrastructure to a hydrogen-based infrastructure.

The design steps for a strategy for introducing Superwind in the energy market is based on several methodologies. First, the present system is explored through socio-technical mapping. At this stage the barriers and drivers are identified which prohibit the introduction of the Superwind innovation. The second stage is an analysis of the potential roles for Superwind in 2050 and the means to realize these; this is done by applying the backcasting method. With the information of these two analyses a market strategy is created with strategic niche management. In addition to the research of a Superwind introduction in the Netherlands, a case study for the short-term introduction of a pilot is analysed. There is a large probability that Nij Bosma Zathe will become the first testing facility for the Superwind pilot project. The case study will be used to reflect on the strategy found for the market introduction of Superwind in the Netherlands and recommendations are made on how to move forward with a project at Nij Bosma Zathe.



Summary

This report describes the results of research into the design of a viable strategy for introducing the technological concept titled “Superwind” to the Dutch energy market. Superwind is a concept devised at Delft University of Technology by the Superwind group. It consists primarily of an Internal Reforming Fuel Cell (IR-FC) which can be coupled with a wind turbine to mitigate the fluctuation of wind energy output. The innovative aspect of this technology is the flexible tri-generation of hydrogen gas and heat (aside from electrical current), making the technology suited for continuously compensating power fluctuations, while both input (wind power and natural- or biogas) and output (electricity, hydrogen, heat) have the potential to be 100% sustainable.

Wind power farms are faced with the problem of unpredictability, causing them problems when trading wind energy on the spot market. The grid manager imposes penalties for every mismatch between power sold and power delivered, to deter energy suppliers from causing imbalances; this however lowers the economic profitability of wind energy, causing a substantial barrier for the further development of this sustainable technology.

Wind power is not the only technology being launched and implemented, which is plagued by output fluctuations. Many installations for generating biogas or creating self-sustaining energy systems can have a (surplus of) electrical energy as a by-product. To stimulate these initiatives, they are encouraged to sell their surplus energy on the spot market, leading to more fluctuations in energy offered to the grid as well as increasing the potential of a local overload. Several dutch grid managers have already stated that to cope with future sustainable technologies, the grid will need a serious overhaul. One of the current measures on the main grid that is specifically mentioned is the ‘spinning reserve’ – an online backup for compensation of undercurrent. Flexible, tri-generating fuel cells could have the potential of replacing the current spinning reserve solutions with a more efficient version, generating heat or hydrogen instead of wasting it when idle.

As with any new technology, Superwind is faced with competition from incumbent technologies. High upfront investment costs and a competing, fully developed, natural gas infrastructure pose significant barriers to developing a commercially attractive product. The technology itself has not had full-scale testing and is faced with competing alternatives being simultaneously developed. Because the Superwind Group believes this technology has real possibilities to offer an efficient and competitive solution to the problems of sustainable energy and electrical grid management, it wants to explore the best possible strategies for introducing Superwind to the commercial energy market.

The Dutch government recognizes these dilemmas and have introduced policies and regulations to improve the chances for the proper development of sustainable solutions that on the short term are not capable of fending off incumbent technologies. The interest by the Dutch government comes from the agreements it has made to reduce the Dutch energy consumption and greenhouse emissions by 2020 with 20% below their levels in 1990. In the opinion of the Dutch government it is possible to have a greenhouse emission reduction of 30%. To achieve these goals, the Dutch government recognised that radical sustainable innovations are needed. That is why it chose to facilitate their development.

There is extensive literature (Kemp et al. 1998; Laak, Raven and Verbong 2007; van Eijck and Romijn 2008) that suggests that radical innovations can profit from proper niche management, cultivating a start-up technology under shielded conditions while building a track record for market introduction. This research has chosen to follow a Strategic Niche Management (SNM) methodology to exploring and designing a viable strategy for the market



introduction of Superwind. As a complement to this analysis, an extensive scan of all relevant technical, political, institutional and social factors currently in play on the Dutch energy market was done using socio-technical mapping (ST-Map) theory. When considering the playing field in which a new technological niche is to be created, it serves a useful purpose to consider not only competing technologies and incumbent systems, but political drivers and barriers as well as social susceptibility and historical precedent.

Because neither SNM nor ST-Map theory deals with properly with the development of long-term future scenario planning, a third important stage in this research report deals with backcasting. Backcasting is a method of scenario analysis which, as opposed to forecasting, is more concerned with the discovery of means necessary to achieve a future scenario. The method prescribes departing from desirable future scenarios and is therefore often better suited to radical and trendbreaking analyses than traditional forecasting methods, which frequently use trend extrapolation to explore the future. Furthermore, in the application of backcasting theory, an extensive comparison was made between methods prescribed by Quist and Robinson, because both were believed to contain essential elements required for the useful derivation of a future vision which is not only trend-breaking and positively encouraging but at the same time as realistic as possible so as to promote acceptance.

Key elements found in the socio-technical map surrounding Superwind concern the current state of technical alternatives, the potential market demand for a Superwind Solution, the political willingness to invest in sustainable energy technology and the social buzz currently surrounding climate change.

Technically, Superwind proves unique in that it combines not only the option for sustainable and flexible generation, but also offers a highly efficient technology by comparison; because fuel cell research is still in its infancy, there is still a lot of potential for the further development of these supporting factors.

Economically, Superwind faces competition from the current leaning of the Dutch government towards the stimulation of electrical cars as the next generation personal transportation alternative. Since part of the Superwind solution relies on the flexible output of hydrogen gas to reach its efficiency, Superwind could greatly benefit from the promotion of a hydrogen infrastructure and accompanying hydrogen-fueled cars. It is believed however that there will be sufficient demand for hydrogen, for instance in the chemical industry to support an economically viable product.

Politically, the climate for sustainable energy solutions has never been better in the Dutch energy market, or for that matter worldwide. With the undeniable effects of carbon dioxide and other emission gasses on global climate, promotion of clean and sustainable energy production have been placed high on the political agenda. There are a multitude of financial incentives and both frequency and volume are expected to increase in the following decades.

Socially, aside from positive attention for its sustainable aspects, the technology is still relatively unknown to the public. Fuel cells are still mostly associated with more efficient use of fossil fuels and on that count have attracted mildly positive attention; their high prohibitive costs work against them however when promoting them as a next-generation energy alternative. In the case of Superwind, the high technical expertise required for the storage and handling of hydrogen gas and the subsequent association with explosive dangers creates an overall hesitance on the part of the public which may require serious marketing efforts to combat.

As derived from an earlier study by the Superwind Group, Superwind is currently believed technically feasible, but economically uncompetitive. The current most promising commercially available fuel cell is still limited in capacity and comparatively expensive. Characteristics of the envisioned technical setup are as of yet unable to reach the instantly responsive characteristics required to make the technology eligible for short-term spinning



reserve. However, given sufficient warning, the technology may be used as a long-term (8 hrs) spinning reserve and it is applicable as compensating factor for power fluctuations at the pre-grid level.

Investigation into the future potential of Superwind revolved around two scenarios: the local application of the technology to mitigate the effects of fluctuating power generation and a central application in a large-scale power plant to regulate all energy generation fluctuations on the Dutch grid. Development of these future scenarios was bounded by a recent future study by ECN, which offers one of the most recent and comprehensive quantitative studies of the impact of energy supply and demand on the Dutch market, given current political plans. For comparison, the horizon of 2050 was adopted for the scenarios studied in this research.

By 2050 the Dutch government plans to have installed 21 GW of wind power capacity. The two scenarios chosen both fulfilled a demand from the electricity sector to compensate for imbalances. Differing in initial design configuration the setup both scenarios showed a difference between technical feasibility, actor participation, and time frame. The decentralized scenario revealed that many actors are to be involved with the diffusion of the technology, while the centralized scenario operated with only a few actors from the same sector. It seems likely, that more actors with different goals will open up opportunities to test the technology in different settings.

Technology wise the central setup was used as spinning reserve. This is an advantage for operating the fuel cell. The fuel cell cannot increase its power quickly. Therefore it is technologically difficult to compensate for wind turbines directly, but if the IR-MCFC is used for the within-8-hours available power reserve, the technological limitation of the IR-MCFC does not have to pose a barrier.

Backcasting analysis has pointed to the following important steps as being critical to the attainment of both developed scenarios. Even though the scenario criterion of compensating for 100% of fluctuations was set ambitiously, it is currently believed that these figures lie within the expected range of future developments. Important steps to realizing a future successful commercial Superwind-product, as identified through backcasting, are the establishment of a long-term policy for promoting sustainable energy, continued and intensified research on fuel cell technology, promotion of hydrogen fuelled transport and an upgrade of the Dutch electrical grid. The Dutch government will have to take leadership in not only promoting new, sustainable production of energy, but also phasing out 'older' and less efficient technologies in a consistent way.

As confirmed through backcasting, the management of actors is the most critical aspect to successfully launching Superwind as a future commercially accepted technology. Designing an actor-centered strategy is the purpose of strategic niche management. To this end it provides tools and a framework while focusing on three central processes:

- Knowledge discovery and dissemination
- Identifying and involving critical actors
- Marketing positive experimental results

One of the first findings when looking at the current positioning of Superwind is that it will greatly benefit from the formation of a consortium to carry out the first experiments. This consortium will require 5 types of actors, being suppliers of labour, capital, knowledge, physical technology and political influence. All 5 of these aspects will need to be sufficiently committed to the start-up of a new technology or else development may slow down or even stall altogether.



A second conclusion stemming from the SNM analysis is that the controlling partner in the start-up consortium will need to have a primary concern with internal dialogue. Because Superwind is being developed in a technological setting where many competing start-up technologies are trying to emerge, each partner in the consortium may at any time change their goals and commitment. It will be vital to keep track of actors' expectations and to actively involve them in shaping the goals and scope of the experiments. A second aspect of the internal dialogue requiring management is the proper setting and preparation of go/no-go decisions; these are the entry and exit moments for actors.

As the technology has gone through several experimental stages and reaches a market niche stage, it will be important to connect with similar experiments. Not only should all actors in the consortium have a positive expectation for the developed technology, but it will become vital to create as much exposure for the positive results and potential applications as can be achieved. Involving a political actor in the consortium at an early stage will pay off when the technology matures into the market niche phase.

Concluding this research, this report describes the setup strategy and conditions as it could be advised for an initial testing site. The province of Friesland and more specifically a small experimental farm, may offer the ideal combination of biogas production, research-minded operation, connections to a sustainable energy grid and involvement of technological and knowledge partners. For the proposed site a local socio-technical map was explored and short term niche development was explored in detail.

One of the interesting findings resulting from this exploration is the differing conditions between several provinces in the Netherlands, concerning political climate. For the test-site at Nij Bosma Zathe, it was also possible to detail the actor map and identify several key actors to attract for an initial consortium. Thirdly, several potential barriers have already been identified which might block initial testing – it will be vital for the Superwind Group to counter these before commencing with the first experiments to avoid any negative backlash before the first positive results can be established.



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ABBREVIATIONS

Abbreviation	Meaning	Explanation
CAES	Compressed Air Energy storage	A mechanical storage device that store air under high pressure. When the air is released it powers a dynamo.
CFC solutions	Carbon Fuel Cell Solutions	A fuel cell manufacturer situated in Ottobrun, Germany
CHP	Combined heat and power generator	In order to increase efficiency of the conversion system the residual heat is also used in stead of letting it dissipate.
ECN	Energieonderzoek Centrum Nederland	Energy research centre in the Netherlands
FC	Fuel cell	
FCE	Fuel Cell Energy	An American fuel cell manufacturer
IR-FC	Internal Reforming Fuel Cell	Fuel cell consisting of an integrated reformer that release hydrogen from hydrocarbons.
IR-MCFC	Internal Reforming Molten Carbonate Fuel Cell	A high temperature fuel cell which integrates a reformer to convert gas into hydrogen before entering the fuel cell.
LPG	Liquefied Petroleum Gas	
MCFC	Molten Carbonate fuel cell	
MEP	Milieukwaliteit Elektriciteitsproductie	Subsidy for the implementation of sustainable generation.
NBZ	Nij Bosma Zathe	An experimental farm of the University Wageningen in Goutum, Friesland.
NREL	National Research Energy Laboratory	Research institute for Energy development in the United States
PEM(FC)	Proton Exchange Membrane (Fuel Cell)	A low temperature fuel cell.
PV	Photo-Voltaic	Solar panels
SDE	Stimulerend Duurzame energieproductie	Subsidy for the exploitation of sustainable energy generation
SMES	Superconducting Magnetic Energy Storage	An electrical storage device which functions as capacitor but a very low temperature.
SNM	Strategic Niche Management	Management aimed at the creation and developed of a protected environment for an innovation.
SOFC	Solid oxide fuel cell	
ST-MAP	Socio-technical map	A map describing the co-evolutionary processes of an innovation.



1 Introduction

Within the process of introducing and marketing of an innovation called Superwind this report describes the research performed on the analysis of a viable market introduction strategy. It encompasses not only technological aspects but also the social aspects. This report follows a feasibility study (Vernay, Hemmes and Steenvoorden 2008) performed by the Superwind development group, a research team at the Faculty of Systems Engineering, Policy Analysis and Management at Delft University of Technology; the group consists of dr. K. Hemmes, ir. G. Steenvoorden, A.L. Vernay, MSc, and ing. M. Bouma. Their study described the economic viability of Superwind. The outcome of that study is that Superwind is a promising technological concept that is theoretically feasible but currently not economically viable. One of the recommendations is to construct a demonstration project to further explore the concept and improve it technologically. Following this research, the group intends to move forward with the Superwind development and eventually introduce it to the Dutch market. Therefore the Superwind development group has requested for a research project aimed at the design of a strategy for the market introduction of Superwind. This master thesis' research is aimed at identifying the drivers and bottlenecks for the development of such a strategy for Superwind in the Netherlands. This report is further augmented by a case study of a potential test location for Superwind. The results of both analyses will then form the basis for reflection on the innovation development strategy.

1.1 Short introduction to the Superwind innovation

The Superwind concept consists of an internal reforming fuel cell (IR-FC) which is used for flexible tri-generation of electricity, hydrogen and heat. One goal of Superwind is to improve the product of wind energy by compensating for fluctuations in wind speed. Another goal is the production of hydrogen which has many uses, for instance in the transport sector. Thus the technology potentially increases the reliability of intermittent power sources and might even stimulate the transition towards a hydrogen infrastructure.

The IR-FC is a high temperature fuel cell that holds several advantages over a low temperature fuel cell; it has a higher conversion efficiency and has less sensitivity to gas impurities. The high efficiency of IR-FC is achieved in part by internal reforming. The integrated technology enables heat created within the fuel cell to be used for the endothermic reforming reaction (Hemmes, Patil and Woudstra 2005). A low temperature fuel cell has an external reformer which leads to higher energy losses. The advantage of the high insensitivity of the IR-FC makes it possible to run the fuel cell on several sorts of gas that contains methane or other hydrocarbons. Therefore the gas supply can be either natural gas, biogas or sewage gas. In combination with biogas Superwind can produce *renewable* electricity and hydrogen in various amounts and ratios.

1.2 The context of the report

The ever growing need for energy poses enormous dilemmas (Ministry of Economic Affairs 2008a). Firstly, the Earth's natural resources are finite and rapidly depleting. Secondly, the emissions produced by the burning of fossil fuels for the production of power are believed to contribute to the global warming. To ensure that the same living standard can be maintained



for next generations, global actions and agreements for sustainability are being undertaken. In 2002 the European Union ratified the Kyoto protocol which specifies the amounts of reduction in energy use and waste for each member state to achieve (VROM 2005; VROM 2008). In 2005 the protocol was put into effect (VROM 2005). As a member of the European Union, the Netherlands has to do their part in this 50% reduction of green house gasses globally by 2050, relative to the levels of 1990 (Ministry of Economic Affairs 2008a)(p.11). The Dutch government has agreed at the European level that Dutch greenhouse gas emissions and energy consumption will be reduced by 20% by the year 2020 (Ministry of Economic Affairs 2008a)(p.62). Also, the share of renewable energy within the energy mix of the Netherlands is to be increased significantly up to 20%. Despite agreeing to a minimum of 20%, the Dutch government is more ambitious in its own plans, striving for a 30% reduction of emissions (VROM 2007). To achieve these goals measures have been implemented such as energy tax, subsidies for sustainable projects and innovations, and billing for CO₂-emissions. The result is that more sustainable and renewable power sources have been installed, research and development of sustainable systems has increased, and public awareness of the energy problem has risen.

Several sustainable innovations to reduce fossil fuel dependency and CO₂ emissions are favoured by the Dutch government; biomass, wind power, and carbon-capture systems (CCS) (Ministry of Economic Affairs 2008a). Other sustainable technologies are still in their infancy or are not able to be implemented on a large scale. Even the large scale introduction of these three favoured technologies is not without problems. Biomass is mostly mixed with coal when burned. Although this means that a new power source is tapped into, it does not reduce the amount of CO₂ emissions significantly. Therefore CCS should be used to capture greenhouse gas emissions from fossil fuel based power plants and to store it in underground pockets. However, if this works CCS might help reach short-term goals for 2020, but it will also reduce the sense of urgency to implement renewable power sources that may prove to be a better long-term solution. Currently, CCS consume much energy and are expensive to implement (ECN 2009). Also, a coal power plant which uses a CCS with a 90% capture efficiency lowers that power plant's energy efficiency by 9% to 13% (Daniëls and Farla 2006). The largest problem of CCS however is liability (De Telegraaf 2008). CO₂ will be stored underground for centuries. Who will be responsible for maintaining the CO₂ storage? Mining laws should be adjusted to encompass this storage as well as extraction (De Telegraaf 2008).

The full scale integration of wind power is not without problems either. Although it is a renewable power source, it is also a fluctuating power source. This makes the integration with the electrical grid very difficult. The rapid increase of wind power in the Netherlands increases chances for a grid overload. It is difficult to predict the amount of power produced by wind turbines at a certain time of the day. Therefore other power generators that are capable to rapidly respond to quick drops and peaks in wind power are required. In Denmark the imbalance problem was first solved by limiting the inrush currents to limit voltage drops (Sørensen, Antonio Cutululis, Lund, Hansen, Sørensen, Hjerrild, Heyman Donovan, Christensen and Kræmer Nielsen 2007). But as the installed wind power capacity grew more unconventional methods were introduced to compensate for wind power fluctuations such as combined heat and power systems (CHP systems) (Sørensen et al. 2007; Suwannarat, Bak-Jensen, Chen, Nielsen, Hjerrild, Sørensen and Hansen 2007). These methods however do not solve the issue of fluctuation completely. As the production of wind energy increases, more power reserve will still be needed. It has been proposed to solve the wind power dilemma by implementing a local buffer to compensate wind farm output. It would reduce the imbalance on the grid. It could also increase the profits for wind turbine owners because it could increase the reliability of the wind power offering. All currently proposed technologies still leave room



for improvement due to inefficiencies and as the demand for a solution increases with the amount of installed wind power, it is believed that new sustainable technologies such as Superwind deserve earnest consideration.

1.3 Problem Definition

In order to solve the problem of power fluctuation and the commercial exploitation of sustainable energy sources the Superwind group developed a technology concept called Superwind. The technology will be capable of flexible tri-generation of electricity, hydrogen and heat. The name Superwind originates from an initial idea in which a wind turbine is connected to a high temperature fuel cell. The technological concept can however be applied to any intermittent power source.

Superwind can be a solution to several problem owners:

Wind turbine owners, both private and **utility companies**, are coping with the unreliability of fluctuating power sources. The fluctuations make it hard to predict the amount of energy produced by wind turbines and reduces their profit at the energy spot market. The spot market is a day-ahead market where producers can offer energy for a certain price. About 20-25% of the total electrical power produced in the Netherlands by utility companies is sold at the spot market (Fens 2009). If the actual wind power output differs from the agreed upon offering, rules on the spot market result in penalties to discourage grid imbalances..

Fluctuations can result in imbalances on the electricity grid, both overload and underload. In some areas in the Netherlands fluctuations have led to net congestions because the supply is too much for the local transport capacity of the grid. **Net managers** have stated that the Dutch electrical grid capacity is far from capable of handling the intended 2020 wind power load (Damveld 2008). With the foreseen increase in power production fluctuations and the shift in production locations, they advised to structurally change the electrical infrastructure in order to handle the new sustainable energy systems.

Both problem owners would benefit greatly from technology that is capable of increasing the reliability of fluctuating power sources, however current technologies seem to only offer a stop-gap solution and thus it is believed that research into new, more efficient and sustainable solutions is required.

Furthermore, in an effort to reduce emissions and fossil fuel dependency new methods of propulsion and means for fueling transport are being researched. Current popular proposals for efficient and clean cars are electrical or hydrogen fuelled types. Unfortunately, the introduction of a new type of car propulsion is hindered by the requirement of a new separate infrastructure due to a lack of compatibility with the currently petrol-based infrastructure. In order to make the transition towards the suggested types of clean cars, both a new infrastructure and new cars are needed. The question is what must come first; Should the **car manufacturers** first produce a new type of cars or should an infrastructure first be created? Who should take on the responsibility for its development? This problem is also known as the chicken-or-the-egg dilemma.



The proposed Superwind installation is able to provide hydrogen for hydrogen vehicles as well as supply the electrical for charging electrical cars. The construction of Superwind could thus be a stimulant to the adoption of 'clean cars', without necessitating a choice of technology.

For any of the above problems, the introduction of new technological solutions faces the dilemmas of high up-front costs, relative lack of knowledge and uncertainty regarding future market dominance of sustainable modes of power supply.

1.4 Goal and Research question

The goal of this research is to develop a strategy for introducing Superwind technology as an economically viable and technically feasible solution for the Dutch energy market by 2050. The main research question is formulated as:

What are the requirements, drivers and barriers for realising the successful implementation of the Superwind technology in the Netherlands and what should be the strategy for its implementation?

This question breaks down into the following sub-questions:

- **What are the drivers and bottlenecks that are already a result of the current state of technological and social development?**
- **What potential role can Superwind fulfill in 2050?**
- **What are the drivers, bottlenecks and requirements for the realisation of that role?**
- **What strategy and the supporting policies should be pursued to facilitate a market introduction of Superwind in the Netherlands?**

To answer the research question several methods are used. First, an analysis to identify the social, technical, and institutional factors in the Netherlands, connected to the development of Superwind, is performed by creating a socio-technical map (ST-map). This analysis provides a snapshot view of the current state and expected developments of the technology dynamics surrounding Superwind.

Secondly, in this research a backcasting method is applied. Two desirable future scenarios for the year 2050 are investigated; the role which Superwind can play in these is analysed and through backcasting the requirements necessary to realize these scenarios are derived. Afterwards the two scenarios are compared to understand which scenario seems best suited to the diffusion of Superwind technology.

Thirdly, strategic niche management (SNM) theory is applied to devise a policy for Superwind's market introduction. Because Superwind is faced with competition from incumbent technologies, shielding it through niche creation seems to be a required and often practiced method (Rip and Kemp 1998; Geels 2002). Through SNM this process of shielding is explored up, to the point where it is released from its protective environment, to identify the critical aspects of the market introduction process. With strategic niche management the necessary conditions to nurture a specific technology are mapped and strategy is built upon those conditions. The information gathered with the socio-technical map and the backcasting will aid in the design of that strategy.



Finally, this research report also contains a case study of a pilot project for Superwind, to be completed in the near future. Contact has been made with a party which is able to offer a test location in Friesland. Linking the analyses in this research with a short-term case study provides the opportunity of comparing a general strategy for market introduction in the long-term with a specific short-term strategy for the local market introduction of Superwind in a test-setting. Thus not only does this research advise upon a strategy for the Dutch market introduction of Superwind; it will also detail initial steps to be taken.

1.5 The research boundaries

This research will collect data about the drivers and barriers that surround the development of the Superwind innovation and investigate how they enable or hamper the implementation of Superwind in the Netherlands. Although other countries are also eligible for the Superwind technology the research is constrained to the Dutch market to achieve an in-depth analysis. This would not be possible for a multi-country analysis within the time span of 6 months reserved for this thesis research.

The technological boundaries that are taken into account for this research are in line with the feasibility study for Superwind (Vernay et al. 2008). The Superwind pilot project (Hemmes, Vernay, Quist, Steenvoorden and Manné 2008) is specified to consist of a high temperature molten carbonate fuel cell and a wind turbine. Although, the IR-MCFC can also be connected to other fluctuating power sources, this report will primarily focus on the combination with a wind turbine. This was chosen for several reasons. Firstly, this specific combination is most likely to be the launch concept. Secondly, data are available from the Superwind feasibility report (Hemmes et al. 2008) for this concept, which makes it possible to quantify certain goals and targets within this research.

When considering tri-generation, this research has not taken into account the several options of using heat as a by-product, nor was the effect of hydrogen production on any other sector but the personal transportation sector studied.

Although values used in the feasibility study were based on a solid oxide fuel cell (IR-SOFC), in this research results are based on a molten carbonate fuel cell (IR-MCFC). This was done following recommendations from the feasibility study, which showed that the most promising currently available type of fuel cell is of the IR-MCFC type. At certain points in this research data from the IR-SOFC model will be used, because the simulation of a new type of fuel cell did not prove possible within the time constraints of this research. It is assumed that results will not differ greatly between both models. The high temperature fuel cell values used for the research are based on a solid oxide fuel cell model made by K. Hemmes, A. Patil, and N. Woudstra in 2005 (Hemmes et al. 2005). The model for the IR-SOFC has been constructed with the use of the computer program Cycletempo. The IR-MCFC data has been added in Appendix B. Further data on the molten carbonate fuel cell is based on the 250 KW MCFC (article nr. HM300) manufactured by CFC solutions (CFC solutions 2008).

1.6 The report outline

The next chapter describes the theoretical framework of the methods that are used for this research. Also, it will discuss how and why these are connected to answer the research question. Chapter three will discuss the results of the socio-technical analysis, applied to Superwind technology. The chapter consists of an examination of the Superwind technology



and an analysis of the recent developments in relevant technological, social, and institutional areas. Chapter four describes how backcasting was applied to the Superwind concept; two desirable scenarios show what Superwind could provide in the future. Furthermore the necessary steps and conditions that will lead to such scenarios are described. In the fifth chapter strategic niche management is applied to Superwind and on the basis of findings in the previous chapters a policy is designed. The sixth chapter will apply the previous used methods to a case study; a pilot project in Friesland. In doing so, the Superwind group is provided with an overview of the relevant factors to the construction of the pilot project and the case study is analysed to see whether it is capable of fulfilling those key factors which are deemed necessary for a successful market introduction of Superwind in 2050. In the final chapter conclusions and recommendations are presented and the methods used for this research are evaluated.



2 Conceptual framework and research methodology

In this chapter the methods used to reach the research goal and answer the research question are explained. In section 2.1 the creation of socio-technical map is described. This method provides an insight into the technical, institutional and social surrounding of the Superwind concept. With backcasting (section 2.2) a projection of future desirable scenarios is made, after which the artefacts, stakeholders and the path needed to reach those scenarios are analysed. Strategic Niche Management (section 2.3) is about creating a policy for the creation and development of a niche. The last section (section 2.4) discusses why these methods are chosen for this research and how these methods are applied to form the research protocol which is used to answer the research questions and research sub-questions.

2.1 *The Socio-Technical map*

A technology as such is often the result of social and technical interaction. The idea that only engineers influence the course of technological development is outdated (Rip and Kemp 1998). Nowadays, technological development is assumed to be a process of co-evolution.

To investigate what interactions, technical and social, are related to a technology socio-technical mapping can be applied. It shows the state of development of a certain technology, the technological alternatives, the involvement of stakeholders, the stakeholders' views and expectations, and strategies relevant to this technology plotted against time (Mulder 2005)(p.31). The socio-technical map can be used to learn how a specific technology came about. Although the Superwind technology is still in its infancy, the ST-map can also be used to map other technologies that are in some way related to Superwind and learn from their development and translate that. For example, technology for harnessing wind power for electricity production has encountered drivers, barriers, and conditions during its development. In fact, it still does. These circumstances might very well be similar in principle for the development of Superwind. To provide an insight into the thought process of a socio-technical map, a guide list consisting of questions which will aid in the creation of a socio-technical map is shown in Table 2-1. The guide is based on a list by dr. K.F. Mulder (2005).

**Table 2-1 The guiding questions for the formation of a socio-technical map.***Building a Socio-Technical map*

- 1. Bounding the technical system**
 - What is the technical system?
 - What is the time frame in which the technical system resides?
- 2. Construction of a crude tree showing hierarchy of technical alternatives and mechanisms plotted against time**
 - Which alternative technologies are being worked on?
 - What choices are made in the process?
 - What alternatives did not make the grade?
- 3. Characterising the alternatives according to contents (cognitive) and origins (social)**
 - Which stakeholders are trying to get which items on the agenda?
 - What are the expectations of stakeholders?
 - What are the links between alternative technologies and any missing knowledge?
 - What are the relationships between stakeholders generating alternatives and the identity of the relevant stakeholders?
- 4. Does trajectory formation occur?**
 - Is there a technology for which stakeholder expectations are high which causes them to disregard alternative technologies?
 - Is there entrenchment?
- 5. What are the environmental effects of the different alternatives?**
 - When have these effects been acknowledged and by who?
 - How are they taken into account?
- 6. Are there critical episodes visible in the technology development?**
 - How can those fractures be characterized in both a cognitive and social way?
 - Through which process did the fractures occur?
 - What roles do the different stakeholders play in this?
 - Was it a matter of anticipation by technologists, or external pressure?
 - How was the social environment affected by the technology?
 - In what way were the technologists put under pressure by their social environment?
 - Were there specific actors linking the technology and its social environment?
- 7. In the periods where no fractures were present, were there attempts to bring about fractures?**
 - Who was responsible for these attempts?
 - Why did they fail?
 - What difference is there with the critical episodes?

Source: (Mulder 2005) (p.31)



2.2 Backcasting

In this section two approaches of backcasting will be discussed because elements of both are used in this research. Firstly, the methodology of backcasting is described through the view of Jaco Quist. He describes a methodological framework for participatory backcasting based on elements of several views of backcasting, including Lovins (1976), Dreborg (1996), Höjer and Mattsson (2000), and Robinson (1990). This provides a clear picture of the backcasting methodology. Secondly, the backcasting approach by J.B. Robinson will be highlighted. His approach of backcasting focuses on the assumption that backcasting scenarios can be specific and based on predictions without becoming forecasting. The forecasting approach is used to discover future scenarios while backcasting is a research methodology that uses a fixed desirable future scenario to discover the intermediate stepping stones leading to that scenario.

The broad definition of backcasting is that the backcaster creates desirable future scenarios and goals and looks 'back' at how these can be reached (Quist et al. 2006; Quist and Vergragt 2006). The key elements are the construction of a desirable future scenario, a broad stakeholder participation, and the combining of the process with the stakeholders' participation. Since Lovins suggested a backward-looking analysis in the 1970's, backcasting has been complemented by Robinson (including feasibility, social, environmental, and political implications), and Dreborg (seeing backcasting as an approach rather than a method). It shifted towards participatory backcasting which is often practiced in the Netherlands (Quist and Vergragt 2006)(p.1031). Participatory backcasting emphasizes broad stakeholder participation. According to

Quist five steps can describe the process of most general backcasting approaches (Quist 2007) (p.28). These steps are shown in Figure 2-1. The first step is about describing the normative assumptions and summing up the goals. Furthermore, a stakeholder analysis relevant to the socio-technical system is made. In the second step a desirable future vision is pictured. The third step consists of analysing the

steps needed to reach the future vision. It includes the changes needed structurally, technologically, and societally. Step four is the step in which short term actions are defined to initiate the trajectory for reaching the desirable future. The last step is implementation. In this step the support of the actors is to be obtained and a set of agreements are to be established for the short –and long-term for the implementation of the project. Between these steps iteration cycles and influences on one another are possible. In Table 2-2 a list of guiding questions for each step is given as suggested by dr. J. Quist (Quist et al. 2006).

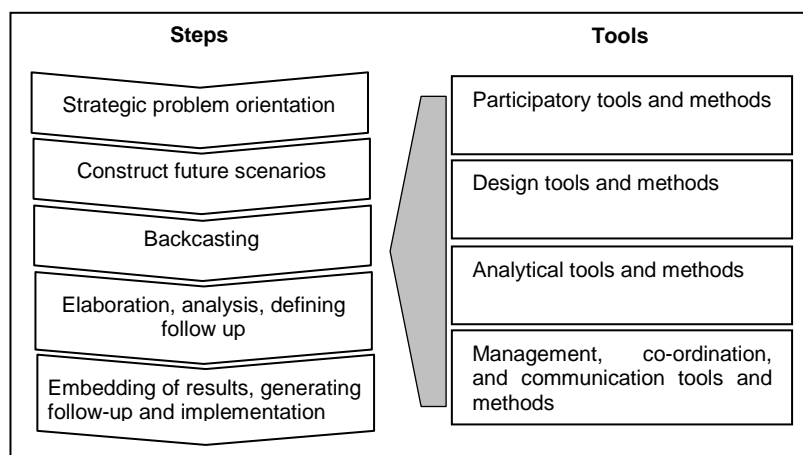


Figure 2-1 Methodological framework for participatory backcasting. Source: (Quist, Rammelt, Overschie and de Werk 2006)



Quist also describes four groups for the toolbox of participatory backcasting.

- A. participatory tools and methods; tools that involve stakeholders, generate and guide interactivity between them (workshop tools, creativity tools) and support backcasting with stakeholders.
- B. Design tools and methods; tools that construct scenarios, elaborate systems and process design tools.
- C. Analytical tools and methods; tools for scenario assessment, process analysis and evaluation, stakeholder identification, stakeholder analysis.
- D. Management, coordination, and communication tools and methods; methods for communication, for shaping and maintaining and constructive technology assessment.

Each tool group can be used within every step of the backcasting process.

The Robinson method distinguishes itself from the generalized method of Quist above because of its tendency to chart scenario targets as quantitative as possible (Robinson 1990). Especially the steps for the problem orientation are more extensive (see the question list in Table 2-3). With Quist's backcasting method the problem orientation is a general overview of the current state of the socio-technical system surrounding an innovation which is then followed by the desired future scenario. In order to be trend breaking the scenario is created with only the desired targets in mind, which are not based on any prediction. Robinson, however, emphasises that the goals, constraints and targets should be as concrete as possible to provide a clear picture of what is analysed. Therefore he indicates that the exogenous variables are useful without having to be too constraining. From predictions, for instance about energy consumption and population growth, the targets of the scenario can be quantitative. These data are not part of the essence of the desirable scenario, but offer a certain constraint. The introduction of a reference scenario is also a method to introduce exogenous variables. It can provide a context and/or constraint for your scenario. It can also help to clarify your backcasting or show why a trend should be broken if the scenario for instance projects an unwanted future (Robinson 1990). Unlike forecasting that uses trends and expert views to predict what is likely to occur in the future, the Robinson backcasting method merely uses the trends as exogenous variables which can provide the context and inputs for a scenario.

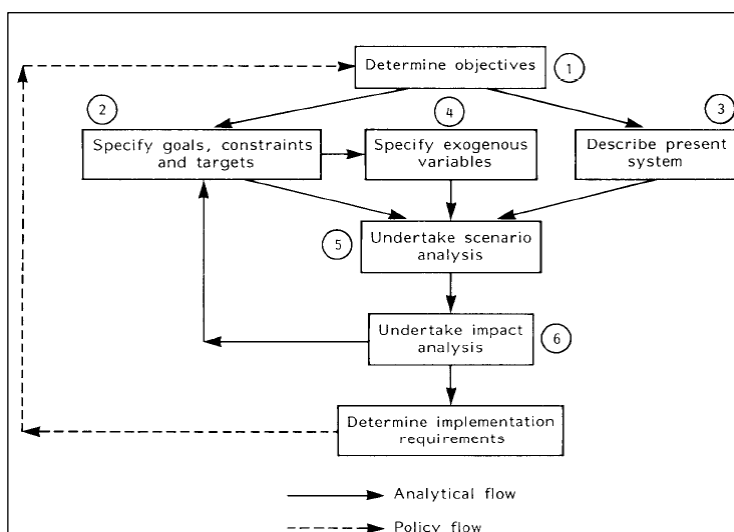


Figure 2-2 The outline of the Robinson backcasting method.
Source: (Robinson 1990)

Quist et al. (2006) have written a list of guiding questions for the method of backcasting. Those questions have been added to this report in Table 2-2. A remark: the participatory framework consists of five steps while the question list consists of four steps. Quist et al. choose to combine step four and five in case of a time limit or changes in stakeholder involvement. Because these reasons apply to this research, I have chosen to follow the guide list. However, due to the fact that a previous research is performed on Superwind it is possible to be more specific about certain targets in the Superwind scenario design. Therefore certain



questions from Robinson are also followed. To show the difference between the two approaches the question list of Robinson is also added in Table 2-3. In section 2.4 this combination of Quist's model with elements of the Robinson model is further discussed.

Table 2-2 The guiding questions for the backcasting method.

<p>1. Strategic problem orientation:</p> <ul style="list-style-type: none">○ What is the (socio-technical) system to be studied?○ Which societal needs/functions are addressed by this system?○ What are important trends and development related to this system/needs?○ What are major sustainability problems and what are the causes?○ How is the problem defined and what are the possible problem perceptions?○ Who are stakeholders and what are their opinions concerning sustainability problems and possible solutions? <p>2. Generating sustainable future visions:</p> <ul style="list-style-type: none">○ What are the demands (terms of reference) for the future vision?○ How does the future sustainable socio-technical system and need fulfilment look like?○ Which sustainability problems have been solved?○ Which technologies have been used in the future vision?○ How are culture and the social and economic structure different?○ How do people live in the future vision?○ How can it be made more sustainable and more attractive? <p>3. Backcasting analysis:</p> <ul style="list-style-type: none">○ What technological changes are necessary for achieving the future vision?○ What cultural and behavioural changes are necessary?○ What structural, institutional and regulatory changes are necessary?○ How have necessary changes been realised and what stakeholder (groups) are necessary?○ Is it possible to define milestones for the identified technological, cultural and structural changes when looking back from the vision? <p>4. Elaboration, design, analysis and defining follow-up agenda:</p> <ul style="list-style-type: none">○ What is a more detailed design of the socio-technical system in the future vision?○ What are the results of different analyses (social, consumer, environmental, economic, etc.)?○ What are drivers, barriers and conditions for the achieving the future vision?○ What could different stakeholder groups (research, government, companies, public interest) do? and what should be on their the action agenda?○ Which activities can be started now and who should do them?○ Elaborate a specific follow-up proposal that contributes to the system change and define who should contribute and what should be contributed?○ What do stakeholders and experts think about the attractiveness and feasibility of vision, analyses and the proposed follow-up agenda? <p style="text-align: right;"><i>Source: (Quist et al. 2006)(p.873)</i></p>
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**Table 2-3 The Robinson model for backcasting.**

- 1. Determine objectives:**
 - Describe purpose of analysis
 - Determine temporal, spatial and substantive scope of analysis
 - Decide number and type of scenarios
- 2. Specify goals, constraints and targets:**
 - Set goals, constraints and targets for scenario analysis
 - Set goals, constraints and targets for exogenous variables
- 3. Describe present system:**
 - Outline physical consumption and production processes
- 4. Specify exogenous variables:**
 - Develop description of exogenous variables
 - Specify external inputs to scenario analysis
- 5. Undertake scenario analysis:**
 - Choose scenario generation approach
 - Analyse future consumption and production processes at the end-point and mid-points
 - Develop scenario(s)
 - Iterate as required to achieve internal consistency
- 6. Undertake impact analysis:**
 - Consolidate scenario results
 - Analyse social, economic and environmental impacts
 - Compare results of step 6(a) and 6(b) with step 2
 - Iterate analysis (steps 2, 4 and 5) as required to ensure consistency between goals and results

Source: (Robinson 1990) (p.824)



2.3 Strategic niche management

It is often the case that radical innovations that offer a sustainable solution to economical, social, or environmental problems have a low chance of success (Kemp et al. 1998; Rip and Kemp 1998; Geels 2002). This is because they do not have a competitive edge yet compared with dominant technologies that reside in the social-technical regime (Geels 2002). To deal with this competitive behaviour of incumbent technologies, firms can choose to create an environment in which the innovation is protected from the normal rules of market competition. Thus it is able to develop its technological aspects and a social network promoting the ideas behind the innovation is created. Such an environment is called a niche. J.van Eijck and H. Romijn describe in their 2008 article “Prospects for Jatropha biofuels in Tanzania: An analysis with Strategic Niche Management.” that before an idea becomes an innovation it often undergoes the stages shown in Figure 2-3.

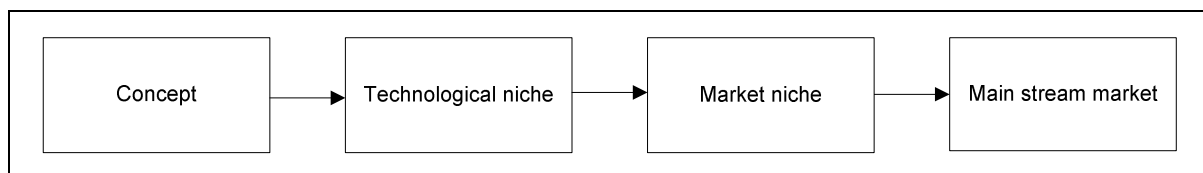


Figure 2-3 The development path of an idea towards the competitive market (van Eijck and Romijn 2008).

The creation of a niche starts with a concept that in theory shows promising results. To learn more about the technology itself and its (future) impact on society and environment an experimental setup is often used. This stage is called a ‘technological niche’. *“Technological niches used to be seen as experiments”* ((Raven 2005)(p.45). The reason behind this, according to Raven (2005), is that the emphasis was on protection which occurs both with experiments and niches. The idea that there is no distinction, however, is too simplistic, because single experiments do not result in regime changes (Raven 2005). An experiment is meant to be a phase in which the possibilities of a technology can be tested on a small scale. It is a learning phase for actors. A niche, however, is a protected environment in which radical innovations are set up as a series of experimental stages to learn from (Raven 2005). Experiments are often used in a technological niche to create something tangible from which its creators can learn about the technology, predicting the societal effect and building a support group.

As the technological research progresses the scale of the experiments increases. More experiments will develop (van Eijck and Romijn 2008), the learning processes are widened, and actor networks increase. The researchers will strive towards user acceptance and institutionalisation. Moreover, the costs will need to be reduced for it to become economically viable in a competitive market. When the focus of learning shifts towards making a technology economically viable, a market niche is created (van Eijck and Romijn 2008)(p.313). This is where the wider diffusion of the technology begins.

It is said that successful shaping of a technological niche and a market niche is dependent on the interaction of three niche processes (Kemp et al. 1998)(p.189)(van Eijck and Romijn 2008):

1. **The voicing and shaping of expectations:** In the early stage of the innovation’s development there not many results produced yet. Not all actors are sure whether it will



become a success in the future. Experiments are a strong attribute in shaping the expectations of actors. The more successful the results, the more actors will be attracted and more resources become available (Laak et al. 2007).

2. **Learning processes;** Many barriers often exist because of uncertainty surrounding the innovation (Kemp et al. 1998). With increasing quality of the learning process, perception is improved and uncertainty reduced (van Eijck and Romijn 2008).
3. **Network formation:** The social network that exists around an emerging niche will nurture the innovation, and influence other actor expectations. In the beginning that network is often small, but as more actors share the same expectations the larger the social network becomes.

Kemp et al. (1998) propose *Strategic Niche Management* (SNM) for the creation of a protected environment for an innovation, managing its development, and prudently moving it to an environment in which normal market rules apply. The aim of SNM is to stimulate the three internal niche processes discussed above. The strategic niche management approach consists of two parts (Raven 2005):

1. The research tool of SNM; a benchmark analysis of niche cases and policies surrounding related technologies to learn about relevant aspects to the management of a new niche in a comparable setting.
2. The policy design tool which consists of five steps; “the choice of technology, the selection of an experiment, the set-up of an experiment, the scaling up of the experiment, and the breakdown of protection by means of policy” (Kemp et al. 1998).

The first tool can be used to gain insight in niche processes of artefacts that are expected to have similarities with the artefact for which one wishes to design strategic niche policy. The second tool proposes a framework which structures the aforementioned design process.

The thought process of Kemp’s SNM policy tool is shown by a question list which is derived from certain elements that are mentioned in his article “*Regime shifts to sustainability through processes of niche formation: The approach of strategic Niche management.*” (1998). It is shown in Table 2-4 on the next page. Furthermore, it is emphasized by Kemp et al. that the tools are not to be applied too ‘mechanically’ and for each step one should always take the three internal niche processes in account.

A comparison between strategic niche management and backcasting shows that both approaches emphasise learning processes and experiments. Also, both are aimed at radical technologies that are long-term and have a high chance of failure (van Eijck and Romijn 2008). The difference is that SNM is focused on the development of an artefact while backcasting is aimed at creating future scenarios that solve problems which seem unsolvable at the current state of the socio-technical regime (Quist 2007).

**Table 2-4 The guiding questions for a niche policy making.***The five steps of niche policy making***1. The choice of technology**

- *Technological precondition: What are the major technological opportunities?*
- *Economical precondition: Are there sufficient steps for branching and extension for overcoming the initial limitations?*
- *Managerial and institutional precondition: Is the technology able to connect to existing forms of organization and control?*
- *Social precondition: Is it compatible with user needs and values?*
- *Is it already attractive to use for certain applications where the advantages outweigh the disadvantages?*

2. The selection of an experiment

- *In what setting should the technology take place? Certain application, geographical area, or jurisdictional unit?*
- *Is it a setting where the advantages outweigh the disadvantages?*

3. Setup of experiment

- *What is the balance between protection and pressure selection?*
- *What are the barriers? Technical, economical, institutional, and social?*
- *Policy on long-term goals should contain:*
 - *How will an actor network be created?*
 - *How will the actors and strategies be coordinated?*
 - *Is support needed? Taxes, subsidies, and public procurement, or setting a standard?*

4. Scaling up the experiment by means of a policy with support from public policymakers

- *Is preferential treatment needed?*
- *How much costs will be carried by a public institution? Subsidies, grants?*
- *How much costs will be carried by other actors?*

5. Breakdown of protection by means of policy

- *Is support still needed?*
- *If yes, what kind of support is needed?*
- *Which actors are to provide certain support?*

Source: Based on (Kemp, Schot and Hoogma 1998)(p.185-189)



2.4 The research protocol

In the previous sections the methods used for this research have been explained. In this section the reason why these methods were chosen and how they have been applied to form the research protocol is explained. The protocol shows which specific questions will that function as checklist to be able to eventually answer the research- and sub- questions.

For the creation of a strategy for the development of Superwind strategic niche management is applied. Kemp et al (1998) describe SNM as “*valuable for an actor who wants to push new (sustainable) technologies on to the market*”.

The strong point of SNM is that it focuses not solely on the technological development of a product within a niche, but also acknowledges the social processes. SNM recognises that the development of a technology is a co-evolutionary process.

The information I gathered on SNM stated the following points (Kemp et al. 1998; Raven 2005; Laak et al. 2007; van Eijck and Romijn 2008):

1. The policy created with SNM should be based on a niche analysis of historical cases.
2. The niche policy is based on the expectations of actors.

The SNM analytical tool is an analysis of historical niche cases to identify bottlenecks and drivers. However, Superwind technology does not exist yet and few comparable niches have been created. Also, no experiments have yet been performed. Consequently, it is difficult to conduct a historical study. One could look to niche developments of other sustainable technologies, but then there is a strong possibility that the analysis is too narrow and that important bottlenecks and drivers that currently have arisen for Superwind are not included. For this reason I have chosen to use the socio-technical map as the analytical tool to chart the relevant factors that presently influence the development of Superwind. The ST-map is a comprehensive analysis of the current status of the economical, institutional, social, and technological developments surrounding the Superwind concept. This is a necessary step to identify the most relevant actors and technology (Ornetzeder and Rohracher 2006)(p.7) concerning Superwind.

Niche policy design begins with the selection of a technology that is to be put in a niche environment. This form of selection is often based on the expectations of actors involved. Such expectations are mostly formed by the current status and trends in technologies. In most cases of radical innovations there is a lack of information which brings high uncertainty about the potential role a technology might play in the future. To create a more solid connection between current reality and a potential future scenario, backcasting is used in this research. Although forecasting is also possible to form an idea about the future role of a technology, it seems unfit for new sustainable technologies, because new emerging technologies generally have insufficient trend data to extrapolate (into a scenario). Furthermore, it is often required with the implementation of new sustainable solutions to use a trend breaking thought process (Dreborg 1996; Quist et al. 2006). If forecasting is used, the potential role of Superwind would be too much bounded by what experts and trends suggest is possible. For actors to have positive expectations about a technology, much less consider supporting a certain innovation, they should have a clear positive picture of the future role that new technology could play. Backcasting is focused on discovering means to realize a desirable future scenario and therefore could aid in the promotion of the technology and the shaping of expectations by providing a positive sense of direction for the development of Superwind (Van Lente 1993;



Dreborg 1996; Laak et al. 2007). Another reason for the use of backcasting is because the main focus of the method is to define the stepping stones that are needed to reach that future scenario. This will identify the instruments for current niche policy to be based on.

To apply backcasting to the Superwind technology I have chosen to use elements from two backcasting approaches: the participatory approach by Quist (2006) and the quantitative approach by Robinson (1990). Both approaches emphasize the social interaction with technology. The difference mainly lies in the extra step that Robinson (1990) adds to create more realistic future scenarios by quantifying by external constraints. The methodological framework applied in this report uses the steps of Robinson's methods in Quist's sequence. This seems to be the more logical approach, because taking the socio-technical map, the present situation, as a starting point provides a more detailed basis for constructing scenarios of the future.

The methodological framework for backcasting applied in this research is as follows:

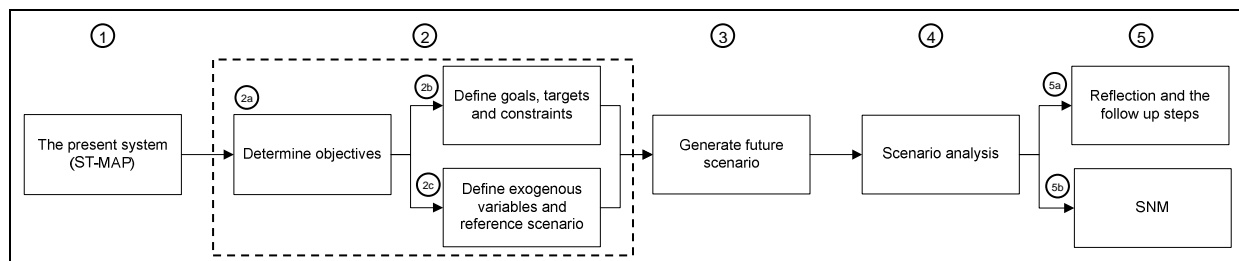


Figure 2-4 Outline of the backcasting approach as a result of a mix between the Quist and Robinson approaches.

The first step is describing the present system, which in this thesis is described with the socio-technical map (chapter 3). The next step (2a) is to 'Determine objectives' and this is where one describes the purpose of the analysis, determines the scope of the analysis and decides on how many scenarios will be created and whether to use a reference scenario. This is followed by step 2b where the context of the future scenario is set and the goals and targets discussed. Furthermore, the exogenous variables and reference scenario are introduced and if possible quantified. The third step is the creation of a future scenario. Here a description of the role of the specified technology, the role of alternative technologies, and the aspects of culture and economy are given. The scenario analysis discusses the necessary changes to reach the future scenario starting from the present system. The last step is where the results from the analyses are compared and follow-up steps are defined.

The method applied is, in fact, sequenced as Quist's model. The extra quantification step that Robinson promotes is added after describing the present system, where, in his model, Robinson introduces the present system after the setting of goals, targets, and constraints. In my experience, however, it is only after first studying the present system that it is possible to specify goals, target, and constraints. In this way the future scenarios will be more realistic.

In short, the analysis for SNM strategy is based on the analysis performed with the socio-technical map and the backcasting method. To connect the three methods to each other, the list of guiding questions were studied. Several sets of questions overlap each other and in some cases the questions listed did not cover all relevant information. How these methods are applied to form the research will now be explained.



In chapter 2 guidelines are shown for each method (Table 2-1 - Table 2-4). These guidelines form the basis for the research protocol questions:

A. Socio-technical map (step 1 in figure 2-4)

These questions are based on the socio-technical guideline given by dr. K.F. Mulder in his reader "The Production of New Technology" (Mulder 2005)(p.31).

1. Bounding the technical system:

What created the opportunity for the conception of Superwind?

What is Superwind?

What are the advantages and disadvantages of Superwind?

2. Construction of a crude tree showing the hierarchy of technical alternatives and mechanisms:

What are the alternative technologies?

What are the benefits of these technologies?

What are the disadvantages of these technologies?

What their impact on stakeholders or environment?

What is the current technological trend for sustainable energy generation?

What are the developments in the logistical systems relevant to Superwind?

3. Stakeholders:

Who are the stakeholders?

What is their relationship with the technology?

Are they a driving force for a particular technology?

Are they combatants of Superwind technology or anything related to the Superwind technology? And why?

Are they open to the Superwind technology?

What are the stakeholders position within the social network?

How are the stakeholders structured?

What are the expectations of the stakeholders?

B. Backcasting

The question header 1 portrays the distinguishing elements of a Robinson model (Robinson 1990)(p.824). The question headers 2, 3 and 4 are from the backcasting guideline written by dr. J. Quist (Quist et al. 2006)(p.873).

1. Determine objectives (step 2a in figure 2-4):

What is the purpose of the analysis?

Can concrete goals be stated?

What are the temporal, spatial and substantive scope of analysis

What is the time frame in which change can accomplished?

What are the geographical, political and jurisdictional boundaries?

What areas are relevant to the subject?(ex. Energy, environment, economy, etc.)

What is the number and type of scenarios?



Will you create a “business as usual case” or a “base case” to compare your scenario with?
What is the reference scenario for your desirable scenario?
Will you produce one or more scenario’s and why?
Are their enough sources to make multiple scenario’s?

2. Specify targets, goals, constraints and exogenous variables (step 2b and 2c in figure 2-4):

What are the highlights of the reference scenario?
Can the constraints provided by the reference scenario be quantified?
What are the targets, goals, and constraints?
Can the targets, goals, and constraints for future scenario be quantified?
What are the exogenous variables?
Can the exogenous variables for the future scenario be quantified?

3. Generating sustainable future visions (step 3 in figure 2-4):

What are the demands (terms of reference) for the future vision?
How does the future sustainable socio-technical system and need fulfilment look like?
Which sustainability problems have been solved?
Which technologies have been used in the future vision?
How are culture and the social and economic structure different?
How do people live in the future vision?
How can it be made more sustainable and more attractive?

4. Backcasting analysis (step 4):

What technological changes are necessary for achieving the future vision?
What cultural and behavioural changes are necessary?
What structural, institutional and regulatory changes are necessary?
How have necessary changes been realised and what stakeholder (groups) are necessary?
Is it possible to define milestones for the identified technological, cultural and structural changes when looking back from the vision?

5. Elaboration, design, analysis and defining follow-up agenda (step 5a in figure 2-4):

What are the results of different analyses (social, consumer, environmental, economic, etc.)?
What are drivers, barriers and conditions for the achieving the future vision?
What could different stakeholder groups (research, government, companies, public interest) do? and what should be on their the action agenda?
Which activities can be started now and who should do them?
Elaborate a specific follow-up proposal that contributes to the system change and define who should contribute and what should be contributed?

C. Strategic Niche Management (step 5b in figure 2-4)

The following questions are based on the five steps of niche policy making mentioned in R. Kemp’s article “Regime shifts to sustainability through processes of niche formation. (Kemp et al. 1998)(p.185-189). Also, the questions have been split up according to the three steps stated by Kemp et al. (1998) in the definition of SNM: Niche creation, the niche development, and the controlled phase out. The first step looks into the setup of an experiment, the second step into the development of that experiment within a technological niche, and the third step into aiming at a market niche and introducing the technology to the energy market. The three



niche process; voicing and shaping of expectations, network formation, and learning processes are considered in each phase.

1. Niche creation:

What is the niche of Superwind?

In what setting should the experiment take place? Certain application, geographical area, or jurisdictional unit?

Is it a setting where the advantages outweigh the disadvantages?

What are the drivers and barriers for the creation of a market niche?

Technical: the technology itself, infrastructure?

*Institutional: policy adjustment? political awareness?
setting a standard?*

Economical: Is support needed? Taxes? Subsidies?

Social: public procurement? Adjusting to user preferences

What changes need to be made to overcome the barriers and create a niche?

What must be the balance between protection and pressure selection?

Stakeholders' participation:

How will an actor network be created?

Which actors are involved with the construction of an experimental setup?

How will the actors and strategies be coordinated?

What expectations are there for this product?

2. Development within the niche:

What are the conditions for the development of Superwind?

Is preferential treatment needed?

How much costs will be carried by a public institution? Subsidies, grants?

How much costs will be carried by other actors?

Stakeholders' participation:

How will the existing actor network be managed?

Which actors are involved in the development of Superwind?

How will the actors and strategies be coordinated?

3. Controlled phase-out:

What is the 'window of opportunity' for Superwind to break out of the niche?

Is support still needed?

What kind of support and from whom?

What changes can occur in the socio-technical regimes due to the pilot project?

Stakeholders' participation:

How will the existing actor network be managed?

Which actors are involved in the development of Superwind?

How will the actors and strategies be coordinated?



3 Socio-Technical map of the Superwind technology in the Netherlands

The socio-technical analysis is used to provide a snapshot overview of Superwind technology and its socio-technical surroundings. For the formation of a socio-technical map the ST-map questions in the research protocol are applied. The results are discussed in the following order; firstly, the technological aspect of Superwind is discussed in paragraphs 3.1 to 3.3 and secondly, the relevant stakeholders in paragraph 3.4.

3.1 Superwind

3.1.1 The opportunity for the conception of Superwind

The Netherlands is investing in renewable energy technology in order to meet the sustainability goals set for 2020. The political support (e.g. subsidies, governmental preferences, energy tax) to accelerate the development and implementation of sustainable innovations increased significantly in this decade. Currently, the most popular energy technologies constructed to increase the share of sustainable energy sources in the total energy mix are biomass plants and wind turbines (Figure 3-1).

The increasing number of wind turbines build in the Netherlands imposes problems on the electricity grid such as net congestion and the need for more balancing reserve. These problems are mainly caused by the fluctuating nature of wind energy which makes their integration with the electricity grid challenging.

Net congestion is an overload in a certain area of the electricity grid due to a sudden increase in power supply in that area. With wind energy production this is often the case. It is difficult to predict how much energy is produced and where. With an increasing share of fluctuating power sources in the total energy supply mix the need for balancing reserve also increases.

To be able to increase the share of wind power a technological solution is wanted that can solve these issues.

Currently, the balancing between energy supply and demand on the electrical grid in the Netherlands is coordinated by Tennet. This agency handles the spot market on which the energy providers can offer their estimated wind power output 24 hours in advance (Beune 2001). Most providers base their power output on the meteorology institute's (KNMI) forecast which is then recalculated to fit the location and hub height of the specific wind turbine. Due

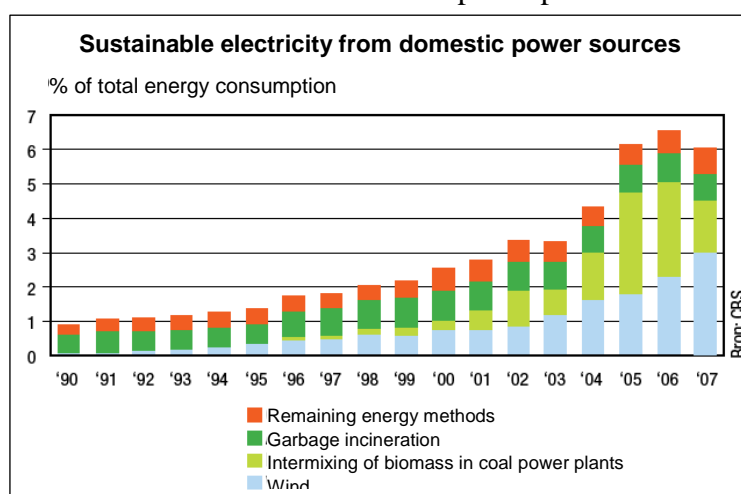


Figure 3-1 Sustainable electricity from domestic energy sources in the Netherlands (CBS 2008a).



to differences between the actual output of a wind park and the output sold on the spot market an energy power imbalance occurs between the demand and the supply side. The balance is guarded by the Tennet system operator (TSO) who has a couple of options for restoring the balance at his disposal; he can ask other sustainable energy providers if they are capable of delivering more power; he can ask conventional power stations to up their power output (balancing reserve also known as spinning reserve), or import electrical energy from abroad. To ensure that wind energy providers deliver what they sold to the APX a penalty-bonus system is used. For every mismatch between energy sold and energy produced the TSO charges imbalance costs. This makes placing a profitable offer on the spot market tedious for a wind energy producer.

Windunie, an association of private wind turbine owners, saw the flexible use of an IR-MCFC as a possibility to improve the wind power reliability which would make wind power a more reliable power source and avoid the negative imbalance costs that occur with a sold energy-supplied energy mismatch.

A second opportunity originates from the transport sector. The car manufacturers are pressed by the European Union directives to reduce car fuel consumption drastically. On short-term the car manufacturers believe they can comply with these directives by adjusting their car design. However, on the long-term this is not a proper sustainable option. New innovations for car propulsion are batteries, fuel cells, and even air-pressure. Unfortunately, these technologies are still in their infancy. There is a high uncertainty about which method of propulsion is the best solution. The hydrogen car seems likely to be technically and culturally preferred to other methods because a fuel cell only produces water and moreover, keeps the freedom that a car offers today. But because a standard is not chosen for the future, there is no investment in upgrading the infrastructure and car manufacturers are not motivated to switch to one of the propulsion methods in the nearby future. Now, this creates a “chicken-or-the-egg” problem. What needs to be created first? The infrastructure or the vehicles? The uniqueness of Superwind is that it is capable of producing hydrogen from biogas, besides electricity. This means that a renewable source of hydrogen production is possible. Superwind could be the flexible hydrogen production method the transport sector is waiting for.

3.1.2 The Superwind technology

As a result of the research on the mixing of hydrogen with natural gas by Hemmes and Patil it was found that an IR-SOFC could be an interesting method for the production of hydrogen (Hemmes et al. 2005). Natural gas or biogas is fed to the IR-SOFC. The hydrogen is produced by the internal reformer and then reacts with oxygen into water and electricity. The reformer's endothermic reaction absorbs the heat that is released inside the fuel cell. The production of hydrogen comes when more heat is produced than is needed for the process. By adjusting the fuel cell from a high efficiency mode to a high power density mode it produces more heat which can be converted into hydrogen¹. Figure 3-2 shows the results found with the SOFC-model made by A. Patil with the program Cycle-tempo. It shows the electric efficiency, the gas efficiency, and the total efficiency of an SOFC. The electric efficiency is the conversion efficiency of hydrogen into electricity. The gas efficiency represents the hydrogen production efficiency and the total efficiency is the sum of the electrical and gas efficiency. With a

¹ For more information about the process of a molten-carbonate fuel cell and the characteristics of other type of fuel cells refer to Appendix A.



decrease in fuel utilization the hydrogen production increases while the electricity production only slightly decreases. The ratio is around 3:1.

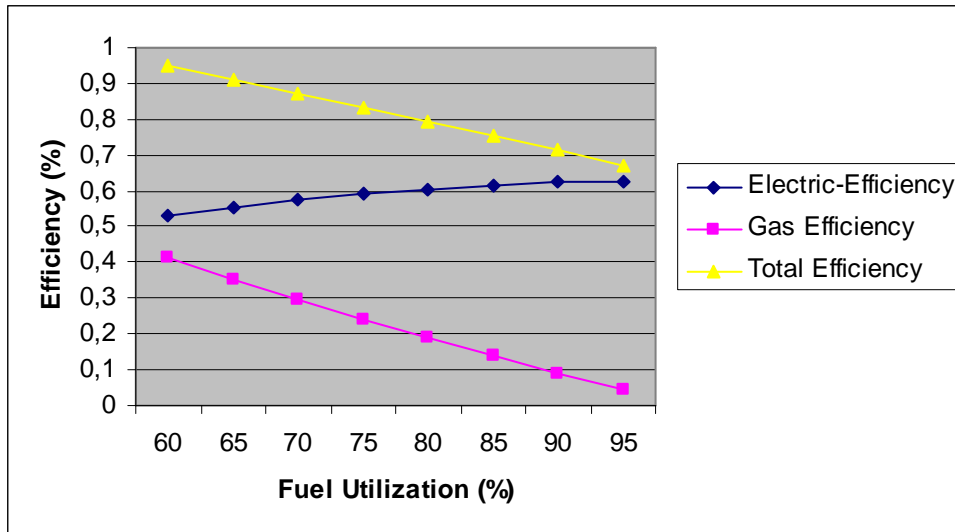


Figure 3-2 Fuel utilisation for high efficiency mode. (Hemmes et al. 2005)

From this research, Dr. K. Hemmes introduced a new conceptual setup in which a flexible internal reforming fuel cell (IR-FC) system is used to compensate the fluctuations of a wind turbine power output. (Figure 3-3). The concept is known as Superwind.

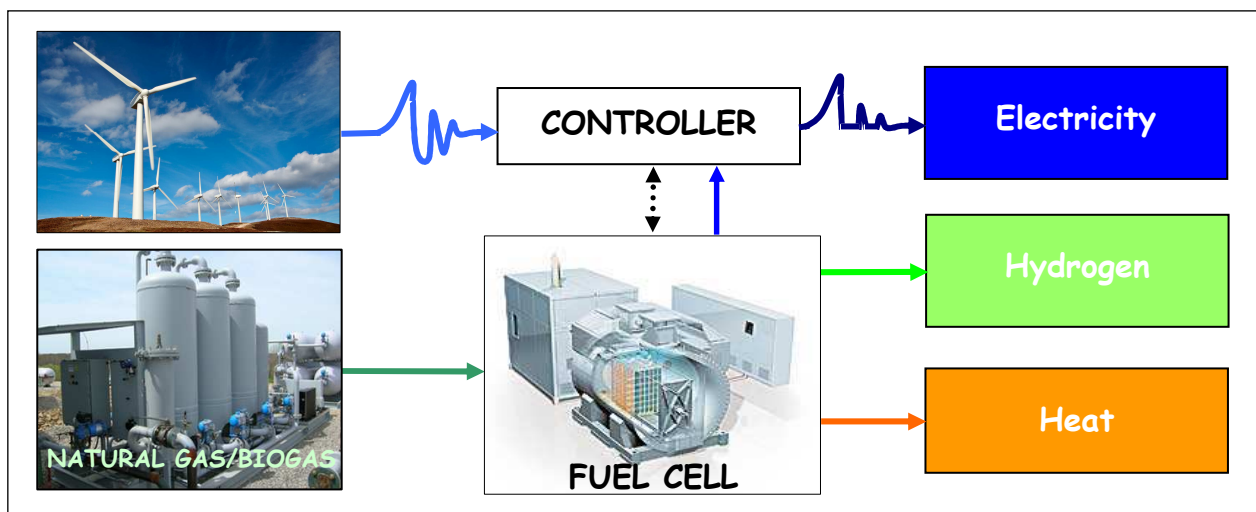


Figure 3-3 The Superwind concept with a internal reforming fuel cell.

With the flexible production capability it also becomes possible to change the balance between hydrogen and electricity output depending on the demand. In this way the IR-MCFC can always be active and producing. Another strong point is that the IR-MCFC is capable of handling a variety of gas sources and qualities. For instance, natural gas, biogas, or sewage gas. That makes Superwind a multi-source and multi-product energy system (Vernay et al. 2008). The concept does not include hydrogen or electricity storage because that would lower the total efficiency due to energy conversion losses. By optimising the match between production and demand the need for storage can be bypassed.



3.1.3 More technical possibilities for Superwind

In the explanation of the Superwind technology Figure 3-3 shows the primary concept which consists of a connection between a wind turbine, an IR-MCFC, and a biogas supply. That is because the idea of Superwind came forth from a request to level wind energy. This is just one format in which Superwind can be constructed. The key element of Superwind is the operation method of the internal reforming molten carbonate fuel used for the levelling of intermittent power sources. This means a large variety of energy sources and applications is possible (Figure 3-4).

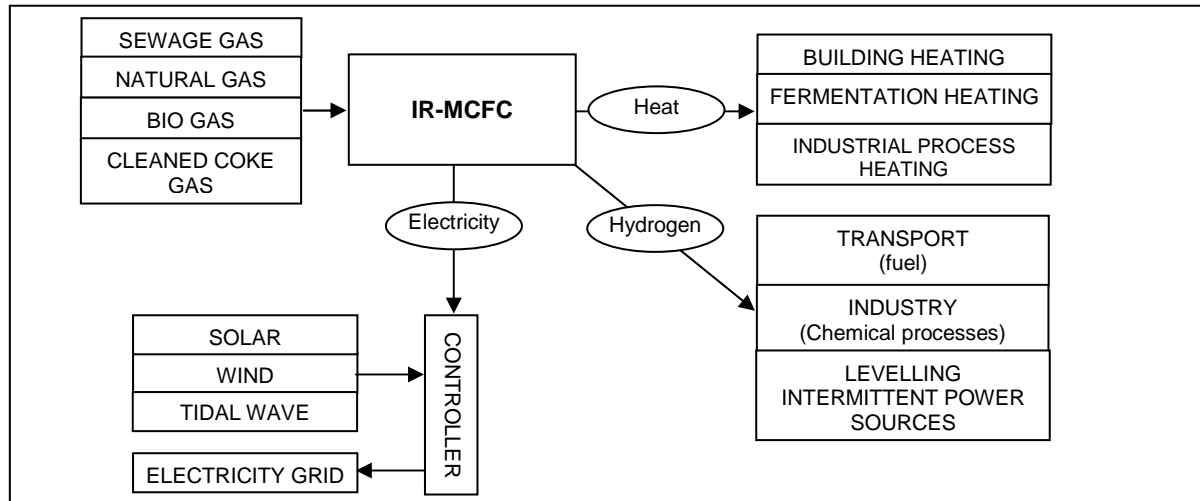


Figure 3-4 The possible types input, output, and applications for IR-MCFC operation method.

The system above implies a decentralized system that aims to fill in the gaps of fluctuating wind energy *before* it is put on the grid. Another decentralized method is to connect the IR-MCFC installations to the grid to compensate for the fluctuations on the grid (Figure 3-5a). These fuel cell installations are not necessarily connected to an intermittent power source. The electricity produced with decentralized Superwind systems can be sold to the net manager.

There is also the possibility to have a centralized system. One power plant filled with MCFC stacks which can be used as power reserve to compensate for fluctuations on the grid (Figure 3-5b). This would cancel the need for the mandatory spinning reserve on power generators larger than 5 MW (Tennet 2009). It would also provide a central system for the clean production of hydrogen.

A Superwind system connected to the grid as power reserve can also be used for addressing a regular demand for extra electrical power. An example is the emergence of the electric battery car. The charging of such cars will most likely be during the night time. Superwind installations could operate in high power mode and supply that needed DC power.

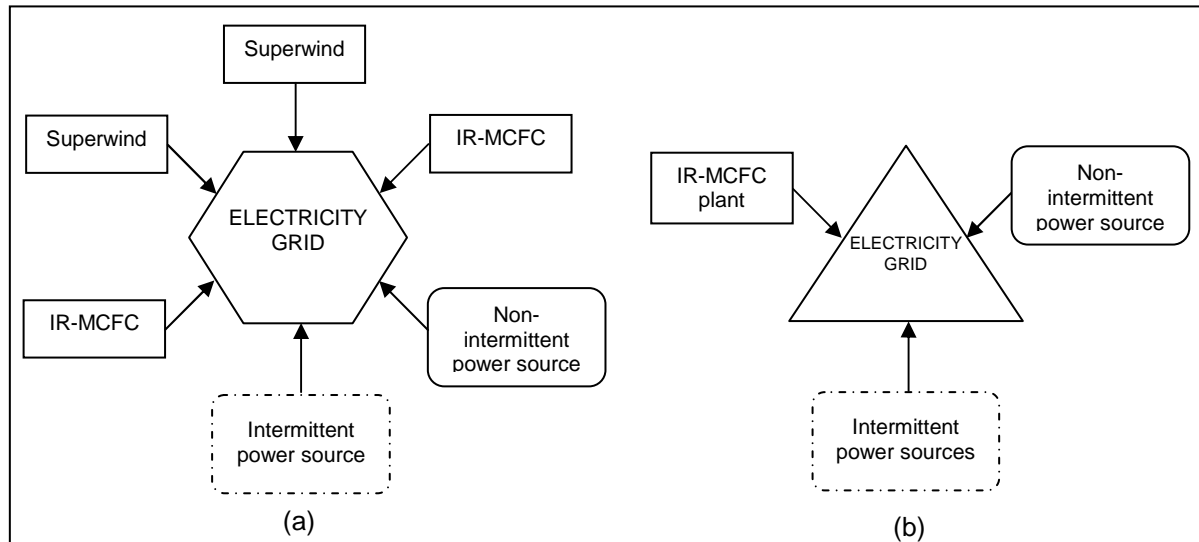


Figure 3-5 Superwind technology used as grid balancers. (a) Decentralized Superwind systems to compensate for fluctuations on the grid. (b) A centralized Superwind system to compensate for fluctuations on the grid.

3.1.4 Superwind as a multi-problem solver!

So far in this chapter, it is discussed that the Superwind technology offers a solution to several problems;

1. Wind power is fluctuating. It is difficult to predict and therefore difficult to integrate into the electrical grid.
2. Due to the unpredictability of wind energy selling wind energy on the energy spot market has a high profit uncertainty.
3. Present methods for producing hydrogen with the use of a surplus of wind energy have a low efficiency.
4. The usual method (e.g. gas turbine) of producing electricity from biogas has a low efficiency.
5. The transition towards a hydrogen based infrastructure is hampered because there is a high uncertainty whether hydrogen is the next energy carrier. As a result there is a problem whether the transport industry should design and construct hydrogen vehicles first, or that first the infrastructure, hydrogen fuel pumps, should be developed. (the chicken-or-the-egg problem)

The next item points out the advantages of the Superwind system which can be used to solve the problems mentioned above.

The advantages of Superwind

1. Flexible production due to control over the output of two of the three products.
 - Hydrogen, electricity, and heat is simultaneously produced
 - The fuel cell is always producing
 - On demand delivery for more electricity or hydrogen
2. Rest heat (400°C) can be used for heating of nearby residential areas, enhancement of the fermentation process, or otherwise.



3. Biogas is utilized more efficiently compared to burning in gas turbine. The gas turbine at maximum has an efficiency of 36% while an MCFC has an efficiency of 70% (depending on the setup).
4. Noise pollution is low compared to a gas turbine.
5. New source of income for farmers; sale of hydrogen. An improved source of income; sale of electricity and heat.
6. No output of NO_x and SO_x and less CO_2 emissions compared to conventional power systems for gas.
7. Instead of wind turbines, also other intermittent power sources could be used, such as solar energy or tidal wave energy.

These technical benefits will lead to:

- Less need for reserve capacity due to fewer imbalances
- The increase of reliability of wind power and therefore:
 - less subsidy is needed for wind energy
 - This predictability increases the potential benefits for wind turbine owners due to an increase in profit on spot market because the offer and supply are better matched. Thus the number of fines given for not providing the amount of power is reduced.
 - lowers imbalance costs due an increase in predictability
 - Net congestion can be avoided due to an increase in predictability
- The use of fuel cells on a larger scale could reduce the production costs.
- Superwind could be a stimulant for hydrogen infrastructure development by local H_2 production
- A reduction of energy consumption for electricity production because of the higher system efficiency.

The following item describes the disadvantages of the Superwind technology currently. The disadvantages are of a technical and financial nature and are expected to be solved over time.

The disadvantages of Superwind

1. The system is rather expensive.
 - The initial investment for a system as Superwind is higher than other methods (e.g. electrolysis). A 250 KW fuel cell (CFC solutions, Munich) is around 1.7 million euro's.
2. Currently quick start-up is not possible, but a quick shutdown is.
 - The reason is that the temperature has to remain the same in order for the fuel cell to properly function. Therefore ramping up its power is a slow process.
3. Regular biogas quality check is needed.
 - However, this procedure does not require highly skilled personnel
 - The system has a high impurity insensitivity compared to low temperature fuel cell, but the quality of the gas still needs to be checked on a regular basis to avoid an emergency shutdown of a molten carbonate fuel cell. The restart of an MCFC is 5000 euro's (information given by CFC Solutions).
4. The life time of a fuel IR-FC has a 4,5 year (about 40.000 hours) system expectancy (W. Frei, CFC solutions)



3.2 The developments of alternative technologies

This chapter describes several technologies that are related to the Superwind technology. Section 3.2.1 looks at alternative technologies that are able to produce similar products as the Superwind technology. Firstly, options that are able to provide a similar tri-generation are looked at. Secondly, the options for the improvement of wind power reliability and thirdly, the alternative technology for hydrogen production.

The following section 3.2.2 is about competing sustainable technologies that are currently in development but do not approach the energy problem in the same manner as Superwind does. Section 3.2.3 the development for vehicle propulsion technology is discussed because the hydrogen produced with Superwind is preferably used for the transport sector. There are a number of alternative technologies that compete with hydrogen in becoming the next fuel standard. In Appendix B the advantages and disadvantages of these technologies are summarized in one table for a quick comparison. An extra column in the table explains which of these technologies forms threat or positive influence to the Superwind market introduction.

3.2.1 Alternative technologies to the Superwind concept

The Superwind hybrid technology is able to produce electricity, hydrogen, and heat flexibly. Momentarily, there is no real alternative to Superwind that is capable of the same tri-generation with an integrated system. Still, there are technologies that are able to fulfil all or some of the needs addressed with Superwind. The list of those alternative technologies is divided in three categories:

- Alternatives to Superwind as a whole (tri-generation) for reduction of power imbalances due to the fluctuating power sources and the production of hydrogen
- Alternatives for the improvement of for reduction of power imbalances due to the fluctuating power sources
- Alternatives to the production of hydrogen

Although there are more alternatives, only the most common methods have been mentioned in this section. The production of heat is not seen as a separate category because it is a by-product which occurs in most production processes. Also, the incumbent systems (oil, coal, nuclear and gas) for electricity production that reside in the socio-technical regime (Geels 2002) are not described. They still form the strongest competition of the development of sustainable technology but their workings are considered common knowledge. The alternatives in this section are constrained to sustainable alternatives.

3.2.1.1 The alternatives to Superwind's tri-generation

An alternative to the Superwind would be to substitute the high temperature fuel cell for a low temperature fuel cell. For instance, a polymer exchange membrane fuel cell (PEMFC). The PEMFC is not capable of the internal reforming of biogas and therefore an external reformer is required (Figure 3-6).

The principle remains the same. The wind turbine's output is compensated by the electricity produced by a fuel cell that runs on hydrogen. The excess wind turbine output can also be



used to create hydrogen using the PEMFC connected to a water input. The weak point of this setup compared to the use of an IR-MCFC is the low efficiency. Not only has the PEMFC a much lower efficiency (36-38%), but due to the non-integrated setup of reformer and fuel cell the system efficiency will be lower. The waste heat is of low quality because the operating temperature of the PEMFC varies between 60 and 120 degrees Celsius depending on its operating mode. The strong point is that it would be possible to connect a water source and produce hydrogen by using the surplus energy of a wind turbine to convert the water into hydrogen. Then the PEMFC would be used as an electrolysis device to produce hydrogen besides converting hydrogen.

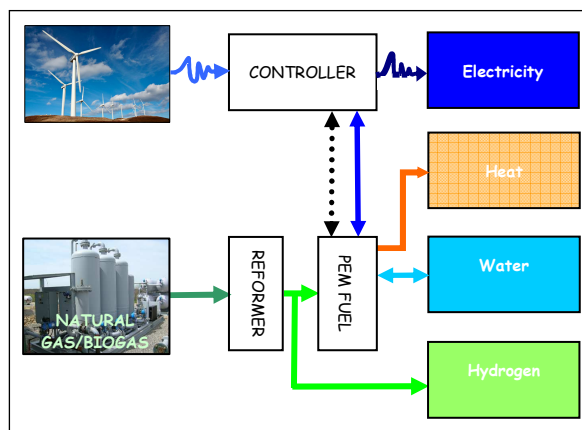


Figure 3-6 The superwind concept with a low temperature fuel cell.

3.2.1.2 Alternatives for the reduction of power imbalances due to fluctuating power sources

There are a number of methods to increase the reliability of wind energy. In this section three methods will be explained briefly. The first is the method of storing the surplus energy delivered by a wind turbine. The stored energy is released when the wind power production is low. The second method is expanding the electricity infrastructure. The expansion can be in the number of different systems that are connected and directed by one computer, or by increasing the network by connecting it to other countries. The third method the improvement of wind forecasting. If it is exactly known what the wind speed will be on a certain hour of the day the turbine owner would know what to expect and adjust his offer on the market accordingly.

Energy storage of surplus wind energy

In a report by the Utrecht centre for Energy Research several methods for energy storage are analysed (Lysen, van Egmond and Hagedoorn 2006). It categorizes the devices as follow: chemical storage, mechanical storage, electrical storage. The appendix explains the characteristics of these devices and their large scale installations that are used to compensate imbalances directly on the grid. Of course, these systems can also be used to compensate the output of a wind turbine farm before it accesses the grid. The storage methods are now briefly explained.

The chemical storage includes batteries and fuel cells. The most familiar types of batteries are the acid lead battery used for car batteries and Li-ion battery used for laptops or other portable devices. The acid lead battery is around for over a 130 years. Facilities containing these batteries to compensate grid imbalance have been built on a large scale since the mid 80's. The energy density is low due to the high weight of lead.

The Li-ion batteries have a high efficiency but the price/KWh is relatively high. The high energy density makes it a favourite battery technology for mobile devices and cars. That is why currently the development for this type of battery is high.

Both batteries have a high conversion efficiency.



The coupling of wind turbines and fuel cells to improve the reliability of electricity that is delivered to the grid is not new. It is often proposed with the use of a PEMFC. For instance, electrolysis in combination with a wind turbine and hydrogen storage is considered (Levene 2006) (Barbir 2005) (Peters, Stevens, Mann and Salehfar 2006). A surplus of wind energy could be transmitted to an electrolyser which then splits water into oxygen and hydrogen. After this fission process the produced hydrogen is stored till it is needed to compensate a lack of wind power. It will then flow through a fuel cell to produce electrical energy.

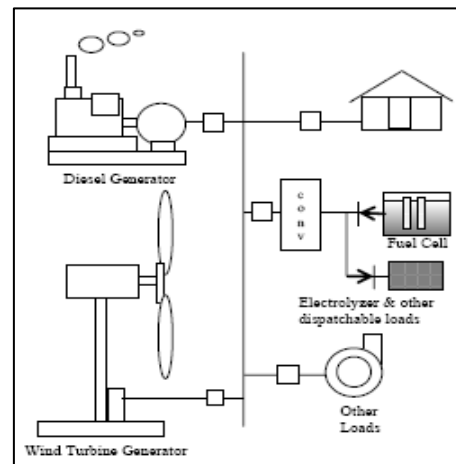


Figure 3-7 Physical diagram of a power system.
(Muljadi, Wang and Nehrir 2004)

The mechanical storage includes Compressed Air Energy Storage (CAES), pump accumulation, and flywheels. The CAES is a system that converts compressed air into electricity. When air is compressed heat is released. To decompress air heat is needed again. The conversion efficiency is about 80% but if the efficiency calculation includes the heat needed for decompression then at most 50% efficiency is reached (Lysen et al. 2006). The financial benefits do not outweigh its system costs yet.

Pump accumulation is a system that pumps up water into a large basin which is placed at a certain height with the surplus wind energy and when a shortage of wind power occurs, the water is then pored back into another water system and when it passes a dynamo it produces the energy to compensate for the wind power shortage. The system has an efficiency between 70 and 85%. A pump accumulation requires a large area for construction. This is problematic for a country such as the Netherlands. That is why it was suggested that a pump accumulation system should be build in the North Sea (Trouw 2007). The system would become an island containing nature reserve and wind turbines.



Figure 3-8 The energy island designed by Lievense, Kema, and Rudolf Das (Lievense and KEMA 2007).



This would reduce the pressure for available land. The price for agricultural ground is becoming too high. A second advantage would be the impulse that such a construction will be for the Dutch knowledge base of sustainable projects. Also, the construction of the island will be good promotion for the Netherlands. The island would form a barrier from the forces of the sea and so form a coastal protection. The idea of the construction met with resistance from public as well as from the political front. Most of the parties that are against the construction of a 'green' island in the middle of the sea think that it will disfigure the coastal view (Gazet van Antwerpen 2007) and a negative impact of wildlife. A second argument is that the island would be used as a nature reserve, but the island would only be economically viable if houses or hotel resorts would be built there. Figure 3-8 shows a design of how such an island could look. On this island the designers have decided to add room for agriculture and industry in order to bypass the concern of economic viability.

A flywheel system is a rotor connected to the a generator which could use the surplus power of wind energy to bring the rotor up to a certain speed. When a shortage occurs the kinetic power of the rotor is converted back into electrical power. The efficiency is around 90%, but requires a continuous power feed to keep the rotor at full speed. It is capable of quickly delivering a high power output but the storage capacity is limited.

The last category is **the electrical storage**. This includes the super capacitor and Superconducting Magnetic Energy Storage (SMES). The first technology works just as a normal capacitor. The efficiency is very high, but the storage capacity is low. Surplus energy is stored in a superconductive coil. However, this system requires large amounts of energy to cool the coil, because it is only superconducting at very low temperatures. This reduces the efficiency of the storage device significantly.

Electrical network expansion

This category contains two options for reduction of imbalances on the grid.

The first option is to build a more controlled wind park feed. Multiple devices, intermittent (wind farm) and non-intermittent (e.g. emergency generator) can be connected to a multi-agent computer which can correct the imbalance by increasing output of a device depending on the market demand. (Warmer 2007) This research showed that using multiple devices which interact through a main computer to compensate for wind power fluctuations is possible. However, the available extra power by non-intermittent devices must be large enough to compensate for the loss in wind power for this concept to succeed. My thought on this is that the complexity of such an infrastructure would require a radical change in the current electrical infrastructure.

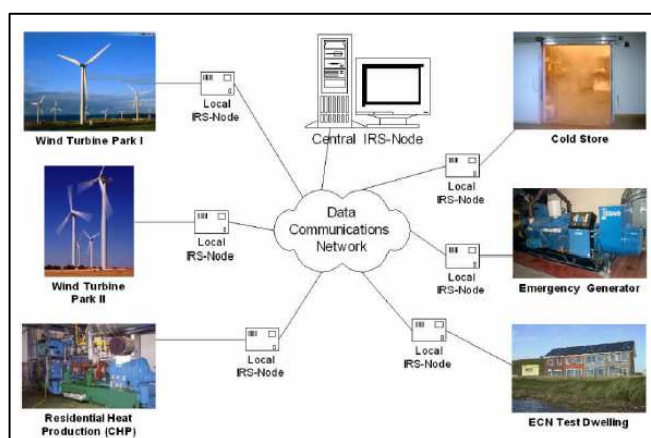


Figure 3-9 Field test configuration for the imbalance reduction system by NREL (Warmer 2007)

The second option is to connect more intermittent wind farms to each other. The difference in wind power generation periods would mean that with an increasing number of connected



intermittent power sources, the power signal will become more stable. The idea is that there is always an area on earth where the wind speeds are high. The European parliament agreed to work on integrating the European wind farms in order to improve wind power generation and reduce oil and gas dependency on February 3, 2009 (Europa NU 2009).

Wind forecasting

Most providers rely on the KNMI forecast on which they adjust the prediction by implementing it in a computer model that adjusts for hub height and the location of the hub. The improvement of wind forecasting methods (improving wind computer modelling) to accomplish a more accurate method for matching the offer with real-time supply is an ongoing development. As computer calculation is increasing rapidly it is possible to add more variables to the model. The model becomes more complex. The more accurate the model the more computational time is needed. If the complexity of the model is too high the calculations could take so long that conditions might have changed during calculation time.

3.2.1.3 Alternatives to the production of hydrogen

Steam reforming

The most common method to produce hydrogen is steam reforming. The process basically has two steps. Natural gas (or biogas) is combined with steam and it reacts into syngas. This consists mainly of CO and H₂. The CO is then directed to a water-gas-shift-reactor where again steam is added to form more hydrogen molecules.

Electrolysis

The example in Figure 3-10 displays an electrolysis device that converts water in hydrogen and oxygen using energy produced by wind turbines. The wind turbines produce electricity for the grid. A local electrolysis device is connected to a water supply which will produce hydrogen fuel to domestic distribution apparatus. Or excess wind energy is used to produce hydrogen which is then delivered to a storage device which is connected to a hydrogen filling station.

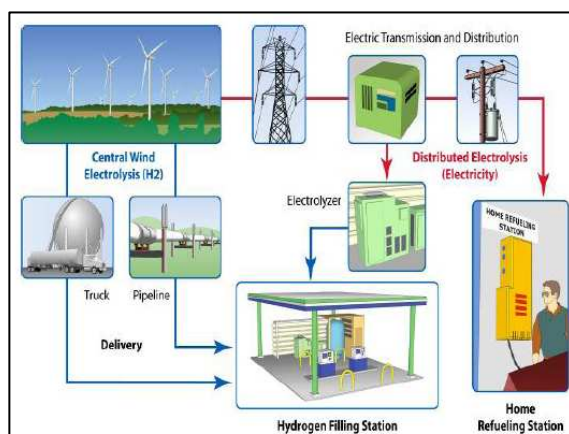


Figure 3-10 Examples of wind electrolysis being produced centrally or distributed at the point of use. Source: (Kroposki and National Renewable Energy 2006)

Algae hydrogen splitting

There is research performed on hydrogen production with algae. Using photolysis it is possible to produce hydrogen from water with algae. However, this form of production of hydrogen is slow and requires a lot of space for the algae culture; 1,5 ml H₂ gas/litre culture



(Maria Ghirardi, Michael Seibert and NREL 2003). The innovation is still in its concept phase.

3.2.2 The trend for sustainable energy production

More and more firms seem to be funding R&D in the field of sustainable power generation. One of the reasons is a growing global market demand for large scale sustainable power generation as a result of environmental regulations and measures. Several of the power generating technologies that are related to Superwind are discussed in this section; biomass technology, wind turbine technology, solar technology, and fuel cell technology.

Biomass energy production

Globally an increase in biomass energy production has occurred. However, certain problems occur with biomass. Biomass, in its current method of implementation, is not sustainable. The biomass intermixed in coal power plants originates from Brazil or Indonesia (van Kann 2008). In these countries it is either a rest product or land is used which first was used to grow plants for food. As a result there is a lack of farmland and parts of forests are cut down (van Kann 2008). Another problem is that the larger part of biomass is mixed into a coal power plant or incinerator plant to produce electricity. Unfortunately, the intermixing of biomass decreases the quality of the fuel which reduces the power output (AVI 2006). In Figure 3-1 you clearly see that the burning of biomass in coal power plants has diminished in 2007. Without subsidizing biomass is not economically viable. In the Netherlands the subsidy on biomass electricity production is 5,3 eurocent/KWh (January 31, 2008).

Biogas is a result of the gasification process of biomass. At this moment it is more expensive than natural gas. Therefore it is subsidized. The report "*Vol gas vooruit!*" by Platform Nieuw Gas stated the need for subsidies will be reduced if biogas is produced on a large-scale and more research is needed to increase production (Wempe and Dumont 2007).

Wind energy

Wind energy is globally seen as one of the promising renewable power sources that can help reduce the CO₂ production on a short-term basis. More and more wind farms are built in Europe. On a institutional several developments in wind power are taking place. The Netherlands plans for off-shore and on-shore wind parks to reach 10 GW of power generation in 2020. This would cover about 16% of the Dutch electricity use. In 2010 two new off-shore areas will be appointed. Economically speaking, wind energy is still within a niche, because it is being protected. Wind production is still subsidized by government (SDE) in order to stimulate companies to invest in their construction and exploitation (Ministry of Economic Affairs 2008a). For the period up to 2014 1,4 billion euro's is available for the SDE subsidizing (Goudsmit 2008). Still, many critics say that the government is not doing enough and therefore the energy goals in 2020 will probably not be met (NRC 2009; Trouw 2009).

It is hard to find good areas for wind parks. Hardly any permits are given because of the large resistance by NGO's who say that wind parks cause noise pollution and landscape (Goudsmit



Figure 3-11 The world's largest wind turbine, Enercon E-126.

Source: (Enercon 2007)



2008). Currently, the Netherlands is far behind compared to other European countries (Trouw 2009). This is because it is difficult to get an approval by the Dutch government for the construction of wind farm in a certain area. Before approval is given, the application by an energy concern needs to pass seven different departments (Stichting Natuur en Milieu 2008). Another reason is the large uncertainty in Dutch sustainable policy (Goudsmit 2008; Hulscher 2009). Many companies are willing to build wind farms, but it is not economically viable without subsidizing. Companies want to be assured that the financial support by the Dutch government will continue long enough to retrieve at least the larger part of their investment.

On a technological level, the wind turbine technology research focuses on increasing the power per turbine. This mostly achieved by increasing its size. The largest know wind turbine can produce 7 MW and is built by Renewable Power. This huge turbine with a rotor diameter of 126 meters and a hub height of 135 meters only turns at a wind speed of 12 m/s (Enercon 2007). Therefore it can only properly function at sea where the wind conditions are better than on land. Research also focuses on the improvement of the wind turbine's life expectancy through the development of improvement of mate. The wind turbines are made higher in order to be able to produce more MW's. The height and size increase has demanded for stronger materials. The increase of height also put the more strain the turbine blades as the move through different forms of wind flow which means that the turbine blade at the top may go through a laminated wind profile and the lower blade through a turbulent wind profile.

Of course, the increase of the wind turbine size increases the impact on the landscape and with it the resistance by public and environmental organisations.

Solar power

The Dutch government is stimulating research and diffusion of solar power because it holds a strong knowledge base on photo-voltaic (PV) cells and wants to increase it. It supports solar power with subsidies (SDE) for 70-80 MW (Ministry of Economic Affairs 2008a). Furthermore, the province of Fryslân has chosen solar power as one of their main technological focus points (de La Vieter 2008). Thus support for solar power also occurs on a regional level.

Decentralized combined heat and power systems

The Netherlands has a large horticultural sector and many entrepreneurs have installed CHP units which provide heat and electricity not only to their greenhouses, but also the Dutch electricity grid. The Dutch government has stated in the 2008 Energy report that the number of CHP's is to grow with 30 to 60% within eleven years. However, this can only be accomplished with a priority rule for CHP's. Momentarily not all CHP's can be connected to the grid because the net does not have the capacity. In the coming years this will become an even bigger problem. It is expected that in 2009 150 MW cannot connect the electricity grid and in 2010 200 MW (Damveld 2008; Ministry of Economic Affairs 2008a).

A smaller version of a CHP is the micro-co-generator. It is favoured by the government as the domestic heating and electricity technology (VROM 2007); in 2009 the first micro-co-generators for home use will be available on the market (Remeha Energy 2008). This decentralized method will deliver a reduction in electricity demand. The demand for gas will, however, increase slightly. Biogas is suggested to be used for this purpose on the long term. This can be positive for Superwind as well as negative. The positive side is that there will be a larger demand for biogas which means that biogas will be exploited on a large scale. However, this demand can also mean that the biogas produced is largely directed at the



building sector in stead of being used for the regulation of wind energy or produce hydrogen for the transport sector.

Fuel cells

Fuel cell research has increased significantly of the last decade. Since the 1960's the fuel cell was of interest for space flight in which the technology advantages outweigh the costs. In this case that meant that the high costs. The last decade the research of fuel cell has been a point of interest again in order to cope with the energy problem. I made a graph using several online databases of patent offices to illustrate the technological development of fuel cells over time (Figure 3-12). It shows hardly any number of patents in the 60's which is logical because that was the time of the space race between the former Soviet union and the United States of America. This kind of research was top secret. In the 70's there is a small spike due to the oil crisis in which the price of oil rose quickly. In the 80's another oil crisis occurred and again we see a rise of patents. The 90's marked the beginning of environmental consciousness. In 2000 the climate change started to create a hype around environment and energy which has caused a steep incline in fuel cell development.

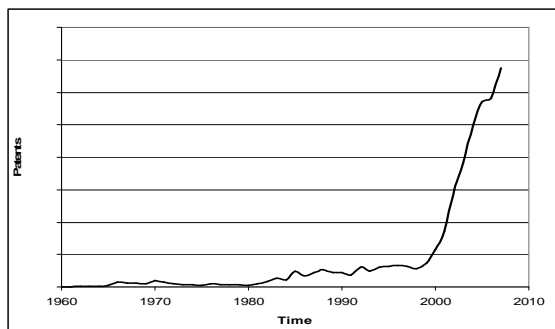


Figure 3-12 Patent development for fuel cells.

Most familiar cells are the PEM cell's which are used to power cars. The fuel cell's are much more efficient than conventional power generation, however, they are far from routine. This is still characterized by high costs, custom manufacture, and a relatively short life time.

The most preferred fuel cell by industry is still the PEM cell due to relative low price and technical characteristics. However, MCFC and SOFC are getting more attention because of their high efficiency compared to other fuel cell types. Fuel cell technology is advancing. Unfortunately these fuel cell types are expensive and are not expected to be profitable in the near future. Because the fuel cells work at a high temperature, they require special materials, which drive up the costs. The high temperature also puts a strain on the fuel cell which puts a strain on the life time (4,5 years). The high temperature dependence also reduces its flexibility to switch between high power output and low power output.

There are not many companies that have a commercially available product. More information about fuel cells is available in Appendix A.

3.2.3 The energy trend in the transport sector

After 100 years car propulsion technology has not changed significantly; fuel is ignited inside a chamber and the rapid expansion of gases pushes a cylinder which is connected to a rod to rotate the wheels. The infrastructure is build to handle this type of car technology and created a lock-in. The transport sector is now pressed to reduce consumption and waste, but no good alternative is yet available. Until now, car manufacturers have chosen to reduce the waste and consumption by creating more intelligent engines and improve the quality of the fuels. This is only a short term solution to keep the cars emissions under the levels set by the European Union. A long term solution for car fuel is needed that is not just efficient and but clean, but above all renewable. There are several technologies proposed as the future car propulsion. That is why car manufacturer and infrastructure developers are reluctant to convert to one



method. There is not certainty which of these method will become the future standard. Thus in order to accelerate the development of a long-term solution for car propulsion a standard must be chosen. Not just by the Dutch government but at a European level.

Still, the Japanese car manufacturer Honda has accepted the risk and is now producing the first large scale manufactured hydrogen car. The first cars have already been delivered to the United States and Japan. No plans are made for Europe until now.

Portugal has signed an agreement with the Renault/Nissan alliance to build 320 charging stations by the end of 2010 and 980 more by the end of 2011. Although it might seem that Portugal has decided on a standard by signing an agreement with Renault-Nissan none of the parties has decided yet who is to pay for the infrastructure.

Source: (Wang 2008)

While writing this report the electric car has increased its foothold in the car market. Alliances are formed between car companies and countries to commence the built of electric cars and an infrastructure for electric cars (Wang 2008). In the Netherlands the first action plan has been launched on how to achieve 1 million electric passenger cars by 2020 (Blikopnieuws.nl 2009). The German energy company RWE has managed to attract 20 car manufacturers to achieve a standard for the electric charging connector for cars (Inia 2009; RWE 2009).

It can be expected that the trucks and heavy machinery will remain using fossil fuels for a long time, because these vehicles require a large amount power and robustness which at the moment can only be promised with the combustion engine; although busses have already been tested with a fuel cell or natural gas powered engines.

In the city of Leeuwarden the city council is aiming to have 500 natural gas powered vehicles being driven in the next coming 2 years. More pumping stations that sell natural gas are constructed in the province of Friesland. In three to four years those same cars are suppose to drive on biogas

Source: (Blikopnieuws.nl 2008)

A list of alternative car propulsion is given below:

- The *bio-diesel powered* car is seen as the short term solution. The car is still based on the combustion engine but only slightly altered to burn bio-fuels. It produces less CO₂ and only small changes to the petrol infrastructure are needed. Unfortunately, it is still requires petrol. Another setback for this technology is the dilemma 'food or fuel'. In Mexico, for instance, the price of corn increased rapidly because of the increase in demand for bio-fuel which is made from plant fermentation.
- The hybrid car; a hybrid still contains a combustion engine, but in combination with an electric engine to reduce fuel consumption. This technology is a step towards an electric car, but still with the connectivity to the petrol infrastructure and keeping the freedom a petrol car offers.
- The *electric car*; The long battery recharging time significantly reduces the freedom of the car which one is used to having with petrol cars. Its radius is limited due to the heavy weight of the batteries. Scientists expect that the quality of batteries will improve significantly.
- The *solar car* is seen as the ultimate car of freedom. The car is independent of charging stations and solely dependent on the amount of sun shine. The solar car is hampered by the low conversion efficiency of solar cells. However, if the technology of batteries improves the solar car can increase its range and independency on sun hours.
- *Biogas powered engines* are also based on the combustion technology. It is cleaner than current petrol cars. Many countries are not in favour of the use of biogas for cars



because of its supposed safety hazards. But gas in cars is not new. An example of gas in cars is Liquefied petroleum gas (LPG). It has already been in use as a car fuel for some time. It also has a cleaner exhaust compared to petrol and diesel engines. Because of safety issues many countries were reluctant to create a LPG infrastructure. Secondly, the price for a LPG engine was much higher than that of petrol engines. However, with the necessity for cleaner fuels, like natural gas and biogas are now are considered as a fuel.

- *The air-powered car* uses the combustion principle, but instead of burning gases which rapidly expand, the air engine uses compressed air which expands and pushes a cylinder. The charging time of 300 bar air tanks varies between 1 and 3 minutes. Only three small companies spend research on this way of propulsion. KLM-Air France have started a experimental program with small personnel and cargo carriers powered by an air engine in 2009.

The pro's and con's of the car propulsion technologies are summarized in Appendix B.

3.3 Power infrastructure

The connectivity of Superwind to the current Dutch infrastructure is a determinant for future development of Superwind. The input of Superwind can be several sorts of gas. The output is electricity, hydrogen and maybe even heat. Therefore the status of three Dutch infrastructures are highlighted; the electrical, gas, and hydrogen infrastructure. The heat infrastructure is not discussed here. This is often a local infrastructure surrounding an industrial complex that has rest heat. The heat infrastructure is not a primary necessity for the development of Superwind.

3.3.1 The status of the electrical infrastructure in the Netherlands

The electrical infrastructure in the Netherlands is extensive. However its capacity cannot match the strong increase in demand for grid connections for alternative power. This is caused by the growth in decentralized CHP, wind turbines and new plans for large power stations. Currently the areas where a strong net congestion risk is, are in the North of the Netherlands and the Westland. The ministry of economic affairs has announced that newcomers are to be connected and the capacity is to be divided on the grid through congestion management (Organisatie voor Duurzame Energie 2008b). Congestion management is meant to divide the transport capacity of the grid among all the suppliers in case of net congestion. This should prevent a grid overload (Tennet 2008).

To aid congestion management smart-meters are proposed to be installed at every power junction. These meters will enable a better match between power supply and demand.

3.3.2 The status of the gas infrastructure in the Netherlands

There is much knowledge on gas transport and it also has a dense gas infrastructure with many connections to surrounding countries. This is because the Netherlands has the largest West-European natural gas bubble (Banning 2009) located in the province of Groningen.

The Dutch vision on gas transport is that the Netherlands should become the most important gas nexus of northern Europe (Ministry of Economic Affairs 2008a) (p.44). The main technological focus point for the Groningen province is the development of its gas platform (knowledge, infrastructure, and technological innovation). At the current gas extraction rate that gas bubble is expected to be depleted by 2025 (Mosselvelde 2009). Therefore it is suggested that the extraction rate is reduced and biogas is used instead (Ministry of Economic



Affairs 2008b). In the future the gas infrastructure can be used for transport of biogas or hydrogen by intermixing them with natural gas (ECN 2007).

3.3.3 The status of the hydrogen infrastructure in the Netherlands

The Dutch gas infrastructure has a high transport density. Because of this the Netherlands might be able to have a relatively small payback period on investments in the hydrogen infrastructure. This was said in 2007 by ECN's manager F. de Bruijn of the section Hydrogen & Clean Fossil Fuel. He also added the Netherlands has much experience with gas transport and infrastructure (ECN 2007). In Rotterdam there is already a large hydrogen network including a large hydrogen production in the harbour and industrial area and since 1985 ECN has worked on fuel cell technology.

Unfortunately, since the appeal to the Dutch government by de Bruin not much has changed. Several small scale projects have started. The latest is the production of hydrogen on the Dutch island Ameland where the knowledge and innovation centre of Eneco is situated. The hydrogen production is indirectly created by the electrolysis of water. The project is mainly aimed at the effects of hydrogen in different sorts of gas pipes (Eneco 2008).

For hydrogen passenger cars there are until now, in the Netherlands, zero pumps available. Arnhem is aiming at becoming the 'hydrogen city' of the Netherlands and wants to have a hydrogen fuel pump mid-2009 (Auto & Motor Techniek 2008).

In spite of increasing R&D on hydrogen related technologies, hydrogen storage and distribution still are critical issues (Quist and Hemmes 2008).

3.4 Stakeholders

The problems that Superwind can solve are related to the exploitation of fluctuating power sources and to the lack of a hydrogen infrastructure in the Netherlands for e.g. car fuel (red. Section 3.1.4). For this reason the number of actors involved and affected by the implementation of Superwind is relatively extensive. This is depicted in Figure 3-13. The figure is designed after two figures in an article by F. van Geels, who made a distinction between the actors that are involved with production of an artefact and the actors that use that artefact (Geels 2004)(p.900,901). The main actors are highlighted beneath the figure.

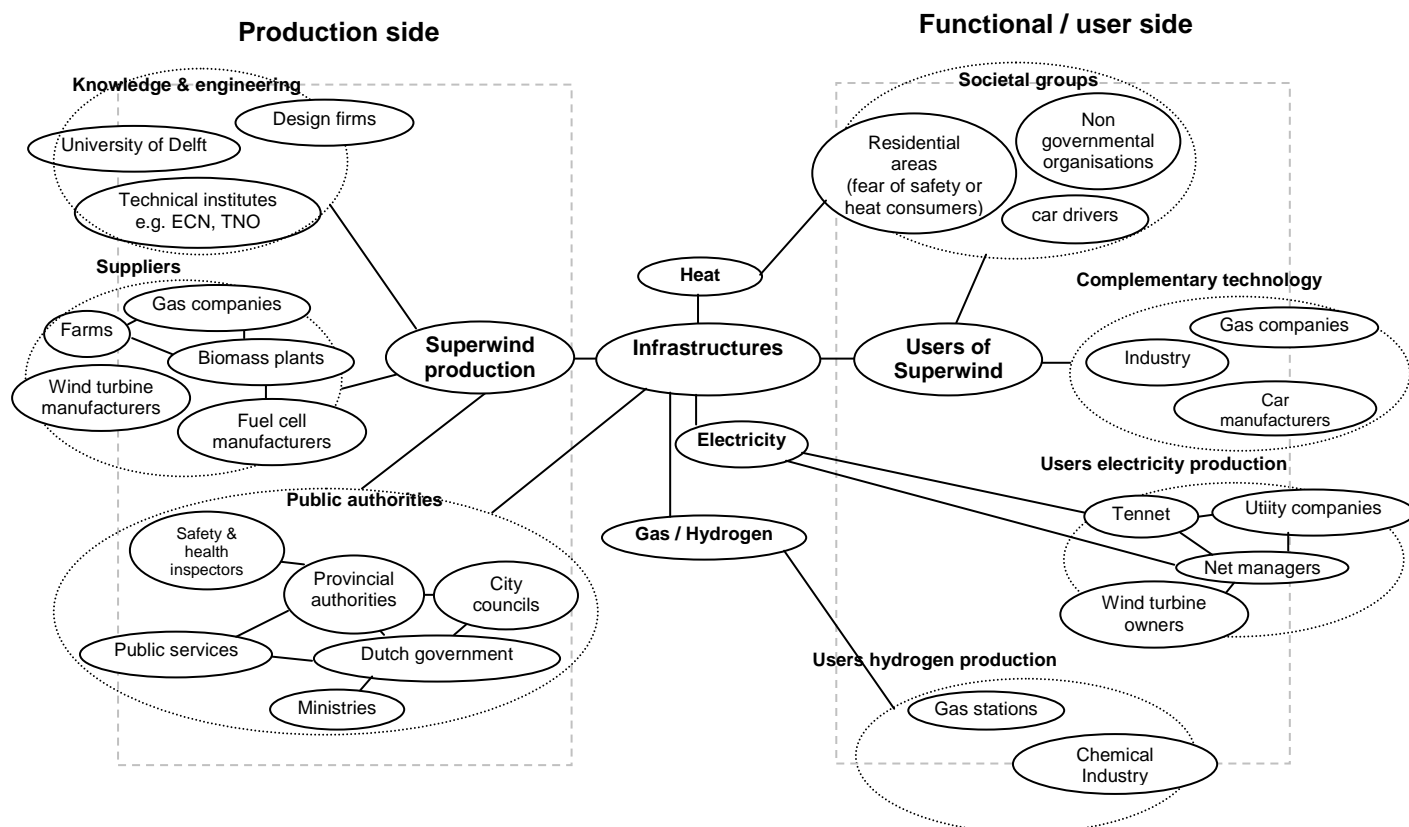


Figure 3-13 Actors involved with the diffusion of Superwind in the Netherlands.

Actors related to the improvement of the reliability of wind power

It can be stated that the following actors are involved with the issues related to wind power exploitation in the Netherlands:

Tennet: This governmental body is the main responsible for the national power grid. It recognizes that net congestion is occurring because the electricity net transport capacity is not large enough. Therefore new systems can not be immediately connected, or not connected at all. Furthermore, the intermittent renewable sources are hard to integrate and create an imbalance on the system. Tennet is in charge of fitting in large scale wind energy in the electricity grid. It therefore prefers to have the availability for more spinning reserve, a radical new infrastructure, systems that improve the power reliability of intermittent power sources. For that reason Tennet urges utility companies and net managers to provide it with such technology.

Currently it uses spinning reserve or a connection to another country to ensure that the amount of supplied power meets the demand for power.

Utility companies: Tennet charges the utility companies for the imbalance costs caused by their systems. This reduces the companies' profit.

Furthermore, the utilities are requested by government to invest in (new) renewable power generation. Competitive pressure for utility companies pushes them to lower their prices and wanting to have a green image (Public awareness)



That is why they prefer their conventional spinning reserve to compensate for fluctuations. No extra investment is needed to activate the spinning reserve. It is also a source of income. Under current law, a company that builds a power plant larger than 5 MW is obliged to also install a certain amount of spinning reserve (Tennet 2009). In other words the utility companies have already invested in the fossil fuel plant and want to achieve as much profit as possible. Investing a new kind of power plant brings new high costs and uncertainty with it. Several Dutch utility companies have chosen to meet the power future power demand by building coal power plants (Groenlinks 2007). Although several alternatives were proposed the uncertainty of alternatives was a big obstacle for the utilities. To be able to meet the mandatory greenhouse emission reduction the utility companies are investing in Carbon capturing systems (CCS).

Net managers: The rapid increase of new (decentralized) power supply has proven troublesome. Net managers are confronted with net congestion due the unpredictability of fluctuating power sources. The increase of reliability of such power sources is required to solve the issue.

Wind turbine owners: (e.g. Windunie): The unpredictability of wind turbines make it hard to match sold energy with actual delivered energy. This decreases their profits. An solution that improves the reliability of the wind turbines output is desired.

Actors related to the lack of a hydrogen infrastructure

The ambitious goals for reduction of energy consumption and emissions also affects the transport sector. To achieve these goals fuel cell technology is seen as possible new vehicle propulsion method. However, due to uncertainty about the future standard car propulsion the fuel cell and hydrogen developments are slow moving. The following problem owners can be stated for the development of a hydrogen infrastructure:

Car manufacturers: They are willing to invest their company's resources in the development of hydrogen car. However, they are reluctant to do so due to the absence of a hydrogen infrastructure. The prospect of such an infrastructure will give car manufacturers more certainty about the future. What has to be developed first? Hydrogen cars or a hydrogen infrastructure? An impulse to move out of the stalemate is required.

On the short-term most car manufactures have chosen to invest in bio-fuel powered engines. Bio-fuels do provide cleaner exhaust gases, but it is still highly inefficient. Their choice to go with bio-fuels is neither seen as purposely combating the arrival of Superwind technology, but their reluctance to agree to a standard for a new radical and sustainable type of propulsion does stagnate the development of a hydrogen infrastructure.

Gas station owners: The same problem applies to the gas station owners as to car manufacturers. The gas station owner might be willing to invest in alternative fuelling devices for the future car, but he needs certainty. If he invests in a hydrogen pump, he should have a market. He also needs a hydrogen source.

In the Netherlands the availability of bio-fuel is also poor. It is clear the larger part of gas station owners have a wait and see attitude.



Additional actors

Besides the problem owners there are actors are affected by the development of Superwind technology in the Netherlands:

The Dutch government: The development of Superwind can provide an impulse to the Dutch knowledge base. It aids in achieving the 2020 targets for reduction of consumption, the greenhouse and emissions. This in turn reduces the oil dependency.

To remove the bottlenecks that occur with the public-private cooperation for the development of sustainable innovations the government has installed services. Some of these are mandated to appoint subsidies to projects (e.g. Senternovem).

It chooses to focus on three innovations which will help achieve the 2020 reduction goals; wind power, biomass, and CO₂ capture. Furthermore, the Dutch governments is concerned whether they will reach their energy targets for 2020.

Provincial and local authorities: The provinces want to create a sustainable image, strengthen their economy through increasing their regional knowledge base. They are allowed to choose how they will reduce their energy consumption and emissions. These has led to several different foci. For instance, the province of Groningen aims at becoming the gas centre of Europe, the province of Friesland aims at solar innovation, and the province Gelderland is aiming at hydrogen innovation. However, having one focal point does not necessarily mean the exclusion of all other innovations.

Municipalities create a green and progressive image which can appeal to companies and people.

Public: The public awareness is growing through education about the energy problem. In case of Friesland high educated people migrate to other provinces due to lack of knowledge centres which require high skilled employees. This influences the regional economy.

Superwind will provide hydrogen for transport fuel. This provides the public with an alternative if hydrogen cars are available.

The public might question the safety aspect of a nearby hydrogen system. Hydrogen is a high fleeing gas which is seen as a safety hazard.

Industry: It is urged by the government to invest in energy efficient solutions and cut back on their energy consumption and emission. New innovations are desired to accomplish this. Superwind can provide a local power and hydrogen source. Investing in Superwind also provides a green image towards the public.

3.5 Discussion

Superwind consist of a combination of an internal reforming molten carbonate fuel cell and wind turbine. It is used to compensate for fluctuations in wind energy which improves the reliability of wind power. The fuel is fed by carbohydrate gas, such as natural gas or biogas. The hydrogen is released in the reformer to electrochemically react with carbonate in water, carbon dioxide. It possible to have a flexible tri-generation of electricity, hydrogen, and heat. The operator can choose to increase the power by changing the balance between the production of electricity and hydrogen. In doing so, Superwind can be used to compensate for



drops in wind power. When an increase occurs in wind power the balance can be shifted to hydrogen production.

Often proposed methods in which a fuel cell is used to buffer wind power fluctuations create and store hydrogen from a surplus of wind energy. When the wind power production drops, the hydrogen is converted into electricity and water. This only reduces the efficiency of such a system. Superwind does not include storage, neither does it use the surplus of energy to create hydrogen.

The uniqueness of Superwind is that it uses gas to produce simultaneously produce electricity and hydrogen efficiently. Because the IR-MCFC is less sensitive to impurities in the gas, many sorts of gases can be used as fuel. This factor makes Superwind a multi-source / multi-output concept. It can therefore be used for many applications.

In this report the primary goal is the compensation of wind fluctuations and the second goal is a local hydrogen source for the transport sector. Therefore only technologies and stakeholders related to these goals have been discussed. The research into technologies showed that there are many technologies that are capable of fulfilling one of the goals, or create one of the products that Superwind does, but none of them provided a integrated system with the same high efficiency. These other technologies are, however, competing with Superwind because they are less expensive and some of them are at a higher development stage.

The trend analysis for sustainable energy production showed that biomass, wind power, and solar technology are seen as the methods to increase the share of sustainable power in the energy production mix in the Netherlands and globally. The research and deployment of these three technologies are subsidized in the Netherlands. As the share of these systems increases so does the need for sustainable solutions that are capable of compensating imbalances on the grid. It can therefore be stated that this development is a driver for the development of Superwind. There is also renewed interest in fuel cells. However, the focus of most fuel cell research is on the PEM-FC due to the interest from the transport sector. There is also a slight increase in the development of high temperature fuel cells, but these are due to a high demands on material characteristics, still very expensive.

The transport sector analysis is focused on the number of alternative propulsion methods. There are a multitude of technologies under development which show potential. Because of the many alternatives the uncertainty about the next future method of transport is too great. Companies are reluctant to choose for one option and develop it. For Superwind the development of hydrogen cars would drive its development. Superwind can also be used for de energy supply for electric cars. These cars charge mostly at night. With Superwind it will be possible to increase the output to fulfil this need.

The chances of success for an innovation increase when its connectivity to the incumbent technologies is high. Therefore the power infrastructure is analysed. The electricity infrastructure is expected to be unfit for the goals of the Dutch government to introduce more sustainable power sources. The increase in renewable power sources and decentralized systems are causing net congestion. This creates a demand for a solution which Superwind can offer.

The gas infrastructure is extensive, but it is only capable of handling natural gas. The Netherlands possesses a large gas deposit located in Groningen. However, the extraction rate is very high and it is expected to be depleted in 2025. It is therefore suggested that investment in the infrastructure are made so it will be capable of handling biogas and hydrogen.

Unfortunately, test on hydrogen transport are only small scale. The lack of proven hydrogen transport and storage technology could hamper the diffusion of Superwind.

The stakeholders analysis showed who could be benefit from Superwind. For now, most actors are expected to opt for other technologies because Superwind is not proven yet and the investment costs are high. The operator of Superwind will not be able to make a profit. The



large scale problem owners such as utility companies and net managers could view Superwind as a long term investment.

On a political level there is much support for the development and implementation of sustainable solutions. The government has installed several services to improve the public-private cooperation for sustainable projects. The Dutch government favours the wide scale implementation of wind energy and biomass. Superwind will make an excellent addition to these two technologies.

The economical climate offers several possibilities for financing Superwind. The government offers subsidies for the research and exploitation of Superwind. Furthermore, there is an increase in hydrogen demand by industry ; for instance, for use in chemical processes.

The government has shown favouritism towards for the electric car. This has an impact on the development of hydrogen technology. Companies that were researching hydrogen technology might be reluctant to continue because it is expected that the largest market for the hydrogen technology is the car industry. The preference by the Dutch government has increased the uncertainty for hydrogen as the next transport fuel.

On an economical level; Superwind needs capital investments. The construction of a Superwind system is currently too expensive to compete with existing technologies. Although it is expected that the fuel cell costs will lower significantly in the coming decades, it is unclear whether this technology is able bring a return on investment.

The results of the socio-technical analysis show that there is a demand for a Superwind product. Although other technologies are able to address the same market niches as Superwind does, they are often not sustainable. The development of Superwind would not only benefit specific actors, but it will induce the development of fuel cell technology as a whole, will increase the Dutch knowledge base, and aid in the reduction of greenhouse emissions and energy consumption.



4 The role of Superwind in a future energy scenario using backcasting

Within this backcasting chapter two paths that Superwind could travel reaching a long term scenario set in 2050 are described. It is written to provide the Superwind energy group with a sense of direction for the implementation of Superwind. To perform the backcasting analysis for the Superwind technology the following steps have been executed:

Firstly, for the part of backcasting called “problem orientation” the socio-technical map from chapter 3 is used to give an overview of the current state and development that are relevant to Superwind. Secondly, the objectives for the backcasting analysis are stated (section 4.1). Thirdly, an energy scenario for Europe is introduced to be the reference scenario in this backcasting. (section 4.2) The energy scenario is written by ECN and contributes to defining the context of the future Superwind scenario. Fourthly, the ECN scenario is worked out and additional factors are introduced for the two future scenarios of the development of the Superwind technology in the Netherlands (section 4.3). The next section describes additional variables calculated for the energy development, the hydrogen development for passenger cars, the production specifications of a Superwind setup and the expectations for the demand of power reserve up. Fifthly, two long-term scenarios are described for Superwind (section 4.4). Next the backcasting analysis is written which describes the necessary changes to achieve the future desirable scenarios and the milestones which connect the present system (chapter 3) to the 2050 scenarios (section 4.5). Finally, this backcasting chapter ends with a comparison between the two scenarios and a discussion about what is expected to be the likely scenario.

REMARK: Section 4.2 to section 4.4 describe in detail the quantification of the reference scenario and additional exogenous factors which have been used for the creation of the scenarios. For those interested in the results can start reading at section 4.5.

4.1 The introduction

The backcasting analysis is applied to explore two scenarios in which Superwind is implemented to primarily aid in improving the balance on the electricity grid and secondly to stimulate the development of a hydrogen transport infrastructure.

Two scenarios are explored. The first is a scenario in which Superwind is constructed as a decentralized system which compensates the electrical power output of all installed wind power capacity in the Netherlands (Figure 3-3). This will reduce the load impact by wind power on the electricity grid. Superwind is able to compensate for other intermittent sources, but only for the wind application is enough data available to quantify goals and targets in the scenario and therefore this scenario has been constrained to the compensation of wind power output fluctuations only. This scenario is created with the data of the feasibility report of Vernay et al. (2008) as discussed in subsection 4.2 and it is based on the current launch concept design of an internal reforming molten carbonate fuel cell coupled with a wind turbine.

The second scenario created describes a centralized system which is connected to the grid and compensates for the fluctuations that occur on the Dutch national grid as a whole (Figure 3-5). This method means that Superwind takes on the role of what is called the spinning reserve.



The first scenario is chosen to explore the diffusion of Superwind if the technology remains equal to the current launch setup (red. Chapter 3.1). By implementing this setup the problem is filling in the gaps of the wind power output and so reducing the load impact on the electricity grid; a *pre-grid* solution. This scenario involves a support group consisting of large to medium scale private parties responsible for the diffusion of the technology.

The second scenario is chosen to explore the Superwind developments when one giant IR-MCFC plant is built. The setup offers an *intra-grid* solution to the problem of imbalances on the grid. In this way, the Superwind technology is used to replace the current inefficient methods for spinning reserve. Here, the diffusion of the Superwind technology is performed by a supporting actor network that mainly consists of large companies.

To summarise; the difference between the two scenarios is technical (decentralized versus centralized) and strategic (small to medium scale developers versus large scale developers). Because of the difference in technical setup between the scenarios it is possible to explore a different solution to the fluctuating power integration problem (pre-grid versus intra-grid solution).

The scenarios are set in 2050 for several reasons. The first being that the time frame has to be large enough to enable the changes needed for the development of Superwind to occur. The second reason is that the year 2050 coincides with the long term energy and environmental milestones of the Netherlands and Europe. The analysis is geographically constrained to the Netherlands because it is considered the first market in which Superwind is introduced. Other countries are also possible, but exploring a Dutch market scenario gives the ability to have a more in-depth analysis about the developments that form drivers or barriers for the market introduction of Superwind.

To be able to quantify the scale at which Superwind is to be build and to specify more concrete goals a reference scenario is used. A report published by ECN is chosen which describes a possible future for the European energy production and consumption up to 2050, called "*De belofte van een duurzame Europese energiehuishouding: Energie visie van ECN en NRG*" (Uyterlinde, Ybema and van den Brink 2007). The general overview of ECN's vision on the future of energy streams aids in providing a clear context and frame for the future Superwind scenario. The Superwind concept fits well within the 2050 perspective as a new hybrid technology that can act as a catalyst in achieving many of the perspective's main points. Although the ECN report describes the European energy development, a similar energy development is expected in the Netherlands. In combination with the Dutch government's Energy report (2008) and the feasibility report of Vernay et al. (2008) the framework for the 2050 Superwind scenario is constrained.

The scenario analyses will describe what changes are needed in the areas of technology, institutions, society, and economy to achieve these visions.

Remark: The use of predictions might seem to connect more to forecasting then backcasting, but the values used are exogenous variables for the 2050 Superwind scenarios and merely constrain the scenarios. The scenarios will still be unconventional (Robinson 1990).



4.2 The ECN report as a background of the 2050 vision

4.2.1 Why ECN created a 2050 vision

The Netherlands has lined up its policy with the European policy on energy and environment. As a reminder the goals are shortly mentioned beneath. All the percentages are in comparison with the levels of 1990.

The European goals	The Dutch goals
2020 A 20% reduction of energy consumption A 20% share of renewable energy in the total energy mix A 20 % reduction in greenhouse gasses A 10 % share of bio-fuels in overall petrol and diesel consumption	2020 A 20% reduction of energy consumption A 20% share of renewable energy in the total energy mix A 30 % reduction in greenhouse gasses An energy saving of 2% a year
2050 A 50 % reduction in greenhouse gasses	

Unfortunately, the Dutch ministry of economic affairs has not brought forward a long term policy (2020-2050), but chose to let the market decide (Ministry of Economic Affairs 2008a). Therefore there is no Dutch goal for 2050 stated in the table above.

The authors of the ECN scenario stated that there is a need for energy consumers to have a concrete picture of the necessary changes to reduce dependency on fossil fuels import and prevent global warming. This was the main reason for ECN and NRG to create a scenario about the sustainable energy management in 2050. (Uyterlinde et al. 2007).

4.2.2 A summary of the ECN's vision

The ECN authors used backcasting to create the 2050 scenario for which, according to them, they used realistic developments and radical developments (Uyterlinde et al. 2007)(p.7). Furthermore the results have been checked with an integrated energy model.

The scenario states that the goals set by the European Union and the Netherlands are met in 2020 and again in 2050. A large reduction has been accomplished in the decades preceding 2050 in the contribution of fossil energy sources and with it the import dependency on sources, such as gas and oil. Coal is the largest energy source and is used to create electricity and hydrogen. The hydrogen is used in the transport sector. However there is a large part generated by sustainable methods, mainly wind energy and biomass. CO₂-capture is implemented on a large scale which accounts for the largest part of the reduction in greenhouse gasses. Energy reduction has been achieved with new technologies. The average household energy consumption is lower in 2050 and is supplied by solar power, electrical energy and natural gas.

In the transport sector the car infrastructure has undergone a radical transformation. The price of transport has increased due to pay-per-kilometre-taxation and the increase in price of fuel. This has pushed car manufacturers to develop more fuel-efficient cars. In 2050 electrical



powered cars and hydrogen powered cars make up for more than 50% of all cars in Europe. Another large part of cars is fuelled with bio-fuels. Only a small percentage is still powered by petrol or diesel.

Industry has replaced oil with biomass to provide the basis for chemicals. The climate policy has pushed the industry in new methods of fabrication and the development of new products. The relevant milestones that are reached in their vision are described in this paragraph in chronological order.

2015

The global oil production has reached its peak which led to a strong increase in the oil price.

- Oil price has gone up to 100\$ per barrel. Inherently gas prices have also increased significantly.

2020

- A 20 % reduction in greenhouse gasses is achieved.
- In 2020 a European '100.000 fuel cell cars' program was the tilting point for the car manufacturers.

2030

- The hydrogen is intermixed with natural gas in the national gas infrastructure.
- The break-even-point between the costs of petrol cars and fuel cell cars is achieved.

2050

- By 2050 there will be 35% share of renewable energy in the total energy mix.
- By 2050 40% of the electricity will still be produced by fossil fuels.
- This is achieved largely with biomass, wind energy, and solar power.
- 100 GW off shore wind parks and 140 GW on-shore wind parks in Europe.
- Fluctuating energy sources have been integrated into the grid by smart coupling and interactive net management. Electricity storage devices have been added to the grid.
- Total energy consumption for the Netherlands is reduced at a rate of 1,5% a year. These goals will only be achieved by investing heavily in energy reduction strategies, new technologies, new energy sources, and a new energy infrastructure.
- In the beginning hydrogen was produced by natural gas, but because the price went up, it is now produced with coal power.
- Coal has been used to produce electricity and hydrogen. The production has been done with large scale CO₂-capture.
- The amount of CO₂ capture is equal to the amount of CO₂-produced which is mainly responsible for achieving the 60% reduction of CO₂ in 2050.
- Biomass will be used, for the most part, in the transport section, because there is not yet a proper alternative.
- The other, smaller, part of biomass is used to create electricity by gasification process.
- Biomass is applied at a flexible large scale with gasification plants which are capable of switching between different sorts of fuel and end products such as heat, electricity.
- Nuclear energy is used on a small scale due to resistance of many countries and has started to be phased out.



- A hydrogen infrastructure for vehicles is established in large parts of Europe
- In 2050 50% of all cars are hydrogen powered.

4.2.3 Stepping stones for the realisation of ECN's vision

ECN has described the conditions which are a necessity for achieving their 2050 scenario. They write that it is only possible if a giant change occurs in energy policy management not just by the relevant authorities but also with consumers. Technological developments must achieve certain milestones and areas outside of Europe must also be active in the area of sustainability. After 2050 sustainability must still be a key issue on the political agenda in order to achieve a real sustainable energy supply.

What must be the approach to reach this phase? ECN calls their strategy ROBUST² and consist of 7 dimensions.

1. Determining long-term goals and their preparation for the mid-term for the emission of greenhouse gases.
2. Determine the mix of technologies and formulate a vision which is needed to realise the goals.
3. Develop a set of policy tools that review the development stages of technologies.
4. Implement maxima for greenhouse gas emissions. Set norms for energy consumption and sustainable energy.
5. Establishing cooperation and communication between the public and private sector to overcome bottlenecks.
6. Evaluation and reflection of the approach and the result and eventually adjust accordingly.
7. Adding an international dimension; to see whether other parts of the worlds can also be reached in this process of achieving a sustainable world.

ECN sees the government as the strongest player to lead a society's transition towards a more sustainable way of living. It should promote development of new technologies and introduce niches in which these new technologies can be experienced. An example given is the "100.000 fuel cell car program in 2020". The number is chosen because it is needed to provide a basis for experience, product advancements, and going towards market dominance. Another strategy can be setting an international technology agreement. Furthermore, the government should set ever stricter regulations to out phase older, less economical installations.

The authorities are responsible for creating a clear long-term vision that gives a signal to companies in which direction they should move.

The public-private cooperation should aim at the removal of bottlenecks that might occur with the introduction or use of a new technology. The government should become an active participant in solving these problems.

And last, but not least, the implemented policies should be evaluated on a regular basis and adjusted where needed.

² ROBUST: Realiseren van een overkoepelende Broeikasgas Uitstootreductie Strategie. Translation: Realising a all over spanning Greenhouse gas Emission reduction Strategy



4.3 Additional input variables for the 2050 scenarios

For this paragraph data is collected from the ECN scenario, the Dutch government's 2008 Energy Report and the online archive of Tennet to predict the numbers about the future energy mix, population, number of fuel cell cars, and necessary power reserve up 2050 in the Netherlands. These are used to calculate the demand for wind power and hydrogen. Based upon those numbers and the Superwind site specifications an estimate is made of the scale at which the Superwind technology is to operate to cover a 100% of the fluctuations of wind turbines for the first scenario and a 100% of power reserve for the second scenario.

4.3.1 The energy mix up to 2050 in the Netherlands

A prediction is made for the electricity production and demand in the Netherlands up to 2050. The Energy report of the Ministry of economic affairs is used as a reference (Ministry of Economic Affairs 2008a). The Energy report holds a table which consists of the predictions for the energy development in The Netherlands based on several other visions. Figure 4-1 shows that vision on energy development.

Biomass and wind power will be the two most constructed sustainable energy generation systems in the future. Biomass will play an important part in the development of energy production in the Netherlands. This form of biomass consists, for instance, of fermentation processes which are not to be mistaken with biomass that is mixed in with coal power plants (named 'Fossil/Biomass' in Figure 4-1). The total amount of wind power, on-shore and off-shore is predicted to grow up to 21 GW of installed capacity in 2050. It is believed that due to a lack of good wind locations, off-shore wind parks will develop more strongly than on-shore wind energy.

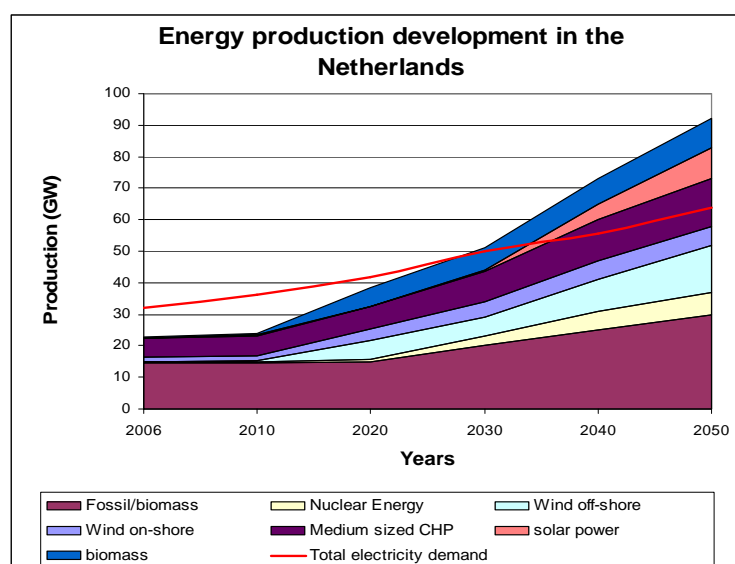


Figure 4-1 The development of energy production in The Netherlands based on the Energy Report 2008 (more specifically Table 3.2 in the 2008 energy report)



4.3.2 The hydrogen development in the transport sector

The secondary goal of Superwind is the production of hydrogen for the transport sector. In this section the demand for hydrogen by fuel cell cars is predicted which will be used as an input variable in the 2050 scenario.

Hydrogen is not yet accepted as the future standard fuel. On the short term the mixing of fossil fuels with bio-fuels is preferred by the Dutch government and industry because no radical changes in infrastructure or technology are needed. Although bio-fuel is a short term solution it does slow the development down for a hydrogen infrastructure. Another competitor of hydrogen fuelled transport is the electric car. A 'no emissions'-car but still hampered by battery technology; a long charging time and the weight of the batteries are obstacles to be overcome. Currently, several hybrid cars are produced that combine fossil fuel engines with electric engines. This type of car has been met with much enthusiasm by the public and showed that the general public is willing to shift to more environmentally cars. Unfortunately, the public is more sceptical about hydrogen cars. The cost of a hydrogen car is still too high compared to conventional cars and a lack of infrastructure prevents car manufacturers to start large-scale production which could eventually lead to economies of scale. However, hydrogen fuel is seen as one of the long-term solutions that contributes to the reduction of greenhouse gasses. It only produces water.

This development is reflected by the ECN scenario for Europe. If it is assumed that the car development in the Netherlands is a portrayal of the European car development, the amount of hydrogen passenger cars in the Netherlands from 2020 to 2050 can be estimated using the percentage values from ECN (Figure 4-2). With that number an estimate on the demand for hydrogen by passenger cars is made for each decade from 2010 to 2050.

The following values are used for the predictions of 2050:

- In 2050 the Netherlands has 16.797.096 citizens (CBS 2008b).
- According to CBS the amount of cars per 100 inhabitants is 45 in 2008 (CBS 2008b).
- This number is assumed on average to remain the same up to 2050 due to car saturation effects, an increase in fuel tax and road tax, and the introduction of pay-per-kilometre tax.
- ECN expects that by 2050 50% of passenger cars will be fuelled by hydrogen (Figure 4-2).

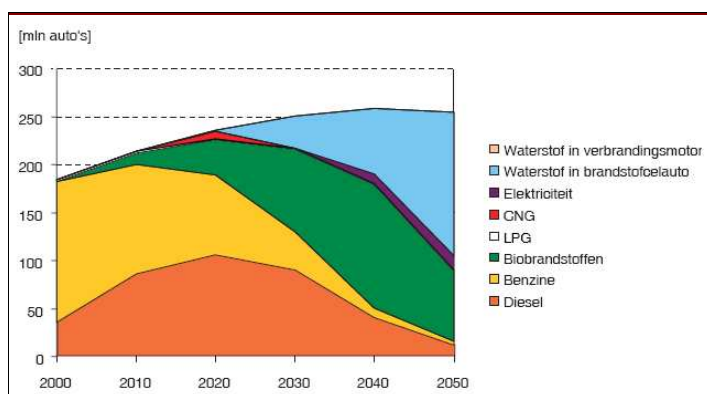


Figure 4-2 passenger cars and fuels in Europe. Source: ECN (Uyterlinde et al. 2007)

- The average distance travelled by a passenger car is 15.000 km (CBS 2008b)
- The average consumption of a hydrogen car is 115 km/kg (Honda FCX)



The calculations for the demand of hydrogen by passenger cars are:

STEP 1. Population x Car/inhabitant = Total amount of cars

STEP 2a. CBS data is used to estimate the number of passenger cars in the Netherlands.

STEP 2b. The percentage of hydrogen cars is derived from the ECN report.

STEP 3. Total amount of cars x Percentage of hydrogen cars = total amount of hydrogen cars.

STEP 4. Total amount of hydrogen cars x Average consumption of a H₂-car/year =
Total amount of kg H₂ /year

STEP 5. Total amount of kg H₂/year x C_{conversion} = Total amount of hydrogen KWh/year

Here is C_{conversion} is the amount of KWh per kilogram Hydrogen:

$$C_{\text{conversion}} = \frac{1 \text{ kg}}{2,016 \text{ g/mol}} \cdot \frac{286 \text{ KJ/mol}}{3600 \text{ KJ}} = 39,4 \text{ KWh/kg}$$

The results from the calculations are shown in the table beneath. The total amount of hydrogen passenger cars up to 2020 is considered to equal to zero. Before 2020 the Netherlands will probably only have some FC vehicles for test purposes. It is expected that in 2020 fuel cell costs have lowered enough for early adopters to invest in a hydrogen car, provided a commercial hydrogen infrastructure is present. With the expansion of the hydrogen infrastructure in the Netherlands and Europe and the ongoing cost reduction in fuel cell technology the number of hydrogen cars increases rapidly between 2020 and 2030. The rapid jump in number of hydrogen cars also occurred due to government campaigning and support (ECN scenario). The rising oil price and large scale production of fuel cells and hydrogen leads to a break-even-point in 2030 (ECN REPORT). The demand for hydrogen by passenger cars reaches about 19,4 million TWh/year in 2050.

Table 4-1 Prediction of the development for hydrogen demand by passenger cars in The Netherlands.

Year	Population	Car per inhabitant	Total amount of Passenger cars	Total amount of hydrogen cars	Hydrogen (kg/year)	hydrogen (MWh/year)
1990	14.892.544	0,34	5.118.429	0	0	0
2000	15.863.950	0,40	6.343.164	0	0	0
2008	16.456.276	0,45	7.391.903	0	0	0
2010	16.503.512		7.413.121	0	0	0
2020	16.747.887		7.522.890	100	13.043	514
2030	16.975.872		7.625.297	762.530	99.460.401	3.919.433
2040	16.963.080		7.619.551	1.752.497	228.586.544	9.007.902
2050	16.797.096		7.544.994	3.772.497	492.064.829	19.390.782



4.3.3 The Superwind production capacity

The feasibility study by A.L. Vernay et al. provides the average amounts of electrical energy and hydrogen delivered by a Superwind site that consists of a 250 KW fuel cell and a 600 KW wind turbine (Vernay et al. 2008). She investigated the feasibility of Superwind, technically and economically. The calculations were based on wind data provided by Wind Unie, which included the predicted wind energy, the on before hand sold wind energy, and the actual sold wind energy per 15 minutes. Because of the high complexity that comes with calculating the optimal operation method of a Superwind installation Vernay divided the calculation in 6 concepts with increasing complexity and concept 6 being the full Superwind concept. These concepts differed in 3 factors; type of fuel cell, input, production of hydrogen. Each concept was also divided into several strategies. The main differences between these strategies were in whether there was full market knowledge or not and how they levelled the fluctuating output signal of a wind turbine. The result was that the imbalance costs, which occurred due the difference between promised energy to APX and the actual delivered energy, were lowered and the profit of wind turbine owners increases. Furthermore the total amount of electricity and hydrogen were taken into account and what revenues they would generate.

To get an idea about the implementation scale of Superwind needed to fulfil a certain amount of coverage for electricity and hydrogen two strategies are chosen for the calculations. In the report of Vernay et al. (2008) the strategies are called strategy 2 and 4 in concept 6. According to Vernay these strategies are the most realistic options among the strategies.

Table 4-2 The description of the strategies. (Vernay et al. 2008)

	Use the fuel to compensate for wind energy production when				Adapt to electricity price		Produce hydrogen	
Concept 6	Too little is produced		Too much is produced		APX			
	Yes	No	Yes	No	Yes	No	Yes	No
Strategy 1	×			×		×	×	
Strategy 2	×			×	×		×	
Strategy 3		×	×		×	×	×	
Strategy 4		×	×		×		×	
Strategy 5	×		×			×	×	

Strategy 2 means that the Superwind concept will only compensate for an electricity shortage and it is able to adapt to the electricity price on the APX market. Furthermore, the fuel cell is utilized in high efficiency mode which leads to a large share of hydrogen output. However, if needed the operation mode can be switched to strategy 4 to create more output. Strategy 4 is characterized by compensating for an overproduction and the capability of compensating for to the actual electricity price on the APX market. Similar to strategy 2 it also produces hydrogen. However, the fuel cell is now operated in high power mode. This means that the amount of output is much higher than strategy 2 but it is less efficient and the share of hydrogen in comparison to electricity is lower.



The production numbers for these two strategies are given beneath:

Table 4-3 The production of electricity and hydrogen for different strategies.

	Mode	Electrical output / Year (MWh/year)	Hydrogen output/ Year (MWh/year)
Strategy 2	high efficiency	2240	864
Strategy 4	high power	4680	3780

These results correspond for *Strategy 2 with 660 households and 168 hydrogen cars* that could be powered by one Superwind site or for *strategy 4 with 1377 households and 735 hydrogen cars*. The number of households is based on an average consumption 3.400 KWh/year of a household (CBS 2007). The number of hydrogen cars is based on the average consumption of Honda's next generation FCX Clarity hydrogen car, 115 km/kg H₂, and the average mileage for a passenger car in the Netherlands, 15.000 km/year (CBS 2007). The wind turbines installed in the future will have on average a 3 MW engine on-shore and 5 MW-offshore (Uyterlinde et al. 2007) but the research for the production of a Superwind site was done by analysing the data for a 600 KW wind turbine. To specify the targets in the scenarios the production values will be multiplied to calculate the total production. This means that for a 3 MW wind turbine it is assumed that a total of 1250 KW fuel cell capacity is used to compensate the fluctuations ($3\text{MW}/600\text{KW}=5$).

To perform calculations for the scenarios the production values are assumed to remain equal till 2050 because of practical computational reasons. However, it is more likely that due to improvement of technology, the efficiency, the responsiveness, and the power density of the fuel cell will increase the next decades.

4.3.4 Calculations for the Superwind scale and coverage

The values from subparagraph 4.3.1 give an insight in the expected energy demand for electricity in the Netherlands and the expected amount of installed electricity capacity up to 2050. The numbers are derived from the 2008 Energy report and are actually numbers which the Dutch government hopes to achieve but concrete plans have not yet been initiated. For the backcasting analysis the numbers are assumed to be achieved.

In subparagraph 4.3.2 the expected demand for hydrogen in the Netherlands by passenger cars is calculated. The numbers are based on a Honda FCX Clarity car because this is the first car to go into full scale production. It is currently only sold in Japan and the state of California (U.S). It is said that the car will be introduced to the European market in 2010.

Subparagraph 4.3.3 describes the potential amount of hydrogen and electricity that is supplied by one Superwind site. The data is taken from the feasibility report of Vernay et al. (2008) which is based on a 600 KW turbine and 250 KW molten carbonate fuel cell.

In this fourth subparagraph those numbers are used to specify exogenous variables and results for the two scenarios. For the second scenario new information is introduced for the expected trend of power reserve in the Netherlands up to 2050.

4.3.4.1 Compensating for installed wind capacity

In Table 4-4 the total amount of expected installed wind capacity is written per decade starting at 2010. The development of the total amount of installed fuel cell capacity, if operated according to the Superwind concept, needed to level 100% of installed wind energy



capacity is calculated. With the values from Vernay's report the corresponding figures for the IR-MCFC's electrical and hydrogen production are calculated.

Calculation example for the year 2050:

Step 1. Total installed wind capacity / wind turbine capacity at test site = # of installations

$$\frac{21 \text{ GW}}{600 \text{ KW}} = 35.000 \text{ Superwind sites}^3$$

Step 2. # of installations x single IR-MCFC capacity = total amount of installed fuel cell capacity

$$35.000 \cdot 250 \text{ KW} = 8.750 \text{ MW}$$

Step 3. At strategy 2 a 250 KW fuel cell produces 2240 MWh/year of electrical power and 864 MWh/year of hydrogen.

Therefore 35.000 sites produce:

$$35.000 \cdot 2240 \text{ MWh / year} = 78.400.000 \text{ MWh/year of electrical power}$$

$$35.000 \cdot 864 \text{ MWh / year} = 30.240.000 \text{ MWh/year of hydrogen}$$

Remark: The reason for the difference between the above result and that of Table 4-4 is because the numbers in Table 4-3 have been rounded off.

The reason that these calculations have been made is to show the scale at which Superwind technology should operate in order to level the installed wind capacity. The numbers in Table 4-4 show that to cover 100% of the installed wind capacity with strategy 2, the high efficiency mode, by 2050 requires 8,75 GW of installed fuel cell capacity. This corresponds with 35.000 Superwind installations consisting of a 600 KW wind turbine and 250 KW fuel cell in 2050. The total production of the Superwind sites is 78,5 TWh/year of electrical output and 30.2 TWh/year of hydrogen output.

From Table 4-1 it is derived that this number corresponds with a bit more than 156% of hydrogen coverage for passenger cars in 2050. Furthermore, the fuel cell alone provides electricity to around 23,1 million households. The expected number of households in 2050 in the Netherlands is around 8,5 million (CBS 2007).

Strategy 4, the high power mode, produces much more compared to strategy 2, however, this strategy is not realistic, because the fuel will not continuously operate in this mode. Therefore the calculation with strategy 2 is an underestimation of the system's potential.

³ The number of Superwind sites corresponding with a certain amount of installed wind power is not shown in Table 4-4 but is shown in Appendix E.



Table 4-4 Wind energy production development and the number of Superwind sites needed to act as an energy levelling assistant.

Year	2010	2020	2030	2040	2050
Predicted total installed off-shore wind capacity in The Netherlands (GW)	0,400	6,00	6,00	10,00	15,00
Predicted total installed on-shore wind capacity in The Netherlands (GW)	1,500	4,00	5,00	6,00	6,00
Predicted total installed wind capacity in The Netherlands (GW)	1,900	10,00	11,00	16,00	21,00
Total installed fuel cell capacity to compensate for a 100% of the total wind energy demand:					
using Strategy 2 (GW)	0,79	4,17	4,58	6,67	8,75
Corresponding Electricity (GWh/year)	7.106	37.400	41.140	59.840	78.540
Corresponding hydrogen (GWh/year)	2.736	14.400	15.840	23.040	30.240
using Strategy 4 (GW)	0,79	4,17	4,58	6,67	8,75
Corresponding Electricity (GWh/year)	14.820	78.000	85.800	124.800	163.800
Corresponding hydrogen (GWh/year)	11.970	63.000	69.300	100.800	132.300

4.3.4.2 Compensating the electricity grid directly for all intermittent power sources.

The scenario in which the fluctuations on the grid are compensated the Superwind technology will, in fact, act as the spinning reserve. In the Netherlands the total spinning reserve is 1400 MW which has to be available within 8 hours. 700 MW of that total spinning reserve has to be up and running within 15 minutes (Fens 2009; Tennet 2009). If spinning reserve is needed the Tennet will notify the relevant parties which are then able of placing an offer for the extra power they will deliver to compensate imbalance on the national grid.

If it is assumed that a fixed percentage of the total energy demand must always be available as spinning reserve, then for each decade an indication of the amount of spinning reserve can be calculated (Table 4-5). However, this is a rough estimate, because it is unclear what the actual impact will be of the increasing share of renewable power generation in the energy mix.

Table 4-5 The expected needed spinning reserve for the Netherlands on basis of the Dutch electricity demand.

Year	2008	2010	2020	2030	2040	2050
Total electricity demand (GW)*	32,2	36,1	41,7	50,0	55,6	63,9
15 minutes reserve (GW)	0,70	0,78	0,91	1,09	1,21	1,39
8 hour reserve (GW)	1,40	1,57	1,81	2,17	2,41	2,78

*= These numbers are based on the Dutch 2008 Energy report (VROM)

The fuel cell plant would need a steady connection to a good quality gas source. In the Netherlands a good location could be in the Groningen province. This province wants to become the gas nexus of Europe. It has explored the gas deposit in Slochteren for several decades and has build up a strong knowledge base. The fuel cell plant would have access to a dense gas infrastructure for natural gas supply but in the future possibly for delivery of hydrogen through the mixing of hydrogen in the infrastructure.



The plant itself will consist of several IR-MCFC's integrated for the most efficient performance.

The current IR-MCFC is not able to ramp up quickly. However, it is able to start up within the 8 hour demand. The 250 KW fuel cell is capable of producing a peak power of 250 KW, however, the network performance is 237 KW. Therefore the plant scale is as follows if a 100% of power reserve is done by the IR-MCFC plant:

Table 4-6 Total amount of fuel cell power necessary as power reserve.

Year	2008	2010	2020	2030	2040	2050
8 hour reserve (GW)	1,40	1,57	1,81	2,17	2,41	2,78
Total fuel cell power (GW)*	1,48	1,66	1,91	2,29	2,55	2,93

*= This number is based on the fuel cell's net performance and back up power in case of a malfunction or maintenance is not included.

In this case the hydrogen output is difficult to predict due to a lack of information about the day-to-day demand for spinning reserve.

Furthermore, there are two main possibilities for the operating method of the plant:

1. If no spinning reserve is demanded the system will operate at the lowest input possible which is able with a gas supply of 100 m³ gas/day. Turning of the power plant is not an option because of high start-up costs and it will not directly be available on request. When there is a demand for spinning reserve a choice can be made which depends on the demand for hydrogen whether to operate only a small part of the fuel cell stacks available at the plant in high power mode or to initiate a large part of the fuel cell stacks to produce at a higher efficiency mode and co-produce hydrogen simultaneously.
2. If no spinning reserve is demanded the fuel cell plant will run at a high efficiency mode which produces the most hydrogen. When there is a demand for spinning reserve the fuel power plant switches to high power mode.

The day-to-day-operation will most likely be a mix of these two. The first method is the best method for spinning reserve because it requires the least amount of installed fuel cell capacity. The fuel cell plant will always have to be in operation, due to the practical reasons explained above, which means that it will always produce a certain amount of electrical which is also delivered to the grid. If the second method is used the plant is equal in its functioning to a conventional power plant. It is a full time power generator with a certain amount of power. This means that if it is to meet the demand of 1400 MW in to regulate power fluctuations, much more installed power capacity than 1400 MW would be needed. However, the second system is operated more as a Superwind system, namely the bi-production of hydrogen and electricity.

4.4 The role of Superwind in 2050 in the Netherlands

This paragraph consists of two subparagraphs and each contains one scenario. The first scenario is where a decentralized setup of Superwind is used to compensate all installed wind capacity in the Netherlands. This is actually the launch scenario of Superwind if it were marketed similar to the concept for a pilot project. The second scenario portrays the Superwind technology as a power plant which is used as spinning reserve in the Netherlands. With this scenario the principle of the concept is taken a level further by creating one large power plant which is owned by Tennet. Both scenarios will include the production of hydrogen as fuel for passenger cars or as resource for industrial processes.



4.4.1 Scenario A: A decentralized Superwind system

The Superwind technology is distributed in the Netherlands in a decentralized manner. The technology is exploited by stakeholders varying from small to large scale actors. Small and medium scale stakeholders are private owners or organisations and the large scale actors are utility companies.

Superwind

The installed wind power capacity in the Netherlands is compensated for a 100% by Superwind technology. Each wind turbine (park) is compensated by Superwind technology. Most of the installations are either owned by private wind turbine owners or utility companies. Medium scale wind turbines owners are mostly owner, while small scaled owners construct Superwind installations by forming conglomerates with other small scaled owners, or have at lease contract with utility companies.

The smaller remaining number of Superwind installations is owned by industrial companies. The total amount of installed wind capacity in the Netherlands is 21 GW. For 21 GW of installed wind power in 2050 8,75 GW of installed fuel cell power is needed. This may seem like much, but unlike spinning reserve the fuel cell does not remain in stand-by until needed. The fuel cell is utilized constantly, with the exception of maintenance time, to either produce electricity or hydrogen. The total amount of electrical power delivered by the wind and the Superwind technology combined is about 104 TWh which is good for about 30 million households⁴. The total amount of hydrogen produced by the Superwind sites is 30 TWh/year of hydrogen. This enough to power about 5,9 million cars.

Energy mix

Within the 2050 Dutch energy supply mix of electrical power 60% is provided by sustainable power methods. Wind power provides 23% of the total energy supply and 32% of the total Dutch energy demand. The difference between these numbers is caused by the fact that the Netherlands has a surplus of energy and is an electrical energy exporting country (Ministry of Economic Affairs 2008a). Other sustainable power sources used in the Netherlands are solar power, combined heat and power generators and biomass. Solar power provides 11% of the total energy supply. The efficiency has increased significantly and most houses are built with solar panels on the roof. CHP's are used in mostly used in horticulture activities and account for 16% of the total electrical power supply. The larger part of biomass is used as fuel (ECN scenario) and all systems are connected to the Dutch gas infrastructure. The existing technology has increased the amount of biogas that can be extracted from biomass and also improved the quality. The other part of the biomass is intermixed with coal power stations for electrical power generation (ECN scenario).

The remaining 40% of the electrical supply is produced with coal and nuclear power. Coal power is responsible for delivering 33% of the total demand in the Netherlands. All coal

⁴ This number is based on a 250 KW fuel cell which is operated in high efficiency mode (strategy 2). However, the real production is expected to be higher because the fuel cell will vary in modus between high efficiency and high power mode. The average household consumes 3400 KWh/year.



power stations are covered by carbon capturing systems (ECN scenario). This is not accepted as a sustainable solution and the plans to phase out coal power stations are implemented. There is still a small part of electrical energy produced with nuclear energy. This method is also being phased out (ECN scenario).

Infrastructures

The electricity infrastructure uses smart meters. The technology aids in the optimisation of the matching between demand and supply. This has reduced the occurrence of net congestion while the share of decentralized power sources and fluctuating power sources is significant. Utility companies are strongly pursuing sustainable methods of power generation (renewable energy and more efficient methods). This is because the governmental pressure to reduce the energy consumption has been strong (energy tax and regulations). Also, the public-private cooperation is optimized for sustainable innovations.

In Europe a handful of utility companies play the electricity market. The physical grid remains under control of Dutch network managers. Each country still has an overall net manager, but these answer to one European net manager, which is responsible for regulating the electricity grid balance, but also monitors the utility companies to prevent an oligopoly market type.

The gas infrastructure is used to transport natural gas as well as hydrogen and biogas. The Netherlands has a fully developed hydrogen infrastructure. The larger part of hydrogen is transported by intermixing the hydrogen with natural gas or biogas into the gas infrastructure. Most of the pumping stations in the Netherlands possess separation systems to retrieve the intermixed hydrogen and make it available for consumers. Those pump stations that do not have a separation device can opt for truck delivery of hydrogen.

The Slochteren gas deposit is still used, but the amount of biogas is increasing. Biogas is created at several large plants, but mostly smaller fermentation plants that are constructed through cooperation efforts between farmers. They are fed by the farms' organic waste. Most of the biogas is then directed to Superwind installations to be refined into hydrogen for transport fuel and industrial purposes or electricity to compensate for wind energy fluctuations.

There are more sustainable innovations available besides Superwind that produce hydrogen, however none of them are capable of reforming gas with such a high efficiency. Most of the hydrogen is still produced by steam reforming to be able to meet demand from the industrial sector. Superwind technology has replaced the gas turbine as a biogas power generator. The high oil and gas prices have made the use of fuel cells an economically viable alternative to a gas turbine. Furthermore, the new environmental laws require that fuel conversion is performed with the minimal amount possible of greenhouse emissions.

Fuel cell technology

Fuel cell technology is routine. The full scale construction of Superwind technology sites created an impulse for high temperature fuel cell research. The production costs have lowered due to new materials and large scale production. The flexibility has improved significantly and the IR-MCFC can respond quickly to energy fluctuations. These factors and active government market guidance (energy tax, innovation subsidies, etc.) have made fuel cell technology economically viable.



Although, the name Superwind still refers to the combination of the IR-MCFC and a wind turbine, other similar installations also exist in which the IR-MCFC is coupled to PV-cells or connected to the grid to compensate for grid imbalances.

Wind turbine technology

The lack of space and protest by environmental organisations led to the decision to built more wind parks at sea. A contributing factor is that the windy conditions at sea were far more suited for the large wind turbines.

The wind turbine technology has reached its maturity. Research and development have increased the average wind power output and the life expectancy. The average power per wind turbine is now 5 MW and the life expectancy is 25 years.

The production of wind turbines is done at a large scale since wind power is the preferred renewable energy source for most countries. This has reduce the costs significantly.

Transport

In 2050 the mix of cars consists of fuel cell passenger cars, electric passenger cars, bio-fuel powered passenger cars, petrol cars, and diesel (ECN scenario). The fuel cell car is the most popular car. It is expected that 50% of the cars are fuel cell cars (ECN scenario). This amounts to about 3,8 million cars in the Netherlands which will need a total of 19.391 GWh/year of hydrogen. If all of the total wind installed power is compensated by Superwind an amount of 30.240 GWh/year of hydrogen will be produced by all the Superwind installations combined⁴. This is 56% more than the demand for hydrogen by passenger cars in 2050. The fuel cell car reached popularity due to a high efficiency (ECN scenario). The break-even point between petrol cars and hydrogen cars was reached in 2030 (ECN scenario).

The number of electrical cars on the road is small because of the low distance per charge. Although the battery power density increased the weight of the batteries is still too high. Transport vans used for intra-city travel are often equipped with a electrical engine which is powered either by battery or fuel cell (ECN scenario). The bio-diesel car accounts for around 30% of the cars in the Netherlands. The bio-fuelled car was the first step to the reduction of greenhouse emissions as the electric cars and fuel cell car were not well developed yet. The larger part of car owners have transferred to bio-fuel cars.

Finance

The development and implementation of new innovations are, if needed, subsidized by the Dutch government. The subsidizing method is either an investment grant or a feed-in tariff based which depends on the sites performance. Which subsidizing method is used depends on the development stage of the innovation. The feed-in tariff is mostly connected to fluctuating power generators. It is used to prevent a concentration of fluctuating power sources high performance areas and to stimulate the implementation of sustainable innovations in lesser performance areas.

Utility companies own the large wind parks and use a Superwind installation to improve the wind power reliability. The combination of a wind park in combination with Superwind is profitable. The utility companies aid in financing Superwind with small scale wind turbine owners. This is done by leasing the fuel cell to private parties. Through this construction the exploitation of the fuel cell is accessible to even the smallest wind energy suppliers. The maintenance is also the responsibility of the utility companies. Therefore private owners do



not need technical know-how to work with a fuel cell. In combination with a lease often a long-base contract is provided.

Regulations and policies

Although a large amount of reduction in greenhouse emissions and energy consumption is achieved the ever growing population in Europe still increases the demand for energy. The Netherlands has a steady population number because emigration is equal to birth and immigration (CBS 2007). However, the Netherlands still feels the responsibility of reducing energy consumption. Therefore environmental and energy policies remain high on the agenda. The Dutch government plays a leading role in the market development for sustainable products.

The output of all fluctuating power sources is compensated and in combination with smart meters the system operator is able to match demand and supply meticulously. The energy companies offer power to the system operator at a certain rate on the Dutch spot market. Energy companies also sell the surplus to other countries which happens at spot markets. Most private owners of a fluctuating power source have a long base contract with utility companies. Most users of the Superwind system have a lease contract in combination with a long-based contract.

Hydrogen technology institutionalized. Regulations include hydrogen transport and implementation.

The policies are aimed at promoting sustainable behaviour within society and stimulating sustainable innovations. It includes priority regulations for sustainable innovations and financial constructions and clear reduction targets.

Culture

The ‘greening’ of the Dutch way of life is still an important issue on the agenda. The Netherlands is coping with a lack of space for housing or large scale energy farms. This has put enormous pressure on reducing the energy consumption of the Netherlands. In 2000 the reduction of energy and greenhouse emissions started as a hype. However, that hype has transformed to integral part of society. Construction of energy systems, transport, or housing that are as sustainable as possible is now common sense environmentally and economically.

The hydrogen car is accepted as the optimal form transport.



4.4.2 Scenario B: A centralized Superwind system

In this scenario the Superwind technology is centralized in one power plant. It contains multiple stacks that are used as the main reserve power for Tennet to compensate for any imbalance that might occur on the electrical grid. Most of the characteristics of scenario A also apply to scenario B. For that reason only the areas that differ are mentioned in this section. The points mentioned in scenario A that also apply to scenario B are summarized in the table beneath:

Table 4-7 The items of scenario A that apply to scenario B.

Energy mix	Infrastructures		Fuel cell technology	Wind turbine technology
<ul style="list-style-type: none"> 60% reduction of greenhouse emissions compared 1990 60% share of sustainable power in Dutch energy mix Wind power is most installed renewable power source in the Netherlands Biomass is mostly used for transport fuel Oil and gas prices are high The Netherlands is an energy exporting country All coal power plants are connected to CCS 	<ul style="list-style-type: none"> The Dutch government allows foreign companies to buy Dutch utility related companies with the exception of net managers Dutch utility companies are part of a multinational utility company Utility companies pursue sustainable solutions 	<div> <div><i>Electrical infrastructure</i></div> <ul style="list-style-type: none"> Smart-meters are installed with every consumer to measure demand </div> <div> <div><i>Gas infrastructure</i></div> <ul style="list-style-type: none"> Gas infrastructure handles natural gas, biogas and hydrogen Biomass mostly used for transport fuel All biogas is direct to Superwind systems Hydrogen pump available at all gas stations </div>	<ul style="list-style-type: none"> Superwind is created an strong impulse for high temperature fuel cell research Fuel cell technology has become commonplace The high temperature fuel cell is economically viable Fuel cell production is large scale 	<ul style="list-style-type: none"> Lack of space, environmental organisation and better wind conditions caused wind sites to be built at sea Wind turbine technology is mature Wind turbines are an economically viable alternative to fossil fuels Wind power is not subsidized Turbine production is large scale
Transport	Finance	Regulations and Policies	Culture	
<ul style="list-style-type: none"> Fuel cell cars make up 50% of the total cars in the Netherlands Petrol and gas are disappearing Bio-fuel makes up for a third of the total cars in the Netherlands Battery cars are used for intra-city travel 	<ul style="list-style-type: none"> Every phase of development of innovations are subsidized 	<ul style="list-style-type: none"> Sustainable policy is a fixed item on the political agenda Government plays leading role in sustainability Sustainable policy is aimed: <ul style="list-style-type: none"> At reduction of energy consumption and greenhouse emissions Stimulating sustainable innovations 	<ul style="list-style-type: none"> Sustainability is an integrated aspect of products and services People do no longer refer to sustainable solutions as remarkable but merely as common sense 	



The following items differ from scenario A:

Superwind

The Superwind technology is implemented as a large power reserve station. It is able to compensate 100% of the fluctuations on the Dutch energy grid. The Superwind plant is a cooperative effort between the public and private sector. Tennet is the main responsible actor and coordinator but all utility companies and net managers own shares in the power plant.

Infrastructures

The Dutch electrical infrastructure in 2050 requires a spinning reserve of 2800 MW to compensate for the fluctuations on the grid within an 8 hour time frame. Half of this capacity amount should be able to activate within 15 minutes. This will require at least a fuel cell plant of 2900 MW in order to be able to generate the required amount (section 4.3.4).

The plant initially started out to act as long-term spinning reserve for the 8 hour in advance demand because it could not ramp out its power quick enough. However, the technological developments in the area of fuel cells have increased the flexibility of the fuel cell and has made the fuel cell plant capable of also being activated within 15 minutes; the short term spinning reserve.

A central plant has decreased the need for power stations to have a spinning reserve. Spinning reserves are still located with large power plants bigger than 5 MW, but these are only addressed when the central Superwind plant is not able to cope with the imbalance.

The central plant is directly connected to the grid and biogas and hydrogen is intermixed with natural gas in the already existing infrastructure. Biogas is delivered by fermentation plants, either owned by utility companies or private owners. This biogas is also transport via the gas infrastructure.

Finance

Tennet uses the power plant as the main spinning reserve for the Dutch electricity grid. The spot market for fluctuating power sources with its penalty system is used. To reduce the penalty costs and to pay for the costs of the Superwind plant energy providers can buy shares in the central power point. The maximum amount of shares bought is equal to the maximum amount of energy a company is able to produce. This is to prohibit large companies to buy up shares meant for smaller companies and private power source owners. Large utility companies have an obligation to invest a certain amount, while small sized private investors do not.

Regulations

The primary power reserve is the Superwind plant. Secondary reserve systems are the spinning reserves with the larger coal power plants. The regulations have institutionalized this format.



4.4.3 Scenario comparison

Both scenarios are placed within a similar context. The highlights of this context that apply to A and B are shown in Table 4-7 in the previous subsection. The differences between the two scenarios are summarized in Table 4-8. The comparison shows that the difference lie primarily in the application. The differences in other areas will become more clear in the description of the necessary changes and milestones for both scenarios.

Table 4-8 A comparison between scenario and B.

	Scenario A	Scenario B
Function	Compensating 100% of wind turbine power fluctuations to reduce the load impact on the Dutch electricity grid	Acting as power reserve to compensate for 100% of electricity grid imbalances in the Netherlands
Secondary function	Local hydrogen source primarily for transport sector and secondarily industry	Large scale hydrogen source primarily for transport sector and secondarily industry
Electricity distribution from Superwind site	Distributed low/medium capacity connection	Centralized high capacity connection
Hydrogen distribution from Superwind site	Distributed low/medium capacity connection directly to fuelling stations (or factories) or via national gas infrastructure	Centralized high capacity connection to fuelling stations only via national gas infrastructure
Gas delivery to Superwind site	Gas is mainly transported directly from fermentation plants to distribution points or storage. Via national gas infrastructure is also performed but at a smaller scale	Gas is transported only via national gas infrastructure to distribution points or storage
Initial stakeholders	Small to medium scale private actors	Large scale private actors
Superwind financing	Superwind operators can invest themselves or lease a Superwind installation from utility companies	The Superwind plant is a mutual investment of government and utility companies.

4.5 The backcasting analysis

The scenarios differ in the setup of the Superwind installations. The decentralized method is used to compensate wind energy fluctuations before the power enters the electricity grid and the centralized method is used to compensate the fluctuations on the electrical grid. Therefore each scenario has its own impact on the stakeholder involvement, the time frame of development, finance, infrastructure, scale, and competing technologies.

On the other hand, the reference scenario and several exogenous factors are equal. Therefore some necessary changes in scenario A and B are equal. With this in mind the necessary changes are sketched for both scenarios in section 4.5.1, the actions that are needed to accomplish these changes are described in section 4.5.2, and finally in section 4.5.3 the actions and changes are translated in milestones per decade up to 2050.

4.5.1 The necessary changes for scenario A and B

The changes that apply to A and B are discussed first and then followed by a comparison between the A and B for each of the following levels: technological, cultural and social, structural, institutional, and financial.



Changes at the technological level

Radical change of electrical infrastructure to prepare for an increase in the share of fluctuating power sources.

The energy infrastructure is still mainly based on fossil fuel technologies. The technology has matured and offers reliable and low cost electricity. With new fluctuating power sources such as wind power and decentralized systems such as CHP problems occur, because the infrastructure is not designed to handle these systems.

The Netherlands needs radically change the infrastructure to implement more sustainable power systems. The smart-meters proposed by the Dutch utility companies are a first step but is merely a short-term solution.

The 'upgrade' of the electrical infrastructure does not only benefit the implementation of sustainable and renewable power sources, but also the connectivity between the Dutch national electricity grid and other national grids. The improvement of the Dutch network will contribute strongly to the 2050 goals in which the Netherlands has a 60% share of renewables in the electricity production mix and is an energy exporting country.

Small Dutch utility companies become part of larger European utility companies.

A small number of companies but large in size affects the development rate of an innovation. It is released quicker to the market. The problem with smaller companies is that a lot of companies perform their own research and development but it often remains at a small scale because of the large uncertainty about a future standard. The larger companies have more resources at their disposal. With a handful of large companies sharing the electricity market and having stakes in most of the European countries a decision for technology standard is likely to be reached quicker. However, this is only true when the European net manager puts pressure on the companies.

Investment in the gas infrastructure for the development of a hydrogen infrastructure.

To reach the 2050 goal of a 100% wind energy to be compensated by Superwind systems an infrastructure capable of working with hydrogen and biogas is a must.

The Netherlands has a good knowledge-base of gas technology, but investment is needed. Groningen is opting to become the 'central gas node' of Europe. However, with a rapid decrease of the Dutch gas supply, new innovations are needed. For instance, a short term plan is to invest in more efficient technology. But if Groningen wants to hold its position it should determine a policy to develop their long-term dominance. For this reason investments in the development of a biogas and hydrogen infrastructure should become a point at the top of its agenda.

An important development for the Superwind diffusion is that experiments for the transport and storage of hydrogen are commenced. Also, the intermixing of natural gas, biogas, and hydrogen is an important point. These developments will save the gas related companies from being stuck with a redundant gas infrastructure in the future.

Currently some experiments to the effects of hydrogen transport in regular gas pipes are investigated. Unfortunately, these tests seem to remain small scale.

At the end of the gas infrastructure access point for vehicles will indirectly advance the quick dissemination of the Superwind technology.

**Choosing hydrogen as the standard fuel.**

In addition to the previous change described above the standardisation of hydrogen as transport fuel will induce the development of a hydrogen infrastructure. The standardisation should also include product quality and safety for hydrogen technology. For instance, the quality of hydrogen and the coupling device respectively.

Choosing Superwind as the standard biogas power generation.

The Superwind technology is chosen as the standard for gas conversion. This is important for the achievement of the 100% goals for compensating wind fluctuations or 100% of the grid imbalances in the scenarios.

The development of hydrogen technology

In both scenarios hydrogen is sold. In the socio-technical map Superwind is discussed as a stimulant for the development of a hydrogen infrastructure in the Netherlands. But for the wider diffusion of Superwind that development should already be at certain technological level. Superwind may be able to deliver hydrogen, but without transport technology for hydrogen it can not grow.

Several changes mentioned above for the technological level are different for the scenarios.

The first change discusses a radical change in electrical infrastructure is for scenario A more important than scenario B. The importance for Superwind to upgrade the electrical grid is that the current electrical grid is not able to cope with the large diffusion of decentralized Superwind systems. For a centralized system, however, the electrical infrastructure does not need a radical change. A centralized system merely replaces the current and less efficient spinning reserve.

The third change is about the development of a hydrogen infrastructure. This is for both scenarios a necessary change, however, the timeframe is different for each scenario. With a decentralized diffusion the Superwind installations can be built in the vicinity of a fermentation plant and/or a fuel distribution point. The piping needed to transport hydrogen can be separate from the gas infrastructure. It is only in a later stage where the wider diffusion and standardization of Superwind needs connectivity to a large physical infrastructure. In comparison, a centralized system needs to be connected to a central node in gas infrastructure almost from the beginning. Or, a separate extensive hydrogen infrastructure is to be constructed. By using the, already developed, gas infrastructure as its source-and-product transport this can be avoided.

The fourth and fifth change discusses the choice of a standard. For both scenarios it is important that industry and government accept hydrogen as the transport fuel of the future. It will improve the rate of fuel cell technology and with it Superwind. In the explanation of the Superwind technology in the third chapter of this report the Superwind is said to be the catalyst for the development of a hydrogen infrastructure. This true for in the beginning of the exploitation of Superwind technology. Later on the wider diffusion of Superwind will depend on the hydrogen infrastructure's rate of development.

For scenario A the Superwind technology should be preferred above other technologies at the wind fluctuating technology. For scenario B the Superwind technology should be chosen as the standard for power reserve method in order to reach the goal of scenario B.



The structural level

The development hydrogen technology will bring about structural changes.

A hydrogen infrastructure can only be accomplished if hydrogen technology such as storage and transport is developed.

The development of a hydrogen infrastructure will require new industry and complementary technology. For example, for the intermixing of hydrogen with gas in the national gas infrastructure separation technology is needed.

The car industry also needs to structurally change. Its value chain will adjust to hydrogen technology (Quist and Hemmes 2008).

Changes at the cultural and social level

A greater acceptance of wind turbines.

The scenario also describes that 21 GW of installed wind power is constructed in the Netherlands. This development is hampered by resistance of the public. Although the public agrees that wind power delivers clean power, the 'not-in-my-backyard-syndrome' appears quickly when a location for wind turbine is appointed. Environmental organisations appreciate sustainability, but do not favour the wind turbine. Disfigurement of the landscape or birds that might get caught by the wind turbine blades are mentioned as the reasons for protest. The resistance delays allocation of areas for wind parks.

Improve public understanding of fuel cell technology.

A condition for the expansion of Superwind is public awareness. A fuel cell, until now, is to most people unknown technology. A demand needs to be created. Not just the MCFC as an efficient electricity generator, but also PEM, which is used for the development of hydrogen car.

With the construction of any hydrogen system safety is an important issue. The public feels that hydrogen tanks pose a danger. To reduce public resistance the understanding of the technology should be improved.

The cultural changes apply to scenario A and B. The first requirement is about the rapid diffusion of wind turbines. This is only necessary if the exogenous goal of 21 GW is to be reached. The goal of scenario A was to level a 100% of the wind power fluctuations. If the amount of wind power is lower than 21 GW it would not effect the goal of the scenario. On the other hand, one could argue that the rapid increase of fluctuating power sources will increase the demand for a solution.

The institutional level

Government is to take up a leadership role in the energy discussion.

At the institutional level the Dutch government needs take more responsibility and a stronger leader-role in the debate on how to achieve the 2020 goals. There is a need for a short and a long-term vision which can be used as a directive for industry, commerce, and policy makers. This vision must contain concrete steps for reaching a particular milestone.

For now, VROM has described in what manner the Dutch government will achieve the energy and emission goals for 2020. These goals have been taken into account for the report of ECN and the vision on Superwind. However, in the long term it decided that the contents of the energy mix will be decided by market parties. This could mean that radical energy innovations will not be likely to be explored by industry because of their uncertain returns.



The government and industry should agree to a standard for energy in different areas, such as the chemical sector, the transport sector, the domestic sector, etc. To Superwind setting hydrogen as the next carrier fuel is the most beneficial.

A request for government leadership also comes from net managers who fear a failure of Dutch electrical infrastructure due to a large increase in connections to sustainable power sources. The net managers are open to sustainable power generation, but say the infrastructure needs drastic restructuring (Damveld 2008). To accomplish that, the government should take a leading role. Public-private co-operation (the government and utility companies) is necessary to ensure an increase in the capacity of the gas –and electric infrastructure in the Netherlands. This needs to be done short-term to be able to allow all sustainable power sources to connect.

Government should pursue a long-term strategy.

Furthermore, it seems that the government is mainly focused on systems that are currently effective at sustaining the environment, but in the long-term are not really sustainable. A CO₂-capture device is seen as a good solution to resolve the issue of greenhouse gasses. However, this technology is far from a sustainable solution.

For Superwind this means, although it is dependent on installations such wind turbines and biomass which are two favoured sustainable energy systems, the Dutch government is not investing enough in radical innovations that might provide a long-term solution.

Utility companies are willing to invest in sustainability, but the Dutch policy on sustainability is not reliable enough. Investors fear that a sound investment in, for instance, wind farms, would become a financial failure the next year because of sudden decision at a political level (Hulscher 2009).

Reduce the bureaucracy to reach energy targets.

The time period for allocating funds and areas for innovations is hampered by an inefficient workflow. Before an permit is issued the plans for a wind park have to be approved by seven government bodies (Stichting Natuur en Milieu 2008). It is expected that for the installation of a Superwind setup the decision process is the same.

However, the possibilities to find support for the build of a Superwind installation or any new innovative system in the Netherlands have improved dramatically the last years. Due to institutes that promote public-private cooperation the government increased the number of innovations and accelerated the process from innovation to market introduction. More subsidy is made available to support specifically sustainable technology.

Regulations are to include hydrogen technology.

The government is responsible for adjusting the policy to new technologies (Quist and Hemmes 2008).

These changes apply to A and B.

Finance

The Dutch government should apply a more active subsidy policy to motivate energy providers to invest in sustainable power generation and innovation.

The Dutch government has to invest more to achieve the 2020 energy and emission goals. Not only, financially, but also manage the development in the energy sector. The report "Schoon



en Zuinig" states that the 2020 goal for a 20% share of sustainable energy in the total energy mix is achieved with biomass, wind power, decentralized co-generation, and investing highly in solar power development. To promote these types of power generators the government provides subsidies and in 2009 will put forward a priority-law.

The Dutch government should maintain and increase the levies dependent on environmental impact.

Currently, taxes are imposed on energy consumption (fuel and electricity) by public and industry and fines are imposed to the industry if certain levels of toxic emissions are breached. This form of active steering should be maintained. Other penalty tools can be charging vehicles per kilometres driven to reduce the use of that vehicle. This policy is not yet implemented in the Netherlands although it has been on the drawing board for many years. The use of this 'penalty' tools increase the rate of sustainable innovations.

Both changes apply to scenario A and B.

4.5.2 The actions to accomplish the necessary changes

To achieve the changes several players are to be actively involved; government, industry, utility companies, net managers, and knowledge institutes.

Government is to become more active in steering the direction of sustainable innovation developments. The industry sector and knowledge sector have invited to do so but the government is reluctant to comply. These sector should impose more pressure. Leadership role is beneficial to these actors because it will increase the certainty for innovation developments. In turn, this will lead to a faster development of sustainable innovations.

The Dutch government can be a leader by providing a short and long term strategy. The long term provides guidance for industry which can be used as a guide for industry and knowledge institutes. Although they have published several policy reports the execution of the policies is lacking (Stichting Natuur en Milieu 2008). The short-term strategy is important for the government to understand if they are reaching the 2020 targets. The policy should have specific goals for each year. Those one-year goals are to be evaluated at the end of the year. The one year evaluation provides feedback why certain targets are not met. Active steering is imposed in those areas that did not reach their target. The strategies include preferred and standard technologies, finance, and the governmental functioning.

In conjunction with the government the industry is to decide upon matters concerning the standardisation of hydrogen and its technology. In addition, Superwind is chosen as the new standard for gas conversion because it offers an extra impulse for fuel cell knowledge base.

In line with the Superwind standard the Dutch government is to create a niche by subsidizing the development of Superwind. For the development of this technology utility companies are involved at an early stage with the development of the technology and the government services provide assistance in the development of the Superwind technology.

Alliances are to be formed between car manufacturers, utility companies, and governments to develop a hydrogen based transport sector. Utility companies and governments install the hydrogen pumps. Car manufacturers decide upon a standard for product quality and product connectivity. Example: every gas station erected is mandatory to have one hydrogen pump.



The European Union is to erect a single European coordinator for the development of the European electricity infrastructure. This European energy coordinator coordinates the European Union's sustainable policy implementation, in charge of European subsidies for energy projects, in charge of balancing European grid. The Dutch utility companies become part of larger European utility companies.

4.5.3 The milestones for scenario A and B

In this section the transformation into the 2050 scenario is described. The transition path is described per time frame; 2009-2015, 2015-2020, 2020-2030, 2030-2040, and 2050. Each time frame will discuss the developments according to the aspects used in the description of the 'necessary changes' and 'necessary actions' in the previous sections. Because scenario A and B have a number of similarities for each milestone towards 2050 each aspect will first describe the development is equal to both scenarios and if there is a different step between for each scenario that will be described.

2009-2015: The experimental phase

Superwind

In this time frame the first Superwind pilot project is constructed. The setup requires a connection to a gas supply and hydrogen pump or storage device. From the storage device trucks service as delivery method to other locations among which gas stations and industry.

The technological level

Wind turbine technology is focused on the increase of the wind turbine life time. This is mainly done by material and aerodynamics research.

Fuel cell technology developments are made in materials. The improvement of materials brings advantages such as the reduction of product costs, the increase in power density, increase of life time of a fuel cell.

Carbon Capture and Storage (CCS) is still in its infancy. The government invest heavily in this technology because it is expected that the use of fossil fuels will be around for a long time. Therefore CO₂ is to be captured to buy some time.

Reduction of the methane production of farms due to cows is becoming a hot topic. Methane is 20 times more harmful than CO₂ (NOS 2009). Experiments are performed on methane capture at farms.

The structural level

The Dutch energy production is rapidly increasing. This is, for the most part, caused by a strong increase in sustainable and renewable power sources. Off-shore wind energy is also starting to grow as the Dutch government is allocating location in the North-Sea for wind farms. The production of fossil fuels remains growing at a steady pace.



The electricity sector is based on the fossil power sources. A priority rule for sustainable and renewable power sources is in effect but in practice this causes net congestion. The net is not able to handle the increase of such power sources. Therefore several developments for infrastructure are in progress; The electricity sector is working on the development of the smart grid which would make integration of intermittent power sources less difficult. This is needed because of the large increase of energy supply that is expected and with it the need for a large buffer.

The method of spinning reserve is still used in this time frame, but under pressure of the public and the Dutch governmental policy the utility companies are forced to look for new sustainable methods. Several energy storage methods are tested to balance supply and demand on the electricity grid among which hydrogen storage.

The electricity segments (distribution, power generation and billing) is split up completely in 2011. Foreign utility companies have taken a large interest in the Dutch utility companies. Part of the sales agreement for electricity segments is the promise that the new owner will pursue the sustainability wishes of the Dutch government and shareholders.

Hydrogen development in the Netherlands is moving slow. There are some test performed on the transport of hydrogen. Some tests have been performed by fleet owners of public transport. However, no follow-up projects have been organized. The problem still lies within the uncertainty in the future fuel. It cost a lot of energy to create hydrogen and the technology for hydrogen such as conversion, transport and storage have not matured yet. There are some fuel cell passenger cars available but due to a lack of any hydrogen infrastructure those cars will not be available in the Netherlands. The only hydrogen infrastructure is for industrial use in Rotterdam. There are plans from corporations to first start the construction of several hydrogen pumps in Rotterdam. However, the city of Arnhem expects to be the first city with a hydrogen pump for commercial use.

Fuel cell technology is getting more attention, but this is mostly for the PEMFC. This is because the PEMFC is interesting for cars. High temperature fuel cell technology is still in its infancy. There are tests performed, but the high operating temperature brings with it higher costs. The high temperature requires more expansive temperature resistant materials.

Due to the interest of many countries in wind energy the scale of turbine production is increasing. Furthermore, the wind turbines are increasing in power capacity. The first tests with wind turbines with a production capacity of more than 5 MW are performed. This might mean less wind turbines need to be built to fulfil the energy demand, but these wind turbines also need windy areas to turn the blades. Because of the Netherlands is densely populated and large wind turbines' need for strong windy areas more wind farms will be build in the North-sea.

The car industry is introducing new technologies: bio-fuel car, electric car, and hydrogen car technology. Subsidies are available for those who want to buy one of these new technologies. Alliances are formed between car manufacturers, utility companies, and cities or provinces to build an infrastructure. The alliances also decide upon technology standards. For instance, the connector between the hydrogen fuel pump and the car.



The cultural and social level

The public is aware of the problems that are created by the current oil based infrastructure because of all the media attention and the government's actions to push the public to reducing their energy consumption. Society is willing to make the transition towards a sustainable way of life if proper sustainable alternatives are available. In this case proper is often seen by the public as reliable and low cost solutions.

Environmental organisations are included in the decision-making process for wind farm and solar farm allocation at an early stage to prevent resistance in the end.

The institutional level

The promotion by the government for a more sustainable way of life is still very active. With an increasing energy prices due to tax and the subsidies on sustainable power generation the government hopes to motivate electricity companies and industry to reduce their energy consumption.

The number of Public-Private co-operations is increasing due to an increase in government subsidy and an increase in efficiency. The latter contributes to reduced waiting period for permits and subsidies. Furthermore, sustainable solutions are getting a priority-treatment. The efficiency is reached by allowing the government services more decisive power. Within the services several experts of the key government bodies are seated.

Government accepts leadership-role and is working on developing a policy and guide for sustainable innovations that contains concrete and specific targets and goals.

Finance

The government finds it vital that innovations in the area of sustainability are stimulated. The investment in sustainability does not only help the Netherlands improve their environment but will also be an strong impulse for the economy. The government feels that the Netherlands will loose it place in the market if it does not keep increasing its knowledge base. It is using the strong knowledge base in the Netherlands as the foundation for further development in the area of sustainability it has now and build upon it to become a frontier in sustainable energy solutions.

However, until now the expansion in sustainable power generation was still very slow compared to other European countries. The utility companies were still a bit reluctant to invest because the government does not offer long term security for new technologies.

Due to pressure from utility companies and the European Union, the Dutch government decided that more budget is made available and a new long term policy is developed.

The stakeholder level

A committee in which an utility company (electricity and gas), regional or local authority, net manager, TU Delft, wind turbine owners, Tennet, and a fuel cell manufacturer reside agree to construct an Superwind pilot project . The committee will be in charge of all matters concerning the setup and development of Superwind. The group starts the realisation of the pilot project for Superwind in 2009 and its construction finishes in 2011.



Scenario A:

The aim of the technology is compensating wind fluctuations. In this stage the testing facility and experimentation focuses on that aim. Therefore the initial actor network for Superwind contains players that pursue that same goal. The pilot project is connected to a 600 KW wind turbine, a gas supply, and a hydrogen storage or distribution device. Due to the decentralized nature of this setup it is chosen to use biogas from a nearby fermentation plant. At the core of the Superwind technology a 250 KW IR-MCFC is placed which produces about 2,2 GWh/year of electricity and around 0,9 GWh/year of hydrogen. This means that the electricity production is enough for 660 households and the hydrogen production is enough for 168 hydrogen cars.

Scenario B:

The aim of the technology is compensating grid fluctuations by acting as power reserve. The initial actor network for Superwind contains power companies, net managers and gas companies. In comparison with scenario A the development of the gas infrastructure needs to commence almost from the beginning to provide the testing facility the chance to upscale.

The experiment is coupled to the electrical grid. Its hydrogen output is stored or connected to a distribution point. The gas input comes from the national gas grid.

The size of the setup is equal to the setup in scenario A: one fuel cell of 250 KW connected to a power plant. No wind turbine is connected. The system be first tested to answer the 8 hour in advance request by Tennet. The demand for spinning reserve in the Netherlands is around 1,6 GW and is increasing towards 1,7 GW in 2015

2015-2020: Upscaling the experiment

Superwind

The Superwind experiment booked success and more actors are involved with the expansion of Superwind. The technology is used in combination with other projects and systems. Within this time frame the technology is growing within a protected niche. The technology is not able to compete yet with incumbent technologies without subsidies.

Scenario A:

More decentralized Superwind are constructed. The sites still operate disconnected from a large hydrogen infrastructure. Delivery is performed by direct connection to a gas station or by truck delivery. The setup designs remain in principle the same. Some sites operate on a different sort of gas then biogas or used in a different setting. This only contributes to perfecting the Superwind technology.

The active campaigning and extra budget by the government for the expansion of the hydrogen infrastructure the demand for Superwind is rising fast. The total amount of fuel cell capacity integrated within Superwind sites is 50MW. This is able to cover 2% of the installed wind turbine capacity.

Scenario B:

Plans to construct a central power plant are designed. The Superwind plant is, at first, to act as the power reserve for electricity requested with a 8 hour start up time. The plant capacity covers 5% of the total power reserve. The power reserve will only cover a minor portion of the request for 8 hour power reserve because the initial plant capacity is low. This is done because incumbent energy providers are partly dependent on the income of their spinning



reserve. The technological reason is an expectance of improvements in high temperature fuel cell developments and the partnership is waiting for that to occur. Furthermore, it reduces the initial capital investment and the large investment that accompanies the replacement of all fuel cells at once when they reach the end of their lifetime. Therefore the plant has a modular design which makes it able to expand capacity easily.

Hydrogen is pumped into a hydrogen storage and if possible a nearby pumping station. Because a hydrogen infrastructure is not completely developed most hydrogen is delivered to gas stations by trucks. The plant is connected to the national gas grid to ensure a high quality gas and reliable flow.

The technological level

Wind turbine technology is focused on material improvement. The wind turbine power capacity is reaching its maximum. An further increase in power capacity would require a further increase in hub height and rotor size. Such a turbine will require wind conditions that cannot be met under normal circumstances.

Fuel cell technology developments are made in materials. The improvement of materials brings advantages such as the reduction of product costs and the increase in power density of a fuel cell.

The first coal power plants are connected to CCS. The first experiments are promising. Research on biomass plants is ongoing.

The interest in methane capture has induced the development of new capture devices. Improvements are made in capture efficiency.

The cultural and social level

‘Being green oriented’ is starting to loose the notion of hype that it had in the first decade of this century. Society is starting to recognize sustainability as common sense, environmentally and economically.

The structural level

The electricity sector has tested the smart grid and is now equipping more and more consumers with a smart meter. These meters have made it easier for the system operator to maintain a balance in the net and prevent net congestion. With an increase in share of intermittent power sources the difficulty remains with net balancing. The renewable power systems such as solar and wind power need more space than conventional coal power plants. This has steered the development of such systems towards on-sea and urban area applications. All Dutch utility companies are now part of an European group of utility companies. This has increased the connectivity between different areas of energy supply. Fluctuating power sources are interconnected.

More biomass plants that run on organic waste from surrounding farms. Most of the plants still apply a gas turbine to generate electricity, but because of subsidisation the government makes the use of an IR-MCFC interesting.



The alliances with car manufacturers and utility companies are working to expand the possibilities of a hydrogen-based transport infrastructure. Car manufacturers invest in hydrogen technology together with the Dutch government. In other countries in Europe more alliances are formed to promote the European hydrogen infrastructure. The alliances reduce market uncertainty for hydrogen products and create an impulse for the European hydrogen technology knowledge-base.

The hydrogen research has helped in decreasing the costs of fuel cells, improved hydrogen storage devices and transport. The decrease of fuel cell costs has resulted in lower prices for fuel cell cars. In 2015 the Dutch government started to expand its hydrogen infrastructure in preparation of the announced '100.000 fuel cells'-program in 2020. More hydrogen cars are appearing in the Netherlands. However, the hydrogen car is still too expensive compared to conventional cars or bio-fuel powered cars. The first public transport companies are replacing the petrol busses with hydrogen busses. City vehicles drive either on a battery or a fuel cell (ECN scenario).

In expectance of the hydrogen infrastructure companies are directing more research to R&D.

More car manufacturers are experimenting with hydrogen cars.

More companies are appearing on the market that offer hydrogen technology and complimentary technology.

The institutional level

The Dutch government sees that the 2020 deadline is close and is increasing the governmental support for sustainability. With increasing energy prices due to tax and subsidies on sustainable power generation the government hopes to motivate electricity companies and industry to further reduce their energy consumption.

The leadership-role of the government has persuaded more companies to enter the market for sustainable technologies. Therefore the government is continuing its active participation. An example is setting the specific targets such as the '500 hydrogen pumps' to prepare a hydrogen infrastructure for the '100.000 fuel cell cars' (ECN scenario).

The financial level

Extra investments are made by the government in the development of a hydrogen infrastructure and wind turbines.

Government is offering long-term subsidizing for sustainable techniques that are expected to be profitable in the future.

Scenario A:

The projects are still protected by the relevant companies. Also, part of the investment is funded by government bodies. However, the combination of biogas and a the large scale of implementation of wind turbine a cross-subsidization is taking place.

Scenario B:

The power plant cannot compete financially yet with standard spinning reserve. Therefore subsidizing is still needed for the Superwind plant. Finance comes from government which is paying for the unprofitable part of the plant operations. By subsidizing the project the government wants to offer utility companies financial security. The end goal of the government is to stimulate fuel cell research which eventually will provide less oil dependence and less greenhouse emissions.



The stakeholder level

The technology has been proven in its single experimental setup. More actors are getting involved to construct new Superwind projects or join in new experiments. The government's clear interest in hydrogen technology has helped to increase the actor network.

Scenario A:

The consortium is still active. The actor network for the Superwind technology is growing rapidly. Interest is coming from utility companies and industry. Utility companies recognize a new energy source which can be tapped into. Chemical industry is interested because of its hydrogen. More biogas suppliers in the Netherlands are attracted to Superwind projects.

Scenario B:

The construction of a plant has a large impact on utility companies who see a source of income, spinning reserve, becoming redundant. That is why the utility companies are involved in the early stages. Further more gas utility companies are also involved. If the plants is to expand any further, the development of a large hydrogen infrastructure is a must.

2020-2030: Wide diffusion of Superwind technology

Superwind

The Superwind technology is taking off. This is because of several reasons. The first is the rapid increase of renewable power sources which increases the demand for solutions to reduce grid imbalance. The second is that the government is favouring hydrogen technology. A third reason that the costs of fuel cell cars are reaching break-even point. Hydrogen cars are becoming a viable alternative to petrol cars due to government subsidies. Superwind is starting to move towards market introduction.

The technological level

Wind turbine technology is becoming a routine technology. Only incremental innovations are made.

The research and development of fuel cell technology developments are reaching the take-off phase as its costs are reduced while the oil price increases.

CCS research is ongoing. More fossil fuel power plants and factories are connected to CCS systems.

Methane capturing is obligatory for livestock farms. The methane is used to generate heat and power for nearby residential areas.

The structural level

The mix of Dutch energy production is still rapidly growing. The share of sustainable and renewable energy production is passing 50%. Coal intermixed with biomass and nuclear energy make up for remaining part of energy production. The CO₂ is captured and stored underground.



The first large scale testing with hydrogen intermixed into the gas infrastructure commences. The hydrogen infrastructure will make it possible for many gas stations to deliver besides the regular fossil fuels, also hydrogen.

The further expansion of the hydrogen infrastructure for commercial use and reduction of fuel cell costs have attracted an early majority of adaptors. More fuel cell cars are bought and public transport companies have almost replaced each of their vehicle with a hydrogen powered one.

The value chain and value system of companies start to adjust to fuel cell technologies.

Scenario A:

Some of the decentralized setups which were directly connected to a storage device of gas stations are now able to connect their storage device of Superwind system to the national gas infrastructure. Trucks are still used at areas where a connection to the gas infrastructure is not possible. The total energy production of Superwind installations provides electrical power to over 2,6 million households and hydrogen is available for almost 700.000 cars.

In this time frame the hydrogen car gains popularity and by the end of this time frame about 750.000 hydrogen passenger cars are bought. The Superwind installations together cover around 25% of the wind turbine capacity.

Scenario B:

The intermixing of hydrogen with the gas infrastructure has made it possible for the large plant to supply directly to all gas stations. Truck delivery for hydrogen is becoming redundant. The plant capacity has increased up to 10% coverage of power reserve which is about 200MW.

The cultural and social level

The aspect of sustainability is integrated in society. Companies that design new products, processes, or services do this with great eye for sustainability. This is caused by the public attitude towards sustainable design. The political pressure to change towards a more sustainable way of life is still felt due to many implementations of energy policies that include maximum consumption and emissions levels, energy tax, etc.

Public is acquainted with fuel cell technology and especially hydrogen cars.

The institutional level

Active steering by the government is still maintained. The government launches its '100.000 fuel cell cars' campaign (ECN scenario). Its efforts in renewable power generation have increased the share of renewable and sustainable energy in the total Dutch energy mix significantly up to 60%.

The hype of sustainability is passed away. Sustainability is now a standard item on the agenda of politics.

European and global agreements about the hydrogen infrastructure are made.

European agreements about the electricity infrastructure are made.

The takeover of Dutch utility companies by foreign companies which operate at an European level put power on the European agenda. To coordinate the European electricity grid a central European system operating agency is founded.



The sustainable targets for 2050 are adjusted by the European Union and in turn by the Dutch government.

The financial level

The financial protection for Superwind technology is still active, but due to developments in fuel cell technology reduced.

Scenario A:

The Superwind installations are subsidized.

The installations are leased for several years by manufacturers or utility companies.

Scenario B:

The IR-MCFC plant is subsidized by feed in-tariff. This means that the more they are used as power reserve the more subsidy is given by the government which takes care of the unprofitable part of using an IR-MCFC power plant

The stakeholder level

Scenario A:

The Superwind technology is increasing in popularity. Therefore more companies enter the market offering a similar product. The initial consortium has transformed in a company.

Scenario B:

The stakeholders that participated with the construction of the power reserve plant are still committed to the use of this technology. Tennet offers the stakeholders enough advantages to participate in the project..

2030-2040: Superwind technology becomes institutionalized

Superwind

Scenario A:

Superwind is now attached to 43% of all wind turbines. The total amount of Superwind installed capacity is almost 5 GW. This has provided ample electricity and hydrogen. The production of electricity reaches 18 TWh/year which is enough to provide 5,3 million houses with power. This contribution to the energy mix has turned the Netherlands into a energy exporting country.

Scenario B:

The technology has matured enough to be used as a reliable source for power reserve. The technology outperforms other gas conversion techniques due to its higher efficiency. The demand for spinning reserve has increased up to 0,6 GW. The IR-MCFC plant now covers 25% of that amount.

The technology is still used as 8 hour reserve, but as the technology starts to reach maturity it is also tested for the short-term (15 minutes) power reserve demand.



The technological level

Wind turbine technology is responsible for the largest share of renewable power in the Dutch energy mix. Due to the large scale the costs of wind turbines has reduced significantly.

Due to the decrease of fuel cell costs and the increase of oil and gas prices the break-even-point between petrol cars and fuel cell cars is reached (ECN scenario). The fuel cell innovation's development has entered the acceleration phase.

The fuel cell capabilities to compensate rapid fluctuations is improving. This increases its market applications.

All fossil fuel power plants are connected to CCS systems and newly constructed factories are obligated to integrate a CCS system. Research is focused on reducing the energy consumption of CCS systems. New innovations in CCS enable it to capture more greenhouse emissions.

Methane capturing is fully integrated within farms and are a common source of income for farms.

The structural level

The energy production increases. The percentage of renewable and sustainable energy falls to a share in the energy production mix of 55%. This has occurred due to the strong increase in fossil fuel production to meet the global energy demand.

The electrical infrastructure is ready to meet with the governments ambition for further increase of renewable power sources.

The gas infrastructure is fully upgraded. Different types of gas are transported over the Dutch gas infrastructure. Fuelling stations all possess the separation systems to extract methane containing gas and hydrogen from the gas infrastructure. Of all passenger cars 10% are hydrogen vehicles and within this time frame it grows up tot 20%.

The supply chain of car manufacturers are now focused on the production of sustainable cars. Many companies have entered the market of sustainable technologies to deliver complementary technologies.

Scenario A:

The decentralized Superwind installations are compensating wind capacity and has reduced the fluctuations on the grid significantly. The installations are connected to hydrogen distribution points, the Dutch gas infrastructure or both.

Scenario B:

The Superwind power reserve plant is the primary balancing system. The power plant is fully connected the electricity grid and the gas infrastructure.

The cultural and social level

Sustainability is fully institutionalized within the culture.
The use of hydrogen technology is part of every day life.



The institutional level

The government is steering sustainable developments to ensure the achievement of the goals for 2050; 60% reduction of greenhouse emissions compared to the 1990 level and 60% of total energy production by renewable and sustainable systems.

The financial level

Sustainable technologies such as wind turbines, biomass, and some fuel cell types are no longer subsidized. The technologies have reached economies of scale.

The innovation policy is still active to reach the 2050 targets. This include tax on less energy efficient technologies such as bio-fuel cars.

Scenario A:

Small and medium scale investors of Superwind are still subsidised if needed.

Scenario B:

The exploitation of the Superwind power reserve plant is not subsidised. The financial construction of the power reserve plant is starting to become profitable.

The stakeholder level

The government is actively steering to reach the 2050 goals.

Utility companies and research institutes are working strongly together to improve energy technology.

Scenario A:

The Superwind technology is a common good. Several companies are setting up Superwind installations. Utility companies mostly lease the installations to private parties. The largest setups are owned by net managers or utility companies.

Scenario B:

The Superwind central power reserve is fully recognized as the future power reserve technology.

2040-2050: Superwind; the logical choice for balancing fluctuations!

Superwind

The Superwind technology is mature. It is capable of fluently following fluctuations. Therefore the technology can be utilised constantly. This enables it to act upon market demand and owners are able to set the technology to optimize their profit.

Scenario A:

The installed capacity of Superwind installations is 4,5 GW. This covers 67% of all wind turbine in the Netherlands.



The total electricity production of all Superwind installations is in 2040 40 TWh/year. This is enough for 11,9 million households. (The expected amount of households in the Netherlands in 2040 is 8,6 million (CBS 2007)). The remaining amount is exported.

The total hydrogen production of Superwind installations in the Netherlands amounts to 16 TWh/year. That powers 30 million hydrogen vehicles. The expected number of hydrogen passenger cars is 3,8 million. The larger part of hydrogen is exported, used in chemical processes, or used for heating purposes.

Scenario B:

The Superwind plant has a capacity of 1,3 GW which is 50% of the total demand for power reserve in the Netherlands.

The technological level

Wind turbine technology responsible for the largest share of renewable power in the Dutch energy mix. Due to the large scale the costs of wind turbines has reduced significantly.

Due to the decrease of fuel cell costs and the increase of oil and gas prices the break-even-point between petrol cars and fuel cell cars is reached (ECN scenario).

The fuel cell innovation's development is in the acceleration phase. Most fuel cell costs are capable of competing with incumbent technologies.

The cultural and social level

At the cultural level a sustainable lifestyle is integrated. People are conscious about the energy consumption and waste.

Wind turbine technology is institutionalised into culture and society.

Fossil fuels are still used in Dutch society, but the government is developing a policy to phase-out petrol cars (ECN scenario).

The structural level

The share of renewable and sustainable energy production has reached the 57 % and it is likely that the government's target of 60% by 2050 will be reached. The total installed energy production of the Netherlands is 73 GW while the energy demand requires a mere installed capacity of 56 GW.

Of all passenger cars more than 20 % are hydrogen vehicles and within this time frame it grows to 50%.

The electricity and hydrogen infrastructure are maturing fast. Obsolete infrastructures are replaced with new systems that will connect to the future sustainable systems.

The car manufacturers are focusing on the production of hydrogen cars. The production of bio-fuel for transport purposes is still active, but it is mostly used for sports cars, heavy machines, and aerospace.



The institutional level

The government is enforcing a policy to phase out petrol (ECN scenario). This will help the environment, but also reduce the dependence on oil exporting countries will be reduced significantly.

Government wants to reach 60%-60% goals for 2050; 60% reduction in greenhouse emissions and 60% share of renewable power in the energy production mix.

The financial level

Superwind is able to fight of incumbent technologies and the protection is released.

The Superwind systems in scenarios A and B are profitable.

4.6 Discussion

The discussion will consists of a comparison between the two scenarios and is followed by deciding what scenario is more likely to happen.

4.6.1 A comparison between scenario A and scenario B

Both scenarios accomplish the same goals; Balancing power fluctuations and providing hydrogen to commercial transport. They differ in how they achieve this. In scenario A the launch concept is used for the technology diffusion while in scenario B a power reserve plant is used for the technology diffusion.

At the technological level in scenario A Superwind installations compensate fluctuations for wind turbines. The target for 2050 is to compensate for 21 GW of installed wind power which is expected to be constructed in the Netherlands. To accomplish this at the current state of technology it would require 8,75 GW of fuel capacity.

In scenario B Superwind is used as the power reserve to compensate imbalances on the grid. The target for 2050 is to have a power reserve capacity of almost 3 GW.

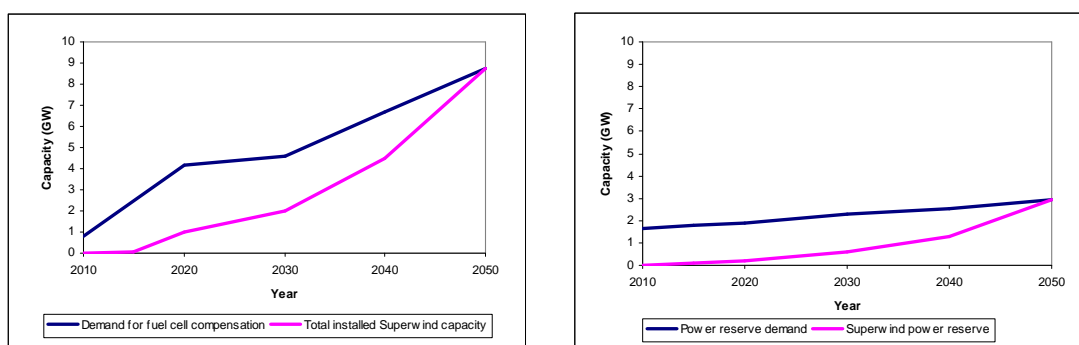


Figure 4-3 Left: Scenario A. Right: The necessary Superwind installed capacity to compensate 100% of the wind turbine power and the actual installed Superwind capacity. Scenario B. The necessary installed capacity for power reserve and the Superwind capacity for power reserve.

Both scenarios started with a small test facility containing one fuel cell of 250 KW cell. After a testing period the installed capacity of A increases rapidly compared to B. Of course, that is



because the end goal of scenario A is much higher and in order to reach that goal within the same timeframe a steeper inclination in capacity can be expected (Figure 4-3). But the difference in inclination might also be attributed to knowledge diffusion. Suppose that for scenario each increase in capacity means an extra installation which in turn means new stakeholders join the exploration of technology then it can be stated that knowledge diffusion in A is much higher than in B. This is logical if it is assumed that with a single power plant the technology is much more likely to stay behind close doors and thus within a small network.

That brings us to another difference between the two scenarios; stakeholder participation. For the construction of the setup both scenarios have a partnership that supports the technology. The difference, however, lies within the type of stakeholders. In scenario A the stakeholders are of all kinds of business backgrounds and have their own interest. In scenario B the stakeholders Tennet are net managers and utility companies.

The actors carrier group in A participate on a voluntary basis whereas the actors in B are obliged to participate. The centralized setup of B the companies that maintain the Dutch gas infrastructure need to be much earlier involved with the project than in A. Where B will be built on a single spot from which its needs to reach its hydrogen customers, the decentralized setups in A enables them to be placed in location which is relatively close by a gas source and hydrogen consumer. Here, I must point out that this might actually be harder to accomplish than it sounds. It is not until around 2030 that hydrogen is intermixed on a large scale. The diffusion Superwind would benefit if it could use the gas infrastructure. For development of Superwind in B it is also imperative that all utility companies are involved because the power resource directly influences their source of income. Utility companies that own a power plant of 5 MW or more are currently by law obliged to have a certain amount of spinning reserve available. They are paid for answering the request of Tennet to produce more to keep the grid power balanced. If the Superwind plant starts to take over that function utility companies are sure to resist. This another reason why the expansion rate of installed capacity is lower for B.

If we look at both scenarios we see that the financial aspect differentiates. In A the financing is accomplished by attracting partners which are willing to invest based on idealistic views or positive expectations of the product or return of investment. With B the financing is more or a less compelled by Tennet.

Several levels are the same for A and B. Namely, the cultural level and the institutional level. Conditions within these aspects play a vital role for the diffusion of the technology for both scenarios. On a cultural level the public acceptance of hydrogen is an important issue. The technology is currently not well known among people and certainly not the advantages. The society in current state is unlikely to move towards sustainability without a sense of urgency. This can be economical or environmental. Another issue is public resistance. Hydrogen is criticised on its safety aspect. Many believe that the gas is too volatile and therefore is an accident waiting to happen.

On an institutional level both technologies benefit from government support. This support can be either in facilitating the diffusion of the technology or by subsidising the Superwind installation(s). The advantages of one Superwind central are from its lower costs in comparison with decentralized stations. Regardless of its lower power output in scenario B. The installations will cost more many if built separately. Furthermore, less extensive changes in electrical and gas infrastructures are needed to connect one power central.

To reach the achievements of both scenarios a technology push by a group of developers is not enough. A partnership can set the first step for the construction of experiments, but the



rate of Superwind's diffusion is influenced by certain events. In Figure 4-4 the events mentioned in the previous chapter have been displayed together with the total installed fuel cell capacity.

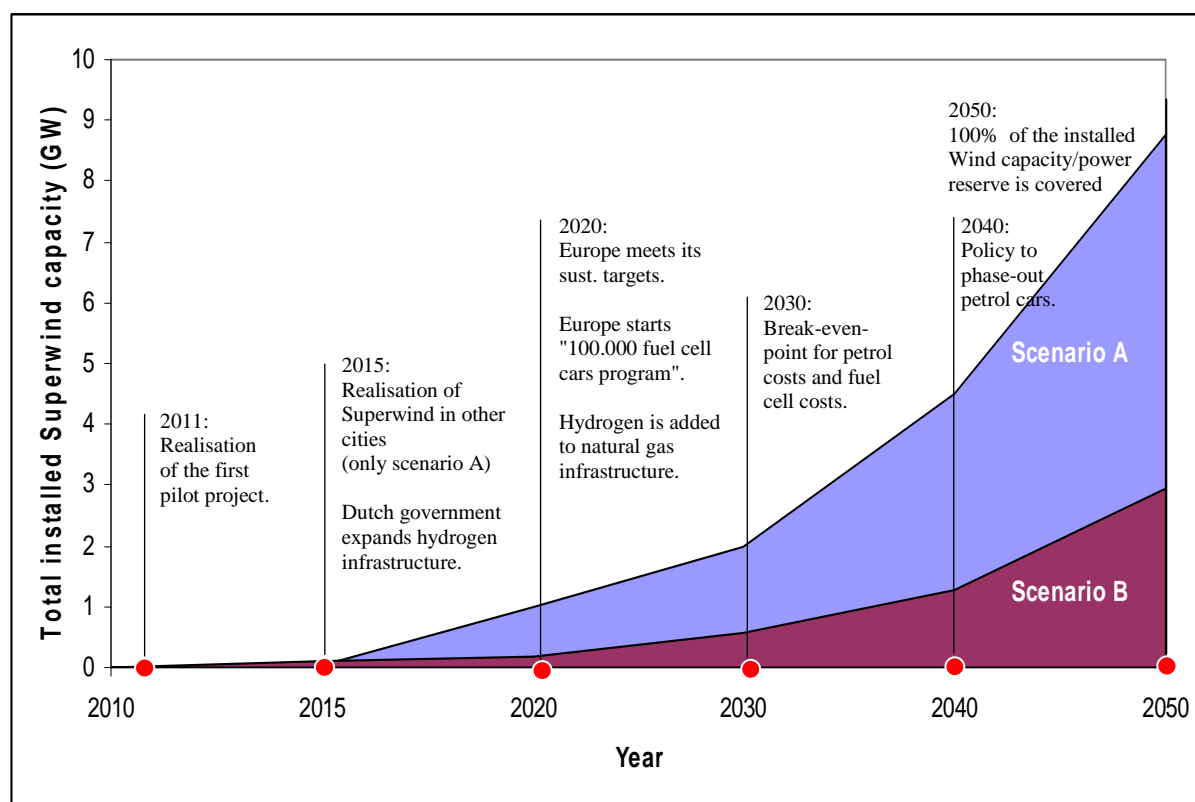


Figure 4-4 The influential events for Superwind and the total installed fuel cell capacity for scenario A and scenario B.

It is still assumed that rate of diffusion can be depicted by the increase of installed capacity in these scenarios. The graph shows that up to 2015 diffusion is expected to be slow. This is the testing period. After 2015 the rate of diffusion increases rapidly due to two events. The first is only true for scenario A; More experiments are tested. With each extra experiment more actors are involved. The technology is tested on a broader scale. More is learned about the technology and the technology is further perfected. This increases the number of applications for which Superwind can be used. The second event is the plans of the government to expand the hydrogen infrastructure to reach its 2020 energy targets and to enable the use of fuel cell cars. This applies to both scenarios. If the government openly supports hydrogen development it gives of a signal to the market. Companies will be more eager to get involved with hydrogen research and development.

In 2020 the diffusion is still strong. The fact that the government achieves its energy targets for 2020 means that the percentage of fluctuating power sources increases dramatically. Thus, the demand for Superwind also increases as a solution to aid in restoring grid imbalances.

The large scale testing of intermixing hydrogen and gas in the infrastructure is making the use of hydrogen anywhere in the Netherlands possible. The government campaign 100.000 fuel cell cars is an example of an active participation to steer towards change. More interest in hydrogen cars will provide a larger demand for hydrogen.

As the fuel cell costs start to diminish due to learning processes and economies of scale it is becoming a viable solution. In 2030 the break-even-point is reached and causes another acceleration. The hydrogen car becomes a popular alternative to bio-fuel cars.



The acceleration in diffusion rate begins in 2040 when petrol systems are phased out. The government implements policies to force public and industry to choose sustainable alternatives.

After comparing the two scenarios it can be stated that:

1. The targets of both scenarios are unrealistically high.
 - They did show that radical changes are needed for reaching the government goals
 - The changes need for other decentralized technologies to be accepted with the least amount of barriers.
2. To achieve scenario A and B the following conditions are needed:
 - Achieving technological breakthroughs in fuel cell technology
 - Government's firm determination to achieve energy targets for 2020 and 2050
 - Government should be convinced of the positive impact of hydrogen technology
 - An actor network should be created to support the Superwind project development
3. Scenario A has higher rate of technology diffusion:
 - Scenario A offers more stakeholders to participate
 - i. More actors lead to a more robust network
 - ii. More actors can mean more experiments for different applications
 - Decentralized setups will bring the technology more under attention of the public
 - There is a strong chance a centralized setup will happen behind closed doors
4. The financial situation of scenario B is more secure:
 - Finance in scenario A relies on the voluntary participation of actors
 - Finance in Scenario B is secured by a 'forced' participation
5. Scenario A initially requires less radical changes in the incumbent gas infrastructure
 - The decentralized setup approach means that it is independent of a hydrogen infrastructure because the location is not fixed but can be chosen to a close by hydrogen distribution point.
 - A centralized system is fixed at one point which means in order to reach all the Netherlands it either creates a whole new hydrogen infrastructure (piping or trucks) or it uses the existing, but upgraded, gas infrastructure.
6. Scenario B has relatively easy access to the electricity grid:
 - The centralized setup is connected to the grid with one access point
 - The centralized setup is supported by actors that control the electricity grid.
 - The decentralized setup will require a new access point with each new setup
7. Scenario B requires less installed fuel cell capacity to solve the imbalance problem (2,9 GW vs. 8,75 GW)
8. A centralized setup might not be able to solve the problems of net congestion if its power cannot reach all grid areas. For example, due to a low maximum transport capacity in certain areas.



4.6.2 A proposal for a setup of Superwind and the short-term follow-up steps

From the results of the two scenarios a new setup can be proposed that enjoys the benefits of both setups and avoid their disadvantages. The new concept involves decentralized setups but with the purpose of acting as power reserve. In Figure 4-5 the schematic representation of such a setup is given. The IR-MCFC's are all connected to the grid without a connection to a fluctuating power source. In the figure the non-intermittent power sources represent the fossil fuel stations. The intermittent power sources are wind power and solar power, etc. As long as the IR-MCFC is not capable of ramping up power quickly, the owners can sell their power to the net manager for the 8-hour-advance request.

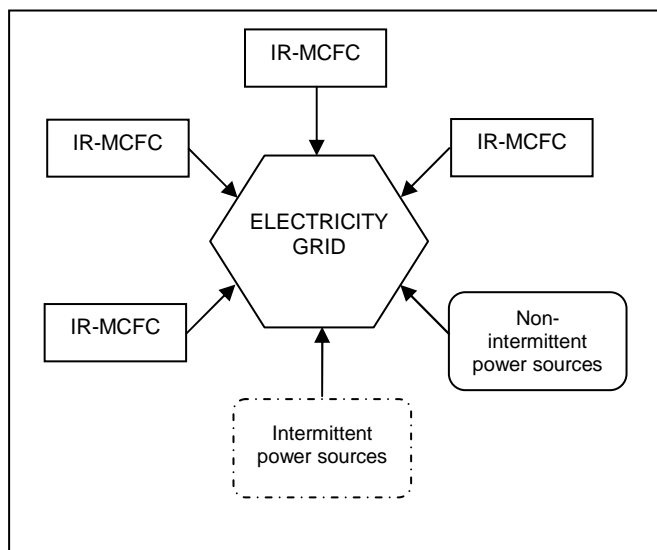


Figure 4-5 The proposed setup for the development of Superwind.

This form of setup is interesting because it uses the decentralized advantage; quicker diffusion, actor network is more robust, more chance that technology is tested with different applications. The centralized scenario showed that the function of power reserve is obtainable from the beginning. The fuel cell can accomplish to ramp up within 8 hours if requested by Tennet. Eventually, the decentralized setup will also be able to fulfil future needs. When hydrogen technology is developed up to a point where the switching to high power takes less time, the systems can also be used to connected to nearby fluctuating power source.

From the results of the backcasting the follow-up steps for the proposed setup can be derived:

1. An actor network is to be created.
The actor network is likely to be in the form of a consortium. It should consists of partners that supply scientific knowledge, labour, technical parts, financial investment, and political influence.
2. A niche is created in the form of an experiment.
Create something tangible which facilitates the technological developments and actor involvement.



Parallel steps are:

1. Lobbying at a political level to obtain support.
From the results of backcasting the government is an important actor. They can influence behaviour of industry. If they voice the technology more actors will be attracted in be involved with the development of Superwind
2. Create a business plan.
A business plan can clarify what needs to be done to achieve the creation of the experiment.

Further specification of the follow-up agenda will be discussed in the next chapter.



5 The market introduction of Superwind in the Netherlands using strategic niche management

5.1 *The creation of a niche*

To create a niche for Superwind the right setting must be found in which the innovation can be protected and nurtured. This first stage of creating a market niche is creating a technological niche. Often this is an experiment in order for the supporting actor network to research its technological and economical feasibility, and the its impact on society and culture.

5.1.1 The technological niche of Superwind

Superwind's primary application is the levelling of a intermittent sustainable power source and secondly providing hydrogen to a fuel distribution point to stimulate the reliability of fluctuating renewable energy sources and the transition from an petrol based infrastructure to a hydrogen based infrastructure. This will to all probability become its market niche. Therefore the optimal setting for an experiment is the same as the market niche it is expected to fulfil. To decide on a proper setting for the experiment we look at the disadvantages of Superwind. In this case the weakest link is the IR-MCFC and hydrogen technology.

The disadvantages of the IR-MCFC are:

- The fuel cell is not capable of instantly compensating the fluctuations.
- The fuel cell requires a large investment.
- The maximum output of a commercial IR-MCFC is 250 KW.
- The production of hydrogen requires expertise for handling and storage.

Based on these disadvantages the experiment will require:

- A setting in which the request for extra power or hydrogen is given a certain time period in advance to enable the fuel cell to adjust.
- A setting in which the investment is covered by either government research subsidies or investment by private actors.
- A setting in which knowledge about handling and possibly the storage of hydrogen is present.

Further requirements are that the setting fulfils the internal niche processes:

1. A setting which provides knowledge dissemination for voicing of the technology.
2. A setting in which the feasibility and social impact can be studied.
3. A setting that provides network formation.

Several examples of settings for the experiment are:

- Industry; In Rotterdam there is already a hydrogen network available for industrial use. Several companies are connected. These can be interested in having there own hydrogen source and electricity production. A gas infrastructure is also available and can be used for supplying natural gas to the MCFC. Wind turbines are also available.



- This group has the knowledge, the presence of a hydrogen and gas infrastructure, and possibly the financial capabilities for the development of such a product.
- Another example of industrial application is a spill over of gas as a result of a production process. Shell, for instance, releases several amounts of gas to the air and ignites it. The quality of the gas is not very high. This where the insensitivity of impurities of the IR-MCFC is so valuable. If the supply is enough, the MCFC could be an efficient way of utilising the gas for hydrogen and electricity production which shell can almost certainly use in their production process.
- Knowledge institute; The motivation for a knowledge institute will most likely be the increase of the institute knowledge base. It is capable of experimenting with the technology and let it develop in a protected environment. However, most institute might not have financial resources to research and develop the technology. External financing is needed.
- Utility companies; In the Netherlands utility companies are willing to invest in sustainable power sources. Wind turbine power and biomass conversion are expected to be the largest implemented technologies in the next decades. Wind turbine power does bring with it fluctuations. Therefore the need for technologies capable of compensating these fluctuations is growing. Superwind offers utility companies a compensating method which complements wind power and biomass at an efficient level. The utility companies do possess the knowledge to exploit the IR-MCFC technology and probably also the financial resources. However, the motivation of utility companies is low because of the high invest and uncertainty of return on investment. If the government promises long term support (financially and politically) utility companies might be less reluctant to invest in new and sustainable innovations.

5.1.2 The drivers and barriers for the creation of an experiment

In this section the drivers necessary to utilise and the barriers necessary to overcome for the creation of an experiment are discussed. They are split up in four categories; technological, institutional, economical barriers, and social.

The technological drivers

- The IR-MCFC is commercially available.
- The IR-MCFC can consume several sorts of (quality) gas.
- Wind turbines and biomass are the expected to be the fastest growing sustainable solutions.

The technological barriers

- The development of the hydrogen transport and storage is still in its infancy.
- Finding a test location suitable which meets the technological needs and institutional needs.
- Connection to the electrical grid. The connection to the electrical grid is hampered by lack of electricity transport capacity.
- Hydrogen as a transport fuel is threatened by the emergence of the electric car. More alliances are made between manufacturers and public authorities to develop a electric car infrastructure. This can decline the interest in hydrogen projects.



The institutional drivers

- The current Dutch and European policy for sustainable innovations provides a variety of support for the development of sustainable projects. Examples are services, subsidies, and cooperation at Netherlands and European scale.
- The sustainable innovation policy is still improving and more budget is made available by the Dutch government for sustainable projects in 2009.

The institutional barriers

- Local authorities are to be convinced of the positive impact of the Superwind technology.

The economical drivers

- The energy price is increasing due to an increase in oil and gas prices
- A multitude of subsidies or funds is available for Superwind in the Netherlands.

Economical barriers

- Financing is needed for the construction and development of the experiment.

The social driver

- The public awareness for the need of a more sustainable way of living is growing. The media spends attention to sustainable method of generating electricity and transport fuel.

The social barrier

- People living in the vicinity of the test location might object because they are afraid the installation is not safe enough.

5.1.3 The initial stakeholders' participation

The stakeholders' participation for the setup of the experiment is looked at in this section. The first topic is the creation of a stakeholder network. The second is about the management of the stakeholder network. The third is about which stakeholders are involved with its construction. The last topic will also discuss what an actor can gain from the experiment and what their expectations are.

The creation of an actor network

To realise the construction of the experiment a foundation of consortium can be constructed in which actors who at first are willing to invest because of idealistic goals. Functioning within a partnership construction is interesting to all parties. The commitment of partners induces predictability of actors which in turn creates trust.



The partnership can include five types of partners. The first type are the investment partners. This includes bankers, governmental institutes, and private investors. An investment can be made from an idealistic view, an expectation of profit, knowledge, or expectations of the products application. The second type are technology partners. These can provide the physical parts for the construction of the experiment. The third type of partners are the managers. Among these are the contractor and the manager for daily operations (sale of products and planning of activities). The fourth type of partners are technological institutes, such as universities, who provide scientific knowledge. The fifth type consists of the political partners. Among these are the government, provincial or local authorities. Naturally, an actor can belong to several types of actors. For instance, industry could provide a fuel cell free of charge which would also make it an investor.

The coordination of actors and strategies

At the initial stage of construction it is important that the actor network addresses several issues to prevent a chaotic nature in the decision-making process during and after the realisation of the Superwind experiment. A number of examples are given below:

- What is the goal of the experiment?
- Are there any sub-goals?
- What is needed to reach a goal?
- What is the maximum time frame to reach a goal?
- What kind of investment do actors wish to make (knowledge, physical attributes, labour, finance) to reach a certain goal?
- What will be the quantity of that investment?
- What do actors expect in return?

The coordination of actors could be executed by one individual who is overseeing the experiment and is responsible for all matters related to the Superwind experiment. There are several possibilities for a coordination point

- One or several partner(s) is (are) appointed manager
- An external manager is appointed

The external manager is interesting when some parties within the network fear that one company gets too much power. Also, when companies lack the man power to coordinate such a project.

The stakeholders in the initial network

To initiate a robust consortium for the construction of technological niche, the following partners are proposed:

A test facility; important to the experiment is the test facility. It should not solely be a location where the technology is placed, but ideally the facility should also be capable of contributing to learning processes. The more can be learned about the technology in the first stage the faster the experiment can be scaled up. Furthermore such a facility should be able to give a voice to the technology. This is important to induce the sharing of the expectations about the technology. These two processes are important to increase the actor network for Superwind.



A utility company; The addition of a utility company to the partnership will create possibilities such as access to inside knowledge of the energy production which can help in optimizing the technology, a financial investments such as a contract for the electricity produced or a initial investment, or the supply of physical parts such as connection to the energy grid. In the Netherlands the net managers and utility companies are still intertwined. Although they should be separate they still have a strong business relationship. Therefore this paragraph also applies to net managers.

A wind turbine owner or manufacturer; For an optimal experiment the IR-MCFC should be connected to a fluctuating power source. The choice for a wind turbine owner or manufacturer is based on the primary concept. This actor can provide the consortium with knowledge. In case it is a manufacturer it might even provide a financial investment in monetary form or the wind turbine. To clarify a wind turbine owner can be a private wind turbine owner (e.g. Wind unie) or an utility company.

An industrial company; Partnering with an industrial company can provide a supplier of physical parts, knowledge, or financial investor to the group. In the first stages of the experiment it is expected that more hydrogen will be produced than the demand of the transport sector. An chemical company could offer a contract for the delivery of hydrogen or even electricity. A large barrier for industry could be that there are currently cheaper sources for hydrogen and electricity. However, an industry might find that having a local energy source outweighs the extra costs incurred.

A fuel cell manufacturer; The fuel cell is the key component of the Superwind experiment. With a manufacturer onboard the connection consortium-manufacturer will provide a strong manufacturer commitment. The involvement of the manufacturer leads to a better customization of the fuel cell for the experiment. The manufacturer could find that the experimentation with his fuel cell is of great value to them for the publicity and for the end-results which enables them to improve their product.

Delft university and Maïke Bouma; As the initiators of the project it is only logical that they participate in the Superwind partnership. Where Delft universities motivation comes from the expansion of their knowledge base, Maïke Bouma's interest come from idealistic views and as an owner of a farm herself she hopes that in the nearby future she will also be able to connect a Superwind installation. The investment that these are able to make are knowledge and an attribution to knowledge dissemination.

Fuel distribution point for commercial use; One of the market niches that we wish Superwind to address is hydrogen fuel for passenger cars. Therefore it would seem an optimal situation if with the experiment a connection to a fuel distribution point is constructed. However, as is mentioned in the paragraph of the industry actor, the number of hydrogen cars within the time frame of the experiment is zero to none. It would be interesting to see whether a public transport company could be interested in joining the experiment. This could be an extra incentive.

Government ; Their presence in the partnership might not be so evident. However, they can provide advise, financial investment, a testing area, and publicity. This can also be possible without them being in the partnership, but we so more government bodies getting involved within partnership to reduce the threshold between public and private cooperation.



In addition to these partners, it is also a strong asset if the following actors can be attracted. These are mentioned separately because they do not have belong to the consortium in the first stage of development of Superwind.

Car manufacturer: A manufacturer that share the same ideas about hydrogen technology strengthens the voicing of technology. The Superwind research and car manufacturer have mutual benefits if they work together; increase in learning processes and voicing of the fuel cell and hydrogen technology.

5.2 The development of the niche

In this section the further development of the technological niche of Superwind that is created with a successful experiment is discussed. According to van Eijk and Romijn (2008) this stage reflects on the exploration of the experiment; striving towards social and cultural acceptance, institutionalisation, the economic viability and to perfect the technology and upscaling the experiment.

5.2.1 The conditions for the development of Superwind

The characteristic of good conditions is to contribute to the three internal niche processes. If these are of high quality the technology starts to strengthen its position among other competing technologies and will eventually give it more chance when it is released to competitive market. The following conditions apply to the further development of Superwind:

1. Preferential treatment
2. Financial investment.
3. Technological investment
4. Partner commitment
5. Possibilities for knowledge diffusion
6. Opportunity to widen the scope of the learning process

Preferential treatment

The exploitation of Superwind would benefit from a grid priority rule for sustainable systems. With such a rule the profit of Superwind could increase because it always able to sell its electricity production.

Financial investment

At this stage the technology is not economically capable of fending off other technology. It requires more funding. Funding can come from the partners within the partnership. It can also come from governmental subsidies. Depending on the setting and the status of the technology a decision is made in what form the investment is acquired and from whom.

Technological investment

The progress of the experiment will bring forward new demand for the supply of technology. This will require more know-how from partners and possibly also difficult demands for the



necessary technology. It is important that the partners view whether they are capable and above all willing to participate.

Partner commitment

Partner commitment is vital in this stage. The group needs to reassess their goals and discuss whether they want to continue under the same conditions as with the initial test stage of the experiment. The partnership is again confronted with the decision whether this technology is worth investing in.

Possibilities for knowledge diffusion

This item refers to public relation. The niche should possess to facilitate the voicing and sharing of expectations. The more actors share the same view about Superwind the more actors are attracted. More actors open up the possibility to join more experiments and gain access to new resources. This again increases the knowledge diffusion.

Opportunity to widen the scope of the learning process

The niche should facilitate the increase of the learning processes. This requires the research to increase its scope, but learning processes are also dependent on actors and the state of the technology. If the partnership is of a collaborative kind which induces an openness of knowledge, it will be able to increase the rate of knowledge creation and innovation development. Whether it is possible to increase the scope depends on the rate of technology. It could well be that the IR-MCFC has improved, but the complementary technology, such as hydrogen transport, did not.

5.2.2 The stakeholders' participation in the development phase

The coordination of actors and strategies

Changes are expected in the partnership. Partners might decide to leave the partnership after the ended their term. They could have reached their personal goal or their expectations of the technology have changed. Other possibilities which might attract or repel an actor are that the purpose of Superwind has changed. A new setting could require different actors.

The development phase is started by joining up experiments. The consortium is still central but the actor network of Superwind expands. This means that more investment is needed by the partners to coordinate the actors and projects.

The stakeholders involved with the development of the niche

In this stage changes occur that affect the need for partners. Hereunder the actors from the niche creation are discussed and how their role is changed.

A test facility; Superwind technology is improved to such a point that an intensive testing facility might not be needed. Test runs can be done in less controlled environments and locations with less know-how about the Superwind technology.



A utility company; Keeping a strong relationship with one or more utility companies is beneficial for the exploitation of Superwind technology. Currently and most likely in the future, all large scale projects of renewable power will be controlled by utility companies.

An industrial company; Attracting more industries to the development of Superwind will offer more possibilities to diffuse Superwind technology.

A fuel cell manufacturer; The research moves forward and with expansion to new settings the learning curve is still steep. The data collected and the possibility for the cell manufacturer to sell more products is important enough for him to stay within the partnership.

Delft university and Maïke Bouma; As the isolated experiment becomes more diffused, the interest of these actors can reduce.

Fuel distribution point for commercial use; The fuel distribution point, if it finds the first experiment a success, can decide to construct a hydrogen pump at several other of its establishments.

Governmental authorities; In the expansion phase the government is expected to retreat. The need for governmental support diminishes.

Car manufacturer; At this stage the car manufacturer should certainly be involved if the hydrogen production for transport fuel is to be utilised. An example the joining up experiments is cars and busses driving on Superwind produced hydrogen.

Capital investor; It is likely that financial investment is still needed in this stage. This can be provided by banks, but it could also one of the aforementioned actors.

5.3 Controlled phase-out

This section discusses how to release the technology into a competitive market. The first paragraph a description of the market niche a technologically perfected Superwind system can address. The second paragraph discusses the necessary conditions for Superwind to be able to step out its protected space. The final paragraph looks at the stakeholders involved in that step and in what network format they are best arranged in order to have an optimal Superwind diffusion.

5.3.1 The market niche

Superwind will eventually be capable of rapid and flexible compensation of the fluctuations of any power source with a high conversion efficiency for electricity and hydrogen. To decide upon a market niche for Superwind the expected capabilities of the technology are taken in account. When IR-MCFC is perfected it will be capable of the following actions:

- It is able to fluently follow the fluctuations of any power source
- It has a high efficiency
- It has a high power density
- Its costs have lowered due to the use of less expensive materials



The end result of Superwind is also dependent on its complementary technologies. The following developments are expected:

- The hydrogen separation has a high efficiency
- Hydrogen transport and storage exceed the safety standard

With this in mind the niche market for Superwind can be the following:

1. The compensation of fluctuating power to alleviate the imbalance on the electrical grid.

Applications: fluctuating power source compensator or fluctuating power compensator for the grid (power reserve)

2. A local source for the production of hydrogen and electricity.

Application: Hydrogen fuel provision for the transport sector and an addition to industrial or chemical processes

5.3.2 The conditions for the market introduction

The market release should occur at a point at which the costs for the exploitation are at a break-even point with competing technologies in the socio-technical regime.

Be aware that the market release will still require financial support and an active actor network that will carry Superwind.

The technology is still not routine. The costs of Superwind are still high compared to other options that fulfil the same niche market. Governmental subsidizing need to be requested for the unprofitable part of the costs for the installation. A choice is to be made between the different forms of subsidy (e.g. initial investment or feed-in tariff).

The actor network important for the further diffusion of Superwind. The group should facilitate the knowledge diffusion and necessary nurturing of the technology. Furthermore, one of the foci of the actor network should also be the expansion of the hydrogen infrastructure and the institutionalisation of hydrogen.

Preference treatment by the authorities would help accelerate the diffusion of the technology. However, it is not a obligatory condition. It is clear that governmental backing has contributed significantly to the exploitation of wind turbine technology, biomass, and CCS technology. Whether you receive preferential treatment probably coincides with the development of a hydrogen infrastructure. This assumption is based on the development of the electric car. Car manufacturers are lobbying for the electric car and as more alliances are made between authorities (local, regional) more cooperation is provided by the government.

5.3.3 Stakeholders' participation

The actor network will remain important with the controlled phase-out. The product is still new and needs to be advertised. The actor network will have to involve more actors to promote the technology.



The stakeholders involved with the niche phase-out

To increase the rate of diffusion the focus of the group should turn to complementary technologies. Examples of actors with which a close relation should be maintained are car manufacturers, chemical companies, public transport companies and gas utility companies. These actors all apply to the secondary goal of hydrogen production. However, the fact that Superwind has a tri-generation capability is what sets it apart of other competing technologies. The production of hydrogen should therefore be fully utilized in the 'sales pitch' From the primary partnership a utility company, an industrial company, a fuel cell manufacturer should still reside. These company gain the most profit from marketing the product.

The coordination of actors and strategies

Before the product is released to the market it is important to know how the product will be sold. It is important to have a group committed to the marketing of Superwind. The partnership could have several options:

1. A spin-off company is created.
This company will consists of several employees of each of the actors within the partnership.
2. One of the partners buys out the other partners.
If it is expected that the production of Superwind provides a significant profit, one company could decide to buy out the other partners. This is often done when some actors do not wish to exploit the product.

However, it is imperative for the diffusion of Superwind that one central player is responsible for its marketing and production.

5.4 Strategic milestones for the diffusion of Superwind

In conclusion of the research performed on the of Superwind the following milestones can be listed;

1. Found a partnership
An actor network is the basis for Superwind. The actors will bring knowledge, technology, and facilitate the expansion of the actor network. Perhaps even to address adjacent markets.
2. Set goals and targets
Project goals should be clearly stated.
Personal goals should also be stated to provide predictability and trust within the partnership.
Set the time frame in which certain goals must be reached.
If possible state the goals and targets in a contract to increase actor commitment.
3. Obtain funding



The largest barrier is funding. Finding investors for Superwind can be difficult.
Make sure you make full use of governmental services.
Involve them in the project. Perhaps by adding them to the partnership

4. Select a test location for a pilot project

The test location is key. It should not just be an area in which the technology can be tested, but especially with the creation of a niche it should facilitate knowledge dissemination.
Keep the three internal niche process (voicing and shaping expectations, learning process, and actor network formation) in mind.

5. Construct and test the experiment

9. Adjust goals and Targets

When the testing time frame has passed set a go/no-go meeting

Readjust goals or set new goals.

Adjust if necessary the partnership format

Are there people that want to leave the partnership?

Should new partners be added?

Is the legal structure of the partnership adequate for continuation of the project?

10. Join-up experiments

With the technology passing its first test goals, it is time to try operating the technology in other environments. The joining of experiments will increase the actor network and provide more chances to voice the technology.

11. Create a company

The diffusion of Superwind on a large scale requires one central company which is in charge of production and installation.

Decide on the optimal structure of a company



6 Case study: The construction of the pilot project at Nij Bosma Zathe

While working on the report for the market introduction of Superwind, the development group made several progresses. Firstly, Nij Bosma Zathe, an experimental farm of the University of Wageningen, agreed to facilitate as test facility. The second progress is that the group has made contact with a fuel cell manufacturer and a fuel distributor. They are respectively CFC Solutions in Munich, Germany and Delta Oil in Leeuwarden, The Netherlands.

This chapter will again apply the socio-technical map and the strategic niche management but now with the test facility in Leeuwarden as the starting point for the diffusion of Superwind. This gives me possibility to list the actors quite specifically and to gather more specific information about them. This has been done by desk research, including internet sources, and by personal communication with several actors.

The research question remains as listed in the beginning of the report. However, the time frame is shorter. In this case study the time frame ends with the release of the Superwind to the market and not as with previous part of this report in the year 2050. The strategy designed will reflect on the knowledge gathered about the actors involved for the case study and aimed at the market introduction. Not the diffusion afterwards.

In section 6.1 the socio-technical map is discussed. Please be aware that many of the developments in technology also apply to this case study. Therefore only the technological developments are specifically happening in Friesland will be discussed. Section In the following section the exploitation of the experiment is explained. Section 6.2.3 discusses how the experiment can contribute to the Superwind market introduction.

6.1 *The socio-technical map applied to the case study*

6.1.1 Technological developments

- The province of Friesland has several technological developments:
- It is strongly focused on the solar power. It wants to increase its knowledge base in solar technology.
- Bus companies in Leeuwarden are driving on biogas
- Technology knowledge investment is seen as a tool for strengthen the economy. Therefore it has erected Energy Valley together with Groningen and Drenthe.
- Friesland is investing in the upgrading of Biomass. It wishes increase the efficiency of the fermentation process (Energy Valley website)
- Friesland is currently rewriting their policy on the exploitation and allocation of wind turbines (Energy Valley website)
- Waste fermentation will direct part of their biogas for the use of cars, busses and trucks (Energy Valley website)



- Friesland wants to phase out petrol cars within 12 years. After 2020 all cars should be driven on biogas or electricity (Energy Valley website)
- By 2015 a 100.000 cars in Friesland, Groningen, and Drenthe combined should be powered by 'clean fuels' (Energy Valley website)

6.1.2 The stakeholder analysis

6.1.2.1 The stakeholders

In this section a list of actors is made. The actors are divided according to their playing level. The list starts at the international level and narrows down to the local level of Leeuwarden in which the Superwind group plans to build the pilot project. The actor analysis includes in what position actors are in structurally, their relationship with Superwind, whether they are drivers or combatants, and their expectations for future sustainable innovations.

International level

At the international level the **European Union** has set the goals for 2020 and 2050. Furthermore, special grants and subsidies are available that are meant to stimulate further research and development of sustainable technology. Also legislation is adjusted to push countries to move towards a sustainable future.

National Level

The **Dutch government** stated the energy goals for 2020 and is promoting sustainable technologies by means of the Subsidy Duurzame Energy, an exploitation subsidy (this replaced the MEP investment subsidy which was cancelled in 2006).

The government has several ministries and subsidiary services that are relevant to Superwind:

Economic affairs, Ministry of Transport & infrastructure (=ministerie van verkeer & waterstaat), and ministry of environment all work together on the selection process of new sustainable technologies. The approving of building permit for new sustainable projects these ministries all have to give their approval. In fact, to get a building permit for a wind park, the project plans pass through seven ministries before it is delivered (Stichting Natuur en Milieu 2008). The Dutch ministry of economic affairs is responsible for arranging the subsidies for sustainable innovations. This is done through a subsidiary service called: **Senter Novem**. With Senter Novem the ministry hopes to lower the threshold for innovators and improve public-private cooperation.

The monitoring office, **Directie Toezicht Energie (DTe)** which is in charge of the execution and supervision on the compliance of the electricity regulation 1998 and the law on natural gas.

Regional level

The province of Friesland is very open to new sustainable technologies. Not only is it in charge of tendering permits, but it can be a source of finance. To promote sustainable innovation in the region a public service has been founded by the Northern provinces



(Friesland, Drenthe, and Groningen) called Energy Valley. The service is to provide support in networking, protocol advice, and finding the right subsidy.

Looking at the electrical infrastructure two main utility companies are relevant for the pilot project. The first is **Essent B.V.** a utility company that is a owner of a large part of electricity grid in Friesland. More importantly, the company has a contract with Nij Bosma Zathe to deliver a certain amount of heat and electricity for domestic purposes.

The second is **Liander**, previously called Continuon, which is the net manager in the province of Friesland and is in charge in the development of the net congestion management.

The NGO: **It Fryske GEA** is a Foundation of environmental protection. Although in favour of sustainability, they do oppose wind energy.

Local level

Narrowing down to the project site several actors are relevant;

The city of Leeuwarden, the champion city of the province of Friesland, is working hard in creating a green image. The city wants to strengthen the local economy by becoming a place that is attractive for high educated people. They intent accomplishing that by creating a 'chain' of knowledge centres in the area (Stuurgroep Gebiedsontwikkeling Nieuwstroomland 2008). Furthermore, the construction of two new 'green' neighbourhood which emphasize the sustainable character that Leeuwarden is aiming for.

The city is in charge of permits, local regulations, inspection, and may be a possible provider of subsidies.

Not far from Leeuwarden the **Airbase Leeuwarden** is situated. This presence of the airbase means that the ministry of defence might rule out a permit for a certain project or area. For instance, the height of wind turbines and their influence on radar interference.

The Fire department Leeuwarden is in charge of safety advise and inspections.

Project level

At the project level actors are placed that are important to the realisation of the pilot project or even the diffusion of Superwind technology. For the pilot project the proper technology and knowledge is needed.

CFC solutions is a manufacturer of molten carbonate fuel cells. Her products are commercially available and at 250 KW output the strongest.

ECN is one of the largest energy centres in the Netherlands. The company has built a strong knowledge base about fuels among which biomass.

Delta oil is a company that is created by idealists that wanted to avoid the chicken-or-the-egg problem and built a fuel station that provides several kinds of renewable fuels.



Fuel Cell Energy (FCE) that is an American company that not only has a commercial MCFC but also hydrogen separation technique. This company used to be one with CFC solutions, however when the companies split up they decided that CFC only works on the European market and FCE on the American market.

GEM Zuidlanden oversees the construction of two new sustainable residential area built in the nearby future in Leeuwarden. De GEM also signed the agreement of Essent en Nij Bosma Zathe to accept delivery of heat and electricity generated by NBZ.

Cartesius institute is situated in Leeuwarden is the Knowledge center for the Northern part of the Netherlands. It is a dependant of the the three Dutch Technical universities. It acts as a technical interface between researchers and the northern regional authorities.

The Wind Unie is a union in which private wind turbine owners are represented. It is interested in the increase in profit that Superwind technology might provide.

Core level

At the core level the drivers behind the research and development of Superwind are situated.

Maike Bouma is the spokesperson and driving force behind the project. Maike Bouma owns also a bio-farm and is familiar with the operation of farms, and that of the city of Leeuwarden.

At the **TU Delft** the research team is situated. Among which **dr. K. Hemmes** who developed the idea of Superwind.

Nij Bosma Zathe is a experimental farm of the University of Wageningen. NBZ has agreed the pilot project of Superwind can be constructed at their facility. Currently, NBZ is testing the production of biogas from manure. The biogas is then burned in a gas turbine to facilitate the new residential areas in heat and electricity. A contract is signed with Essent, GEM zuidlanden, Gemeente Leeuwarden for providing Electricity and heat.

6.1.2.2 Drivers for a particular technology

Three actors are really a driving force, **Maike Bouma** and **K. Hemmes** and **Nij Bosma Zathe**. The other actors in this section could become a driving force for the project, because they are highly motivated to find sustainable power sources for the Northern Region of Friesland.

K. Hemmes who is the initiator of the Superwind concept hopes that the project will be realized in the short term. He sees the project as a good addition to Dutch knowledge and innovation base. **Maike Bouma** has a biological farm in the west of Friesland and sees Superwind also a good addition to her farm and that of others. They both realise that building a social group for the project is a must if a Superwind demonstration is to be constructed.

That is why a research facility in Friesland has been asked to join the group. The facility is located in Goutum. It is an experimental farm, called **Nij Bosma Zathe**, of the University of Wageningen with about 300 cows. The chief coordinator at Nije Bosma Zathe is **Durk Durksz**. He is very keen to get the project realized. Currently, an expansion of the fermentation plant is constructed.



A contract is signed with the **municipality of Leeuwarden** and **GEM Zuidlanden** who are the main responsible actors for development of new residential areas. Also the utility company **Essent** joined the contract that states NBZ will deliver electricity and heat to two new residential areas by burning biogas with a gas turbine. NBZ has an abundant of biogas to enter a high temperature fuel cell. GEM Zuidlanden and the city of Leeuwarden want to promote the Zuidlanden area as one of the most sustainable living areas in the Netherlands. They are open to sustainable energy provision.



Figure 6-1 The construction of a manure tank at Nij Bosma Zathe.

The **province of Friesland** is very open to sustainable innovation. Their new plan on strengthening the economic situation is built on stimulating innovations and knowledge centres in the province. Therefore it has also founded **Energy valley** to increase knowledge and innovations specifically in the Northern region of the Netherlands. This could be an entry point to get the attention of the right actors.

Unfortunately, the Frisian energy coordinator, **Bouwe de Boer**, is not yet convinced that hydrogen is the next energy carrier. Although, he is interested in Superwind, he first wants to know how much CO₂ the system will produce compared to a conventional system and how before he backs it up. Momentarily de Boer prefers natural gas as a fuel and has promoted the construction of ten natural gas pumps in the North of the Netherlands. Furthermore, negotiations with public transport firms to introduce natural gas powered busses are ongoing (Senternovem 2007; Senternovem 2008a).

Another benefit of NBZ as a test location is that it is near the largest fuelling station in Europe for renewable fuels, run by **Delta Oil**. Delta Oil is interested in hydrogen production possibility of Superwind, however, want to see more actors joining the Superwind group to gain enough confidence that this project is being realized.



Figure 6-2 dhr. Jansema, chairman of Delta Oil posing at largest European fuel station of renewable fuel in Leeuwarden.

The German company **CFC solutions** is a manufacturer of a commercially available molten carbonate fuel cell of 250 KW. The company has been contacted and Superwind has been discussed. The company is interested but how or if it will participate depends on what markets Superwind will address. The company hopes to gain knowledge from the Superwind project.

6.1.2.3 Combatants of Superwind technology

The organisation in northern region of the Netherlands that concerns itself with environment is **It Fryske GEA** (NGO). On the website of It Fr. Gea it is clearly stated that it dislikes wind turbines as they disfigure the landscape and could have a giant impact on wild life. On the other hand they do emphasize the need for sustainable energy. Involving them in the process towards the realisation of Superwind is important as to avoid the NGO of becoming a combatant.



NBZ is also near to **Airbase Leeuwarden**. The only relationship between the airbase Leeuwarden and Superwind is that certain regulations which are installed for the safety aspects of an airfield could mean certain restriction for the construction of a demonstration project at Nije Bosma Zathe. For instance height of wind turbines could be restricted.

Liander has trouble allowing combined heat and power systems on the net since July. Unfortunately, net congestion has caused problems since a couple of years and especially in the North of the Netherlands. If customers want to get their grid chp-system online, it will be under the condition of a net congestion management (Organisatie voor duurzame Energie 2008a; Tennet 2008). Although the 2008 energy report stated that renewable energy has preference in the grid over unsustainable generated power this is not the case in reality (Damveld 2008; Ministry of Economic Affairs 2008a; Organisatie voor duurzame Energie 2008a).

6.1.2.4 Other actors related to Superwind

The first part of the research of the project performed was funded by **Senternovem**. The service has received the mid-year report and thinks that this project can make an interesting innovation.

The wind data is provided by **Wind Unie**. The union of private wind turbine owners is interested in the results and hopes that the Superwind could increase their profit of wind energy sales.

ECN has experience with separation systems and actually are testing a CO₂ pressure adsorption swing right now. The question is whether they might be able help with the development of Superwind.

Fuel Cell Energy (FCE) used to be connected to CFC solutions under MTU. The MTU split and FCE is now working on the U.S. market and CFC Solutions on the European market. Unfortunately, the relationship between the two companies has not been preserved. The hydrogen separation technology is produced by Fuel cell energy, but not by CFC. This still means that FCE is to be contacted in order to see whether both systems are compatible.

One of Superwind goals is to provide hydrogen to the public. But this means that motorists should be aware that there is an option for alternative fuels. That the motorists are becoming aware of the need for cleaner fuels is clear. Oil manufacturers are stepping up their research towards biodiesel, bio-ethanol, improving existing diesel, petrol, and gas fuels.

The role for transport associations is therefore important towards informing and even motivating the end user (citizen) about the benefits of hydrogen. An end user, however, is not specifically aware of Superwind. The question is do they need to? Important is that the public does understand that hydrogen itself may only result in pure water, but to create hydrogen a great amount of energy is needed and that current methods create hydrogen in an unsustainable way which would make hydrogen as clean energy carrier solution complete useless.

Local public transport: Connexion is the public bus company in Leeuwarden. Since February 2008 it launched 27 busses which are powered by bio-diesel in Friesland.



The bus company is also developing with Shell hydrogen busses to be driven in Rotterdam, Zuid-Holland. The reason the companies choose Rotterdam is because of the already existing hydrogen infrastructure.

The busses are constructed by MAN, Germany.

Nuon Noord-Oost B.V; It is not sure whether NBZ can expand its contract with the utility company Essent to include the Superwind demonstration. There might be a need to find other partner utility companies in the area. As one of the biggest utility companies in this region, Nuon Noord-Oost B.V, could be an interesting partner.

6.1.2.5 Stakeholders' expectations

At an international level the **European Union** and **the Netherlands** address the need for policy making in the field of sustainability. It is expected that without political steering no critical breakthroughs will be made in the area of sustainability. The Netherlands follows the guidelines of the EU and sees that reaching the goals are not met if political steering mechanisms are not installed or exercised. The Dutch government thinks that the Netherlands need to get on board of the sustainable technology market now. It fears that without innovation the Netherlands will fall behind and loose it knowledge position on the world market.

The actors at the national level are governmental institutions and non-governmental organisations. **SenterNovem** sees that Superwind holds opportunities and has awarded a subsidy for the first part the research of Superwind. For the realization of Superwind on a test site a new proposal is to be made for the request of new funding.

Ministry of Transport & infrastructure follows Dutch planning on increasing the share of renewable energy sources in the Dutch energy mix, but holds no specific expectations for Superwind.

The **transport association ANWB** sees an increase in demand from members for cheap fuel because the oil prices are rising and government taxes fuel consumption to push the consumer to reduce the use of cars. However, for most consumers there is no alternative to their car or motor. Also, no alternative vehicles are offered than the standard petrol powered vehicles. Hydrogen might be a new option, but the infrastructure and vehicle availability is lacking. The vehicle manufacturers see no demand for hydrogen vehicles because there is no hydrogen infrastructure. The gas stations do not see a demand because there are no hydrogen cars to fuel. Hence, the chicken-or-the-egg-dilemma.

Narrowing down to the regional level and the local level the actors the **Province of Friesland** and the city of **Leeuwarden** come into play. The province sees the city of Leeuwarden as its champion. The have high expectations of the new areas in Leeuwarden. These areas are to attract high income habitants and also keep more high skilled workers in Leeuwarden. To do that the Frisian authorities are working a chain of knowledge institutions of which Nij Bosma Zathe is partner. Currently, they are still looking for ways to stimulate a hydrogen infrastructure on a long term basis. Their first effort was the subsidisation of Frisian boat builders to develop hydrogen boats.



The **utility companies** expect a large expansion of the wind parks and biomass in the future; however these companies have not shown any interest, or are unaware of the Superwind concept at the moment.

As already mentioned the Wind Unie is aware of theoretical possibilities and is awaiting further developments.

At the project level the expectations of possible partners for the project show the actors not completely convinced that the project can be realised.

GEM Zuidlanden is hardly aware of the project yet. They may have heard about it, but have not been approached directly. CFC Solutions thinks that the idea of Superwind could open new markets for the MCFC. But, it also mentioned that they were not very sure if operating the fuel cell in a flexible way is positive for the fuel cell itself. It could deliver too much strain on the fuel cell and therefore shutdown, or in the worst situation damage. They rather see that it is operated in the standard operation.

Delta Oil likes to see Superwind succeed and obtain hydrogen from a nearby renewable source. It also expects a strong demand for renewables and planning to further expand the amount of renewable fuel stations in Friesland

The core level consists of the actors that are currently the driving force and are positive about the concept. **Maike Bouma** is positive towards the project and thinks that if the project works, it will benefit a lot of farmers.

TU Delft has tested the feasibility of the project for SOFC, but still needs data on the MCFC. Their expectations are that these results will also show promise. The expectation is that the development of the project will take 2 years. The testing 1 year.

Nij Bosma Zathe expects that the Superwind project could be a demonstration project for the farm and that the knowledge diffusion is good because of the many visitors to the company.

6.1.2.6 Stakeholders' influence on developments

At the technological level the developments in sustainability have rapidly increased. This is because of subsidizing and a higher demand. For Superwind it seems that this is the right time to be developed. The Dutch government is opting for biomass and wind power as the main technologies to reach the 2020 targets. Superwind can be an excellent complimentary system to these technologies and offer many advantages.

However, obtaining a foothold for the construction of Superwind is not without problems. For instance, the lack of governmental guidance for long-term sustainability goals.

There are many sustainable technologies currently under development. Although, the Dutch government has set goals for the reduction of energy consumption., it has only stated how to reach the short-term goals for 2020. For this it wants to utilise technologies that are currently reasonably well developed and can be made operational in the next coming years. However, these technologies may provide quick results but do not form a long-term solution.

For the decision what the new energy standard will be, the government has decided to let the market decide for itself. Furthermore, the government has not set directives on how each regional or local authority should help achieve the 2020 results. This means the Groningen Province wants to mainly focus on strengthening their position as a knowledge centre in gas distribution. The Fryslan province has focused on solar energy. In practice this might hamper



the shaping of expectations for Superwind because it might not fit into the province goals. However, the trend in Netherlands is that sustainable innovations are better supported compared the last couple of decades.

A second obstacle is the obtaining a permit. Although strong improvements have been made in the area of public-private cooperation the obtaining of a license could take some time because many authorities have to agree with the construction of Superwind.

6.1.3 Finance opportunities for sustainable innovations in the Netherlands

One of the most common bottlenecks for the development of an innovation is a lack of finance. To overcome this dilemma, financial sources are made available to stimulate innovations, especially those which only succeed over a long period of time. The financial opportunities for sustainable innovation in the energy sector extent from the European level to a local level. These subsidies are specifically for sustainable solutions that strengthen the knowledge position of Europe, the Netherlands or even at a more local scale.

In this section a number of finance possibilities relevant to Superwind are described. The subsidy descriptions are from websites and have been translated into English.

6.1.3.1 European subsidy

The European committee wants to increase the European knowledge base and strengthen the economy. Therefore it is possible to apply for subsidies with the European committee if your project or study involves the cooperation of at least one other partner that originates from one of the European countries. The following subsidy is an example of this.

EG Liasion wants to stimulate the development of new products or services in cooperation with foreign partners. The reason is that the European committee wants to strengthen the market position of Europe and solving social issues. The European committee made 50 billion euro's available between 2007 and 2013 (Senternovem 2008b). The money is extracted from the KP7 program (het zevende kaderprogramma). That program is setup in such a way that it covers all research and development areas.

6.1.3.2 National subsidy

The Dutch government has improved the accessibility of subsidies. The ministry of economic affairs is head responsible for the availability of subsidies for sustainability. The ministry has founded a subsidiary service Senternovem to manage the subsidy application. The subsidies described in this section are also available at Senternovem.

The *SDE-subsidy* stands for Stimuleren Duurzame Energieproductie. The subsidy is the successor of the MEP-subsidy (subsidieregeling Milieu kwaliteit Elektriciteitsproductie) which was cancelled in 2006. The SDE-subsidy is aimed at projects in the area of renewable gas and electricity and compensates for their unprofitable parts. It is a more flexible arrangement which is able to adapt to market development and prevent over-subsidizing (Senternovem 2008b). Senternovem is responsible for the allocation of the SDE. The subsidy is applied more specifically to the systems that generate sustainable electricity or gas by waste



incineration, fermentation of manure, fermentation of green waste (fruit, vegetables, garden waste, and the thermal conversion of solid flows of biomass.

SDE also applies to on-shore wind farms and solar systems. The wind farms are subsidized for the amount of MWh delivered to the national electricity grid (€45/ MWh). In case of a year in which the average wind speed was low, the SDE is increased. The subsidy for solar power is meant for the solar roof panels and is based on a payback period of 15 years. For each KWh delivered to the national grid the operator receives 0,33 ct.

The *Energy research subsidy* (EOS). This subsidy program is setup by the ministry of economic affairs to stimulate innovation in the area of clean, reliable, and affordable energy management. The program is aimed at the whole cycle of energy management (source, conversion, transport, and consumption) (Senternovem 2008b).

There are four stages to which an innovator can apply:

1. The New energy research stage (NEO): This includes feasibility studies and the research and development to increase the scientific understanding of an apparatus, system, or technology, or its preparing for a technical setup.
2. The short-term stage (KTO): KTO is meant for the research –and developed project and feasibility studies. It is to support non-commercial projects. The applicants must be companies which are cooperating with other companies or knowledge institutes.
3. The long term stage (LT): This part of EOS applies to researchers that have promising plan which are likely to lead to a sustainable energy management. It covers fundamental research that is meant at expanding scientific knowledge bas, without industrial and/or commercial goals. But also industrial research that is used to acquire new knowledge in order to develop new products or services, which are an improvement on existing ones.
4. The Demonstration stage (DEMO): The subsidy is to support demonstration projects that either or a new system of a combination of already existing technologies that promise a new method of function in the area of energy management.

The subsidy for investments in the knowledge infrastructure (Bsik). This subsidy is aimed at five areas: micro/nano technology, Advanced spatial utilisation, ICT, Sustainable system innovation, and health, nutrition, genetics, and biotechnological innovations. The Bsik-subsidy only covers 50% of the project costs. The other 50% is to be paid by the involved companies (Senternovem 2008b).

Loan interest and/or Tax reduction for sustainable projects.

In order to make investing in ‘green’ projects more appealing, the government decided to provide tax reduction and/or a low loan interest for investors of sustainability. The criteria for these benefits are for the creation of environmentally friendly projects, but which are not economically viable yet. This includes sustainable power generation. (Senternovem 2008b)

6.1.3.3 Regional subsidy

Almost all the Dutch provinces have a subsidy arrangements to stimulate innovation in sustainability. All subsidies have in common that the project has to set in the province that awards the subsidy and that the project must be in combination with small and medium sized companies within that province. Not all of the subsidy arrangements are directly accessible for a university, but they are for local small/medium sized firms.



Two examples of such subsidies are given beneath.

*Regional Innovation Program Fryslan (RIPF)*⁵ is created to stimulate innovation. The program, also known as Fryslân fernijt, is erected in 2003 (Fryslân Fernijt I) and because of its success extended in 2008 (Fryslân Fernijt II) and ends in 2011 (Fryslân Province 2008). Head responsible for the management of the program is the department of Economy, Recreation and Tourism.

Through innovation, the province believes, the market position of Frysian companies and the economic growth can be improved. According to the Brochure Fryslân Fernijt II, the RIPF is aimed at experimental and risky public-private innovative projects in three areas: Recreation and tourism, Sustainable Energy, and Water. In the theme “Sustainable Energy” four categories are given: solar energy, clean propulsion, energy from waste, and urban energy reduction. To apply for this subsidy the project should not only fit within one or more of those categories, but the project’s approach to several issues must be clarified:

1. How will the project contribute to the enhancement of the regional cooperation in the Frysian energy sector?
2. How will the project strengthen the regional knowledge base and transfer between knowledge institutes and the regional trade and industry?
3. How will the project stimulate the development of new product-market combinations?
4. How will the project decrease the dependence on fossil fuels?
5. How will the project decrease CO₂-emissions?

Subsidy for sustainable energy and energy reduction in Overijssel.

In the province of Overijssel firms and organisations can apply for subsidy for studies and projects that lead the energy reduction and sustainable energy. Subsidies are available for the topics such as: bio-energy, energy reduction for industry and firms, energy reduction and sustainable energy generation in residential areas, energy in agriculture/horticulture, and energy and fuel for the transport sector.

The project has to take place in Overijssel, the feasibility study is finished within one year, and the project is concluded within 3 years after a subsidy has been rewarded (www.antwoordvoorbedrijven.nl 2009).

⁵ For more information about RIPF: www.fryslanfernijt.nl

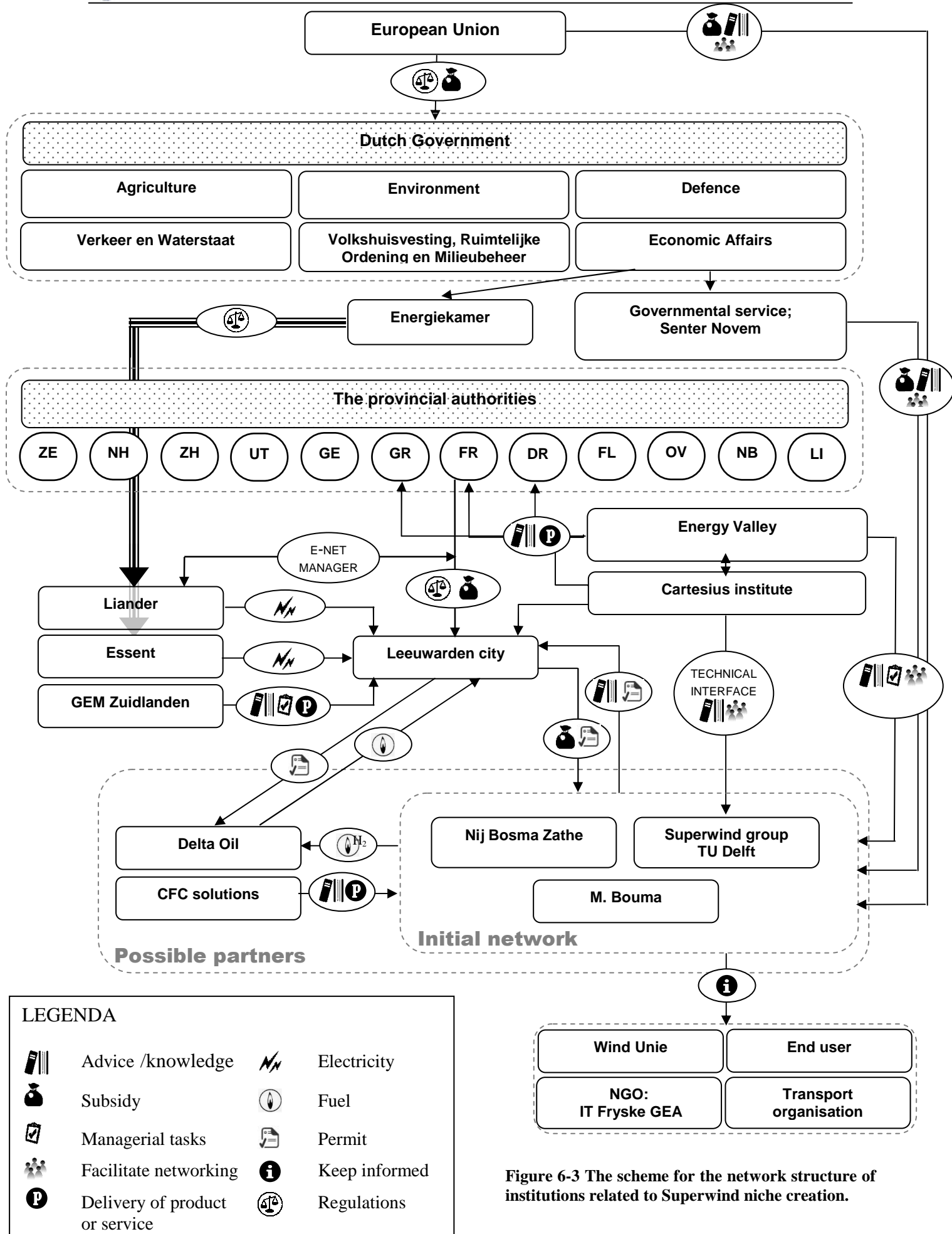


Figure 6-3 The scheme for the network structure of institutions related to Superwind niche creation.



6.2 Strategic niche management applied to the case study

The development of the Superwind is still in the initial stage. Therefore the technology has not yet proven itself. In section 6.2.1 “The creation of a niche” the information gathered first hand from the Superwind group is used to provide an insight in the accomplishments that the Superwind group has had so far. The next steps and recommendations provided in this section and sections 6.2.2 “The development of the niche” and 6.2.3 “The controlled phase out”, however, are based on theoretical expectations.

6.2.1 The creation of a niche

The experiment in Friesland is the beginning of the niche creation. To accomplish the construction, the right setting for Superwind is to be found, barriers are to be overcome, and more actors are to be attracted.

6.2.1.1 Superwind market niches

As mentioned in chapter 3 Superwind’s primary application is the levelling of a intermittent sustainable power source and secondly providing hydrogen to a fuel distribution point to stimulate the reliability of fluctuating renewable energy sources and the transition from an petrol based infrastructure to a hydrogen based infrastructure. To choose this setting the Superwind thinks it is possible to obtain a higher profit through a better matching of the sold wind energy to APX and the supplied actual wind energy. Furthermore, the better matching also decreases the balance costs. Also, being able to sell hydrogen will increase the profit.

To test the feasibility of this technology an experimental setup is to be constructed at Nij Bosma Zathe in Gouthum where the application will be the levelling of wind energy fluctuations and providing hydrogen to the nearby renewable fuelling station of Delta Oil.

The location at NBZ offers a number of important benefits to the pilot project:

1. NBZ is an experimental farm related to the University of Wageningen.
2. NBZ is part of the knowledge chain in the Northern region of the Netherlands.
3. NBZ is in possession of large fermentation processors which deliver biogas.
4. NBZ is situated in the Province of Friesland which has directed their policy towards becoming the most environmentally conscious province in the Netherlands.
5. The research facility holds over 200 cows. The biogas production is about 1,5 million m³ per year by fermenting a combination of cow manure and bio-waste.

The geographical benefits of NBZ are (Figure 6-4):

6. NBZ is closely located to a Delta Oil pumping station, which is the largest distribution point of renewable fuels in Europe.
7. NBZ is close to the Van Harinxma canal which is used for inland shipping and recreational boating. The province of Leeuwarden appointed several Frysian boat builders to construct recreational fuel cell boats.
8. NBZ is located near Leeuwarden's residential housing that could receive heat created by the fuel cell.

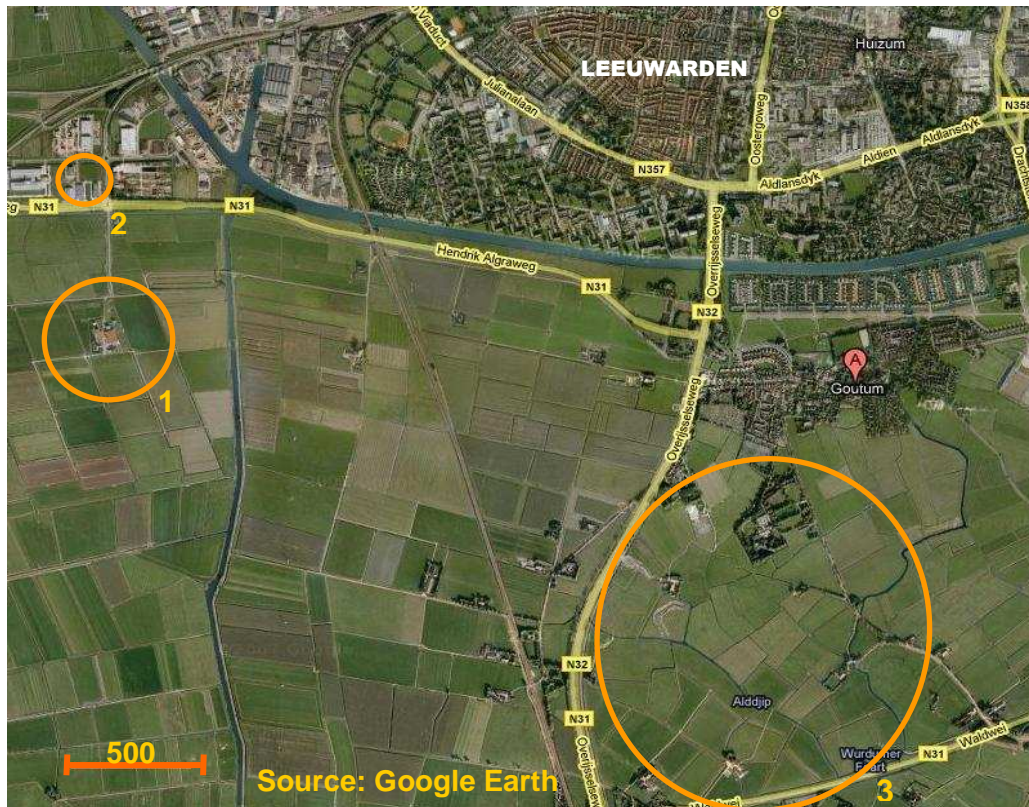


Figure 6-4 The position of Nij Bosma Zathe (1), Delta Oil (2), and the new planned residential areas (3).

How does the experiment set up at NBZ contribute to the three internal niche process?

Learning process

As an experimental farm of Wageningen University NBZ offers experience with the development of new technologies. The tested with a fuel cell before and is currently operating and testing a fermentation for the process of gas. Besides a research facility it functions also as a knowledge supplier (Nij Bosma zathe 2008).

Voicing and shaping expectations

Nij Bosma Zathe has facilities for knowledge dissemination. On average 2000-3000 people yearly visit the farm. It is close to Leeuwarden with over 90.000 inhabitants. NBZ is also part of the knowledge chain in Friesland which consists of several technical institutions and governmental services (Stuurgroep Gebiedsontwikkeling Nieuwstroomland 2008).

Network formation

The experiment will contribute to the sharing of expectations of actors. The experiment will be tangible and with positive results more actors will see the benefits of Superwind.



6.2.1.2 The conditions for the construction of a technological niche

For the construction of an experiment several barriers are identified:

The technological barriers

An IR-MCFC is not fully flexible. The performance of the fuel cell is strongly dependent on its operating temperature. This prevents it from rapidly increasing its electrical output. However, a rapid decrease is possible.

The improvement of the fuel cell flexibility will increase the return on investment because it can better follow the dynamics of demand.

Currently the spot market information is not accessible beforehand. The APX market does not have a signal that directly transmits information that shows whether there is a shortage or surplus. There is, in fact, an information delay to prevent suppliers from making a decision whether to supply energy or not.

However, with a direct signal the system would be able to adjust better to demand. The system could very well be used for net balancers.

Complementary technology.

Such a device is available at Fuel Cell Energy in the United States. The company, however, only delivers to the American market. Whether European companies are capable of the production of such a device is not known.

The costs of a Superwind installation need to be decreased.

For a market introduction it is important for the developers to strive to a low costs to make a system have competitive edge against the incumbent systems. More fuel cell research is needed to decrease the costs with the use of new less expensive materials, increase the life span of the system, and the reliability.

The institutional barriers

The province of Friesland made PV-technology its main focus point among the sustainable technologies. Choosing to level wind power at the experiment might have caused less interest. It is important to show that Superwind is also valuable for the levelling solar energy fluctuations to gain more support from the province of Friesland and the city of Leeuwarden.

Economical barriers

This barrier has a strong influence on the realisation of the project. The initial stakeholders who were contacted are not capable of investing in the project. The finance needs to be subsidised by authorities, such as the European Union, the Dutch government, or regional and local authorities.

There are many applicants and only a fixed total amount of subsidy available. That is why it is important that the sense of urgency for this project is clear.



Managerial barrier

The initial stakeholders do not have the personnel capacity to oversee the realisation of the experimental setup. There is a possibility that Energy Valley will put forward a project manager.

The drivers for the construction of a technological niche

Currently the political climate is in favour of the stimulation of sustainable innovations. Many subsidies are available in order to help finance the construction of a pilot project. However, here is key that the project's benefits are clear to the subsidy provider.

Governmental services are founded to assist not only financially, but also provide advice, facilitate networking, and even in managerial tasks.

The public awareness for the need of a more sustainable way of living is growing. The media spends attention to sustainable method of generating electricity and transport fuel.

6.2.1.3 The initial stakeholders' participation

The creation of an actor network

Until now, the actor network has been created by the efforts of M. Bouma and K. Hemmes. They contacted Nij Bosma Zathe, Delta Oil and CFC solutions. However, these are just the technological partners.

These actors made it clear that more actors are needed. Neither one is capable of financial support or has the personnel to complete such a project. Therefore there are partners needed that are able of either finance or managing the project.

According to Mark de La Vieter at the research institute Cartesius Institute the north regional cooperation Energy Valley is able to assist in providing a project manager and facilitate in expanding the actor network.

Most subsidies that are available for Superwind (Section 3.3.3) are either awarded by Senternovem or can be requested at or with the help of Senternovem.

Momentarily, the initiative for the expansion of the network lies with the Superwind group at the University of Delft. To set things in motion a business plan for Superwind is needed.

6.2.1.4 The actors involved with the construction of an experimental setup?

For the construction of the pilot project actors in various fields are required.

For the technological part of the construction:

The Delft University is involved in the primary stages of the setup of Superwind, but will only contribute in performing fundamental research.

CFC solutions: The company manufactures a molten carbonate fuel cell of 250 KW. The group is interested in the experiment. The fuel cell costs are not carried by CFC. The company will help where possible with the construction of the fuel cell and likes to have access to the data. The spokes has shown an interest in the participation in a Superwind consortium.



ECN: The Dutch research institute can be a good partner in the development of the product towards a market proof technology. The company performs research in the area of fuel cells and gas separation device. The practical design of Superwind is not ready yet. Perhaps ECN is able to design it.

FCE: IT is known that FCE has hydrogen separation technology. The only drawback is that it seems only to be active in the United States and it is unclear if it is possible to have them construct such a device.

Delta Oil: The construction of a hydrogen pump at the Leeuwarden fuel station is the responsibility of Delta Oil.

Essent B.V.: For the practical connection to the electric grid and the sale of energy Essent B.V. should be approached. The company already has a contract with NBZ for the delivery of electricity and heat to the grid. Essent is the netmanager in which NBZ is resides.

In the area of safety **the fire department** needs to be involved .They provide safety advice and inspection of the experiment.

Nij Bosma Zathe: This actor offers the location for the test project. It offers good facilities and knowledge dissemination. The farm is familiar with experiments and can be responsible for the practical daily operation of the Superwind system.

For the political and financial part:

Financially this project is a typical long term project from which its future is uncertain. That is why it is unlikely that companies want to invest in its development. Subsidiary services, such as **Senternovem** should be approached and subsidy programs, such as EG Liason should be applied to.

The **province of Friesland** and the city of **Leeuwarden** are key players financially and because they have a strong blocking power. If these authorities are not convinced a building permit is not awarded.

6.2.1.5 The coordination of actors and strategies be coordinated

To regulate the involvement of actors and coordinate the strategies for the development of Superwind a consortium is created. The manager can be from either one of the consortium companies or external from an engineering company. The consortium will advice the project manager.

The manager is in responsible for all matters related to Superwind and its daily operation; operating method, the sale of the products, and knowledge dissemination.

Essent is strongly involved with the arrangements of infrastructure connections and the net regulations. Furthermore, the contract that Nij Bosma Zathe has with Essent is to be expanded to include the Superwind installations or a new contract is signed which ensures the collaboration with Essent for the duration of the experiment.



The design and the construction of the installation at Goutum is outsourced to an engineering company. Energy Valley can advise the consortium on the appointment of an engineering company.

The supporting partners are ECN and FCE are involved for the construction of the production. For both parties financial compensation is needed.

Essent is to be attracted as an advisory partner for its knowledge of the electricity market.

6.2.1.6 The stakeholders' expectations for Superwind?

The actors find the product promising, but the research done until now is fundamental research which has explained the economic value of Superwind. The actors want more concrete data which show what the environmental contribution is; the reduction of emission and energy use. Furthermore, the province is interested but also wants to know how the system can contribute to the knowledge base in the region and eventually to the regional economy.

CFC solutions finds it an interesting project, but is afraid the flexible operation method will cause problems for the fuel cell.

6.2.2 The development of the niche

This phase reflects on the exploration of the experiment; striving to a reduction of costs and to improve the technology.

6.2.2.1 The conditions for the development of Superwind

After the testing period within a controlled environment it can be chosen to redefine the goal of the experiment. Depending on the state of the technology the system can be joined up with another experiment.

This will improve the three internal niche processes. The scope of the research can widen which means more can be learned about the technology. It increases the number of actors involved which means more actors will share expectations about Superwind. With more actors from different experiments those expectations become more robust.

An example of the joining up of an experiment is given Figure 6-5 The schematic representation of the Superwind Test setup within the Delta Oil energy network.. It is a suggestion by Delta Oil. The fuel distributor is working on the construction a geothermal plant and sees how Superwind can become an integrated part of network of sustainable energy systems.

Several conditions will still need to be in place:

For the development of the experiment preferential treatment is needed. The electricity generated by the Superwind connection should fall under the grid priority rule for sustainable electricity generators.

Subsidy is needed for the unprofitable part of the wind turbine. This is an indirect subsidizing of Superwind.



The development of the technology requires further investment by the actors. The costs for the investment of and exploitation is subsidized for the large parts by authorities. However, research costs for the improvement of the system need to be carried by the participants.

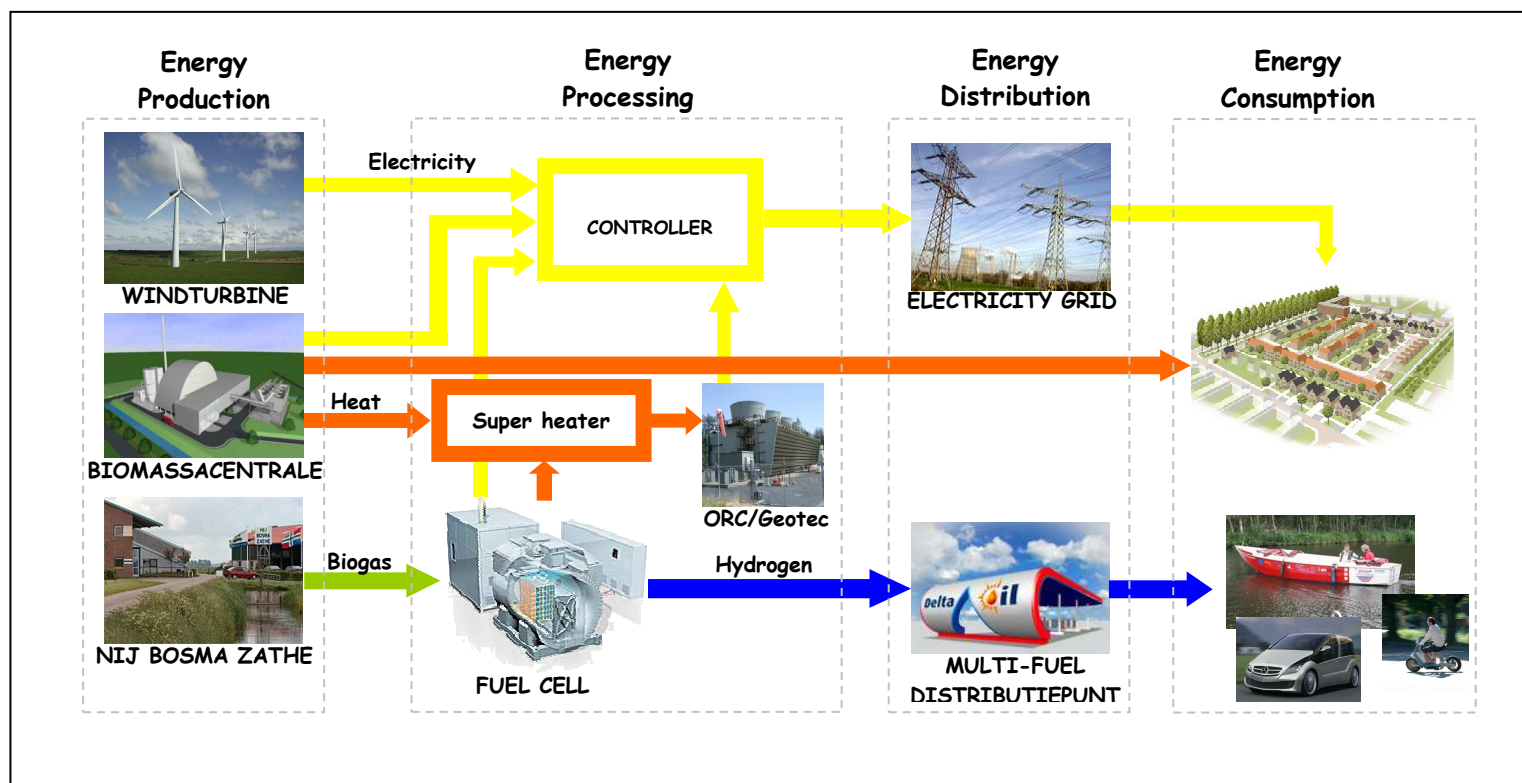


Figure 6-5 The schematic representation of the Superwind Test setup within the Delta Oil energy network.

6.2.2.2 The stakeholders' participation in the development phase

The stakeholder involvement in niche development

The consortium still maintains its participants;
CFC, TU Delft, Essent, NBZ, Maïke Bouma, Delta Oil.

In addition;

Hydrogen car manufacturers, municipality of Friesland, public transport company

The coordination of actors and strategies

The consortium will maintain its initial partners. The goals after the first experimental period of Superwind are redefined.

New goals include which niche market is addressed and what strategy should be followed.

The changes in actors' behaviour

The actors are expected to either lose interest due to non-satisfying results or increase interest due to new positive results. If the results are positive the commitment of the initial partners in the consortium remains.

As more results are released, more interest is to be expected from other (external) actors.

With Superwind technology in different settings the robustness of shared expectations increases. This attracts more actors.



6.2.3 Controlled phase-out

6.2.3.1 The market niche

The niche market of Superwind in Friesland will be exactly the same as for the whole of the Netherlands:

1. **The compensation of fluctuating power to alleviate the imbalance on the electrical grid.**
Applications: fluctuating power source compensator or fluctuating power compensator for the grid (power reserve)
2. **A local source for the production of hydrogen and electricity.**
Application: Hydrogen fuel provision for the transport sector and an addition to industrial or chemical processes

The development of Superwind technology will also provide Friesland and Leeuwarden with an impulse in their knowledge base on hydrogen technology. The experiment is not to become a behind-closed-doors experiment but will involve many companies with its construction and further development. From the knowledge chain to installation companies.

Furthermore, the experiment aids in achieving Friesland's reduction goals of energy and greenhouse gasses.

6.2.3.2 The conditions for the market introduction

- The introduction of Superwind to the market will, as wind turbines, initially will need financial protection. The investment of the technology is still high.
- The electrical infrastructure should be upgraded to a level where it is capable of more adding more sustainable power systems. (decentralized and centralized)
- It is also desired that transport and storage for hydrogen is improved.
- Furthermore, the presence of hydrogen powered vehicles also aids in the acceptance of the market.

6.2.3.3 Stakeholders' participation

The actor network will remain important with the controlled phase-out. The product is still new and needs to be advertised. The actor network will have to involve more actors to promote the technology.

The stakeholders involved with the niche phase-out

The stakeholders are CFC, TU Delft, Essent, NBZ, Maïke Bouma, Delta Oil.

A strong relation is to be kept with:

Hydrogen vehicle manufacturers and public transport companies, and Dutch government.



The coordination of actors and strategies

Before the product is released to the market it is important to know how the product will be sold. It is important to have a group committed to the marketing of Superwind. The partnership could have several options:

1. A spin-off company is created.
This company will consist of several employees of each of the actors within the partnership.
2. One of the partners buys out the other partners.
If it is expected that the production of Superwind provides a significant profit, one company could decide to buy out the other partners. This is often done when some actors do not wish to exploit the product.

However, it is imperative for the diffusion of Superwind that one central player is responsible for its marketing and production.

6.3 Discussion

The socio-technical map in chapter 6 is, in fact, an extensive stakeholder analysis. The information gathered about the technological development in Friesland is comparable with the technologies shown in chapter 3. To do an analysis of all the sustainable technology applied in the province of Friesland would be more fitting for a comprehensive socio-technical map, however, such analysis would not fit into the time frame set for this thesis.

The technology assessment did describe the preferred technologies and project by Friesland. The stakeholder analysis of the socio-technical map shows the many actors involved with the creation of a pilot project. The problem owners for the case study are Essent who is the net manager for the Leeuwarden area and Tennet who has to cope with the net congestion in Friesland. Important actors for the creation of a pilot project are the provincial and regional authorities. Their cooperation is important for the facilitation; subsidy and permit allocation. With SNM a description of a strategy for the development of Superwind is given. The first section about niche creation could for the larger part be answered with actual data retrieved from the Superwind group. The section about niche development and controlled phase-out were based on theoretical expectations. That is why these sectors have shown similarities with chapter 5 of this report. When comparing the steps that the Superwind has already taken to the strategy proposed for the general strategy discussed in chapter 5 it is possible to state that the Superwind group has initiated the steps to create a niche. Actors have been attracted and test facility has been found. The actor group consists of a knowledge institute (TU Delft), a promoter (Maike Bouma), a fuel cell manufacturer (CFC Solutions) and a fuel distribution point (Delta Oil).

The test facility Nij Bosma Zathe is an experimental farm of Wageningen University and is geographically well situated for a superwind pilot project; close by Delta Oil and access to biogas. Furthermore, Nij Bosma Zathe is familiar with experimentation and knowledge diffusion. The farm does not only receive many visitors each year but is also part of the Friesland knowledge chain which has as main goal knowledge dissemination.

Thus, the test location which facilitates the three internal niche processes which are according to Kemp (1998) recommended to work well, if an innovation is to be successfully developed.



When comparing the general strategy for the Superwind group, it can be stated that they are in the right direction for the implementation of Superwind. Currently, their next move is to create an actor network that will support the construction of the pilot project. Thus far, there are several steps that still need to be taken.

1. The actor network should attract more partners.

The network consists of partners that provide technical support and scientific knowledge, but it is missing the following partners:

- A manager who will oversee the construction and operation of the project.
- A design firm which will be design the technical design of the pilot project.
- A manufacturer for complementary technology.
- The fuel cell is not enough. A system that separates the hydrogen is needed, hydrogen (and storage) transport technology
- A political figure is a strong addition in the voicing of the technology at the political level.
- A financial investor is a must. Currently financing is not arranged for the pilot project. The investor can be the authorities or a private investor.

2. Address more market applications.

The focus of the group lies on one test facility with the primary goal to test the compensation capability of the fuel cell for wind power and the secondary goal of delivering hydrogen to a fuel distribution point for personal transport. The testing facility seems perfect, however, the goals of the experiment should be re-evaluated.

- The fuel cell manufacturer is not keen on the rapid switching between modes. This is needed for the compensation to of wind power. If, the goal would be to function as 8-hour-ahead-power reserve the stress load on the fuel cell.
- The second goal of delivering hydrogen for the transport sector is a risk. There is too much uncertainty whether hydrogen will be the next transport fuel. Finding other purposes is a must.

3. Search for more test locations in the Netherlands.

There is a mismatch between the chosen sustainable technologies of the province of Friesland and those for initial testing of the Superwind group. Each province has there own sustainable goals and preferred technologies. Therefore most provinces facilitate sustainable innovations in different networks and with other means. It is recommended that test locations in other provinces are analysed.



7 Conclusion, discussion and recommendations

7.1 Conclusion

This research was firstly aimed at gaining insight into the barriers and drivers that the Superwind innovation might encounter when introduced to the market in the Netherlands. Secondly, the research translated those barriers and drivers into strategy for the development of Superwind.

To perform this research three methods were applied; Socio-technical mapping, backcasting, and strategic management. The first subquestion to this research “What are the drivers and bottlenecks that are already a result of the current state of technological and social development?” is answered with the socio-technical map.

The technology of Superwind was discussed and with it the many applications this technology can have because of its multi-source / multi-output character. An analysis of technologies for the compensation of fluctuating power sources or the production of hydrogen revealed that there is no other technology currently available that offers an integrated solution capable of flexible tri-generation with the same high efficiency as Superwind. Some of these technologies do offer a less expensive solution to one of the applications of Superwind.

The analysis of the user side showed that the need for hydrogen is growing, however, not because of demand from the transport sector. It is the industry sector that has an increasing demand for hydrogen which is mainly used in chemical processes. The hydrogen transport sector is still plagued by the chicken-or-the-egg dilemma. The research and development of a hydrogen transport infrastructure is virtually zero in the Netherlands.

The user side also showed that there is a demand for a local buffering technology to solve the issue of fluctuating power at the source. As the government promotes the increase of the share of sustainable power in the total Dutch energy production mix so does the demand increase for an adequate solution to the integration of renewable power sources. The infrastructure is far from ready to handle the expected increase in fluctuations and concentration of local power generators.

The stakeholder analysis discussed numerous actors related to the development of Superwind. Because of the multi-source / multi-output character the actors network is extensive. Each source and output addresses new applications and with it new actors. This research has been constrained to the actors related to the primary goal of compensating wind fluctuations and the secondary goal of hydrogen production for the personal transport sector. Each stakeholder was analysed for its expectations of Superwind and their technology preference. While researching actors' behaviour it became clear that the cultural and social conditions are accommodating for Superwind.

The public awareness of sustainability is growing. People are choosing more environmentally consciously. This results in companies who are working to create a ‘green’ image to attract customers. To further their sustainable image, these companies are looking for more possibilities to expand their knowledge base for sustainable solutions. This shift has initially been influenced by new environmental policies which made the production of greenhouse emissions and the high consumption of power more costly.

The political climate for a sustainable project is also better than ever before. Today, sustainability is a hype. The item is high on the agenda and politicians are susceptible to development of sustainable innovations. A variety of funds is available for sustainable projects and the trend is that that variety is expanding.



The second and third sub-question are answered with the backcasting method.

- What are the drivers and bottlenecks that are already a result of the current state of technological and social development?
- What potential role can Superwind fulfill in 2050?

The method is used to explore the possibilities for the diffusion of Superwind which aided in providing a sense of direction for the design of a market introduction strategy, but also to show what the future potential of Superwind can be. This led to developing scenarios that showed the role of Superwind 2050 and its impact on the energy supply mix. By analysing which steps are needed to reach that scenario one is able to identify the means necessary for reaching those scenarios and the bottlenecks that are encountered on the way towards those scenarios.

The scenarios were based on an energy scenario by ECN. The ECN scenario specifies a detailed overview of the expected energy mix in Europe. It included the necessary technological and institutional steps. This scenario's targets were the energy and emission reduction goals that the Dutch government signed for at an European level in 2020 and 2050. It showed that unless a change occurred for which the Dutch government is mainly responsible those goals would not be reached. This provided a background which allowed the goals, targets and constraints to be quantified. In addition to this report the 2008 Energy report was used for further information on energy variables.

The two scenarios differ in technical setup: decentralized and centralized. However, it became clear in the analysis that they also differ in actor participation and societal impact. The decentralized setup is derived from the launch concept which functions as a local buffer to wind energy. The goal for this scenario is to compensate for all wind turbines by 2050 in the Netherlands. The centralized setup of Superwind was, in fact, the replacement of the spinning reserve. The goal here was to compensate all grid imbalances in the Netherlands by 2050.

The decentralized setup already has one problem and that is the power-up time needed by the IR-MCFC. It is not capable of quickly ramping up power which means that compensating quickly for wind power can be problematic. If the IR-MCFC is to act as power reserve which must be available within an 8 hour time frame, the IR-MCFC has enough time to ramp up. When MCFC technology has progressed up to a point where it can rapidly adjust to demand, it can be used for the power reserve that is to be available within 15 minutes.

The decentralized setup needed for the development of Superwind to involve more actors than the central setup. With the central setup the actor network was constraint to several utility companies and Tennet. For knowledge diffusion it is a logical expectation that more actors means a higher diffusion rate.

Financially, the scenarios also differed. The actors involved in this setup all cooperated in the beginning on a voluntary base, while in the central setup the actors participation was compulsory. The central setup does offer more security. The decentralized diffusion could fail on a lack of actor commitment.

From the results of the two scenarios a new setup for the diffusion is proposed that would reap the benefits of both scenarios. The new setup is a decentralized IR-MCFC that acts as power reserve. Such a system has the following advantages:

- Acting as power reserve that has to be available within an 8 hour period is possible with the IR-MCFC. When the technology develops further, it is expected that the power-up time will shorten, which means that eventually it might also be available within 15 minutes.



- More actors are likely to be involved with a decentralized diffusion, while a single centralized experiment is more likely to stay within a small group of actors.
- A large scale centralized power source can only solve net congestion in the whole of the Netherlands if the transport capacity is large enough. Therefore it is more likely to have distributed power reserves which can locally compensate grid imbalances.
- A decentralized diffusion can benefit small to large scale actors due to variable size.
- This setup does not require a fluctuating power source such as wind turbines or solar panels like the launch concept.
- In the beginning an intensive network for the distribution of hydrogen is not necessary. With decentralized distribution the goal of supplying hydrogen to fuel stations can still be addressed if wanted.
- As technology matures this setup provides benefits of both scenarios because the technology is then able to still connect to a wind turbine or other intermittent power sources.

For this proposed setup general follow-up steps are suggested which can set the trend in motion for reaching that scenario. The first step is forming an actor network. This is mostly likely to take a consortium form. The second step is to decide upon a final design for the experimental setup. This steps suggest the forming of a protected environment.

The third step would be testing. Parallel to these steps the consortium needs to focus on political lobbying and the application for grant and subsidy programs. More details of the follow up step were given with strategic niche management.

Strategic niche management is applied to devise a strategy for the development of Superwind within a niche and eventually introduce it to the market. The strategy is based on the proposed setup derived from backcasting, namely decentralized IR-MCFC power reserves. The first stage of niche management was the creation of a technological niche. Therefore the setting in which the advantages of Superwind should be nurtured was chosen. To understand what setting would be appropriate for Superwind the current technological barriers were taken in account.

Furthermore, the settings must also be able to facilitate the three internal niche processes; learning processes, voicing and shaping of expectations, and network formation. Next, the drivers to utilise and the barriers to overcome for the creation of an experiment were discussed. Eventually, the initial stakeholder's participation with the niche creation was discussed. This included the necessary stakeholders and their coordination.

These steps have been taken for each stage; The development of the niche and the controlled phase-out. The results of SNM were recommendations and suggestions for the development of Superwind about the coordination of stakeholders, the possible niche markets, and the strategic milestones which are the steps that need to be taken.

From studying the case of Nij Bosma Zathe it is shown that the Province of Friesland has high ambitions. It wants to become the number one province in sustainability in the Netherlands. Investments are made in solar power and biogas development. These conditions are right for Superwind. It can compensate the solar power fluctuations and convert the biogas in a more efficient way than is currently done in Friesland, namely with gas turbines. Currently, Friesland is involved with the development of biogas as a transport fuel.

Friesland's direction of focusing on solar power and biogas might object with Superwind's intentions of compensating wind power and supplying hydrogen.



The first steps for the development of the Superwind have already been undertaken by the Superwind group. The group has contacted several companies and government officials. From the meeting with fuel cell manufacturer CFC Solutions, and sustainable fuel distributor Delta Oil it became clear that these companies were willing to cooperate. However, if a consortium is to be founded it should contain more actors. Nij Bosma Zathe has agreed to facilitate the experiment. CFC is at the moment capable of delivering an IR-MCFC. It is one of the most commercially advanced IR-MCFC available in Europe. Delta oil has a gas station in Leeuwarden close by the NBZ. It is the largest renewable distribution point for the transport sector in Europe.

The test location in Friesland seems to be ideal for knowledge diffusion. NBZ is able to receive visitors that are interested in the technology. It is connected to a chain of knowledge institutes within Friesland. From a technical aspect it is capable of facilitating the experiment. It is familiar with research and development being a experimental farm of the Wageningen University. The geographical situation is close by a fuel distribution point that is able to facilitate a fuel pump connection. The farm also has a connection to the grid from an earlier experiment which consisted of biogas conversion with a gas turbine.

7.2 Discussion

The effects of climate change have created a hype around the notion of ‘being green’. Politicians have put energy and sustainability higher on the agenda than ever before. The political influence has been translated in new policies, services, and regulations to promote the use and implementation of sustainable solutions. Many possibilities have opened up for the development of sustainable innovations. The cooperation between the government and the private sector in the area of sustainability has increased. Policies have sharpened to provide a stimulating environment for entrepreneurs to develop sustainable technologies quicker with the result of a higher chance of success.

As industry feels the pressure of the stricter regulations they are more active in the area of sustainability. Therefore industry has developed a keen interest in the development of sustainable technology.

There are many technologies available that are able to fulfil the same applications as Superwind, however, there is no integrated system available which is capable of flexible tri-generation with a similar efficiency. The competition of other technologies, at the socio-technical regime and even at niche level do hamper the diffusion rate of Superwind. This is mainly because they provide a cheap alternative to one of Superwind’s products or applications.

Hydrogen production is one of the applications that provides Superwind with its uniqueness and is, in this report, presented at a stimulant for the development of a hydrogen infrastructure. Several factors may impact that goal:

- The law and regulations are not yet adjusted to hydrogen technology and infrastructure
- Hydrogen technology, such as transport and storage is not yet well developed.
- The Dutch government is leaning towards the implementation of the electrical car, because their expectation is that the battery issue which hampers the electrical car is to be overcome within a decade. The positive expectations of politicians about the electrical car is created by the fact that the developments in the area of battery technology are at a high pace due to huge interest originating from high-tech companies that develop mobile devices.



Although Superwind is presented as a stimulant, there still has to be a certain demand for hydrogen from the transport sector, to convince and attract actors to invest and implement Superwind installations. The demand could come from authorities that promote the hydrogen cars or because hydrogen cars are available in the Netherlands on a commercial market.

Hydrogen for the transport sector is in this report taken as its sole target market for hydrogen. It is important to attract other parties that might be interested in Superwind for different applications.

There is a strong demand for sustainable solutions that act as a local buffer for wind turbines.

The method of spinning reserve, which is currently used, is not sustainable. This means that a part of the renewable power produced is offset by the extra energy needed to compensate. The use of spinning reserve is nothing more than fighting symptoms.

Superwind delivers an efficient compensating process and as a local buffer it solves the issue at the source. It is not just a sustainable solution due to its high efficiency, but if operated on biogas it is even a renewable power source.

Methodological reflection

Firstly, this reflection will discuss every method applied separately. At the end of this methodological reflection the overall use of these methods will be discussed.

Socio-technical mapping

The ST-map was quite comprehensive and possibly it has been applied too extensively for this report. Most likely, the problem orientation suggested by Quist's question list would also suffice for this research. Moreover, the ST-map did lack specific questions about the connectivity with incumbent technology and logistics. Furthermore, the policy which will influence the development progress of Superwind is also not mentioned specifically. These factors can, however, be mentioned for a study about other technologies that have already developed to a certain point or have failed because of them. With these factors added the socio-technical map provides enough information to identify the drivers and barriers.

Backcasting

The Quist model provided a good basis for the application of backcasting. The checklist that Quist created has helped building the scenarios.

The model promotes the creativeness of the backcaster when designing a future scenario by letting him, directly after analysing the present system, design future scenarios. The fact that the scenario designer is largely unbounded by constraints enables him to be more creative compared to the Robinson method.

For this research, however, the Robinson quantitative approach is a good addition to providing the target group of the thesis with realistic scenarios. Thus, providing a clear picture of the potential role a Superwind installation can play in the future.

There is the danger that the line between forecasting and backcasting is unintentionally crossed.

The model to which backcasting was applied in this research had a couple of flaws:

- Due to the many calculations and constraints before creating the scenarios the part of defining the milestones per decennia seems redundant. These milestones, however, do not solely reproduce the calculated result, but also add the necessary qualitative steps to reach these scenarios.



- The calculations in this report for backcasting could be an overkill to readers who are only interested in the result.

The use of two scenarios provided good insights into the Superwind diffusion possibilities. One scenario would not have been sufficient and other scenarios would only explore variants of these two scenarios.

The use of an ECN scenario provided exogenous variables; the future energy mix and the number of hydrogen vehicles.

SNM

The use of the SNM policy tool seems only possible if enough information is provided. For the creation and development of the niche, one can still rely on information gathered with the ST-map. However, when asked to describe the further progress of the niche development of Superwind and its controlled phase out it becomes speculative due to lack of information.

The use of SNM to describe the development of a niche for Superwind really demanded to think about the three internal processes.

SNM was the starting point of this research purely because it was already known through participation within the Superwind group that a protective environment for the nurturing of Superwind was favoured, although in fact, the choice for strategic niche management could also follow from the results of backcasting where one of the follow-up steps would be to form a niche for Superwind.

Overall method:

The combination of the three methods provides an in-depth research, more complete than if only one of these methods was used. It can be questioned whether the depth is necessary for the goal of this research and its target group. To my opinion this research could also have been performed by applying solely Quist's general model of backcasting. The depth and scope of the problem orientation could have been enough for this research. Furthermore, the milestones and follow up steps of backcasting could have provided the target group with sufficient information.

The socio-technical map is used as the problem orientation for backcasting and the analytical tool for strategic niche management. This has proven to be possible, although certain factors needed to be added to have a clear picture.



7.3 Recommendations

Recommendations for the further development of Superwind

Analyse other technology mixes

Superwind is currently presented as a solution to the compensation of wind power. However, there are a number of applications. To address different actor networks a technical analysis of a Superwind setup that shows the impact of the technology will aid in convincing them.

Change the startup focus

Because the fuel cell is not yet able to compensate on short notice, it might be interesting for the first experiments to focus on a system of collaborating with the Dutch grid manager to compensate for predictable grid imbalances.

Investigate other testing locations

Several provinces may have a different focus on sustainable technology and some conditions might be more favourable to Superwind than others.

Attract more actors to the network/consortium

The consortium will benefit from more actors that supply labour, knowledge, financial investment, complementary technologies and a political influence. Especially a cooperation with knowledge institutes, possibly even internationally, might further rapid learning about the innovative applications of fuel cells.

Lobby for hydrogen technology

The Dutch government currently seems set on promoting electrical technology. The Superwind Consortium should actively lobby for better understanding of hydrogen technology, a more appropriate regulation of its safety and quality and the promotion of its economic application.

Find collaborating partners in adjacent markets

To voice Superwind technology, do not solely focus on one market. Try to find other companies that are also looking to develop flexible IR-MCFC technology but for another markets.

Actively market fuel cell technology

While Superwind relies mainly on fuel cell for flexible tri-generation, fuel cells might be a very efficient solution in any current fuel consuming system. As a transition technology before society reaches a point of using 100% sustainable sources, fuel cells might be a stimulating and appropriate intermediate technology. It will at the same time greatly increase research in fuel cell technology and thus increase development of more flexible and responsive fuel cells for Superwind.

Recommendations for the methodology

Implement a quantitative backcasting model only when realistic scenarios are required.

The backcasting model applied in this research was quite comprehensive. It provided a strictly constrained scenario, which may not be useful nor appropriate in all situations.



A method for the socio-technical analysis which aims specifically at radical technologies is to be developed.

The socio-technical map is a comprehensive model. However, it proved not to answer certain questions specific to radical innovations that are still in a research stage. Another method that would aim at areas where the main barriers and drivers for radical innovations apply, might more appropriately target the analysis. This can provide a clearer picture.

Develop methodology for strategic niche planning

The theory of SNM is currently insufficiently developed to cope with both the need of planning ahead for a strategic niche, as with Superwind, and dealing with the processes occurring during niche phases. It is recommended that a new methodological instrument is developed, specifically tailored at designing a prospective niche strategy. A toolbox, helping researchers in answering specific (sub-)questions regarding niches would also be a valuable addition.



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Appendix A: Fuel cells

A.1. Introduction

Fuel cells are interesting because their conversion efficiency is higher than the conventional methods of burning fossil fuels. Unfortunately, the cost of a fuel cell is very high because the materials needed for a power cell are expensive. The research of fuel cells is far from matured and economies of scale are not reached yet. However, fuel cell systems are really up and coming. The industry is moving forward into introducing fuel cell systems to be used for the automotive industry (pictures on the right), stationary applications, such as back-up power or as power generators inside a chemical process (AkZo, Delfzijl).

The most commonly used is the polymer exchange membrane fuel cell (PEM). This cell is because of its characteristics and its low price an interesting cell to replace power generators. The cell has a low operating temperature and ($60-90^{\circ}\text{C}$) and has a quick start-up time. But, the PEM cell has the lowest efficiency ($\pm 35\%$) among the fuel cell types.

High temperature fuel cells are slowly reaching the market. The high temperature fuel cells have a couple of advantages in comparison with the low temperature fuel cells. They are more efficient and less sensitive to impurities in fuel.

People associate fuel cells immediately with hydrogen fuel. The hydrogen enters the fuel at the anode side and oxygen, or air, enters on the cathode side. An electrochemical reaction takes place between hydrogen and oxygen which are combined to water and releases electrons which in turn lead to a current.

However, a fuel cell is also capable of producing hydrogen. In PEM electrolysis device the opposite reaction delivers hydrogen. Electricity is consumed and water molecules are split up into hydrogen and oxygen.

A second method is the reforming of natural gas. Momentarily around 48% of the worldwide hydrogen production is done by steam methane reforming. (Dunn 2002) However, the reforming of gas can also be done by an internal reforming fuel cell as well as an molten carbonate fuel cell.

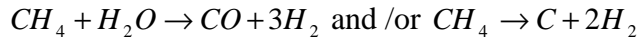
To build up towards explaining the Superwind concept the reforming method with high temperature fuel cells will be explained in paragraph A.2. More information about the types of fuel cells can be found in the at the end of Appendix A.



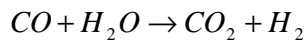


A.2. Tri-generation with an internal reforming fuel cell

The internal reforming process basically has two steps. Firstly, the methane, from which natural gas mainly consists, is combined with steam (700-800° C) and reacts into synthesis gas (syngas). The hydrogen atoms are then released from the hydrocarbons. (NYSERDA 2006)

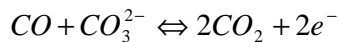
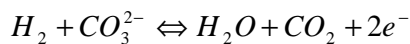


Secondly, the resulting CO is lead through a water gas shift reactor to release more hydrogen molecules. This is done by adding steam. This happens in two stages. A high temperature shift (HTS) at 350°C and a low temperature shift (LTS) at about 200°C

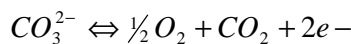


A solid oxide fuel cell (SOFC) or a molten carbonate fuel cell (MCFC) is capable of internal reforming due to their high operating temperature, between 800-1000°C and 600-700 °C respectively.(Heidebrecht and Sundmacher 2003) A great advantage of internal reforming fuel cells (IR-FC) is that the heat produced by the oxidation and reduction reactions is more than enough to sustain the endothermic reforming reaction process. As where more energy loss occurs when an external reformer is used.

Furthermore the hydrogen and carbon monoxide bind with carbonate at the anode and produces a current.



At the cathode the following reaction occurs:



In Figure A-1 a schematic picture is given of an IR-MCFC that clarifies the workings of internal reforming fuel cell.

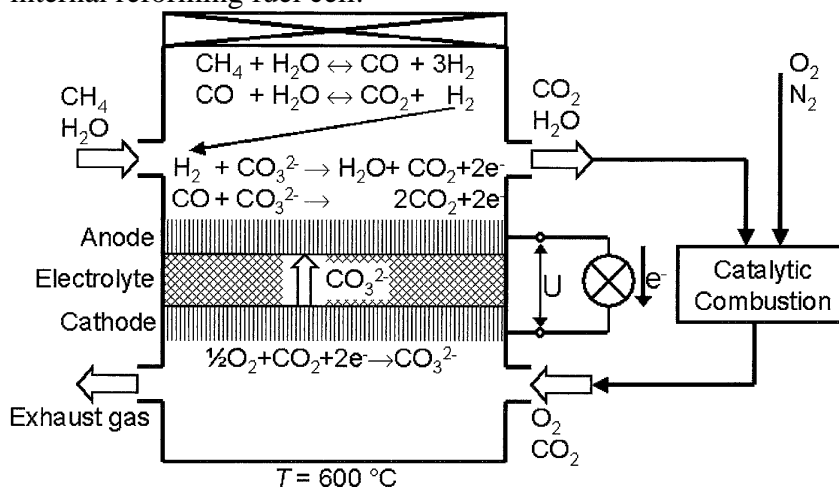


Figure A-1 The working principle of a MCFC with internal reforming. (Heidebrecht and Sundmacher 2003)



A.3. Flexibility with a high temperature fuel cell

When research was performed by K. Hemmes and A. Patil on the integration of hydrogen into the natural gas network for the Netherlands (Hemmes et al. 2005) alternative hydrogen production methods were explored. The IR-SOFC showed to be a good alternative to steam reforming and produces hydrogen in addition to electric power. Flow sheets with Cycle-tempo were made with cycle tempo of an SOFC in the following operation modes (Figure A-2).

a. High efficiency mode

The input of natural gas is kept constant and the current density decreases thereby decreasing the fuel utilisation.

b. Constant current density mode

The current density is constant while the input flow is increased which results in a decrease of the fuel utilisation.

c. High power mode

In this mode the cell voltage was kept constant (0.5 V) giving high current densities. The increase in input flow causes a decrease in fuel utilization.

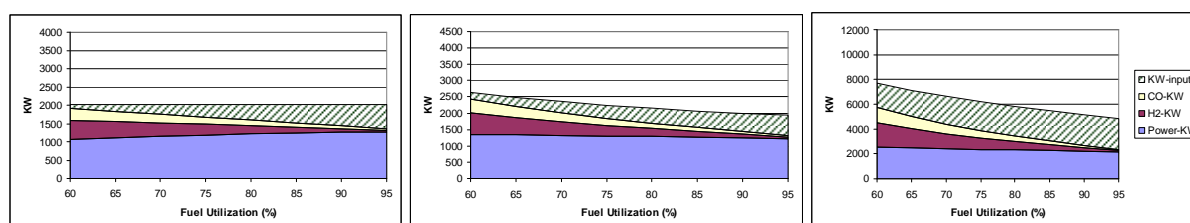


Figure A-2 Left: High efficiency mode, Middle: Constant current density mode, Right: High power mode

Interesting fact is that for the high efficiency mode the flow sheet displayed that there was a large increase of anode gas power output relative to a small decrease in electricity power output.

In high power mode there is a lot of excess heat which is useful for the reforming reactions and more natural gas can be reformed than in the other modes. A lower electric efficiency is compensated by the out relatively large output of hydrogen and H₂ en CO.

The conclusion of this research was that an IR-SOFC can be designed that operates in standard mode, producing mainly electricity and heat or in co-production mode. In the latter the system produces hydrogen, electricity and relatively little heat. Because it is an internal reforming cell, the waste heat is used more effectively and this enables the cell to be run at high power density.

Important is that co-production flexibility enables a IR-FC system to adjust to the demand for hydrogen, electricity or heat and therefore fuel cell does not necessarily have to shut down when the demand for a specific demand is too low. Its utilization is optimized and thereby the economic efficiency is optimized. Investing in such a system becomes more attractive.



Appendices

Table A-0-1 Information about fuel cell types

	Proton Exchange Membrane (PEM)	Alkaline (AFC)	Phosphoric Acid (PAFC)	Molten Carbonate (MCFC)	Solid Oxide (SOFC)	Direct Carbon (DCFC)
Chemical Reaction	$\text{Anode: } H_2O \rightarrow H^+ + OH^-$ $\text{Cathode: } 2H^+ + 2e^- \rightarrow H_2$ $\text{Net: } 4OH^- \rightarrow 2H_2O + O_2 = 4e^-$	$\text{Anode: } H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$ $\text{Cathode: } \frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^-$ $\text{Net: } H_2 + \frac{1}{2}O \rightarrow H_2O$	$\text{Anode: } 2H_2 \rightarrow 4H^+ + 4e^-$ $\text{Cathode: } O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ $\text{Net: } 2H_2 + O_2 \rightarrow 2H_2O$	$\text{Anode: } H_2 + CO_3^{2-} \rightarrow H_2O + CO_2 + 2e^-$ $\text{Cathode: } CO_2 + \frac{1}{2}O^{2-} + 2e^- \rightarrow CO_3^{2-}$ $\text{Net: } 2H_2 + O_2 + CO_2 \rightarrow 2H_2O + CO_2$	$\text{Anode: } H_2 + O^{2-} \rightarrow H_2O + 2e^-$ $\text{and: } CO + O^{2-} \rightarrow CO_2 + 2e^-$ $\text{Cathode: } O_2 + 4e^- \rightarrow 2O_2^-$ $\text{Net: } H_2 + O_2 + CO \rightarrow H_2O + CO_2$	
Transfer Ion	H^+	OH^-	H^+	CO_3^{2-}	O^{2-}	
Catalyst	Pt	Pt	Pt	no	no	no
Electrolyte	Solid Polymer	KOH	Phosphoric Acid	Molten Salt (Metal Carbonate)	Solid Ceramic Oxide	Molten Carbonate/Molten Hydroxide/YSZ Electrolyte
Operating Temperature (°C)	40-120	80-250	150-250	600-700	800-1000	600-1000
Operating Pressure (Atm)	1-8	1-10	1-8	1-10	10	-
Efficiency (%)	36-38	35-50	40	50-55	50-55	Theoretically 100 Current available 70-80%
Prime cell components	Carbon-based	Carbon-based	Graphite-based	Stainless-based	Ceramic	Stainless-based
Product water management	Evaporative	Evaporative	Evaporative	Gaseous product	Gaseous product	-
Sensitivity to impurities	Very high and can reduce the performance	Very high and can reduce the performance	Very high and can reduce the performance	Moderate but dependence with temperatures, pressures, gas composition and cell components	Moderate and very sensitive to H_2S , HCl and NH_3	Moderate, for molten carbonate and hydroxide are sensitive with Sulphur. YSZ has a better performance with coal without pre-treatment
Reforming	External	External	External	External/Internal	External/Internal	External/Internal



Appendix B: Sustainable technologies

Table B The advantages and disadvantages of the alternatives of Superwind.

Technology	Advantage	Disadvantage	Driver, complementary, or Combatant
<i>Alternatives for tri-generation of hydrogen, electricity and heat</i>			
Superwind with a PEM Cell.	<ul style="list-style-type: none"> •Electrolysis devices can be used to split water into hydrogen with excess wind energy. Hydrogen is stored. With wind energy shortage hydrogen is guided back through fuel cell to convert with oxygen in water. •PEM cell can be used to perform electrolysis •PEM cell are relatively far advanced compared to other fuel cell types •PEM cell have good characteristics (quick start up and response) •PEM cell is relative cheap •Clean •No fossil fuels used •Lower imbalance costs 	<ul style="list-style-type: none"> •Low efficiency due to the conversions needed. (<63%) •High sensitivity to impurities •Non-flexible 	This method is a combatant. It provides the same products as Superwind with a high temperature, but with a cheaper system. However, the efficiency is much lower due to external reforming and converting.
<i>Alternatives for the improvement of wind power reliability</i>			
multi-agent computer	<ul style="list-style-type: none"> •Able to allocate proper amount of power. •Improves fuel consumption of generator •Lower imbalance costs •Flexible system 	<ul style="list-style-type: none"> •Complicated infrastructure •Expensive infrastructure 	It is a combatant because it is would alleviate the fluctuating problem without the need for large investments in radical innovations. However, it does require a radical change of infrastructure.
Wind forecasting model	<ul style="list-style-type: none"> •Improve the wind prediction •Improving the correspondence of supply and demand of wind energy •Increasing profit on spot market •Lower imbalance costs •Improve allocation of power 	<ul style="list-style-type: none"> •Improving forecast does not directly improve wind turbine output reliability •Computational model becomes more complex, inherent to this is its calculation time. 	This method at the moment not a combatant. Wind forecasting will remain having a large uncertainty. The complexity of wind calculations demands too much computing power and time in order to get an accurate prediction.



Technology	Advantage	Disadvantage	Driver, complementary, or Combatant
<i>Alternatives for hydrogen production</i>			
Steam reforming	<ul style="list-style-type: none"> • Relatively low costs • Already performed at a large scale (>48%) 	<ul style="list-style-type: none"> • High energy consumption needed • High temperature needed • Slow start up • High costs for high temperature materials • Low efficiency (<65%) 	Combatant and a driver. Currently sustainable systems are not available to produce large amount of hydrogen. However, to enter an hydrogen infrastructure this a must. On the other hand, the large scale production means hydrogen is produced much cheaper than new methods such as Superwind.
Decentralized hydrogen production	Easy access to hydrogen Hydrogen-on-demand	Expensive system for domestic use	A driver, the idea can be used for Superwind.
<i>Sustainable energy production methods</i>			
Biomass/coal mix	<ul style="list-style-type: none"> • Reduction in coal demand 	<ul style="list-style-type: none"> • Low efficiency • Low quality fuel in coal power plant 	Combatant, the energy production is cheaper than new sustainable power innovations which makes market introduction difficult. The infrastructure is also aimed at this method. It is a questionable method of reaching sustainable goals.
Tidal wave power?	•	•	
Wind power	<ul style="list-style-type: none"> • Clean; zero emissions 	<ul style="list-style-type: none"> • Weather dependent; fluctuating • low efficiency • need for large windy grounds 	Driver, the technology is part of Superwind concept
Solar power	<ul style="list-style-type: none"> • Clean; zero emissions • Able to be decentralized; solar panels on each roof. 	<ul style="list-style-type: none"> • Weather dependent; fluctuating • Solar cell have a low efficiency • High costs due to expensive solar cells • Need for large area to construct centralized solar power plants 	Driver, the technology can be part of Superwind concept



Technology	Advantage	Disadvantage	Driver, complementary, or Combatant
<i>Sustainable transport methods</i>			
Hydrogen powered car	<ul style="list-style-type: none"> • Clean; emits only water vapour 	<ul style="list-style-type: none"> • No infrastructure available • High energy needed to produce hydrogen fuel 	Driver if it is developed.
	<ul style="list-style-type: none"> • 	<ul style="list-style-type: none"> • 	
	<ul style="list-style-type: none"> • 	<ul style="list-style-type: none"> • 	
Battery powered car	<ul style="list-style-type: none"> • Clean; zero emissions • Latest examples have engines in wheels creating a multitude of options to reconfigure car. • Electric low voltage infrastructure available. 	<ul style="list-style-type: none"> • High costs due to expensive Li-ion technology • Refueling (recharging) time is over 16 hours at high voltage access point • Very heavy due to batteries • Small travel radius 	Combatant, the electric car is seen as a feasible option for the replacement of a petrol car. Several countries are moving forward with upgrading the infrastructure for electric powered car. Although the cars have a travel radius of 300 km, 50% of car do not make trips of over 200 km per day.
Solar powered car	<ul style="list-style-type: none"> • Zero emissions • No fuel costs • No fuel needed, infrastructure is not needed 	<ul style="list-style-type: none"> • Highly expensive • High dependency on weather • Recharge is dependent on battery • Low power density, meaning large surface of solar cells needed. • Need for large surface decreases car shape options. 	Combatant, the solar car is too dependent on the weather, but with the improvement of batteries the need for hydrogen is almost zero in the transport market. This would make the ability of hydrogen production with SW redundant if the transport sector is the only receptor.
Biogas powered car	<ul style="list-style-type: none"> • Cleaner fuel for transport sector • Can be integrated with gas infrastructure 	<ul style="list-style-type: none"> • Still greenhouse emissions 	The car version can be a combatant because biogas is easily integrated in the Dutch gas grid, and its production does not require a radical innovation. However, it can also be a driver. The creation of biogas cars can also create a higher demand for biogas which increases the production.
Air powered car	<ul style="list-style-type: none"> • Low costs • Quick recharge (+/- 1 minute at high power compressor) • Input air/output air • Vehicles are light due to small engine 	<ul style="list-style-type: none"> • Low torque • Car travel distance is low • No infrastructure available 	Nor a combatant nor a driver, the air powered car is not yet far developed enough to form a threat



Appendix C: Backcasting data

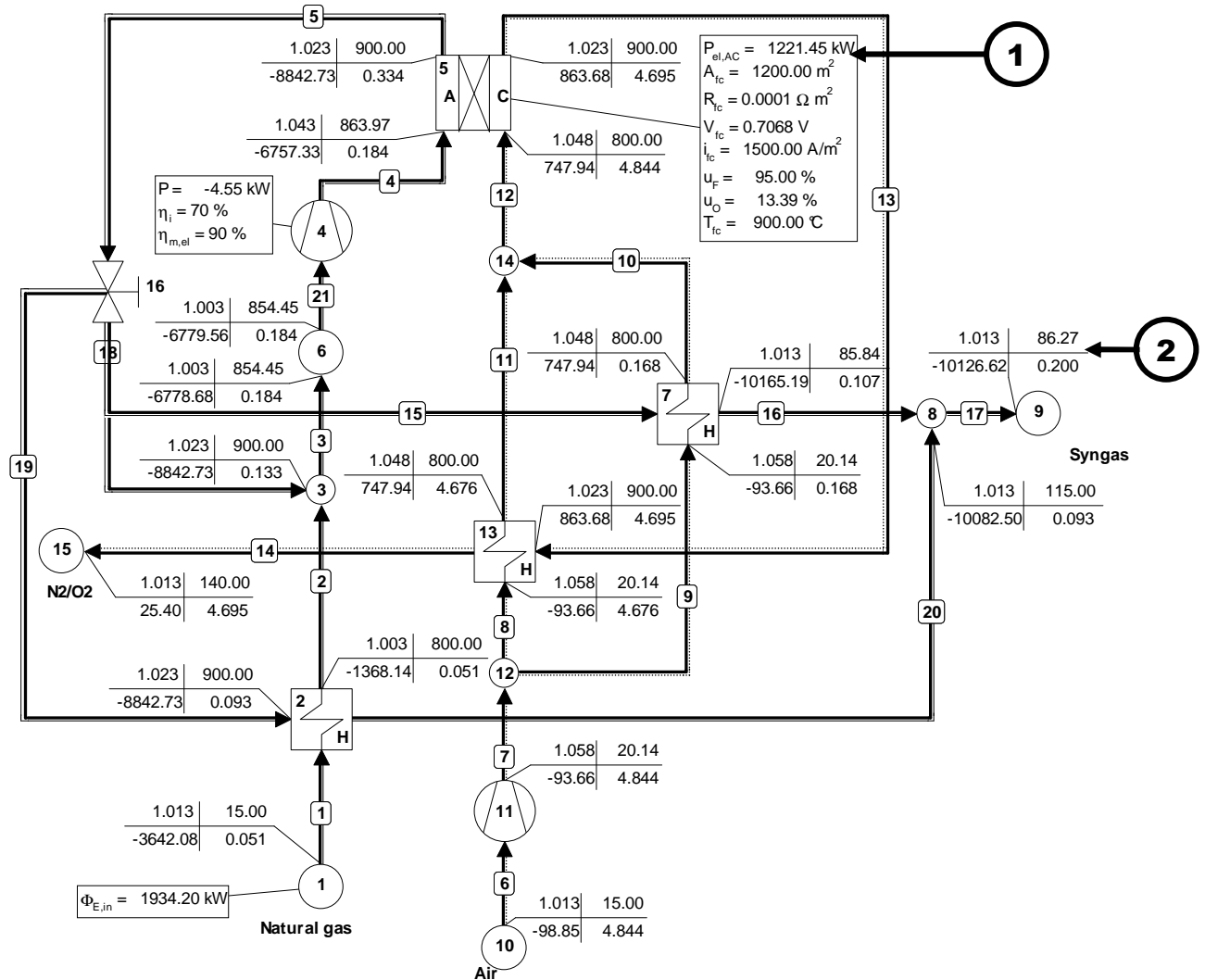
Table C Wind energy production development and the number of Superwind sites needed to act as an energy levelling assistant.

	2010	2020	2030	2040	2050
Predicted total installed off-shore wind capacity in The Netherlands (MW)	400	6.000	6.000	10.000	15.000
Predicted total installed on-shore wind capacity in The Netherlands (MW)	1.500	4.000	5.000	6.000	6.000
Predicted total installed wind capacity in The Netherlands (MW)	1.900	10.000	11.000	16.000	21.000
Number of Superwind sites with a 200 KW fuel cell needed to fulfill:					
100% of the total wind energy demand using Strategy 2	3.167	16.667	18.333	26.667	35.000
Corresponding Electricity (MWh/year)	7.106.000	37.400.000	41.140.000	59.840.000	78.540.000
Corresponding hydrogen (MWh/year)	2.736.000	14.400.000	15.840.000	23.040.000	30.240.000
50% of the total wind energy using Strategy 2	1.583	8.333	9.167	13.333	17.500
Corresponding Electricity (MWh/year)	3.553.000	18.700.000	20.570.000	29.920.000	39.270.000
Corresponding hydrogen (MWh/year)	1.368.000	7.200.000	7.920.000	11.520.000	15.120.000
10% of the total wind energy using Strategy 2	317	1.667	1.833	2.667	3.500
Corresponding Electricity (MWh/year)	710.600	3.740.000	4.114.000	5.984.000	7.854.000
Corresponding hydrogen (MWh/year)	273.600	1.440.000	1.584.000	2.304.000	3.024.000
100% of the total wind energy using Strategy 4	3.167	16.667	18.333	26.667	35.000
Corresponding Electricity (MWh/year)	14.820.000	78.000.000	85.800.000	124.800.000	163.800.000
Corresponding hydrogen (MWh/year)	11.970.000	63.000.000	69.300.000	100.800.000	132.300.000
50% of the total wind energy using Strategy 4	1.583	8.333	9.167	13.333	17.500
Corresponding Electricity (MWh/year)	7.410.000	39.000.000	42.900.000	62.400.000	81.900.000
Corresponding hydrogen (MWh/year)	5.985.000	31.500.000	34.650.000	50.400.000	66.150.000
10% of the total wind energy using Strategy 4	317	1.667	1.833	2.667	3.500
Corresponding Electricity (MWh/year)	1.482.000	7.800.000	8.580.000	12.480.000	16.380.000
Corresponding hydrogen (MWh/year)	1.197.000	6.300.000	6.930.000	10.080.000	13.230.000



Appendix D: Cycle tempo data

The IR-SOFC Cycletempo scheme



The SOFC scheme by Theo Woudstra. (Hemmes et al. 2005)

The scheme is used to calculate the flexible coproduction of hydrogen and electricity with a internal reforming solid oxide fuel cell by Anish Patil (Hemmes et al. 2005). The figure above shows one set of values for a fuel utilisation Of 95% at an operating temperature of 900°C. The

The electrical output of the fuel cell is given in the frame next indicated by point 1. The amount of hydrogen power produced is calculated from the values at point 2.

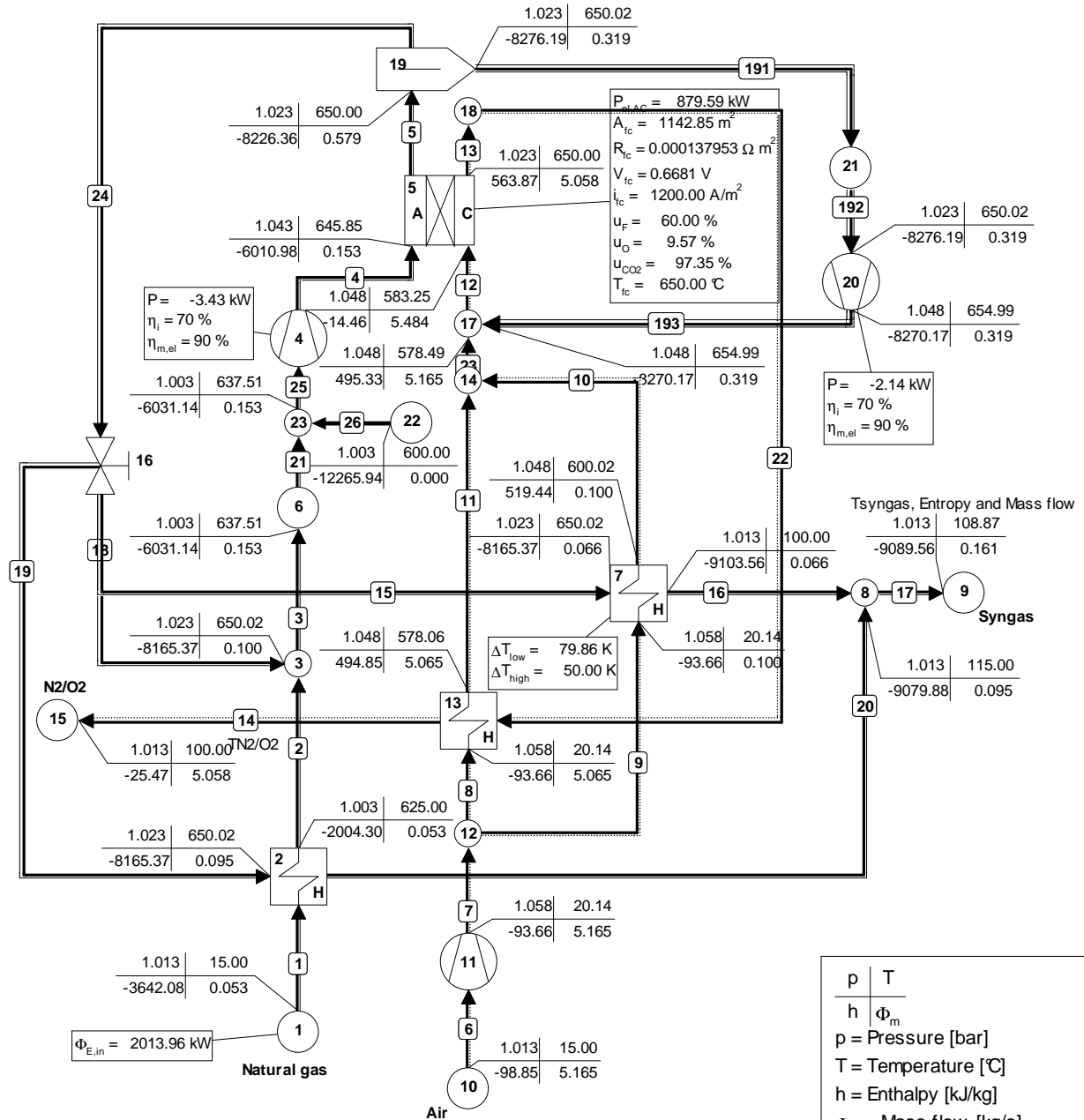
On the next page the same scheme is used but with a IR-MCFC. Several alterations have been made to integrate the MCFC. For instance, the separator at the anode. It separates the CO₂ from the end flow and sends it back to the intake at the cathode.

p	T
h	Φ _m
p = Pressure [bar]	
T = Temperature [°C]	
h = Enthalpy [kJ/kg]	
Φ _m = Mass flow [kg/s]	
P _{el,AC} = AC Power [kW]	
Φ _{E,in} = Energy input [kW]	
A _{fc} = Cell area [m²]	
R _{fc} = Cell resistance [Ω m²]	
V _{fc} = Cell voltage [V]	
i _{fc} = Current density [A/m²]	
u _F = Fuel utilisation [%]	
u _O = Oxidant utilisation [%]	
P = Power [kW]	
η _i = Isentropic efficiency [%]	
η _{m,e} = Mechanical*Electrical eff. [%]	
T _{fc} = Fuelcell temperature [°C]	
ΔT _{low} = Low end temp. diff. [K]	
ΔT _{high} = High end temp. diff. [K]	
u _{CO2} = CO2 utilisation [%]	



All data sheets related to the calculations of cycle-tempo are included on the report's CD-ROM.

The IR-MCFC Cycletempo scheme



The MCFC scheme by Theo Woudstra.



Appendix E: A table of actors for the pilot project

Table E A summary of the actors' gain, (blocking) power and conflicts with other actors.

Actor	Stake	Conflict	Gain	Power	What can he add to the project?
European Union	<ul style="list-style-type: none"> Global increase in temperature leading to changes in climate and hence in ecological systems. Global water shortage 	<ul style="list-style-type: none"> Countries > values, norms, equality issues. 	<ul style="list-style-type: none"> Economical gain for all its members. Improvement living standard for all its members. 	<ul style="list-style-type: none"> Law making and also the control of it for every member of the EU. Control of the legislation is done with a penalty system (fines) Reward system (subsidies) 	<ul style="list-style-type: none"> Subsidies Leniency in policy and permits.
University	<ul style="list-style-type: none"> Loss of the opportunity to strengthen their reputation as an institute of sustainable solutions. 	<ul style="list-style-type: none"> Government, subsidies aren't distributed equally (more to industry than Universities) 	<ul style="list-style-type: none"> Knowledge creation Money Image 	<ul style="list-style-type: none"> Knowledge Great need for sustainable innovations in the area of hydrogen. 	<ul style="list-style-type: none"> Knowledge Monetary investment Labour investment
Cartesius institute	<ul style="list-style-type: none"> reputation 	<ul style="list-style-type: none"> 	<ul style="list-style-type: none"> 	<ul style="list-style-type: none"> Network Knowledge 	<ul style="list-style-type: none">
Dutch government	<ul style="list-style-type: none"> Not reaching the CO₂-reduction mark set by the E.U. Not reaching the % of renewable power production set by the E.U. The above leads to monetary fine. 	<ul style="list-style-type: none"> Industry > legislation, creation of economical prosperity European Union holds government to protocols and agreements. Env. organizations promote their ideals. End User benchmarks government decisions Civilians expect creation of jobs. 	<ul style="list-style-type: none"> Image (support of civilians) Ideal gain E.U. subsidies Keeping and promoting the Netherlands as top knowledge based country 	<ul style="list-style-type: none"> Law making power (Trias Politica) Control of Subsidies 	<ul style="list-style-type: none"> Subsidies Advise expansion of hydrogen infrastructure.
Environmental Organizations IT FRYSKE GEA	<ul style="list-style-type: none"> By opposing the concept, they hamper the development of technology to improve that which they set out to preserve, the ecological system. 	<ul style="list-style-type: none"> Government > law Industries End user, ideals can lead to conflict. 	<ul style="list-style-type: none"> Clean environment Improving the way of live Ecological system preserved 	<ul style="list-style-type: none"> Support of inhabitants of the Netherlands 	<p>Awareness among its members</p>



Actor	Stake	Conflict	Gain	Power	What can he add to the project?
Airbase leeuwarden		<ul style="list-style-type: none"> Wind turbines could inhibit fly paths due to their height. 	<ul style="list-style-type: none"> Access to hydrogen and renewable electricity eventually. Even the airbase of Leeuwarden has to comply with environmental agreements 	<ul style="list-style-type: none"> No power, except for its necessity which is determined by the Dutch government. 	Consumer
Transport associations	<ul style="list-style-type: none"> Reputation? 	<ul style="list-style-type: none"> Misinformation may lead to a reduction in members. 	<ul style="list-style-type: none"> Image Ideal The chance of being involved in the development of a new standard for car fuel. 	<ul style="list-style-type: none"> Many members Increasing the chances of success by informing and stimulating the use of hydrogen in the transport sector. 	<ul style="list-style-type: none"> Creating awareness
Ministry of transport & infrastructure	<ul style="list-style-type: none"> General improvement of the energy carrier infrastructure. 	<ul style="list-style-type: none"> Diffusion of subsidies might form a problem 		<ul style="list-style-type: none"> Not a direct power 	<ul style="list-style-type: none"> Indirectly the M.T.I. can adjust its policy to add to the chance of success.
Industry	<ul style="list-style-type: none"> Monetary investment Labour hours Knowledge creation 	<ul style="list-style-type: none"> Governmental legislation stands in the way of unlimited ways of construction Environmental organizations protests 	Profit, Image, Knowledge	<ul style="list-style-type: none"> Knowledge and the possession and supply of materials. 	<ul style="list-style-type: none"> End consumer Monetary investment Labour knowledge
Ministry of economic affairs		<ul style="list-style-type: none"> A choice has to be made between this and other projects 	<ul style="list-style-type: none"> Strengthen the economy by increasing knowledge in the NL. 		<ul style="list-style-type: none"> Subsidies (although through other services such as Senternovem)
End User		<ul style="list-style-type: none"> Having to choose between hydrogen en conventional fuels. 	<ul style="list-style-type: none"> High living standards Financial gain through less energy use. Idealism 	<ul style="list-style-type: none"> Right to vote (indirectly influence politicians) Will they buy H₂ or not? 	<ul style="list-style-type: none"> consumption



Actor	Stake	Conflict	Gain	Power	What can he add to the project?
Installation & maintenance company	<ul style="list-style-type: none"> money knowledge reputation time 	<ul style="list-style-type: none"> time allocation 	<ul style="list-style-type: none"> money reputation knowledge 	<ul style="list-style-type: none"> exclusive knowledge of operation and maintenance contract 	<ul style="list-style-type: none"> expertise labour
Nij Bosma Zathe	<ul style="list-style-type: none"> image 	<ul style="list-style-type: none"> Increase in biogas demand could put a strain on the farm. 	<ul style="list-style-type: none"> image knowledge money due to sale of hydrogen money due to decrease of energy bill of external supplier. 	<ul style="list-style-type: none"> Contract Owner of a suitable location for the test site. 	<ul style="list-style-type: none"> Test site Labour monitoring
Leeuwarden	<ul style="list-style-type: none"> Loosing an opportunity for a hydrogen pump based on renewable bio-gas. 	<ul style="list-style-type: none"> Allocation of subsidies Opposed citizens. 	<ul style="list-style-type: none"> Image Strengthening of the economy Increase of knowledge in the province Attracting more people with higher income. Moving towards the realisation of their sustainability policy. 	<ul style="list-style-type: none"> Permit Subsidies allocation Regulations 	<ul style="list-style-type: none"> Subsidy Advise Support in the expansion of the hydrogen network throughout the province.
Province of Friesland	<ul style="list-style-type: none"> Loosing an opportunity for a hydrogen pump based on renewable bio-gas. 	<ul style="list-style-type: none"> Allocation of subsidies Opposed citizens. 	<ul style="list-style-type: none"> Image Strengthening of the economy Increase of knowledge in the province Attracting more people with higher income. Moving towards the realisation of their sustainability policy 	<ul style="list-style-type: none"> Subsidies allocation Regulations 	<ul style="list-style-type: none"> Subsidy Advise Support in the expansion of the hydrogen network throughout the province.
Essent	<ul style="list-style-type: none"> Contract with NBZ Income 	<ul style="list-style-type: none"> 	<ul style="list-style-type: none"> Improving their position in sustainable energy market. Improving image as sustainable e. provider. Attracting more costumers 	<ul style="list-style-type: none"> Contract with NBZ Electricity provider in friesland and throughout the Netherlands. 	<ul style="list-style-type: none"> Advise Labour (e.g. APX) Financial investment Long base contract



Appendices

Actor	Stake	Conflict	Gain	Power	What can he add to the project?
Nuon	<ul style="list-style-type: none"> Biggest Energy provider in the north of the Netherlands 	<ul style="list-style-type: none"> As biggest provider Nuon might be willing to offer better conditions than Essent. Essent already has a contract with NBZ. 	<ul style="list-style-type: none"> Image Insight into the first fuel cell system that provides hydrogen and electricity in a sustainable way. 	<ul style="list-style-type: none"> Network 	<ul style="list-style-type: none"> Advise Labour (e.g. APX) Initial Financial investment Long base contract.
Delta Oil	<ul style="list-style-type: none"> Leader position in renewable fuel distribution in the Netherlands / Europa 	<ul style="list-style-type: none"> 	<ul style="list-style-type: none"> Hydrogen fuel More customers Money Image 	<ul style="list-style-type: none"> Pumping installation Physical distribution centre in the vicinity. 	<ul style="list-style-type: none"> Fuel distribution in the province of Friesland.
Energy Valley	<ul style="list-style-type: none"> Loss of opportunity to build towards a sustainable Friesland 	<ul style="list-style-type: none"> 	<ul style="list-style-type: none"> Serving their purpose 	<ul style="list-style-type: none"> In charge of innovation management in Friesland 	<ul style="list-style-type: none"> Advise Aiding in finding partners Aiding in finding the proper funds
Senternovem	<ul style="list-style-type: none"> 	<ul style="list-style-type: none"> Allocation of subsidies 	<ul style="list-style-type: none"> Serving their purpose 	<ul style="list-style-type: none"> In charge of subsidies allocation. Knowledge 	<ul style="list-style-type: none"> Subsidy Advise Aiding in finding partners
Energiekamer	<ul style="list-style-type: none"> 	<ul style="list-style-type: none"> 	<ul style="list-style-type: none"> 	<ul style="list-style-type: none"> Supervision Monitoring if energy law is obeyed 	<ul style="list-style-type: none">
CFC solutions	<ul style="list-style-type: none"> Loss of investment 	<ul style="list-style-type: none"> 	<ul style="list-style-type: none"> Practical knowledge about the FC Expanding client network Image awareness through fundamental experimentation. 	<ul style="list-style-type: none"> They built only on of few working molten carbonate fuel cells. 	<ul style="list-style-type: none"> Fuel cell Expertise Labour (maintenance)
GEM zuidlanden	<ul style="list-style-type: none"> Money Image 	<ul style="list-style-type: none"> Depriving habitants of the choice to get cheaper energy if a contract is made with NBZ. 	<ul style="list-style-type: none"> Image of Zuidlanden as a top living area to attract higher incomes. Image as an example for a sustainable housing area 	<ul style="list-style-type: none"> Close by residential area for demand of electricity and heat. In the vicinity of Delta oil 	<ul style="list-style-type: none"> Long based contract
Wind unie	<ul style="list-style-type: none"> 	<ul style="list-style-type: none"> 	<ul style="list-style-type: none"> Increase in profit for wind energy 	<ul style="list-style-type: none"> Wind turbine owners Provider of wind energy data. 	<ul style="list-style-type: none"> Experience

Appendix F: Flyers Superwind

Flyer 1: The Superwind concept

Flyer 2: The Supercombi-project

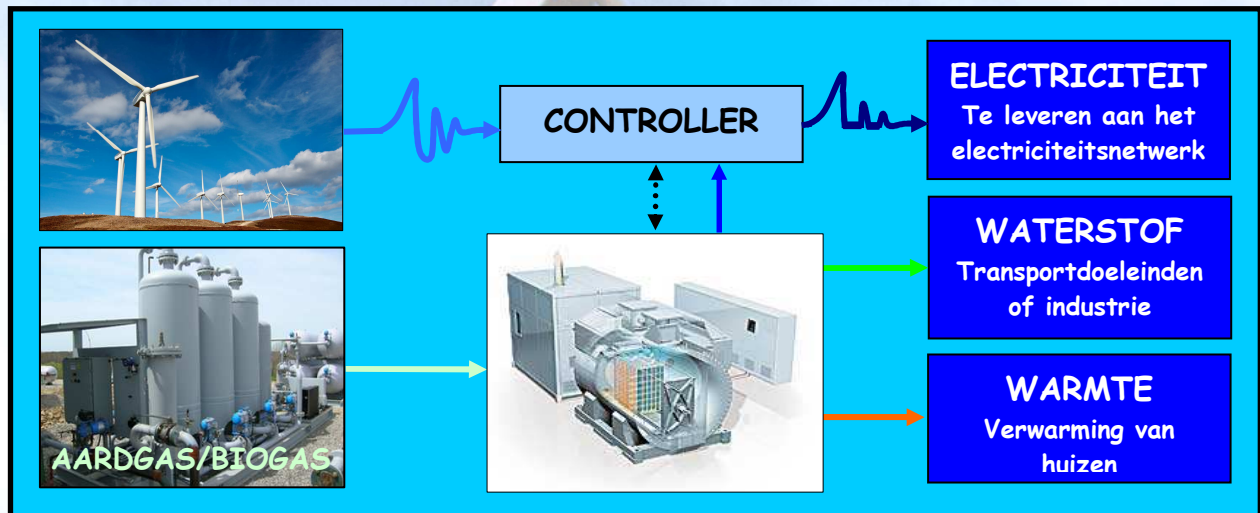
SUPERWIND

MULTI-OUTPUT BRANDSTOFCEL EEN MULTI -PROBLEEMOPLOSSER!

Probleemstelling

- ⇒ De fluctuerende en matig voorspelbare stroomproductie van windturbines veroorzaakt een slechte inpassing in het elektriciteitsnet.
- ⇒ Boetes voor niet geleverde windenergie hebben een sterk negatief effect op de rentabiliteit van een windturbine.
- ⇒ De meestal geopperde oplossing is waterstofproductie uit overtollige windenergie en terugconversie naar elektriciteit wanneer nodig. Dit heeft een zeer laag overall rendement en hoge investeringskosten, terwijl de dure installatie maar een fractie van de tijd zal worden gebruikt.
- ⇒ Het rendement van elektriciteitsproductie uit biogas is laag.
- ⇒ De transitie naar een duurzame en schone transportsector met waterstof en brandstofcellen wordt belemmerd door het 'kip-ei probleem' met betrekking tot waterstofauto's en waterstofpompstations. Kip-ei probleem: Geen waterstof auto's zonder voldoende waterstof pompstations en omgekeerd

Het Superwind Concept



Figuur 1: Concept voor de integratie van een interne reforming brandstofcel met een windturbine.

Betrouwbare windenergie!

Door de koppeling van de windturbine aan de brandstofcel kan de onbalans tussen de voorspelling en de daadwerkelijke elektriciteitsproductie geminimaliseerd worden en is een flexibele productie van elektriciteit, waterstof en warmte mogelijk.

De flexibiliteit van het systeem kan worden gebruikt om:

- ✓ de hoeveelheid elektriciteit te leveren, die voorspeld en op de markt aangeboden is, waarmee boetes kunnen worden vermeden
- ✓ bij een grote vraag naar elektriciteit (hoge prijs) extra elektriciteit te produceren
- ✓ de productie van waterstof aan te passen aan de naar verwachting geleidelijk toenemende vraag naar waterstof
- ✓ de brandstofcelkosten per kW te halveren door een verdubbeling van de elektrische output van de brandstofcel (de grotere warmteproductie wordt dan nuttig aangewend voor de productie van waterstof)
- ✓ warmte terug te koppelen voor het versnellen van het biomassa vergassingsproces.
- ✓ Naar behoefte warmte te leveren aan een woonwijk of industrie

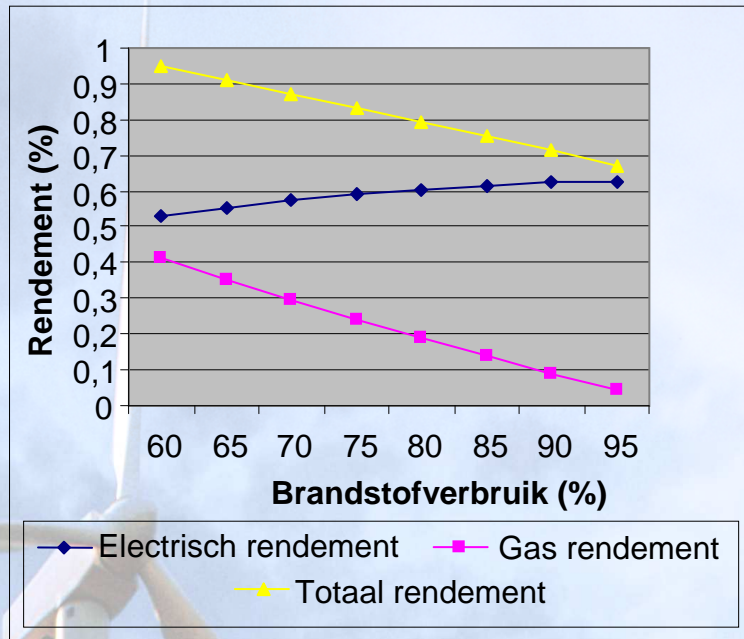
Superwind zorgt ervoor dat:

- ✓ In het net er minder onbalans zal zijn, ook bij een toenemend aandeel windenergie
- ✓ windenergie beter ingezet kan worden als reguliere elektriciteitsbron
- ✓ ook zonne-energie (PV) grootschalig kan worden geïntroduceerd zonder de nadelen van de fluctuerende energiebron
- ✓ energie wordt bespaard door het hoge systeemrendement en het regelvermogen zonder rendementsverlies
- ✓ biomassa efficiënt kan worden toegepast
- ✓ door de betere inzetbaarheid van windturbines er minder subsidie voor windenergie nodig is
- ✓ windenergie beter geaccepteerd wordt
- ✓ brandstofcellen op grote schaal zullen worden toegepast waardoor deze goedkoper worden
- ✓ een schone transportsector op basis van waterstof zich kan ontwikkelen
- ✓ Alle factoren tezamen bijdragen aan een duurzame energievoorziening met lage CO₂ uitstoot

Tussentijdse resultaten

Recente ontwikkelingen tonen aan dat het mogelijk is om interne reforming brandstofcellen te gebruiken als aardgas reformer, d.w.z. als producent van waterstof uit aardgas waarbij in tegenstelling tot conventionele reformer's tegelijkertijd elektriciteit wordt geproduceerd (coproductie van waterstof en elektriciteit en warmte). Door nu een combinatie te maken van een aantal windturbines en interne reforming brandstofcellen ontstaat een zeer flexibel en betrouwbaar elektriciteitsproductiesysteem dat een constantere hoeveelheid stroom kan leveren en zich goed kan aanpassen aan een fluctuerende vraag naar elektriciteit (en eventueel waterstof).

Aan de Technische Universiteit Delft is onderzoek verricht naar de technische haalbaarheid van het concept. De brandstofcel is zo te regelen dat niet al het aardgas wordt verbruikt (lage 'brandstofverbruik'). Het aardgas is in de brandstofcel omgezet in waterstof. Het restant verlaat dus de brandstofcel in de vorm van waterstof. Een lagere brandstofutilisatie gaat gepaard met een grote toename van waterstof productie (paarse lijn in figuur 2) en slechts een kleine afname van elektriciteitsproductie (blauwe lijn in figuur 2) in een verhouding van ongeveer 3:1. Hierdoor kan het totale systeem rendement voor de productie van waterstof en elektriciteit samen, oplopen tot boven de 90 procent! (Gele lijn in figuur 2) Dit sluit niet uit dat eventuele rest warmte (typisch 400°C) ook nog nuttig gebruikt kan worden. Door toepassing van biogas in plaats van aardgas kan de duurzaamheid van concept worden vergroot.



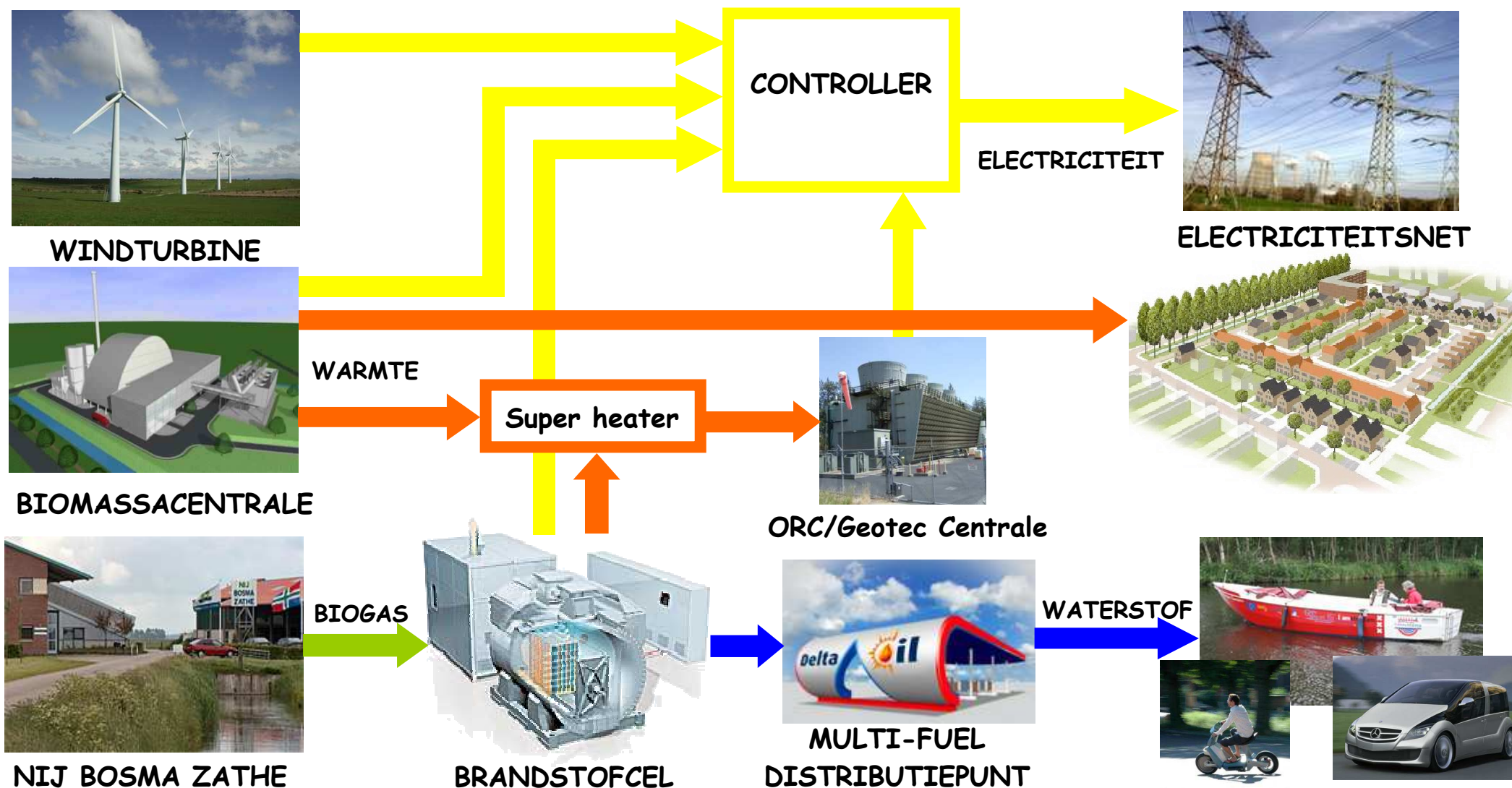
Figuur 2: Het rendement voor omzetting van brandstof naar elektriciteit, waterstof en het totale rendement van de brandstofcel.

Plan van aanpak

- ⇒ SenterNovem NEO haalbaarheidsstudie (oktober 2007 tot oktober 2008). Het resultaat is een beter inzicht in de technisch en economische haalbaarheid van het Superwind concept
- ⇒ Ervaring in de praktijk wordt opgedaan in een proef- en demonstratieproject bij bijvoorbeeld de proefboerderij Nij Bosma Zathe. Hierbij zal:
 - De bedrijfsvoering van de brandstofcel door middel van een computermodel moeten worden afgestemd met de elektriciteitsvoorspelling en elektriciteitsproductie van de windturbine en actuele prijzen voor elektriciteit (en waterstof) op de korte termijnmarkt en de behoeften aan warmte.
 - De vrijkomende warmte van de brandstofcel nuttig gebruikt worden voor verwarming van gebouwen of als proceswarmte bij de productie van biogas.
 - De geproduceerde waterstof nuttig gebruikt worden voor industriële processen of als brandstof in de transportsector.
- ⇒ De opgedane ervaringen met de koppeling van de windturbine aan de brandstofcel zullen worden gedeeld met de Windunie. Hierdoor ontstaat een efficiënte overdracht van de opgedane kennis naar de praktijk

Wat is er nodig?

- ⇒ Om de doelen te kunnen bereiken en te starten met de proefopstelling is een ondersteuning nodig voor de investering in de brandstofcel.
 - ⇒ Proeflocatie, bijvoorbeeld Nij Bosma Zathe te Goutum
 - ⇒ Ook zal gebruik gemaakt moeten worden van de SDE-subsidie voor de windturbine, exploitatie ondersteuning en een verzekering van de brandstofcel.
- Onderzoekssubsidies zijn nodig voor het ontwikkelen van het computermodel, de koppelingen naar de software van de windturbine en brandstofcel en onderzoek naar het bedrijven van een brandstofcel onder fluctuerende en extremere condities dan bij standaard gebruik.



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