Hopes, Hypes and Disappointments:

On the role of expectations for sustainability transitions

A case study on hydrogen and fuel cell technology for transport

ISBN: 978-90-393-6353-9

Printing: druck.at

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On the role of expectations for sustainability transitions

A case study on hydrogen and fuel cell technology for transport

Hoop, hype en teleurstelling:

De rol van verwachtingen in duurzaamheidstransities

(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor aan de Universiteit Utrecht op gezag van de rector magnificus, prof.dr. G.J. van der Zwaan, ingevolge het besluit van het college voor promoties in het openbaar te verdedigen op maandag 8 juni 2015 des middags te 2.30 uur

door

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geboren op 2 september 1984 te Wenen, Oostenrijk

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This thesis was partly accomplished with financial support from the Austrian National Science Fund (FWF), the AIT Austrian Institute of Technology and the Public Employment Service Austria (AMS).

Acknowledgements

Hopes, hypes and disappointments. Everybody has probably experienced this pattern already. The same holds true for me and working on this thesis. Starting with big hopes, what can be done in a PhD project, culminating into a personal “thesis hype”, these expectations were followed by the numerous hours doing research on the role of expectations for transitions. Sometimes there was even disappointment when an idea did not work out or a paper was not good enough yet. However, periods of disappointment can, and are often interpreted as a challenge to overcome by researchers. They are part of the research process and experience, developing great hopes, and sometimes even disappointment makes research exciting. It would be boring to be able to exactly assess in advance what can be done and where research would lead us eventually. Personally, there were periods of high hopes, but there were challenging times as well, however eventually I finished this thesis. So the initial statement has to be supplemented for this thesis: hopes, hypes, work, disappointments, more work, hopes, no time to work on the thesis, work, hopes, and finishing (a kind of hype).

Writing this thesis would not have been possible without the help and input of many people. Unfortunately I cannot mention all of them here, but I would like to express my gratitude to my supervisors Floortje Alkemade, Marko Hekkert and Matthias Weber: First for giving me the opportunity to conduct a PhD project, second for their valuable inputs and comments and third for their patience. I want to thank in particular Floortje for her valuable, detailed and swift feedback over the last years. In addition I want to thank Kornelia Konrad for sharing and discussing many ideas and writing papers together. I would like to thank Sjoerd Bakker for the inspiring and fruitful discussions about the future of alternative drivetrains and discussing what we have both learned from our studies on expectations and hydrogen. It is nice, that our informal discussion in a café in Utrecht about the lessons learned from the hype surrounding hydrogen and fuel cells resulted in a joint paper. Even though we did not manage to write a paper together (yet), I want to thank Marloes Dignum for the discussions we had about our common research interest over the years: fuel cells, hydrogen, visions and expectations.

I always appreciated visiting conferences to present my research and to develop new ideas and of course to meet other researchers, who have become friends over the years. In this sense I want to highlight the Sustainability Transition

Research Network (STRN) conferences, which have always been relevant, interesting and inspiring. Moreover, coming to the transition conferences has always been a very much welcomed opportunity to meet colleagues and friends.

Even though not always related to research or academia at all, I am grateful for all the academic discussions and the non-academic chats with my colleagues at AIT. I want to thank all those brave researchers who are spending many days, evenings and sometimes weekends at “the loft”, doing great research, or joining me for a coffee. Thank you as well to Joyce Zwartkruis and Alexander van der Vooren and all the other people from the Innovation Studies Group in Utrecht, for telling me more about the Dutch way of life (and of course their research) while I was staying in Utrecht for two months. Not only staying in Utrecht, but research as such is resource intensive and not possible without financial support, thus I want to thank the Austrian National Science Fund (FWF), AIT – Austrian Institute of Technology, the Public Employment Office Austria (AMS) and the University of Utrecht for their support. In addition I would like to thank Beatrice Fröhlich-Rath for her assistance regarding the layout of this thesis.

The academic community is essential for doing good research and writing a thesis. What is even more important is the support by friends and family. I want to say thank you to all of them, especially my parents who have always supported me.

Doris, I want to thank you for your love and patience. Thank you for supporting me with the right words, by taking over some duties and being patient when I was spending so many evenings and weekends at the office.

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1 Introduction

'Today the race to develop the fuel cell car is over […] Now we begin the race to lower the cost to the level of today's internal combustion engine. We'll do it by 2004.' Jürgen Schrempp, Chairman of the Board, Daimler Chrysler, The Economist 22.03.1999

In 1999 this was a remarkable statement, made by the chairman of the board of DaimlerChrysler, one of the major global automotive manufacturers. Only three years later, in 2002, the vice-president of General Motors announced that 1 million fuel cell cars would be sold by the end of 2010 (Larry Burns, Vice-President General Motors, Handelsblatt 04.09.2002). At that same time other members of the top management of competing car manufacturers also made very optimistic statements concerning the market introduction of fuel cell vehicles. Experts, analysts and journalists all expected fuel cell vehicles to enter the market on the short term.

These expectations turned out to be wrong and had to be adjusted. By 2014, no fuel cell vehicles were on regular sale for private customers. Fuel cell vehicles are, however, not the only innovation, for which initially very optimistic expectations had to be adjusted. In general, expectations about innovation and technology can and do change quite rapidly. These expectation dynamics from hopes to hypes to disappointment can be observed for many technologies in various industries, e.g. Voice over IP technology, gene therapy or high temperature super conductivity (van Lente et al., 2013). Even though expectations often tend to be overly optimistic in retrospect, they do play an important role in decisions about new technologies. Since resources are limited, decisions concerning different technological paths have to be taken, even though these decisions may prove misguided in retrospect. Actors have to anticipate the future and consequently they generate expectations about the future and use them to guide their decisions.

The role of expectations and their effects on technological change have been studied in different disciplines. Already in the 1940s economists recognized the importance of expectations for understanding and explaining the behaviour of market agents*: 'In modern theory the introduction of expectations has opened new vistas to the economist and, at the same time, set him a new problem. It has made him realise that economic action concerned with the future, so far from being strictly determined by a set of objective 'data ', is often decided upon in a penumbra of doubt and uncertainty, vague hopes and inarticulate fears, in which* *ultimate decision may well depend on mental alertness, ability to read the signs of a changing world, and readiness to face the unknown. But it has also compelled him to reflect on the causal explanation of expectations, to ask himself why they are what they are. This problem bristles with difficulties.'* (Lachmann, 1943, p.12)

The statement above concisely summarizes the importance to take into account expectations when studying decisions of actors on the one hand, and, on the other hand, the challenges which come with the conceptualization and analysis of expectations. Despite these challenges Rosenberg (1976) argued that expectations are key to understand innovation processes and in particular diffusion patterns of new technologies. He argued that consumers may not adopt a new and apparently superior technology even though it would make economic sense to them. Actors expecting rapid technological progress may decide to postpone the adoption of a new technology when they expect the next generation to provide even greater benefits. Rosenberg concluded that technological expectations are a key element to study and understand technological change and that analysis has to go beyond studying expectations about future prices (Rosenberg 1976), but also for guiding and motivating innovation activities. As Borup et al. (2006) phrase it, 'by definition, innovation […] is an intensely future oriented business' (p. 285). Every person who has to take decisions has to anticipate the future; he or she is generating expectations about the future and uses them to guide her/his decisions. This holds in particular true in the field of innovation, which is by definition about new technologies, applications, markets and/or organisations. Thus expectations guide the decisions of actors when there is high uncertainty about future innovation trajectories. This is in particular the case if innovations are not only incremental improvements, but more radical and require long time spans for their development and diffusion and/or if there are various competing options and visions for the future. All these are characteristics of transitions; these are innovation processes aiming for major changes of whole socio-technical systems, such as the mobility or energy system. Transitions go beyond incremental improvements of specific artefacts in a system, but encompass changes of technologies, institutions, regulation, user practices, industrial networks, infrastructure and even symbolic meaning or culture (Geels, 2002). Such transitions of large socio-technical systems like the mobility system, however, require long periods of times and consequently a long term perspective. The improved understanding of the role and impact of expectations is needed to enable a more reflexive approach to decision making, eventually facilitating a sustainability transition in the mobility sector.

In the literature on transition studies the role of expectations, and in particular the role of visions[1] is widely acknowledged (Geels et al., 2008; Kemp et al., 2001; Schot and Geels, 2008) ; however there remain ambiguities, with regard to the underlying processes leading to the emergence of expectation dynamics ('hypes and disappointment') and how these changes influence actor strategies (see Chapter 0). Another literature stream, rooted in the wider community of Science and Technology Studies (STS) the so called 'sociology of expectations' is dealing extensively with the performative role of (technological) expectations for innovation processes and the phenomenon of hype-disappointment cycles (Borup et al., 2006; van Lente, 1993). Concepts such as the promise-requirement cycle provide insights why expectations can change quite rapidly (van Lente, 1993). The basic idea of this concept is that initial promises are strategically used to attract interest and resources and are becoming gradually translated into requirements a technology has to fulfil in later phases, otherwise disappointment occurs (see Chapter 1.1 for a more elaborated discussion). This concept and a number of other studies in both literature streams were already taking into account the dynamics of technological expectations concerning the future development of certain technologies (Alkemade and Suurs, 2012; Geels, 2012). However, the literature focusses mainly on changing (technological) expectations, and does not take into account systematically how these technological expectations are related to other expectations, for instance regarding the future development of the mobility or energy system or the economy as such. Therefore it is not clear in how far technological expectations have to be seen in context with other expectations referring to broader trends either at the sectoral or societal level. Consequently it remains vague how these expectations concerning the future framework conditions of a technology, may influence the expectations about the technology itself. Therefore it is argued that it is necessary systematically take into account these expectations and to better understand the underlying processes that generate these expectations and how these expectations are influencing transitions. Consequently the overarching aim of this thesis is to better understand the role of (changing) expectations for innovation and transition processes. It aims to gain insights in the processes and mechanisms leading to periods of hypes, followed by disappointment and the effects of such expectation dynamics on transitions.

Empirically this thesis focusses on the mobility system and the transition towards sustainable mobility. The mobility system is under increasing pressure to address

[1] Visions can be interpreted as a coherent set of expectations, often with a normative connotation

sustainability issues, such as climate change, air quality or depleting fossil fuel resources. Currently there are a number of innovations, ranging from electric vehicles to alternative and intermodal transport modes put forward to realise the vision of a more sustainable mobility system. This thesis focusses on visions and expectations concerning a specific technological innovation proposed for the propulsion of the vehicles of the future: fuel cells. Already during the 1990s fuel cell technology became one of the most promising technologies to power the car of the future. Early optimistic expectations concerning battery electric vehicles in the beginning of the 1990s however could not be met and the initial expectations turned into disappointment. This pattern of initial high hopes followed by disappointment can be observed in various cases: In the beginning of the new millennium biofuels were expected to be a highly promising technological option. The emerging success of hybrid electric vehicles in the early 2000s spurred the interest in this technology, and more recently expectations concerning battery electric vehicles became increasingly optimistic (Bakker, 2010). Even though expectations were high and announcements highly optimistic, none of these technologies could live up to the very high expectations surrounding it at a specific time (Bakker, 2009; Geels, 2012). More recently there are voices warning that the optimistic expectations, announcements and policy targets concerning battery electric vehicles may turn into appointment (Steinhilber et al., 2013).Since these expectation dynamics apparently repeat themselves every few years in the automotive industry, it becomes inherently difficult to take decisions for the long term. This is in particular challenging with regard to fuel cell innovation, which would require the build-up of a dedicated fuelling infrastructure. Thus fuel cell innovation does not only require innovation with regard to vehicle technologies but implies a transition of the mobility system and the coordination of a variety of actors.

In order gain a better understandings of the role of expectations for such transition processes the following Chapters will address a specific dimension of expectations and transition processes, starting with a focus on the dynamics of expectations in different discourse spheres in Chapter 2. In order to gain a better understanding of expectations, it is essential to observe how expectations have evolved over time. Since the prospects of fuel cell technology were discussed in different settings, such as in the mass media or in the science or policy discourse, the research question guiding this Chapter is in how far expectations between these discourse spheres differ and if a common fuel cell hype can be identified. Thus, Chapter 2 analyses the expectation dynamics and their interaction in five different discourse spheres (mass media, finance, science, professional and policy discourse) in order to gain a better understanding how fuel cell expectation evolved in the different discourse spheres.

The third Chapter addresses the question how expectations, and in specific expectation dynamics influence actor strategies. In particular the relationship between changes in expectations and changes in actor strategies is relevant to understand if the sometimes rather sudden changes of actor strategies and behaviour can be understood as a consequence of volatile expectations. In addition to expectations concerning fuel cells as such, other expectations regarding the future of the energy and mobility systems, or expectations concerning larger societal developments are taken into account in the analysis. To distinguish expectations with regard to the object they refer to, the multi-level perspective of transition theory (see Chapter 1.2) will be used. In addition it will be discussed what role expectations referring to the future prospects of a technology, the future energy and mobility or future development at the level of the future socio-technical landscape system play for specific actor groups. Expectations concerning the future development of a technology may be more important to some actor groups (e.g. technology developers), whereas societal trends and challenges could be more important to others (e.g. policy actors). To conclude, the third Chapter will focus on the role of (changing) expectations for actor strategies.

The fourth Chapter deals in particular with the positive and negative effects of hype and disappointment. Whereas positive expectations culminating in hypes regarding a technology contribute to the mobilization of actors to join innovation and transition activities the effects of a subsequent phase of disappointment may even exceed the initial positive effects. The effects of hype and disappointment in the case of fuel cell technology are analysed and implications (and limits) for the management of expectations will be discussed. Thus, the Chapter will focus on the relation of expectations in particular expectations dynamics and actor behaviour. Whereas the previous Chapter addressed in particular the role and impact of (changing) expectations on actor strategies, this Chapter extends the perspective by emphasizing as well the role of actors in shaping expectations and contributing to the emergence of hype-disappointment cycles.

The fifth Chapter is dealing with the question if dedicated communication activities by automotive manufacturers are contributing to expectation dynamics. With regard to actor activities it distinguishes two types of activities: Communication activities and innovation activities in a more narrow sense of research and development activities. Communication activities and positive expectation statements may cause widespread optimism and very optimistic expectations, however, if they are not adequately backed up by innovation activities, it is likely that the initial expectations have to be postponed or adjusted, and disappointment will set in. Chapter 5 discusses two alternative drivetrain technologies and the corresponding communication and innovation activities by automotive manufacturers: One the one hand hybrid electric vehicles (HEV), in which case hardly any hype-disappointment cycle could be observed, and on the other hand fuel cell technology, which was subject to hype and disappointment. The Chapter focusses on the question how this difference can be explained and if the characteristics of a technology have an influence on the relation of communication and innovation activities and eventually the emergence of hype-disappointment cycles.

Subsequently Chapter 6 shifts the focus to the governance of fuel cell innovation and the interaction of different kinds of expectations. It focusses on the question how expectations referring to different levels of a future socio-technical system may interact. By studying a specific discourse sphere (policy, in this case), the Chapter scrutinizes how different kinds of expectations interact and on the other hand how these processes eventually impact policy strategies and measures. More specifically the Chapter discusses the expectation dynamics concerning fuel cell technology in the German policy discourse and scrutinizes in how far these dynamics can be explained by the interaction of expectations regarding fuel cell technology and those concerning the future of the energy or mobility system or expectations regarding broader societal trends. Thus, the Chapter uses the differentiation of different types of expectations developed in the third Chapter, which distinguishes expectations with regard to the object they refer to. The Chapter goes beyond the discussion of the expectation dynamics per se and aims to understand how the expectation dynamics and interaction between different kinds of expectations affected the policy support for fuel cell technology in Germany.

The remainder of this first Chapter is structured as follows: First, the state of the art with regard to the role of expectations for transitions processes will be discussed, with a focus on the literature on socio-technical transitions and the sociology of expectations. Second, the research question and methodology of this thesis will be presented.

1.1 Theoretical background

Innovation is not only decisive for the competitiveness of modern economies, but there is also a growing consensus that several forms of innovations are necessary to cope with major societal challenges such as climate change (Mowery et al., 2010; Weber and Rohracher, 2012). The idea of innovation being the foundation of economic growth dates back to the 20th century and economists such as Joseph Schumpeter and John Solow (Schumpeter, 1939, 2006; Solow, 1956). Schumpeter identified that innovations frequently change the way the economy works; this process is labelled 'creative destruction'. Old technologies and business models become outdated and are replaced by new and superior technologies and business models. Based on these basic ideas a number of literature streams dealing with the emergence and role of expectations have emerged.

Since this thesis aims to understand the role of expectations for transition processes it will combine two specific bodies of literature: transition studies and the so called 'sociology of expectations'. Transitions studies are a useful approach since fuel cell innovation induces respectively requires a transformation of the current mobility and energy system. A socio-technical transition approach takes into account the specific characteristics and challenges which are related with such system changes. Approaches related to the 'sociology of expectations' are extensively dealing with the role of expectations for science and technology offering important insights and conceptual approaches to understand the role of expectations for innovation processes. The combination of both literature streams will help to understand the specific role of expectations in the transformation of socio-technical systems.

Transition studies offer a broad and comprehensive understanding of the transformation of socio-technical systems, such as the mobility or the energy system. Besides the processes and mechanisms facilitating transitions, it emphasizes the barriers, difficulties and extended time horizons usually necessary for a transition to take place. The transition studies literature covers useful analytical tools (such as the multi-level perspective – MLP) and more management oriented approaches aiming to support decisions makers and make transitions actually happening, at the same time (Geels et al., 2008; Geels, 2002; Kemp, Loorbach, et al., 2007). The second main literature stream, the so called 'sociology of expectations', an approach rooted in science and technology studies (STS), emphasizes the role of expectations for science, technology and innovation. STS in general has been studying the phenomenon of expectations in the social construction of technology extensively (Bijker and Law, 1992; Jasanoff, 2001;

Jasanoff and Kim, 2009; Latour and Woolgar, 2013; Nowotny, 2014; Schot and Rip, 1997).

The 'sociology of expectations' is particularly interested in the performative character of expectations, i.e. how expectations motivate and guide actors involved in research and innovation. Expectation dynamics, such as hype and disappointment cycles and the processes leading to them have been discussed within this literature stream intensively for several years. The articles referred to as being part of the sociology of expectations deal more generally with science and emerging technologies in different domains such as bio-, nanotechnology or ICT, as well as biogas or hydrogen technologies (Brown, 2003; Brown et al., 2000; Eames et al., 2006; Hedgecoe and Martin, 2003; Konrad, 2006b; Wyatt, 2000).

This thesis aims to bring together key concepts from both literature streams; though it should be noted that these literature streams have not developed independently. There are existing links between transition studies and the sociology of expectations[2] respectively both streams build upon the same theoretical foundations rooted in innovation studies, science and technology studies and/or evolutionary economics. Against this background the following sections discuss theoretical concepts which are relevant to understand innovation and transition processes and the role of expectation therein. It will start with a more general review of influential concepts in innovation studies followed by a discussion of the literature on the sociology of expectations and on transitions. Many of the approaches in innovation studies do not conceptualise the role of expectations explicitly, however they are important to gain a better understanding of innovation processes as such and take expectations into account implicitly due to the future oriented nature of innovation and transition processes as such (see above). Even though the boundaries between these approaches are ambiguous and there are strong links between them, for reasons of clarity the literature review will follow the categorization into innovation studies, sociology of expectations and transition studies.

Innovation and expectations

Although this section does not aim to provide a full picture of scholars who were studying the phenomenon of innovation from different angles, a short summary of the origins of the field of innovation studies and the most relevant work for this thesis will follow.

[2] e.g the paper by Geels and Raven (2006) studying the case of biogas

As discussed above Schumpeter emphasized the role of innovation for (economic) development. On the contrary to the founders of neoclassical economics and its equilibrium models, Schumpeter criticized these static models and put emphasis on processes leading to change. He highlighted the role of entrepreneurs enabling innovation and change, although in later phases of his work Schumpeter argued that industrial R&D department had become decisive to develop and diffuse innovations. Without any doubt Schumpeter was one of the most influential academics laying the foundations of the field of innovation studies (Fagerberg and Verspagen, 2009). Even though expectations were not conceptualised explicitly, they play a key role to motivate entrepreneurs to engage in innovation activities. The *expectation* of future profits, which would be higher for the successful innovator, until imitators follow, is considered a major driver of innovation activities. Moreover, the ability to deal with uncertainty, and thus to rely on expectations, can be regarded as a key characteristics of entrepreneurs in a Schumpeterian sense (McMullen and Shepherd, 2006; Schumpeter, 2006).

The economist Rosenberg (1976), mentioned already in the introduction, studied the diffusion of technological innovations. He argued that expectations concerning future technological change are decisive for the diffusion of a technology. If actors expect that a future technological generation would provide even greater benefits than the current one, they may decide to postpone the acquisition of the technology and wait for the next generation technology. Thus, expectations concerning a rapid technological progress could hamper the diffusion of technologies. Of particular relevance for this thesis is, that Rosenberg was one of the first authors emphasizing the role of expectations for technological change, and in particular those of expectations concerning the future technological development. Although Rosenberg has a rather narrow understanding of the role of expectations for innovation processes, it is one of the key publications in innovation studies highlighting the important role of expectations for innovation.

Of particular importance for the field of innovation studies was the emergence of evolutionary economics at the end of 1970s, providing the foundations for a number of highly influential approaches thereafter. Expectations are not at the heart of the literature on evolutionary economics, however these approaches are crucial to understand the challenges an emerging technology, such as fuel cells, are confronted with. Nelson and Winter and their seminal work on an alternative model of economic and technological change laid the foundations of evolutionary economics (Nelson and Winter, 1977; Nelson and Winter, 1982). With regard to citations the book *An Evolutionary Theory of Economic Change* is one, or depending on the counting method, the most cited source in innovation studies (Martin, 2012). Evolutionary approaches build upon the basic idea that economic and technological change is based on the creation of variety on the one hand, and a selection mechanism on the other hand. These variations can be interpreted as new products, services or technologies which are typically developed and commercialised by firms competing on markets. The selection mechanism is provided by the market, which reduces the variety by 'selecting' certain innovations. Another important concept of evolutionary approaches is the idea that the development of innovations, such as new products and services is guided by routines. These routines and processes are frequently leading to self replication and potentially favouring more incremental improvements rather than radically new ideas and innovations. The concept of technological paradigms and trajectories by Dosi (1982) can be regarded as an example. He argued that it becomes increasingly difficult to establish thoroughly new technological solutions once a technological paradigm is established. The development will rather follow a relatively stable technological trajectory. Similar ideas can be found in the more management oriented literature in the form of the concept of a 'dominant design' (Abernathy and Utterback, 1978; Utterback and Abernathy, 1975). Tushman and Anderson (1986) illustrated how technological breakthroughs or discontinuities lead to periods of large technological variation, followed by selection processes taking place eventually leading to the emergence of such a domninant design. Once such a dominant design is established the focus of innovation activities shifts to incremental improvements of this design. An empirical example emphasizing the role of such path dependencies which is often referred to is the publication by David (1985) analysing why the QWERTY layout for typewriter persisted although more efficent designs would have been available for a long period of time. With regard to expectations it can be followed that the prospects of emerging technologies are usually assessed as being relatively low and not solely dependent on the performance of an innovation as the example of the keyboard layout shows. Thus, uncertainty which and why certain innovations prevails and others do not, can be challenging for actors involved in innovation activities. This holds in particular true in situations of technological breakthrough or other discontinuities, when technological variety tends to be high and when it is not clear which technological configuration will emerge as the future dominant design. In such situations actors apparently have to rely on the expectation they hold.

Following the ideas of evoltionary economics Abernathy and Clark (1985) developed a typology of innovations based on an analysis of the early years of the US automotivde industry. Based on 'transilience maps' Abernathy and Clark distinguished innovations which are competence enhancing or disrupting in terms of technology and regarding markets. Thus, four different types of innovations are identified: regular (no disruption), niche creation (disruption regarding the market side), revolutionary (disruptive concerning the technological dimension) and architectual innovations (disruptive concerning the technological and the market dimension). The concept of architectual innovations puts attention to the obstacles for such innovations and improved the understanding of different types of innovation going beyond the distinction in incremental and radical innovation. The idea of architectual innovations was later taken up by Henderson and Clark (1990), who scrutinized the related management challenges in case of architectual innovations and why established firms are struggling with this type of innovations. Event though expectations are not explixitly conceptualised in these concepts, it becomes clear that the ability to recognize disruptive change, either regarding the market or technological dimensions is a key challenge for firms confronted with architectual innovations.

The phenonomen that established companies often face difficulties when alternative innovations with different characteristics than the established ones emerge, were in focus of the analyses by Christensen (1997) who argued that management practices regarded as good management eventually lead to failure when companies are faced with disruptive innovations. Christensen's analysis of US American companies leading a industry at a certain time reveals how 'good' management practices like listening to customers or allocating investments to innovations which were promising to receive the greatest return for the company eventually lead to the failure of the company in case of disruptive innovations. Thus, the focus of the analyses is on the management implications of disruptive change. Another example why incumbent firms frequently struggle with innovations beyond the dominant design is the importance of 'rules of thumb' and routines which guide the organisation and improve the capabilities of the dominant design. Once the dominant design has emerged 'rules of thumb' and routines are developed, which increase the capabilities of the dominant design. Even organizational models of companies are often adjusted to a dominant design, as we see in the case of General Motors (GM). The organisational division of GM followed the principle of the dominant design in so far that the company used to assign subsystem design teams such as ignition, electrical systems, fuel system, etc. (Christensen, 1999). Regarding the role of expectations for innovation and transition activities, the work by Christensen shows how successful companies focus on the dominant design, while they tend to ignore or underestimate the prospects of more radical or architectural innovations.

Moreover the rules of thumbs developed concerning the dominant design, are probably applied to assess emerging technologies, even though they may not fit to the characteristics of the new technology.

Another influential literature stream are the different innovation system approaches. This stream of the literature emphasizes that innovation requires the interaction and cooperation of a wide range of actors, networks and institutions. Consequenlty the focus shifts from single actors or companies towards their interaction and the role of policy for innovation. First mentioned at the end of the 1980s almost simultanously by Freeman (1988) and Lundvall (1988) innovation system approaches became in particular influential in the field of research, technology and innovation policy. The main idea of these approaches is to look beyond the innovating actors and/or the market and to take into account the wider context of innovation processes. Whereas Freeman introduced the term in context of his research explaining the success of Japanese companies in the 1980s, Lundvall was argueing more theoretically that innovation studies have to take into account the role of the context beyond user-producer interactions (Freeman, 1988; Lundvall, 1992; Lundvall, 1988). Initially developed to analyse national innovation systems, in more recent years the concept of innovation systems was applied to sectoral (Malerba, 2002) or regional innovation systems (Cooke et al., 1997). Another stream of the innovation system literature, the technological innovation system approach focusses on the processes or activities within an innovation system regarding a certain technology. Bergek et al. (2008) and Hekkert et al. (2007) proposed a list of 'functions' or key activities which are necessary for a well functioning technological innovation system (TIS). By doing so these authors shifted the attention towards the dynamics of an innovation system, in contrast to other approaches which were often used to compare different structures in national, regional or sectoral innovation. With regard to expectations, they are described as an important although elusive phenomomen essential for the guidance of the innovation system. Expectations are described as a potential trigger for the dynamics of the innovation system, as 'actors are often driven by little more than a hunch' (Hekkert et al., 2007, p 423). Moreover positive expectation dynamics, such as succesful research providing guidance to the actors in the innovation system can trigger the provision of more ressources (another function of the system) leading to more research activities creating more knowledge, eventually resulting in even more resources (virtous cycles). Similar dynamics could occur in form of a vicious cycle, in case of disappointment. However expectations are not the only source for the dynamics of an technological innovation system, since changes in other functions can also lead to a virtuous or a vicious cycle (Hekkert et al., 2007).

1.1.1 Sociology of expectations

As Mokyr (1992) phrases it, in the early stages, technologies are often not more as 'hopeful monstrosities'. Hopes concerning the technology are often high, however it is not clear how technological development will progress, so there is hardly anything more than expectations we can base our decisions on.

Building upon a number of approaches from the sociology of technology and science, history, economics and innovation studies Borup et al. (2006) described the central themes and principles of what they called the 'sociology of expectations'. Thus, 'sociology of expectations' can be interpreted as a term summarizing several approaches dealing with the role of expectations in science and technology emphasizing the role expectations have for the guidance and coordination of different actors and actor groups.

(Technological) expectations in the sense of the sociology of expectations are defined as 'real time representations of future technological situations and capabilities' (Borup et al., 2006, p.286). Borup and colleagues argue that innovation activities are almost by definition future oriented, and therefore accompanied by high uncertainty. Accordingly expectations play an important role for the speed and direction of technological change, since future technologies and innovations first 'exist' in the form of imaginations, such as expectations and visions before they are realized (Borup et al., 2006). It is argued that expectations are key to understand innovation processes, since expectations' guide activities, provide structure and legitimation, attract interest and investment. They give definition to roles, clarify duties, offer some shared shape of what to do prepare for opportunities and risks' (Borup et al., 2006, p.286). In particular expectations, which become central reference points in a discourse, or as Konrad (2006b) phrases it, become part of a social repertoire are considered to be influential. Although actors may not share these expectations, they are aware of them and refer to them and take them into account in their decisions processes. These collective expectations emerge for the interaction of a large number of actors and are mediated in societal discourses (Konrad, 2006b). The central role of discourses for the emergence and shaping of expectations is generally acknowledged in the 'sociology of expectations', since discourses allow a mutual positioning of actors respectively (their) expectations. (Borup et al., 2006; Brown, 2003; Hedgecoe and Martin, 2003; Konrad, 2006b).

Even though expectations have long been as important for innovation, they seem to become increasingly important due to the 'strategic turn' in science, technology and innovation policy. In times when researchers have to acquire an increasing share of their resources from research funding bodies, rather than from long term institutional funding sources, promises about potential results of their research are becoming more important. On the other hand, decision makers in policy and industry are increasingly confronted with these promises, making decision processes increasingly challenging (Bakker et al., 2012; Borup et al., 2006).

Changing expectations have been one of the key topics of the sociology of expectations (Borup et al., 2006; van Lente, 1993; van Lente et al., 2013). Hype-disappointment cycles, which are characterized by periods of very optimistic expectations and promises, followed by a period of disappointment can be observed with regard to a large variety of technologies (Bakker, 2010; Brown, 2003; Konrad, 2006b). Frequently disappointment with regard to a technology or a specific technological configuration lasts only until the next technological promises concerning different technologies or applications arrive and replace the 'failed' expectations which caused disappointment (Brown, 2003). Due to their practical relevance in terms of misallocated resources and investments, these hype-disappointment cycles have been discussed not only by the academic literature, but also by consultancy companies such as the Gartner Group. The so called Gartner hype cycle (Fenn and Raskino, 2008) has become widely known among decision makers as a simplified model of changing expectations. The Gartner hype cycle model has five phases and assumes that a 'technology trigger' leads to very optimistic expectations culminating in an 'expectations peak'. After the expectations peak, disappointment may set in and the technology has to go through a 'trough of disillusionment', which is however followed by a 'slope of enlightenment' before a technology reaches a 'plateau of productivity' (Fenn and Raskino, 2008; Linden and Fenn, 2003). From the perspective of the sociology of expectations, there are some critical issues with this hype cycle model: First, the model is too general, and thus not taking into account variations in expectation dynamics, as many empirical examples show that expectation dynamics do not follow the patterns indicated by the Gartner model and that expectation dynamics may be different depending on the characteristics of a technology (van Lente et al., 2013). In addition van Lente et al. (2013) argue that the Gartner hype cycle describes hype cycles in already established industrial environment, whereas the model is less suited to deal with emerging technologies. Another critique addresses the point that many technologies do not recover at all from the trough of ‘disillusionment’. In addition the Gartner hype cycle model follows a linear model of technological change which does not take into account path dependencies and re-configurations, which may be important since many technologies may be reconfigured over time (Borup et al., 2006).

A key difference of the sociology of expectations and many other approaches in economics or the Gartner hype cycle is the interest in the performative role of expectations. The sociology of expectations does not aim to distinguish a difference between expectations and a ‘real world’ state in order to identify hypes and to make expectations more rational. In contrast, the sociology of expectations focuses on the performative role of expectations. It is ‘not interested in hypes as more or less accurate forecasts, but as collectively pursued explorations of the future that affect activities in the present’ (van Lente et al., 2013, p. 1616). Following this argument the sociology of expectations focusses on the one hand on the emergence of expectations and on the other hand of the consequences of expectations, and the interactions of these two dimensions. Therefore it is not possible to assess the relation between expectations and the real world ‘fundamentals’ without ‘trying’ the technology, which means already innovating. By doing so the initial expectations had already an impact on the ‘real world’. The initial expectations worked already in a performative way. Consequently it is highly problematic from this perspective to try to compare ‘real world’ fundamentals behind expectations to analyse if hype is taking place or not. Alternatively Brown and Michael (2003) suggest to analyse the discourse concerning a technology and to search for rhetorics of revolution which frequently indicate a hype.

Hypes and high rising expectations should rather be seen as something which hardly ever materializes exactly in the way anticipated, however they pre-determine the structure and shape of future technologies (Borup et al., 2006; van Lente et al., 2013).

With regard to the performative role of expectations van Lente (1993) described the performative role of expectations, respectively expectations dynamics with his concept of ‘promise-requirement cycles’. Starting with initial promises, often strategically employed to attract interest, these initial promises turn into requirements in later phases. He argued that these expectations, which are shared by an increasing number of actors, are gradually transferred into requirements for the technology in focus. Thus, the technology would be assessed concerning it is initial promises, and if it fails to fulfil these requirements, disappointment may set in. Likewise the vague initial expectations about a technology become translated into guidelines or specifications of the technology and contribute to the shaping of the technology (van Lente, 1993, 2000).

An important notion with regard to the performative role of expectations is the concept of ‘prospective structures’ (van Lente and Rip, 1998). van Lente and Rip propose to conceptualize expectations as prospective structures, since expectations may function in a similar way as if they had materialized already. Expectations in the form of prospective structures may pre-determine the future structures of a field and lead to self-fulfilling prophecies. Referring to the long lasting discussions between functionalist and structuralist approaches in sociology van Lente and Rip argue that these prospective structures have a mediating role between actors and structure. On the one hand expectations in the form of prospective structures constrain the possibilities of actor behaviour in the future; on the other hand, actors are engaged in the shaping of these structures. As van Lente and Rip phrase it: ‘[…]prospective structures emerge, i.e. arrangements that do not yet exist, but are nonetheless forceful due the perceived implications of the projected future’ (van Lente and Rip, 1998, p. 206). Actors engage actively in the shaping of these prospective structures, which eventually have an impact on the ‘real’ structures in future. They even try to ‘colonize the future’ (Brown et al., 2000) by articulating expectations which correspond to a desirable future from their perspective or as Berkhout formulates it, visions and expectations are strategically used by agents to follow their individual interests (Berkhout, 2006). These strategic interests of different actors or actor groups are an important reason why discourses about the future are frequently highly contested with often conflicting expectation statements about the future.

Similar to transition studies which developed a multi-level perspective to distinguish activities and developments, authors related to sociology of expectations differentiate between specific levels of expectations. van Lente (1993) describes expectations at the micro level such as research groups or individual firms, at the meso level, such as a technology field and at the macro level of technology. Expectations at the macro level are more related to expectations beyond the technology field and its application and refer to broader societal developments. He argues that these different types of expectations serve different functions, i.e. expectations at the macro level may become selection criteria for lower level expectations (van Lente, 1993). A similar line of argumentation can be found in a study by Ruef and Markard (2010) who distinguish expectations at the project level, technology field and social framings in their study of the effects of disappointment. Their main argument is that the effects of disappointments depends on the level of expectations which turned out to be too optimistic, and that disappointment of expectations at the project level may have different consequences than at the level of a technology field. Disappointment at the project level often does not have direct consequences on actor strategies, whereas failed expectations at the level of a technology field or changing social framings have an impact on actor strategies (Ruef and Markard, 2010).

Besides the differentiation of expectation with regard to the subject they refer to, expectations can be differentiated with regard to actors. Usually expectations and the perceived (and actual) uncertainty concerning a technology differ between actor groups. The perceived uncertainties can depend for instance on how ‘far’ people are from the actual research and development activities (Brown and Michael, 2003). There are as well hints that even the same people may state different expectations according to the role they are in. For instance researchers may be promising more in the role of entrepreneurs when they have to raise money for their research, however they are more cautious discussing the promises of their research with scientific peers (Borup et al., 2006).

1.1.2 Transition studies

Whereas the introduction of radical and in particular architectural innovations can be considered as a risky long term process, in which many innovations eventually fail, the situation is even more complex in case of the transformation of whole infrastructure systems, like in the fuel cell case.

In addition to the challenges architectural innovations are confronted with, the situation can be even more complex in case of ‘green’ or ‘low carbon’ innovations. Unruh (2000) describes this phenomenon as ‘carbon lock-in’, which explains the persistence of the current fossil fuel based infrastructure systems. ‘Green’ or ‘low-carbon’ innovations are confronted with three characteristics which make transitions even more challenging (Geels et al. 2008). Usually new technologies are more expensive than the established technologies profiting from scale effects. While market niches, where the new technology offers quite specific advantages for a certain application, regularly provide the entry point for new technologies, the situation with green innovations can be more complicated. Because of the collective good character of a clean environment, green innovations provide a benefit to the society, whereas the individual users have to bear the higher costs of the technology. In addition uncertainties are higher in case of transition activities, which are often dependent on policy interventions such as innovation support and (environmental) regulations. Another obstacle is that companies do not yet understand the complex market for green innovations and incumbents fear that such innovations would cannibalise their current products (Geels et al. 2008). Moreover, green technologies envisioned to be part of wider sustainability transitions are often facing a mismatch to existing user lifestyle and behavioural patterns (Freeman and Perez 1988 in Geels et al. 2008).

Geels et al. (2008) identifies four strategies based on different theoretical foundations to respond to these challenges: 'neoliberal strategies', 'ecological modernisation', 'deep ecology' and 'socio-technical transitions'. Whereas neoliberal strategies focus on 'getting the prices right', the main focus of ecological modernisation approaches is on clean technologies and smart innovations which would contribute to more sustainability and economic growth at the same time. Deep ecology approaches emphasize the necessity of behavioural changes and the underlying norms and values (Geels et al., 2008). Although these approaches offer valuable insights to the issue of sustainability, this thesis follows the socio-technical transition approach, which highlights that the sustainability challenge can only be mastered by a combination of new technologies, changes in markets, user practices, cultural discourses and governance institutions. The socio-technical transition approach aims to take into account all of these dimensions and their interaction and co-evolution, rather than markets, technology or behavioural change only (Geels et al., 2008).

A key concept in transition studies is the multi-level perspective (MLP), which aims to explain the complex interaction between activities on several levels in socio-technical systems. A key assumption of the MLP is that transitions of socio-technical systems emerge from the complex interaction of processes at three levels: the niche, regime and landscape level. This analytical distinction in three levels helps to explain and understand transitions which are understood as changes or shifts at the regime level (Geels, 2010). Niches are those spaces, where radical innovation frequently takes place, since they are protected from the prevailing selection mechanisms of the market. These niches enable experimentation, learning processes of several kinds and the development of social networks concerning a radical innovation which would not be competitive under the current regime, e.g. the current energy or mobility system with its rules and selection mechanisms (Geels, 2002, 2012). The regime level encompasses for instance the established selection mechanisms, suppliers, producers, user groups, user practices, specific rules, routines and institutions related to an established socio-technical system. Referring to Kemp et al. (1998) a regime is mainly understood as the rules in a wider sense including roles and practices that are established, thus the regime can be interpreted as the underlying logic of a socio-technical system. Thus technological regimes can be compared to the concept of a paradigm, however in a broader sense, since it encompasses as well the broader social context of technological paradigms. The socio-technical regime creates economic, technological and cognitive and social barriers for (radically) new technologies (Kemp et al., 1998)

To be more precise, Geels (2002) distinguishes seven dimensions of a socio-technical regime: technology, user practices and application domains (markets), symbolic meaning of technology, infrastructure, industry structure , policy and techno-scientific knowledge. These different dimensions represent the regime in a specific sector or concerning an infrastructure system and can develop dynamically, potentially creating tension within the regime. The third level of the MLP is the socio-technical landscape which may put pressure on the regime and can open windows of opportunities for niches to become integrated in or replace the regime.[3] Such developments at the landscape level could be cultural changes, demographic trends or the emergence of alternative societal priorities.

The main argument of the MLP is that transitions occur through the interaction of developments at each of the three levels and can be analysed using the MLP as an analytical and heuristic framework to understand the complexity of such transitions (Geels, 2002). The MLP builds upon earlier work by Kemp et al. (1998); Schot et al. (1994) and others who developed the approach of Strategic Niche Management (SNM).

Starting point was the question why environmentally friendly vehicle technologies were not introduced to the market and how the potential of more sustainable innovations could be exploited. Kemp et al. emphasize that environmental innovations are typically struggling since technological change is locked into dominant technological regimes. Based on these findings of evolutionary economics (see above) they concluded that historically specific kinds of niches were crucial for the development of radical technologies. Such niches, created through military demand or specific market demand for certain applications were instrumental for the further development of many new technologies and the emergence of a new technological regime. In addition to the provision of financial means and demonstration of the viability of a technology, Kemp et al emphasize that niches are essential to build a constituency behind a technology and to enable learning processes and institutional change. Niches are crucial for radically new technologies since they provide space for experimentation and learning

[3] more on the potential interactions between niche-regime, see Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Research Policy 36, 399-417.‘

processes.[4] SNM is a governance approach to create, develop and phase-out protected spaces for promising technologies. It was developed to support innovations which are socially desirable with respect to their sustainability promises which are confronted with a mismatch regarding their requirements and the existing infrastructure, established user practices, regulations, etc. (Schot and Geels, 2008).The main idea is that protected spaces enable learning beyond technological learning and help to articulate necessary changes in technology and the institutional framework, to learn more about the technical and economic feasibility and environmental gains of different technology options, to stimulate the further development of these technologies, to achieve cost reductions through mass production, to promote the development of complementary technologies and skills, to stimulate changes in social organisation and to build a constituency behind a product (Kemp et al., 1998). As stated above the SNM builds upon early work by Schot et al. (1994) which criticizes evolutionary models of technological conceptualizing variation and selection processes. Their main criticism is that variation and selection mechanisms are seen as independent processes, whereas they argue referring to constructivist sociologists (e.g. Callon, 1980; Pinch and Bijker, 1987) that variation and selection are frequently coupled. Actors engaged in innovation activities (creating variation) are frequently involved in selection process as well. Thus, they propose to either speak about a co-evolution of technology development (creating variation) and the selection environment, since actors try to anticipate and influence the selection mechanisms. This argumentation was in line with the emergence of the quasi evolutionary model of technological change proposed by Rip (1992), arguing that technological change is directed to some degree and not random.

Schot et al. (1994) identify three coupling mechanisms which actors can use to anticipate and influence the selection environment: (1) voicing and articulation of expectations, (2) shaping of the technological nexus, institutional carriers which act on the variation and selection process simultaneously, (3) creation of niches in which new variations are exposed to selection pressure in a controlled way, but protected against too harsh selection (Schot et al., 1994). This list of processes which are regarded to be important for the successful development of a niche, in terms of developing into a market niche and eventually leading to a regime shift

[4] An underlying hypothesis of SNM is that such niches may function as 'proto-markets' which can lead to the emergence of market niches, which eventually grow and may overturn the current market structures, respectively the socio-technical regime. However niches in the sense of transition studies in general or SNM in specific and market niches as used in a more common sense cannot be used synonymously.

gives a hint for the processes which are frequently mentioned as being the three key internal processes of a technological niche:

1. The articulation of expectations and visions
2. The building of social networks
3. Learning processes at multiple dimensions (Schot and Geels, 2008, p.540)

Concerning expectations, it was hypothesized that they would be most supportive for the niche development if they would be shared by many actors (robust) and specific enough, since too vague expectations would not be able to provide guidance. In addition expectations are supposed to be backed up by actual projects supporting them (quality of expectations) (Schot and Geels, 2008). Social networks are assumed to contribute to the development if a variety of actors are integrated (including outsiders) in these networks and able to articulate different views and perspectives to open up cognitive frames and to mobilize resources. Moreover second order learning processes – changes in cognitive frames and assumptions - are regarded of particular importance (Schot and Geels, 2008; Truffer et al., 2002). Empirical case studies applying the SNM approach as analytical concept, rather than a policy approach, show that in the case of renewable energy in the Netherlands all three key processes (articulation expectations and visions, building of social networks, learning processes) are prone to barriers or even failure (Verbong et al., 2008). Regarding expectations it can be observed that transition processes usually take several centuries, with periods of high expectations followed by disappointment. Even though (positive) expectations can guide transition processes, disappointment in form of overly pessimistic expectations may hamper the development of a specific technology or optimistic expectations 'switch over' to an alternative technology. These repeated hype-disappointment cycles may have a negative impact on transition activities as such, since transitions are long term processes and actors engaged in transition activities require reliable policies (Verbong et al., 2008).

Another influential policy approach aimed to support transitions towards more sustainability was developed under the heading of 'Transition Management' (TM) (Kemp, Loorbach, et al., 2007; Loorbach, 2007; Rotmans et al., 2001). Similarly to SNM it highlights the importance of visions and experiments to eventually enable a transition; however it focusses stronger on the governance of transitions and tries to facilitate the coordination of different levels of government. Self-organisation and new types of interactions and learning processes are at the heart of the approach. Transition management distinguishes three levels, which co-evolve through the process: the strategic, tactical and operational level (Kemp, Loorbach, et al., 2007). Visions and expectations are crucial at the strategic level, since the approach foresees processes of vision development, strategic discussions and long-term goal formulation as key activities at the strategic level. In order to facilitate these processes it is suggested to set up so called 'transition arenas' which aim to provide a platform for vision building and strategic discussions including a large variety of stakeholders.

However, this focus on the governance of transition by vision building exercises and strategic discussions, led as well to criticism about the lacking impact of TM. Schot and Geels (2008) argue that many vision building exercises were followed by few substantive follow up activities and that actors may express good intention not backed up by activities ('impression management') (Schot and Geels, 2008, p.542).

To conclude, both SNM and TM emphasize the important role of visions and expectations for sustainability transitions. Nevertheless the processes and mechanisms how expectations influence transitions and how transition activities influence visions and expectations are still unclear. Related to this it remains ambiguous when and how expectations and visions are guiding transitions. In addition hype-disappointment cycles represent a problem to long term transition processes if they lead to frequent policy changes, making policy unreliable from the perspective of the actors involved.

1.2 Research question & methods

This thesis aims to understand the role and influence of expectations for transition processes. The sociology of expectations has revealed how expectations guide innovation, in periods of high (technological) uncertainties inherent to innovation processes. This thesis focusses on the role of expectations for so called socio-technical transition processes. As the literature on sustainability transition illustrates, such transitions of large socio-technical systems usually require very long time horizons (often decades) and go beyond the development and diffusion of a single technology. Consequently uncertainty is even higher in case of transition processes, compared to innovation processes regarding a specific technology. Consistently transition studies have emphasized the importance of expectations for the guidance of transition activities. The processes, however; through which expectations influence transition activities remain rather unclear.

Thus, this poses the research question:

What are the processes through which expectations influence transitions of socio-technical systems?

To study these questions, the role of different kinds of expectations, going beyond technological expectations, will be studied. Expectations will be differentiated depending if the refer to the future of a technology, the mobility system or future developments at the societal level (as illustrated on the left in Figure 1, below).

Since expectations do not evolve independently from communication activities and expectations statements by actors, the role of actors in the shaping and emergence of expectations is also taken into account. As expectations are shaped in discourses (Konrad, 2006b), these communications about the future are conceptualised as the key element linking the conceptual elements of actors and expectations. On the one hand actors are trying to shape expectations through their communication activities, and on the other hand they use expectations of other actors circulating in discourses for orientation. This thesis is on the one hand interested in the role expectations play for actors and their behaviour and on the other hand in the shaping and emergence of expectations in discourses Actors are assumed to contribute to the discourses through their (communication) activities, i.e. expectations statements, and so to the emergence of expectations. Likewise discourses and expectations circulated and discussed within discourses are an important references for other actors. Since a single medium or discourse on fuel cell technology probably does not exist, the discourse is conceptualized as being constituted by several discourse spheres. These discourse spheres are the ‘arenas’ where expectations are emerging, shaped or contested. To cover different facets and dimension of the overall discourse spheres are conceptualised: mass media, professional, science, finance and policy.

Another main conceptual building block are actors. This thesis will look into the role expectations, shaped in different discourse spheres, play for the behaviour of actors. It will look in particular on the level of actor strategies, which are assumed to pre-determine the activities of a specific actor. Moreover, this thesis scrutinizes how actors – deliberatively or not – contribute to discourses and the shaping of expectation through their activities. Consequently two types of activities, innovation activities and communication activities are analytically distinguished.

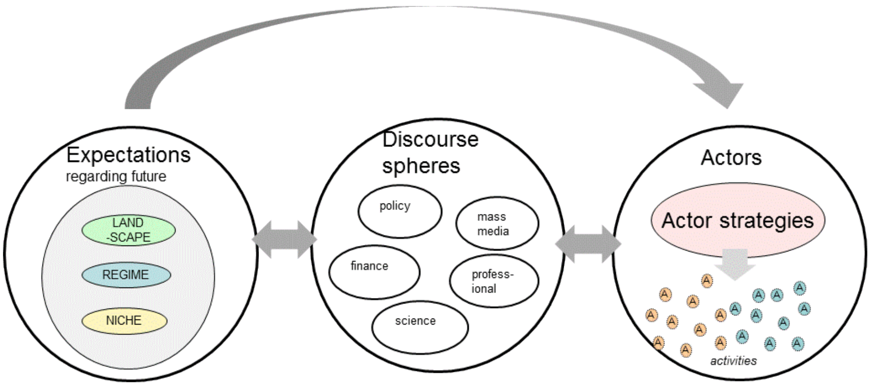

Figure 1: Schematic illustration of the main conceptual building blocks

To conclude, this thesis will combine insights from two literature streams, transition studies and the ‘sociology of expectations’, to gain a better understanding of the role and the impact of different types of expectations for transitions processes. Particular emphasis will be put on the phenomenon of hype-disappointment cycles, i.e. why expectations are frequently changing and what the impacts on transitions processes are.

Research concerning the role of expectations has to deal with a number of challenges: First, expectations are often tacit, contested and difficult to grasp from a researcher’s perspective. Second, actors asked about past expectations may not remember what expectations they were holding in the past or engage, intentionally or not, in ‘retrospective sense making’ (Eisenhardt, 1989; Eisenhardt and Graebner, 2007). Interviewees may present answers from the perspective of the time of the interview, reducing potential contradictions or neglecting expectations which turned out to be inadequate. In addition any form of interview or questionnaire has to take into account a potential social desirability bias (DeMaio, 1984; Krumpal, 2013). Since the automotive industry is under political and societal pressure to address environmental concerns such as greenhouse gas reductions, there may be incentives for interviewees to highlight activities which they perceive as socially desirable. Schot and Geels (2008) emphasized the problem of impression management in a transition context and even argued that many of the vision building exercises are used to state good intentions only. Actors follow their individual strategies and hidden agendas, thus expectation statements are frequently not only pristine materialisations of the expectations held by an actor, but are strategically deployed (Berkhout, 2006). In addition innovation strategies in the automotive industry are highly confidential due to their strategic importance (van den Hoed, 2005).

To address these challenges, this thesis is based on a mix of methods, to study the different dimensions and facets of the role and impact of (changing) expectations for transition processes. The mostly qualitative approaches are supplemented by quantitative methods, following the concept of 'triangulation'. Triangulation is originally a navigation concept, which emphasizes the importance of multiple reference points in order to locate the position of objects, which translates in the context of social science to the use of different, qualitative and quantitative methods to minimize a potential bias and misleading conclusions (Jick, 1979). This thesis follows a case study approach to gain in-depth context of the empirical phenomena studied and to facilitate learning processes at the researchers side regarding the field of interest (Flyvbjerg, 2006; Yin, 2002). The research process itself is guided by the proposed case study research process suggested by Eisenhardt (1989).

Starting from the overarching research question regarding the role and impact of expectations for transition processes five more specific research questions addressing different dimensions and facets of expectations and transition processes were derived, guiding each Chapter. Depending on the specific research questions a different set of methods will be applied including discourse analysis, (semi-structured) interviews and patent statistics (see Figure 2). These will be applied in an iterative manner to eventually shape hypotheses and to contribute to the existing literature.

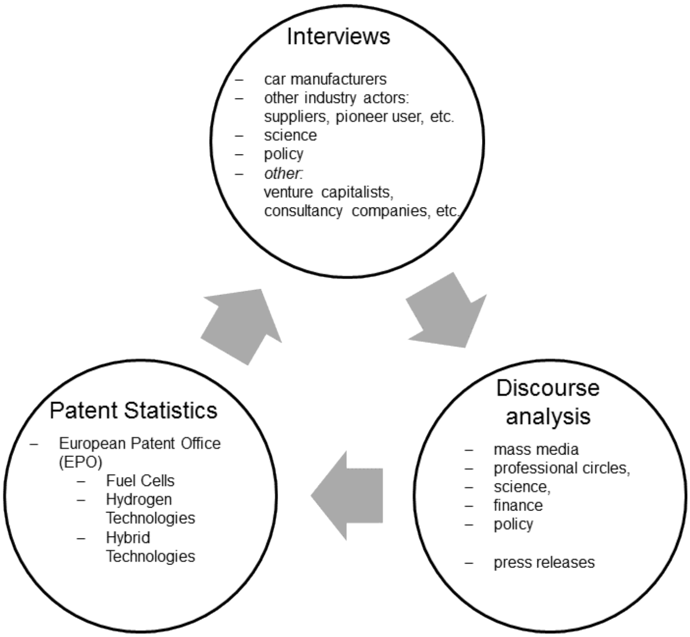

Figure 2: Research design: Triangulation of Interviews, Discourse analysis and Patent Statistics

Discourse analysis is one of the main pillars of this thesis, since expectations are usually shaped and mediated in discourses (Konrad, 2006b). Actors are usually involved in a number of public, semi-public or private discourses about the future of an innovation. On the one hand these interactions are influential for the expectations actors hold since expectations of other actors provide guidance in particular in situation of high uncertainty; however, on the other hand actors are contributing to discourses, or even try to actively shape these discourses (see Chapter 0). Thus, a discourse based approach allows tracing the emergence and changes of different expectations over time. However, the analysis is limited in terms of understanding how (changing) expectations are influencing the (innovation) strategies of actors.

Therefore the second main source of empirical data is *semi-structured interviews* with actors from the field of hydrogen and fuel cell technology. Interviews allow understanding the developments and strategies in the field from the perspective of the individual actors. Interviews can provide important contextual information, which may have been overlooked otherwise. During the selection of interviewees, one aspect will be to include as well retired decision makers from industry, since they can speak more openly about past developments than representatives of automotive companies. To address the issues of retrospective sense making and a potential social desirability/impression management bias the information gathered through interviews will be triangulated with the insights from the other sources.

As a third method *patent statistics* will be used as an indicator for innovation activities, since patent statistics provide additional, highly standardised information concerning the research and development activities of an organisation. In particular when innovation activities are highly confidential due to their strategic importance, as in the automotive industry, patent statistics are an important and widespread source of information (Frenken et al., 2004; Järvenpää et al., 2011; Oltra and Saint Jean, 2009b; van den Hoed, 2005). Nevertheless, patent statistics have some limitations and drawbacks: patents do not cover all innovation activities, not all inventions can be or are deliberately kept secret to avoid informing competitors about research and innovation strategies (Kleinknecht et al., 2002; Zuniga et al., 2009). Taking into account the strengths of patent statistics, in particular the high availability of quantitative data and categorization tools such as patent classes, patent statistics are an essential element of the triangulation approach followed throughout this thesis.

2 The Fuel cell hype and the co-evolution of discourse spheres[5]

2.1 Introduction

Innovative technologies are typically subject to high uncertainties with respect to technological characteristics, future applications, commercial potential and societal impacts (Kline and Rosenberg, 1986). Thus, innovation and societal actors have to rely on expectations rather than on robust knowledge for assessing new technologies and taking decisions. These expectations are largely mediated and negotiated in public discourses (Konrad, 2006b). Strikingly, technology-related expectations frequently develop very dynamically. A typical pattern are early phases characterized by a high level of attention and the emergence of optimistic expectations, followed by phases of disappointment marked by decreasing attention and more moderate expectations, up to strong disappointment, if expectations are not fulfilled. This pattern is reflected in various concepts. For innovative technologies, it has been widely discussed as hype cycles in recent years, most prominently with reference to its use by the consultancy firm Gartner Group (Fenn, 2006; Fenn and Raskino, 2008), but also within Science & Technology Studies (Brown, 2003; Konrad et al., 2012; Ruef and Markard, 2010; Sperling and Gordon, 2009; van Lente et al., 2013; Verbong et al., 2008). As a general phenomenon, not necessarily linked to new technologies, the pattern is known for some time. For organizational innovation and management techniques it has been researched as managerial fads and fashions (Abrahamson, 1991; David and Strang, 2006); with regard to public attention to certain issues in general, the dynamic is well-known as issue-attention cycle (Downs 1972; Nisbet & Huge 2006, similarly Luhmann 1971).

However, technology hype cycles have often been described either by following the coverage of a topic within public mass media (Ruef and Markard, 2010; Väliverronen, 2004) or as a general increase or decrease in visibility without referring to a specific empirical point of reference (Fenn, 2006; Verbong et al., 2008). Considering findings from communication and policy studies we argue that this perspective, following a general discourse only, risks neglecting relevant discourses beyond mass media. Communication and policy studies have shown

[5] This Chapter is the result of joint work with Kornelia Konrad and to be submitted as journal article as Konrad, K, and Budde, B, The Fuel cell hype and the co-evolution of discourse spheres.

that an issue may be taken up, presented and discussed in quite distinct ways depending on where the specific discourse takes place. Thus, we refer to these different dimensions of the overall discourse on a topic as discourse spheres. Different framings, different rules of selectivity and different time horizons are structuring these discourse spheres and consequently the dynamics of the discourse spheres differ frequently from each other (Gamson and Modigliani, 1989; Hajer, 1993; Nisbet and Huge, 2006; Weingart et al., 2000).

Following this line of argumentation we hypothesize that it is inevitable to take into account several discourse spheres, to fully understand hype cycles. We assume that a focus on mass media alone for analyzing technological expectations is likely to capture only one facet of the expectation dynamics. Expectation and ultimately hype dynamics may be restricted to certain spheres or show different patterns in different spheres. Different facets of a topic are likely to be more in focus in some discourse spheres than in others and, hence, also different sets of expectations may prevail. Moreover, as shown by Weingart et al. (2000; 2008) in a study of the climate change discourse, discursive dynamics may result from the interaction of discourse spheres, such as media, science and politics. Literature on the role of expectations for innovation has shown that, discourses respectively expectations emerging from discourses have an influence on the speed and direction of innovation processes (Borup et al., 2006; Konrad, 2006a). Nonetheless, some discourse spheres could have a different influence on innovation processes than others. Yet, the analysis of the influence of different discourse spheres on innovation processes requires the conceptualization of such discourse spheres. Distinguishing discourse spheres is furthermore relevant to understand the performative role of expectations in innovation processes, since most innovation and societal actors are likely to focus on some discourse spheres and respective expectations more than on others.[6]

Thus, *in this article we examine for the case of fuel cells, how expectation dynamics have evolved in a set of discourse spheres, including mass media, professional circles, finance, science and policy*. In particular, we inquire *if and how dynamics differ among the spheres and for what reasons* in order to gain a better understanding of the development of the overall hype.

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[6] The actual impact of fuel cell expectations on innovation strategies is examined elsewhere Konrad, K., Markard, J., Ruef, A., Truffer, B., 2012. Strategic responses to fuel cell hype and disappointment. Technological Forecasting and Social Change 79, 1084-1098.and Budde, B., Weber, K.M., Alkemade, F., 2012. Expectations as a key to understanding actor strategies in the field of hydrogen and fuel cell vehicles. Technological Forecasting & Social Change 79, 1072-1083.

We use fuel cell technology as a case study, since the technology has already gone through several periods of high hopes and subsequent disappointment. Fuel cells have attracted attention as a very efficient energy technology since they are able to convert energy stored in energy carriers, for instance hydrogen, natural gas or methanol into electricity and heat. The working principle is already known since the 19th century, and hopes that fuel cells could play a major role in future energy production rose already in the 1960ies, although followed by a downturn in the 1970ies (Schaeffer, 1998). Fuel cells can be used for a variety of applications: Most prominently, they are used for vehicle propulsion as cars, buses and many others - in the following called mobile applications. Stationary applications range from combined heating and power systems at the household level, so-called micro CHP, to smaller or larger power plants. Portable applications provide power for various small devices as laptops or mobile phones.

In the 1990ies, fuel cells appeared again in the discourse as a promising energy technology. Eventually expectations concerning fuel cell technology turned into hype around the turn of the millennium. This paper will analyze this most recent fuel cell hype in several discourse spheres. Our study covers a period of 15 years, thus including the time periods when expectations were rising respectively declining. Geographically, we focus on Germany, which is a leading country in fuel cell innovation in Europe (Neef, 2009).

In the remainder of the paper, we present recent findings on expectation dynamics and the concept of interrelated discourse spheres which guides our analysis. In Chapter 2.3 we compare the quantitative attention dynamics on fuel cells observed in the different discourse spheres and continue with a qualitative analysis of the expectation dynamics in each sphere. Finally, in Chapter 7 we compare the overall dynamics, analyze the interrelations and present our conclusions.

2.2 Expectation dynamics in multiple discourse spheres

2.2.1 Social dynamics of collective expectations in innovation processes

A growing number of studies, within the sociology of expectations (see Borup et al., 2006) – a strand within science and technology studies -, but also organization and management studies, have shown how innovation-related expectations motivate researchers, designers and adopters of innovations, legitimize the allocation of resources, guide the interpretation of novel technologies and co-ordinate heterogeneous actor groups (Borup et al., 2006; Broto, 2012; Swanson and Ramiller, 1997; van Lente and Rip, 1998). This holds in particular true for collective expectations, that is, expectations which are part of a debated or widely accepted social repertoire of specific communities or even in the public in general (Konrad, 2006b). Collective expectations emerge within organizations, communities and discourses, largely as a result of mutual orientation. As a further effect, collective expectations tend to exhibit self-reinforcing dynamics, which may even evolve quite independently from experience and evidence. These dynamics can contribute to the emergence of hype-disappointment cycles. Failed expectations, that is, expectations which eventually turn out as having been too optimistic, affect innovation processes as well; depending on the specific form of disappointment, support for certain innovations may cease or be reduced, search directions modified or other legitimizing resources mobilized (Bakker, 2009; Brown, 2003; Konrad et al., 2012; Ruef and Markard, 2010). However, if the reasoning why a technology may be promising would be different between discourses spheres, disappointment may be specific as well to a certain discourse sphere. Some expectations may be more important for the framing of fuel cell technology as a promising technology in one discourse sphere than in another. Likewise, the importance and influence of discourse spheres on innovation processes could differ, which requires a conceptualization of several discourse spheres in order to analyze the potentially varying influence on innovation processes.

The different literature streams which have discussed hype-like phenomena describe these cycles in very similar ways as following a sequence of stages (Abrahamson and Fairchild, 1999; Downs, 1972; Fenn, 2006; Luhmann, 1971). After a first phase of latency, where the topic is confined to specific expert or interest groups, some triggering event sparks off broader interest and leads to a phase of growing interest and enthusiasm. However, this seems to be almost inevitably followed by a phase of waning interest and disappointment, once it is realized that the innovation does not deliver what it promised or hurdles for implementation prove more severe than expected. Often this is the moment when another issue (or innovation) captures widespread attention. Still, despite the decrease in attention, activities and learning may continue, for instance as a result of new institutions, programs and policies that have been created in the hype phase, which may in the long run lead to a realization of – at least some of – the initial promises (Bakker and Budde, 2012).

The general pattern of hype cycles is widely acknowledged[7], within academia and in the form of folk theories circulating among engineers and policy (Rip, 2006). However, the underlying processes of hype dynamics are less clear and, as mentioned in the introduction, it is also often not specified, where hype dynamics are precisely 'located'. Often, mass media is blamed for the emergence of a hype (Ransohoff and Ransohoff, 2001; Vasterman, 2005).

A number of propositions for understanding the underlying mechanisms have been made. Some refer to generic processes explaining common features of hype dynamics and some to specific processes explaining variety and changes in the course of dynamics (van Lente et al., 2013).

Mechanisms underlying the dynamic evolvement and the sometimes sudden changes in collective expectations, frequently referred to, are the mutual orientation and interaction among actors, different levels of expectations (e.g. projects and technology field), and interlinkages and competition between expectations (Geels and Raven, 2006; Konrad, 2006b). Authors affiliated with the consultancy Gartner Group explain the hype cycle dynamic as a result of the different time scales of societal attention dynamics and – the usually slower - innovation dynamics (Fenn and Raskino, 2008). Differences in the specific characteristics of a technology field, e.g. a technology being more or less generic, have been proposed as impacting the dynamics, since generic technologies may allow for easier shifts of expectations (Borup et al., 2006; Ruef and Markard, 2010; van Lente et al., 2013). The complexity of a technology and the related need to motivate other actors (e.g. suppliers or infrastructure providers) to join an innovation race concerning a new technology may provide incentives for actors to

[7] Given the basic pattern, there is still a lot of space for variety, regarding the duration of phases, the types of disappointment, recurrence of hype cycles or the coupling of attention and expectations which needs to be compared across innovations and. This is, however, beyond the scope of this paper.

inflate expectations regarding a technology and contribute to the emergence of a hype-disappointment cycle (Budde et al., 2015).

Variety in expectation dynamics across time and across places or arenas have been examined by Nisbet & Huge (2006) who show that the types of policy arenas and media involved make a difference due to more or less dramatic framing of an issue.

In sum, we see a number of indications of how different arenas or spheres matter for understanding expectation dynamics, but propose to draw on insights from the sociology of expectations, discourse theory and communication studies for further insights and conceptualization.

2.2.2 Discourse spheres

In general, we understand discourse as 'public communication of actors on themes, related positions and justifications as well as communications regarding other actors' (Gerhards & Lindgens 1995). Following a number of authors (e.g. Nisbet and Huge, 2006; Weingart et al., 2002), we assume that there is not just one homogeneous discourse on a specific theme like fuel cells. We assume that the societal discourse rather differentiates into multiple discourse spheres which can be differentiated by specific discourse arenas. Discourse arenas are the sites and structures in which the discourses are produced, e.g. media or conferences, where discourse actors make communicative contributions. Furthermore, each discourse is constituted by a specific public of actors perceiving communicative contributions (Gerhards and Schäfer, 2009). This differentiation is important, since each discourse sphere exhibits specific rules of selectivity, rationalities, different time horizons and favors certain frames more than others. Depending on the specific rules of selectivity certain issues or certain features of an issue may receive more or less attention or get re-interpreted as they are taken up in different spheres.

Hence, in every discourse sphere, issues – or as in our case, expectations - are represented and debated differently giving emphasis to technological, economic, societal, or financial aspects, to short-term or long-term prospects etc. Depending on the generating and mediating structures of a discourse sphere, processes of discourse formation may differ also in timing. In addition, the differentiation of several discourse spheres is relevant since innovation and societal actors are likely to focus on specific discourse spheres while others may not as relevant for a certain group of actors.

The differentiation of discourses in the literature is partly conducted ex-ante along the lines of functional societal subsystems i.e. science, politics, economy in Gerhards and Schäfer (2009) or science, politics and media in Weingart et al. (2000) and partly ex-post following empirically diverging discourses (Hajer, 1993). For our analysis with its interest in innovation-related expectations we chose an ex-ante differentiation of discourses, which went beyond the classical differentiation of media, science and policy. We differentiated between more specific discourse spheres supposed to be related to different types of innovation actors fulfilling specific roles in the innovation process, namely the science, professional, policy and the mass media discourse. Mass media probably play a specific role, since they are supposed to refer largely to other more specific arenas, filtering and reflecting them according to the rationality of the mass media, i.e. focusing on what is newsworthy and of interest to a more general public (Gerhards and Schäfer, 2009).

Separate discourse spheres are, however, not supposed to be isolated. Following Weingart et al. (2000) interactions across different spheres can be expected to take place as well. Thus, this paper will focus on the comparison of five discourse spheres and take into account their interactions in the case of fuel cell technology.

2.2.3 Methods: Selected discourse spheres and samples

We chose five different discourse spheres for our analysis, all being related to innovation activities regarding fuel cells in Germany and likely contributing to the overall expectation dynamics on fuel cells.

Public discourse: The public perception of major techno-scientific developments is typically reflected in the mass media. We chose the German daily newspaper *Frankfurter Allgemeine Zeitung (FAZ)* as a representative for the German public mass media discourse. It is one of the major German newspapers and the one which reported most extensively about the topic of fuel cells.[8]

Professional discourse: Research and Development departments play a key role for fuel cell innovation and are subject to high-level strategic decisions (Konrad et al., 2012). The most relevant public discourse is captured by specific professional magazines. Thus, we analyzed fuel cell coverage in a major, weekly German engineering journal, the *VDI nachrichten*.

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[8] The attention for fuel cells in the FAZ exhibits the same dynamic pattern as the average of five major German speaking daily newspapers (besides FAZ, Süddeutsche Zeitung, and Die Tageszeitung for Germany, the Swiss newspapers Neue Zürcher Zeitung and Tagesanzeiger).

Science discourse: Research institutions and universities can be considered to be crucial to fuel cell innovation. We focused our analysis on the Journal of Power Sources (JPS), which is one of the most important scientific journals in fuel cell research as data from the ISI Web of Knowledge, a database of scientific articles, and a survey we performed at two fuel cell conferences showed.[9]

Policy discourse: Policy contributes to fuel cell innovation, both by regulating and by providing financial and institutional support. Analyzing the policy discourse is somewhat complicated because it takes place at multiple levels that are not represented in an overarching journal or database. Policy measures related to innovation activities in Germany and, supposedly, related discourses take place at the level of the national state, the various federal states, which entertain specific fuel cell initiatives, and the European Union. For practical reasons, we limit our analysis to the national level. We analyzed parliamentary protocols and key policy documents referring to fuel cell technology, in the 'Parliamentary Material Information System' (DIP, Dokumentations- und Informationssystem für Parlamentarische Vorgänge) of the German Bundestag, supplemented by key documents identified by expert interviews. The search query[10] yielded plenary protocols, parliamentary inquiries, strategy documents which refer to fuel cell technology to different degrees. Whereas articles in the other discourses can be different they are in principle the same format and thus relatively straight forward to count. However, in the policy discourse there are considerable differences between a stenographic protocol of a plenary discussion and a parliamentary inquiry or a strategy document. Thus we did not quantify the policy discourse.[11]

Finance discourse: Finally, we examined a fraction within a larger business-oriented discourse, which is particularly concerned with investment opportunities, mostly, though not exclusively, those related to the stock market. The finance discourse deserves special attention, since fuel cell stocks were increasing their price dramatically exactly within the period we observe the general fuel cell hype. Expectations within the investment community are important for some of the

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[9] We conducted a mini survey at two relevant fuel cell events in Austria respectively Switzerland, we received 96 questionnaires, which indicated that the Journal of Power Sources and the Journal of the Electrochemical Society were regarded as the most relevant Journals.

[10] Primarily we used the search term 'fuel cell" (Brennstoffzelle) and its respective truncations, for some periods a dedicated key word 'fuel cells" was available. Results from this key word list were checked manually for relevance, since it provides a large number of articles not related to fuel cells.

[11] A plenary protocol can and does contain in some cases only one reference to fuel cell technology by a single speaker, whereas on the other extreme one protocol can cover a plenary session focussing on fuel cell technology only.

firms involved in fuel cell innovation, namely those which are listed at the stock exchange or which are dependent on Venture Capital. We chose the German *Handelsblatt* as the basis for our sample, one of the leading German-language financial and business newspapers. As financial articles make up only part of the articles within *Handelsblatt* we restricted the sample to all articles containing the keywords *fuel cell* and *stock exchange* with its respective truncations.[12]

For all discourse spheres we conducted a quantitative and a qualitative analysis. The quantitative analysis – based on the number or ratio of specific articles - served to ascertain and to provide indications to compare the different attention and expectations dynamics in the various discourse spheres. For the latter, we coded the appraisal of fuel cell technology within the articles. Articles were coded as 'very optimistic' if they were referring to a great potential of the technology or a market introduction on the short term, without referring to any drawbacks or hurdles. Articles considered as 'optimistic' exhibited a positive general appraisal of the technology also on the short-term, but mentioned minor drawbacks or hurdles. 'Moderately optimistic' articles, though, are acknowledging the general potential of the technology; however the technology is described as being a long term option with rather severe problems on the short term. Articles which emphasize hurdles, but acknowledge some potential of fuel cell technology in general were coded as 'skeptical'. 'Pessimistic' articles do not mention any short, medium or long-term potential for the technology.

Furthermore, in the qualitative analysis we analyzed in more detail the expectations and justifications related to fuel cells and the discourse actors that are either cited or mentioned. In the following section we compare the attention dynamics in the different discourse spheres as a first indicator of similar or diverging attention dynamics, before we present the qualitative analysis in more detail.

2.3 Attention and expectations dynamics

A hype-disappointment cycle, characterized by highly optimistic expectations which turn into disappointment, is typically indicated by a strong increase in attention given to a specific topic within one or multiple discourse spheres, followed by a drop of attention. Figure 3 presents a comparison of the discourse dynamics within the mass media, professional, financial and science discourse

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[12] Of course we used the German terms ('Brennstoffzelle" and 'Börse". In so doing, we were able to yield almost all articles covering fuel cells from a finance perspective as a comparison with all *Handelsblatt* articles containing the term *fuel cell* for the years 2001 and 2007 showed.

sphere.[13] Within the mass media, in Figure 3 represented by all *FAZ* articles referring to fuel cells in their title[14], we observe a strong increase in attention followed by a drop in attention during later phases. The first articles on fuel cells appeared in 1994, followed by a steady increase of articles until 2001. After 2001, attention dropped significantly and remained at a low level during following years. Within the professional discourse, illustrated by all articles in the *vdi nachrichten* referring to fuel cells in their title, we observe a similar dynamic until 2000. The peak in 2001 was however more pronounced and the attention remained at a moderate level during the years 2002-2004, before it decreased considerably from 2005 onwards. Within the financial discourse, fuel cells were taken up much later. The number of articles between 1997 and 1999 was very low, followed by a sudden upsurge in 2000 and 2001. After 2001, attention dropped again to a low level, comparable to the dynamics in the mass media. Hence, attention dynamics indicate that a hype-disappointment dynamic took place in these three discourse sphere, but discourse-specific dynamics seem to be involved as well.

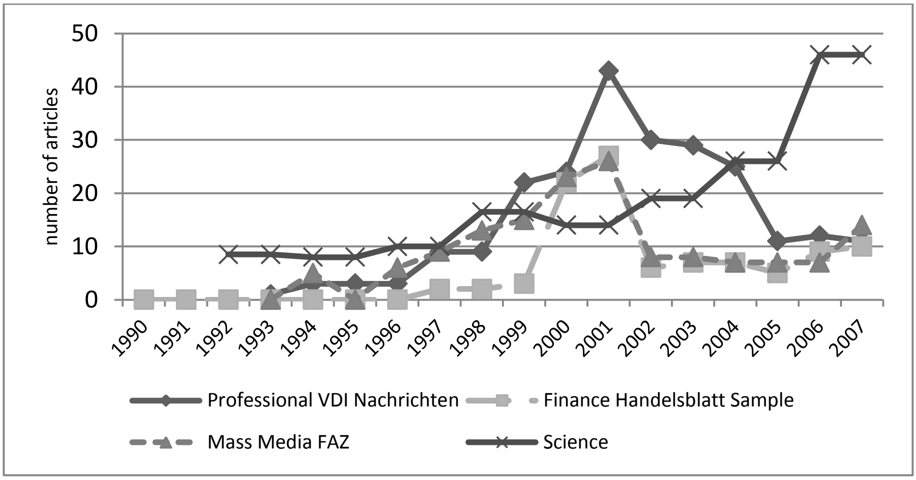

Figure 3: Coverage of fuel cells in different discourse spheres

Within the science discourse sphere, however, the attention dynamics show a different pattern. The number of scientific fuel cell publications increased

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13 Even though the absolute numbers of articles cannot be compared directly, due to the different characteristics of the media and journals, we are primarily interested in a comparison of the attention dynamics. Thus the comparison of numbers of articles in different spheres should be considered with caution and is predominantly intended as a comparison of dynamic *patterns*. For instance, the relative frequency of articles per issue is much higher in the professional discourse than in the mass media, since *VDI nachrichten* are published on a weekly basis only.

14 Articles mentioning fuel cells in the full text show a similar dynamic pattern, with the exception of a less acute downturn in article numbers after 2001.

continually over the years and even shows a particularly steep increase after 2003. As mentioned above we did not quantify the policy discourse due to the different nature of documents.

In sum, the attention for fuel cells in the different discourse spheres seems to be related in most, but not all spheres, to a fuel cell hype culminating around 2001.

Although these numbers give an indication about the diverging coverage of fuel cell technology and the expectation dynamics in the different discourse spheres, we cannot assume a direct link between attention for fuel cell technology and positive expectations. Thus, in the following qualitative analysis we will examine to what extent attention dynamics were indeed related to changes in expectations and analyze the specific topics and expectations discussed in each discourse sphere. Thereby, we will be able to contribute to an understanding of the specific dynamics in each sphere.

2.3.1 Mass media[15]

In the mass media discourse, attention increased almost steadily from 1996 to 2001, but expectations were particularly optimistic from 1998 to the first half of 2000. In this period the appraisal expressed in the articles was mostly optimistic or even highly optimistic (see Figure 4). While in 2001 attention continued to rise, appraisal changed with less than half of the articles being optimistic and quite a number of skeptical articles. Between 2002 to 2005 attention was comparatively low and articles only rarely optimistic. The articles published in 2006 and 2007, however, were becoming more optimistic again. So, the change in collective expectations, indicated by the change in appraisal first, was followed by a drop of attention with a time lag.

[15] The qualitative analysis is based on the sample of articles mentioning fuel cells in their title, complemented with a small number of articles mentioning fuel cells in the body text only, but providing additional insights. *Quantitative* statements are based on the sample with fuel cells in the title only, in order to ensure comparability.

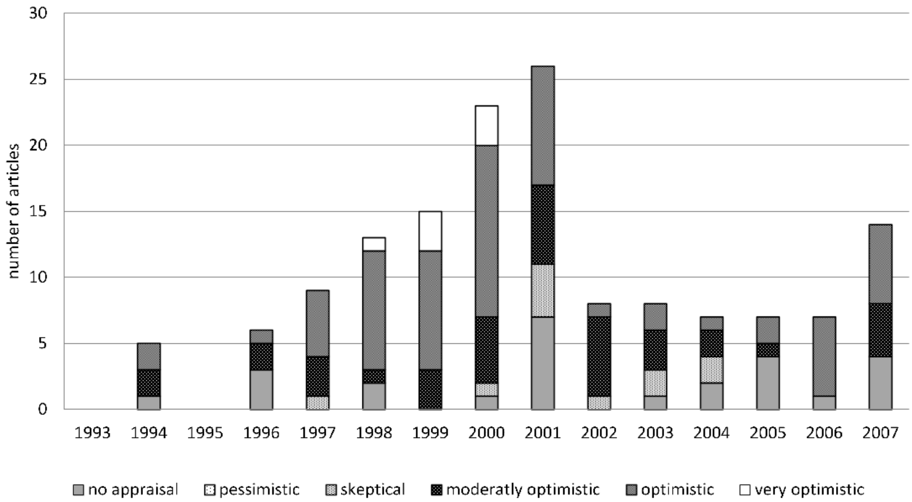

Figure 4: Appraisal and attention for fuel cells in FAZ articles mentioning fuel cells in their title, 1993-2007

Concerning the applications of fuel cell technology, Figure 5, shows that mobile applications, particularly passenger cars, caught most of the mass media interest. This holds in particular true until 1999, when the vast majority of articles was dealing with mobile applications, only since 2000 fuel cells were discussed either with regard to multiple applications or stationary applications such as heating systems.

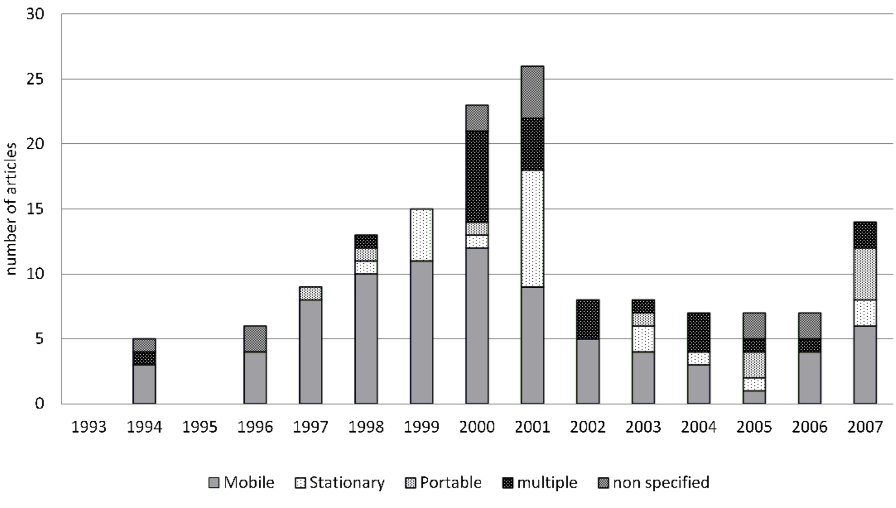

Figure 5: Application focus of FAZ articles mentioning fuel cells in their title (1993-2007)

Period I (1994-1996): Exciting news - Daimler presents its 'NECARs'

This period shows beginning media interest for fuel cells, with a few spectacular announcements about successful fuel cell developments, first and foremost by the automobile manufacturer Daimler-Benz. In particular the presentations of its two prototypes NECAR I and II in 1994 respectively 1996 raised attention for fuel cell technology. In 1994, the NECAR (New Electric Car) was presented as a 'decisive, basic breakthrough for mobile fuel cells in cars' – a car that actually works. Serial production, however, was considered to be 'far away', about 10 to 20 years ahead, according to the head of research at Daimler-Benz.[16] The prototype was actually fuelled by hydrogen, but methanol or other fuels which allowed to reform hydrogen on board, while using existing fuel infrastructure, were considered as the most promising fuel option.

1996, a year earlier than initially promised, Daimler-Benz announced remarkable progress in fuel cell development and presented a new prototype, a much smaller type of vehicle, which promised further rapid advancements. A decision about serial production was announced to be taken within 3 years. Daimler-Benz' head of research was cited again saying that fuel cell cars might be a mass product in about 15 years, but definitely more than 10 years from then. While in 1994 the announcement of Daimler-Benz to have achieved a major breakthrough for fuel cell cars was presented as the firm's 'belief' by the journalist, the announcement of 1996 was tagged as a 'spectacular presentation' and praised as 'surprising progress'[17]. Intended by Daimler-Benz or not, the presentation of the new prototype one year ahead of schedule wakened hopes for more such fast progress. The subtitle of one article raised the question whether serial production was to be expected even earlier than announced.[18]

Period II (1997): Nascent Hype - Other actors enter the stage and market entry is preponed

While in the years before, commercialization, in particular serial production, was presented as somewhere in the longer-term future, in 1997 it became a more prominent issue. Five articles referred to serial production respectively market entry in their title and time horizons were successively preponed. At the beginning of 1997, Chrysler announced serial production within 10-15 years.[19] In April,

[16] *Elektrizitätswerk an Bord*, FAZ 19.04.1994.
[17] *Mit Wasserdampf-Fähnchen in die Zukunft*, FAZ 21.05.1996
[18] *Mit Wasserdampf-Fähnchen in die Zukunft*, FAZ 21.05.1996
[19] *In Detroit ein Heimsieg für Chrysler*, FAZ 14.1.1997 and *Wasserstoff aus Benzin gewinnen*, FAZ 18.2.1997.

Volkswagen expected serial production in about 10 years.[20] Shortly after that, Daimler-Benz was cited with the intention to be the first to present a serial produced car on the market, and in September this was specified saying, they would have a serial car ready for 2005.[21] Finally, at the end of the year, Ford joined the cooperation between Daimler and the fuel cell company Ballard.

What we observe here at the beginning of the hype dynamic seems to be the interlocking and alignment of expectations and strategies of a constellation of competing and cooperating innovation actors. While the first 'NECARs' constituted a more diffuse promise with comparatively little pressure for action, this promise had now transformed into a quite specific, collective expectation. Actors had to respond to it in some way, and for many actors the promise transformed into a requirement (Konrad, 2006a; van Lente, 1993).

In contrast to fuel cell cars, stationary applications were not presented as something highly promising or spectacular; and apart from PAFC (phosphoric acid fuel cell) based systems, which were already on the market in specific market niches, commercialization was not an issue.

Period III: Hype (1998-2000)

In 1998, the collective expectation of a 'serial production of fuel cell cars starting around 2004' was stabilized, and kept up in the following two years, fed by statements from managers and engineers of large car manufacturers as General Motors, Ford or Daimler-Benz. This was further fuelled by expectations about future sales of fuel cell vehicles. The Daimler-Ballard-Ford Alliance was said to aim at a production of 100.000 fuel cells for cars in 2004[22]. According to a planning of GM/Opel, by 2010 10% of their cars might already be fuel-cell driven[23]. The consultancy firm Frost & Sullivan forecasted that fuel cell turnover might achieve almost four billion by 2004[24]. The rising number of actors engaged in fuel cell activities was also reflected in a 1999 article featuring the German car exhibition IAA saying that 'almost every car manufacturer joins in the way to the fuel cell car'[25]. In addition, suppliers were hooking onto the hype. SGL Carbon was said to put high hopes in the development of fuel cells and considered to become a supplier for the technology.

[20] *Volkswagen entwickelt Brennstoffzelle auf Methanolbasis*, FAZ 16.4.1997.
21 *Die A-Klasse mit Brennstoffzelle*, FAZ 16.9.1997
[22] *Die Abkehr vom Verbrennungsmotor ist nicht mehr aufzuhalten*, FAZ, 12.1.1998
[23] *Das kalte Feuer für die Zukunft*, FAZ, 21.12.1998
[24] *Langsam kommt die Brennstoffzellen-Technik aus den Kinderschuhen*, 28.9.1998
[25] *Schon wieder zwei Jahre näher an der Zukunft*, 14.9.1999

Hurdles, particularly high production costs and the necessary infrastructure, if mentioned at all, were presented as possible to overcome. Only one clearly critical actor was cited: Greenpeace which referred to the fuel cell activities of the car manufacturers as 'technological adventure' obstructing the commercialization of very low-consumption gasoline cars, such as the Smile concept car developed on behalf of the NGO[26].

Attention for stationary applications, most notably so-called 'fuel cell heating devices' for single houses, producing heat and electricity at the same time, started in 1999, though still at a low level. Expectations, however, were rising substantially. This was related to the announcement of Vaillant, a large German heating systems manufacturer, to aim at being the first to offer a market-ready and affordable system by the end of 2001. Media representation was, however, a bit vague, once referring to market introduction and once to first pilot plants being expected for 2001.[27] In addition, a calculation was presented, according to which Vaillant expected a turnover with fuel cell heating systems in 2010 that would be only somewhat less than the turnover made with conventional heating systems in the year 1997. Another article cited RWE, one of the largest German utilities, expecting (larger) fuel cells to be market ready in 5 to 10 years and 20-40% of electricity to be produced in a decentralized way in 2010, partly by fuel cell systems at the household level[28]. So, for fuel cell expectations as promoted by the utility RWE, the link with an expected general trend towards decentralization in the electricity system was put up front, whereas articles focusing on heating manufacturers mentioned this rather as a side issue. Expectations on stationary applications seemed to be rather contested though at the time. Buderus, another large heating system manufacturer, did not expect marketable systems within reasonable timeframes.[29]

Finally, we observed some, though little reflection of the debate in the German Parliament on whether fuel cells should be included within the CHP[30] bill or not (see section on policy). In 2000 a small number of articles referred to the emerging policy interest in and the debate on fuel cells.

Similar to the *Handelsblatt* (see finance discourse sphere), in 2000 the number of articles focusing on the investment potential of fuel cells increased strongly,

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26 *Erstes Brennstoffzellen-Auto der Welt vorgestellt*, 15.5.1998, *Greenpeace: Verbraucher für einen 'grünen Stromwechsel' gewinnen*, FAZ 18.8.1998
27 *Vaillant baut Brennstoffzellen-Heizgerät*, FAZ 25.10.1999
28 *RWE und Siemens bauen Brennstoffzellen-Anlage*, FAZ 03.07.1999
29 *FAZ Buderus setzt auf schrumpfendem Markt sein Wachstum fort*, FAZ 24.3.1999.
30 CHP, Combined Heat and Power

though not as pronounced as in the financial oriented Handelsblatt. The topics and the tenor were comparable to the Handelsblatt sample, though somewhat less optimistic.

In autumn 2000, expectations started to change, indicated firstly by contradictory statements. On the one hand, a rather skeptical article cited a Daimler-Chrysler 'expert' saying that 'externally people pretend that it is only one step to solving the problems on the way to a fuel cell car. However, problems were actually piling up in front of the developers.'[31] Two weeks later, Daimler-Chrysler CEO Schrempp and the German chancellor Gerhard Schröder gave both very optimistic statements.[32] Though the tenor of the articles was highly optimistic, a closer look reveals that the specific expectations concerning commercialization had been adjusted: Daimler-Chrysler CEO Schrempp was cited saying that 2004 the first passenger cars would be delivered - while in 1998, a number of 100 000 fuel cell cars on the road was projected for 2004[33].

Period IV: Market entry for automobiles postponed, attention shifts temporarily to fuel cell heating systems (2001)

2001 was marked by disappointment about the commercialization prospects of mobile applications. Ford and Daimler-Chrysler stated that they expected serial production of fuel cell cars not before 2010[34]. Similarly, a report on the German car exhibition IAA stated that commercialization was not expected on the short term, even if almost all car manufacturers seemed to work on fuel cells. Hurdles, such as technical problems, hydrogen storage and production, infrastructure and costs, which before were presented as something to be overcome, now appeared as real problems.[35] At the same time, attention on stationary applications, most notably fuel cell heating systems, suddenly increased. Articles about mobile applications were largely skeptical or moderately optimistic, whereas those on stationary applications gave a more optimistic picture.[36] Still, expectations on fuel cell heating systems differed significantly between the various system manufacturers and utilities.

Thus, we may speak of a shift in expectations from mobile to stationary applications. This, as will be seen in the following, was not a lasting phenomenon

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31 *Skepsis bei der Brennstoffzelle*, FAZ, 24.10.2000
32 *Daimler investiert 2 Milliarden DM in die Brennstoffzellentechnik*, FAZ 8.11.2000
33 *NECAR 5 rollt*, FAZ 14.11.2000
34 *Auf dem mühsamen Weg in eine Zukunft ohne Schadstoffe*, FAZ 18.09.2001
35 *Noch kein Ersatz für Verbrennungsmotoren*, FAZ 11.9.2001
36 *Nicht jeder träumt von der Brennstoffzelle im Auto*, FAZ 16.10.2001

though. Overall, the fuel cell hype came to an end. In the last quarter of 2001 articles were either moderately optimistic or skeptical.

Period V (2002-2005): Disenchantment

In following years only a very small number of articles sketched an optimistic picture of the fuel cell future. Moderate optimism or even skepticism was prevailing. Various articles reported on ongoing activities, but highlighted that commercialization was way ahead. In 2002 and 2003, we observe some announcements for 2010, later on stretched to 'in about 10 years'[37]. Quite a number of articles elaborated on problems and hurdles. So, while there was substantial disenchantment about the short-term prospects of fuel cells, the technology was not fully dismissed, but a general potential in the middle- to long-term future was largely acknowledged. Furthermore, statements concerning the future fuel to operate fuel cell vehicles were modified: On-board reforming of methanol or other fuels were not promoted anymore; if the articles discussed this question, most of them referred to the direct use of hydrogen.

The application focus remained broader than in the 1990ies, including stationary but also portable applications. Still, contrary to 2001, articles dealing exclusively with stationary applications were rare.

Period VI (2006-2007): Regaining confidence in mobiles and niche applications?

The tenor of the articles in 2006 and 2007 was generally more positive than in the former years, even if commercialization prospects were somewhat mixed, reaching from 2010 (GM) until 2020 or later (VW). Besides articles featuring automobiles, in 2007 about a third of all articles focused on very specific applications like power supply for caravans or various remote applications. These articles were largely related to the initial public offering of the company 'Smart Fuel Cell' in 2006 and another emission of shares in May 2007.[38]

Summary

The qualitative analysis illustrated that there was indeed a hype around fuel cells in the mass media. Not only attention, but also expectations increased between 1997 and 2000, but were adjusted substantially afterwards. Commercialization

[37] *Mit Wasserstoff durch L.A.*, FAZ 24.06.2003 & *Washington fördert den Brennstoffzellenantrieb*, 14.01.2002
[38] *Vorschusslorbeeren für Brennstoffzellen*, FAZ 25.05.2007 & *Brennstoffzelle für Concorde-Reisemobile*, FAZ 16.10.2007

prospects of fuel cell cars featured most prominently, while commercialization prospects of small combined fuel cell heating and power systems caught some attention between 1999 and 2001. The mass media discourse was characterized by a large number of articles referring to car manufacturers, in particular Daimler. This holds true especially until the year 2001. Generally speaking we can conclude that the hype was resulting from an interlocking of expectation statements which eventually turned into an expectations race among car manufacturers.

2.3.2 Professional discourse sphere

Similar to the mass media discourse, in the professional engineering discourse attention to fuel cells was rather low until 1997. The first remarkable increase in attention occurred from 1998 onwards. In 2001, the number of articles reached an absolute peak. The appraisal was largely optimistic or even highly optimistic, but still more moderate compared to the mass media discourse. While attention decreased in the following three years - to a level slightly above the 1998/1999 level, expectations remained quite positive. From 2005 onwards, attention for fuel cells decreased once more, comparable to the level of 1996/1997, still no clear disappointment could be identified.

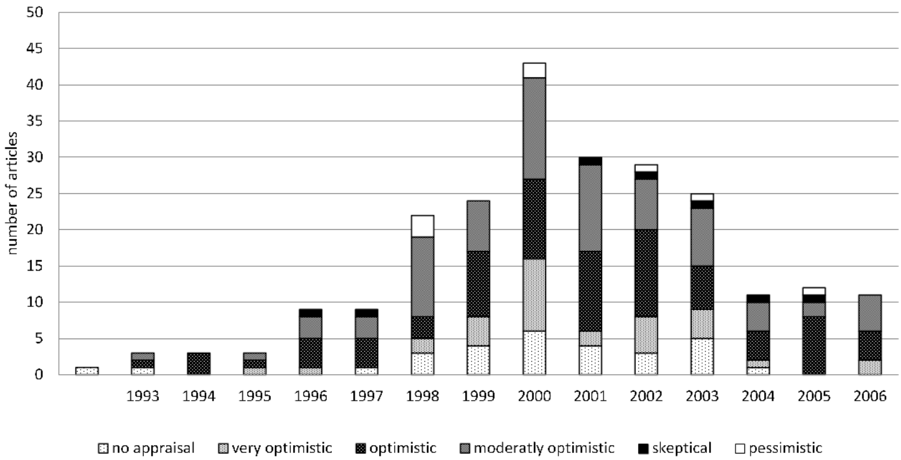

Figure 6: Appraisal and attention for fuel cells in vdi nachrichten, 1993-2007

Another remarkable difference compared to the mass media discourse is the attention given to particular applications (Figure 7). Stationary applications played a larger role in the professional discourse than in the mass media in almost all the years we investigated.

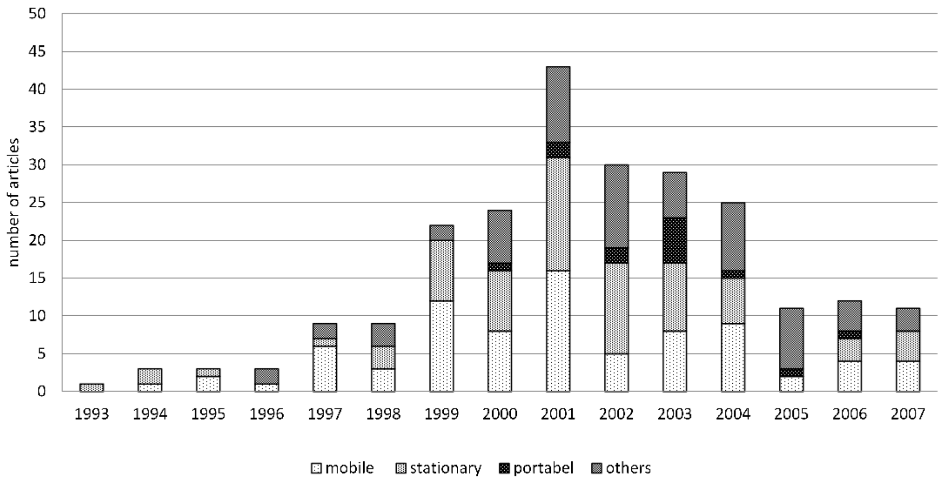

Figure 7: Application focus of vdi articles mentioning fuel cells in their title (1993-2007)

Period I (1993 – 1996): First announcements of promising projects

The first period from 1993 to 1996 shows a low number of articles and moderate expectations. Many articles reported on stationary applications powered by PAFC[39] technology.[40] Furthermore, mobile applications of fuel cells, for instance fuel cell buses by Daimler[41], were mentioned as a viable option. Compared to the mass media articles, more attention was given to the possible embedding of fuel cells in a larger energy system linking up to visions of a hydrogen economy, increased use of renewables or a decentralization of electricity production.

Period II (1997 – 2001): High hopes for near-term commercialization

In the following years, attention for fuel cells increased and – except for 1999 – roughly half of the articles reported in an optimistic or even highly optimistic way about fuel cells. However, compared to the mass media coverage, expectations seemed to be more moderate. A closer look reveals a lot of similarities in the concrete topics and expectations treated, such as the fuel cell activities and commercialization prospects promoted by Daimler and other cooperating or

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[39] PAFC - Phosphoric Acid Fuel Cells, a specific type of fuel cells

[40] *Brennstoffzellen erfolgreich im Test, Direkte Umwandlung von Gasen in elektrischen Strom und Waerme,* VDI-Nachrichten, Nr. 021, 26.05.1995

[41] *IAA Nutzfahrzeuge Õ96 in Hannover: Alternative Antriebskonzepte sichern Mobilitaet im Omnibusverkehr - vom Erdgasbetrieb zum Brennstoffzelleneinsatz*, VDI Nachrichten Nr. 037, 13.09.1996

Brennstoffzelle im umwelt-gerechten Auto der Zukunft, Daimler-Benz: Alternative zum Verbrennungsmotor, VDI-Nachrichten, Nr. 020 vom 19.05.1995 competing car manufacturers, or the discussion, if methanol or hydrogen is the more promising fuel. However, the – generally more elaborate - articles describe more explicitly possible hurdles and challenges and dedicate more attention to critical voices, such as the Federal Environment Agency (UBA). Its studies and statements doubt the short- and medium term potential of mobile fuel cell technology to reduce emissions, because of the energy needed for producing hydrogen or methanol. Stationary applications on the contrary were expected to be a more viable technology to improve energy efficiency in the housing sector and in industrial applications.[42][43]

We observed that the interest in stationary applications increased over the years, both in terms of attention and concrete expectations. Particularly in the years 2000 and 2001, articles were largely optimistic or even highly optimistic, more than articles dedicated to mobile applications at the same time. While fuel cell systems based on PAFC technology were mostly perceived as being not efficient enough and too expensive, small-scale systems for single houses based on PEMFC or SOFC[44] technology were promoted as promising by many actors. Generally, stationary fuel cell systems were expected to enter the market in larger numbers from 2004 onwards.[45] The first commercial products were announced for 2001 (by Sulzer Hexis) and 2003 (by Vaillant).[46] Stationary fuel cell systems were frequently mentioned in context of an expected decentralization of the electricity system, and thus considered to be a major building block of the future electricity system.[47]

Period III (2002 – 2004): Disenchantment with mobile applications, but expectations carried on by micro CHP applications

After 2001, reporting on problems and warnings about potentially inflated expectations was becoming more prominent. In particular high production costs were considered to be a barrier, probably delaying market introduction. Thus, voices calling for a more cautious step-by-step approach became more evident in

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42 *Fahrzeugantrieb: Brennstoffzelle übertrifft Verbrennungsmotor beim Wirkungsgrad Brennstoffzelle konkurriert mit der Batterie im Auto*, VDI-Nachrichten, 06.04.2001

43 *Automobil: Energieverluste bei Methanol- und Wasserstoff-Gewinnung zehren Vorteile auf Brennstoffzellen-Auto erhält vom Umweltbundesamt schlechte Noten*, VDI-Nachrichten, 21.05.1999

44 PEMFC - Proton Exchange Membrane Fuel Cell, SOFC - Solid Oxide Fuel Cell

45 *Ab 2004 rechnen Experten mit ersten Fertigungskapazitäten für Brennstoffzellen-Massenprodukte Verschiedene Typen ringen um Marktanteile Brennstoffzelle drängt mit Tempo auf den Markt*, VDI-Nachrichten, 06.07.2001

46 *Dezentrale Energieversorgung Brennstoffzellen auf dem Sprung in die Anwendung*, VDI – Nachrichten, 13.07.2001

47 *Die Revolution im Heizungskeller Die Brennstoffzelle kommt Das »Heimkraftwerk« im Karton verpackt*, VDI – Nachrichten, 06.07.2001

the discourse.[48] Still, fuel cells were expected to become available on the market eventually, yet not in the short term. In particular, expectations concerning mobile applications were more moderate, after the prospects for market introduction had shifted to the period 2010-2015. For instance, Daimler manager Hubbert was cited saying that price, weight and reliability targets had not been met.[49]

Expectations concerning stationary micro CHP applications were more optimistic, in particular in the beginning of this period. In particular electricity companies and their expectation statements played a prominent role, e.g. RWE and Eon, two German utility companies, as well as indirectly via a study conducted by Arthur D. Little, according to which the majority of utility companies expected fuel cells to play a key role in the future.[50] This was the same study, which was as well discussed in the mass media (see above). Among the manufacturers, Sulzer and Vaillant made optimistic statements about the status of their stationary fuel cell systems, while another company Viessmann was skeptical.[51][52] Across this period, an increasing number of articles referred to a virtual fuel cell power plant project supported by the European Union, in which Vaillant, various large German electricity and gas companies and others participated. The project tested the joint operation of a large number of fuel cells to replace conventional power plants in the long term.[53] However, commercialization prospects had to be postponed for micro CHP as well: for instance, in 2003, serial production was envisaged 'in a

48 e.g. *Energie: Kosten und Kinderkrankheiten bremsen Markteinführung, Brennstoffzelle: Euphorie wäre zu früh*, VDI-Nachrichten, 13.12.2002

49 *Automobil: Erste Probefahrt mit Brennstoffzellen-Autos - Ford Focus FCEV Hybrid und Mercedes A-Klasse F-Cell ab 2003 im Flotteneinsatz bei internationalen Kunden, Stromer von morgen im Test: Einer klingt nach Straßenbahn*, VDI-Nachrichten, 18.10.2002

50 *Energie: Durchbruch kommt später als erwartet, Studie: Brennstoffzelle wird mittelfristig hohe Bedeutung für Haushalte haben*, VDI Nachrichten, 23.05.2003

51 *ISH 2003: Zukunftsweisende Heiztechnik bietet mehr Gesprächsstoff als Produktpräsentation Demosystem im laufenden Betrieb, Brennstoffzelle bleibt ein Thema,* VDI-Nachrichten, 28.03.2003

52 *Gebäudetechnik: Bei der Entwicklung von Brennstoffzellensystemen will Viessmann nur mit deutschen Partnern kooperieren, Brennstoffzelle: Der sonst so rührige Heiztechnikanbieter nimmt sich plötzlich Zeit*, VDI Nachrichten, 22.02.2002

53 *Energie: Energieversorger testen Dezentralisierung der Strom- und Wärmeversorgung Energiemanagement wird erprobt, EU-Feldtest »Virtuelles Brennstoffzellen-Kraftwerk« nimmt seinen Lauf*, VDI-Nachrichten, 20.02.2004

couple of years'[54], in 2004 the fuel cell program manager of Vaillant 'hopes to achieve serial production by the end of the decade'[55].

Period IV (2005-2007): Perseverance?

After 2004, attention for fuel cells dropped and the discourse focused on more detailed research and development questions and the development of periphery systems, whereas possible dates for market introduction were hardly mentioned. Still, the overall tenor of most articles was optimistic or at least moderately optimistic, even when problematic news for stationary applications were reported, when one of the key actors. Sulzer sold their fuel cell activities and RWE did not continue with major R&D cooperations.[56] Furthermore, as already visible in the 2nd half of the former period, attention shifted partly to small portable fuel cells supposed to power electronic devices and various niche applications.[57]

Summary

We observed strong similarities to mass media, yet a stronger interest in stationary applications resulted in a different shape and timing of the hype dynamic. The disenchantment regarding mobile applications was initially compensated by stationaries. Furthermore, the dynamic was less pronounced, with some more moderating statements in the hype phase and less expression of disappointment when expectations had to be adjusted. In substance, however, the expectations did not differ from the mass media discourse.

2.3.3 Finance discourse sphere

The attention peak on fuel cells in the finance discourse shows similarities with the development of share prices of a major fuel cell firms (Figure 8).[58]

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[54] *Dezentrale Energie Versorgung Energieversorger gehen mit Brennstoffzellen-Kraftwerken in die Praxis, VDI-Nachrichten,* 28.03.2003

[55] *Energie: Energieversorger testen Dezentralisierung der Strom- und Wärmeversorgung Energiemanagement wird erprobt, EU-Feldtest »Virtuelles Brennstoffzellen-Kraftwerk« nimmt seinen Lauf*, VDI-Nachrichten 20.02.2004

[56] *Hausenergie: Bei Brennstoffzellen-Kleinkraftwerken treiben einige Firmen die Entwicklung voran, während andere sie aufgeben*, VDI-Nachrichten, 10.03.2006

[57] *Energie: Bundesforschungsministerium sieht Chancen für die mittelständische deutsche Industrie - Die Minizellen überzeugen durch ihre lange Betriebszeit, Kleine Brennstoffzellen sorgen für mehr Mobilität*, VDI Nachrichten, 22.09.2006

[58] Considering the market capitalization of a larger number of fuel cell firms, we observe a similar dynamic with strongly rising share prices around early 2000 and a gradual decline until the end of 2001 Wüstenhagen, R., Wübker, R., Bürer, M.J., Goddard, D., 2009. Financing fuel cell market development: Exploring the role of expectation dynamics in venture capital investment, in: Pogutz, S., Russo, A.,

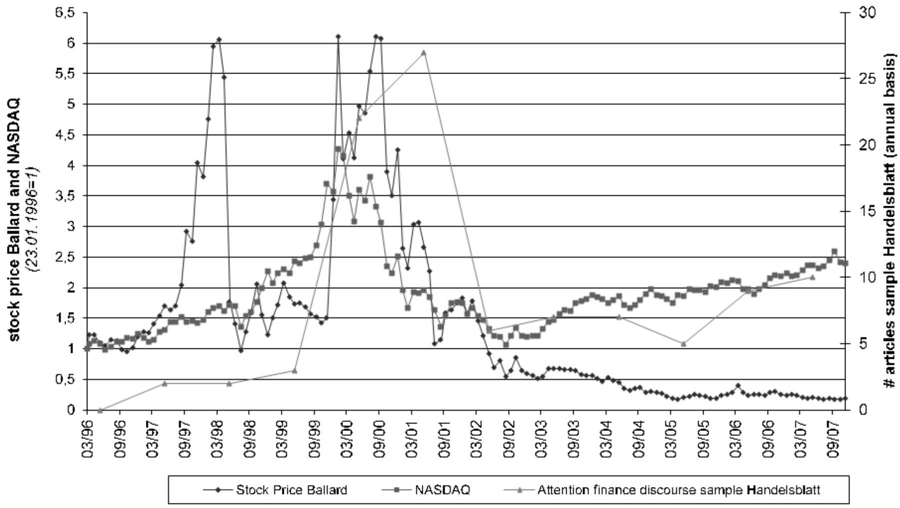

Figure 8: Attention dynamics finance discourse and stock price developments

Hence, attention and the development of share prices seem to be coupled. This coupling could be due to expectations and attention influencing fuel cell share prices or due to share prices creating attention and high expectations. Probably both factors played a role. Concerning the attention dynamics, we have to consider that in 2000, due to the so-called 'New Economy' respectively 'Tech Stock Hype', attention for stock market events in general was peaking. We checked if the attention peak could be explained by the New Economy Hype alone. The ratio of fuel cell finance articles in comparison to all articles mentioning the stock exchange showed a peak in the years 2000 and 2001. While attention for the stock exchange in general was declining after 2000, the number of fuel cell finance articles was still increasing. Thus, rising attention was also related to fuel cells as such, and not merely a side effect of the new economy hype. The 'New Economy Hype' may have pushed the interest in fuel cells, but fuel cells were able to 'survive' the burst of the dot.com 'bubble' at least for some time, before they were taken by a negative dynamic too.

Migliavacca, P. (Eds.), Innovation, Markets, and Sustainable Energy: The Challenge of Hydrogen and Fuel Cells. Edward Elgar, Cheltenham, pp. 118-137.

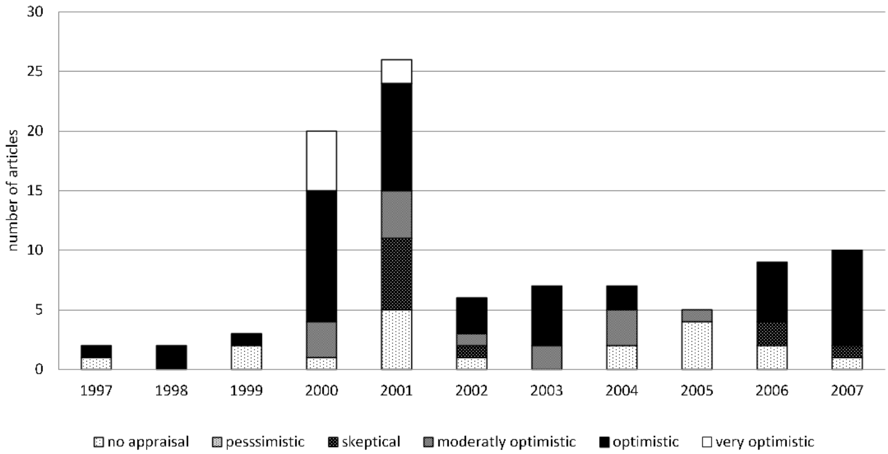

Figure 9: Appraisal of fuel cells within the finance discourse

Period I: Incipient interest (1997-99)

In this period attention was marginal and fuel cells were mentioned casually - as one technology among other promising investment options. Fuel cells were enumerated among other 'New Economy' investment options as software, media, biotech or environmental technology.[59] Applications were either not specified or the article referred implicitly to mobile applications. No specific prospect of commercialization was given. This could be due to the very casual references to fuel cells, which hardly provided space for specification.

Period II: 'Hype' (2000 – spring 2001)

In 2000, the number of articles shows a sudden increase with articles being mostly optimistic or even highly optimistic. In contrast to the first period a number of articles treated fuel cells as the main topic or assigned substantial space to them. Only two articles presented fuel cells as tech stocks, whereas a third of all articles referred to fuel cells as clean energy technology. Clean energy stocks were considered as a promising investment alternative after the burst of the 'dot-com-bubble', supposedly becoming the next boom sector at the stock market.[60] So, the interest of the financial community in fuel cells seems to have been coupled to more general trends, with fuel cell stocks escaping the bursting of the 'dot.com bubble' for some time by hooking up to the clean energy hype.

[59] *Die Pipeline für den Neuen Markt ist lang genug*, Handelsblatt 10.12.1997
[60] *Banker mögen alternative* Energien, Handelsblatt 19.1.2001

Almost all other articles were dedicated to specific firms, which were in some way active in fuel cell innovation. Two points are noteworthy. These were not the firms producing fuel cell systems or components, such as Ballard, Plug Power or Fuel Cell Energy, but large companies, for which fuel cell related activities were just marginal, such as SGL a large company specialized in all kinds of products made from carbon. 'But', a as a financial analyst was cited, 'this is likely to change in a few years.'[61]

Some, but only a minority of the optimistic and highly optimistic articles reported that commercialization was expected in the near future. Others did not give any specific estimation on that issue. However, we also found the first more cautious voices referring to the formerly rising clean energy stock values as 'hype' and expecting a further downturn, while preserving longer-term expectations in the year 2000.[62]

Stationary applications appeared almost as often as mobile applications. Yet, the majority of articles did not even specify applications or mentions various applications. Finance actors, largely analysts and fund managers, constitute the vast majority of discourse actors. More rarely, system integrators, infrastructure providers and suppliers entered the stage.

Period III: Disenchantment (spring to end 2001)

In between March and May 2001 the appraisal of fuel cells changed significantly to the negative. Increasingly, ‚fundamentals' as turnover and gains and losses were taken into account when assessing the value of a stock respectively company.[63] This indicates that evaluation criteria that had been 'suspended' before, were reactivated (Konrad 2006), which has been reported to have taken place for dot.com stocks in general after the burst of the 'dot-com bubble' (Wheale and Amin, 2003). Furthermore, while some actors continued to present rather short-term commercialization prospects, more skeptical views prevailed. Finally, the plummeting of stock values of fuel cell producers as Ballard or Plug Power led to more cautious assessments. In sum, it seems likely that - just as the positive expectation spiral - the negative disappointment spiral was a mixed effect of the more general dynamic of the stock market and the specific fuel cell expectation dynamic.

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61 *Banker mögen alternative* Energien, Handelsblatt 19.1.2001
62 *Sonne, Wind, Wasser und Geld*, Handelsblatt 31.10.2000
63 *Riskante Wette auf Brennstoffzellen*, Handelsblatt 4.5.2001

Period IV: Marginal interest (2002-2008)

Even though the tenor of the articles was somewhat more positive from 2002 to 2005, attention for fuel cells was only marginal. From 2004 onwards, fuel cells as a clean energy investment regained some interest. Throughout this period we saw articles which explicitly reflected on the former euphoria for fuel cells and the disenchantment that had taken place. In 2006 and 2007 attention and appraisal became more positive; however in 2007 interest was focused largely on the initial public offering of one firm – Smart Fuel Cell (as well reported in the mass media, see above) - and in 2008 attention dropped to zero.

Summary

The financial discourse shows a sharp attention dynamic and a clear, yet less acute dynamic in expectations. This indicates that financial actors reacted very sensitively to changes in expectations. Furthermore, the interest in fuel cells was related to more general trends and speculative dynamics at the stock markets as the New Economy boom or the clean energy boom, though also showing dynamics of its own.

2.3.4 Policy discourse sphere

In the following the developments in the policy discourse sphere will be discussed.

Period I: First wave of interest: stationary fuel cells as CHP technology? (1994-2002)

The first time fuel cells were discussed in the German parliament in the 1990s was in 1994, however at this time the interest remained rather low, and attention remained limited. Only in 1997 fuel cells were debated with reference to the first 'NECAR' fuel cell prototypes by Daimler Chrysler, however expectations remained rather modest, and a market introduction was not expected before 2005 (DIP, 1997a). Later in this period, in particular from 1998 onwards fuel cell technology was intensively discussed referring to the pros and cons of the use of hydrogen. However, expectations remained rather modest and the German government developed a critical perspective about the high costs of hydrogen (and fuel cell) technology (DIP, 1998). Nevertheless fuel cells were considered to be a promising technology, in particular stationary systems since these systems would be more flexible regarding their fuel (natural gas, biogas and hydrogen) (DIP, 1998). However fuel cells were not intensively discussed in the following years.

Only in 2001 attention and expectations concerning fuel cell technology were rising again, with a focus on stationary fuel cell applications. Fuel cells were mainly addressed in the context of an ongoing legislation process centering on the question if stationary fuel cell systems should be entitled to receive support as combined heat and power (CHP) systems under the German CHP law. In general, expectations on the technological maturity and commercialization prospects were optimistic. A market introduction of stationary systems was expected between 2005 and 2010 by the minister of economic affairs (DIP, 2001b). These optimistic statements were often made while referring to the same industry actors that appeared as prominent discourse actors in the mass media. With reference to the German heating system manufacturer Vaillant, serial production of small stationary fuel cell systems was expected *'within the next years'* (DIP, 2001b). Similarly, mentioning statements of CEO Schrempp, the car manufacturer Daimler-Chrysler is said 'to have the models ready and to be able to exchange diesel and gasoline motors with fuel cells within the next years in series' (DIP, 2000).

Fuel cell technology and its characteristics and potentials were discussed more specifically in 2002. In contrast to the former reliance on a small number of industry actors, a report by the parliamentary Office of Technology Assessment (Oertel and Fleischer, 2001) provided the main point of reference for appraising the technological characteristics of fuel cell systems. In the parliamentary discourse, expectations were less optimistic than in the years before, nevertheless in particular stationary fuel cell systems appeared as a very promising option. Fuel cell vehicles, however, were contested due to concerns with the production and on-board storage of hydrogen. Discourse actors were, just as in the other periods, parliamentary and government members of different political parties.[64]

Period II: Fuel cells as a side issue (2003-2004)

From 2003 to 2004 attention dropped. Fuel cell technology was only mentioned as one out of several promising technologies, in the context of more general discussions on future high-tech industries supposed to improve Germany's competitiveness, or technologies supposed to contribute to reductions in greenhouse gas emissions. Still, the appraisal was very positive, but not as euphoric as before.

Furthermore, hydrogen and fuel cells were increasingly recognized as complementary technologies to renewables like wind- and solar energy to balance

[64] There was no clear-cut distinction in positioning between members of different parties observable.

energy production and consumption, which was expected to become a problem with the increasing diffusion of renewable energy sources, such as photovoltaics and wind. No specific statements were made on commercialization prospects and particular applications.

Period III: The emergence of the national innovation program (2005-2008)

From 2005 to 2008 attention was somewhat more volatile. While attention appeared to grow in 2005 and 2006, it dropped drastically in 2007. The appraisal was rather positive. Fuel cell technology was expected to contribute to addressing societal challenges, in particular climate change, limited fossil energy resources, international competition and high unemployment rates. Both stationary and mobile applications were discussed, but towards the end of the period the focus shifted to mobile applications. In contrast to the rather critical perspectives on hydrogen in the years before, fuel cell technology was increasingly dealt with in combination with hydrogen technology. Furthermore fuel cell technology was increasingly discussed as a key technology to maintain or improve the competitiveness of the German industry, thus fuel cell technology was considered as a promising energy technology which was taken into account in the German 'High Tech Strategy' (DIP, 2006b).

From 2006 onwards, the setup process of what later became the National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP) attracted attention. The NIP - a research, development and demonstration programme, providing 500 million EUR over 10 years – seems to some extent to be a reaction to the ups and downs of expectation dynamics. The proponents of the NIP frequently emphasized the importance of the 10 year focus of the programme, which would enable it to provide a stable framework irrespective of 'daily opinion changes' (Expert 5). Concerning the commercialization prospects, a time frame of 10 years was implicitly assumed, since the NIP was intended to support the market entry of fuel cell technology within this time span. In addition, policy documents presented detailed roadmaps towards market diffusion of fuel cell technologies (Strategierat Wasserstoff und Brennstoffzellen, 2007).

Summary

The German policy discourse on fuel cells was triggered most likely by the same expectations put forward by a number of industry actors as the mass media hype. Besides timely coincidence, this is indicated by the references of policy actors to statements made by Vaillant or Daimler-Chrysler, which in the beginning were assumed rather uncritically, up to being presented even more optimistically than the original statements. Only at a later stage, a more independent appraisal of the technology took place. In contrast to the mass media, the attention focus was on stationary fuel cells due to the linkage with an ongoing legislation process. While the first peak of interest was followed by reduced attention, which could be interpreted as being largely in line with the development in the mass media, it was followed by a phase of re-interest related to the set-up of the NIP support programme, which had no counterpart in the mass media or any other discourse. This shows, as well as the rather positive appraisal of fuel cells in the years before, that the disappointment related to the prospects of commercialization had no obvious counterpart in the policy discourse. The embedding of fuel cell expectations, to expectations about the future energy systems and the potential role of fuel cells for the German economy appears relevant in this discourse sphere. In sum, the fuel cell hype seems to have been very important for triggering a policy discourse on fuel cells in Germany, but the further attention dynamics as well as the specific expectations were strongly shaped by internal dynamics of the policy process.

2.3.5 Science discourse sphere

The periodization of the scientific discourse is less obvious than in the other discourse spheres. The attention increased almost continuously. While in our main source, the Journal of Power Sources, we observed diverging rates of increase (as illustrated by Figure 8), the number of all fuel cell publications within the ISI Web of Knowledge as well as the number of ISI fuel cell publications from Germany evolved more evenly (Ruef and Markard, 2010). Thus, we rely on the qualitative analysis for defining periods. The qualitative analysis was performed on a sample of expectation related articles[65] from 1992 to 2007 and focused on the abstracts. Articles were analyzed more thoroughly, if they dealt with expectations and future prospects more intensively.

Period I: Optimistic expectations: 'Stationary fuel cell systems will be on the market soon' (1992-1997)

Taking the absolute number as well as the percentage of fuel cell articles within the Journal of Power Sources (JPS) as an indicator, we observed a rather steady attention for fuel cells within the first period from 1992 to 1997. Most of the

[65] This sample contains articles including one of the following terms: 'market", 'status", 'commercialization", 'commercialisation", 'prospect" or 'expect". The attention dynamics of all fuel cell related papers in the JPS and our expectation related sample follow the same patterns.

articles treated stationary applications; quite often a prospected decentralization of energy supply was used as legitimizing scenario. Only a small number of articles reported on mobile applications. While for stationary applications based on PAFC technology widespread commercialization was expected within a decade, expectations regarding mobile applications were moderate and no statements about the time span to commercialization were made.

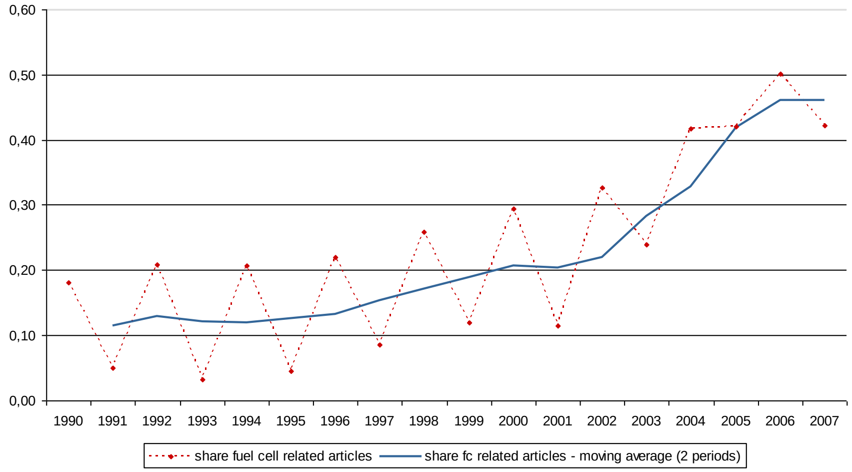

Figure 10: Share of fuel cell articles in the Journal of Power Sources (1990-2007)

Remarkably, optimistic statements about a market introduction within the following years were largely made by authors related to industry actors; in particular those aiming to bring stationary fuel cell systems to the market. More generally, a significant number of authors were not affiliated to public science institutions, but rather to industry companies or policy agencies from different countries, in particular the United States, Japan and the European Union. Thus, we may deduce that expectations within the scientific discourse were to a significant extent shaped by actors participating in other discourse spheres as well.

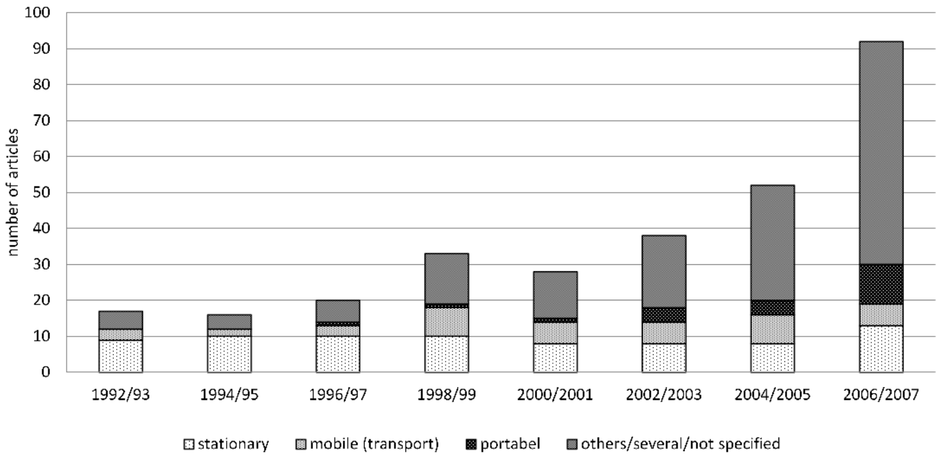

Figure 11: Application focus of articles Journal of Power Sources (1990-2007)

<u>*Period II: Increasing attention for mobile applications (1998-2001)*</u>

In the second period from 1998 to 2001, the number of articles and the share of fuel cell related articles was increasing moderately. First commercial PAFC stationary fuel cell systems were deployed by ONSI Corporation, and other companies like Westinghouse[66] announced optimistic plans to commercialize SOFC-based stationary fuel cell systems from 2001 on. In contrast to the previous period, attention for mobile fuel cells was almost as high as for stationary applications. The delivery of first fuel cell powered busses to customers was expected in late 1997.[67] As before, industry and policy actors were rather active within the scientific discourse. Industry actors now legitimated fuel cell activities and expectations by pointing out investment opportunities, whereas previously mainly environmental concerns were addressed. While most scientists from public research institutions did not state particular dates, policy actors, in particular those affiliated to the California Air Resources Board (CARB) and the US Department of Energy (DoE) announced very optimistic targets. The decentralization of the energy supply system was still considered as a kind of 'obvious truth', while the main legitimation for policy actors to engage in fuel cell activities and eventually in the science discourse, was the reduction of local air

66 respectively Siemens-Westinghouse

67 Especially in scientific journals there is a significant time span between the submission of a paper and its publication, therefore a paper published in 1998 is stating plans for late 1997.

pollution. Greenhouse gas emissions were not yet considered a main driver for fuel cell activities.

Period III: Increasing attention for portable and niche markets (2002-2007)

In the third period, lasting from 2002 to 2007, the total number of articles increased considerably. The share of fuel cell articles in the JPS doubled from approximately 20% in 2002 to 45% in 2007 (see Figure 10). The total number of articles increased as well.

Attention shifted towards portable and niche market applications. In contrast to the previous period, hardly any market or near market experiments were reported. Although this may be interpreted as disappointment, the general appraisal of the technology was still positive, with no clear indications of disappointment. Whereas the fuel of choice for fuel cell vehicles was a matter of controversy in the beginning of the period, later on most authors advocated hydrogen. Consistent with this development fuel cell technology was increasingly discussed with reference to the vision of a hydrogen economy. Other alternative automotive propulsion systems such as electric or natural gas vehicles, framed as supplementary to fuel cell technology in former years, were now discussed as competing alternatives. In the later years of the period, new types of fuel cells entered the stage, however they were expected to be at a low technological maturity level, but promising for the future.

Summary

Judging from our analysis, the scientific community was the least clearly affected by the recent hype-disappointment dynamics regarding fuel cells. So, while we even observed a significant overlap of actors from other discourse spheres as policy or professional circles (industry), the scientific discourse seems to follow a dynamic of its own. Most probably, the science discourse has profited from the hype, as indicated by the increase in publications, but not strongly suffered from disappointment. There are no statements of disappointment in the science discourse. However, the shifts in promoted application fields and fuel cell types may have been a compensation for disappointment with former candidates.

2.4 Discussion and conclusions

Despite the obvious differences between the spheres we investigated, we do observe a joint core of the fuel cell hype: optimistic expectations on the commercialization of fuel cells appear in one way or other in all spheres.

However, the focus of expectations, the expectation dynamics and attention differed clearly between spheres. Thus, the question if there was a hype cycle, including a hype and disappointment phase, on which expectations it was based and when exactly it took place has to be answered differently for each discourse sphere.

Table 1 provides an overview about the main phases of hype and disappointment in the different discourse sphere. From the comparison it becomes clear that there was a joint core of highly optimistic expectation in all discourse spheres. The science and the policy discourse however, did not exhibit such a clear hype as the mass media, finance discourse and professional discourse sphere. The mass media followed rather clearly a hype cycle pattern with a triggering event – a series of announcements about commercialization prospects of mobile applications -, rising expectations and subsequent disappointment due to non-fulfillment of the initial expectations. The professional discourse shows a prolonged hype due to the broader focus on the types of applications and disappointment is rather expressed in shifts of expectations to other application fields than by explicit statements of disappointment. In the finance discourse, which shows the most compressed hype cycle dynamic, with the hype lasting not much more than a year, the link to the core expectations is not even always explicit, but expectations refer to the related investment opportunities, which are also coupled to more general trends in finance and finance specific hypes (e.g. dot.com, clean-tech). Both, the policy and science discourse do not show a typical disappointment phase. In the science discourse, disappointment with particular applications or fuel cell technologies seems to be most easily compensated by expectations shifting to other applications and types of fuel cells. In the German federal policy discourse, the prolongation of commercialization horizons has been translated successfully in a need for policy support, rather than actual disappointment.

<table>
<tr><th></th><th>science discourse</th><th>professional discourse</th><th>mass media</th><th>finance discourse</th><th>policy discourse</th></tr>
<tr><td>1992</td><td rowspan="6">Optimistic expectations: Stationary fuel cell systems will be on the market very soon</td><td colspan="4" rowspan="2"></td></tr>
<tr><td>1993</td></tr>
<tr><td>1994</td><td rowspan="3">First announcements of promising projects</td><td rowspan="3">Exciting news - Daimler presents its NECARs</td><td rowspan="3"></td><td rowspan="9">First wave of interest: stationary fuel cells as CHP technology?

(Moderate hype)</td></tr>
<tr><td>1995</td></tr>
<tr><td>1996</td></tr>
<tr><td>1997</td><td rowspan="5">High hopes for near term commercialization (Hype)</td><td>Nascent Hype - Other actors enter the stage and market entry is preponed</td><td rowspan="3">Incipient interest</td></tr>
<tr><td>1998</td><td rowspan="4">Increasing attention for mobile applications (optimistic expectations, no real hype)</td><td rowspan="3">Hype</td></tr>
<tr><td>1999</td></tr>
<tr><td>2000</td><td>Hype</td></tr>
<tr><td>2001</td><td>Market entry for automobiles postponed, attention shifts temporary to heating systems</td><td>Hype until spring, then Disenchantment</td></tr>
<tr><td>2002</td><td rowspan="6">Increasing attention for portable and niche markets</td><td rowspan="3">Disenchantment</td><td rowspan="4">Disenchantment</td><td rowspan="6">Marginal interest</td></tr>
<tr><td>2003</td><td rowspan="3">Fuel cells as a side issue</td></tr>
<tr><td>2004</td></tr>
<tr><td>2005</td><td rowspan="3">Perseverance</td></tr>
<tr><td>2006</td><td rowspan="2">Regaining confidence in mobiles and niche applications?</td><td rowspan="2">From 2005: The emergence of the national innovation program</td></tr>
<tr><td>2007</td></tr>
</table>

Table 1: Comparison of discourse spheres

The embedding of fuel cell expectations within more general expectations, for instance concerning a decentralization of the energy system or policy priorities such as industrial competitiveness or tackling climate change appears crucial in the policy discourse. We suggest that these differences in the expectations dynamics in each sphere can be explained by different rules of selectivity, different time horizons and different response times of the particular spheres: which application fields are deemed interesting? Which types of promises are relevant? Which adjustments of expectations are considered as major disappointments?

Supposedly, for the mass media innovative car technologies are deemed a more newsworthy topic for the general public than developments related to heating and electricity generation. Such a bias could explain why the hype around stationary fuel cells is rather weakly visible in the mass media compared to the professional discourse. For the finance discourse, we already mentioned that the coupling with more general hype dynamics has most likely been an element in shaping the fuel cell expectation dynamics. In addition, the prolongation of commercialization prospects has been particularly problematic for fuel cells' promise as an investment option. On the contrary the principal promise of fuel cells to contribute to long-term policy goals, such as climate change mitigation had not be to be adjusted, thus the policy discourse sphere appears to be less affected by the postponement of commercialization. Also, the scientific relevance of fuel cells was not immediately put into question, instead the focus was shifting to different applications and types of fuel cells which promised to overcome the barriers experienced in the past.

Still, while our analysis clearly showed that the different spheres exhibit particular dynamics following their specific rules, these dynamics interact. This is indicated by overlap in concrete expectations, partly similarities in dynamics and overlap in discourse actors. We see a clear link between the mass media and the professional discourse, even though there is the bias towards mobile expectations mentioned above in the mass media. Furthermore expectations are a slightly more leveled in the professional discourse. The finance discourse shows linkages to mass media and professional discourse, though restricted in time and possibly dependent on the occurrence of a specific coupling with further expectation dynamics and processes within this sphere, namely the dot.com bubble. Drawing on the discourse analysis alone, we cannot easily clarify to what extent the strong resonance of fuel cell expectations in the finance discourse with the rise of fuel cell stocks has fed back on the general expectation dynamics on fuel cells. Still, some feedback effects seem likely, and at least part of the firms listed at the stock exchange intensified discourse activities or even inflated expectations strategically to profit from the interest of the financial community (Konrad et al., 2012). The interest for fuel cells in the German policy discourse seems to be triggered by the general fuel cell hype, yet also here depending on and shaped by a coupling with particular policy processes. On the one hand public statements by top management members of German automotive companies and producers of heating systems were triggering interest and were used as a source of legitimation in the policy discourse. On the other hand specific discourses in the policy domain such as the climate change debate as well as more specific policy processes, i.e. CHP legislation or the formation of a government coalition influenced the dynamics of the discourse on fuel cells. Also here some feedback effect may have occurred, since fuel cell actors managed to bring the 10 year national innovation program on the policy agenda when a new government was formed, leading to subsequent discussions regarding fuel cells in the policy discourse again.

For the scientific discourse, we see linkages to the professional discourse with regards to discourse actors and concrete expectations, even though the attention dynamics followed a different pattern. While the general hype has probably contributed to the increasing scientific attention to the topic, in particular the steep increase of articles after 2001, the effects of disappointment can mainly be traced at the level of concrete expectations, at least in our period of investigation. However, the science discourse does not appear to take up discussions about failed expectations and disappointment on a larger scale, but focusses on new applications and fuel cell technologies.

In sum, while we are able to trace elements of the popular hype cycle pattern in fuel cell discourse, a closer look revealed that the pattern is too simplified, showing that 'the' hype consists of a set of interwoven expectation dynamics in different discourse spheres, differing both in the dynamics as well as in the concrete expectations underlying the dynamics. Still, the dynamics in the different discourse spheres are coupled – to a larger or smaller extent depending on the specific interactions of discourse spheres. These couplings were mediated partly by circulating expectations and partly also by discourse actors appearing in different discourses. Even though we observe a joint 'core' of the hype, that is, high expectations on the commercialization of fuel cells, which could be observed in all discourses in some way, the specific importance for the discourse and the expectation dynamics in each discourse spheres differed substantially. Hence, in the fuel cell case, and supposedly also in other cases of technology-related expectation dynamics, no single discourse sphere gives a comprehensive picture of the expectation dynamics; in particular, the mass media do not necessarily mirror the full picture.

For our understanding of how expectation dynamics may affect innovation processes, our findings have implications as well. A hype or any other expectation dynamic within a techno-scientific field does not automatically spread to all spheres, and ultimately all types of actors involved in an innovation process. Rather, a certain set of expectations has to interlock with processes going on in the different discourse spheres, and expectations have to develop which are attuned to its specific interest in and perspective on the innovation. Similarly, for understanding the effect of a certain 'hype' on an innovation process we have to carefully examine, which discourse spheres and innovation actors are 'participating' in the expectation dynamic and how, respectively what role a specific discourse sphere has for the innovation strategy of an actor. In a similar vein, just as optimistic, hype-like expectations will not necessarily spread to and affect all spheres and ultimately actor groups to the same extent, disappointment is not necessarily pervasive. While it is often claimed that disappointment of overly optimistic expectations have primarily detrimental effects (as the Gartner hype cycle implies), our results indicate that some actors might be harmed much more than others, depending on the degree to which they are refer to expectations circulating within a particular discourse sphere.

Our results show that while it is possible to identify a joint core of expectations supporting hype-like expectations, the particular expectation dynamics differ significantly between the discourse spheres. We suggest that it is less appropriate to conceptualize hype as a monolithic hype cycle, but rather as a coupled/interrelated set of expectation dynamics in multiple discourse spheres. Therefore we propose to refer to a co-evolution of discourse spheres.

3 Expectations as a key to understanding actor strategies in the field of fuel cell and hydrogen vehicles[68]

3.1 Introduction

Concerns about climate change, air quality, and depleting fossil resources raise new priorities for the current mobility system and the way energy for transportation is provided. Innovation is necessary to transform the current fossil-fuel based automotive transportation system into a more sustainable one. The improvement of existing technologies through incremental innovation alone will not be sufficient to realize the CO_2 reductions necessary to mitigate climate change (IPPC, 2007; Stern, 2006; UNFCCC, 2009). Radical and systemic innovations are needed, and while a number of promising technological innovations have emerged, the transition of the current energy and mobility system towards sustainability remains a great challenge (Geels et al., 2008).

Since the late 1990s several theoretical frameworks have been developed to understand and support transitions to sustainability (Dosi, 1982; Nelson and Winter, 1982). In recent years two approaches have become central references in both the academic and practitioners' discourses, namely: the (technological) innovation systems approach, and the multi-level perspective on transitions (Markard and Truffer, 2008b). Both lines of reasoning have contributed to the understanding of transition processes; however, they have also both been criticized for lacking an adequate analysis of actor strategies (Alkemade et al., 2011; Markard and Truffer, 2008a).

The literature on strategic management explains changes in strategy by shifts in underlying factors such as resources or capabilities (Barney, 1991; Barney et al., 2011; Furrer et al., 2008; Teece and Pisano, 1994). However, changes in resources or capabilities are not able to explain two observations from empirical case studies of emerging technology developments. First, these case studies show that actors sometimes rather suddenly enter or exit a particular technological innovation system or niche whereas changes in resources or capabilities are generally more gradual (Alkemade et al., 2007; Farla et al., 2010; Negro et al.,

[68] This Chapter is published as: Budde, B., Alkemade, F., Weber, K.M., 2012. Expectations as a key to understanding actor strategies in the field of fuel cell and hydrogen vehicles. Technological Forecasting and Social Change 79, 1072-1083.

2011). And second, it is difficult to explain why actors operating under similar circumstances in terms of resources and institutional context choose different strategies.

This paper argues that these changes and differences in strategy may be explained by the volatility of actors' expectations. In other words, expectations can be regarded as important determinants at the actor level of sustainability transition processes. We therefore propose to examine actor behavior through the analysis of expectations. Rather than assessing the relative importance of different factors influencing actor strategies such as institutions, competitors, markets and technologies as such, the analysis focuses on the actors' expectations concerning the future of these factors. A more systematic analysis of the relation between expectations and actor strategies promises new insights into the strategic motivations of actors in sustainability transitions.

The main research question of this paper is therefore: *What is the relation between changing actor expectations and changing actor strategies?*

A conceptual framework for the analysis of the relation between actor expectations and actor strategies is developed in Section 2 and applied to a case study of expectations and strategies for fuel cell and hydrogen vehicles in Germany in the period 1990 - 2009. The case study focuses on three different actors, namely the automotive manufacturers BMW and Daimler, and the German government. The two German car manufacturers are included as they have selected quite distinct strategies. In addition to BMW and Daimler the German government is included as governments generally have an important role in the development and implementation of infrastructure-dependent technologies, like hydrogen cars, due to the large-scale investments and coordination requirements associated with infrastructure systems (Gómez-Ibáñez, 2003).

The remainder of this paper is organized in four main sections. The theoretical overview in Section 2 provides a discussion of different perspectives on the role of expectations in the innovation literature and introduces the proposed conceptual framework. Section 3 briefly explains the methodology used for conducting the case studies which are presented in Section 4. Conclusions and issues for further research are outlined in Section 5.

3.2 Theoretical background

The role of expectations has been acknowledged in a broad range of disciplines including sociology (Dahrendorf, 2006; Luhmann, 1984; Parsons, 1964); economics/finance (Lachmann, 1943; Lundberg, 1937; Rosenberg, 1976, 1995); marketing studies (Cardozo, 1965; Teas, 1993); and medicine/health care studies (Thompson and Sunol, 1995). The strategic management literature, in particular the early work on the resource-based view of the firm (Furrer et al., 2008; Wernerfelt, 1984), also emphasizes the role of expectations. Barney (1986), for example, argues that the success or failure of strategies of firms can be explained only by their ability to generate adequate expectations (or by good fortune and luck) (Barney, 1986).[69]

3.2.1 Expectations in the innovation systems literature

The innovation systems approach is based on evolutionary thinking and has proven to be useful in explaining the emergence and diffusion of innovations. Developed from the late 1980s onwards, this research strand has become a key reference in the scientific and policy debates in the field of science, technology and innovation. Early studies focused mainly on innovation system structures and institutions, thereby distinguishing national, regional and technological innovation systems (Carlsson et al., 2002; Carlsson and Stankiewicz, 1995; Malerba, 2002, 2005).

Questions regarding whether different approaches share a common understanding of what actually happens within innovation systems have shifted the focus of theory development towards the processes that are central to the development of the innovation system itself (Bergek et al., 2008). This later inroad makes use of the concept of functions and has identified seven functions to describe the key processes within a technological innovation system (Bergek et al., 2008; Hekkert et al., 2007).[70] One of these functions is 'guidance of the search' or 'influence on the direction of the search' which relates to the development of expectations and beliefs about growth potential (Bergek et al., 2008; Hekkert et

[69] It needs to be added, however, that Barney (1991) introduced some additional concepts to explain the performance of companies (e.g. about resources of a company and their (future) value). Nevertheless, his basic assumption is that expectations (or good fortune and luck, in the sense of residues) are the key characteristics which explain the performance of a company's strategy.

[70] These functions are: F1: entrepreneurial activities; F2: knowledge creation; F3: knowledge diffusion; F4: guidance of the search; F5: market formation; F6: resources mobilization; F7: creation of legitimacy. Bergek (2008) uses a set of similar functions as those outlined by Hekkert et al. (2007). Other authors using the functional approach use different categorizations of functions.

al., 2007). Expectations are described as an important driving force for realizing this function, since most actors are often 'initially driven by little more than a hunch' (Hekkert et al., 2007). However, it remains unclear *how* expectations guide the innovative behavior of actors (Bergek et al., 2008).

3.2.2 Expectations in the transition studies literature

Transition studies, and the related governance approaches strategic niche management (SNM) and transition management (TM), have emerged primarily from science and technology studies, though with some strong links to evolutionary economics (Geels et al., 2008).[71] Transition studies and SNM emphasize the role of expectations in guiding transition processes (Geels et al., 2008; Schot and Geels, 2008). A key concept of this strand of literature is the multi-level perspective (MLP), which distinguishes between the niche, regime, and socio-technical landscape level (Geels, 2002). On each of these different levels, but also between them, interdependent processes occur that influence the pace and direction of the overall transition process. Using the MLP, several studies have analyzed long-term transitions of large socio-technical systems. One of the key findings from these studies is that most new technologies that can contribute to a larger transition need a form of niche protection in order to grow and evolve. This kind of protection ideally leads to changes at the regime level and thus to a comprehensive transition process. The successful development of a niche depends on three internal key processes: (1) The articulation of expectations and visions; (2) The building of social networks; and (3) Learning processes at multiple dimensions (see Schot and Geels, 2008 for an overview).

Expectations are thus considered important for the development of a niche since they provide guidance to learning processes, attract attention, and provide a special kind of protection to a niche (Schot and Geels, 2008). A number of studies concerning niche development in the Dutch energy sector, explicitly incorporate the analysis of expectations and their dynamics in the analytical framework (Verbong et al., 2008), thereby emphasizing the question how these expectation dynamics accelerate or slow down the development of the niche.

In summary, the theoretical approaches to the study of sustainability processes outlined above acknowledge the important role of expectations but, while they focus on how aggregated or shared expectations influence transition processes at

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71 For an extensive discussions on the transition approach, the multi level perspective and its origin, and links to other social theories see Geels, F., 2010. Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. Research Policy 39, 495-510.

a meso level, they do not provide insight in the relation between expectations and specific actor strategies.

3.2.3 The sociology of expectations literature

The relationship between expectations and actor behavior has been studied in the context of the sociology of expectations, which analyzes expectations and their role in emerging science and technology (Borup et al., 2006; Konrad, 2006b; van Lente, 1993; van Lente and Rip, 1998). Pioneering work in this emerging research field was done by van Lente (van Lente, 1993) and van Lente and Rip (van Lente and Rip, 1998). With regard to technological expectations, van Lente demonstrates how vague initial promises about technologies turn into requirements that have to be fulfilled. If these increasingly demanding expectations are not met, support for the technology may easily diminish. In general, expectations about the future capabilities of a technology can legitimize and mobilize support, and more generally speaking, enable decision-making under conditions of uncertainty (Borup et al., 2006; van Lente, 1993).

Other studies have shown how actors consciously stimulate or even inflate expectations about the technology they are working on (Alkemade et al., 2011; Bakker et al., 2012; Brown et al., 2000; Konrad et al., in preparation). For the case of stationary fuel cells Ruef and Markard for instance, show that changes in innovation activities can be traced back to changing expectations (Ruef and Markard, 2010). Their analysis of the effects of changing expectations is based on the analysis of scientific publications and patent activities, the emergence of conferences series, public funding schemes, or industry-wide overviews of R&D projects as indicators of innovation activities. These indirect, meso-level indicators do however provide little insight in the role of expectations at the level of individual actors, and their motivations to engage or disengage in innovation activities.

Van Lente and Rip (van Lente and Rip, 1998) focus on the role of expectations as so-called ‘prospective structures.’ They argue that expectations about future social structures may exert a similar influence as if they had materialized in the ‘real world’ already. Such prospective structures can be regarded as mediating devices between actors and (real) structures: On the one hand, actors are engaged in the shaping of expectations (and thus of prospective structures), which may ultimately lead to decisions that change real structures. On the other hand, prospective structures provide an orientation to the actors. Since expectations can act as prospective structures, and thus have a guiding function, they are often highly contested. This contestation manifests itself in different kinds of discourses (Konrad, 2006b). Because of the important role of expectations any analysis of such discourses also has to take into account the tacit and often strategic dimensions of expectation statements (Berkhout, 2006).

The work of Van Lente (1993) distinguishes micro, meso, and macro levels of expectations. For Van Lente, the micro level encompasses expectations about the technology in focus, while the meso level focuses on visions and expectations which are more general than the specific future capabilities of a single technology. Macro level expectations are located on a broader societal scale and are particularly important in opening up opportunities for new ‘promising’ technologies, thus creating protected spaces for niche developments. Van Lente also discusses the ‘function’ of the different levels of expectations, stating that micro level expectations are important for search activities, while meso level expectations represent functional requirements and criteria for the selection of a technology. Macro level expectations can contribute to the legitimation of a technology and thus open up opportunities for that technology. Geels and Raven (Geels and Raven, 2006), building upon the work of Van Lente (1993) and Hoogma (2000), use a similar framework to study the relationship between micro and meso level expectations in their study of the transition and expectation dynamics in the case of the biogas niche. Geels and Raven account for external circumstances to explain the developments in that niche, which could be interpreted as macro expectations in the sense of Van Lente.

3.2.4 A multi-level perspective on expectations and strategies

In this paper expectations are defined as ‘real time representations of future situations’ building on the work of Borup et al. who describe technological expectations as ‘real time representations of future technological situations and capabilities’ (Borup et al., 2006, p.286). In our analysis of the influence of both technological and non-technological expectations on actor strategies we focus on the anticipatory character of expectations (in contrast to a mainly normative view on expectations). The strategic management literature describes these actor strategies as:

> ‘[…] the determination of long-term goals of an organization that guide decision making, management activities and the necessary allocation of resources.’ (Chandler, 1962; Markard and Truffer, 2008b)

This definition argues that the strategies of an organizational actor determine the activities of this actor. In emerging innovation systems, which are characterized by high levels of uncertainty, it is clear that these strategies rely mostly upon expectations although these expectations are often diverse and highly contested, sometimes even within a single organization (Eames et al., 2006).

Regarding strategy in general Barney already stated that expectations are crucial to understand and explain the performance of a firm (Barney, 1986; Furrer et al., 2008). This influence of the role of expectations, although still important, decreases when the technology becomes more mature. When the technology diffuses to the market more robust knowledge (e.g. sales levels, launches of competitors) becomes available and reduces the level of uncertainty. However the phase of uncertainty is generally quite long for sustainability transitions as they are characterized by large investments and long time horizons (Alkemade and Suurs, 2012). Furthermore they are influenced not only by market forces but by other societal and political processes as well. As this suggests a particularly important role of expectations in transition processes there is a need for a more detailed classification of expectations than is currently provided by the TIS and MLP approaches. In constructing such a classification, we build on the literature described above and hypothesize that different types of expectations are important for different types of actors.

In addition to the different types of expectations discussed in the literature (Berkhout, 2006; Borup et al., 2006; Truffer et al., 2008; Verbong et al., 2008), we propose an analytical distinction into different levels of expectations. It builds on the idea of different levels or layers of expectations as described in different forms by Truffer et. al (2008), Geels and Raven (Geels and Raven, 2006) and van Lente (van Lente, 1993).

We propose to use the multi level perspective (MLP) of transition theory (Geels 2002) as a framework to analyze expectations in addition to 'real world' developments and activities.[72] While studies using the MLP investigate the role of expectations these studies did not use the MLP as such to structure and classify the expectations. Starting from the MLP, which conceptualizes three levels relevant to sustainability transition processes (niche, regime, and socio-technical landscape level), the framework builds on the assumption that there are not only activities and institutions, but also expectations and visions about future activities

[72] See Budde, B., Konrad, K., 2009. Interrelated visions and expectations on fuel cells as a source of dynamics for sustainable transition processes, KSI International Conference 2009, First European Conference on Sustainability Transitions: Dynamics & Governance of Transitions to Sustainability, Amsterdam. for a more extensive discussion about the use of the multi level perspective to analyze expectations.

and institutions related to these levels. Expectations about the future of a specific new socio-technological configuration in a narrow sense, such as fuel cells or battery electric vehicles are regarded as expectations related to the niche. Expectations about the future structure and rules of the sector are regarded as expectations related to the regime level. Expectations about deep structural trends providing an external structure for the interaction of actors are defined as expectations related to the landscape level.

Actual developments at the different levels can mutually reinforce (or weaken) one another, and ultimately exhibit complex dynamics (Geels, 2002). We argue that the same holds for expectations and visions. Expectations that refer to the landscape level, such as an expected shortage of fossil energy resources, may support expectations related to the regime level, such as expectations of a future energy system based on renewable energy. Furthermore, expectations regarding landscape developments (e.g. about climate change or local air pollution) may support expectations regarding specific niche innovations, as observed in the case of fuel cells and climate change (Budde and Konrad, 2009).

Expectations about future developments at the different levels in turn influence the strategies of (organizational) actors. While assuming that all expectations have an influence on the strategic actions of actors, we argue that the expectations related to a certain level are not equally relevant to all actors. Figure 1 presents our conceptual framework with the different levels of expectations starting from the niche level on the bottom to the regime and the landscape level. It also illustrates the relation between expectations related to the different levels and actor strategies and activities. The expectations influence actor strategies which lead to activities which eventually contribute to the transition dynamics at a meso level. The dotted line at the bottom describes the feedbacks that occur when for instance activities reinforce or dampen expectations.

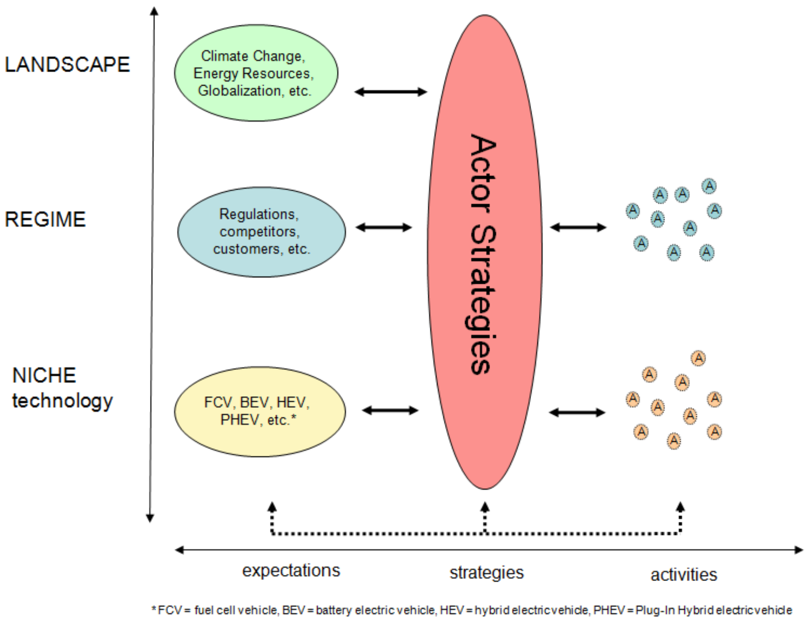

Figure 12: Conceptual framework of the relation between expectations and actor strategies

The temporal dynamics of expectations are very distinct and often more erratic or volatile than those of activities (Bakker, 2010; Bakker and Budde, 2012; Budde, 2011; Ruef and Markard, 2010). Whereas transition dynamics usually require much more time to evolve, expectations can change quite quickly. To summarize, we assume that actor strategies are determined by the expectations an actor holds about future developments at the niche, regime, and landscape level. Actor strategies are then translated into activities that contribute to overall transition dynamics, for instance by stimulating niche developments or regime changes. At the same time, the character and intensity of actors' engagement in transition processes contributes to the emergence and shaping of expectations. These feedbacks between expectations and strategies are depicted by the bottom arrows in Figure 12.

3.3 Data and Methodology

This paper analyzes the relationship between expectations and actor strategies. We examine this relationship by studying three case studies of key (organizational) actors in the field of hydrogen and fuel cell vehicles in Germany (VES, 2007; Weider et al., 2003, 2004).

The three actors are two original equipment manufacturers (OEMs), BMW and Daimler, and the German government. The paper draws upon evidence collected using a mix of methods, namely: literature analysis; interviews; and discourse analysis. The necessity to draw on a number of sources emerges from several problems. First, research and development strategies and related activities in the automotive industry are considered highly confidential due to their strategic importance. Second, actors may not remember past strategies and expectations or engage in 'retrospective sense making' (Eisenhardt, 1989; Eisenhardt and Graebner, 2007). Third, expectation statements are often *not* expressions of the 'pure' expectation held by an actor, but, as stated by Berkhout (see section 2.3) are strategically deployed. Finally, expectations are often tacit and contested and difficult to capture from a researcher's perspective. Therefore the case studies are based on a number of sources about past strategic decisions. We refer to Budde (2011) for a more elaborate discussion of the strategic dimension of expectation statements concerning alternative propulsion technologies.

First, we reviewed the extensive literature on the strategies of automotive companies and policy makers concerning alternative propulsion technologies (Greaves and Hart, 2004; Greaves and Sharman, 2003; Kalhammer et al., 2007; Kalhammer et al., 1998; Maruta, 2008; van den Hoed, 2004; Weider et al., 2003, 2004). Although most of this literature does not deal explicitly with the role of expectations the review provided basic information about the strategies and activities of the key actors. In addition, an overview of contextual dynamics at the meso level was constructed by including a number of studies describing the general niche dynamics or technological innovation system dynamics in our review (e.g. Hekkert et al., 2007; Oltra and Saint Jean, 2009a; Schaeffer and Uyterlinde, 1998; Truffer et al., 2002; van den Hoed, 2004; Verbong et al., 2008; Weider et al., 2004).[73]

[73] Although not with the same conceptual framework or empirical focus, these studies refer explicitly or implicitly to the transition dynamics related to hydrogen and fuel cell technology at a meso level.

Additionally, a discourse analysis provided insights into the expectations that actors held as expectations are mediated and shaped through discourses (Konrad, 2006b). The discourse analysis focused on public media sources, such as newspaper articles, policy debates in the German parliament, engineering journals and scientific articles[74]. Such a broad discourse analysis (see Konrad et al., in preparation) reduces the potential bias caused by retrospective sense making during the interviews.

Lastly, 31 semi-structured interviews with key actors[75] in the field of alternative drivetrain technologies concerning hydrogen and fuel cell technology were conducted in the period 2007 – 2009. The interviewees were identified during the discourse analysis and through the snow ball method (Biernacki and Waldorf, 1981). In order to allow the interviewees to speak relatively open, they were guaranteed confidentiality and the reference section of the paper only states the general position of the interviewee, and the date and place of the interview.

The first step of the analysis of the empirical data was to classify the expectation statements according to the level they referred to. When expectations referred to the future development of fuel cells and the surrounding socio-technical arrangement such as expectations about the future of fuel cell technology as such or the behavior of fuel cell specific actors, such as fuel cell R&D organizations these expectations were considered to be *niche expectations*. Expectations about the future mobility or energy system, on a larger scale, were regarded *as regime level expectations*. Examples are expectations about the future of private owned cars in contrast to car sharing models, customers or regulations. Expectations about changes at the larger societal level, such as climate change or the depletion of fossil energy resources, were labeled as *landscape level expectations*.[76]

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74 Newspaper: Frankfurter Allgemeine Zeitung, Süddeutsche Zeitung Handelsblatt; German Bundestag: protocols of plenary sessions; scientific articles: Abstracts of a subsample of articles in the Journal of Power Sources, for more information see [16]

75 The interviewees include employees of car manufacturers (BMW, Daimler, GM, Volvo, VW: 8); other industry actors (supply companies, pioneer user – such as fleet operators: 7), science (universities, research centers: 8), policy (public agencies/ministries: 5), other (venture capitalists, consultancy companies: 3).

76 This follows the principal argumentation of the MLP. While studies using the MLP are assigning activities/institutions/etc. to a certain level, this paper follows a similar procedure, but uses expectations as the unit of analysis.

3.4 Analysis of strategies and expectations

The empirical analysis encompasses an analysis of three major actors in the field of hydrogen and fuel cell vehicles and a comparison of the three cases. In general, the field is characterized by high levels of uncertainty regarding future key actors, future dominant designs, and future standards (van den Hoed, 2004).

The two organizational actors BMW and Daimler are similar in terms of the automotive markets they serve. Both produce primarily premium vehicles under the BMW and Mercedes brands respectively. The Daimler Corporation, however, offers a broader range of products and services including for example trucks and busses and is considerably larger than BMW.[77] In general, both Daimler and BMW are regarded as key actors in the expectation formation process about the future of the automotive industry.[78] Furthermore, the case studies include the government perspective because of its influence on the transition process, particularly through the provision of research funding, the development of regulation, and the build-up of infrastructure. This section starts with a general description of the strategies and expectations and then discusses how these relate to the levels of expectations later in the section.

BMW Group

The case of BMW is of special interest since BMW has pursued a technologically different strategy than most other original equipment manufacturers (OEMs) in recent years. Whereas most OEMs focused on fuel cells, the focus of BMW was on the use of hydrogen in modified combustion engines. In general, BMW's level of R&D activities concerning alternative drivetrain technologies can be considered modest in comparison to the investments of other OEMs (Nygaard, 2008; van den Hoed, 2004; Weider et al., 2004).

The starting point for BMW's activities concerning alternative drive train technologies stemmed from the expectation held by BMW management that environmental regulations would become increasingly difficult to comply with in the long-term, using gasoline and diesel powered internal combustion engines. BMW started its hydrogen related R&D activities in the 1970s after the local air

[77] BMW has annual turnover of approximately 60 billion EUR, while Daimler has a turnover of approximately 98 billion EUR (data for 2010) BMW Group, 2010. Geschäftsbericht 2010 [Annual Report], Munich., Daimler AG, 2010. Innovation aus Tradition, Stuttgart.

[78] As expressed by stakeholders during several workshops and strategy consulting exercises in the field attended by the authors.

pollution problem led to the compulsory introduction of the catalytic converter. Given the expectation that regulations would become even stricter in the future, and thus harder to comply with using powerful gasoline/diesel engines, BMW began testing different configurations of electric vehicles in the 1980s and 1990s. The tests indicated that the technology was not suitable for introduction by BMW on the short term. BMW expected its customers to continue to demand sportive, luxury cars placing great value on vehicle characteristics such as acceleration and engine sound. These expectations regarding future demand also excluded fuel cells as a suitable technology for BMW (Expert 11).

Pressures to invest in new technological options increased in the 1990s, when expectations emerged in the BMW strategy department, that future regulation would not only concern local air pollution, as in the 1970s and 1980s, but also CO_2 emissions (Expert 11). The Californian zero emission vehicle mandate (ZEV mandate) further increased the pressure to invest in alternative drive train technologies although BMW was not initially affected (Weider et al., 2004). In 1998 the European Automobile Manufacturers' Association (ACEA), presented a proposal for the self-regulation of CO_2 emissions (Expert 11) and although the first target of 140g CO_2 per km was thought to be achievable with conventional technologies, it was expected that CO_2 target levels would become increasingly strict. BMW realized that on the long-term, more rigorous CO_2 regulations would require an alternative propulsion technology (Expert 11).

Given these expectations BMW invested in a technological trajectory aiming to use hydrogen in modified internal combustion engines. This technology was expected to satisfy customer demands about car characteristics while minimizing emissions and thus complying with expected future regulations (Expert 11). Hydrogen powered combustion engines would not suffer from range limitations, (opposed to battery electric vehicles) and they would provide sports car characteristics, including the sound of an internal combustion engine (ICE), long range capabilities and fast refueling times (Expert 6; Expert 9; Expert 11).

Despite the choice for hydrogen powered combustion engines, the presentation of the electric NECAR vehicles and in particular the NECAR II by Daimler (see the Daimler case study), further spurred the interest of BMW in fuel cell technology (Expert 11). BMW regarded fuel cells as a viable option in supplementing or replacing the conventional battery on board in order to meet the expected increased electricity needs of the car for entertainment, on-board computers, etc. (Expert 11). Thus, the expectations Daimler raised by presenting the NECAR prototypes also influenced the strategy of BMW.

In recent years BMW's expectations regarding the importance of local air pollution reduction in future regulation turned out to be inaccurate as energy efficiency and the reduction of CO_2 emissions became political priorities. This development decreased the competitive advantage of the hydrogen combustion engine since it was not expected to reach the same degree of efficiency as fuel cell or battery electric vehicles.

Recently BMW has invested in demonstration projects with electric vehicles in California and Germany and made product announcements for electric vehicles in the upcoming years, since the company increasingly acknowledges that the mobility system may change (expectations related to the regime). In this future mobility system customers may ask for different types of vehicles, not necessarily delivering long range capabilities and sportive engine sound (Expert 11). However, these latter activities concerning electric vehicles are related to the Mini brand or a potential new brand. A potential explanation lies in the still dominant expectation about customer demands in terms of high range and sportive driving characteristics (including sound) from BMW branded vehicles (Bakker and Budde, 2012).

Daimler

Daimler[79] is widely described as fuel cell pioneer as it was the first major car manufacturer to present prototypes of fuel cell vehicles, after the fuel cell experiments conducted by General Motors (GM) in the 1960s (Aigle et al., 2007; van den Hoed, 2004, 2005; Weider et al., 2003, 2004).

Following similar expectations about the stringency of local air pollution regulation as BMW, Daimler investigated all major alternative drive train configurations including pure battery electric vehicles, hybrid electric vehicles, and fuel cell vehicles (Expert 4; Expert 5; Expert 6). Daimler obtained fuel cell technology competences through the acquisition of the aerospace subsidiary Dornier. The Daimler Corporation bought Dornier because of the top management's vision to develop into a leading global technology company by constructing a network of companies with links to the European aerospace industry (Expert 5). In the 1990s, Dornier had a small team developing fuel cells for the European space glider project 'Hermes'. When Hermes was cancelled, the engineering team searched for alternative application fields within the company.

[79] The corporate name was DaimlerChrysler from 1998 to 2007; nevertheless this paper refers to Daimler since the major share of the fuel cell activities within the corporation were conducted at the European Daimler facilities.

In line with their expectations regarding the need for more environmentally friendly propulsion technologies in the future, Daimler top management decided to start a relatively small research project aimed at demonstrating the principal feasibility of fuel cells powering vehicles (Expert 5). In 1994 Daimler presented its first prototype, NECAR I[80], triggering a large interest in the technology. Consequently, in the 1990s Daimler focused its research in the field of alternative propulsion technology on fuel cell technology (Expert 5; Expert 6). The next generation of the prototype, NECAR II, raised even greater interest since the Daimler engineers managed to miniaturize the fuel cell system, creating optimism and motivating other actors to investigate fuel cell technology (Expert 6; Expert 9; Expert 11). The reviews by experts and journalists were very positive after the presentation of the NECAR II prototypes, causing widespread optimism with regard to fuel cell vehicles among a broader range of stakeholders.

In 1997 the dominant expectation within the Daimler Corporation was that the company would be affected by future regulations, i.e. the ZEV mandate in the medium term. Moreover, general expectations about the future performance of fuel cells were rather positive and management decided to intensify investments in fuel cell vehicles. This decision was supported by expectations about the future mobility system: Daimler's top management did not expect any fundamental change in automotive-based transport systems, which meant that long-range capabilities and short refueling time were expected to remain important characteristics. While batteries were evaluated as a technological option, they were not expected to deliver the required range (Expert 5; Expert 6). Furthermore, Daimler regarded itself as a leading car manufacturer in terms of technology, particularly with their Mercedes brand. Daimler's management expected that their business model would continue to require the most advanced technology to succeed in the targeted premium market. In contrast to BMW, Daimler expected that their customers would ask for the most advanced technology such as fuel cells (Expert 5; Expert 6).

Therefore, in 1997, Daimler intensified its research efforts focusing on the market introduction of fuel cell vehicles. Internally the status of the fuel cell project changed from a 'basic research' project into a 'development project', aimed at producing marketable products (Expert 5). Daimler expected customers to adjust to fuel cell technology, because it would offer efficiency advantages over the use of hydrogen in combustion engines. Daimler expected itself to secure its role as a

[80] New Electric Car, also referring to the Neckar river near Daimlers headquarter in Germany

technology leader, which was assumed to contribute to Daimler's unique selling proposition (Expert 5; Expert 6).

In the following years, Daimler made several announcements stating that the first commercial vehicles would hit the market in 2004 and a large number of vehicles (up to 100.000) would follow shortly, thereby seeking to raise expectations among a broader set of stakeholders and the general public:

> 'TODAY the race to develop the fuel cell car is over […] Now we begin the race to lower the cost to the level of today's internal combustion engine. We'll do it by 2004.' (Jürgen Schrempp, Chairman of the Board, Daimler Chrysler, in The Economist, 1999)

Despite these positive (public) expectations Daimler did expect major challenges with the set-up of an infrastructure for fuel cell vehicles. In order to address these challenges Daimler followed separate strategies for the introduction of hydrogen to the fleet vehicle and personal vehicle markets.

For the personal vehicle market Daimler proposed to develop a methanol-based solution using on board reformers to produce hydrogen. This strategy was based on the expectation that consumers would favor a liquid and relatively easy to handle energy carrier such as methanol over hydrogen (Expert 5; Expert 6). Furthermore this technological option is compatible with the existing refueling infrastructure. However, expectations regarding this technological trajectory diminished as key actors from the oil industry opposed the idea of methanol and on-board reforming (Expert 5; Expert 6; Expert 7). After the emergence of technical difficulties with on-board reforming of methanol to hydrogen in addition to the opposition of the oil industry, Daimler stopped its activities in this trajectory. At the same time the development of vehicles fuelled directly with hydrogen was continued. These were initially aimed at the fleet vehicle market since infrastructure requirements were expected to be lower for fleet operators, which usually plan the deployment of vehicles on given routes in advance.

Another expectation influencing the strategy of Daimler was that the company would be dependent on other car manufacturers for the deployment fuel cell vehicles. Therefore, Daimler initiated a joint venture with Ford Motor Company and the Canadian fuel cell company Ballard, in order to license Daimler/Ford/Ballard technology to other car manufacturers for use in their vehicles (Expert 6; Expert 7). Furthermore, Daimler managers played a leading role in establishing the California Fuel Cell Partnership (CaFCP), motivating innovation activities on a global scale (Expert 6; Expert 9; Expert 11). Despite changes in the organization and distribution of shares in the joint venture by Daimler, Ballard and Ford, Daimler has continued to increase its investment in these joint ventures over time (Expert 7).

In recent years, Daimler has changed its strategy. Fuel cell technology is now only one of several technological options for Daimler and battery electric vehicles are now considered an option for certain markets. This change in strategy arises from changing expectations related to the regime level, i.e., about the configuration of future mobility systems: While today's mobility systems are based on individual ownership and vehicles that must fulfill all transport needs including long-distance travel, expectations about future transport solutions which combine the use of shared vehicles and public transport became more influential within the Daimler management.

In recent years these expectations led to Daimler's investment in car sharing enterprises.[81] Despite becoming less optimistic about large-scale introduction of fuel cell vehicles in the next few years, Daimler still pursues the development of fuel cell vehicles. Furthermore, fuel cells are expected to provide a feasible solution when it comes to providing extra power to battery electric vehicles in order to overcome their shorter range (Expert 7; Workshop 1).

A policy perspective: the German government [82]

To differing extents, the German government supported and partially funded fuel cell research activities over the last 30, almost 40 years. Fuel cell funding was initially triggered by the oil shocks in the 1970s. In later years policy focused more on stationary applications (Weider et al., 2003). Due to concerns about security of oil supply following the oil shocks in the 1970s policy actors became interested in the emergence of a solar hydrogen economy (Expert 6; Expert 12) and realized that the realization of their expectations would require policy support (Weider et al., 2003). The solar hydrogen economy assigned a key role to fuel cell technology as the main converter of solar produced hydrogen (potentially produced in large scale solar farms in the desert) into electricity. In addition to its advantages for the

[81] Daimler was conducting a number of smaller car sharing experiments in the period of observation. However, just recently Daimler's car sharing initiatives were triggering large interest with its 'car2go' project (www.car2go.com)

[82] In this short discussion, the German government is presented as one organizational actor, to provide an overview. A more detailed analysis about the relation and interplay of different ministries, departments, political parties and other actors was conducted but beyond the scope of this paper. However, the main points and the relative importance of expectations (and levels thereof) appear to be in line with the more in-depth analysis.

security of supply, the use of hydrogen would dramatically reduce or eliminate the emission of air pollutants, which were considered a large issue in the 1970s and the 1980s (Expert 6; Expert 6; Expert 7). Given expectations that energy security and air pollution would remain major societal challenges into the future, the German government funded a large number of hydrogen and fuel cell research, development, and demonstration projects until the 1990s.

Despite these expectations, during the 1990s the issues of local air pollution and acid rain became less pressing due to better filter technologies and the mandatory introduction of the catalytic converter (Expert 5; Expert 6; Expert 9). Eventually policy actors lost interest in hydrogen and fuel cell technology, and, despite considerable technological progress with these technologies, research funding was dramatically reduced in 1995 (Weider et al., 2003, p. 11). This reduction of funding was motivated by the argumentation that most of the previously specified R&D targets were achieved, and that hydrogen technology was ready for deployment. Nevertheless large-scale introduction was not expected nor considered necessary from a societal welfare perspective. Market introduction without public support was expected at the earliest in 30 or 50 years from then (Weider et al., 2003, p. 11)

The funding for hydrogen and fuel cell research was reduced from over 25 million DM (appr. 12,8 mio EUR) annually in 1994 to approximately 14 million DM (appr. 7,1 mio EUR) in 1999 (Weider et al., 2003). At that time only the industrial activities, especially by Daimler and government support programs in Japan and the United States, kept fuel cell technology on the agenda (Weider et al., 2004).

When funding was increased again at the turn of the millennium, and in particular from 2004 onwards (Budde and Konrad, 2009), this was related to a different set of expectations expressing that fuel cell technology would be necessary to maintain the competitiveness of the German automotive industry (Expert 5). Expectations that other nations like Japan and the USA would support fuel cell technology became very influential and provided legitimacy to the upscaling of the hydrogen and fuel cell research program of the German government. This line of reasoning can been seen in one of the early key documents (BMVBS et al., 2006) related to the National Innovation Programme on hydrogen and fuel cell technology. The document stated that Germany was the leader in hydrogen and fuel cell technology within Europe, but that Japan and the USA would become the internationally leading countries. As a result, 250.000 German automotive industry jobs would be lost (BMVBS et al., 2006, p.4). Subsequently, the document contained an analysis of established and expected funding schemes in Japan, the

USA, and at the European level. Fuel cell proponents used the argumentation that referred to employment because they were aware that employment was and would be a major societal challenge and one that was particularly important for policy actors (Expert 5).

Furthermore, policy in California and in particular the ZEV mandate, which required the large car manufacturers to produce a certain amount of zero emission vehicles in order to reduce the air pollution in (Southern) California, triggered action in Germany since California is an important export market for German cars. Nevertheless German public funding at the national level increased considerably only when the issue of climate change emerged as an additional expected major societal challenge and critical issue in German politics (Budde and Konrad, 2009).

Comparing case studies

Table 1 summarizes the actor expectations described above. With regard to expectations related to the *socio-technical* landscape level all three actors initially expected that local air pollution and the supply (and costs) of fossil resources would determine future developments. More recently the issue of climate change became more relevant. The strategy of the German government seems mostly aligned with expectations about future challenges related to the socio-technical landscape level. For the automotive manufacturers expectations related to this level appear to become relevant, only once they are 'translated' into expectations about regulations.

The analysis of the expectations and strategy of the German government indicates that government strategy is mostly aligned with expectations about the landscape level. The German government reduced public funding in 1995, despite the fact that expectations about fuel cell technology were rather positive at the time. Although expectations about niche technologies, such as hydrogen and fuel cell technologies, were positive, investing in these technologies did not address any urgent challenges related to the socio-technical landscape level. These technologies only regained a high priority when the expectation that manufacturers located in other countries would deploy hydrogen and fuel cell vehicles thereby eventually harming employment in Germany. The renewed interest coincided with a time when employment was expected to pose a major challenge for Germany. It was argued that Germany then had to achieve or maintain its leading position in hydrogen and fuel cell technology, simply because it was regarded as a future key technology by other countries. In addition, the climate change issue became a major point of reference in the policy debate and policy support was rising again. Thus the level of expectation related to the landscape appears to be important for policy makers.

Looking at the *expectations related to the regime level* the car manufacturers both expected increasingly strict emission regulations, which eventually would require alternatives to gasoline/diesel powered combustion engines. Even more influential were the expectations BMW held about its future market (and the performance customers would expect from a BMW car). The management assumed that the demands from customers would remain stable in the future: customers were expected to continue to demand powerful vehicles with long range capabilities.

Daimler's management had slightly different expectations about future demand and selected a different technology. Expectations about the future regime, and BMWs position as a relatively small manufacturer supplying luxury sports cars to the market, were crucial factors in BMWs innovation strategy. The announcements of competitor Daimler raised expectations that this competitor would deploy fuel cell vehicles to the market at a large scale. Out of concern for its position within the future mobility system BMW decided to assess fuel cell technology again. Subsequently the research on fuel cells as auxiliary power units, supplying electricity for the electronics system onboard, was intensified. In more recent years expectations related to the regime level, i.e. about the future mobility system and customer demands changed, eventually leading to the setup of a research and development program for battery electric vehicles at BMW.

Daimler had slightly different expectations about the future regime level and expected that its customers would demand premium cars with the most advanced technology, namely fuel cells. Implicitly, both car manufacturers expected that the mobility system would remain relatively stable during the 1990s, without major disruptions concerning new intermodal modes of transport. In particular the expectation that a future mobility system would be similar to the current system and the expectation that a hydrogen economy would eventually emerge were influential expectations related to the regime level.

	BMW	**Daimler**	**German Gov.**
Landscape	Local air pollution *(early period)* Expected price of oil *(early period)* Climate change *(more recently*	Local air pollution *(early period)* Climate change *(more recently)*	Future oil prices (*early period*) Local air pollution (*early period*) Competitiveness / employment (*in between*) Climate change (*more recently*)
Regime	Regulation will become stricter *(all periods, while with different intensity)* Future customers will expect luxury car (long range, fast refueling, sportive) (*decline more recently)* Mobility system may change (*more recently*) Customer demands may change (*more recently*)	Regulation will become stricter *(all periods, while with different intensity)* Future customers will expect most advanced technology (long range, fast refueling) (*all periods*) Mobility system may become more diverse, space for new business models and EVs (*more recently*)	A hydrogen economy will emerge eventually *(all periods, while with different intensity)*
Niche	Hydrogen very promising, no range issues hydrogen ICE will remain less efficient than fuel cell) Electric vehicles / battery technologies become better and viable (*more recently*)	Similar to BMW (hydrogen very promising, fuel cells are more efficient than ICE) Electric vehicles / battery technologies become better and viable (*more recently*)	Expectations about fuel cells remained rather positive, even during times of reduced funding (*all periods, while with different intensity)*

Table 2: Overview of expectations related to the three levels

Daimler's rejection of methanol on-board reforming provides another example for the relevance of expectations related to the regime level and illustrates how the volatility of expectations can eventually lead to strategy changes. When Daimler's management did no longer expect the oil industry to provide methanol for these vehicles the option of methanol on-board reforming was rejected as a viable strategy due to these changed expectations related to the regime level (in conjunction with some technological difficulties).

To conclude, expectations about the future regime, including regulations and competitors and their future role, appear to have played a significant role for both car manufacturers. Particularly the interviews with representatives from OEMs indicate that, expectations about the future (automotive) mobility system and their position in the market for vehicles were of major importance..

The expectations related to the niche level were relatively similar for all three actors. The expectations about the potential of hydrogen combustion (in the case of BMW) and fuel cell technology (in the case of Daimler) had to be optimistic and fit into the expectations about the future mobility system, since a car manufacturer would hardly invest in a technology if the management is not convinced that the technology as such is working. With regard to he expectations related to the niche level BMW's technological expectations about hydrogen combustion engines, fuel cell vehicles, or electric vehicles, were not considerably different from the expectations held by Daimler at the time. However, the assessment of technologies within the car companies was mainly done with regard to expected future markets (expectations at the regime level).

3.5 Concluding remarks

This paper outlines an approach to explore the actor strategies in sustainability transition processes by analyzing expectations and their influence on actor strategies. The findings presented here suggest that changes in actor strategies as well as differences between the strategies of actors can be regarded as a consequence of different expectations related to the various levels. Furthermore the analysis shows the influence of non-technological expectations on actor strategies. Expectations related to the socio-technical landscape level, or regime level influence the decision of actors to engage in certain technological trajectories.

In particular, the case study of the German government showed that although expectations about the niche of hydrogen and fuel cell technologies were rather positive, the German government decided to reduce its support of these technologies. Due to changing expectations related to the socio-technical landscape level, the government decided there would not be any need for hydrogen technologies in the short and medium term.

Our analysis can explain why actors operating under rather similar contexts in terms of institutional settings or resource endowments choose distinct strategies and why rather positive transition dynamics can suddenly change into negative transition dynamics. These similar contexts and changes in the environment can lead to distinct outcomes, since the state and the history of the organization will have an influence on the interpretation of these changes. Thus, even actors operating under apparently similar circumstances can develop different expectations and following from that distinct strategies. Furthermore it can be discussed to what extent Daimler and BMW are operating under similar environments. On the one hand, the markets for their passenger vehicles are similar: both produce cars for the premium segment and are located in Southern Germany. However, there are other factors, like the size of the companies, other products, firm culture, etc. which are influenced by the history, which eventually influence the way expectations are generated within the company and which strategies are considered viable.

Finally, the case studies illustrated that different types of actors seem to relate their strategies stronger to specific levels of expectations. By analyzing the underlying expectations of two major automotive manufacturers and the German government it became clear that the automotive manufacturers appear to refer strongly to expectations related to the regime level while expectations related to the socio-technical landscape level seem to be most important to policy actors like the German government for their strategy formation.

This paper is a first step towards a better understanding of actor strategies in the field of fuel cell and hydrogen technology. Further research is necessary to provide more empirical evidence supporting the conceptual considerations presented here, e.g. about the emergence and shaping of expectations and their dynamics or the influence of strategic behavior on expectations. Moreover, studies looking even deeper into the organizations (i.e. how different sub-units of organizations, which were treated as organizational actors in this study, interact with each other), appear to be promising. Furthermore it is not fully clear to what extent the insights from this paper can be generalized beyond the field of hydrogen and fuel cell technology. We assume that the results can probably be generalized to similar technologies which are dependent on the interplay of actors from industry, research and the government, in order to build up an infrastructure. However, it remains an open question to what extent the insights can be generalized to more mature sectors and technologies, in which cases more robust knowledge is already available. Nevertheless we assume that the analysis of expectations is a fruitful approach to improve our understanding of transition processes beyond the field of this paper.

4 Technological hype and disappointment: lessons from the hydrogen and fuel cell case[83]

4.1 Introduction

Radical innovation is a complex and uncertain endeavour. Incumbent industries and their products and processes are in general well aligned with existing institutions and consumer demands. The actors that try to develop and commercialize an innovation that does not match the criteria that are shaped by current practices, fight an uphill battle. It is therefore not surprising that those actors are often reluctant to be the first to engage in that battle and a waiting game may be the result. This is especially true in the case of system innovations in which multiple actors need to cooperate and coordinate their efforts. In such cases, actors are only likely to move once they are assured that others will play along, while from a societal perspective positive action may be very much desirable.

In our contribution to this special issue we elaborate on the possibilities for breaking out of waiting games from the perspective of the sociology of expectations (Borup et al., 2006; van Lente, 1993; van Lente and Bakker, 2010). More specifically, we explore the potential and risks of technological hypes for breaking out of waiting games. Hype can be effective in avoiding or overcoming waiting games and it may even trigger actors to engage in an innovation race to be the first to develop and commercialize an emerging technology. However, there is a substantial risk that hype is followed by disappointment and this may slow the pace of innovation down again. Such hype and disappointment dynamics are more likely to occur, we argue, when many actors engage in an expectations race rather than an actual innovation race. These issues of technological hype and the dynamics of hype and disappointment were subject of earlier studies (Brown, 2003; Rip, 2006; Ruef and Markard, 2010). We build on these studies and we ask the question: what are the net effects of hype and disappointment and what lessons can be learned for the management of expectations?

We make use of the hydrogen and fuel cell car as an example of a radical and architectural innovation that has gone through phases of both hype and

[83] This Chapter is published as: Bakker, S., Budde, B., 2012. Technological hype and disappointment: lessons from the hydrogen and fuel cell case. Technology Analysis & Strategic Management 24, 549-563.

disappointment. Being radically and architecturally different from today's cars, the hydrogen car is an example of a system innovation that depends on a multitude of actors to succeed. For a number of reasons, it presents a case of innovation in which a waiting game would be likely to occur. First and foremost, radical innovation in general is difficult as a result of dominant technological trajectories, which gain their stability from 'technological paradigms' (Dosi, 1982) and 'regimes' (Nelson and Winter, 1982). Progress along these trajectories is limited to cumulative and continuous change, while discontinuous change is discouraged. One reason is found in the existing selection environment that favours existing solutions due to economies of scale and lock-in effects (Abernathy and Utterback, 1978; David, 1985), and is thus hostile to new, diverging solutions. Radical innovation becomes even more difficult in the case of eco-innovations. That is, eco-innovations score high on performance criteria that are normally not those of the market (Faber and Frenken, 2009). The transition from old products and practices to new ones is in those cases not necessarily desirable from a regular market perspective. They are desirable from a societal and environmental perspective, but regular market incentives, towards higher performance levels and lower costs, are thus lacking for firms to develop eco-innovations. It is only because of anticipated governmental regulations and expected changes in market forces (e.g. rising oil prices in the case of the automobile) that they are developed at all (Budde, Alkemade, et al., 2012)

An additional reason to expect a waiting game is that the success of the hydrogen car is also dependent on a complementary refuelling infrastructure. There are no incentives for infrastructure providers to build an infrastructure as long as there are no cars available and vice versa. Thus the situation would even be more likely to turn into a waiting game, or a 'chicken and egg' dilemma as it is often referred to (Tollefson, 2010).

In fact, the absence of radical innovations concerning the powertrain during the last decades empirically indicates the occurrence of waiting games. Although a large number of alternatives have been proposed (e.g. biofuels, electric vehicles, natural gas, and LPG), only the relatively incremental options were introduced to the market. However, they did not gain major global market shares. Even the catalytic converter, another incremental innovation, was introduced largely due to public pressures and regulations against the resistance of the automotive industry (Gerard and Lave, 2005).

During the recent hydrogen and fuel cell hype, these barriers were overcome and an innovation race was triggered instead of a waiting game. This innovation race ended however when disappointment took over from hype. Before we analyze the hydrogen and fuel cell case in more detail in Section 4, we first discuss the concepts of technological expectations and hype in Sections 2 and 3. In Section 5 we explore the potential of expectations management to balance the pros and cons of hype.

4.2 Technological expectations

Technological expectations, ideas on what a technology is capable of in the future, have a long history in management and innovation studies. For instance, Cyert, March, and Mill have already written about the role of expectations in business decision making in the 1950s (Cyert et al., 1958) and Rosenberg (1976) referred to expectations as those ideas that make that consumers postpone purchases in hope of better or cheaper alternatives in the future (effectively a type of waiting game). Whereas these interpretations are mostly concerned with individual expectations and their role in economic decision making, Van Lente has brought a sociological interpretation of technological expectations to the attention of innovation scholars. His interpretation is that expectations guide technological innovation and that they are an essential element of technology dynamics (van Lente, 1993).

This perspective has been developed further and now known as the sociology of expectations (Borup et al., 2006; Brown and Michael, 2003). A working definition of expectations was proposed as well: '[technological expectations are] *real-time representations of future technological situations and capabilities'* (Borup et al., 2006). Technological expectations are thus not only about future capabilities, or performance levels, of a single technological option, they may also relate to societal acceptance and market uptake and the conditions to make this possible. Technological expectations are the product of human agency and they are circulated actively by different actors. The voicing of positive or negative expectations is often part of a deliberate communication strategy of actors that have an interest in relation to, the success or failure, of the technology. Actors with an interest in a technological option might try to influence others with their statements and by doing so they attempt to '*colonize the future'* (Brown and Michael, 2003) with their option. Or, along the same lines, they make a *bid* on a desirable future outcome of the innovation process (Berkhout, 2006). In such cases where expectations are used deliberately and rather normatively, one can also speak of promises (Borup et al., 2006).

Expectations however, are only powerful once they are shared by many actors. In the sociology of expectations, these expectations are called 'collective expectations' (Borup et al., 2006; Konrad, 2006b). A collective expectation is an expectation that is shared or at least known by many actors, acting as a point of reference. In the sociology of expectations, the analysis thus focuses on the performativity of expectations: on what expectations can *do*. That is, expectations are performative in the sense that they influence innovation processes as they can help to steer, stimulate, and coordinate actors' actions and decisions towards the future.

From this perspective the question whether or not expectations are voiced genuinely or not becomes mostly irrelevant. However, and this is important to our analysis, the extent to which actors are genuine in their expectations (and promises) may be of relevance to the chance of disappointment setting in. One can assume that the more genuine the actors are in their statements, the more are these promises backed by actual R&D efforts and investments and hence the greater the chance that positive expectations and their effects can be sustained for prolonged periods. We therefore make a distinction between discourse, or expectations, strategies and the actual innovation strategies of actors (e.g. firms). The latter then relates to R&D activities, while the former is moreover the domain of marketing departments (Budde, 2011). To truly break out of waiting games and avoid the backlash of disappointment, discourse alone is not enough and the expectations need to be complemented with actual innovation activities.

4.2.1 Enactors and selectors

To understand the build up and impact of collective expectations, and ultimately of hype, a strictly sociological perspective does not suffice (Bakker et al., 2011). Building on the work of Garud and Ahlstrom (1997) and Rip (2006), we continue our discussion with the differentiation between enactors and selectors. Here, the enactors are those actors that develop and simultaneously 'enact' a (radically innovative) technological option. Part of the enactment is the voicing of positive expectations of their option. As there are many technological options that are being developed, there are many expectations, and promises. Not all of them become collective and some selection is necessarily made. The selection process, on the basis of different types of assessments, relates to selection in terms of funding allocations by governmental agencies and also in terms of firm-level decisions on viable R&D trajectories. And at the same time the selection process relates to expectations as well, the so-called selectors assess the different expectations and promises in terms of credibility and their judgments are crucial to the emergence of collective expectations. From their interplay, the actors that voice the expectations and the actors that assess them, collective expectations emerge.

The distinction between enactors and selectors is not as straightforward and certainly not as static as it might be taken from the description above. These are not fixed positions of the actors in the innovation process. They are rather roles that actors play in a given context of innovation. An actor can perform both roles, sequentially or even simultaneously in a hierarchy of technologies and systems. Sequentially, an actor might select a technological option and enact it from that moment onwards. For instance, a car manufacturer may decide to engage in the development of fuel cell technology (selection), and becomes an enactor afterwards when it tries to find support from governments and acceptance by future customers. The same goes for a scientist that enters a research field, say metal hydrides for hydrogen storage: he or she selects that field and becomes an enactor of the same field from there onwards. An actor who is active at the level of hydrogen systems acts as an enactor of the hydrogen vision as a whole. Simultaneously, this actor is also engaged with the selection of hydrogen technologies. To illustrate, a lead developer of hydrogen cars in an automotive firm enacts the hydrogen vehicle as a whole and at the same time acts as a selector for the storage method to be incorporated in the vehicle.

While communities of enactors are held together by a shared interest in a specific technological option, they are often not necessarily tied to this option. That is, some may be truly dependent on the success of a specific technological option and its technological community (e.g. an entrepreneur who invested all of his capital in the development of a single product), while others may be less dependent on that single option and be more flexible in that respect (e.g. a car manufacturer that develops a portfolio of different powertrains and effectively takes part in multiple technological communities). This distinction is of relevance to the dynamics of hype as the former set of actors will be affected more by the hype itself, but especially by the consequences of disappointment that follows hype.

4.3 Hyping out of a waiting game

In the following section we elaborate on the notion of technological hype and its potential to overcome waiting games. Technological hypes can be understood as an extreme manifestation of technological expectations (Brown, 2003; Rip, 2006; Ruef and Markard, 2010). A popular depiction of hype that is often taken as reference is the '*Gartner hype cycle*'. It is a tool that is used by the Gartner consultancy firm to position emerging technologies on a timescale and to make recommendations about the timing of strategic investments in the technology. Even though hype cycles take place on different shapes and sizes for different technologies (van Lente et al., 2013), the Gartner cycle provides a clear illustration of the basic dynamics. It should be noted though that the Gartner model was developed to track the (market) diffusion of ICT innovations (Fenn and Raskino, 2008), and thus not with a focus of pre-market innovation dynamics.

The graph that Gartner uses, plots the expectations about a technology on a timeline.[84] An archetypal illustration of the timeline is presented in Figure 13. After a first technology trigger, expectations rise sharply and culminate in to a hype, until the peak of inflated expectations. As the peak is reached, it becomes clear that not all expectations can be met (in time) and disappointment starts to surface. When this disappointment becomes stronger, expectations drop rapidly, resulting in the trough of disillusionment. After some time the technology might recover and slowly but surely expectations rise again (but only to modest levels) and the technology might make its way to the market after all.

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84 In earlier versions of the hype cycle the terms 'visibility' or 'attention' are used, the term 'expectations' is used in more recent publications by Gartner. We have decided to use the latter as it matches more directly with our main argument. Furthermore, and this could very well be the reason for Gartner to abandon these terms, 'visibility' and 'attention' are not necessarily positive and could also be used in situations in which a technology is heavily criticized (i.e. the food vs biomass debate). A similar interpretation of expectations is also possible, however less likely. To avoid confusion we use the terms 'positive expectations' and 'negative expectations' when needed.

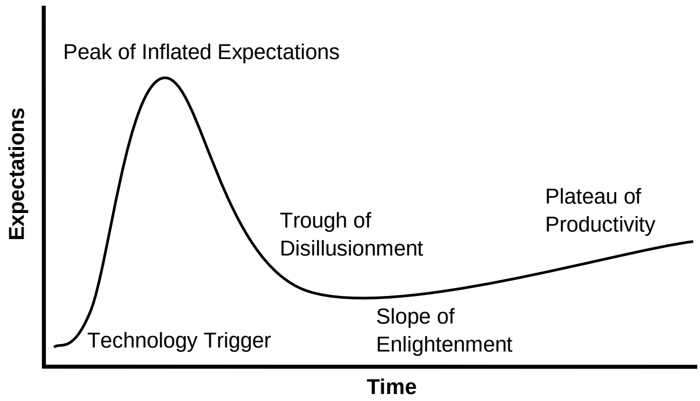

Figure 13: The Gartner hype cycle (Fenn and Raskino, 2008).

While this representation of technological hypes is alluring to practitioners, policy makers and researchers, there are some difficulties as well. The most poignant issue is without doubt the use of the term ‘inflated expectations’. The extent to which expectations are inflated (i.e. unrealistically optimistic) can only be truly assessed in hindsight and it is also not our objective in this paper. However, while enactors are often keen to inflate expectations of their options, there are also actors that actively aim to debunk the hype and to deflate this. We propose to study the dynamics of hype and disappointment and the effects these have on innovation trajectories from a constructivists’ perspective, along the lines of the sociology of expectations. In our definition hype is thus a peak of positive expectations, without claiming that these expectations are necessarily and intrinsically inflated. The notion of peak does however imply that preceding and following the peak, expectations were significantly lower. From our perspective, the peak is thus a period in which the enactors are successful in communicating their positive expectations (and promises), as they are then shared or at least acknowledged by others, while in the surrounding periods they are less successful and their positive expectations are not part of the collective repertoire anymore. Even more so, the negative expectations as they are voiced by competitors or other criticasters are likely to become collective, and substitute the earlier positive ones in that respect, during such a phase of disappointment.

From the perspective of the sociology of expectations, hypes are potentially powerful triggers for innovation (Borup et al., 2006; Brown, 2003) and likewise they can be triggers to break out of technological waiting games. During the upward slope, technological hypes may attract actors to join or support the innovation trajectory while they were reluctant to do so beforehand. This is the stimulating and coordinating role of, positive, technological expectations in its extreme manifestation. Ideas that previously were considered possible only in parts of the internal discourse of the community are then also taken up by outsiders, and thus also by selectors, become part of the collective repertoire of technological expectations. The fact that more actors join in due to the hype, improves the chances of the expectations to be realized: the well-known effect of self-fulfilling prophecies (Merton, 1948).

However, the community of enactors, with their different interests and intentions, might overstate its expectations to the level that these cannot be met by actual achievements. In such cases, in hindsight, one could say that these expectations were indeed inflated and that reality has inevitably overtaken them, leading to disappointment among supporting actors and withdrawal of funds. For hypes to be effective in breaking out of technological waiting games, the gains of the upward slope should be larger than the losses of the downward slope. In a worst-case scenario, from the perspective of the enacting community, the disappointment is so destructive that it triggers the death of the initial prophecy: suicidal prophecies.

In the next sections we discuss the recent global hydrogen and fuel cell hype, that peaked around 2002, and we show that the net effect of this hype differs per region and is very much dependent on the institutionalization of positive expectations in long term policy measures. Furthermore we ask the question what form of expectations management could have yielded a steadier and more predictable innovation journey for the hydrogen car. Our findings and insights are based on two (PhD) projects. Both projects used a mix of methods including discourse analysis, patent and prototype analysis and semi-structured interviews. Our analysis covers the global scale, with data and interviews from several European countries, the US and Japan. When appropriate, references are provided to specific publications.

4.4 The Hydrogen hype

The hydrogen car was and still is one of the contenders to become the car of the future. A number of characteristics make it an attractive option for both car manufacturers and fuel companies. Technologically, hydrogen can be used as fuel for internal combustion engines and, more sophisticated and efficient, for fuel cells (European Commission, 2003). For car manufacturers it is therefore an option that offers similar performance characteristics, to their consumers, as the conventional car. To fuel companies, hydrogen may be the successor of gasoline and diesel that safeguards their position in the transport sector, whereas electric vehicles would open the chance for electric utility companies to gain a vital role in the transport sector and eventually replacing today's fuel companies (ERTRAC, 2010)

Hydrogen has been on the energy agenda for at least four decades (Dignum and Verbong, 2008; Hultman, 2009) as a fuel, or more precisely as an energy carrier, of the future. Rising expectations about fuel cells have formed the 'carrot' in the expectations race that we describe in the following. Over the years hydrogen has been at the centre of attention a number of times and most recently a hydrogen and fuel cell hype arose from 1997 onwards and lasted up till 2006 (Bakker, 2010). The Californian zero-emission-vehicle mandate can be regarded as an important factor contributing to the hype. Even though it was relieved in the end, the industry interpreted it as a warning that less polluting vehicles were inevitably going to be needed in the future. These ideas formed the 'stick' type of expectations in the expectations race. The industry's response was not only found within the laboratory gates. The industry highlighted their efforts with the presentation of prototypes and concept cars towards a wider public (Budde, Alkemade, et al., 2012). Accompanying the prototype models, were highly optimistic statements, from the manufacturing firms in their roles as hydrogen car enactors, about plans for commercialization car; it was a matter of years, rather than of decades (Bakker, 2010). Attention in the media rose accordingly and governments sponsored (i.e. selected) further development of the technologies. Hydrogen programs were set up in Japan, the US, the EU, and in many of the individual European countries as well. Research was performed on fuel cells, hydrogen production methods, storage systems, and refuelling infrastructures. Next to the research that was done in the firms' R&D labs and at universities and other public research facilities, demonstration projects were also set up. From hydrogen buses in European cities, to test fleets of tens (or even hundreds) of fuel cell vehicles on the three continents. Despite all the efforts and the considerable progress that was made, in terms of cost reductions, efficiency gains and improved vehicle ranges, commercialization did not take place within the timeline that was promised earlier by the automakers. Hydrogen became known as the technology that 'always needs another ten years'[85] and sentiments turned

[85] This is a widely referred to statement, amongst others in the following interviews: CEO of a German Research Center, 26 February 2008, Head of a Swiss Research Group, 2 April 2008, Former senior researcher Daimler 8 April 2008, Manager of the

negative in the second half of the first decade of the 21st century. With too little visible results, at least to policy makers and the wider public, a number of selectors started to withdraw their money. Venture capital was difficult, if not impossible, to acquire, fuel cell companies were valued less on the stock markets, and the US Secretary of Energy, made an attempt to end all federal support for hydrogen technologies (Service, 2009). The U.S. Congress decided otherwise and the budget was restored. However, in the 2011 White House's Blueprint for a Secure Energy Future, hydrogen was fully absent again (The White House, 2011).

The hydrogen community has profited a lot from the hype, despite the later phase of disappointment, and it is difficult to gauge whether it would have been more favourable for the technology's development if the expectations dynamics would have been less dramatic. Positive, from the perspective of the hydrogen community, is the fact that some car companies are still continuing their hydrogen efforts and it is not likely that all knowledge is lost[86]. Moreover, many technological difficulties which were not known or not understood at the beginning of the hype could be identified and in some cases even overcome. These were for instance the cold start issue of hydrogen fuel cell systems when temperatures were below zero degree and thus the water was freezing in the systems and eventually damaging it or the degradation behaviour of hydrogen fuel cells[87]. Whereas many of these problems contributed to the delays in terms of market deployment of hydrogen vehicles, and eventually to the collapse of expectations, these issues probably would not have been identified or even solved without the research activities that were enabled by the hype. In other words: the picture about the issues necessary to be solved for a market introduction of hydrogen vehicles today is much clearer than it was a few years ago (Expert 7).

For smaller dedicated firms that rely fully on the commercial success of hydrogen or fuel cells, the situation is probably different and more problematic. Venture capital is nearly impossible to acquire (Bakker et al., 2012) and it will take longer for any serious market for hydrogen technologies to take off, if ever.

The continuation of public funding for hydrogen and fuel cell technology development differs per country and region. In those cases where funding was continued, it should be questioned whether this was the result of deliberate

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German Hydrogen Association 13 November 2007. The names of these and following interviewees are withheld by mutual agreement.

[86] Companies like Daimler, GM, Toyota, and Hyundai continue to claim that hydrogen and fuel cells are in their R&D portfolios.

[87] Daimler press release: 'B-Class with fuel-cell drive proves its worth during winter testing in Sweden', Stuttgart, 17 March 2008

action or simply because policy making is too slow to keep up with the hypes and disappointments. Empirical findings from Germany and the European level indicate that the continuation was indeed deliberate, rather than just slow or delayed policy making (Budde and Konrad, 2009). In the case of the German National Innovation Programme (NIP) on hydrogen and fuel cell technology, the aim was to set up a long-term research programme (i.e. 10 years). Moreover, it was supplemented by the foundation of a dedicated organisation managing this long term programme (BMVBS et al., 2006). The long time period of the programme and the set-up of this organisation, the National Hydrogen Organisation (NOW) was aimed at providing policy stability, respectively making the programme more 'robust' against expectation dynamics (Expert 5). Similar processes can be observed in the case of the emergence of the Joint Technology Initiative (JTI) on hydrogen and fuel cell technology at the EU level, which encompasses a long term research programme and the set-up of a dedicated organisation (European Commission and New Energy World IG, 2008; HFP Europe, 2006, 2007). The hydrogen and fuel cell activities of Daimler are also an example of prolonged commitment to the innovation trajectory. In this case the investment of Daimler in the Canadian fuel cell company Ballard, and the subsequent setup of a joint venture to develop (hydrogen) fuel cell systems, was aimed to show the commitment of Daimler and to provide stable framework conditions for R&D activities within Daimler (Expert 6).Therefore this internal institutionalisation stabilized the positive outcomes of the hype. In contrast, in the Netherlands, no such institutionalisation took place and hydrogen disappeared rapidly from relevant policy agendas (Expert 13). This lack of institutionalization can be explained partly by the absence of car manufacturers which resulted in limited lobbying power for the hydrogen community.

Against this background, the institutionalisation of the positive effects of hypes appears to be a viable strategy in order to secure the policy support and the public funding over a longer period of time, when the hype itself has already turned into disappointment. Furthermore the stabilization of policy support and the establishment of long term funding schemes may provide some additional support to raise private capital, since uncertainties are reduced. Moreover, such long term programmes are reported to have a stabilising signal within the companies involved in hydrogen research. It supports the claims of the hydrogen enactors within private companies to back their R&D activities: Since the project proposals are evaluated by external reviewers (often hydrogen enactors themselves), their positive feedback provides good arguments to convince internal selectors. To illustrate, a BMW strategist remarked: 'public funding plays a strategic role, because it shows that the state values the activities of the company. It is a signal that the technology is important for the state and it reduces uncertainty. […] It shows that you are not doing something esoteric. Public funding is not extremely important in terms of money, but it is a signal to our decision makers and our board that the issue of hydrogen and fuel cells has reached the national government.'(Expert 11)

Nonetheless, the hydrogen community will be evaluated again and by that time (around 2015 in Germany and the EU) continuation of the programmes is no longer guaranteed.

4.5 Expectations Management

The net effects of the hydrogen hype and the phase of disappointment that followed, depend very much on the specific contexts and the extent to which the high expectations during the hype were solidified in robust institutions. Nevertheless, we assume that communities of technology developers would be better off with more stable and predictable funding and that these dynamics result in suboptimal returns on both public and private investments that are made by the selectors. Both enactors and selectors thus have a shared interest to balance the advantages and risks of high expectations.

After the hype, the enactors of the hydrogen car have claimed in hindsight, that they should have managed the expectations better to avoid overpromising. And as Rip showed in the case of nanotechnologists, the notion of hype and disappointment is very much part of a repertoire of folk theories that circulate among engineers and scientists (Rip, 2006). According to their reasoning, hype should have been avoided and more 'realistic' expectations should have been voiced from the start. As other studies have shown, all sorts of actors know how to take advantage of hypes (Konrad et al., 2012; Wuestenhagen et al., 2009). But it is less clear if and how it would be possible for the enacting community to actually avoid hype while still raising high enough expectations to be granted a mandate for their work and draw out other actors as well. In comparison to the hype cycle, an 'ideal' expectations curve following this reasoning, would be a flat line at a moderate and realistic, but nonetheless effective, level of expectations or a rather straight ascending line of expectations that are continuously reinforced by actual achievements (Figure 14).

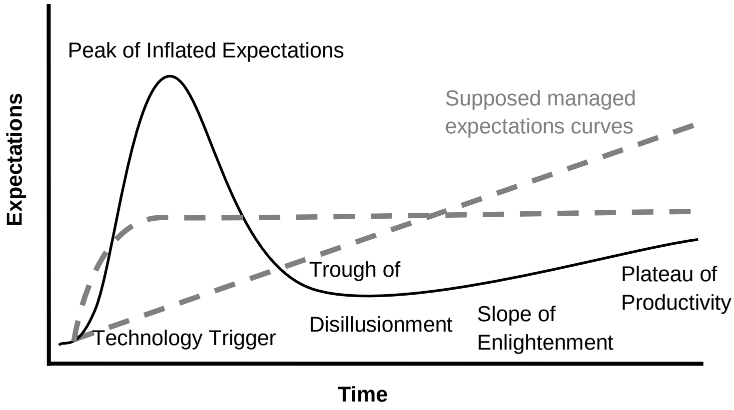

Figure 14: Supposed expectations curves in the case of optimal 'expectations management'

4.5.1 The enactors' dilemma: to hype or not to hype?

The enactor-selector distinction is relevant when asking whether or not some form of expectations management is possible. While both have an interest in avoiding hype and disappointment, they have different roles in trying to do so. Engineers and other members of an enacting community need to communicate to their sponsors why their option is promising and why support is thus legitimized (Rip, 2006). For them there is hardly any incentive to be modest as they need all the support they can acquire and this is done best with high expectations and bold promises. The risk of overpromising and the subsequent backlash of disappointment are necessarily taken for granted. In other words, for individual enactors there is a strong incentive to voice high expectations of their own technological option as this will provide them with the desired resources. Furthermore in particularly stable sectors such as the automotive industry[88] it is even harder to mobilize actors and resources for radical technological innovations and this presents an additional incentive to hype.

However, there is an incentive to remain modest and to avoid hype, but it is a collective incentive and it is only rewarding in the long run: the community as a whole is ultimately affected by the disappointment and not only the individual

[88] In terms of propulsion technologies the number and quality of incremental innovations should not be neglected, however radical innovations especially with regard to propulsion technologies are very rare in the sector.

enactor. This condition can be compared with the characteristics and underlying processes of a multi-player prisoner's dilemma or the similar 'tragedy of the commons'. The outcome of the individual's decision is dependent upon the decision of the other(s). And cooperation, by being modest, presents less direct rewards for the individual agent. A hypothetical matrix of the enactor's dilemma is depicted in Table 3 .

The enactors' dilemma	**Modest enactor**	**Hyping enactor**
The community is modest	Low reward for all in the community (and steady)	Low reward, but more than competitors in the community (and steady)
The community is hyping	High reward, but less than competitors (short period only)	High reward for all in the community (short-period only)

Table 3: Hypothetical table of the enactor's dilemma of raising expectations and avoiding hype. Individual enactors are likely to 'hype' instead of being modest as it brings them the highest reward (at least in the short term) in terms of private or public funding or other resources.

Even more so, different actors with diverging interests are involved in the expectations work of the community. Some of those have an interest in the final outcome of the innovation trajectory and their ambition is to commercialize and deploy hydrogen vehicles onto the road in large numbers. This is particularly true for dedicated firms and small projects that rely on external funding. These actors actually have the collective incentive to avoid overpromising and hype, in order not to jeopardize the innovation trajectory. Others however have only short term interests. The venture capitalist, for instance, who has invested in a start-up company, has every reason to create hype as this will generate a high return on his investment. The venture capitalist's consideration does not include the negative results of eventual disappointment: the consideration is about 'stepping out' before disappointment sets in (Wuestenhagen et al., 2009).

The car industry has played a particular role in this respect. These firms have used a double repertoire of statements about hydrogen in order to 'manage' the expectations of governments and the wider public. On the one hand they made highly optimistic statements to demonstrate their innovativeness and willingness to develop more environmentally friendly vehicles. And on the other hand, and in a later phase, they made more modest statements to prevent all too strict regulations that would actually require them to bring these vehicles to the market (Bakker, 2010). In the 1990s the car manufacturers were obliged to deliver zero emission vehicles under the California zero emission vehicle (ZEV) mandate, which was meant to enforce the market deployment of battery electric vehicles (Collantes and Sperling, 2008; Kalhammer et al., 1998; Larrue, 2003). However, the automotive industry was not expecting batteries to be a viable solution to satisfy the propulsion needs of cars. Therefore they had to present an alternative to regulators and the public, in order to show their real commitment to develop and deploy low or zero emission vehicles. In this situation car manufacturers, like Daimler decided to proactively position fuel cell technology as 'the' future technology being superior in competition with battery electric vehicles instead of fighting the California regulation as such (Expert 6). The car industry has started an expectations race (who is the most innovative and responsible car maker?) without necessarily engaging in a true innovation race. And as a consequence they have triggered many actors and governments to break out of their waiting game, while not breaking out themselves with matching efforts.

Management of expectations after the hype often aims at renewing, or even reframing, the older expectations. One of such strategies was pursued by the Hydrogen and Fuel Cell Technical Advisory Committee of U.S. Department of Energy. From the moment that battery-electric vehicles started 'chipping away funds' from the hydrogen car, this committee of hydrogen enactors proposed to reframe hydrogen as a complementary option of electric vehicles, rather than as a competitor. In their words, they started aiming at 'enlarging the pie' rather than securing the largest piece of the pie (Bakker et al., 2012). A similar strategic move is the repositioning of fuel cell vehicles as a part of the future electric drive portfolio by Daimler (Daimler AG, 2011).

Additionally, the proponents of technologies often aim at (re-)connecting with other technological communities. The hydrogen community for instance managed to establish strong links to communities around renewable energy technologies (i.e. wind energy) and to establish the term 'new and renewable' energies and thereby to subsume hydrogen and fuel cell technology and renewable energy technology on the European level (Budde and Konrad, 2009). By stressing the expected challenges at the societal level (e.g. climate change) and the need of both technologies to cope with them by proponents of several technological communities these strategies can be regarded as a strategy to enlarge the pie of available funding (Budde and Konrad, 2009).

4.5.2 The selector's dilemma: to select or not to select?

Like the enactors, the selectors also have an interest in less dramatic expectations dynamics. While this difficult to achieve by the selectors, as we have argued, the specific role of the selectors allows them to manage expectations to some extent at least.

First of all, it would be advisable for technology selectors to refrain, as much as possible, from choosing sides at all. And second, if selection is unavoidable, it should be avoided to do this all too hastily and drastically. That is, selectors should be aware of the ongoing expectations race and be careful not to react immediately to any hype as it comes by (Fenn and Raskino 2008, p.52). Likewise, in the case of disappointment, they should avoid dropping the disappointing option immediately and completely. Indeed, hydrogen funding has been relatively stable as compared to the high amplitudes in the various expectations curves that occurred (Bakker et al., 2012). The DOE funding was restored to more or less regular levels and the EU Hydrogen Joint Technology Initiative (JTI), a 1 Billion Euro private-public funding program, guarantees the continuation of hydrogen projects in Europe (FCH, 2011).

These selectors have thus not reacted directly and drastically to the disappointment that followed after the hype. This however, holds no guarantees for the future and the question remains: can technology selectors manage expectations more deliberately? We argue that this is possible through technology-agnostic policies that trigger innovation without selecting winners or dropping losers. The well-known Californian zero-emission vehicles mandate was designed to be technology-agnostic (Collantes and Sperling, 2008), and so is the anticipated EU regulation on fleet-average emission standards (European Commission, 2010)[89]. Such regulations force demand for zero- or low-emission vehicles and trigger automakers to innovate without selecting a certain option a priori. Governments can choose to compliment such regulations with R&D support schemes that are equally technology-agnostic. The U.S. FreedomCAR

[89] There are some bonuses however for zero-emission vehicles, from a tailpipe perspective and disregarding the electricity/hydrogen production methods, and these can be regarded as (mildly) technology specific. However, the rationale is to trigger radical innovation rather than these specific options per se.

project, a collaboration of the three U.S. car manufacturers and the federal government, in contrast, was solely meant for hydrogen vehicles and would not fit such a strategy. And, for instance, the EU could have chosen to set up a car-of-the-future-JTI, rather than a hydrogen-and-fuel-cell-JTI. The problem of picking and dropping is then not removed completely, but shifted from policy makers to car manufacturers themselves. On a speculative note, one could assume that within firms the enactors and selectors (e.g. a fuel cell engineer and the firm's R&D management) are closer to one another and that knowledge is more equally spread throughout the organization, as compared to firm-government enaction-selection processes. In such cases expectations are assessed more thoroughly and more regularly, and, therefore, less prone to inflation. However, this bears the risk of inducing waiting games in the organization itself, since the competition between technologies then takes place internally. Another option to manage expectations from the selectors' side is to introduce more explicit accountability in the expectations race. The EU Hydrogen and fuel cell JTI is a 50/50 match of public and private funding and the firms and organizations that profit from the JTI funds need to invest themselves as well. To some extent at least, this makes the expectations race between enactors and selectors more balanced as they co-select.

The selection problem remains with regard to start-up firms and other dedicated hydrogen developers. After the hype, these actors rely on government support to continue the development of their products. Private investors are not willing to support them any longer and their products are not yet commercially viable. The dilemma then, for policy makers, is to either end the support (thereby effectively losing the previous investments) or to continue the support in a higher risk context. In order to address this problem we suggest performing a re-evaluation of a technology with regard to possible robust side knowledge, as we label it here. Some competences initially developed with a certain technology in mind, may prove very useful to apply in other technological fields. Sometimes even the institutional structures can be used to support the progress of another technology. In the case of hybrid and electric vehicles competences and knowledge were built in a number of companies already in the early 1990s[90]. However, they did not expect a major market for these technologies and ended their research efforts. From today's perspective some car companies regret that they are no longer able to access these resources (experienced engineers, competences, etc.) immediately in-house (Expert 11). The same holds for fuel cell

[90] For instance the GM EV1 (electric vehicle) the Audi Duo (hybrid car) and a BMW hybrid prototype.

technology: a large share of competences or even specific components can be used in both hydrogen powered fuel cell vehicles and battery-electric vehicles.

Furthermore, we suggest that when governments do select 'winners' and the winning options receive funding, it would be wise to evaluate the results over relevant (i.e. longer) time spans. Continuous evaluation is a necessity to keep developments on the 'right' track, but selectors should keep in mind that radical innovation is a lengthy, and bumpy, process.

4.6 Conclusions

We have shown that technological hypes are potentially powerful phenomena that can trigger actors to engage in an innovation race instead of continuing their waiting game. Hypes can attract actors, funding and favourable regulations (and other institutions) that would otherwise not be attracted. Hypes are however also difficult, if not impossible, to control and expectations are likely to become overly optimistic and subsequent disappointment can cause a standstill once the hype is over.

During the hype that surrounded hydrogen and fuel cell technologies, all major car manufacturers started developing hydrogen cars and national and international R&D programs were set up. All of this happened in an industry that has been dominated by a single design and in which radical (eco-) innovation stood little chance. Hydrogen and fuel cells were already seen as a promising option, but the hype made it the option that no firm could risk to miss out on. Perhaps not all of the actors that jumped on this bandwagon did so with full commitment, but a lot was learned and achieved during this period in the form of many working prototype cars and some small production series for test and demonstration fleets. The hype has passed and in its aftermath many hydrogen and fuel cell enactors are left without funding or other support for their work. Insofar as hydrogen is still being supported after the hype, it is in those contexts in which the hydrogen hype was solidified in long-term and stable institutions. Looking back, the hydrogen and fuel cell enactors have profited from the hype but the overall outcome is probably suboptimal given the limited opportunities that they have today. The same goes for the technology selectors, those that have supported the development of these technologies, as their investments have so far not resulted in commercially available or even viable cars.

The innovation race that was spurred by the hype was also very much an expectations race. Those actors that make the highest bids, i.e. that promise the most in terms of technological and commercial achievements, are likely to profit most from the resources that become available during the hype. Next to that, actors in general, and the car manufacturers especially, are likely to make these high bids also as part of a communication strategy to highlight their innovativeness and willingness to develop clean cars. These incentives to voice high expectations, and to hype, make ‘expectations management’ in practice a difficult task for the enactors. We conclude therefore that expectation management is more likely to be achieved successfully by the selectors. They can do so for instance through the establishment of long-term programs that guarantee some level of continuation once the hype has passed. Next to that, technology selectors can choose for support schemes in which the supported enactors bear more responsibility and are therefore less likely to overpromise.

The availability of a number of potential cars of the future, and increased pressure from governments, make it unlikely that the automotive industry will return to its waiting game. Car manufacturers have selected different portfolios of technological options and it is no longer just a competition between firms, but also a competition between the different cars of the future. Firms therefore need to move towards commercialization, not only because the public and policy makers want them to, but because they may lose their competitiveness if they wait too long instead of entering the innovation race at full throttle.

5 On the relation between communication and innovation activities: A comparison of hybrid electric and fuel cell vehicles[91]

5.1 Introduction

The transport sector is one of the most polluting sectors and several technologies have been proposed in the last decades to improve the energy efficiency and reduce the emissions generated by the sector (Geels, 2012; Sperling and Gordon, 2009). At different times during previous decades different technologies such as battery electric vehicles, fuel cells or bio-fuels, were considered the most promising candidate to reduce the environmental impact of the automotive-based transport system. However, many of these technologies could not fulfill their initial promises and positive expectations turned into disappointment. More specifically, we observed several hype disappointment cycles with regard to these green propulsion technologies (Bakker, 2010; Geels, 2012). The observed hypes eventually collapsed when the initially very positive expectations could not be met, and turned into disappointment (Linden and Fenn, 2003; van Lente, 1993; van Lente et al., 2013). These hype cycle dynamics are not just an artifact of the discourse around a technology, they also influence and are influenced by the actual innovation activities. Previous studies have shown, for example, that discourse activities are pivotal to expectation building processes and thus to policy and investment decisions (Borup et al., 2006; Konrad, 2006b). But whereas the uptake of the hype cycle can trigger innovation activities, the subsequent downturn may lead actors to eventually withdraw from their activities in the field (Bakker and Budde, 2012; DIP, 1997b). In a worst case scenario the negative dynamics may even stop the further development of a technology. Thus the analysis of the patterns and causes of such expectation dynamics and insights in the role and nature of communication activities and their relation to innovation activities are important for actors involved in the development of a technology.

The main topic of this paper is therefore the extent to which the *announcements*, i.e., the communication activities of sustainability innovations by the automotive industry (‘*talking*’), are matched by a corresponding level of activities for

[91] This Chapter is published as: Budde, B., Alkemade, F., Hekkert, M., 2015. On the relation between communication and innovation activities: A comparison of hybrid electric and fuel cell vehicles. Environmental Innovation and Societal Transitions Volume 14, March 2015, Pages 45–59.

development and deployment ('*doing*'). The analysis of the relation between these two kinds of activities is in particular relevant since a gap between the promises made in the communication and the innovation activities may eventually lead to the emergence of a hype-disappointment cycle. In this paper we will therefore make an analytical distinction between activities focusing on the '*doing'*, referring to them as innovation activities, and the '*talking'*. The latter we refer to as communication activities. Following this analytical distinction we scrutinize the relation between the communication activities and the innovation activities in the automotive industry. We chose to analyse two clean vehicle technologies that differ with respect to market penetration: hybrid electric vehicles and fuel cell vehicles. While hybrid vehicles are widely diffused to the market, fuel cell vehicles are still not for sale to the general public. More specifically, this paper analyses the communication and innovation activities of the two leading car manufacturers of these technologies, Toyota (HEV) and Daimler (FCV).

Therefore we raise the following research questions:

> RQ: *What is the relation between innovation and communication activities in the automotive industry and are there differences observable with regard to HEV and FCV and – if there are differences, how can these differences be explained?*

The remainder of the paper is structured as follows: Section 2 discusses the conceptual framework, which is based on the literature on the sociology of expectations, (organizational) legitimacy and transition studies. In Section 3 we focus on the methods and the empirical data used for this paper, including descriptions and definitions of the two drivetrain technologies. Section 4 will present the empirical data, followed by conclusions in section 5.

5.2 Theoretical background: Expectations, discourses, legitimacy

This paper builds primarily on the literature on expectations which emphasizes the important role of communication activities for the motivation, guidance and coordination of innovation activities. First, we discuss the role of (collective) expectations shaped in discourses as described in literature on the sociology of expectations. Second, we will discuss the role of legitimacy and environmental pressures for the emergence and persistence of organizations and the role communication activities may play in these processes.

Innovation is a risky, long-term process in which many technologies eventually fail. This holds particularly true once a technological paradigm (Dosi, 1982) or dominant design has emerged (Tushman and Anderson, 1986). Due to increasing returns to scale for the dominant technological configuration, it becomes increasingly better and more and more resources are spent in order to improve this dominant design. Once a dominant design has emerged 'rules of thumb' and routines are developed, which increase the capabilities of the dominant design, making it more difficult for alternative technologies to enter the market. While these difficulties arise in all radical innovation processes, low carbon technologies suffer from additional and specific obstacles. Unruh (2000) describes this situation as a 'carbon lock-in', caused by a number of forces that support the persistence of the current fossil fuel based energy and mobility systems. If an innovation requires an additional infrastructure, a further obstacle can be expected: Infrastructure providers are hesitating to invest in infrastructure when there are no users (e.g. cars) taking advantage of that infrastructure. However, potential users are not willing to invest in a new technology when there is no infrastructure available yet. This specific situation is often referred to as a 'chicken and egg' dilemma which may results into waiting games (Bakker and Budde, 2012; Schumacher et al., 2009).

Expectations: Since innovations are by definition future oriented, actors have to operate under conditions of great uncertainty and, in the absence of more 'robust' knowledge about the future, they have to rely on their expectations (Budde, Alkemade, et al., 2012). Following Borup and colleagues we define expectations as 'real time representations of future technological situations and capabilities' (Borup et al., 2006, p. 286). Expectations allow decision-making and reduce the uncertainty that characterizes innovation processes. In their expectation building actors regularly refer to expectation statements by other influential actors in the field. Eventually, some of these expectations become a central reference in the discourse and an increasing number of actors consider these expectations as relevant. These '*collective expectations'* emerge from discourses (Konrad, 2006b). The importance of (collective) expectations has been shown by several studies on the 'sociology of expectations' which focuses on expectations and their role for emerging science and technology (Borup et al., 2006; van Lente, 1993; van Lente and Rip, 1998).

Several authors have investigated how expectations influence innovation processes. It has been shown that expectation statements in the discourse, for instance about the future capabilities of a technology, can legitimize the strategies and actions of organizations. Therefore expectations can help to mobilize resources and attract the attention of other actors (Bakker and Budde, 2012; Konrad et al., 2012; van Lente, 1993). van Lente and Rip (1998) emphasize the coordinating role of expectations and suggest interpreting expectations as 'prospective structures'; expectations about future social structures may act as if they had materialized already, which may eventually result in self-fulfilling prophecies. Summarizing, expectations have a mediating role between actors and structure and play a key role in mobilizing, legitimating, guiding, and coordinating innovation activities (Konrad, 2006a, 2010; van Lente and Rip, 1998).

However, expectations are frequently subject to strong hype-disappointment cycles (Bakker, 2010; Ruef and Markard, 2010; van Lente et al., 2013). van Lente (1993) explains these dynamics by the concept of promise-requirement cycles: Vague initial promises about a technology turn into requirements that have to be fulfilled. If these requirements cannot be met, disappointment sets in. The occurrence of hype cycle dynamics appears more likely if the statements and promises made in the discourse on a technology turn into an expectation race, rather than an innovation race (Bakker and Budde, 2012). Furthermore it has been shown that the specific features of technology hype cycles differ between technologies in specific fields (voice over ip, gene therapy, high temperature superconductivity), however little is said about the reasons for differences in the same sector (van Lente et al., 2013). Studies have shown that actors may try to inflate expectations about a technology they have an interest in, in order to increase their chances to mobilize resources (Bakker and Budde, 2012; Bakker et al., 2012; Brown and Michael, 2003). In related work Berkhout also emphasized the role of strategically deployed normative expectation statements (Berkhout, 2006).

In case of the automotive industry, central actors of the current automotive-based transportation system may have strong incentives to voice positive expectations about their innovation activities to show their responsiveness and willingness to address environmental challenges. The ability and willingness of central actors of the current mobility system is increasingly challenged, because of its increasing CO_2 emissions and its dependence on fossil fuels (Geels et al., 2012). In response to this legitimacy challenge actors started to discuss and develop new options, such as alternative drivetrain technologies.

Thus the voicing of high expectations can be understood as strategies to create, maintain or restore the legitimacy of organizations in the automotive industry. Even though organizations may not be able to adapt their behavior or performance in a way audiences expect them to do, organizations can maintain their legitimacy if they demonstrate their responsiveness to the concerns of the audiences (Suchman, 1995). Frequently, this kind of responsiveness and acknowledgement of requirements is more important than immediate results as such (Meyer and Rowan, 1977). Following this argument by Meyer and Rowan (1977) and other proponents of the strategic tradition in the study of legitimacy (see Suchman, 1995 for an overview) we conclude that organizations are conducting certain kinds of activities to show the audiences of the organization (e.g., the public or policy makers) their responsiveness, for instance by announcements to work towards the desired outcome, even though that may take time. Against this background, announcements fuelling positive expectations about clean technologies could be interpreted as a means to improve the legitimacy of the automotive industry. However, these communication efforts are sometimes not backed up by changes in the actual activities of the companies, a strategy referred to as 'greenwashing' (Wæraas and Ihlen, 2009).

Summarizing the literature above, we conclude that both are emphasizing the role of communication activities respectively discourses. Taking into account the argument of legitimacy studies that organizations try to maintain their legitimacy by showing signs of responsiveness to stakeholders and the importance of expectations shown by studies related to the sociology of expectations, we propose to analytically distinguish innovation and communication activities.

Innovation activities are activities that aim directly towards the diffusion of an innovation in a narrow sense (research, development, demonstration, etc.); in other words: the activities one would refer to as 'doing' or working on (towards) the innovation itself. By *communication activities* we refer to all kinds of communications related to an innovation. Thus, communication activities represent the 'talking or discussing' about the innovation.

To summarize, communication activities are stimulating and supporting innovation activities, but their relationship is complex and communication activities may not provide a comprehensive view or be the best indicator of innovation activities in a narrow sense. For a firm, there may be incentives to communicate intensively about green technologies to improve its legitimacy. Sometimes a gap between the discourse and innovation activities becomes apparent, when the claims and announcements made in the discourse cannot be realized. This paper aims to gain more insights in the role and nature of communication activities and in particular their relation to innovation activities in a narrow sense.

5.3 Definitions, data and methodology

This paper analyzes the relationship between innovation and discourse activities in the automotive industry, using the cases of hybrid electric vehicle (HEV) technology and fuel cell vehicle technology (FCV). In this section we will first define what we understand by HEV respectively FCV and what characterizes both technologies. Second, we elaborate on our research methodology, which encompasses a mix of qualitative and quantitative methods.

5.3.1 Definition of technology: HEV & FCV

Hybrid Electric Vehicles (HEV) are vehicles combining a conventional international combustion engine with an electric drivetrain. Therefore, HEV can be used like conventional gasoline/diesel vehicles and the battery is charged by the use of regenerative breaking. In other words: HEV are able to store the energy that is otherwise lost (transformed into heat at the brakes), into their battery (Staunton et al., 2006). The vast majority of current HEV models on the market by Toyota and others do not require (or offer the possibility) to charge the battery of the HEV from the electricity grid. Thus, the operation of HEV does not require any additional infrastructure, like charging stations or battery swapping stations[92].

Fuel Cell Vehicles (FCV) are powered by a fuel cell which produces the energy necessary for propulsion, and do not require an internal combustion engine. The fuel cells itself have to be fuelled by an energy carrier, for instance hydrogen or methanol, thus the operation of fuel cells need the build-up of a new infrastructure. The on-board fuel cells produce electricity, which can be stored in an intermediate battery. The battery is used to assist the fuel cell during

[92] More recently the concept of Plug-In Hybrid Electric Vehicles (PHEV) has been proposed, which is basically a HEV with an increased battery capacity and the opportunity to charge the battery from the grid (Sovacool and Hirsh, 2009).

acceleration and to improve the durability of the fuel cell. Therefore FCV can be and are regarded (or marketed) as fuel cell hybrid vehicles (FCHV) by some OEMs, which was taken into account in our search strategies (see below). However, for reasons of clarity we will stick to the abbreviation FCV for vehicles propelled by a fuel cell in the remainder of the paper. FCV are not commercially available yet, but a relatively small numbers of vehicles are deployed within demonstration projects or on special lease contracts to selected customers only (US DoE, 2011a).

5.3.2 Quantitative methods: media data, patents

We use media attention and patent statistics as quantitative indicators to measure the level of communication respectively innovation activities

Media data: press releases

In order to measure the level of discourse activities we choose to use the number of press releases in two major channels for the publication of press releases: Business Wire and PR Newswire. Both companies describe themselves as market leaders in commercial press release distribution on a global scale (Business Wire, 2012; PR Newswire, 2012). Although media attention in newspapers has been used as an indicator in a number of studies (e.g. Weingart et al., 2002), we choose to use the number of press releases since they are a closer indicator for the communication activities of a company, than media coverage in newspapers. The articles were retrieved through the media database Factiva (Factiva, 2013). The first step of the identification of the technology specific articles was done by using the search terms 'hybrid' respectively 'fuel cell*' and its respective truncations. The search was not limited to titles or abstracts, but the whole corpus of the articles was included. In order to relate articles to a certain organisation (Daimler, Toyota) we used the Intelligent Indexing function provided by the Factiva media database. Intelligent Indexing is a proprietary taxonomy structure provided for all articles in the Factiva media database. It assigns every article (or press release in our case) to a company, taking into account not only the company name itself but as well quoted subsidiaries and key unquoted subsidiaries (see Factiva, 2012; Sykes, 2003)[93]. Therefore a search using for instance 'Daimler AG' as the chosen actor will also yield articles related to subsidiaries of the Daimler Corporation. In addition we measured the coverage of the respective technology in three major newspapers (New York Times, Washington Post, Wallstreet Journal) to compare

93 A detailed list of codes and criteria for coding is available at http://factiva.com/content/indexing/indexing2.asp

the communication activities of Toyota and Daimler to the uptake of these communication activities in the general press.

Patent statistics

We used patent statistics as an indicator of innovation activities. Despite of its limitations, patent statistics remain an important and widespread used information source to obtain information about innovation activities, in particular in sectors where innovation activities are highly confidential as in the automotive industry (Frenken et al., 2004; Hekkert and van den Hoed, 2004; Järvenpää et al., 2011; Oltra and Saint Jean, 2009b; van den Hoed, 2005). Nevertheless patents may not capture all innovation activities; Among the limitations of patent analysis is that patent applications are potentially part of a deliberate patent strategy, and not all inventions are patented (OECD, 2009), for example in order to keep them secret from competitors (Kleinknecht et al., 2002; Zuniga et al., 2009). Moreover, we are aware that some technologies provide more opportunities to patent than others and patent classes are not directly comparable since some have a broader coverage than others, thus the total numbers of patents cannot be compared between HEV and FCV (Archibugi and Planta, 1996). Moreover the patent intensity may differ between countries, with some countries like Japan having traditionally a higher patent intensity than the US (Cohen et al., 2002). However this paper focuses on the dynamics of patent activities in relation to communication activities rather than on counting patents and comparing the innovation activities between the two technologies. The patterns can be compared for Toyota and Daimler, as earlier studies indicate that the patenting strategies of these companies are similar although their technological focus differed in the past. (van den Hoed, 2004, 2005) We used the Espacenet database provided by the European Patent Office (EPO), which encompasses more than 70 million patents from 90 countries worldwide (EPO, 2011). We followed the patent search strategies for environmental-related technologies proposed by the OECD which specifies relevant patent classes for specific technologies (OECD, 2011). To identify fuel cell related patents we used the proposed patent classes 'Fuel Cells' (Y02E60/3*) and 'Hydrogen Technologies' (Y02E60/5*) and the patent class 'Technologies specific to hybrid propulsion' (B60K6 and B60W20) for HEV technology. Furthermore 'Daimler*' respectively 'Toyota' were used to filter the relevant patents. The time lag between research activities and patenting was minimized by the use of the priority date to assign a certain patent to a specific year.

5.3.3 Qualitative methods: interviews, discourse analysis

To understand the nature of the relation between communication and innovation activities we draw on the qualitative analysis of semi-structured interviews with decision makers in the automotive industry and qualitative analyses of media articles. In the period from 2007 – 2009 we conducted *31 semi-structured interviews* with key actors in the field of alternative drivetrain technologies: The interviewees include employees of car manufacturers (8); other industry actors (supply companies, pioneer users – such as fleet operators: 7), scientists (universities, research centers: 8), policy makers (public agencies/ministries: 5), and others (venture capitalists, consultancy companies: 3). The interviewees were identified during the discourse analysis and through the snow ball method (Atkinson and Flint, 2001). In order to allow the interviewees to speak relatively open, they were guaranteed confidentiality and the reference section of the paper only states the general position of the interviewee, and the date and place of the interview. Although interview data can be biased due to impression management or retrospective sense making by the interviewees, interviews are a highly efficient way to gather relevant data (Eisenhardt and Graebner, 2007). In order to limit this potential bias we interviewed experts from different hierarchy levels whereas most of the data in particular in the case of Toyota were in senior/top management positions at the time when the first HEV vehicles at Toyota were developed. This data was gathered during a series of workshops (Japan, Sweden, USA, and Germany in 2008/09) organized within the context of an International Energy Agency (IEA) task force scrutinizing the development of electric and HEV in the 1990s.[94]

A *qualitative discourse analysis* of the press releases (see section 3.3) provided insights into the content and dynamics of statements made by the actors. The analysis was supplemented by public media sources, such as newspaper articles, policy debates and engineering journals. The qualitative analysis enables and supports the interpretation of the results. Furthermore additional information is required to understand the rationales of the actor strategies. Some of the most relevant interview data was gathered through interviews with retired employees who could speak in a rather free manner. However, the names of the interviewees remain confidential by mutual agreement.

[94] IEA Implementing Agreement on Hybrid and Electric Vehicles: Task 14, Market Deployment of Electric Vehicles: Lessons Learned

5.4 Empirical findings

The empirical analysis consists of an analysis of the communication and innovation activities of Toyota regarding HEV technology and Daimler concerning FCV technology. The innovation trajectories of those two technologies have evolved completely different; while HEV are available for purchase on the market and sold in meaningful numbers (cumulated sales 1999 – 2010: 1,9 million vehicles, (US DoE, 2011b)), fuel cell vehicles are currently only deployed in research or demonstration projects and not yet available for regular customers.

5.4.1 HEV & Toyota: Innovation and Discourse patterns

In 1997 the *Toyota Prius* was the first HEV introduced on the market in Japan. Three years later, in 2000, the Prius became available in the US and some other countries. Honda followed with the development and introduction of its hybrid model *Insight* in 1999 (the first to offer a HEV in the US), and Ford with several models including the sports-utility-vehicle *Ford Escape hybrid* in 2004. In subsequent years, most major car producers developed and marketed HEV with different configurations. In 2011 there were HEV from Toyota, Honda, Ford, GM, Nissan, BMW, Hyundai and Volkswagen for sale in the US, and cumulative sales in the US from 1999 to 2010 were 1.9 million vehicles (US DoE, 2011b). Toyota was and still is the industry leader in HEV technology and sales (Nonaka and Peltokorpi, 2006; Pohl and Elmquist, 2010). Despite the fierce competition from other car manufacturers Toyota maintained a market share of 69% of all HEV sold in the US in 2011, followed by Ford and Honda with approximately 12% each (US DoE, 2011b). The remainder of this section focuses on the history of HEV technology at Toyota, the technology and market leader in HEV technology.

Within the Toyota company discussions concerning sustainability and the future need to reduce the environmental burden of cars started in early 1992. In response to the 1992 'Earth Summit'[95] conference in Rio, Toyota's top management introduced guiding principles emphasizing the role of forest management, conservation, and sustainable development. Based on these guiding principles the Toyota Earth Charter was drafted, which states the policy and guidelines of the company on how to achieve a more sustainable business, emphasizing the importance of more efficient vehicles (Expert 1; Hino, 2005; Toyota, 2012).

[95] United Nations Conference on Environment and Development (UNCED), Rio de Janeiro, Brazil, also known as 'Earth Summit" or 'Rio conference".

Furthermore, the Low Emission Vehicle (LEV) program that was introduced in California in 1990 (see Collantes and Sperling, 2008; Kemp, 2005), which would have eventually required automotive companies to achieve an increasing share of LEV and Zero Emission Vehicles (ZEV) of their overall sales in California, caught the attention of Toyota's management. The implementation of the LEV program and further discussions concerning future regulations added momentum to the debates on more environmentally friendly technologies within the company. One option that was considered was to avoid the high costs of developing new technologies and to eventually pay fines in case future regulations would require more environmentally friendly technologies. However, this option was abandoned since it was not in line with the overall strategy defined by the Toyota Earth Charter (Expert 1; Expert 3). Furthermore, management aimed to give Toyota the image of a 'green brand', and this required compliance with environmental regulations and. As a result, Toyota management decided to develop more environmentally friendly technologies (Expert 3).

At that point it was not clear if battery electric vehicles (BEV), fuel cell vehicles (FCV) or HEV were the most promising technology. Technology assessment exercises for the different technological options were conducted in the early 1990s, and in 1994/95 the outcomes were presented to the top management. Toyota decided that HEV technology was most promising and that HEV development activities should be intensified (Expert 3). More specifically, in late 1995, Toyota decided to develop the Prius model and initially planned to start serial production in 1999 (Expert 1). Later on, top management shortened the research and development time and ordered that the Prius should already be presented in 1997, when the Kyoto conference[96] on climate change took place in Toyota's home country, Japan. Although Toyota was known for its relatively short development cycles in the industry, this decision was highly risky and experts were skeptical if it would be possible to develop the Prius within this timeframe (Expert 1; Expert 3). Concerns especially focused on the feasibility of the development of the control system and the battery within such a short time frame (Expert 3). Despite these concerns Toyota and its suppliers managed to present the Prius in 1997 and it turned out to be a huge success, compared to the initial expectations within the Toyota R&D team (Expert 1). The Prius model played a decisive role in pioneering HEV technology at Toyota and beyond.

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96 Conferences of the Parties (COP) 3 in Kyoto, generally known as the 'Kyoto conference".

Figure 15 shows the quantitative indicators describing the innovation and communication activities of Toyota. More specifically, it shows the total number of PR articles (as an indicator of communication activities) and the total number of patents applied for by Toyota with regard to HEV technology (as an indicator of innovation activities). Patenting activities started already in 1991 at a small scale, and subsequently increased in 1993 and 1994 to 28 respectively 33 patents. At the same time press coverage was limited with only a few articles from 1990 to 1995. After the decision to develop the Prius in 1995, the number of patent application increased sharply to 122 patents in 1996. Concerning the communication activities it is remarkable that no press release concerning the development of a HEV could be identified prior to 1997, when the first releases occurred, which were mostly related to the market introduction of the Prius in Japan. However, communication activities remained modest with less than 10 press releases per year until 1999. A similar pattern can be observed with regard to the press coverage of HEV technology in general. Moreover, as Toyota was modest concerning the content during that time. Most press releases mentioned the market introduction of the Prius in Japan. Market introduction in the USA was announced 'after observing consumer reaction and performing further evaluation in Japan' and 'as early as possible, and before the end of this century' (PR Newswire, 1997), which was slightly delayed but confirmed in the following year by Toyota President Okuda (PR Newswire, 1998a). In addition a number of press releases announced ride and drive events for the motor press and selected customers prior to the official market introduction in the US (e.g. PR Newswire, 1998b). Although Toyota was praising the advantages of HEV technology, there was hardly any revolutionary rhetoric and many press releases regarding HEV technology were mentioning the potential of full electric vehicles (PR Newswire, 1997).

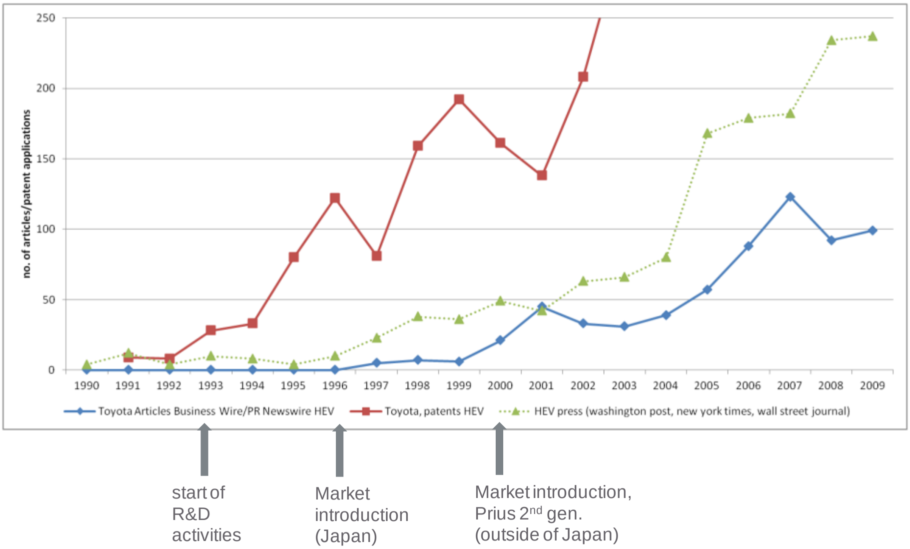

Figure 15: number of HEV patents and PR articles per year[97]

The communication activities by Toyota itself increased sharply from the year 2000 onwards; the time of the market introduction of the Prius in the US. That can be explained by the use of our databases focussing on the US. However, a similar pattern concerning the communication activities can be found in Japan, where HEV technology was hardly mentioned in the press prior to the market introduction of the Prius in 1997[98]. After the global rollout, innovation and communication activities generally increased until 2007, with some decrease in 2008 and 2009. Patent applications were still rising in recent years indicating the further development of HEV technology.

To conclude, Toyota started its innovation activities prior to its communication activities. The database contains no press releases by Toyota before the market introduction of the Prius. A similar picture holds true for Japanese media, where hardly any newspaper articles related to HEV technology were published before the market introduction of the Prius. Communication activities substantially increased in conjunction with the market introduction of the Prius in the US.

97 To maintain clarity and visibility the y – axis is limited to 250 patent applications per year. Otherwise it would be hardly possible to recognize the pattern in earlier years due to the large increase in patent applications from 2001 onwards . The number of patent applications for the years not visible in figure 1 are 607 (2005), 841 (2006), 1209 (2007), 1148 (2008).

98 A media analysis presented by Akiteru Maruta during an IEA meeting (26.05.2008) revealed that hybrid vehicles were only mentioned 11 to 23 times per year from 1991 to 1996, and 356 times alone in 1997 in five major nationwide newspaper in Japan (Nihon Keizai Shimbun, Yomiuri, Asahi, Mainichi, Sankei).

5.4.2 FCV & Daimler: Innovation and Discourse patterns

In contrast to HEV technology, FCV technology is not yet commercially available. However demonstration projects exist in Europe, USA, Japan, Korea and China involving most of the large car manufacturers (Bünger et al., 2010). Fuel cell technology has already been through several hype disappointment cycles: Whereas expectations initially were highly optimistic and a market introduction was already announced for the early 2000's these positive expectations subsequently turned into disappointment (Bakker, 2010; Bakker and Budde, 2012). The remainder of our description focuses on Daimler, generally described as the fuel cell pioneer in the automotive industry (Aigle et al., 2007; Bakker, 2010; van den Hoed, 2005; Weider et al., 2004). In the 1990s, Daimler focused its research on alternative propulsion technologies mostly on fuel cells (Expert 6; van den Hoed, 2004) and it was the first major car manufacturer presenting prototypes of fuel cell vehicles, after the initial fuel cell experiments by General Motors (GM) in the 1960s in the USA.

In 1994 Daimler presented its first prototype *NECAR I* (New Electric Car, but also referring to the Neckar river near Daimlers headquarter in Germany) triggering large interest in the technology. With the presentation of these prototypes, in particular the following NECAR II which demonstrated a large progress compared to former prototypes, Daimler generated optimism and high expectations about fuel cell technology (Expert 6; Expert 9). During the 1990s Daimler made several announcements of the market introduction of relatively large number of vehicles (up to 100.000) within a short time frame. It was announced that the first commercial vehicles would hit the market until 2004 (see for instance Jürgen Schrempp, Chairman of the Board, Daimler Chrysler, The Economist 22.03.1999). However, no fuel cell cars by Daimler or any other manufacturer have been introduced on the market as of the beginning of 2013. Nevertheless, a number of car producers including Daimler and Honda are deploying smaller series of fuel cell vehicles (up to several hundred) to selected customers in order to test them and gain data about FCV in real world conditions (Bünger et al., 2010).

Figure 16 shows the selected quantitative indicators for the case of Daimler. It shows that Daimler's first patent application regarding FCV technology was in 1991. Subsequently, the patenting activities increased from 7 to 13 applications annually between 1993 and 1996. This pattern matches with qualitative information concerning the start of R&D activities and the presentation of the first prototypes in this time period. The level of communication activities remained very low with only one press release annually until 1997. From 1999 to 2001 we observed a modest increase in patent activity with around 20 to 30 patent applications every year, while the communication activities were intensified. Starting from only four press releases in 1998 this number increased to 10 to 20 press releases annually in the period 1999 to 2001. In 2002, both innovation and discourse activities rose to 65 patent applications and 56 press releases. After this peak in 2002, both innovation and communication activities decreased. Whereas the level of communication activities decreased even further during the subsequent years, the number of patent applications rose again to the peak level of 2002.

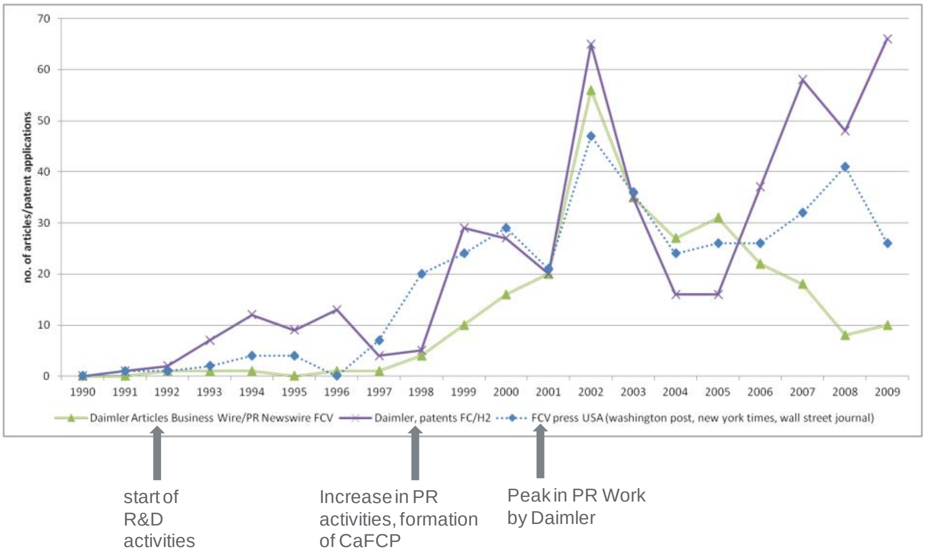

Figure 16: number of FCV patents and PR articles per year

FCV coverage in the three major newspapers developed similar to the pattern of Daimler’s communication activities with high levels of coverage from 1998 onwards and a peak in 2002.

Although the total number of patent applications cannot be compared directly between the case studies, due to the different underlying technologies and potential differences in the general patentability (see Chapter 5.3), the analysis of the temporal dynamics and relation of both indicators reveals some important differences between FCV and HEV. In the case of FCV we observed that innovation and communication activities exhibited similar patterns during the period 1990-2005. Daimler started its FCV communication activities already in the late 1990s and intensified them from 2000 until the peak in 2002. Daimler was already undertaking communication activities during the R&D period, while Toyota only started its HEV communication activities at the time of the market introduction of the technology.

In summary, Daimler's FCV communication activities co-evolved with FCV innovation activities. Thus we observe a different relation between innovation and communication activities in the two cases. In the following we will analyze and compare the rationales behind these patterns.

5.4.3 Comparative analysis of the two cases

This section compares both cases and scrutinizes the reasons for the differences identified in the previous section. The analysis of Toyota's HEV strategy showed an intensification of innovation activities, and no communication activities before the market introduction. Communication activities started just shortly before the market introduction of HEV technology in Japan. A major increase of communication activities took place in conjunction with the market introduction in the US. Most press releases were related to the market introduction of the Prius and emphasized the advantages of the new technology in general and of the Prius in particular and Toyota was not creating attention for its HEV technology before the market introduction. In the case of FCV and Daimler we observed that the communication activities co-evolved with the innovation activities. Daimler already engaged in communication activities several years before a potential market introduction. Daimler thus pursued a different strategy for its FCV communication activities than Toyota did in the case of HEV. We will argue that this discrepancy is related to the different technological characteristics of the two technologies: While HEV are note dependent on new infrastructure to operate them, FCV rely on a completely new infrastructure. We argue that Toyota had no incentive to create attention and positive expectations already years before the actual market introduction was planned. The successful introduction of HEV did not require widespread optimism about the potential of the technology in order to mobilize other actors (outside of the supply chain), to develop components or services in order to be able to operate HEV. On the contrary, in a highly competitive industry like the automotive industry, it contributes to competitive advantage if R&D activities are kept secret as long as possible. Although positive expectations about the technology help to generate demand for the technology, it appears sufficient when these expectations are raised around the time of the market introduction.

From the interviews it becomes apparent that the incentives were different for Daimler. Daimler was developing different types of FCV which could be fuelled by hydrogen or methanol, however the latter was given up later due to technical problems and a lack of commitment by the oil industry and other car producers (Expert 5; Expert 7). The build-up of a hydrogen infrastructure requires large investments and a coordinated effort by various stakeholders (BMW Group et al., 2006; HFP Europe, 2007; HyWays, 2008; US DoE, 2001). Due to the technological and organizational complexity of FCV and the required infrastructure, Daimler's management regarded it as essential to mobilize several stakeholders to join the efforts.

'The development of such a technology [fuel cells] cannot be managed by a single car manufacturer […] [Thus] we had to find partners in order to have a large enough momentum to get states, energy companies and other automotive companies on board. It is necessary that many others join to achieve a technology change. However Daimler has to stay in the leading position.' (Expert 6, translated from German)

Thus Daimler as a pioneering company was dependent on the support of other stakeholders and needed them to join the race. Therefore Daimler was confronted with a situation in which incentives were given to raise positive expectations about fuel cells. In this period Daimler managers gave very optimistic statements concerning the future deployment of FCV. Asked for the background of these optimistic statements one of our interview partners stated:

'I thought it [the fuel cell commercialization] would go faster […]. Second, you had to fly your flag in order to get some people together. […] Thus, we said, in order to get some attention, that we can imagine to produce 25 000 cars by 2004. However we really had the hope [to achieve that], since we were really satisfied with the performance of the technology. It was time to reduce costs and to extend reliability. We had a really nice plan for that, therefore we announced that number [25.000 vehicles by 2004]. It had an effect, it was positive. Daimler showed the way and everything was very optimistic' (Expert 6, translated from German)

These statements indicate that Daimler was following the incentives to spur optimistic expectations about fuel fell technology to raise awareness and mobilize other actors. Eventually this strategy was relatively successful in motivating other car producers and policy actors to engage in the field of fuel cell technology. Other car producers intensified their activities in the field, at least partly, motivated by the momentum which was caused by Daimler's activities (Expert 6; Expert 8; Expert 9).

'And there was a strong sense of competition [in the industry]. When one automotive manufacturer says that it will change the whole automotive world in five years, the others are listening carefully. And I think this impulse was necessary to convince almost the whole automotive industry that this technology [fuel cells] is the right one in the long term' (Expert 10, translated from German)

Furthermore Daimler was able to mobilize some policy support:

'The [subsequent] policy programs did not evolve independently from the automotive industry. It is always the case, that they are emerging from discussions with those, who are supposed to be supported. And of course it [the communication activities by Daimler] were important to raise the willingness of politics to join. And on the long term it [fuel cell development] doesn't work without policy support, industry alone is not enough' (Expert 9, translated from German)

However, as other interviewees point at, it was only possible to motivate other actors, since expectations about fuel cell technology were rather optimistic within the Daimler company (and its subsidiaries developing fuel cell components) and the fuel cell community as such. An engineer involved in the development of FCV at another large car manufacturer summarized it as following:

'[…] Nobody [of the engineers working on FCV] really believed it [market introduction of FCV] would happen in 2004, however hardly anybody working within the topic, was believing that it would happen so late.' (Expert 9, translated from German)

To conclude, the positive expectations about fuel cell technology, and its market introduction within a relatively short period of time, were largely triggered by the optimistic statements made by Daimler representatives during a period of rather optimistic expectations about FCV in the fuel cell community and the automotive industry in general. Daimler managers raised expectations about FCV in order to mobilize other actors to join the innovation race, since they realized that a complex technology such as FCV could not be developed and deployed by a single car manufacturer.

We argue that the differences we found in the analysis of communication and innovation activities cannot be explained by cultural differences between Toyota/Daimler respectively Germany/Japan. Although a number of car manufacturers (e.g. GM, Ford, Chrysler, Volkswagen) developed HEV in the early 1990s, none of them conducted intensive communication activities concerning

HEV during that time, as can be seen from the total number of HEV articles in the press. Furthermore we checked the number of press releases from the automotive industry, which exhibit a similar pattern to Toyota's communication activities. Relatively few articles during the 1990s and a steep increase from the year 1999 onwards Although a number of press releases were launched during the early 1990s concerning HEV these statements were rather modest and mostly discussing HEV as a side issue to EV development. HEV technology was framed by the car manufacturers, which presented and produced a small number of HEV (GM, Volkswagen, Ford) already in the early 1990s, as one option among several others (PR Newswire, 1991a, b). Thus even though other car manufacturers from Europe and the US developed HEV, none of them conducted intensive communication activities concerning the technology.

5.5 Conclusions

This paper discusses the relationship between innovation and communication activities in the automotive industry. The analysis shows the strategic character of communication activities, but also points out the need for a technology-specific interpretation.

The comparison between HEV and FCV technology reveals that the underlying characteristics of the specific technology have an influence on the relation between communication and innovation activities. Whereas it has been shown that actors with a stake in a certain technology have an incentive to voice optimistic expectations about the technology since that will facilitate the mobilization of resources fur further innovation activities, this paper shows that these incentives can differ considerably between different technologies in the same sector.

The most remarkable difference between HEV and FCV is the complexity in technology and infrastructure development. While HEV are not dependent on the build-up of a new infrastructure, the operation of FCV would require the development of a dedicated infrastructure. Furthermore the development of FCV also requires new modes of cooperation between actors from different fields. A variety of actors is necessary to finance the development and build-up of a completely new system encompassing the vehicle and the infrastructure. Therefore Daimler, as a pioneering company and in particular the fuel cell division of Daimler, had a strong incentive to raise expectations in order to motivate other actors (other automotive companies, energy industry, policy) to join their innovation activities in the field of fuel cell technology.

Promises and positive expectations about a technology are probably necessary to mobilize actors and resources with regard to almost all innovation activities. However, in case of HEV and Toyota these processes probably took place within the company and its suppliers. In the case of Daimler, the positive expectations about FCV technology also had to be expressed outside of the company in order to motivate and coordinate external actors due to the complexity of fuel cell technology. Cultural differences may play a certain role to explain these differences; however we argue that the technological characteristics are more influential, since none of the other car manufacturers developing HEV in the early 1990s engaged intensively in communication activities stimulating optimistic expectations about HEV, although they developed market ready HEVs (Wyczalek, 1999). Moreover, whereas we have not seen hype in the media concerning HEV before its market introduction, FCV were going through a strong hype-disappointment cycle. Around the turn of the millennium, almost all car manufacturers, including Toyota, raised very optimistic statements about FCV contributing to the hype (Bakker, 2010), while Toyota did not in case of HEV.

To conclude, the need to motivate and coordinate actors from different fields to develop and introduce a complex and infrastructure dependent technology such as fuel cells provides an incentive to raise or even inflate expectations. This finding indicates why complex and infrastructure dependent innovations seem to be particularly prone to strong hype disappointment cycles. as expectations have an even more important role in coordinating innovation actors. This motivating and coordinating role of expectations has been identified in the literature on the sociology of expectations before (Borup et al., 2006). However no differentiation with regard to the characteristics of the underlying technology was made, whereas we argue that more complex technologies require more (positive) expectations to coordinate innovation activities.

These insights contribute to discussions about the role of (incumbent) actors in transitions (see Farla et al., 2012). Whereas the automotive industry probably engaged, and probably continues to engage in activities which we refer to as ‘window dressing’ or ‘green washing’, this paper shows that there can be motivations to spur expectations about emerging technologies which co-exist with strategies to motivate other actors to engage in innovation activities.

However, this paper does not aim to judge if the automotive companies in focus are working towards a transition or not. Whereas probably some of the communication activities by the automotive industry were (are) aimed to delay a transition towards sustainability or not, however the main argument of this paper is that there are technology specific reasons which contribute to expectation dynamics. Therefore these technology specific incentives to inflate expectations probably supplement other motivations (maintaining legitimacy, delaying regulation, ‘green image’) which eventually culminate into hype.

Even though the rationale to showcase new environmentally friendly cars may be beneficial to the legitimacy of an automotive manufacturer and play a role in the decision to engage in communication activities, our empirical case studies indicate that the technological characteristics appeared to be more influential on the nature and timing of communication activities. Furthermore, the Toyota case shows that the company was not raising expectations prior to the market introduction of the Prius, although the company was confronted with the upcoming Low Emission Vehicle (LEV) regulation and the upcoming Zero Emission Vehicle (ZEV) mandate. Finally, from a policy perspective, our results indicate that the analysis and interpretation of hype disappointment cycles should take into account the specific technological characteristics of the underlying technologies.

6 Governing Fuel Cell Innovation in a Dynamic Network of Expectations[99]

6.1 Introduction

The emergence of new technologies is characterised by a broad array of inherent uncertainties. This holds all the more for technologies which bear the potential to trigger radical innovation. These technologies typically pose particular technological challenges and they promise to allow new ways of application, which often require the adaptation of regulatory frameworks and potentially affect established business models. In addition, new constellations of innovation actors have to emerge. In the face of these uncertainties, actors involved in innovation and governance processes have to rely on expectations rather than on robust knowledge for developing strategies and policies. Especially collective expectations, i.e. expectations that are part of a widely acknowledged social repertoire, have been shown to be particularly influential (Borup et al., 2006; Konrad, 2006b; Raven et al., 2008). Collective expectations act as provisional, and in that sense tentative, but forceful assumptions on the future potential and requirements of an emerging technology, and thus constitute a core element in the governance of innovation processes (Borup et al., 2006). The important role of expectations is also acknowledged by approaches dedicated to governing radical innovation processes, such as transition management and strategic niche management (Geels et al., 2008; Geels and Raven, 2006; Raven et al., 2008; Sondeijker et al., 2006). However, collective expectations often develop quite dynamically, up to sudden changes, due to developments within a technology field, as well as external developments in related sectors or competing technologies (Borup et al., 2006; Geels and Raven, 2006; Konrad, 2006b; van Lente, 1993). The highly dynamic evolvement of expectations creates challenges for related governance processes, which have to deal with the dynamics and tentativeness of expectations, either ex post when expectations have changed, or ex-ante, when possible future changes in expectations are taken into account in the set-up of governance measures. Thus, governance itself may become tentative in the sense outlined by Kuhlmann et al. (in preparation), either as de-

[99] This Chapter is the result of joint work with Kornelia Konrad and submitted to a special issue 'Getting hold of a moving target - the tentative governance of emerging science and technology (working title)", Research Policy to be published as Budde, B, Konrad, K., Governing Fuel Cell Innovation in a Dynamic Network of Expectations.

facto tentative when flexibility is the outcome, or in a purposeful manner, when flexibility is actively sought.

Against this background, this article investigates how expectations on fuel cell technology developed in the German policy arena, taking into account expectations on the technology and its applications, as well as on further influential developments, e.g. related sectoral dynamics. Moreover we consider how these expectation dynamics affected the governance of the field and how governance processes and structures dealt with the uncertainty and changes in expectations. We focus on Germany, one of the highly active countries in fuel cell innovation, in the time period 1994 to 2011 (Neef, 2009). In this period fuel cell expectations were changing considerably: At the turn of the millennium many expected fuel cell technology to become widely implemented within a few years from then, for propulsion of vehicles, as combined heat and power systems at the household level (micro CHP), or as highly efficient replacements of conventional power stations. A number of companies announced the market introduction of fuel cells within the first half of the 2000s (Bakker, 2010; Ruef and Markard, 2010), and policy programmes to support the technology were initiated around the globe (Bernay et al., 2002; Neef, 2009). However, fuel cell technology did not live up to these optimistic expectations and the hype around fuel cell technology turned into disappointment (Bakker, 2010; Sperling and Gordon, 2009). In the second half of the 2000s, expectations about battery electric vehicles became increasingly optimistic, putting additional pressure on fuel cell expectations (Bakker, 2010; Bakker and Farla, 2015; Sierzchula et al., 2012). In Germany, actors with stakes in fuel cell technology managed to translate fuel cell expectations into stable support structures, which were maintained - though adjusted – in times when battery electric vehicles were generally expected to be more promising. This is in contrast to other countries, e.g. the Netherlands or the US, where fuel cell technology rather disappeared on the policy agenda, or was at risk to receive considerably less funding after the hype (Bakker et al., 2012; Sperling and Gordon, 2009; Tollefson, 2010).

Conceptually, this paper draws on two bodies of literature: the sociology of expectations (Borup et al., 2006) and the multi-level perspective of transition studies (Geels, 2010; Geels, 2002). Both literatures have shown the importance to consider different levels of, on the one hand, expectations and, on the other, 'real-world' processes, to understand the complex dynamics of innovation, up to broader sectoral transition processes (Geels, 2002; van Lente, 1993). Building on this, we develop a conceptual framework for the analysis of interrelated visions and expectations – networks of expectations. Based on this framework, we analyse how visions and expectations related to different levels, such as a technology field, sectoral developments or broader societal trends, developed and influenced each other over time in the German policy discourse on fuel cell technology. Empirically we draw on a discourse analysis of German policy documents from 1994 to 2011, complemented by expert interviews.

Thus, the main research question of this paper is: *To what extent can the dynamics of fuel cell expectations and visions in the German policy discourse be explained by changes in the broader network of expectations and how have these dynamics affected policy support for fuel cell technology?*

With this paper we want to (a) contribute to a better understanding of the dynamics of expectations, which takes into account the complex interactions – or co-evolution – of collective expectations, and (b) we want to explore how policy responds to these dynamics in more or less tentative manners.

The remainder of this paper is organized in 5 sections: First, we present the theoretical background, and develop our concept of networks of expectations. Subsequently, we present the methodological approach, followed by an analysis of the German policy discourse regarding fuel cells and if and how these triggered or legitimated governance measures, be it in the form of regulatory measures, support schemes or further dedicated articulation of expectations. Finally, we conclude our main findings and discuss if and in which sense the German fuel cell policy can be characterized as tentative.

6.2 Conceptual background

Expectations are specific assumptions about future developments or states, which are assigned a certain likelihood. Whereas in the sociology of expectations, expectations are often confined to 'real time representations of future *technological* situations and capabilities' (Borup et al., 2006, p. 286), for the purpose of this article we reopen the scope of expectations to be considered to real time representations of future situations. We take into account non-technological expectations, because expectations concerning the future socio-economic environment or the institutional framework conditions can have a major influence on the technological innovation itself (Budde, Weber, et al., 2012; Geels and Raven, 2006), and technological and other expectations may be closely linked. Expectations are frequently used in combination with the related concept of visions, causing ambiguity about commonalities or differences between the two concepts. Thus we define a vision as a *coherent set* of possible future states and developments. Furthermore, visions often have a normative connotation, for instance as imaginations about a desirable future (Berkhout, 2006; Eames et al., 2006). If visions are assigned a certain likelihood, they can be considered as – a specific type of - expectations as well. In this article, we are predominantly concerned with expectations which circulate within certain discourses and which have become part of a common repertoire, up to being widely accepted within a discourse, thus turning into collective expectations.

Expectations and visions are a major driver of innovation activities. Although from different backgrounds and perspectives, a number of literature strands, such as science and technology studies, institutional theory, strategic niche management, foresight studies and innovation economics have scrutinized the role of expectations and visions for innovation processes (Barney, 1986; Borup et al., 2006; Geels, 2004; Kemp et al., 1998; Rosenberg, 1976, 1995; Sondeijker et al., 2006; Swanson and Ramiller, 1997; van Lente and Rip, 1998). Some of these focus on the management of innovation in organisations, whereas our particular interest resides with the governance of innovation at the level of innovation fields. Hence, we focus on two, partly overlapping bodies of literatures related to science and technology studies, which discuss the relation between expectations and the governance of innovation: The literature on transition studies (Geels et al., 2008) and the literature on the sociology of expectations (Borup et al., 2006). The literature on sustainability transitions emphasizes the role of expectations for the governance of long term transitions and particular innovations which may contribute to a transition. The sociology of expectations literature is concerned with the performative role of expectations on the one hand, and with the shaping and dynamics of expectations on the other.

Together these two strands of literature suggest a complex set of relations between expectations, innovation and the governance of innovation. The remainder of this section first discusses the insights from both strands of literature before proposing an integrated approach.

<u>Governing transitions: the role of visions and expectations</u>

The multi-level perspective analyses the development of radical innovations and major structural changes in established socio-technical systems, so-called transitions, as the outcome of processes at different levels and their interactions: the level of established socio-technical systems (regimes), of protected spaces, where radical innovations which are difficult to integrate in established regimes can develop (niches), and the level of broader societal developments, influencing the development of regimes and niches (socio-technical landscape).

The multi-level perspective and, in particular, related governance approaches like transition management and strategic niche management emphasize the crucial role of expectations and visions in guiding and coordinating transitions (Geels et al., 2008; Späth and Rohracher, 2010). Strategic niche management regards the alignment and successive articulation of expectations and visions as one of the three key processes for the successful development of a niche (Geels and Raven, 2006; Hoogma, 2000, p.86). The development of such niche-related expectations has been shown to be influenced both by learning processes within the niche, as well as by niche-external developments in related sectors or competing technologies (Budde, Weber, et al., 2012; Geels and Raven, 2006).

Within the transition management approach, vision building processes are key to develop visions in order to guide transition processes (Späth and Rohracher, 2010). However, the dedicated construction of a guiding vision has also been criticized by others as either not likely to be forceful enough, or prone to be captured by particular interests (Berkhout, 2006; Schot and Geels, 2008). While visions can be the result of dedicated vision-building processes and may remain confined to limited circles of actors, they may also be taken up or emerge in discourses and turn into 'collective' visions, thus becoming part of a widely acknowledged discursive repertoire. Still the challenge remains that these visions are often 'moving targets', showing ups and downs and changes in meaning.

Several studies of past transitions have been performed, which allow to identify the eventual outcome of a transition by hindsight (Geels, 2002, 2006; Hofman and Elzen, 2010; Raven, 2004; Verbong and Geels, 2007). It is, however, considerably difficult to identify – and even less so to predict – specific transition processes ex-ante, since ongoing transformation processes may or may not result in fundamental transitions. Moreover they may unfold into different directions and multiple transition processes may interrelate (Konrad et al., 2008). Sustainable transitions have been described as open-ended and uncertain processes, which create a tension with ambitions to govern them (Frantzeskaki et al., 2012). In addition, the different visions and expectations circulating in discourses might appeal to different actor groups, making it difficult to identify a single guiding vision (Budde, Weber, et al., 2012). Especially technologies considered important in sustainable transitions are often embedded in several diverging visions of projected transitions in the discourses that provide legitimacy and guidance to the actors involved in the transition process (Raven and Verbong, 2007). A single technology may thus link up with different visions of projected transitions, due to diverging normative considerations about what would be the most desirable transition, as well as to the inherent uncertainty of the on-going transformation processes (Farla et al., 2010). As a result, the embedding of expectations about a technology in a specific vision is frequently only tentative and may change over time. The changing linking of expectations about a specific technology to broader economic or societal challenges on the one hand, and the necessity to deal with dynamic, potentially inflated technological expectations on the other, creates challenges for governance about how to deal with these dynamics and uncertainties.

Expectations in innovation

As has been shown in various studies, expectations, in particular widely acknowledged collective expectations, play a key role in mobilizing, legitimating, guiding and coordinating innovation activities and consequently in the governance of new and emerging technologies (van Lente 1993; Borup et al. 2006; Konrad et al. 2012; Budde et al. 2012). At the same time expectations are themselves shaped, coordinated and mobilized, and in this sense governed in various ways by diverse actors, be it in rather formalized procedures as technology assessment or roadmapping exercises, or in the form of contributions to public and other discourses by publications, talks etc. (Konrad, 2010; McDowall, 2012). To understand the role of visions and expectations for innovation processes, Van Lente and Rip (1998) suggest to interpret expectations as ‘prospective structures’, since expectations about future social structures may function in a similar way as if they had materialized already, and they may eventually result in self-fulfilling prophecies. Thus, expectations have a mediating role between actors and structure. Actors try to shape expectations (prospective structures), which may eventually have an impact on the real structures (van Lente and Rip, 1998). It has been emphasized that struggle and power relationships play an important role in the shaping of these prospective structures; actors try to ‘colonize the future’ by articulating expectations corresponding to a future desirable from their perspective (Berkhout, 2006; Brown et al., 2000). Thus discourses about the future reflect the contested nature of expectations with diverging and often opposing perspective on the future stated by different actor groups, since discourses are crucial in the mediation and shaping of expectations (Konrad, 2006b; Wyatt, 2000). To conclude, expectations interpreted as ‘prospective structures’ have a key role for the guidance of a field and are pre-structuring future developments. Therefore actors engage in the discourse to actively shape prospective structures. Since discourses are key for the shaping of expectations, and thus the prospective structures, they provide the opportunity to study the emergence of future structures through discourse analysis.

As shown by several studies, actors may consciously stimulate or even inflate expectations about a technology they have stakes in (Brown et al., 2000; Budde et al., 2015; Petersen, 2009). This tendency, as well as possible learning, e.g. about unexpected hurdles, and changes in the environment of an innovation field (see above) contribute to the dynamics of collective expectations, with phases of quickly increasing and spreading expectations, up to hype, phases of disappointment and shifts in what is considered as most promising options at a time (Alkemade and Suurs, 2012; Bakker, 2010). As an implication, while potentially becoming a quite forceful element in the governance of innovation, as indicated in the concept of prospective structures, collective expectations are likely to fulfil this role only tentatively.

So far, studies in the sociology of expectations have focused on the role and dynamics of expectations among researchers, industry actors, or in media discourse. Although many activities are aimed to mobilize policy actors, policy actors respectively policy discourses have received less attention (for exceptions see Berti and Levidow, 2014; Beynon-Jones and Brown, 2011; Eames et al., 2006). This raises the question about the particular role of policy actors. In general, we expect policy actors to be rather in a position of observers and possible 'selectors' of expectations promoted by others, for instance particular innovation communities. Therefore, they are likely to follow to some extent the dynamic evolvement of expectations, though only as far as these are able to link up with policy priorities, for instance relevant societal needs. Still, certain policy actors may at times also turn into spokespersons for particular options (Bakker, 2010). Furthermore, policy may contribute to expectation dynamics, when decisions for support measures and public funding programmes can feed back on the development of expectations.

Similar to transition studies, several authors have emphasized the importance of considering multiple levels of expectations and their mutual interactions, though making slightly diverging distinctions. Mostly they refer to a level of technology- or project specific expectations, to expectations referring to the perspectives of a technology field, and to broader societal developments (Geels and Raven, 2006; van Lente, 1993). Drawing on the multi-level perspective, Truffer et al. (2008) have furthermore differentiated between expectations referring to developments at the niche, regime and landscape level.

Dynamic networks of expectations and implications for governance

Thus, both strands of literature provide insights in the complex relation between expectations and visions and innovation processes, and the governance thereof. We build on these insights and suggest a framework which, in line with Truffer et al. (2008) uses the levels of the multi level perspective (niche, regime, and landscape) not only to distinguish processes and activities, but also to classify expectations. What is more, we suggest drawing on the MLP as a heuristic for identifying possible interrelations and interactions between expectations and visions.[100] Finally, we will reflect on possible directions how governance may respond to the dynamic evolvement of expectations.

As demonstrated by a number of studies, 'real-world' niche, regime and landscape developments can support and reinforce or contradict and weaken each other leading to complex dynamics (Geels, 2002; Schot and Geels, 2008).

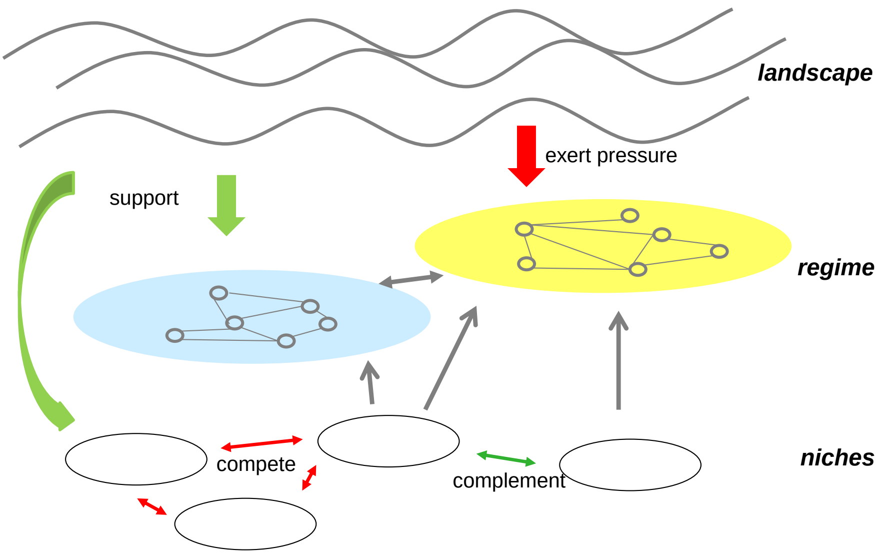

Figure 17: Interactions in the multi-level perspective

[100] Budde, B., Weber, K.M., Alkemade, F., 2012. Expectations as a key to understanding actor strategies in the field of hydrogen and fuel cell vehicles. Technological Forecasting & Social Change 79, 1072-1083. studied the relevance of visions and expectations related to the different MLP levels for actor strategies, but not how visions and expectations as such interact across levels.

In principle, the same holds for expectations and visions; expectations at the landscape level, for instance an expected shortage of fossil energy resources, may support visions and expectations at the regime level, such as the vision of an energy system based on renewable energies. Following the argumentation by Van Lente and Rip (1998), changes in the structure of the field can be mediated by visions and expectations, in the form of prospective structures which eventually lead to actual structural changes. Thus, we expect structural similarities between the patterns of interactions, of activities at different levels (e.g. niche-regime) and the interaction of expectations and visions related to different levels. Besides the one already mentioned, further patterns of interaction well-known in transition studies may occur between visions and expectations at one or different levels. Expectations regarding landscape developments may support expectations about promising niche innovations. Expectations on niche innovations may align with a specific or even with several different visions related to the future of the regime level. These can be competing visions on potential transformations of a specific regime, or visions regarding different regimes the innovation may align with. The latter corresponds to interactions and dynamics of multiple regimes as described by Konrad et al. (2008) and Raven and Verbong (2007). Finally, expectations on different niche innovations may compete or support each other, comparable to real-world multiple niche dynamics. Accordingly, the relations between these visions and expectations can be analysed as a *network of expectations* with a vertical and a horizontal dimension. On the one hand, there may be linkages and interactions between visions and expectations related to niche, regime and landscape level (vertical), on the other hand, linkages and interactions of visions and expectations occur at the same level, such as complementary or competing niche expectations and regime visions (horizontal).

While we expect to see similarities in the ways expectation networks and 'real-world' processes interact, it is important to consider the differences as well. Certain 'real-world' states or processes constitute structural, constraining or enabling conditions for other 'real-world' processes, in particular at lower levels. Expectations as 'prospective structures' may work as a sort of functional equivalent to structural constraints, but need to be perceived as such, so will hardly work as hidden structure. Furthermore, in general 'prospective structures' will be more fragile and destabilize more easily – thus exhibiting a high degree of policy tentativeness may be required to cope with uncertainty. This can for instance be seen in the case of strong hype-disappointment cycles and the sometimes very sudden destabilizing of certain expectations if related expectations and visions, which so far created a protected space are shifting

(Konrad, 2006). Furthermore, the fact that competing ‘prospective structures’ can co-exist simultaneously, has no straightforward equivalent in the real-world. Thus, while we assume that the multi-level analogy is helpful for identifying dynamic processes within expectation networks and relating them to real-world processes, there are also limitations of the analogy.

Exactly these ‘limitations’ - uncertainty and contestedness about which expectations and visions to embrace, and the possible changes over time – open the question of how governance may respond to them. One possibility would be to adjust governance when changes in expectations, learning or other new insights occur. Adaptation of guiding visions or more concrete options pursued is advocated within the transition management approach, as a means to respond to the open-endedness and uncertainty of sustainability transitions (Frantzeskaki et al., 2012; Kemp and Loorbach, 2006; Kemp, Rotmans, et al., 2007). This requires, however, that there is sufficient flexibility to do so. A recent study on UK biofuel policy suggested that policy may also remain locked-in to former decisions. In the case investigated, policy support for first-generation biofuels had been promised, but could hardly be revised without losing credibility to key actors, even though collective expectations on first-generation biofuels had become more sceptical (Berti and Levidow, 2014). Adaptation may either happen in a reactive manner, once changes occur; an approach which can be described as de-facto tentative governance. Furthermore, governance may also be tentative in an anticipatory and reflexive way. When possible future changes in expectations and visions – or other conditions and reference points – are taken into account and governance is deliberately organized in a way that it either prepares in advance for such changes or is setup in a way that it should be able to respond to such changes if they occur, we speak of deliberate tentative governance (Kuhlmann et al., in preparation).

6.3 Data and methodology

We use the suggested framework for analysing the dynamics of fuel-cell related visions and expectations in the German policy discourse as represented in the German parliamentary documentation system. We examine how these expectations were discursively related to policy measures. We start our analysis in 1994, when fuel cells are mentioned for the first time in our sample reaching back to 1990, and continue up to 2011, covering a number of changes in both expectations and policies.

We decided to focus our analysis on the discourse in the German parliament, the *Bundestag*, which is very well documented in the ‘Parliamentary Material

Information System' (DIP, Dokumentations- und Informationssystem für Parlamentarische Vorgänge). The DIP database contains information and protocols of all activities in the German *Bundestag*, including stenographic protocols and all other printworks, such as strategy documents of the government and ministries at the federal level (DIP, 2013). While the plenary protocols, parliamentary inquiries and strategy documents represent only a part of the wider policy discourse, it allows identifying the major discourse phases and the main argumentation lines, it shows what is widely agreed or an issue of contestation, and links with debates on and decisions about policy measures become apparent.

Our discourse-based approach allows examining how expectations and visions are discursively related to policy measures, for instance legitimating certain policy measures. Moreover it is possible to identify expectations which are discursively linked to each other. Following the theoretical concept of prospective structures, previously discussed in the theoretical section, we assume that it is theoretically possible to trace actor and power relations on the discourse level, since actors engage in the shaping of 'prospective structures'. They are engaging in these processes since these prospective structures are eventually pre-determining the future structure of the field. It is however not possible to follow the policy-making process and relevant power relationships in all its facets. Accordingly, our study allows to observe only some forms of tentativity in the governance of fuel cells, for instance in the form of de-facto tentative governance (Kuhlmann et al., in preparation) when policy measures are adapted to changing expectations. Furthermore, intentional tentativity may come to the fore, if for instance the need for flexibility or reversibility is explicitly discussed in the discourse, or if uncertainties are reflexively taken into account. A more comprehensive analysis would also address considerations and steps during the policy-making process, but this is mostly beyond the scope of this paper. Still, in order to cross-check if our analysis covered the most important processes, and to learn about some of the considerations of key fuel cell actors involved in the policy process as well, we complement the discourse analysis with data from a series of semi-structured interviews conducted with key actors in the field of fuel cell technology.[101]

We created our sample by using multiple steps. Firstly, we searched for all documents assigned to the keyword/topic fuel cell ('Brennstoffzelle'), as pre-defined in the database. However, after a manual screening we had to sort out a number of documents, where no relation to fuel cells was apparent. Furthermore,

[101] These interviews mainly served to analyze the interaction between strategy-building and dynamics of collective expectations which were in the focus of a further step of our research project (Konrad et al. 2012; Budde et al. 2012).

the pre-defined keyword/topic was not available for the whole period of investigation. Thus, for the remaining years we used a full text keyword search for fuel cells including relevant truncations, followed by a manual screening of these documents.[102]

In a first step we compiled a summary of the main lines of argumentation. Subsequently, we identified expectations and visions (following the definition mentioned above) explicitly mentioning fuel cells, as well as further expectations and visions which were discursively related to them, e.g. if used for justification of fuel cell expectations. In addition, we classified them according to the level they referred to. Expectations referring to the future development of fuel cells and the surrounding socio-technical arrangement were coded as niche expectations. Expectations and visions about the future mobility or energy system were coded as regime level expectations, for instance expectations about the future role of privately owned cars in contrast to car sharing models, assumed common preferences of future car users, future emission regulations for vehicles or the role of renewable energy in the future energy mix. Expectations about relevant aggregated developments external to niches and regimes, such as climate change, the depletion of fossil energy resources or the further general economic development qualified as landscape level expectations. Subsequently we focussed on the links between expectations coded as being related to three different levels to analyse their linking and if these expectations were supporting or contradicting each other.

6.4 Expectation networks in the German policy discourse

In this section we use our framework to interpret the development of fuel cell expectations in the German policy discourse, and examine how the development of expectations related to policy measures targeted at fuel cell innovation. In particular, we examine how fuel cell expectations were linked with and influenced by expectations and visions related to future regime or landscape developments. As we will see, the dynamic development of fuel cell expectations was not only a result of processes within the fuel cell niche, but as well affected by developments

[102] The keyword used was 'Brennstoffzell*" (fuel cell*). In total 268 printworks (plenary protocols, parliamentary inquiries, legislative texts incl. drafts thereof, strategy documents, technology assessment reports, etc.) were identified as being relevant. However, the number of documents does not necessarily correspond to level of activities related to fuel cell technology, since a plenary protocol of intensive discussions counts as one document, while a parliamentary inquiry and the answer by the government are two separated documents in the database.

in related streams of expectations. Furthermore, changing linkages in the network of expectations introduced additional dynamics.

Period 1: First discussions on fuel cells (1994 – 1997)[103]

In 1994, fuel cells caught attention in the German parliament for the first time. A member of parliament raised the question how the government assessed activities concerning stationary fuel cell technology (in particular Phosphoric Acid Fuel Cells, PAFC) in the USA and Japan (DIP, 1994). The responsible secretary of state in the ministry for research and technology responded that these activities were not considered as promising for German industry due to the advance of US and Japanese industry, and thus observing activities would be sufficient for German industries. (DIP, 1994). This lack of interest may be interpreted against the background of collective fuel cell expectations at the time. While optimistic expectations about the commercial potential for large-scale stationary applications of (PAFC-)fuel cells circulated in the international scientific discourse, attention in public media as newspaper and professional journals was still low (see Chapter 2). The hype around mobile and small-scale stationary applications of fuel cells, which approximately lasted from 1997 to 2000 for mobile, and from 1999 to approximately 2003 for small-scale stationary applications, was yet to come. Actually, the parliamentary discourse on fuel cells took off from 1997 onwards, with a focus on stationary applications, now based on emerging fuel cell technologies such as Molten Carbonate Fuel Cells (MCFC) and Solid Oxide Fuel Cell (SOFC) (DIP, 1997b). In 1997, mobile applications, in particular for car propulsion, were discussed for the first time, referring to the first prototype cars presented by the automobile company Daimler[104] in previous years. However Proton Exchange Membrane Fuel Cells (PEMFC) – supposed to be the most promising fuel cell technology for the application in vehicles - were considered as too expensive for commercial purposes at the time. Still, a potential market introduction in 2005 was discussed (DIP, 1997a).

Thus, the policy discourse in this early period shows some reflection of the incipient rise of expectations on the future technological and economic potential of fuel cell technologies, with two streams, concentrating on either stationary or

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103 The periodization in this Chapter may differ slightly from other Chapters due to the different research foci.
104 The corporate name of Daimler changed several times between 1990 and 2010. From 1926 to 1998 the official company name was Daimler-Benz, which changed into DaimlerChrysler from 1998 to 2007 and Daimler from 2007 onwards. Nevertheless this paper refers to Daimler to maintain clarity, since the major share of the fuel cell activities within the corporation were conducted at the European Daimler facilities

mobile applications. However, these niche level expectations were not explicitly linked to expectations referring to developments at the regime or landscape level, and no need for active governance measures was deduced.

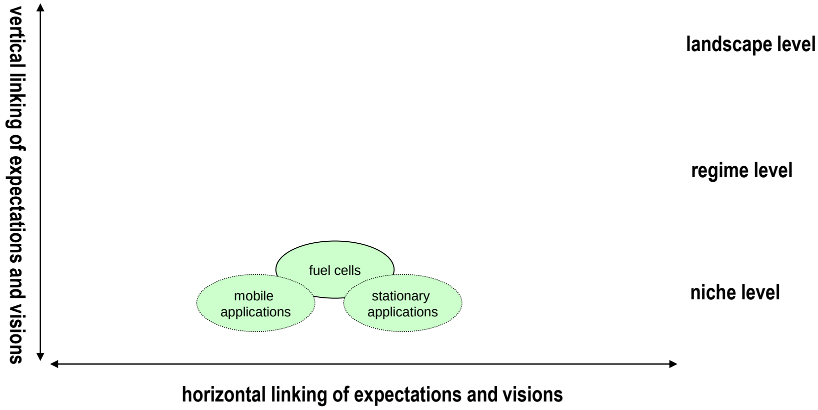

Figure 18: Period 1 - First discussions on fuel cells

Period 2: Linking up with regime visions (1998 – 2002)

In 1998, mobile fuel cell technology was increasingly mentioned in relation to the regime level vision of a future hydrogen-based energy system, a 'hydrogen economy'. In an economy based on the universal use of hydrogen as an energy carrier, fuel cells would be the ideal technology to transform hydrogen into electricity for the propulsion of vehicles (DIP, 1998). However, this link of fuel cell technology to the vision of a hydrogen economy did not strengthen fuel cell expectations in the German policy context at the time. An intensive discussion in 1998 revealed that the government was very critical about the future use of hydrogen. Criticism focussed in particular on the high costs of hydrogen technologies which would require substantial subsidies over a long time period (DIP, 1998). The German government stated that the widespread use of hydrogen was not expected until 2030 to 2050 (DIP, 1998). So, linked with the vision of a hydrogen economy, which was expected being a prerequisite for the diffusion of fuel cell technology, fuel cells for transport applications were not perceived as a technology ready for deployment on the short or medium term.

Still, the development of fuel cells as a technology was explicitly discussed as a promising field, and stationary applications were presented as more promising due to higher flexibility in the fuel to be used, which – besides hydrogen – could also be natural gas, biogas, or coal gas (DIP, 1998). Thus, expectations concerning stationary fuel cell systems were not only linked to expectations about an upcoming hydrogen economy, but were also perceived as compatible with other possible future energy systems, relying on different energy carriers. Against the background of these discourses and diverging expectations about fuel cell technology (mobile, stationary, link to a hydrogen economy) the Office of Technology Assessment at the German *Bundestag* (TAB) conducted a comprehensive technology assessment project , which was, however, not reflected in the documented parliamentary debate (TAB, 1997).

Even though in the public media fuel cells for mobile applications were presented as highly promising at the time (Bakker, 2010), there was hardly any mentioning of fuel cells in the following years in the policy discourse. Only from 2001 on, the attention for fuel cell technology in the policy discourse was rising again, coinciding with a swing of attention and expectations towards stationary applications in public media, in particular small-scale combined heat-and-power systems for single houses. At this time, the minister of economic affairs and technology stated that he expected stationary systems to be introduced to the market between 2005 and 2010 (DIP, 2001b). In particular, the question whether stationary fuel cell systems should be entitled to receive support as combined heat and power (CHP) systems under the German CHP law was debated intensively (DIP, 2001a). Thus expectations concerning fuel cell technology got linked with an ongoing governance process (CHP law), which was strongly related to the regime level vision of a decentralized energy system.

In 2002, a second report by the Office of Technology Assessment at the German *Bundestag* (TAB), building on the first one mentioned above, was at the core of an intensive debate about fuel cell technology and its future potential. The report was initiated with the explicit aim to provide a ‘realistic, holistic and differentiated picture of the state of development and future perspectives concerning a widespread use of fuel cell systems and its consequences [translated from German by the authors]’ (DIP, 2002, p.7). Finalised at the end of 2000, the report was first discussed within the committee on education, science, research, technology and technology assessment. All parties expressed agreement with the key findings of the report, that fuel cell technology would be in a ‘decisive phase’ in which it was time for ‘setting the course for innovation [Weichenstellungen]’ (DIP, 2002, p.6). Furthermore, development activities around the world undertaken by large enterprises and public funding schemes ‘document the expectation, that fuel cells have significant market potential and could provide solutions for the transport sector and the energy industry’ (DIP, 2002, p.6).

Despite the general optimism, the TAB report mentioned a number of hurdles, such as 'numerous technical barriers, yet to overcome' and high production costs of fuel cells. In addition, the need to take into account competition with established conventional and other emerging technologies was stressed (DIP, 2002). The report assessed stationary fuel cell systems as a promising technological option, in light of the expected decentralisation of the energy system. In a decentralised energy system, fuel-cell based CHP would be able to supply heat and electricity to households. Furthermore, these systems could provide electricity to the grid and visions of large numbers of stationary fuel cell systems operating as coordinated virtual power plants were discussed intensely. Such virtual power plants would facilitate the reliable operation of electricity grids, in an electricity grid which would be increasingly reliant on wind and photovoltaics. In contrast, the prospects of fuel cell vehicles (mobile applications) were contested, in particular with regard to the production of hydrogen and technical problems concerning the on-board storage of hydrogen (DIP, 2001a). The main findings of the report appeared to be shared by the different parties represented in the *Bundestag*, however the parties derived different policy implications:

Referring to the technology assessment report, the opposition party FDP (liberals) argued in favour of more dedicated public funding for fuel cell technology, which was opposed by the government parties SPD (social democrats) and the Green party. The latter called for a more balanced view taking into account the whole energy system (DIP, 2002). Furthermore, the government parties argued that they had initiated already important funding schemes to support fuel cell R&D in previous years which would be continued. One of the most important sources for these funding schemes was the so called Future Investment Program ZIP (Zukunfts-Investitions-Programm). The ZIP was financed by the revenues the state generated from the auction of the UMTS mobile communication licences and enabled different future investments, among those fuel cell research (60mio EUR from 2001 to 2003) (DIP, 2002, p.6 & p.88-90).

Whereas the potential of fuel cell technology was not disputed, initial discussions within the committee focused on the question of energy carriers used to operate fuel cells. In particular the production of hydrogen from nuclear power was controversial and led to different perspectives on the future of hydrogen. The Green party strongly opposed the use of nuclear power to produce hydrogen, because of low efficiency and called for the use of biomass to produce hydrogen (DIP, 2002, p.8). In addition, expectations about the potential impact of fuel cells on the energy system were disputed: While the government parties expected a decentralisation of the energy systems (including more combined heat and power (CHP) systems), other parties expected the use of nuclear power, thus a more centralised energy system, to produce hydrogen to power fuel cells (DIP, 2002).

To summarize, most expectations concerning fuel cell technology were strongly linked to expectations at the level of future energy regimes, either a hydrogen economy in the case of mobile applications, or a decentralized energy system in the case of stationary fuel cell technology. Different from the previous phase, the link of fuel cell expectations with the vision of a decentralized energy system enabled the community around stationary fuel cells to link up with an ongoing governance process (reform of the CHP law). However, in the case of mobile applications, the regime vision of a hydrogen economy was arguably too controversial to trigger further governance measures to support the technology. The link to landscape expectations was emerging, but still rather weak. With respect to the governance *of* expectations, in this period we now see dedicated efforts for the further articulation of expectations in the form of technology assessment studies.

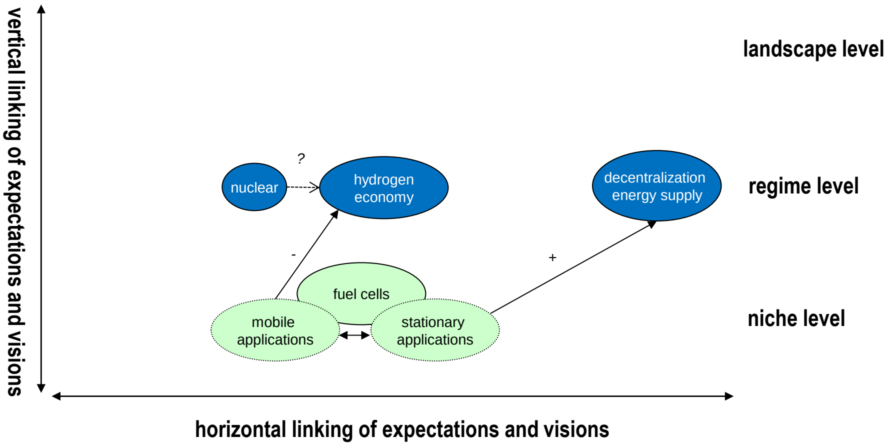

Figure 19: Period 2 – Linking up with regime visions

Period 3: Fuel cells - one promising technology among others (2003-2005)

After 2002, attention for fuel cells decreased within the parliamentary discourse, with fuel cells being mainly discussed as a side-issue in more general discourses about industrial/technology policy (DIP, 2003a) or export of military technology (fuel cell systems for submarines) (DIP, 2003b). In 2004, the government initiated the development of a German fuel strategy (Kraftstoffstrategie), as an element within a German sustainability strategy. Based on a stakeholder process, different options on how to reduce the use of fossil fuels, increase energy security, and reduce greenhouse gas emissions were assessed. Hydrogen and fuel cell technology were assessed positively, but only on the very long term (DIP, 2007g).

In 2004, the opposition party CDU/CSU (Christian Democrats) launched a parliamentary inquiry on climate change and future energy resources including 73 questions to the government concerning its expectations about climate change impacts, future energy resources, energy efficiency, the future development in different sectors (e.g. transport, buildings, and industry), future technologies and how the government assessed these technologies at the time. Among others, the inquiry raised the question when the government expected mobile respectively stationary fuel cell technology to be ready and competitive for a widespread application (DIP, 2004b). Furthermore, the Christian Democrats proposed to focus governmental activities on concepts for the build-up and operation of a hydrogen infrastructure and the production of hydrogen (DIP, 2004a).

The government eventually answered the parliamentary inquiry in 2005, stating that new technologies would broaden the portfolio of technological options to cope with climate change and the expected energy scarcity. Among these technologies, carbon sequestration ('clean coal'), hydrogen and fuel cell technology and technologies to increase the efficiency of fossil fuel technologies were mentioned. The use of hydrogen for transport was regarded as an 'important field of application' of new technologies referring to the ongoing strategy processes for new energy carriers for transport, and the clean energy partnership (CEP), a large hydrogen demonstration project in Berlin (Bonhoff, 2008; DIP, 2004a). However the government clearly stated that the efficiency and desirability of fuel cells and hydrogen would depend on the primary energy source (DIP, 2005a). Hydrogen was discussed as a promising universal energy carrier to store energy from different sources, with renewable energy sources being the most desirable option to produce hydrogen. However a large share of electricity from renewable energy sources would be available on the long term only, when fluctuating energy sources such as wind or solar energy would provide large shares of electricity in the grid. Consequently, the decisions concerning 'investments in the infrastructure for [energy] storage [were] significantly influenced by the development of fluctuating energy sources. An authoritative forecast [was] not possible.' (DIP, 2005a, p.10). Furthermore, an 'assessment concerning the broad application in mass markets' did not seem possible either (DIP, 2005a, p.12). According to some speakers, the use of nuclear power would have negative effects on new innovative technologies, such as gas turbines, renewables or fuel cells (DIP, 2005b). Thus, fuel cells were regarded promising, but as one technology among others.

While in the previous period fuel cells had been positioned mainly in relation to the visions of a hydrogen economy and a decentralization of the electricity system, in this period these visions were complemented by expectations and visions about an energy system based on renewables, which were at least to some extent shared by the parties. However, due to the long term horizon and perceived uncertainties, the governmental actors did not identify an immediate necessity for an intensification of support measures in the field of fuel cell technology. Expectations concerning the landscape level, in particular with respect to climate change, became more relevant, but not closely linked to the regime and niche level expectations. Policy dealt with the issue with a combination of dedicated expectation-building and strategy-building in the form of the German fuel strategy process.

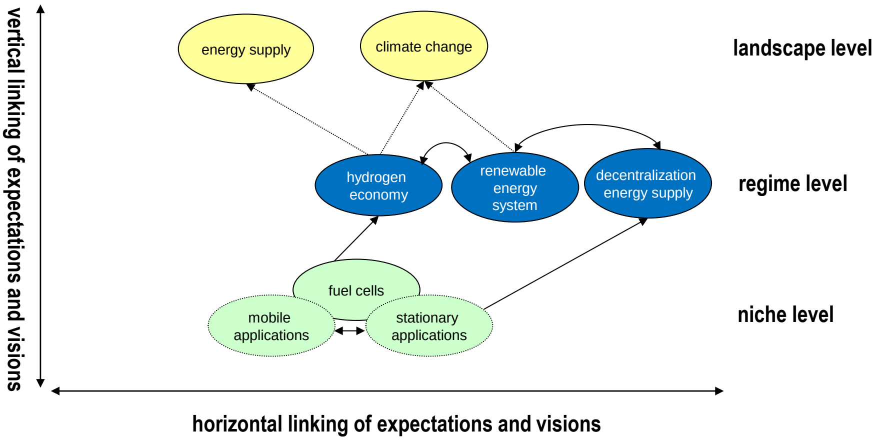

Figure 20: Period 3 - Fuel cells as one promising technology among others

<u>Period 4: Strengthening of links with landscape expectations (2005-2007)</u>

The fourth period is characterized by the recurrence of attention for fuel cell technology, the creation of a strong link with a discourse on competitiveness as well as the issue of climate change, and the decision to launch a large fuel cell and hydrogen support programme.

In 2005, Germany saw a preponed change in government, a grand coalition of Christian Democrats and Social Democrats replaced the previous coalition of

Social Democrats and the Green party. In this year, the liberal party called for a climate protection initiative 2006 (Klima-Schutzoffensive 2006) promoting policy action on the international and national level, aimed at furthering the Kyoto process and the reduction of greenhouse gas emissions. As one of the key points, policies were to be developed that would establish 'Germany as a high tech region to focus its forces, in order to maintain and further develop a technological leadership role in energy technologies' (DIP, 2005a, p.3). The further development of fuel cell and hydrogen technologies and the erection of a hydrogen infrastructure was advocated, as a way 'to make sure that renewable energies, beyond fuels based on biomass, will be a viable and economic option in the transport sector' (DIP, 2005a, p.3). At the same time, the government aimed at developing policies to improve industrial competitiveness and address societal challenges, in particular energy security and climate change (DIP, 2005b). In parallel, the committee on education, science, research and technology and technology assessment of the German *Bundestag* contracted the TAB to prepare a report about future transport technologies, which could contribute to a significant reduction of CO2 emissions. This report was eventually published and discussed in 2007 (DIP, 2007c, see below).

The new government emphasized the role of technology and innovation to maintain and improve the competitiveness of the German economy; from 2006 onwards the government initiated 'lighthouse projects' to strengthen the position of 'Germany as a hotspot for technological innovation', including the field of fuel cell technology (DIP, 2006c). In order to support growth and new jobs, the government developed a 'High Tech Strategy' (DIP, 2006a, b), as part of which six billion EUR were allocated for implementing different measures and initiatives. New energy technologies were chosen as one focus area, in light of the expected societal challenges of climate change and the depletion of fossil energy resources (DIP, 2006b). Hydrogen and fuel cell technologies among others were part of the list of promising technologies to be supported. The assumption that on the long term the ideal and most sustainable option would be the use of hydrogen produced from renewable energy sources, remained unchanged, and the further development of renewable energy technologies was declared as another area with high priority in the high-tech strategy (DIP, 2006b). In general, the vision of a hydrogen economy was discussed with a more positive attitude now, as it would create new opportunities for renewable energy technologies such as wind and photovoltaics.

In 2006 the government announced the launch of a ten year national innovation programme (NIP) on hydrogen and fuel cell technology, financed by funds from the High Tech strategy (DIP, 2006a). The aim of the NIP was to maintain and enhance the competitiveness of German research and development actors in the field, and to accelerate market introduction (DIP, 2006a). A budget of one billion EUR was assigned to the programme, 500 million EUR provided by the government, and at least another 500 million EUR by industry (DIP, 2006c). Following the commitment of industry actors, it was agreed that the programme would be managed by a specifically established organization, the National Organization Hydrogen and Fuel Cell Technology (NOW), supported by an Advisory Board, thus staying in close collaboration with key stakeholders (Expert 4; Expert 5; Garche et al., 2009). The programme primarily aimed at accelerating and supporting the market entry and diffusion of mobile, stationary and portable fuel cell applications, but it was acknowledged that one of the 'fundamental questions to be answered' was how to provide the necessary amounts of hydrogen in an efficient and environmentally sound way (DIP, 2006b, p.36).

According to a key industry expert involved in the setup of the NIP, research and industry actors convinced policy actors that hydrogen and fuel cell technology needed more time and stable framework conditions, and to move 'away from the expectation to deliver results in three or five years [...] the call for a ten year programme [was] chosen in order to avoid immediate euphoria, and to avoid a negative twist in case public opinion changes in three years. To avoid throwing out the baby with the bathwater [translated from German by the authors]' (Expert 2).

To summarize, while still being seen as part of a portfolio of promising options, fuel cells were more and more emphasized as one of the key technologies of the future. Fuel cell expectations remained strongly linked with the vision of a hydrogen economy, which gained in attractiveness the more it was linked with renewable energies. Jointly, expectations about fuel cell and hydrogen technologies linked up with expectations referring to the landscape level, in particular expectations about climate change and the expectation that fuel cell technology would maintain and improve the competitiveness of German industry players and support the creation of new jobs appeared to be important. This linking to expectations at the landscape level appeared to be stronger than in previous phases. The expectation that hydrogen and fuel cell technology would contribute to greenhouse gas emission reduction was used frequently, as the issue of climate change became increasingly important in the parliamentary discourse. According to one of the industry experts involved in the set-up of the programme, the promise to be able to reduce CO2 emissions of houses by 30% using stationary fuel cells in small scale CHP systems (micro CHP), was one of the main arguments to convince policy to grant the support programme (Expert 4) .

In contrast to the years before, this period saw the emergence of dedicated policy support for fuel cell technology, with the establishment of the NIP. This policy measure was facilitated by the change of government, which created an opportunity structure to position the outline for a support programme, recently developed by a network of fuel cell actors. Actually, the decision to create a fuel cell support programme was part of the coalition negotiations (Expert 2; Expert 4; Expert 5). On the discursive level, the emergence of a strong link between fuel cells, hydrogen and the topic of economic competiveness in an increasingly globalising world and climate change, was supportive as well. This linking to current expectations in line with current policy priorities was actively sought, as reported by two major fuel cell actors involved in the development of the programme outline (Expert 4; Expert 5). Remarkably, the launch of the 10 year NIP was intended as a means to deal more reflexively with the expectation dynamics experienced in the recent past. The creation of such a long term programme and a dedicated hydrogen and fuel cell organisation was an attempt to 'stabilize' the governance of fuel cell technology and reduce the uncertainties, at least with regard to national RTI policy in the field.

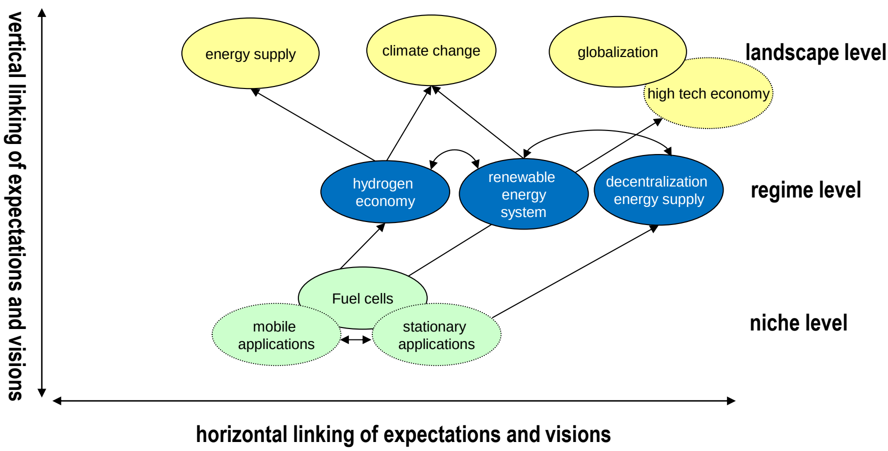

Figure 21: Period 4 - Strengthening of links with landscape expectations

Period 5: The rise of electric mobility (2007-2011)

In the following years, fuel cell expectations were on the one hand strengthened, due to a number of supportive expectations in the network gaining in importance, and at the same time challenged by the emergence of optimistic collective expectations on battery-electric vehicles.

Climate change remained, if not even increased in importance, as a major priority on the parliamentary agenda. With respect to the transport area, a report published by the office of technology assessment in 2007, emphasized that transport was the only sector with increasing CO_2 emissions in previous years, requiring further action (DIP, 2007c, p.4). The report provided an overview of technological options for alternative drivetrain technologies and fuels. The market introduction of fuel cell vehicles was expected earliest 15-20 years in the future, since the 'euphoria of the 1990s has [had] cooled down' (DIP, 2007c, p.6). Still, the technology was considered as promising, though dependent on the future production of hydrogen and the progress of renewables. The hype around fuel cells was reflected even more critically in a further technology assessment report on demand oriented innovation policy: 'Communication activities for fuel cell systems gave the impression that already tomorrow whole fleets of clean vehicles would be on the road [...] These communication activities raised counterproductive expectations, which could not be fulfilled considering the state of the technology, causing scepticism regarding fuel cells.' (DIP, 2007e, p.102) Apparently, this scepticism was not shared by the authors of the report, who called for additional supportive policy measures (demonstration projects, regulations, etc.). They furthermore emphasized the importance of vision building processes, roadmaps and the like: 'The importance of such consensus- and communication processes cannot be overestimated, because they provide orientation for private and public investment decisions and reduce uncertainties' (DIP, 2007e, p.14). In line with this, key stakeholders and policy actors developed a fuel cell roadmap, the national development plan (Strategierat Wasserstoff und Brennstoffzellen, 2007), which became the key orientation point for the NIP providing detailed information about supported topics, time scales and budgets – the 'bible', as it was called by one of the experts involved in the NIP (Expert 4).

Expectations on stationary fuel cells and the electricity system more broadly did not change substantially in this period. Expectations concerning climate change and emerging markets for new technologies remained closely linked, as manifest in terms such as 'future market climate change' circulating in the discourse (DIP, 2007f). Hydrogen and fuel cell technology were particularly discussed as possibly going to play a key role for storing excessive electricity from renewables as (off shore) wind parks and photovoltaics, or as virtual power plants (DIP, 2007b, 2008b).

Alongside the discussion of fuel cells, very positive expectations concerning (battery) electric vehicles emerged in the public discourse at the time, and were reflected as such in the parliamentary discourse. The green party called for the formulation and implementation of a comprehensive climate protection strategy and the support of alternative drive train and storage technologies in vehicles, going 'beyond fuel cell and hydrogen technologies, to support batteries, plug in hybrid technologies and pure [battery] electric vehicles' (DIP, 2007a, p.3). Subsequently it was discussed if the title of the NIP should be extended to cover hybrid and electric vehicles as well, however this proposal was eventually rejected by a broad majority (DIP, 2007d).

In 2008 (battery) electric vehicles were gaining more momentum and four ministries decided to set up a coordination platform and to develop a national development plan for 'electric mobility' (DIP, 2008c, d). Expectations on 'electric mobility' were, just like hydrogen and fuel cell expectations, linked to the anticipated need to balance supply and demand in the electricity grid, resulting from an increasing share of renewables. 'The battery of the electric vehicle can provide an important contribution to [an efficient] management of the grid. [...] [The government] aims to focus and increase its activities in the field of electric mobility [...]' (DIP, 2008d, p.96).

In addition, some disappointment concerning hydrogen and fuel cell technology was articulated in 2008, when an inquiry led by the Liberal party was referring to the 'sluggish' development in the area of hydrogen and fuel cell technology and a 'dynamic' development in the field of battery technology (DIP, 2008a, p.1). Also here, large parts of the network of expectations sketched around battery electric vehicles was congruent with the one around fuel cells: CO2 reduction and 'efficient use of renewable energy, since electric vehicle promise to provide an option to store electricity from fluctuating sources' (DIP, 2008a, p.2). In 2009, the Green party argued likewise calling for more support for electric vehicles due to the expected complementarities with renewable energy sources (DIP, 2009b). Although electric vehicles would be on the market on the short term, research funding in Germany was considered to be modest in comparison with other countries like Japan and 'still' focussed on fuel cell and hydrogen technologies (DIP, 2009b, p.9). However, the Green party expected fuel cells to play a role in the long term as range extenders for electric vehicles [105], referring to prototypes by General Motors and Daimler (DIP, 2009b, p.9). This perspective, of fuel cells

[105] Fuel cells were envisioned to charge the batteries of an electric vehicle to enable a range of up to 600km.

being part of the vision of electric mobility, was emphasized by the government, stating that all electric propulsion systems such as hybrid, battery and fuel cell vehicles had great potential to reduce emissions and to reduce the dependence from fossil fuels. Furthermore the government shared the expectation that electric vehicles would help to integrate more renewable energy in the electricity grid (DIP, 2009a).

Consequently, the government launched a 500 Mio. EUR stimulus package which included new funding schemes to support electric engines, hydrogen and fuel cells and energy storage, since 'Germany cannot afford to bet on a single technology', reflecting the high level of uncertainty at the time (DIP, 2009a, p3.). In addition, the government set the target of having one million electric vehicles on the road in Germany by 2020 (DIP, 2009a). This figure included both battery and fuel cell electric vehicles. Among these measures from the stimulus package was the setup of a programme respectively funding scheme for model regions for electric mobility (DIP, 2009c, p.49). Remarkably, it was decided that the program would be managed by the National Organization Hydrogen and Fuel Cell Technology (NOW), the organisation initially founded for the management of the hydrogen and fuel cell innovation programme.

Despite these activities by the government, the Green party raised doubts if these policy initiatives would be sufficient and identified a lack of knowledge concerning battery technology in Germany. Furthermore the Green party doubted if hydrogen and fuel cell technologies were still promising, given that major automobile companies as Ford or BMW had reduced their involvement in development of fuel cell and hydrogen technologies (DIP, 2010b, p.8). The government answered that 'electric mobility [was] used frequently in a restrictive way and synonymously with battery electric vehicles. The term electric mobility, however is [applied] overarching for all approaches electrifying vehicles and includes electric, hybrid and fuel cell vehicles' (DIP, 2010a, p.2).

In 2011 minor adaptions of the NIP were implemented. Still, the government repeatedly emphasized that there would be a role for hydrogen fuel cell vehicles, provided that hydrogen would be produced from renewable energy sources, supplementing battery electric vehicles, not the least because of their superior range, (DIP, 2010c, 2011). Thus, fuel cell vehicles were reframed as being part of the vision of an electrification of transport.

To conclude, in the fifth period fuel cell and battery vehicle expectations took a very similar position within the broader network of expectations, which predestined them to a competitive position in relation to each other. While the two technologies were indeed mostly perceived as competing (Bakker, 2010), the German policy discourse *and* the supportive governance arrangements were adjusted in such a way, that these technologies were rather reframed and positioned complementary in relation to a broader regime level vision of an electrification of transport, even though this was not uncontested. Figure 2 provides a summarizing overview of the main linkages between expectations and visions at different levels.

As in the period before, we see indications of a reflexive governance of expectations, which tries to respond to the perceived and potential future dynamic evolvement of expectations. The main strategic thrust pointed towards stabilization, be it in the form of the set-up of a robust, long-term funding programme, or the crystallization and fixation of expectations in a roadmap, arguably as a response of the hype-disappointment dynamic which took place within the fuel cell niche. However, stabilization alone was not sufficient to respond to the 'external' dynamics of the rise of battery-electric vehicle expectations; now adaptation took place as well.

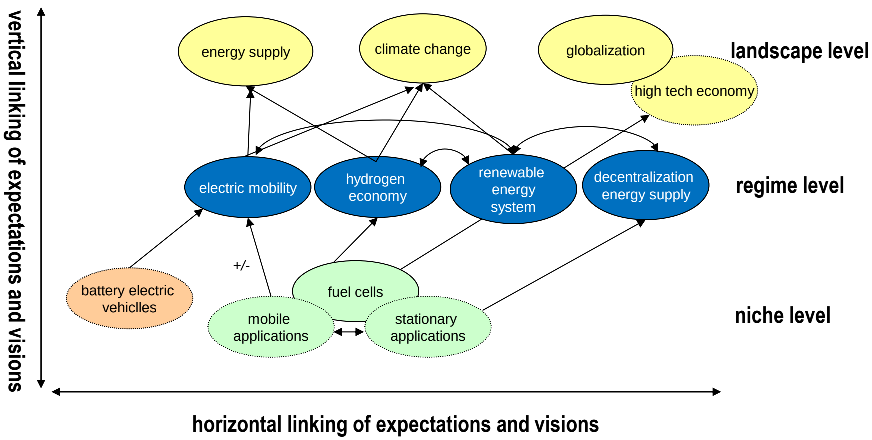

Figure 22: Period 5 – The rise of electric mobility

6.5 Discussion and Conclusions

In this article, we set out to follow the multi-level dynamics of fuel cell and related expectations and visions in the German policy discourse, to examine if and how policy measures were discursively related to these expectations, and how policy dealt with the dynamic evolvement of expectations.

Our analysis showed that collective niche expectations were an important reference point in the policy discourse. However, it became also clear that niche expectations alone were not sufficient to trigger substantial policy measures, as exemplified by the fact that the hype around mobile fuel cell applications did not result in immediate policy action. Apparently, only once and as far as expectations about fuel cell technology linked up with visions and expectations at the regime and landscape level, they were able to facilitate the setup of supportive policy measures. In addition, but not surprisingly, linking to regime and landscape level expectations was only supportive, if these were widely shared and assessed positively across the policy spectrum, or the governing parties at the time.

The types of links and interactions we observed within this dynamic network of expectations reflect the broad variety reported in the literature of strategic niche management and transition studies for 'real-world' processes. We identified more or less supportive links at the discourse level between niche and regime expectations, supportive linkages between niche and landscape expectations, and competing and complementary linkages between expectations concerning different niche technologies. Niche expectations were discursively related to multiple regime expectations and visions, both in the form of expectations referring to multiple systems a niche may relate to, such as visions regarding the electricity and the mobility system. Furthermore niche expectations were related as well to competing visions about the future of a particular system, for instance visions about a hydrogen economy based on renewables or nuclear energy, or a mobility system based on fuel cell versus battery-electric vehicles or – in the case of battery electric vehicles - to an overarching vision of an electrification of transport. These linkages at the discourse level are not stable, but change over time. A further dynamic element is introduced due to changes in the assessment of linked visions, as in the case of the vision of a hydrogen economy, or the assessment of battery-electric vehicles.

Dynamics do not only include reshufflings of the network of expectations. In addition, we observed a successive articulation of expectations – mainly in the later periods -, largely by way of dedicated expectation-building measures within working groups, which were initiated by actors of the ‘fuel cell community’ (Expert 4), but joined by policy actors and became increasingly institutionalized. In parallel, the expectations qua content got more and more institutionalized as well, starting with discussions in working groups, and then getting inscribed into strategy papers, a roadmap and eventually turning into a ‘national development plan’ providing guidelines for a funding program. In this way, the increasingly articulated expectations served to mobilize policy support, and to coordinate and guide concrete support measures. Dedicated articulation of expectations was, however, not only limited to the fuel cell community, but also initiated by policy actors in the form of technology assessment studies, which mostly became important reference points in the parliamentary discourse.

Thus, this network of expectations functioned indeed as a prospective structure, which increasingly materialized in the governance of the field – including regulatory measures, support schemes and organizational structures - and with actors working actively towards stabilizing both the prospective-discursive and the material structures. At the same time, the discursive structures proved to be prone to change, and these changes led to adaptations of the governance structures, thus creating an element of tentativeness.

A case in point are the emerging links of expectations regarding fuel cell technology and battery electric vehicles under the regime level vision of an electrification of transport, which could be traced in the organizational structure of the field as well, as the example of the NOW above shows, which broadened its scope from a dedicated fuel cell and hydrogen support organization to administrating both fuel cell and battery-vehicle support schemes. Moreover, this joint regime vision allowed fuel cell and hydrogen technology to remain high on the agenda of the German government unlike in many other countries where fuel cell and hydrogen actors were struggling to maintain or restore (networks of) expectations concerning these technologies (Bakker et al., 2012). Therefore, the governance of fuel cell innovation can be characterized as dynamically stable. A similar phenomenon can be found on the regional level where the fuel cell initiative in Lower Saxonia (‘Landesinitiative Niedersachsen’) turned into the fuel cell and electric mobility initiative (‘Niedersächsische Landesinitiative Brennstoffzelle und Elektromobilität’). More recently the initiative changed its name again to an energy storage and –systems initiative, responding to the perceived need of future energy storage technologies (Landesinitiative Niedersachen Energiespeicher und -systeme, 2013).

While these adaptations of support schemes following the discursive dynamics constitute a form of de-facto tentative governance, responding to the dynamics within the network of expectations when they occur, we observed reflexive strategies trying to cope in an anticipatory way with possible further dynamics of expectations as well. The hype-disappointment cycle around fuel cells at the turn of the millennium was reflected within technology assessment studies and by key fuel cell actors. As a response, fuel cell actors worked towards a supposedly more robust governance structure for supporting fuel cell development, by stabilizing expectations via roadmaps and by lobbying successfully for a long-term funding scheme. Thus, future dynamics and uncertainties were taken into account, yet the intended response was only partly flexibility, but also stabilization in the context of a dynamic environment. Apparently the dynamics anticipated focused on possible further developments in fuel cell expectations, whereas changes in the broader network of expectations, in particular the rise of battery-electric expectations resulted in additional dynamics. This created a pressure to respond not only to the prolongation of time horizons (which could be addressed by a long-term program), but also to respond to the shift in expectations, which led to the described expansion of the scope of support programs. Thus, we see that anticipatory and de-facto tentative governance may well be intertwined. In addition, our case shows that reflexively dealing with dynamics may also include dedicated and successful efforts to create stabilized – though not rigid - policy support, aimed to create some resilience, in order to avoid that policy support simply follows expectation dynamics.

Thinking beyond this paper, our framework could be further developed and inform a reflexive approach of dealing with the dynamics within networks of expectations. The multi-level analysis of expectations may serve to identify weak, latent or potential future relations and interactions of visions and expectations, which may affect future discourses and ultimately governance processes. Thus this paper emphasizes the importance of taking into account expectations and visions related to all three levels linking up to emerging discussions among experts in the German fuel cell community, that higher level expectations were not taken into account sufficiently in previous expectations work (HyTrust, 2013) . Thus an analysis based on the insights of this paper could eventually contribute to a reflexive governance approach, which does not only respond ex post to shifts in expectations and expectation networks, but tries to anticipate to some extent possible future dynamics and reshufflings of expectations, for instance as a result of changes in related expectations or due to the intensification o so far weak or latent links.

7 Conclusions

This thesis analyses the influence of expectations on transition processes and the processes through which expectations emerge and realize this influence. The main conclusions of this thesis are that expectations are important elements for transition processes, and that a more comprehensive conceptualisation of expectations is needed to understand the role of expectations for transition processes. In order to understand the processes through which expectations influence transition processes, this thesis presents a more comprehensive conceptualisation of expectations, taking into account that,

(1) expectations are shaped in different discourse spheres,
(2) expectations beyond technological expectations are relevant and that
(3) expectations are interacting with each other ('network of expectations').

Expectations are shaped in different discourse spheres

Starting point of the empirical analyses presented in this thesis was the empirical observation how expectations regarding fuel cells developed over time (see Chapter 2). The thesis showed the occurrence of a hype-disappointment cycle for fuel cell technology, but interestingly the analysis revealed that there ***was not a single hype about fuel cells.*** The discourse analysis of different discourse spheres showed that expectations concerning fuel cell technology differed remarkably between different discourse spheres, i.e. between the mass media, finance or the policy discourse sphere. This finding has two implications: First, the circulating folk theory (Rip, 2006) that mass media is responsible for the frequently occurring hype-disappointment cycles has to be adjusted in the case of fuel cell technology. Second, to understand expectations dynamics it is necessary to conceptualise different discourse spheres, since expectation dynamics can develop differently in the various discourse spheres. As the discourse analysis in Chapter 2 shows, fuel cells raised high interest due to different reasons and attention was directed at specific applications (i.e. fuel cell vehicles in the mass media, stationary systems in the professional discourse). When disappointment set in in some discourse spheres the rhetoric of different generations in the science discourse sphere prevented disappointment. Even though problems and barriers were discussed, these were related to the current generation of fuel cells, whereas the emerging next generation of fuel cells would be able to overcome these barriers. Without conceptualising different discourse spheres and thus empirically taking into account the different discourse spheres there would be the inherent risk of neglecting these important varieties in the discourse on fuel cell technology.

The specific rules of selectivity, framings and interpretations of the prospects of a technology are essential to understand the attention and assessment of technologies in a discourse sphere. Often specific applications are of greater interest in one discourse sphere than in another, or specific aspects of a technology (e.g. expected costs or energy sources to power fuel cells) are of key importance in one discourse sphere while the issue may be hardly relevant in another discourse sphere. Looking at the role of expectations for actors, the distinction into several discourse spheres becomes even more relevant if we assume that actors refer more intensively to a specific discourse sphere than to another. This is in particular important in a situation where disappointment occurs in one discourse sphere but not in another. Due to the different application focus or framings a technology may be not promising anymore in one discourse sphere while it remains attractive in another discourse. The conceptualisation of different discourse spheres is therefore relevant to better understand the emergence of hype-disappointment cycles and the effect on actor strategies.

Expectations beyond technological expectations are important

Whereas the role of expectations is generally acknowledged, most literature in transition studies and the sociology of expectations either focuses on the role of technological expectations or does not distinguish expectations regarding future technological capabilities, from expectations regarding markets or expected developments at the societal level which may influence the further progress of a technology. This thesis shows that it is crucial to **systematically take into account different kinds of expectations beyond technological expectations** in order to gain a better understanding of hype-disappointment cycles and their impact on transition processes. Whereas technological expectations, i.e. expectations regarding the future performance of technology dominated the discussion concerning fuel cell technology, this thesis shows that other expectations are equally and in some situations even more important than technological expectations. As the analysis of the actor strategies of two German car manufacturers and the German government in Chapter 0 showed, that expectations concerning the future mobility or energy system and regarding future developments at the societal level were crucial. Expectations about the future mobility system were highly influential for the strategies of the car manufacturers, whereas expected societal challenges such as a loss of competitiveness of the domestic (car)industry and expectations concerning climate change were important reference points for the German government.

This thesis proposes to distinguish different kinds of expectations with regard to the object the expectations refer to. In order to do so, it applies the multi-level perspective (MLP) of transition studies, initially developed to analyse (historic) developments in the 'real world' enabling or restricting a transition of a socio-technical system (Geels, 2002), to analyse expectations referring to future developments.

Although previous studies using the MLP to study transition processes analysed the role of expectations for these transition processes, they did not use the MLP as such to differentiate different types of expectations.[106] In this thesis the three levels, niche, regime and socio-technical landscape, are used to categorize expectations with regard to the level they refer to. Thus, expectations about the future of a specific new socio-technical configuration in a narrow sense, for instance fuel cells or battery electric vehicles, are regarded as expectations related to the niche level, while expectations about the future structure and rules of the mobility or energy sector are related to the regime level, since they represent images about the future regime. Other expectations about deep structural trends at the societal level, such as demographic change or the further development of the world economy are defined as expectations related to the landscape level.

This differentiation of expectations using the MLP is important since actors differ with regard to the importance technological expectations or expectations regarding the future of the regime or socio-technical landscape level have for their strategy.

First, Chapter 3 and 6 illustrate that expectations which are not concerning the future performance or characteristics of a technology are decisive for actor strategies. Chapter 6 illustrates that even though expectations regarding fuel cell technology had been more positive over time, substantial policy support was just mobilized when the expectations concerning fuel cell technology were strongly related to expectations concerning a hydrogen economy based on renewable energy sources. Thus, fuel cells powered by renewably produced hydrogen appeared to be very promising solution for a number of future societal challenges, such as climate change. Thus, these expectations concerning the future regime

[106] An exception is a foresight study by Truffer et al. (2008), which uses the levels of the MLP as one dimension to map expectations of stakeholders.

(energy system based on hydrogen and renewables) and the future socio-technical landscape level (increasing importance to address climate change) were crucial to initiate policy programmes on fuel cell technology.

Second, Chapter 3 reveals that different types of actors relate their strategies stronger to a specific level of expectations: Automotive manufacturers relate their strategies strongly to expectations referring to the regime level (in particular to expectations about the future mobility system), whereas expectations regarding the socio-technical landscape level are more relevant for policy actors. Nevertheless expectations regarding different levels have to be analysed together, since technological expectations are still an important reference for both actor groups mentioned above. On the one hand actors will take into account expectations referring to all three levels in their strategy formation processes, although some are more influential than others, and on the other hand **expectations regarding different levels do interact** with each other, as the discourse analysis of the debates in the German Bundestag, discussed in Chapter 6 illustrates.

Expectations are interacting with each other ('network of expectations')

Expectations concerning the future of the energy sector may support technological expectations about fuel cells, while expectations regarding climate change may support expectations and visions regarding a change of the future energy system towards more sustainability. Conceptualizing different levels of expectations with respect to the object they refer to using the MLP, enables us to scrutinize these interactions. This way the interactions and relations between expectations referring to the three different levels can be analysed more profoundly which enables the researcher to gain a better understanding how these different kinds of expectations are influencing each other, eventually leading to hype-disappointment cycles. By applying this perspective, it becomes clear in how far expectations concerning the future framework conditions, such as the future socio-technical regime or the future socio-technical landscape of a technology, affect the expectations of the future of a technology as such. The approach developed, goes beyond the analysis of technological expectations and takes into account (changing) expectations about the mobility or the energy sector or the development of the society as such, systematically.

This thesis conceptualises and understands expectations surrounding a technology as a **network of expectations**. This network consists of expectations regarding different technologies, expectations and visions concerning the future energy/mobility system and concerning future developments at the societal level. These expectations interact with each other, providing momentum for a technology or lead to more pessimistic overall assessment of a technology. In the case of fuel cell technology, the linking of expectations concerning the future of fuel cell technology and the vision of a future hydrogen economy was crucial for the emergence of the hype around fuel cell technology. This example shows how the conceptualisation of networks of different types of expectations helps to understand the emergence of hype-disappointment cycles, and why 'the' expectations regarding a technology change so frequently.

Chapter 6 shows that expectations regarding the different levels are interacting in similar ways as developments in the 'real' world. As it is important to take into account the three levels of the MLP to understand 'real' world developments, the same holds true for the analysis of expectations. The relationship and linking of expectations referring to the future development of each of the three levels is key to understand the volatility of expectations. Expectations regarding the socio-technical landscape level, for instance an expected shortage of fossil energy resources, can link and re-enforce expectations about a future energy system based on renewables and hydrogen. These expectations again can and did link up with expectations about the prospects of fuel cell technology causing widespread optimism and interest. Changes in this broader network of expectations can lead to rather sudden changes in the assessment of a technology even though the expectations about the future performance and capabilities of a specific technology as such have not changed at all. In the case of the German debate on fuel cells, changes regarding the feasibility or desirability of a hydrogen economy (expectations referring to the future of the energy regime) were causing adjustments regarding the expectations concerning the development of fuel cells (niche level).

To conclude, it **proved useful to think about a network of expectations**, rather than of fuel cell expectations as such. Applying this perspective on fuel cell technology revealed new insights regarding the expectation dynamics observed in the past: It becomes clear that positive expectations regarding fuel cell technology alone were not sufficient to trigger large interest and the emergence of a hype situation. The relation between expectations regarding fuel cells and expectations regarding a future hydrogen economy and the link of these hydrogen expectations to expectations regarding an energy system based on renewable energy is crucial to fully understand the fuel cell hype around the turn of the millennium and its influence on transition processes.

Strategic (policy) implications

The results of this thesis have three major **strategic (policy) implications**.

First, positive, and in many cases overly optimistic expectations can act as a driver of change bringing together a large variety of actors. Even though initial expectations have to be adjusted and turn into disappointment in many cases, they can initiate innovation and transition activities. In order to use the momentum positive expectations or hype can create it is important to stabilize these expectations in forms of more stable institutions such as longer term funding schemes or commitments by a larger variety of actors (car manufacturers, suppliers, infrastructure providers, etc.). Thus, highly optimistic or even inflated expectations and visions (hypes) can have a positive effect with regard to innovation and transition activities. Nevertheless the frequently observed hype-disappointment cycles also have negative consequences, which leads us to the second policy implication

Second, policy actors have to be reflective about the strategic use of expectations and the specific role expectations have for transition activities. The results from this thesis indicate that innovations that are envisioned to be part of a wider system transition are more prone to hype-disappointment cycles (see Chapter 0). Incentives to hype are generally higher in case of such system innovations, since these kinds of innovations usually depend on the coordination and cooperation of a large variety of actors. As Chapter 4 demonstrates expectations are key for enactors (actors with stakes in a technology) to mobilize resources for their research and innovation activities. Enactors however do have incentives to inflate expectations concerning the technology they have stakes in. Selectors, those actors who decide about the distribution of resources, for instance research funding, have to base their decisions on the expectations put forward by the enactors and should take the incentives for enactors to hype into account. The empirical analysis of the behaviour of the auto manufacturer Daimler, a key actor with regard to fuel cell technology, discussed in Chapter 0, demonstrates that optimistic expectations were used as a tool to motivate other actors to join their transition activities. Daimler communicated very optimistic expectation statements to motivate other car manufacturers to develop fuel cell vehicles, which the management considered necessary to address the technological complexity, and probably even more important, to motivate infrastructure provider to build a hydrogen infrastructure. In the case of Toyota and HEV, however hybrid technology did not require motivating other actors to develop HEV, since there was no need for a new infrastructure and technological challenges could be managed within the company and its supplier networks. Thus it can be concluded that, the incentives to inflate expectations are higher when the innovation is more complex. This example shows that technological characteristics play an important role for the kind and intensity of hype-disappointment cycles.

The third major implication concerns the possibilities and limits of expectations management. On the one hand the analyses conducted, illustrates that a more active form of expectations management is necessary to use the positive effects of expectation dynamics, while avoiding the negative consequences of disappointment as far as possible. On the other hand however there are principle limits to the management of expectations. As the illustration of the 'enactor's dilemma' in Chapter 4 shows any form of expectations management has to deal with the situation that there are incentives to inflate expectations. Being aware of these underlying processes is probably a first step towards a more pro-active and reflexive form of expectation management. In addition the concept of networks of expectations can be a useful tool to better understand and finally manage expectations more actively and reflexively. The conceptual framework could be used to identify already established or emerging links of expectations causing momentum in the network of expectations. Beyond these already existing or emerging links the framework could be used to proactively identify potential or latent interactions possibly causing positive or negative dynamics in the future. Such an expectation management approach, still to be developed in more detail in further research, could help to develop a form of expectations management which does take into account potential changes in expectation networks ex-ante, instead of reacting only when negatives consequences of a disappointment have to be expected. Moreover the analysis presented in Chapter 6 reveals the power expectations can unfold as prospective structures. As some of the examples of names and scopes of policy initiatives show, the linking of expectations can have an impact on the governance structures. Thus this thesis supports the claim of several approaches in transition studies which emphasize the importance of policy actors to pro-actively engage in the shaping of expectations. This thesis adds to this proposition some reflections in how far expectations can be managed and with the concept of 'networks of expectations' an analytical tool to better understand the volatility of expectations and to anticipate potential dynamics in these expectations networks.

Outlook: The future of fuel cell technology

Looking at the case of fuel cells, or the competition for the dominant design of the drivetrain of the future, the race is still not decided. Even though fuel cells were not attracting large interest over the last few years, more recently the presentation of a number of new prototypes, in particular the Toyota Mirai (Japanese for 'future') raised interest for fuel cells again. In November 2014 Toyota announced that large progress was made and that the company will start sales of its Mirai fuel cell vehicle, by December, 15th 2014 (Toyota, 2014). Although this is not the first 'market introduction' of smaller fleets of several hundred vehicles the reports about recent progress with regard to cost reductions raised attention for fuel cell technology. Almost at the same time, the managing director of NOW the National Organisation Hydrogen and Fuel Cell Technology in Germany stated at a policy event: *'All the hopes we had and have in this technology, are justified [translated from German by the authors]*[107]*'* (Hydrogeit, 2014). Yet it is unclear if fuel cells will ever be diffused on a large scale. However, even if fuel cells may not play a role in the mobility and energy systems of the future, the experiences and learning effects of the past concerning fuel cells will eventually enable us to create a more sustainable society – with or without fuel cells. Thus, the efforts of all actors which have been involved in this innovation journey provided learning opportunities going beyond technological learning, whatever the future will look like. As one of the pioneers of the automotive industry formulated it once:

'Life is a series of experiences, each one of which makes us bigger, even though sometimes it is hard to realize this. For the world was built to develop character, and we must learn that the setbacks and grieves which we endure help us in our marching onward.' Henry Ford, 1863-1947. American industrialist. Founder of Ford Motor Company

[107] 'All die Hoffnungen, die man in diese Technologie gesteckt hat, sind berechtigt.' Original quote in German

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Samenvattning

Verwachtingen over nieuwe technologie volgen vaak een patroon waarbij perioden van hele positieve verwachtingen, hypes, gevolgd worden door perioden van teleurstelling. Elektrische auto's zijn een mooi voorbeeld: In de jaren 90 van de vorige eeuw dacht men dat het niet lang zou duren voordat de elektrische auto de vervuilende benzine auto zou vervangen. Slechts enkele jaren later was de hoop gevestigd op biobrandstoffen en brandstofcel technologie voor de auto van de toekomst, en werden elektrische auto's gezien als een mislukte technologie. Recentelijk hebben we weer een periode van zeer optimistische verwachtingen rond elektrische mobiliteit doorgemaakt hoewel in veel landen de realiteit achterblijft bij de verwachtingen en beleidsdoelstellingen.

Dit proefschrift analyseert de dynamiek van verwachtingen en de invloed van verwachtingen op innovatie-, en transitieprocessen voor brandstofceltechnologie. De analyses laten zien dat hypes niet alleen veroorzaakt worden door technologische verwachtingen maar door het samenspel van verschillende typen verwachtingen op verschillende niveaus, zoals bijvoorbeeld algemene verwachtingen over duurzaamheid of energie. Een hype ontstaat als de verschillende verwachtingen elkaar versterken en een "netwerk van verwachtingen" vormen.

Dit proefschrift laat zien dat deze hypes, ondanks de negatieve connotatie, een belangrijke rol spelen bij het motiveren en mobiliseren van de actoren die zich bezighouden met onderzoek en innovatie.

Curriculum vitae

Björn Budde (1984) is a researcher at AIT Austrian Institute of Technology. He holds a master degree in Socio-economics from the Vienna University of Economics and Business Administration (2007). He has completed his master studies with a thesis on the role of different spatial levels for the development and diffusion of fuel cell technology.

Since 2008 Bjoern works at the Innovation System Department of the AIT, in different academic and advisory projects related to Research, Technology and Innovation (RTI) policy. His focus is on (policy) strategies to support the emergence and diffusion of sustainable innovations in different domains.

Bjoern presented his research results at numerous international conferences and published his results in *Technological Forecasting and Social Change, Technology Analysis and Strategic Management, Environmental Innovation and Societal Transitions and Construction Innovation*. In 2010 he was awarded the best poster award at the EU-SPRI international conference on tentative governance in emerging science and technology.

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