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What happens after a hype? How changing expectations affected innovation activities in the case of stationary fuel cells

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Innovation processes are influenced by the dynamics of expectations. This paper addresses the question of what happens after a hype. It takes a closer look at the case of stationary fuel cells, for which a hype could be identified in 2001 followed by a clear downscaling of expectations and disappointment. Innovation activities, however, remained largely unaffected by the disappointment. We offer two explanations. First, only generalised expectations were adjusted after the hype, while overarching expectations (frames) remained stable and continued to legitimate the technology. Second, emerging institutional structures lead to increasing positive externalities thus stabilising ongoing innovation activities. These institutionalisation processes, again, were supported by a transformation of promises into requirements during the hype and the fact that the frames continued to legitimise the technology afterwards. We conclude with the proposition to differentiate disappointments according to which type of expectations changes after the hype.

Keywords: hype cycle; expectation dynamics; disappointment; innovation processes; stationary fuel cells

1. Introduction

The development of new technologies is often accompanied by hype, a phase characterised by an upsurge of public attention and high rising expectations about the potential of the innovation. Hypes are, per definition, followed by a considerable decline of attention that may go hand in hand with a disappointment of the hyped expectations. The ups and downs of expectations can have a strong impact on innovation processes. A hype phase with its enthusiastic expectations about the future of an innovation can add considerable momentum to the innovation process in terms of pace and direction. An increasing number and variety of actors may be attracted and further resources mobilised for the development of the innovation. If the hyped expectations are widely shared, they act as a coordinating device for the innovation activities of heterogeneous actors. The subsequent drop of attention and a disappointment of the hyped expectations may have negative

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effects on the innovation process. Failed expectations can undermine the reputation of the new product or technology and of its developers. As a consequence, resource mobilisation becomes much more difficult and actors may even withdraw from the field.

Science and technology studies examine hypes as part of the larger research agenda on expectation dynamics and their influence on innovation processes (Borup et al. 2006). A prominent theme is that expectations, once they become broadly shared, may act as requirements which can hardly be ignored by the innovating actors (van Lente 1993; van Lente and Rip 1998). Shared expectations thus not only mobilise resources but also guide and coordinate innovation activities. High rising expectations can even form a crucial impulse for the emergence of new technological or research fields (Felt and Nowotny 1997; Hedgecoe 2003; van Lente and Rip 1998). One of the major reasons for the emergence of hypes is the fact that actors strategically inflate and communicate technological promises in order to attract attention and resources (Brown 2003; Geels and Smit 2000; Guice 1999). However, here also lies a dilemma: while high promises are often necessary to attract resources, the risk that they cannot be fulfilled is also high. Non-fulfilled promises and a collapse of earlier expectations may cause high costs if they damage the reputation of the innovation or the whole technological field (Brown et al. 2003; Callon 1986).

The occurrence of hypes has as well inspired technology managers and consultants. The underlying rationale is that enterprises should not invest in a technology just because it is being hyped, nor should they ignore a technology just because it is not living up to early 'over-expectations' (Fenn 2006). The Gartner group advocates a so-called 'hype cycle model' which claims that new technologies typically pass several phases of visibility: A 'technology trigger' at the beginning of the cycle is followed by a 'peak of inflated expectations'. Then visibility passes through a 'trough of disillusionment' before reaching a 'slope of enlightenment' and a final 'plateau of productivity' (Fenn 2006). Although the proponents of the Gartner model acknowledge that these stages can be passed at different speeds and that 'unusual circumstances' may sometimes lead to different patterns, the claim that innovations will reach a productive phase sooner or later has to be questioned as we know from many abandoned technologies (Konrad 2004).

As was pointed out before, hype can be followed by disappointment, which can also have considerable impact on the innovation process. Such down-turns in expectations have been found to occur very rapidly, with potentially detrimental effects on the whole field (Brown 2003; van Lente 1993). It seems very common that early images of technological development do not materialise. This can be due to the strategic inflation of expectations but also because of several other reasons such as the fact that expectations tend to neglect the coupled nature of socio-economic and technological developments (Geels and Smit 2000).

Compared to the various analyses of the mobilising effects of hype, the study of disappointments and their effects on innovation processes has received much less attention in the STS literature. Nor does the Gartner model deal with the nature and effects of disillusionment phases in any detail. In this article we therefore address the question of what happens after a hype. What can be said about the nature of disappointments or disillusionments and how do they affect innovation processes?

The paper is based on an empirical analysis of the expectation dynamics and the innovation activities for the case of stationary fuel cells in German speaking Europe over the last decade. Stationary fuel cells can be used for distributed energy supply (power and heat) of residential buildings, offices, production facilities, hospitals, etc. They are currently applied in pilot projects and first field tests but still far more expensive than conventional energy supply alternatives (Adamson 2006; Markard and Truffer 2008a). For the electricity sector, a widespread diffusion of stationary fuel cells would represent a radical innovation (Markard and Truffer 2006).

Media attention for fuel cell technology strongly increased at the end of the 1990s and peaked in 2001 before it came to a clear drop of public interest. Highly optimistic expectations about a short-term commercialisation of stationary fuel cells which had to be adjusted significantly afterwards confirmed the occurrence of hype at that time. Innovation activities, however, largely continued after 2001. Only some projects were abandoned and even new activities were launched.

We make three claims in order to explain these developments. First, a decline of previously high media attention does not necessarily imply that there is also a disappointment of expectations. Both attention and expectation cycles may coincide but are not necessarily coupled. Second, some types of expectations may be sharply adjusted after hype while others remain unchanged. In the case at hand, overarching expectations (frames) about the role of fuel cells in society remained positive and continued to legitimate the technology, while more specific expectations about applications and commercialisation perspectives were tuned down significantly. We thus propose to differentiate disappointments according to which type of expectations changes after the hype. Third, the effect of disappointments on the innovation process also depends on structural developments in the field. More formal, supportive institutions that have emerged during the hype phase can back-up innovation activity in a later phase of disappointment.

The remainder of this article is structured as follows. After an introduction of the key terms of our analysis and the methods used (Sections 2 and 3), our empirical findings on the development of expectations in the case of stationary fuel cells are presented in Section 4. We introduce the types of expectations identified and their change over time before we interpret their development in terms of expectation dynamics. Section 5 then provides evidence on the development of innovation activities and Section 6 develops explanatory elements for the observed development of expectations and innovation activities. The results suggest conceptual refinements of typical hype dynamics which are discussed in a concluding section.

2. Concepts and definitions

In this section we reflect and define the key terms of our analysis, namely hype and disappointment. We also discuss potential developments in a technological field after a hype phase.

Hype is a contemporary term but of hybrid origin and has thus different meanings. It partly originates from 'hyperbole', which according to the American Heritage Dictionary is 'a figure of speech in which exaggeration is used for emphasis or effect'. Hype therefore stands for 'extravagant claims' that can be deliberately misleading or deceiving. At the same time, hype can be understood as 'excessive publicity' due to the attention a subject receives for example in the mass media. The notion of hype is thus charged with a rather negative connotation, and implies a drop of publicity as well as the possibility of disillusionment or disappointment of extravagant claims. In the following we will use the term hype for a combination of a phase of high media attention *and* of high rising expectations, which can turn out to be exaggerated *ex post*. Hype culminates in a peak of attention and of expectations, and is followed by a decline or downturn of both. It can only be detected *ex post*. Typically, increase as well as decline of media attention is steep, and the decline should be significant but does not have to go back to zero (cf. Figure 1).[1] Increase and decline of expectations are more difficult to identify and require a qualitative analysis of future images, which are for example expressed in newspaper articles. As an indicator for hyped expectations, we take a peak of highly optimistic, extravagant or enthusiastic and largely uncritical expectations. Before and after the peak, expectations are less optimistic, more critical or negative. Note that a single peak represents just a stylised pattern for a limited time span. Actual developments may

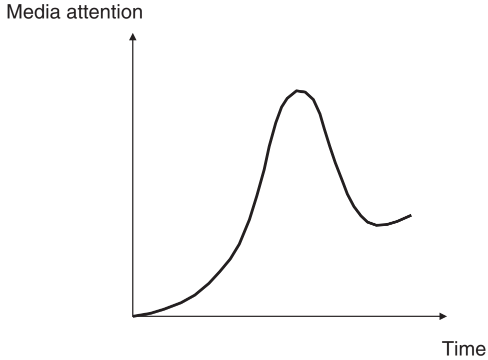

Figure 1. Stylised ups and downs of media attention in case of hype.

be more complex as they encompass, for example, subsequent peaks or waves of enthusiasm and concern (Geels, Pieters, and Snelders 2007).

Disappointment can be defined as a 'feeling of being let down: a feeling of sadness or frustration because something was not as good, attractive, or satisfactory as expected, or because something hoped for did not happen' (http://encarta.msn.com/dictionary_). Disappointment, or disillusionment, is clearly related to failed expectations, i.e. if technological development is perceived as not living up to the former promises. According to the conclusions drawn from the disappointing technological results, the expectations will be adapted (e.g. scaled down), criticised or abandoned.[2] Failed expectations and disappointing results are not as widely publicised as positive expectations, and thus more difficult to identify at the level of a technological field than hype, but as an indicator for widely disappointed expectations, we assume to find a change towards negative or at least more moderate (adapted) expectations expressed in the same newspapers.

With these definitions, we conceptually separate attention and expectations. We argue that hype, and especially disappointment, cannot be deduced from a peak (and decline) of media attention as attention and expectations are not necessarily related. We know from studies on so-called 'issue-attention cycles' (Downs 1972) that public attention to politically relevant issues such as environmental problems can rise and fall more or less independently of the factual development of the underlying issue (Newig 2004). Or issues remain on the public agenda on a higher level after an attention cycle and may be more easily activated for a new cycle (Newig 2004). Note that our definitions are based on coupled attention and expectation dynamics. A phase of high media attention without highly optimistic expectations, for example, is not considered as hype and a drop of media attention has to be accompanied by clear changes at the level of expectations in order to mark a disappointment.

Hype and subsequent disappointment can affect innovation processes. The emergent effects of hypes are rather well described while the impact of disappointed expectations on technological development has not been as systematically examined. Failed expectations can have more or less detrimental effects on an innovation process. They may damage the reputation of an innovation and weaken the trust relationships among the actors in that field (Brown 2003). As a consequence, additional resources will be more difficult to mobilise. If a vicious cycle of disappointment (cf. Schneider 1989) occurs, more and more innovation actors give up their technological development projects and the field might eventually be abandoned.

In principle, technological development can either be affected by hype and subsequent disappointment or not and effects can be severely negative or less far-reaching. For the following, we distinguish three stylised patterns of development that we may think of. These patterns represent guideposts for our analysis of innovation dynamics in Section 5. First, innovation activities may be cut down drastically and the technological field may finally be abandoned (innovation abandoned). Second, activities may be slowed down and overall efforts reduced significantly or get directed at different specifications of the technology (innovation delayed or modified). Third, we might also see a development in which projects largely continue without any major backdrop of innovation activity. Activities can get somehow re-aligned or adapted but the remaining efforts basically follow the same targets as before the hype (innovation sustained).

3. Sources and methods

For an empirical study of hype and disappointment, we analysed publicity, expectations and innovation activities. The analysis of publicity and expectations and their change over time allowed us drawing conclusions about the occurrence of hype, while disappointment was mainly assessed on the basis of changing expectations. Innovation activities were analysed with several indicators at the level of the technological field. Details on the methods are given below. In our analysis we concentrated on stationary fuel cells and we limited the scope to German speaking Europe. In temporal terms, the time period from 1993 to 2007 was covered.

Publicity, or media attention, was measured by frequency analyses of the occurrence of the German term for fuel cells 'Brennstoffzelle*' in major German speaking daily newspapers. We determined the number of articles in which the term was mentioned with full text-searches in the electronic archives of the following newspapers: Frankfurter Allgemeine Zeitung and Süddeutsche Zeitung for Germany, as well as Neue Zürcher Zeitung for Switzerland.[3] We differentiated articles that concentrated on stationary fuel cells from those with a focus on mobile fuel cell applications (cars or buses) and more general articles.[4]

Expectations were assumed to be expressed in public discourse. The emergent quality of discourses corresponds well to the nature of collective technological expectations and their role in innovation processes (Konrad 2006).[5] Thus, newspaper articles about fuel cells of the four German and Swiss newspapers also formed the source for the analysis of expectations, which were examined in an in-depth, qualitative discourse analysis (Keller 2005). We concentrated on the future-oriented part of the mass media discourse on stationary fuel cells to track the change of expectations over time. Expectations were understood as 'real-time representations of future technological situations and capabilities' (Borup et al. 2006, 286) and operationalised as future-oriented statements or phrases with explicit or implicit references to the future of fuel in the press articles. An important assumption of our analysis is that expectations expressed in those articles, with the exception of statements referring to (place-) specific projects or products, are accepted or shared – or at least broadly visible – and thus relevant at the level of the technological field.

For the discourse analysis, we selected articles about fuel cell technology in general and/or about stationary applications, excluding those dealing only with mobile or portable fuel cells. Furthermore, we limited our sample to articles of impair years (1993, 1995, … 2005), i.e. we examined only half of all available articles in the selected period. A sample of 46 articles longer than 200 words mentioning fuel cells in their title or headlines was analysed in full text – each document representing a 'fragment of discourse' (Jäger 1999). We adopted a grounded theory approach (see e.g. Strauss and Corbin 1996) to identify relevant types of expectations.

The innovation activities were tracked with the help of different publicly available data sources (databases, event calendars, websites, newsletters, newspapers, professional magazines, reports, etc.). We set a focus on Germany, as a large part of the European fuel cell activities is carried out in this country (Geiger 2003). A general challenge was to get access to data that could be related to stationary fuel cells in Germany. Where this information was not readily available, we also refer to data on fuel cells in general or complemented the picture by developments at the international level. In summary, we tracked scientific publications and publications in the larger field of fuel cells in Germany and internationally which we complemented by data on conference activities related to hydrogen and fuel cells in Germany. We also traced the development projects of the key firms including manufacturers of stationary fuel cells and utility companies active in the German market. In addition, the emergence of fuel cell networks and initiatives as well as the set up of research and development programmes at the national and sub-national level were observed. While we were able to cover different dimensions of the emerging innovation system, our analysis did not cover all potential indicators nor did we carry out an encompassing assessment in terms of innovation system functions. As a matter of fact, we tried to identify the general pattern of technological development (cf. Section 2).

It is important to note that the differentiation between discourse and innovation activities, which is necessary for an assessment of how expectations influence innovation processes, is not always straightforward as both may be closely intertwined. Innovation activities are often coupled with discourse activities, and discourses hold information about innovation activities (e.g. a fuel cell manufacturer usually communicates the launch of a new prototype in a press release). Conferences are a typical example for which the analytical distinction is ambiguous. We regarded them as innovation activities because they promote knowledge diffusion but, at the same time, they serve as platforms of discourse at which expectations are generated, exchanged and adapted. As shown below, conference activities indeed seemed to follow attention dynamics rather closely.

4. Media attention and expectations

This section presents the empirical findings from the frequency analysis and the discourse analysis. We will show that the attention cycle related to fuel cells in the mass media provides a first hint to a hype phase. The results from the discourse analysis support this interpretation: expectations changed significantly over the whole period and exhibit a particular form of a hype and disappointment dynamic.

4.1. *Development of media attention*

Media attention to fuel cells in general shows a remarkable increase from 1993 onwards and a peak in 2001 with more than 200 articles in the three daily newspapers we looked at. At that time, fuel cells were mentioned on average in more than every fifth issue of each newspaper (cf. Figure 2).[6] The peak was followed by a significant drop of attention until 2004 when attention was about half as high as in the peak year. Since then, overall attention on fuel cells has risen again to a level comparable with the year 2000. This recent increase, however, can mainly be attributed to mobile fuel cell applications, while attention for stationary fuel cells remained at about the level of 2004.

Note that on average about 50% of all articles had a focus on mobile applications and just 25% concentrated on stationary fuel cells. Around 2001, however, the difference between mobile and stationary was less accentuated (38% to 28%). As a consequence, the attention peak and the subsequent decline are much more pronounced for stationary fuel cells (see Figure 3). A guiding

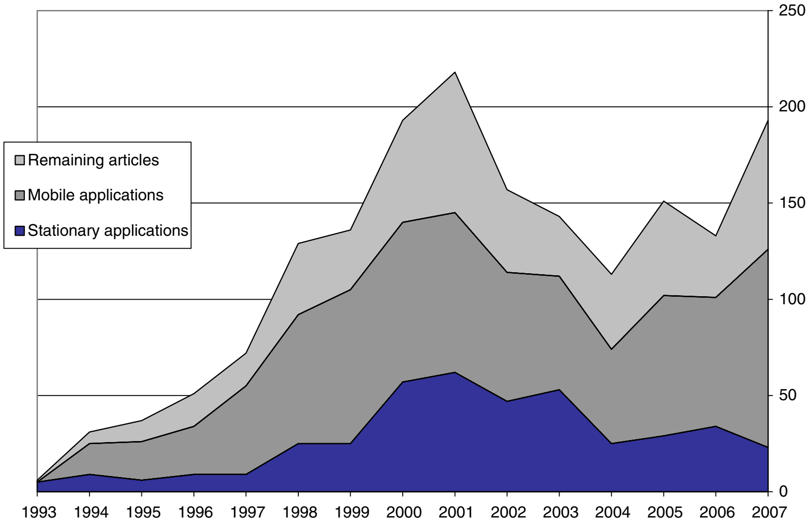

Figure 2. Articles on fuel cells in three German-speaking daily newspapers.

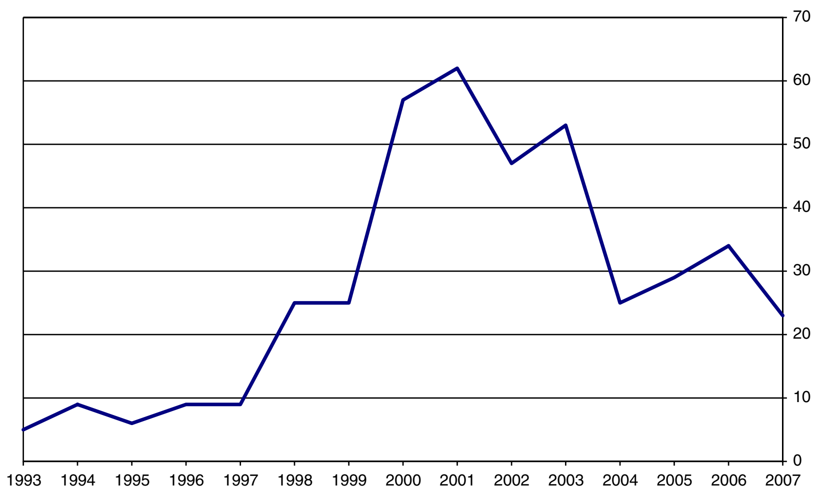

Figure 3. Articles on stationary fuel cells and resulting media attention curve (enlargement of data from Figure 2).

hypothesis for the following discourse analysis was thus that highly optimistic expectations might coincide with the peak of publicity in 2001.

4.2. *Types of expectations*

In the discourse analysis, we identified three different types of expectations: *product- or project-specific expectations*, *generalised expectations* about the future of the technological field, and interpretative schemes *or frames* referring to the role of fuel cell technology in society.[7] Future characteristics of fuel cells specific to products or projects are usually expressed in statements of individual actors (*specific* expectations). Expectations referring to *generalised* features of stationary fuel cells are rather expressed in impersonal statements (*generalised* expectations). Both types can contain more or less detailed or vague information about the expected potential, application contexts, the time frame for commercialisation, etc. Frames, the third type of expectations, are of a different nature. They are rather overarching expectations which place the technology in the context of generic societal problems or visions.[8] Such more or less explicit references to scenarios or concepts such as climate change or technological progress underline the usefulness or legitimacy of the technology.

The three inductively identified types of expectations are comparable to typologies proposed in the STS literature on expectations. Most authors distinguish at least two types of technological expectations: (i) (place-)specific expectations about specifications of the artifacts, systems or processes to be developed; also called 'search expectations' (cf. Geels and Raven 2006); and (ii) generalised expectations about functions the technology is presumed to fulfill in the future, or about opportunities the field offers. Some scholars also identify a third type: (iii) socio-technical visions in the form of scenarios about the technology as a whole, about social, political and economic aspects of the new technological field or about broad societal trends (Konrad 2006; van Lente 1993; van Merkerk and van Lente 2004), while others rather see 'external circumstances' at work (Geels and Raven 2006). Our three types of expectations correspond quite well to types (i)–(iii) as they both distinguish different groups of objects the expectations relate to, i.e. application specific, general and broader societal aspects of the innovation.[9]

In the following we will describe the development of expectations about stationary fuel cells in detail. We will concentrate on *generalised expectations* and *frames* because we are mainly interested in collective expectations to trace the effects of expectation dynamics. As a general finding, we can say that all three types of expectations changed over time but not in the same way. Specific and generalised expectations developed in a parallel way with significant changes in terms of vagueness, optimism and time horizons for commercialisation. Frames also changed as some of them gained or lost importance over time. However, the framing of fuel cells remained very positive over the whole period and seemed to develop rather independently from the other two types of expectations.

4.3. *Development of generalised expectations and frames*

With regard to the development of expectations, we distinguished three major periods: A period of public rediscovery[10] of fuel cells from 1993 to 1997, a hype phase with high expectations (1999–2001) and a subsequent period of adjusted expectations, which we call disillusionment (2003–2005). Very recently (i.e. in 2007), new optimism seems gain ground with niche-applications of uninterruptible power supply systems becoming commercially available, but it is yet too early to tell whether this already marks the end of the phase of disillusionment.

Changes of the generalised expectations

The generalised expectations changed not only with regard to the future they depicted for stationary fuel cells, but also in the way they were expressed. Table 1 depicts the main changes identified over time.

The *rediscovery period* (1993–1997) was characterised by rather vague expectations about the future of fuel cells. Thanks to its high (future) degree of efficiency, the technology was thought to

Table 1. Changes of the generalised expectations.

	Rediscovery 1993–1997	Hype 1999–2001	Disillusionment 2003–2005
Function	Electricity production	Cogeneration, heating	Energy production
Application	Small power plants for industrial or public use	Residential energy supply systems (fuel cells combined with gas boilers) for private use or Small power plants for industrial or public use	Cogeneration of heat and power for private, public or industrial use, eventually combined to virtual power plants
Capacity	Not specified (about 50–200 kW)	1–5 kW or 100–300 kW	1–5 kW or 100–300 kW
Time horizon for commercialisation	Not specified (many years to go)	Short-term (3–4/4–5 years), about 2003–2005	Medium- to long-term (up to 10 years), about 2010 or later
Vagueness	Very high	Low	High

be promising for energy conversion, mainly for electricity generation. If application fields were differentiated, 'small' or 'compact' fuel cell power plants were mentioned as future stationary applications. Commercialisation prospects were hardly discussed. It seemed to be clear, however, that the technical development was quite advanced (at least for certain types of fuel cells) while still requiring many years of research and development.

In the *hype period* (1999–2001), the number of specific statements about applications and commercialisation prospects strongly increased together with increasingly optimistic vague expectations about the potential of fuel cells. The functional focus shifted from electricity production to cogeneration, and the relatively new idea of heating private buildings with micro fuel cells (1–5 kW, combined with gas boilers) moved to the centre of interest. Indeed, expectations about this particular application – referred to as 'fuel cell heating systems' – dominated the discourse. Residential cogeneration was seen as a highly promising field for the commercialisation of stationary fuel cells, and the first serial productions were expected to start in less than five years (i.e. by 2003 or 2004). Only a few more reluctant voices warned from too much euphoria, but their time horizon was not much longer, i.e. commercialisation by 2005 or 2006, or in the second half of the decade.

In the *disillusionment* phase (2003–2005), no such specific forecasts were made anymore. As a matter of fact, the goals of the hype phase had not been achieved or seemed not realistic any more, even if this was not directly expressed in the articles. For the first time, hurdles on the way to commercialisation were broadly discussed, emphasising above all the necessity of cost reduction, but also technical requirements (such as a long enough lifetime) still to be reached. A wider introduction of fuel cells into the market was now expected to require another 10 years; at least it seemed not realistic anymore before 2010. Residential cogeneration still received a lot of attention, but a range of other stationary applications were considered similarly promising for decentralised energy supply (heat/steam and power). In this context, the idea of virtual (fuel cell-) power plants was occasionally referred to.[11]

Changes of the frames used

Table 2 provides an overview of the frames identified in the discourse. Most frames were used in parallel, but some gained particular weight during one of the periods. The dominant frames (highlighted in the table) are briefly characterised below.

During the whole *rediscovery period* (1993–1997), the development of fuel cells was mainly framed as part of 'technological progress'. In this frame, progress is an intrinsically positive phenomenon which is very often implicitly alluded to. Fuel cells were presented as a 'new' technology which was going to achieve product status (and contribute to a 'better world') sooner or later. In this context, investments in fuel cell projects did not need any justification – on the contrary, because the progress of this technology ought not to be stopped. Other frames such as the 'protection of climate and environment' or 'energy supply' were used to underline the contribution of the new technology to the solution of existing problems.

The frame of 'market potential', which was used only occasionally in 1997, became dominant in the *hype period* (1999–2001). The development of fuel cells was increasingly seen as lying in firms' strategic interest in new products and markets. On the one hand, first mover advantages were (implicitly) assumed to be an important motivation for 'pioneer' firms to invest in fuel cell

Table 2. Overview of frames identified in the discourse analysis.

Context	Frame	Role of fuel cells in the scenario	Occurrence
Progress* (society)	Technological progress	Part of the process of ongoing evolution towards 'better technologies'	mainly 1993–1997
	Revolutionary potential	Substitute conventional heating systems and change decentralised energy supply	2003–2005
Ecology (environment)	Protection of climate and environment	Prevention of pollution and climate change (no/less CO_2 emissions)	1993–2005, always in combination
	New energies	Provide (transition to) non-fossil energy	1993–2005, always in combination
	Hydrogen economy	Key technology in new energy 'era', in combination with hydrogen	2001, 2003–2005
Energy policy (politics)	Energy supply	Provide an alternative to secure (national) energy supply	1993–2005, always in combination
	Decentralisation	Part of the trend towards more decentralised energy production	2003–2005
Strategy† (economy)	Market potential	Promise new markets and opportunities for first-movers resp. challenges for others	1997, mainly 1999–2001, 2003–2005
	Utilities	Opportunity to stay competitive in changing (liberalising and decentralising) energy sector	1999–2001, 2003
	Nations	Opportunity for a nation (or Bundesland) to develop a hightech-industry resp. technology in which it has to stay competitive with others	2003–2005

Notes: *Cf. Van Lente's (2000) description of the ideograph of technological progress and the narrative of 'Inevitability and technological progress' (Eames et al. 2006).
†Cf. the narrative of 'staying in the race' (Eames et al. 2006).

projects. On the other hand, the competition to 'stay in the race' was seen as a driver for the commitment of others. Both version of the frame – market opportunity vs competitive challenge – were found for manufacturers as well as for utilities, but by 2001, fuel cells were more and more often presented as a competitive challenge about future market potential. During the hype, the other frames were less often used, but a new frame underlined the great potential the technology was ascribed: the vision of an emission free energy future, a 'hydrogen economy' with fuel cells as a key technology.[12]

During the *disillusionment* phase (2003–2005), the strategic frame of 'market potential' was less prominent than in the hype phase, and it was mostly used to emphasise the competitive challenge imminent for the heating and the utility sector. Instead, the frame of competitive challenge between nations gained increasing importance during this period. It was used above all to underline the need for political support and funding for the technology. The trend towards a higher degree of 'decentralisation' in the energy sector appeared as an opportunity for the market introduction of stationary fuel cells. Occasionally, the technology was even assigned the potential to revolutionise energy supply as a whole. In the context of climate change, fuel cells were more and more associated with renewable energy (biogas etc.) in recent years, while at the same time the frame of a hydrogen economy was discussed increasingly critically.

4.4. *Interpretation of expectation dynamics*

The change of expectations together with the peak in public attention in 2001 and the subsequent decline can be interpreted as a hype-disappointment dynamic. Different aspects point to hyped generalised expectations in the period from 1999 to 2001. First, the increasing focus on one particular application of fuel cells, i.e. residential energy supply systems, for which high market potential was imagined. Second, the sudden belief in short-term commercialisation prospects and mass production within less than five years. Finally, there was a striking bias towards the advantages and the ecological potential of fuel cells combined with a quasi-absence of any critical discussion of technical or economic problems on the way to commercialisation.

After the hype, expectations had become less optimistic and more critical, but not negative. The formerly enthusiastic expectations were clearly adjusted: The expected time horizon became longer and more vague. Problems and additional requirements of the techno-economic development now took a prominent place in the discourse and applications for decentralised energy supply were discussed more generally, though previously hyped residential application was still on the agenda. We interpret this scaling down of expectations as an indicator for a moderate disappointment in the field.

In contrast to the generalised expectations, the framing of fuel cells remained stable over the whole period. All frames ascribed positive future roles to fuel cells and the general technical feasibility or usefulness of fuel cells was never questioned. The framing of fuel cells also relates to the broader vision of a hydrogen economy.[13] Due to stable, positive framing the general legitimacy of fuel cell technology remained intact. In fact, the frames acted as a stable backbone, which alleviated a positive interpretation of non-fulfilled specific and generalised expectations. Instead of a downright negative interpretation of failed expectations, an adjustment or scaling down of expectations was thus possible and legitimate. Had the framing been less positive or even negative after the hype, we might have seen a far more pronounced disappointment.

We can also conclude from the discourse analysis that expectations transformed from promises into requirements (cf. van Lente and Rip 1998). In the hype phase (1999–2001), the frame of strategic interest became increasingly dominant, and the framing switched from market opportunity to competitive challenge during that period. In other words, the promising opportunity of 'conquering' the future market for fuel cell heating systems was more and more communicated as a requirement to stay competitive. The two formerly independent sectors of electricity supply and heating had started a competition for the supposedly promising field which increased the pressure for incumbents from both sectors to become active. After the hype, the frame of strategic interest was rather used to underline the challenge for nations to stay competitive in technology development. In the context of the climate change discussion, fuel cell technology was still ascribed a great potential in the future energy economy. As a result of constantly positive framing and the transformation of promises into requirements, the need for further investments and continued efforts was (and could be) stressed in the post hype fuel cell discourse. We will now turn to the question how innovation activities developed before and after the hype.

5. Innovation activities

In the following we give an overview of the results from our analysis of innovation activities including scientific publications and patents, conference activities, major R&D activities of private firms, the development of innovation networks and public funding. From these indicators we conclude that technological development in the period from 1993 to 2006 is characterised by a considerable rise of activities at the end of the 1990s without any notable break-in after the end of the hype in 2001.

5.1. *Scientific publications and patents*

At an international level, scientific publications related to fuel cells increased continuously since the 1990s. An analysis of all publications indexed in the Web of Knowledge shows a considerable increase from about 100 publications per year in 1993 to more than 1400 in 2007 (see Figure 4).

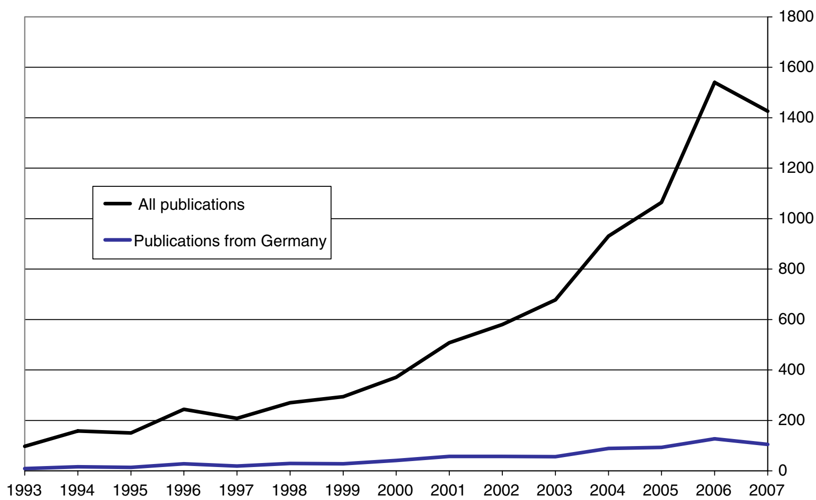

Figure 4. Scientific publications related to fuel cells from 1993 to 2007.

Fuel cell publications by authors from Germany show a very similar development over time. They account for a share of about 7% of all articles.

Fuel cell patents filed at the European Patent Office also showed a significant increase over time. The share of fuel cell patents in total patent applications rose from about 0.10% in 1990 to about 0.70% of national total patents in 2004 with a sharp increase since 1997.[14] Germany contributed on average about 15–20% of all fuel cell patents over time, being the second (1995–1999) or third main contributor after the USA and Japan (2000–2004).

5.2. *Conference series*

From 1999 on, German-speaking Europe shows a bulge of interest in fuel cells in terms of conference activities. While only a few conference series about hydrogen and fuel cells were held annually or bi-annually during the 1990s, quite a number of new series were launched especially in 2001 and 2002 (see Figure 5).[15] Later, several of the conference series were stopped, mostly in 2005 and 2006. As a matter of fact, the majority of the conference series still exist today and all of the new series survived for at least three to four years. Despite a slow-down of the conference activities in recent years, the number of conference series kept up in German speaking countries clearly indicates a sustained interest in fuel cell technology.

5.3. *Public funding*

In a similar vein, German public funding of hydrogen (H2) and fuel cells (FC) shows a steep increase from 1999 on, especially since 2002 (see Figure 6). Public funding programmes for hydrogen and fuel cells had already existed since the 1980s but were subject to major cuts during the 1990s. In 2000 and 2001, however, Germany launched extra programmes for hydrogen and fuel cells: a special programme for residential fuel cell power plants, and the Zukunfts-Investitions-Programm, from which more than half of the funds for fuel cells (about €60 million for three

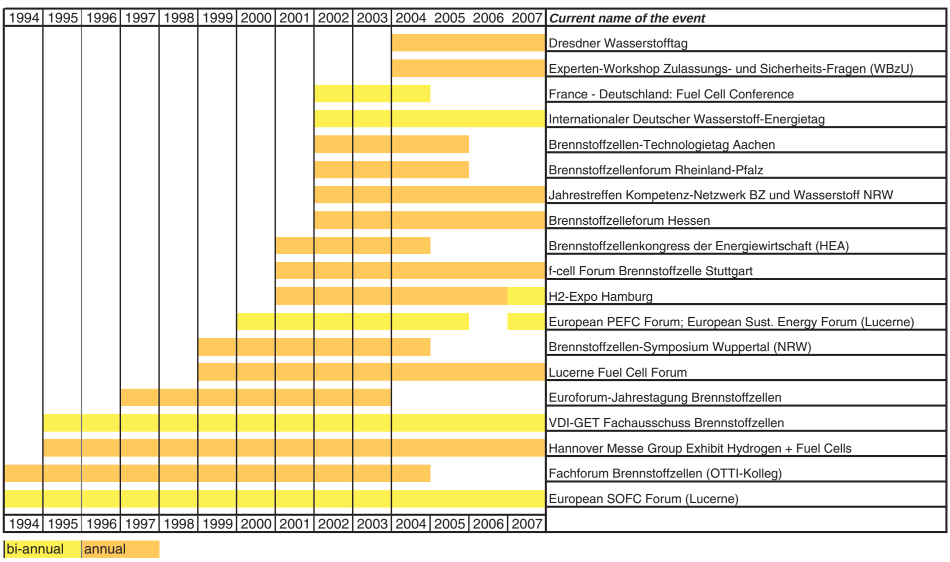

Figure 5. Development of conference activities in German-speaking Europe from 1994 to 2007.

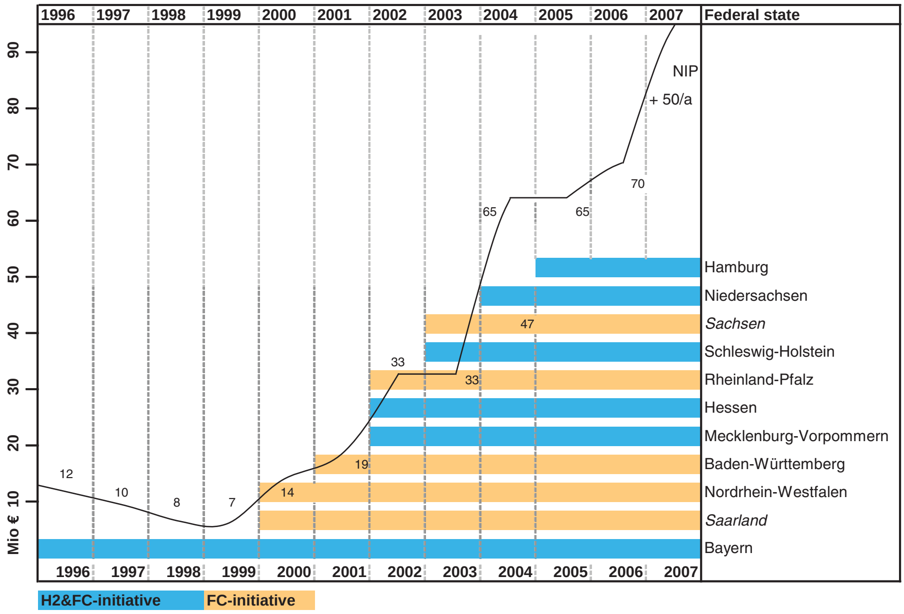

Figure 6. Public funding and fuel cell initiatives in Germany since 1996 (€ millions).

years), flew into stationary applications (Weider, Metzner, and Rammler 2003). Furthermore, a law supporting cogeneration of heat and power was enacted in 2002, which provides a bonus for small cogeneration units (<50 kW) such as fuel cell heating systems (Kraft-Wärme-Kopplungsgesetz 2002). In the same period of time (2000–2005), many of the German Bundesländer launched their own initiatives to foster high-tech fuel cell and hydrogen R&D activities and collaborations in their territories.[16]

5.4. *R&D projects of fuel cell manufacturers and utility companies*

Industrial R&D activities for stationary applications increased already since the end of the 1990s and there were a number of new entrants in the field of small fuel cells below 10 kW_{el}. Originally Sulzer-Hexis was the only company active in this particular application area in Europe but from 1997 on, R&D activities for fuel cell-heating systems were started by many of the established manufacturers in the field of boilers for residential heating (Figure 7). In the area of medium size fuel cell power plants (200–250 kW), the two major manufacturers remained active over the whole period although their firm structures changed. The activities of the only new entrant in this segment, Ballard's German subsidiary, were closed down again.

In the field of small stationary applications several manufacturers reached the field test phase and developed new generations of their fuel cell systems. However, contrary to earlier announcements, none of them was able to commercialise their products so far. Most prominent was the cut back of activities at Sulzer-Hexis in 2005, and there are no news available from the fuel cell programme at BBT Thermotechnik. The other firms have carried on their activities until today.

The commitment of electricity and gas suppliers to fuel cell R&D saw a phase of early adoption at the beginning of the 1990s followed by some kind of backdrop and an increasing interest since

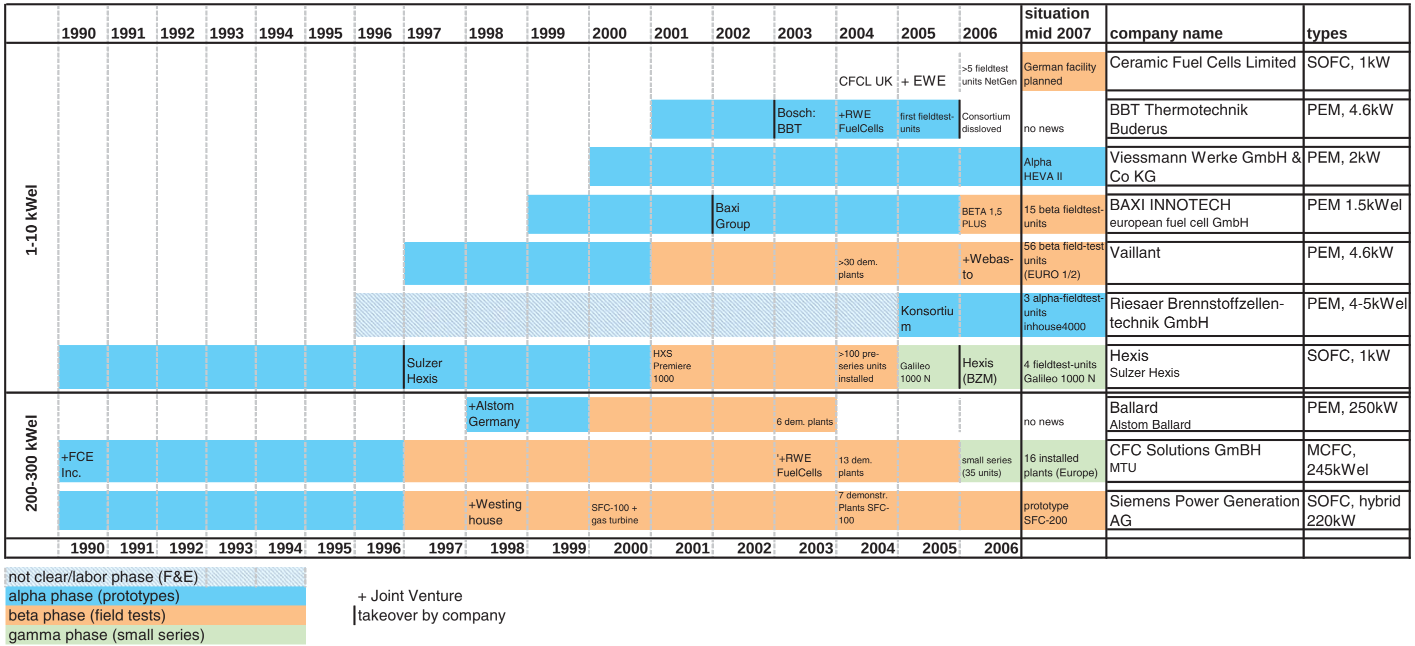

Figure 7. R&D projects for stationary fuel cells of firms (active in Germany) since 1990.

the end of the 1990s (Markard and Truffer 2008a). Many of the early demonstration projects of utility companies with Onsi's 200 kW Phosphor Acid fuel cell, which were set up at the beginning of the 1990s, saw no follow up and some of the early adopters chose an observation strategy afterwards. Since 2000, however, many utilities have taken up fuel cell activities (again) and showed special interest in the residential fuel cell market and the possibilities of integrating decentralised cogeneration units into so-called virtual power plants (Markard, Truffer, and Imboden 2004; Markard and Truffer 2008a). Most prominently, big German utilities such as EnBW, RWE or Ruhrgas/E.ON intensified their fuel cell activities and adopted quite dedicated strategies. R&D projects are carried out with different partners and types of fuel cells (above all PEM and SOFC of different capacities). With the exception of a larger international project on an MW-class fuel cell power plant,[17] no failures or abandonment of demonstration projects are known.

5.5. *Networks and initiatives*

Besides joint ventures and inter-firm partnerships (between suppliers, manufacturers and utilities), bigger networks and fuel cell initiatives (with members from different sectors and public funding) have been initiated since the year 2000. In the field of stationary applications, a number of utilities (EWE AG, MVV Energie AG, E.ON Ruhrgas AG, and VNG AG) launched the 'Initiative Brennstoffzelle' in 2001. Together with leading manufacturers, the utilities aim at fostering the commercialisation of residential fuel cell systems. As mentioned above, a growing number of German federal states initiated their own fuel cell or hydrogen initiatives together with industrial partners since 2001, only the programmes of Bayern, Baden-Württemberg and Nordrhein-Westfalen dating back to the end of the 1990s. The year 2004 saw the foundation of the Brennstoffzellen-Bündnis Deutschland BZB bringing the 20 leading associations and fuel cell initiatives together with another 300 members to mobilise political support for the technology.

5.6. *Interpretation of innovation dynamics*

At the beginning of the 1990s, R&D activities were slightly increasing and there were a few large industrial companies concentrating on the development of medium size fuel cells in Germany. Public funding was reduced at the same time. Since the end of the 1990s, the number of firms involved in stationary fuel cells increased considerably and so did pilot projects, development activities, etc. Most remarkable is the growing number of firms (manufacturers and utilities) engaging in the development and testing of residential fuel cell heating systems since 1999. Simultaneously, innovation networks not only grew larger but also showed an increasing number of formalised relationships such as joint ventures, officially announced co-operations or alliances. After the hype in 2001 and up to now, there was no major decrease in innovation activities – except for the number of conferences. While single conferences were already reduced from 2002 on, conference series were only terminated from 2005 onwards. The field also saw some reduction of R&D activities of industrial firms but hardly any quit the field. However, many new partnerships and initiatives were founded and even new conference series on hydrogen and fuel cells were initiated after 2002. In particular, political support for the development and commercialisation of fuel cells gained importance with several public-funding programmes in Germany making special allowances to residential fuel cell applications.

This development largely corresponds to the pattern called 'innovation sustained' introduced at the end of Section 2. Innovation activities continued and institutional structures even grew stronger despite the hype and the subsequent adjustment of the earlier expectations. In particular, the considerable amount of activities initiated in the field of small stationary applications (residential cogeneration systems) since the end of the 1990s proved to be basically sustainable even after the hype.

The survey of innovation activities also showed clear signs of institutionalisation processes including, for example, the formation of fuel cell associations, of committees concerned with standardisation or the set up of public research programmes and funding schemes. In other words, emerging niches for the new technology at the firm level and in the energy sector were increasingly supported by a broad set of institutions (Bender 2005). This was complemented by the emergence of various innovation networks at a national and international level. Although our analysis was not encompassing enough to track all the different elements of innovation activity, we might even say that we observed the emergence of a technological innovation system (cf. Markard and Truffer 2008b) in our case.

6. Conclusions

From our analyses we conclude that there was hype around stationary fuel cells in German speaking Europe with an attention peak and highly optimistic expectations in 2001. This was followed by a drop of attention and a clear downscaling of generalised expectations which we interpreted as a moderate form of disappointment. Innovation activities, remained largely unaffected by the end of hype. Our explanation for the ongoing innovation activities is based on two major elements.

First, the stable and constantly positive framing of fuel cell technology supported its legitimacy before as well as after the hype. This prevented a strong disappointment and allowed adjusting the generalised expectations to longer time horizons. The technology as such was not put into question and the non-fulfilment of earlier promises was not interpreted as a general failure of the technology. On the contrary, several frames were available that emphasised the importance of further enhancing fuel cell development in order to reach the positive future sketched in the scenarios. The strong and intact legitimacy of fuel cells after the hype, in other words, limited the negative effects of disappointed expectations on innovation activities.

Second, emerging institutional structures lead to increasing positive externalities in the field of stationary fuel cells. As a matter of fact, they stabilised ongoing innovation activities and triggered even new ones although the earlier expectations were not met. Institutionalisation processes went hand in hand with the partial alignment of innovation activities of different actors towards residential energy supply, which might even be interpreted as a phase of path creation and subsequent path dependency.

These institutionalisation processes, again, can be linked to the dynamics of expectations. When promises were transformed into requirements during the hype phase, many innovation projects were started and new players entered the field, above all competing for the development of residential fuel cell systems. Expectations thus contributed to mobilising private and public actors and they also guided innovation activities toward a particular application of the new technology. Moreover, the stable, positive framing of the new technology supported the emergence of institutions as it provided legitimacy.[18]

6.1. *Conceptual refinements*

Our analyses were guided by the question of what can happen after a hype. Now, we propose some conceptual refinements, which in our view are able to explain a broader range of real world developments than the traditional hype-disappointment concept. Our proposition is based on the assumption that frames and generalised expectations can develop and change rather independently.[19] This was the case in our example but still has to be confirmed in other empirical studies.

Our suggestion is to distinguish frames as well as generalised expectations according to whether they depict the corresponding innovation either in a positive or in a negative way. Then we get four stylised patterns of hyped expectations over time (cf. Figure 8).

At the beginning (i.e. before a hype), frames and generalised expectations are rather neutral or not existent at all. Later, in a hype phase, frames as well as expectations are highly positive. After the hype we may see either minor adjustments on both dimensions (curve 1) or a complete switch of expectations and frames from positive to negative (curve 4) or adjustments on either of the two dimensions (curves 2 and 3). For each of these four endpoints, we can then describe the corresponding type of disappointment and postulate what effects this might have on the innovation at hand (cf. Table 3). The innovation effects are based on the insight that frames provide legitimacy in a more general way while generalised expectations guide the direction of innovation activities, e.g. with regard to application contexts.

If frames and generalised expectations are somehow adapted after the hype but remain positive and in favour of the technology, we may call this disillusionment or a moderate form of disappointment (type 1, cf. Figure 8 and Table 3). Such a constellation supports ongoing innovation activities and to continue on an existing path of development because legitimacy and guidance are intact. If frames remain positive but generalised expectations have to be adapted to a large extent and put the expected potential into question, a stronger and more widespread disappointment may be the consequence (type 2). While the technological legitimacy is intact, guidance will be weakened or disrupted. This means that there are incentives to go on with the technology but to try new application contexts, which might turn out to be more successful (shift of direction). Our fuel cell case can be assigned to the first type but we also saw indications that guidance was somewhat weakened, which means that there is a connection to type 2.

If, on the other hand, frames switch from positive to negative, legitimacy is undermined. Still, generalised expectations may remain largely positive, e.g. if the contexts in which the technology was applied show positive results. Actors who continue their activities then have to promote the innovation under different frames. An example for this development (disenchantment, type 3) are innovations that seem to become successful in technological and economics terms but for

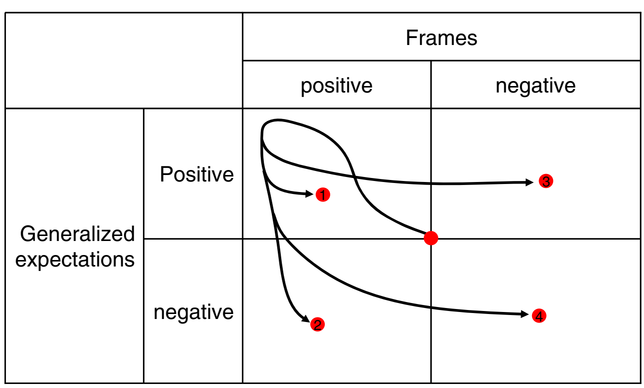

Figure 8. Stylised patterns of hyped expectations.

Table 3. Different types of disappointments and potential effect on innovation.

		Frames	
		Positive	Negative
Generalised expectations	Positive	**Disillusionment** • legitimacy intact • guidance intact **Innovation sustained** • innovation activities continue • former direction of development maintained	**Disenchantment** • legitimacy lost or contested • guidance intact **Innovation delayed/modified** • decrease of societal/public support • potential shift to alternative technologies
	Negative	**Disappointment** • legitimacy intact • guidance lost or weakened **Innovation delayed/modified** • innovation activities reduced • potential shift to other applications of the technology	**Total disappointment** • legitimacy lost • guidance lost **Innovation abandoned** • innovation activities cut down significantly or abandoned • shift to other technologies

which social acceptance has significantly declined due to risks that became clear in the course of the development. Opponents of the new technology may demand a shift of direction towards a technological alternative. Finally, total disappointment may be the result if both frames and generalised expectations switch from positive to negative after the hype (type 4). In such a case, innovation activities are likely to be cut down significantly and the innovation might eventually be abandoned.

6.2. *Final remarks*

The proposed conceptual refinement may help us to further our understanding of the complex interactions between public attention, expectation dynamics and innovation activities. It was able to explain our observations in the case of stationary fuel cells though expectation dynamics and the particular stability of frames were, of course, not the only factors affecting the intensity and direction of technology development. In our case, institutionalisation processes that were triggered during the hype phase also explain why innovation activities largely continued after the hype.

The proposed concept with different types of disappointments is based on the assumption that frames and generalised expectations develop independently. Frames, for example, may be linked to (and influenced by) other issues on the broader societal and political agenda while generalised expectations are related to the discourse activities of players in the field and to actual technological achievements. Whether this assumption also applies for a broader set of cases still has to be seen.

From a methodological point of view, the study showed that the investigation of expectations and hype-disappointment dynamics requires research designs with in-depth expectation analyses. Such analyses must allow for an adequate reconstruction of the different types of expectations and their development over time. In our view, further systematic research on the interaction of innovation activities in parallel with expectation dynamics seems to provide us with promising insights into the complexities of technological development.

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Notes

1. It is not always clear what is measured on the *y*-axis of hype cycle graphs. Some writers refer to 'visibility' of an innovation without defining it (e.g. Fenn 2006). In this article, we will take media attention as the variable that can be measured in quantitative terms and plotted in a graph (cf. method section).
2. Gaps between promises and actual technological achievements are not always straightforward to identify, and these results are subject to flexible interpretations (Konrad 2004, 2006). Under favourable conditions, the achievement of the expected technological results can be regarded as merely delayed (and the expectations adjusted), while a negative interpretation might regard them as not achievable and abandon the expectations.
3. The Austrian newspapers Standard and Presse as well as the Swiss Tagesanzeiger were excluded from the frequency analysis because their archives did not reach back to 1993.
4. We had to test a number of search criteria in order to determine whether an article was dedicated to stationary or mobile fuel cells. A combination of the term 'Brennstoffzelle' with 'Energie' or 'Strom' or 'Haus' was finally used as the proxy for stationary applications, and a combination of 'Brennstoffzelle' with 'Motor' or 'Bord' or 'Fahrzeug' or 'Antrieb' for mobile applications. In our search we made sure that the two categories stationary and mobile were mutually exclusive. We therefore get a residual number of articles, in which either both applications were mentioned or portable fuel cells or fuel cells in general.
5. Discourses as 'structured and structuring structures' (Keller 2005) may influence actors' practices by offering normative orientations, rules of signification for meaning constitution or legitimisation for action. So do collective expectations as they provide justification for innovation activities and guide the strategic allocation of resources to a specific product or technology. Finally, discourses form orientation points for the coordination of heterogeneous actors in the same way as collective expectations do.
6. The magnitude of this peak is comparable with media attention peaks in other cases (see Newig 2004). The death of Lady Diana Spencer in 1997, as an illustrative though somehow different example, was covered by 170 articles in the Frankfurter Allgemeine Zeitung, while 120 articles dealt with fuel cell technology in the same newspaper in 2001.
7. Note that we did not explicitly analyse whether and how far expectations were commonly *shared* or how they really affected innovation activities, but we conducted a discourse analysis of a small sample of professional magazine articles that showed that the public discourse mainly reflects the ideas expressed in the discourse among fuel cell professionals (Ruef 2005).
8. We understand the concept of frame according to its use in the literature on discourse analysis, see (Keller 2005) or (Gamson and Modigliani 1989). The German term *Deutungsmuster* can also be used in a similar sense.
9. We will not talk about expectations at the micro-, meso- and macro-level (cf. van Lente 1993, 182ff.) because this might cause some confusion whether this means that the subject (who holds an expectation) is acting at a specific level or the object (what the expectation is about) relates to that level.
10. The period is termed re-discovery because the actual discovery of the fuel cell principle goes back to the end of the nineteenth century and the technology went through a long period of neglect or very limited innovation activity.
11. This idea had not been very present before: The term 'virtual power plant' explicitly appeared for the first time in the daily press only in 2003 while it had already been mentioned occasionally in the weekly press (*Zeit* and *Spiegel*) from 2000 on.
12. This vision had only once been alluded to in the rediscovery period (1993–1997) but appeared explicitly in the press only from 2001 on.
13. See the work of Eames et al. (2006), in which the authors identify six competing narrative themes within the overarching vision of a hydrogen economy. The frames identified here link up to these themes.

14. See OECD, *Compendium of Patent Statistics* (2007) (www.oecd.org/sti/ipr-statistics) for data on fuel cell patents.
15. The development of single conferences on the subject is shaped differently. It shows a considerable increase from 2000 on, peaking in 2002 and decreasing somewhat since then (results not depicted here). The development of conference activities resembles the attention curve in the mass media, except for the fact that the peak 'follows' a year later (2002 instead of 2001-peak in the daily press) and we can assume that single conferences are subject to the influence of public attention. Conference series, however, not only require a stable institutional structure to be organised but also continued interest from participants in order to be kept up. We thus interpret conference series as an indicator for sustained interest in the subject.
16. Hydrogen and fuel cells have also become a prominent subject on the European political agenda. The commitment of the EU has especially increased since 2003 when the European Initiative for Growth assigned the projects 'Hycom' and 'Hypogen' extra funds of €2.8 billion for the support of hydrogen and fuel cell technologies for 2005–2015. Recently, the activities at the EU level culminated in the launch of a Joint Technology Initiative on Hydrogen and Fuel Cells (https://www.hfpeurope.org/hfp/jti).
17. The joint project of Siemens and several utilities (with EU and US public funding) for a 1 MW-fuel cell combined with a small gas turbine had to be given up in 2002, because no such small turbine was available on the market.
18. In fact, frames as well as generalised expectations also represent institutions and are thus part of the institutionalisation process, although we have discussed them separately for analytical reasons.
19. In our view, frames as broad societal (problem) scenarios are not technology-specific and thus rather influenced by issues on the broader societal and political agenda. The development of generalised expectations, on the other hand, depends on the innovation process and discourse activities of involved actors. Even if technological expectations usually appear in combination with one or several frames (we even assume that their 'success' might depend on the popularity of the associated framing), they can switch or use different frames.

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