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Technological Hype and Disappointment: Lessons from the Hydrogen and Fuel Cell Case

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Abstract

Technological hypes are powerful manifestations of expectations and can trigger actors to break out of their waiting games. There is a risk however that all too high expectations eventually lead to disappointment. In this paper we study the role of hype in technological trajectories and we make use of the recent hydrogen and fuel cell hype as an example. The hydrogen hype has triggered an actual innovation race and a rhetorical expectations race. The eventual disappointment affected mostly those contexts in which high expectations were not translated into stable institutions and long term commitments.
Furthermore we investigate the notion of expectations management and the possible roles therein for the innovating actors, the enactors, and the actors that choose to support them, the selectors.

Keywords: communication, fuel cell, hydrogen

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 [1-3]. 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 [4-6]. 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 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' [7] and 'regimes' [8]. 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 [9-10], 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 [11]. 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 [12].

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 [13].

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 [14].

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.

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 [15] and Rosenberg [16] 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 [2]. This perspective has been developed further and now known as the sociology of expectations [1, 17]. A working definition of expectations was proposed as well: '[technological expectations are] *real-time representations of future technological situations and capabilities'* [1]. 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'* [17] with their option. Or, along the same lines, they make a *bid* on a desirable future outcome of the innovation process [18]. In such cases where expectations are used deliberately and rather normatively, one can also speak of promises [1].

Expectations however, are only powerful once they are shared by many actors. In the sociology of expectations, these expectations are called 'collective expectations' [1, 19]. 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 [20]. 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.

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 [21]. Building on the work of Garud and Ahlstrom [22] and Rip [6], 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.

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 [6, 23-24]. 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 [25], 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 [26], 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[i]. An archetypal illustration of the timeline is presented in Figure 1. 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.

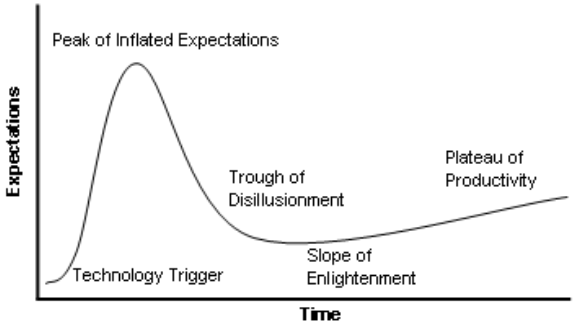

Figure1: The Gartner hype cycle [24]

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 [1, 24] 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 [27].
However, the community of enactors, with their different interests and intentions, might overstate its expectations to the level that these can not 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 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 [28]. 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 [29]

Hydrogen has been on the energy agenda for at least four decades [30-31] 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 [32]. 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 [12]. 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 [32]. 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'[ii] and sentiments turned 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 [33]. 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 [34].

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[iii]. 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[iv]. 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[v]. 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 [35] 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 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 [36]. 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 [37]. 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.[vi] 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 [38-40]. 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.[vii] 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.[viii] 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."[ix]

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.

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 [6]. 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 [41-42]. 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 2).

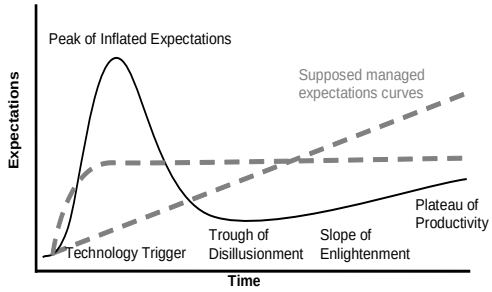

Figure2 Supposed expectations curves in the case of optimal 'expectations management'

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 [6]. 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[x] 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 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 1.

Table 1: 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.

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)

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 [41].

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 [32]. 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 [43-45]. 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.[xi] 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 [35]. A similar strategic move is the repositioning of fuel cell vehicles as a part of the future electric drive portfolio by Daimler [46].

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 [36]. 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 [36].

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 [24]. 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 [35]. 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[xii].

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 [43], and so is the anticipated EU regulation on fleet-average emission standards [47][xiii]. 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 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[xiv]. 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[xv]. The same holds for fuel cell 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.

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.

References

[1] M. Borup, N. Brown, K. Konrad, H. van Lente, The sociology of expectations in science and technology, Technology Analysis & Strategic Management, 18 (2006) 285-298.

[2] H. van Lente, Promising Technology: The Dynamics of Expectations in Technological Developments, Twente University, Enschede, 1993.

[3] H. van Lente, S. Bakker, Competing expectations: the case of hydrogen storage technologies, Technology Analysis & Strategic Management, 22 (2010) 693-709.

[4] A. Ruef, J. Markard, What happens after a hype? How changing expectations affected innovation activities in the case of stationary fuel cells, Technology Analysis and Strategic Management, 22 (2010) 317-338.

[5] N. Brown, M. Michael, A Sociology of Expectations: Retrospecting Prospects and Prospecting Retrospects,

Technology Analysis and Strategic Management, 15 (2003) 3-18.
[6] A. Rip, Folk Theories of Nanotechnologists, Science as Culture, 15 (2006) 349-365.
[7] G. Dosi, Technological paradigms and technological trajectories, Research policy, 11 (1982) 147-162.
[8] R.R. Nelson, S.G. Winter, An evolutionary theory of economic change, Belknap Press, 1982.
[9] P.A. David, Clio and the Economics of QWERTY, The American Economic Review, 75 (1985) 332-337.
[10] W.J. Abernathy, J.M. Utterback, Patterns of Industrial Innovation, Technology Review, 50 (1978) 41-47.
[11] A. Faber, K. Frenken, Models in evolutionary economics and environmental policy: Towards an evolutionary environmental economics, Evolutionary Methodologies for Analyzing Environmental Innovations and the Implications for Environmental Policy, 76 (2009) 462-470.
[12] B. Budde, K.M. Weber, F. Alkemade, Expectations as a key to understanding actor strategies in the field of fuel cell and hydrogen vehicles, Technological Forecasting & Social Change, (forthcoming).
[13] J. Tollefson, Hydrogen vehicles: fuel of the future, Nature, 464 (2010) 1262.
[14] D. Gerard, L.B. Lave, Implementing technology-forcing policies: the 1970 Clean Air Act Amendments and the introduction of advanced automotive emissions controls in the United States, Technological Forecasting & Social Change, 72 (2005) 761-778.
[15] R.M. Cyert, W.R. Dill, J.G. March, The role of expectations in business decision making, Administrative Science Quarterly, (1958) 307-340.
[16] N. Rosenberg, On technological expectations, The Economic Journal, (1976) 523-535.
[17] N. Brown, M. Michael, A Sociology of Expectations: Retrospecting Prospects and Prospecting Retrospects, Technology Analysis & Strategic Management, 15 (2003) 3-18.
[18] F. Berkhout, Normative expectations in systems innovation, Technology Analysis & Strategic Management, 18 (2006) 299-311.
[19] K. Konrad, The social dynamics of expectations: The interaction of collective and actor-specific expectations on electronic commerce and interactive television, Technology Analysis & Strategic Management, 18 (2006) 429-444.
[20] B. Budde, "The talking" and "the doing": Discourse and innovation strategies in the automotive industry, in: 2nd International Conference on Sustainability Transitions, Lund, Sweden, 2011.
[21] S. Bakker, H. van Lente, M. Meeus, Arenas of Expectations for Hydrogen Technologies, Technological Forecasting & Social Change, 78 (2011) 152-162.
[22] R. Garud, D. Ahlstrom, Technology assessment: a socio-cognitive perspective, Journal of Engineering and Technology Management, 14 (1997) 25-48.
[23] A. Ruef, J. Markard, What happens after a hype? How changing expectations affected innovation activities in the case of stationary fuel cells, Technology Analysis & Strategic Management, 22 (2010) 317-338.
[24] N. Brown, Hope Against Hype - Accountability in Biopasts, Presents and Futures, Science Studies, 16 (2003) 3-21.
[25] H. van Lente, C. Spitters, A. Peine, Comparing Technological Hype Cycles: Towards a Theory, Technological Forecasting & Social Change, (submitted).
[26] J. Fenn, M. Raskino, Mastering the hype cycle: how to choose the right innovation at the right time, Harvard Business Press, 2008.
[27] R.K. Merton, The self-fulfilling prophecy, The Antioch Review, 8 (1948) 193-210.
[28] European Commission, Hydrogen Energy and Fuel Cells - A vision of our future, in, Office for Official Publications of the European Communities, Luxembourg, 2003, pp. 36.
[29] ERTRAC, Electrification Roadmap: European Roadmap Electrification of Road Transport, in, 2010.
[30] M. Dignum, G. Verbong, The History of the Concept of the Hydrogen Economy, in: SHOT Annual Meeting, 2008.
[31] M. Hultman, Back to the future: The dream of a perpetuum mobile in the atomic society and the hydrogen economy, Futures, 41 (2009) 226-233.
[32] S. Bakker, The car industry and the blow-out of the hydrogen hype, Energy Policy, 38 (2010) 6540-6544.
[33] R.F. Service, Hydrogen Cars: Fad or the Future?, Science, 324 (2009) 1257-1259.
[34] The White House, Blueprint for a Secure Energy Future, in, Washington D.C., 2011.
[35] S. Bakker, H. van Lente, M.T.H. Meeus, Credible expectations – the US Department of Energy's Hydrogen Program as enactor and selector of hydrogen technologies, Technological Forecasting & Social Change, (forthcoming).
[36] B. Budde, K. Konrad, Interrelated visions and expectations on fuel cells as a source of dynamics for sustainable transition processes, in: KSI conference, Amsterdam, 2009.
[37] BMVBS, BMBF, BMWi, Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie, in, Bundesministerium für Verkehr, Bau und Stadtentwicklung, Bundesministerium für Bildung und Forschung, Bundesministerium für Wirtschaft und Technologie, Berlin, 2006.
[38] HFP Europe, Achievements and Perspectives - 2006, in, European Hydrogen & Fuel Cell Technology Platform, 2006.
[39] HFP Europe, Implementation Plan - Status 2006, in, European Hydrogen & Fuel Cell Technology Platform, 2007.
[40] European Commission, New Energy World IG, Developing New Energy for the future: Europe launches a 1 billion Euro project to get into pole position for the Fuel cells and Hydrogen race, in: Press Release, Brussels, 2008.
[41] R. Wuestenhagen, R. Wuebker, M.J. Buerer, D. Goddard, S. Pogutz, A. Russo, P. Migliavacca, Financing Fuel-Cell Market Development: Exploring the Role of Expectation Dynamics in Venture Capital Investment, in: Innovation, Markets, and Sustainable Energy: The Challenge of Hydrogen and Fuel Cells, Edward Elgar, Cheltenham (UK) and Lyme (US), 2009.
[42] K. Konrad, J. Markard, A. Ruef, B. Truffer, Strategic Responses to Fuel Cell Hype & Disappointment, Technological Forecasting & Social Change, (2012).
[43] G. Collantes, D. Sperling, The origin of California's zero emission vehicle mandate, Transportation Research Part A, 42 (2008) 1302-1313.

[44] P. Larrue, Lessons learned from the Californian ZEV Mandate: From a "technology-forcing" to a "market-driven" regulation, (2003).
[45] F.R. Kalhammer, P.R. Prokopius, V.P. Roan, G.E. Voecks, Status and Prospects of Fuel Cells as Automobile Engines, in: State of California Air Resources Board, California, Sacramento, 1998.
[46] Daimler AG, Daimler 360 - Fakten zur Nachhaltigkeit (Daimler 360 - Facts about Sustainability, in, Daimler, AG, Stuttgart, Germany, Stuttgart, 2011.
[47] European Commission, A European strategy on clean and energy efficient vehicles, in, 2010.

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[i] 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.

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

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

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

[v] Based on an interview with a Daimler senior researcher 8 April 2008.

[vi] Based on an interview with a former Daimler senior researcher 8 April 2008.

[vii] Based on an interview with a former Daimler top manager, 9 April 2008

[viii] Based on an interview with a Dutch Hydrogen policy actor, 26 November 2010

[ix] Based on an interview with a BMW strategist, 26 February 2008

[x] 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.

[xi] Based on an interview with a former Daimler top manager, 9 April 2008

[xii] www.fchindustry-jti.eu/

[xiii] 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.

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

[xv] Based on interviews with a BMW strategist, 26 February 2008, and a former Daimler top manager, 9 April 2008