Participatory technology development and assessment: In search of a sustainable use of fuel cell technology at the municipal level

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Abstract

The transformation towards a more sustainable society certainly is deeply intertwined with the development and introduction of new technologies. Since many years fuel cell technology – at least from a theoretical point of view – is seen as an option with an enormous ecological potential. Although there is much research effort to improve fuel cell technology, it is still not clear in which fields of application and under which institutional settings fuel cell technology could contribute best as a sustainable solution. This paper reports on experiences using a Constructive Technology Assessment (CTA) approach to search for and evaluate sustainable options for fuel cell technology at the municipal level. Based on a background study covering technological trends and socio-technical aspects of fuel cell technology in Austria, a workshop series with three meetings was organised. The results show that the applied workshop design contributed considerably to the anticipative, reflexive and social learning capacities of the actors involved. However, some structural shortcomings like problems concerning continuity and demand articulation, lack of commitment and dominance of short-term interests have been detected and should be dealt with in more detail in future research.

1 Introduction

Ecological as well as conventional technologies often fail on the market because of lacking consumer acceptance. This situation can partly be explained by the fact that in conventional innovation processes the ideas and experiences of users are considered – if at all – at very late stages of development. In this stage, at the end of a long chain of decisions, substantial changes in the design are not possible anymore. In the case of sustainable innovations (e.g. eco-design) positive environmental effects can only be achieved when ecological products are successful on the market and when they are widely used. As a consequence, effective strategies to support the development of sustainable technologies not only have to focus on the technical side of innovation but should also support the social embedding of these technologies.

In Austria, a research and demonstration programme on sustainable production "Factory of Tomorrow" has been inspired by such insights. While most parts of the programme focus on technological research and development, the programme management was also interested in broadening the design arena for the development of environmental technologies. Indeed, the market success of sustainable products may better be achieved by involving users and other relevant social groups early on and by considering their ideas in the design, than by marketing campaigns in the dissemination phase. Of course the involvement of users need not imply that the technology is evaluated with respect to its ecological impact. However, environmental technologies may require special attention to their contexts of use in order to realise their ecological potential. Thus, participatory approaches may be of particular importance in this context. Also, emerging technologies claiming environmental benefits may specifically attract environmentally-aware users who then play a special role in their development and diffusion.

However, it is still an open question how a more socially inclusive design process can be achieved in practice. The project 'Open Innovation' this paper is based upon has been funded by the Austrian Federal Ministry of Transport, Innovation and Technology within its programme 'Factory of Tomorrow' and aims to develop user-centred development strategies for two selected environmental technologies. Two particular technological fields - fuel cells and wood-plastic composites (WPC) – were chosen, because in both cases several technological research projects are part of the programme. Process technology to produce wood-plastics composites is already rather mature and the problem rather is a lack of applications with sufficiently high added value for users. The case of fuel cell technology is different, as ambitious long-term visions of green hydrogen futures abound while the basic technology for converting hydrogen or other fuels into electricity directly is still in the research and early demonstration stage. This is even more true for integrated fuel systems designed for specific applications such as combined heat and power generation in households.

In both case studies, fuel cells and WPC, the characteristics of the current state of the innovation field and the main challenges and problems for further developments have been investigated. This was done by. mapping different development pathways, specific actor constellations (concentrating on Austria in a global context) as well as visions and expectations about the future of these technologies.

Seeing fuel cells and wood-plastic composites differed in the socio-technical constellations framing their development, two different strategies to broaden the design process were chosen. In the case of WPC a lead user process has been set up to explore potential fields of application which create added value for users. In contrast, fuel cell technology – especially in its Austrian context with firms focusing more on system integration than on the development of the generic technology – is lacking an exemplary embedding in specific social contexts that could help to learn more about its potentials as a sustainable and user-friendly technology. Within the project 'Open Innovation' it was therefore decided to implement a process drawing heavily on the principles of constructive technology assessment (CTA). More specifically, the potential use of fuel cell technology at the municipal level stood at the centre of a social learning process realised within the project.

In this paper we will present and discuss this process of bringing together experts on fuel cell technology with representatives of local and regional authorities as the potential users of fuel cell technology. This can be seen as part of a strategy to broaden the design base for sustainable fuel cell systems in a municipal context. In a first step, we will sketch out the main ideas of constructive technology assessment and some results of our mapping of the current state of fuel cell development and use. The paper will be concluded by a discussion of the main experiences with the CTA process and some suggestions how this method could be developed further.

2 CTA and participatory TA

Based on the premise that technological innovations are essentially to be interpreted as the result of social processes deriving from economic interests, political power constellations and cultural value concepts, new approaches in the field of technology assessment (TA) have been developed, no longer concentrating on the evaluation of new technologies but rather focussing on the processes by which technologies are designed, developed and implemented.

Such approaches attribute a significant role to the potential users of such technologies. Through the broadening of the design process, possible problems that only become visible within corresponding contexts of use can be dealt with already at an early stage by making appropriate changes. Technology assessment becomes increasingly a participatory process accompanying and shaping the design of technologies and products, and systematically nurtured not only by scientific know-how but also by the everyday experiences of technology users and relevant stakeholders (Joss and Belluci 2002).

The approach of 'Constructive Technology Assessment' (CTA) and the discussions within the CTA community have been of major importance for the development of participatory TA. Since CTA was chosen as the theoretical and methodological starting point for our case study, we will discuss some important aspects of this approach in this section.

The overall claim of 'Constructive Technology Assessment' is to narrow the gap between innovation and the societal evaluation of new technology. Whereas in traditional TA concepts the focus is on early warning, the assessment of external effects of new technology and the choice between different technological options, CTA shifts attention to the steering of innovation processes (Schot 1992).

From a theoretical point of view the development of CTA was strongly influenced by insights from science and technology studies (STS). Based on empirical findings it was argued that technology do not develop as a result of some inner logic but, rather, as function of social, economic, technical, and political factors. In short, technology appeared to be as socially shaped (MacKenzie and Wajcman 1985). During the course of technological development, choices are constantly being made about the form, the function, and the use of that technology, and consequently, technological development can be steered to a certain extent (Schot 1992).

In an early theoretical paper on CTA Rip and van den Belt (1988, cited in van Boxsel 1994) distinguish three strategies of CTA:

(1) Supporting the development of desirable technologies;

(2) Technology forcing (by regulation); and

(3) Influencing ongoing transformations of technologies.

In our context the third aspect is of capital importance. Taking this strategy CTA represents a new design practice, in which impacts are anticipated, and users and other concerned communities and social groups are involved in an interactive way from the start. CTA therefore offers opportunities for technology related societal learning (Schot and Rip 1997). It is on this account that the term 'constructive' has been used to characterize the approach; as a form of TA directed to the construction, to the design and social embedding of emerging technology. It seeks to open the design process at early stages in order to discuss probable (negative) effects before they become entrenched and to find alternative development pathways.

According to van Boxsel (1994), early CTA projects have been organized in the following way:

- First, a 'socio-technical' map of various social groups is drawn up. This step was necessary to identify the most relevant social actors concerning a specific technology: technology developers, government departments, and groups in society.
- Second, a state of the art and a technology forecast study is prepared.
- Third, a debate between the various social actors is organized. In the beginning the various participants are informed separately. At the end of this step, a representative cross-section of the socio-technical map is brought together in a strategic conference.
- Finally, a synthesis report is written and the results are disseminated.

Based on this general structure, Merkerk and Smits (2006) recently have presented a well-elaborated process design for the debate between the various social actors. In this approach the major focus is on the visions and expectations of relevant social actors that influence the development of emerging technologies. In this case, the most important aim of CTA is to enable all relevant social actors to play their role in role in innovation processes of emerging technologies. Therefore the authors propose a 3-step approach:

(1) information is provided to participants

(2) participants construct individual scenarios

(3) dialog workshops are conducted.

Each workshop consists of three rounds, starting with two rounds focused on the scenarios followed by a brainstorming in which the participants are asked to formulate technology options for specific markets or practices. Merkerk and Smits have tested the 3-step approach within a TA study on Lab-on-a-chip in the Netherlands by organizing four different dialogue workshops with about 50 participants. Based on these results the authors conclude that working with a mixed composition of actors is more valuable regarding learning and reflection. In the Lab-on-a-chip case it also turned out that the chances for a CTA project to be successful significantly increase when participants are intrinsically committed, or in other words, when there is a 'sense of urgency' in the field. Moreover the case study shows that CTA projects are confronted with 'intramural effects', which means that there is a gap between effects perceived in the workshop and effects in the normal working environment of the participants.

Merkerk and Smits also point out that CTA processes need a research design to assess the effects from the beginning. Schot (2001) argues, that the following three criteria could be used to monitor the quality of CTA practices: (1) anticipation, (2) reflexivity, and (3) societal learning. These criteria are intended to observe whether the design process itself is changing, or whether a modulation of the network and actual content of the interaction is required. It is obvious that anticipation is a major feature in all kind of TA concepts. For CTA this means that involved social groups should be able to define problems by themselves or even test technological options in societal experiments. It is important that those processes are not too much structured in advance. Having in mind that the technological development is non-linear and unpredictable to a large extent, anticipation has to be organised as a regular activity during both design and implementation. Moreover it is important to structure technology development processes flexibly, so that choices can be deferred or altered. Reflexivity refers to the ability of social actors to consider technology design and social design as one integrated process. By broadening the innovation process it should become clear that social effects are coupled to specific technical options and designers do not only design technology but also co-design social effects as well.

CTA thus has to provide space for social learning processes. The aim is to organise the design process more symmetrically from the beginning. Designers, future users, and other relevant social groups should have the opportunity to question their own presumptions and come to new specifications. According to Schot (2001) learning occurs on two different levels. First-order learning refers to the ability to articulate user preferences and regulatory requirements and to connect such conclusions to design features. Second-order learning means to question existing preferences and requirements in a more fundamental way and maybe to come up with quite different demands or radical design options.

In our case study CTA was chosen as a methodological frame for designing a participatory process that aimed at exploring and assessing possible social contexts of use of fuel cell technology. The first part of the case study consisted of a series of interviews with fuel cell technology experts and an accompanying literature research. This preparatory study served to map the innovation field of fuel cell technology, in particular with respect to the situation in Austria. Furthermore it provided the basis for designing and implementing a workshop series which focussed on the potential future use of fuel cell technology at the municipal level. The following section gives an overview of the innovation field of fuel cell technology, derived from the preparatory study. Section 4 then proceeds to describe the implementation and the results of the workshop series. In a concluding section, the workshop results and experiences are evaluated in terms of the aims and requirements of CTA processes.

3 The innovation field of fuel cell technology

Basic application areas and environmental potentials

The basic principle of a fuel cell consists of transforming the chemical reaction energy of a fuel (e.g. hydrogen) and an oxidant (e.g. oxygen) into electrical energy. Hydrogen is the most commonly used fuel, although alternative fuels such as methanol are also applied in special types of fuel cells. However, hydrogen should not be thought of as an energy source but rather as an energy carrier. It is not directly available - rather, hydrogen has to be produced, typically by extracting it from fossil energy sources (steam reforming of natural gas or coal gasification) or by electrolysis.

There are various types of fuel cells that can be distinguished on the basis of their operating temperature and the fuel that is used. The application areas for fuel cells are usually divided into the three main fields of mobile applications ('fuel cell vehicles'), Stationary applications (mostly decentralised energy supply for households, businesses and public facilities as well as off-grid energy supply, e.g. for gauging stations) and Portable applications (as a substitute for rechargeable batteries, e.g. in laptops, mp3-players, mobile phones, etc.)

Since the late 1950ies fuel cells have time and time again been the focal point of waves of high expectations, succeeded by phases of disappointment when high striving goals could not be met. Of all application areas the field of fuel cell vehicles was most strongly characterised by such cycles of hype and disappointment and several announcements concerning imminent market breakthroughs had to be postponed or taken back. Today experts have become more cautious and are usually quite reluctant to make any prognoses concerning the timeline for the introduction of fuel cells to the mass market.

The high expectations with regard to fuel cell technology are to a large extent related to the high ecological potentials associated with it. Firstly, fuel cells at least in theory operate at a much higher level of energy efficiency than the conventional combustion engine. Secondly, fuel cells locally contribute to a significant reduction of greenhouse gas emissions: The only waste product generated from the use of hydrogen fuel cells is water or steam; in the case of methanol fuel cells also small amounts of CO_2 are emitted.

However, a comprehensive assessment of the environmental sustainability of fuel cells must also take into account emissions generated in the production of the fuel that is employed. Currently by far the largest part of hydrogen produced world-wide comes from steam reforming of natural gas. The 'ecological vision' regarding fuel cells, however, consists of using energy from renewable sources to generate the fuel, e.g. producing hydrogen via electrolysis using electricity from wind or solar energy. Hydrogen thereby becomes a form of energy storage, which can provide a bridge between the production and consumption of renewable energy, when the times and places where renewable energy sources can be exploited do not meet demand curves. However, due to the high costs this combination of fuel cell technology with renewable energy technologies entails, it is currently only a realistic option for niche applications, such as off-grid power supply (see section on future potential applications below.)

Another strand of research and development is also exploring various possibilities for using biogas for fuel production, as an alternative renewable source (e.g. sewage gas or biogas produced from biogenous household wastes).

Environmental risks associated with a more widespread use of fuel cells concern a reinforcement of the energy regime based on fossil fuels, if hydrogen production continues to rely on steam reforming of natural gas. Also, a growing demand for hydrogen could create a boost for nuclear power, an energy source whose environmental soundness is itself highly disputed. Both off-peak electricity production and lost heat in nuclear reactors could be exploited for hydrogen production, either via electrolysis or in thermo-chemical processes.

Status quo: Existing niche applications and open questions

Existing niche applications can almost exclusively be found in areas where costs only play a minor role: Space technology, military applications, energy supply for yachts and travel vans as well as publicly funded pilot projects - e.g. fuel cell vehicles in local public transport or small-scale combined heat and power appliances for households or businesses.

This already points to one of the major problems inhibiting large scale market introduction. Although fuel cell technology has already reached the level of concrete product developments (prototyping), production costs are generally still too high for market introduction. Most experts agree that these high costs cannot yet be sufficiently levelled by economies of scale and further R&D efforts are needed in order to reach a competitive cost level. Apart from that, improvements still need to be made with respect to the durability and the energy efficiency of fuel cell stacks.

Beyond the actual fuel cell technology a number of questions arise that concern the production, distribution and storage of fuels. In particular, the supply of hydrogen poses a number of problems that still need to be solved (economic and ecological modes of hydrogen production, technical improvement of hydrogen storage, build-up of hydrogen-distribution infrastructure).

Firms aiming to establish themselves in the area of fuel cell technology also need to decide where to position themselves along the supply chain. This is an intricate question, as such supply chains in the area of fuel cell technology are only starting to emerge (Hendry, Harborne and Brown 2004). Furthermore virtually all application areas are still lacking dominant technical design variants. For firms, and in particular for SMEs, it can therefore entail a high risk to focus on one specific technical design option.

Future potential applications

When thinking about possible future development pathways for fuel cell technologies it has to be kept in mind that in practically all areas of application fuel cells are in competition both with established conventional and with other alternative energy technologies. While it is hard to predict any long-term developments, it seems likely that within the next years the application of fuel cell technology will be limited to further niche applications. Apart from the niches referred to above, there are a number of other potential applications, where fuel cell technology may provide a specific advantage over competing solutions:

- *Emergency power supply*, e.g. for hospitals or computer servers:
  The limited durability of fuel cell stacks is less of a problem (only occasional use of backup system) and the possibility of remote control and maintenance provides an extra benefit compared to the conventional diesel aggregate.
- *Off-grid gauging and transmitting stations*:
  In off grid applications the price level fuel cells have to compete with is higher than in regular electricity supply. Also, synergies with other decentralised energy technologies may be exploited (e.g. load balance for photovoltaics systems).
- *Battery-independent energy supply for automobiles*:
  Apart from the use of fuel cells as propulsion unit they may also be used for battery-independent on-board electricity supply for automobiles (e.g. for refrigerated trucks).
- *Fuel cell vehicles in public transport*:
  For use in local public transport the problem of establishing a hydrogen infrastructure is less salient. A single supply station will generally suffice to operate a local bus fleet. Also, the avoidance of local emissions can provide a sufficient incentive for local authorities to accept the higher costs fuel cell vehicles entail.
- *Hybrid utility vehicles (electric/ fuel-cell driven):*
  Compared to purely electrical utility vehicles combined electric / fuel cell driven hybrids have an

extended range and are able to cover peak-loads (e.g. for motor start) without an oversized battery. Examples of use include industrial sites, airports, hospitals or city cleaning.

R&D on fuel cell technology in Austria

At the international level the lead in fuel cell technology development has been taken mainly by the United States, Canada, Japan and Germany. The volume of Austrian R&D activities in the area of fuel cells is comparatively small, in particular with respect to the development of actual fuel cell stacks. A number of Austrian firms, however, are involved in R&D concerning the integration of fuel cell systems into specific applications, such as fuel cell propulsion systems for automobiles, small electric utility vehicles or integrated systems employing fuel cells as a load balance to photovoltaics. (Excess electricity from the photovoltaics facility is used for hydrogen production via electrolysis. Hydrogen-fuel-cell-system then functions as a load balance.) Further R&D actors are involved in fuel processing and component development. In addition to that some basic research on fuel cells is also conducted at university-based research institutes. (See also Simader et al. 2004)

Seeing that at least in the private sector Austrian fuel cell R&D activities are very much centred around system integration with respect to specific applications, it is not surprising that there is a strong interest from the side of technology developers for the concrete implementation of these technologies, e.g. through pilot- and demonstration projects. Indeed, some pilot projects have already been realised in the area of stationary power supply and a hydrogen fuelling and testing station was set up as a demonstration project in Graz. However, these individual efforts still seem to be lacking a strategy or common vision concerning the future use of fuel cell technologies. The 'technology-push' does not appear to be appropriately matched by a demand-side orientation or considerations concerning the societal embedding of fuel cell technology.

4 Workshop series on the municipal use of fuel cells and hydrogen

Within the project 'Open Innovation' the situation described above was taken as a point of departure for organising a series of workshops that aimed at discussing and assessing potential contexts of use for fuel cell applications. In order to root the process in a specific community, it was decided to focus on the municipal level, taking the city of Graz as a concrete example.

Municipalities are of course strongly dependent on larger-scale developments at the national and international level. However, this is not to say that they cannot provide significant impulses concerning the application, regulation and maturation of emerging technologies. Indeed, enabling niche learning processes in relation to the use of new technologies has been highlighted as one of the most important conditions for kicking off transformation processes (Hoogma et al. 2002). Municipalities or regional authorities may contribute to such niche learning processes, e.g. by the implementation of pilot projects or permanent installations (the municipality as 'early adopter'), but also by acting as a policy maker or as a promoter or sponsor of technological development.

From the perspective of a municipality, an engagement with fuel cell technology may be of interest for a number of reasons, most notably the desire to improve local air quality. The use of fuel cells can be attractive in this context, as it contributes to a reduction of local emissions, regardless of the way hydrogen or an alternative fuel is produced. More generally, municipalities often have an interest in profiling as a 'sustainable city' or a high-tech site. Seeing that 'clean' and 'high-tech' are two attributes frequently referred to in the characterisation of fuel cells, they can be of particular interest for municipal projects. Finally, at the local and regional level, the implementation of environmental technologies such as fuel cells may be designed towards the involvement of regional firms, thereby strengthening the regional economy.

Within the project 'Open Innovation' the decision to implement a technology assessment process in the area of fuel cell technology in the form of a participatory scenario process at the municipal level in the city of Graz, was informed by a number of factors. Firstly, while the detailed functioning mechanisms of fuel cells certainly constitute a highly technical matter – largely black boxed from the end user – the concrete implementation of fuel cell systems is tied to a number of political and societal questions, relevant to a broad range of stakeholders. In particular this holds true for the choice of the fuel to be employed and the modes of fuel production and distribution. This also implies, that the assessment of fuel cell technologies needs to be viewed from an integrated, systemic perspective rather than being located at the individual product- or end-user level.

Secondly, fuel cell technology still is in a relatively early development stage and patterns of future application heavily depend on a broad range of technical, economic and social factors. Here scenarios can serve as a valuable tool, providing orientation points by describing a variety of potential future development pathways, when precise predictions can hardly be achieved (Vergragt and Brown 2007). Finally, as noted above, it was seen as vital to relate the assessment process to a concrete community. Within Austria, Graz arguably can be seen as the city with the best preconditions for an early implementation of fuel cell applications. First of all a significant number of firms and research institutes with R&D activities in the area of fuel cell technology are situated in and around Graz. Also, a hydrogen fuelling- and testing station is located there, set up as a demonstration project in 2005. In addition to that, due to the geographical location of Graz (surrounded by hills), the problem of particulate matter emissions (fine particles that are inhaled and can cause a number of health problems) is particularly salient. Fuel cell applications thus could constitute one means of achieving a reduction of particulate matter emissions

Conceptualisation and Implementation

The workshop series consisted of three workshops held in the time-span from mid-June to early July 2007 in Graz. Prior to the workshops, some preparative interviews with experts in the field of fuel cell technology were conducted which provided the basis for a background document sent out to participants of the workshop series. Stakeholders invited to the workshop series included fuel cell experts from basic research and industry as well as municipal actors and representatives of intermediary organisations (local and regional energy associations and agencies).

The workshop series was devised as a three-step process, following a design successfully applied earlier by Weber et al. (2005):

- *Workshop 1*: Identification of framework conditions influencing the future use of fuel cells, development of basic scenarios concerning future fuel cell use
- *Workshop 2*: Fleshing out of scenarios, choice of sustainability assessment criteria, qualitative assessment of the strengths and weaknesses of various elements of the scenarios
- *Workshop 3*: Strategy development at the municipal level

The three workshops were attended by a total of 16 stakeholders, where participation in individual workshops fluctuated between six and ten participants. The larger part of participants consisted of experts in fuel cell technology (R&D actors from basic research and industry), while only relatively few actors from the municipality and intermediary organisations took part. The workshops followed a bottom-up approach, using various interactive techniques, group work and plenary discussions for developing and assessing the scenarios and for strategy analysis. The following table summarises relevant details of the implementation process:

	Central questions	Methods	Participants (affiliation)
Workshop 1: Framework conditions and scenarios	Which types of development pathways concerning the future use of fuel cells are conceivable and plausible?	Brainstorming on framework conditions, development of 'storylines' in small groups (partial cause-effect relationships based on possible framework conditions), grouping of storylines to scenarios by the project team after the workshop	Municipal department for energy (1) Private firms involved in fuel cell R&D (5) Research institutes (4)
Workshop 2: Sustainability assessment	What are the strengths and weaknesses of various fuel cell application areas according to sustainability criteria? (Ecological, social and economic dimension)	Plenary discussion and extension of a set of sustainability criteria proposed by the project team; individual assessment of the application areas 'transport', 'staionary power supply' and 'backup-systems' by participants, followed by presentation and discussion in plenary	Private firms involved in fuel cell R&D (2) Research institutes (4)
Workshop 3: Strategy development	How can municipal pilot projects in the area of fuel cell technology contribute to the development of sustainable technology applications? Which requirements need to be met?	Plenary discussion, presentations by individual participants on existing pilot- and demonstration projects	Director of the municipal department for energy (1) Energy agency of Graz (1) 'Eco-Energy Network of the Province of Styria' (1) Private firms involved in fuel cell R&D (2) Research institutes (4)

Results

Future developments

Although the aim of the first workshop was to develop general scenarios for the use of fuel cells, most participants were reluctant to engage with this global and long-term perspective and a significant part of the discussions centred on short- to medium term prospects for the use of fuel cells at the municipal level. Both the field of stationary power and mobile applications were discussed. In the field of stationary power supply, participants saw the most promising field for fuel cells in combined heat and power applications at the medium-scale (joint energy supply for several households and energy supply for large buildings such as hospitals). The discussion of mobile applications focussed mainly on the integration of fuel cell vehicles to municipal mobility concepts for the inner city, including the delivery of goods, public transport as well as individual car traffic. Arguments concerning the plausibility of possible future developments in these areas were based on framework conditions such as economic competitiveness, municipal policy strategies, competing technological options, energy prices, technological breakthroughs, public perception and societal needs (e.g. mobility).

The 'storylines' produced by participants (partial cause-effect relationships), were grouped to four basic scenarios by the project team after the workshop. However, seeing that global long-term developments were not systematically discussed during the workshop, the formulation of these scenarios was also heavily based on existing literature in the field (Dutton et al. 2005).

Sustainability assessment

The qualitative assessment of various application areas (transport, stationary power supply, back-up systems) of fuel cell technology with respect to sustainability criteria on the one hand re-emphasised some of the most pronounced potentials and also problems of fuel cell technology, such as its potential contribution to a reduction of greenhouse gas emissions and the problems of high production and maintenance costs as well as the dependence on the availability of hydrogen (build-up of an infrastructure). In addition to that a broad range of further details were also discussed, most notably the potential for regional value creation, issues concerning energy and resource efficiency and the problem of lacking societal know-how concerning the handling of hydrogen.

However, possibly the most notable result of this workshop consisted of an assessment concerning the relative significance of various application areas for the use of fuel cells at the municipal level. According to the workshop participants' estimation, the largest sustainability gains could be achieved by an introduction of fuel cell technology to the transport system (fuel cell vehicles, e.g. in public transport, municipal utility vehicles, logistics system for transporting goods to the inner city, on the longer term also private cars). Also backup systems, such as fuel cell use as a load balance for renewable energy sources, were seen to have a significant potential. The use of fuel cells in stationary power supply was rated as the least interesting field for municipal applications by most workshop participants, although some differences of opinion emerged on this point. It was noted that stationary applications currently do not offer significant advantages over conventional systems, both in economic and environmental terms. This ranking may in part be related to specific conditions in Graz – both in terms of prevalent municipal problems (particulate matter emissions) and in terms of the specific competencies of regional actors in fuel cell R&D, where an emphasis on technology development for transport applications can be made out.

Requirements for municipal pilot projects

The discussion concerning requirements for municipal pilot projects in the area of fuel cell technology above all highlighted that a considerable number of pragmatic issues need to be taken into account in order to appropriately address the needs, potentials and (political and financial) means of the municipality. Among other things, the multiplicity of roles a municipality may take on - or be expected to take on - with respect to pilot projects deserves special attention. At the most basic level, the municipality may simply take the role of an early user of fuel cell technology, implementing certain applications in municipal utilities, while additional costs are covered by extraneous sources. However it could also act as a promoter and sponsor of the technology and – in addition to that - as a policy maker incorporating pilot projects in longer-term strategies as well as passing relevant legislation. However, municipalities in several cases will not have the means to provide substantial financial support for pilot projects. Also, explicit technology strategies which pilot projects may relate to are typically developed at higher levels of governance (e.g. national level). In the case at hand, for the above named reasons, the municipality appeared to be highly reluctant to consider taking on any role going beyond that of a simple 'user' of fuel cell technology.

Further pragmatic issues that need to be taken into account in the conceptualisation of pilot projects include the organisational complexity (e.g. number of actors that need to be involved and co-ordinated) and the political timeliness of an issue. While on the one hand a pilot project should address current problems and relate to the municipality's policy strategies, a pilot project touching upon areas of highly controversial political debate may stand low chances of being implemented. This was judged to be the case for attempting to implement an access-control system in Graz, only permitting zero-emissions vehicles (e.g. fuel cell vehicles) to enter the city at free charge.

Apart from these criteria addressing the need for well-devised organisational and political strategies, the contribution of pilot projects to the advancement of the innovation field of fuel cell technology was also discussed. In this context the need for a competent consortium and the engagement of a highly committed individual person or partner organisation as 'lead actor' was highlighted.

5 Conclusions

From a methodological point of view we are not only interested in the direct outcomes of the workshops as described above, but also in more process-related aspects such as the effects of the discussions during the dialogue workshops or problems with the design of the CTA process. In our following evaluation of the CTA process we will refer to the criteria suggested by Schot (2001): anticipation, reflexivity, and societal learning.

Judged along these categories, the CTA workshop series was at least partially successful:

- Societal learning occurred at different levels. Seeing that workshop participants represented different professional backgrounds it is not surprising that learning about personal perspectives and values as well as institutional conditions and restrictions occurred. Several technology experts pointed out that they learned a lot about the perspective of municipalities ("the municipal perspective was completely new for me") – the specific demands and visions the city representatives articulated, the technologies they would prioritise (e.g. biofuel-driven buses over fuel cell buses), or the specific restrictions of municipalities (lack of financial resources; self-perception as facilitators but not as project funders). Such insights could be valuable in the future, given that most technology representatives are highly interested to be part of a pilot project at the municipal level. This process of learning about other perspectives was also true for city representatives, who usually had not been confronted with technology opportunities or the need of a 'home market' for export oriented companies. While discussing some options for fuel cell pilot projects it also became clear that existing social networks would have to be extended, e.g. by private package delivery companies.

- The workshops provided a platform for the interaction of different supply-side, demand-side and intermediary actors in the field of fuel cells. Technology experts had the opportunity to exchange up-to-date experiences related to fuel cell technology; about solved and still unsolved technical problems (e.g. problems with cold starting) or about sustainable options for producing hydrogen or fuel substitutes. Participants used the workshops to establish new contacts and develop plans for further collaboration. While this aspect has not been evaluated systematically there is at least anecdotal evidence of joint project proposals and meetings between companies and municipal representatives resulting from the contacts made in the workshops.
- For CTA anticipation means that involved social groups should be able to define problems by themselves and participants take long-term effects into account. The workshops have been at least partially functional in kicking-off debate about sustainability aspects of fuel cell technologies (e.g. importance of system boundaries, local vs. global emissions) and about different socio-technical scenarios and trajectories for the further development and use of fuel cells. However, anticipating a range of possible developments through the lens of scenarios worked differently at different levels: In the first workshop, when we proposed to develop and discuss future scenarios for the use of fuel cell technology, most participants did not see any sense in that task. Both technology insiders as well as representatives of the municipality were first of all interested to develop concrete strategies able to be realised within the next years. However, when we asked the participants to assess various fuel cell application areas using criteria for sustainability most of them referred to long-term effects and conditions. As a result some well-informed and comprehensive mini-assessments were produced in a quite short period of time. In this sense the CTA process also contributed to the reflexivity of the actors participating in the workshops and was helpful to embed their short-term interests into broader perspectives.
- The CTA process has also been successful in identifying and characterising relevant application fields for fuel cells in municipal contexts. A rather broad agreement could be achieved about interesting fields for further demonstration projects and strategic niche management processes, such as the issue of city logistics based on fuel cell cars. The fields selected could integrate a number of perspectives: the problem situation of the municipality, the interest of technology suppliers (e.g. demonstrating specific strengths of the technology, potential for up-scaling markets) and sustainability requirements (at least based on a rough qualitative assessment).

However, while the CTA process was functional in starting off a number of processes to embed the development of fuel cells in a broader socio-technical context, a number of shortcomings restricted the potential long-term impacts of this specific CTA exercise:

- Continuity: The time frame and limited resources of a research project were sufficient to start a process of learning and reflection, but – from the present point of view – have not been enough to keep this process alive. Workshop participants did express their interest in having a more continuous platform to interact with municipalities (e.g. city networks) and to develop demonstration projects in close cooperation with municipal and other demand side actors. However, chances are high that this system-oriented view will split up again into isolated technology demonstration projects without further process facilitation. How can the development of joint visions and the organisation of social learning processes become a more integrated part of technology development? This is still an open question for us, and CTA-processes over a limited time span are only a partial answer.

- Lack of commitment and short-term interests: The workshops suffered from a low participation rate and lack of commitment of municipal actors on the one hand, and short-term interests of commercial actors who – especially in the beginning – strongly pushed their company interests and the products they developed. While part of this problem may result from the particular design of our workshops (recruitment strategy, topics etc.), there are also other issues involved which are probably characteristic for CTA-type projects. The CTA process is time consuming and needs substantial resources from participating actors. At the same time the idea is to go beyond short-term interests and develop a 'common goods' perspectives, even if the participating actors may individually profit in the long term from a better social embedding of the technology as well. This shift from short-term, self-interest goals to a long term, societal perspective is difficult to achieve. However, where the commitment was sufficiently high to engage in interaction and debates over a longer period of time, participants indeed adopted also a more long-term, public-goods stance.
- Demand articulation: CTA processes start from a particular technology field and carry with them a certain technology-bias. At least in the process we organised, it turned out to be difficult to give the demand side an equal weight to the technology perspective. On the one hand demand is often highly dispersed and it is difficult to find appropriate spokespersons who can represent this demand (if they exist at all). On the other hand the demand side actors often differ a lot between different areas of application. This is especially the case for a rather generic technology like fuel cells, where demand-side actors of a city-logistics project are completely different from the users of stationary fuel-cells in households. Moreover, in the run-up to the workshops a higher effort was put in mapping the technology and its applications than in mapping and articulating demand. Though more emphasis could be put onto the demand side, the technology bias seems to be a structural problem of CTA.

Summing up, the way we chose to implement methodological principles of CTA as a limited intervention in the process of technology development appears to have contributed to the anticipative, reflexive and social learning capacities of the actors involved. However, some problems we encountered in this process appear to be of a more structural nature related to the CTA concept and should be dealt with more systematically in the CTA research community: How can we provide for a lasting effect of CTA interventions? How can we arrive at a more balanced representation of both the supply and the demand side? How can we increase the commitment of important actors to the CTA process? Problems like these call for new organisational forms to increase the effectiveness of CTA as a tool to actively shape the development of new technologies.

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