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Middle-Range Transitions in Production-Consumption Systems: The Role of Research Programmes for Shaping Transition Processes Towards Sustainability

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Introduction

It is common knowledge today that moving towards sustainable development is a long-term process that requires major changes and adaptations in many different realms of society. The approach of transition management has been suggested as a framework to guide such long-term processes of smooth system transformation towards sustainability. In contrast to other, more technology-oriented attempts to drive socio-technical change towards sustainability, it is based on the notion of a co-evolutionary and multi-level process of change, involving technological as well as socio-economic, organisational and institutional changes.

RTD[1] programmes for sustainable development

RTD represent one of the building blocks of any long-term strategy to move towards sustainable development. As a consequence, many research programmes have been conceptualised and implemented over the past years that explicitly aim at contributing to a move towards sustainable development, both at the level of European Member States and of the EU. Several programmes even carry the explicit label of sustainability or sustainable development in their title, while others are rooted in sectoral or thematic domains where a re-orientation towards sustainable development is sought (Whitelegg/Weber, 2002; CEC, 2001).[2] However, it is still an unresolved issue how to design research programmes to enhance their impact with respect to the objective of a transition path towards sustainable development. What can they realistically achieve in the context of the national-sectoral innovation system and a national sustainability strategy? How should programmes be defined, set up, structured and implemented to ensure their orientation towards sustainability?

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1 RTD = Research and Technology Development Programmes

2 Examples of thematic programmes can be found in areas such as mobility, energy and water supply, but also in production technology.

Many sectoral or thematic programmes share certain characteristics which compromise their potential to contribute to transitions to sustainable development:

- Programme definition and the role of research for sustainable development: The role of sustainable development as a policy objective to be taken into account in research and technology programmes is not always very well defined, for instance in terms of an explicit sustainability policy and strategy, from which programme objectives are derived. The potential role also depends on the wider context of the national sustainability strategy and the national innovation system.
- Intermediate layer between guiding visions and concrete projects: While there may still be widely shared agreement about the overarching objectives of sustainable development, it is very difficult to operationalise these at the level of individual thematic programmes. There may be catchy guiding concepts in place (e.g. sustainable mobility), as well as specific technologies or socio-technical projects (e.g. to reduce particle emissions from diesel engines), but an intermediate level that bridges generic visions and concrete technologies is often missing. This, however, would be a good level to define and specify tasks for research programmes.
- Operationalisation of criteria for the assessment of projects: In most cases, sustainable development represents just one of the programme objectives, next to their main objective, such as the improvement of competitiveness of industry, the stimulation of research and development in a certain technology area, etc. Moreover, in order to stimulate bottom-up initiatives the work programmes of RTD-programmes are often defined by broad categories (such as 'efficient process technologies' or 'renewable resources' in the case of the 'Factory of Tomorrow' programme in Austria). Too generic thematic categories of the programme structure tend to lead to heterogeneous, unconnected, individual projects with little integration in a transition path. In more operational terms, there is a need to assess individual projects with respect to sustainability and a transition path. At programme level this requires corresponding assessment criteria and mechanisms to be in place in order to ensure that a transition towards sustainability is seriously taken into account.
- Broadening the scope of programmes beyond technology: Many RTD-programmes aiming at sustainable development still follow a rather technology-centred path, implicitly assuming that the development of environmental technologies alone is sufficient to trigger transitions towards sustainability. Accompanying transformations at the institutional and social level (as foreseen in most sustainability strategies) are not taken into account in such programmes, although the development of new technologies cannot be separated from these changes. Without a broader perspective on socio-technical transitions it is not possible to assess the strategic relevance of technical innovations and create conditions where such innovations make a significant contribution to policy aims such as sustainability.
- Specific difficulties arise in small countries with small RTD-programmes: What difference can comparatively small programmes make with regard to objectives as broad as sustainability? Is it better to focus on a few priorities, or to promote the growth of a broad range of small-scale initiatives?

Strategic support for 'Factory of Tomorrow'

These and similar issues have also been raised in the context of the ongoing Austrian research programme "Factory of Tomorrow", where several research projects have been funded over the last years. The programme is faced with a number of specific difficulties that need to be taken into account in the design of the project. The overall funding volume is comparatively small, while production represents a very broad research domain, even when projects are clustered around a small number of

sustainability principles as in the case of the programme in question. As we will argue later in this chapter, the specific conditions of RTD-programmes in general and of the Austrian 'Factory of Tomorrow' programme in particular represents a challenge for the concept of transition management in several ways and require a number of adaptations and modifications.

The project aims to explore exemplary transition paths at an intermediate level of *transition fields*, a level that is geared to the requirements to sustainability-oriented research programmes that need to bridge between highly abstract guiding visions and very concrete (technology) projects. As such, the results of the project are expected provide a *methodological* orientation and – by way of example – explore transition paths for selected *thematic* fields that are of potential relevance for the future development of the programme.In this chapter, we will first introduce the programme "Factory of Tomorrow" and some of the conceptual building blocks underlying the project approach and methodology. Apart from transition management itself, we will concentrate on the question of operationalising the approach of transition management at a level that is geared to the specificities of a research programme in the field of manufacturing. Subsequently, we will present the methodology of the project and then introduce the three candidate transition fields to which the methodology shall be applied in the course of the project. We will end with some preliminary conclusions and an outlook on what we expect the project to deliver at the end of its two-year duration.

The programme "Factory of Tomorrow"

"Factory of Tomorrow" is one of the subprogrammes of the Austrian research and technology programme "Technologies for Sustainable Development" which has been initiated and financed by the Austrian Federal Ministry of Transport, Innovation and Technology (BMVIT).[3] The programme is intended to have an impact on the Austrian economy and innovation system and to support the structural shift towards eco-efficient management and a sustainable production system through research, technological development, demonstration and dissemination measures. Beside "Factory of Tomorrow" two more subprogrammes have been established so far: "Building of Tomorrow" and "Energy Systems of Tomorrow".

Towards a sustainable production system

With respect to sustainable development, the programme is based on a number of "guiding principles of sustainable technology design":

- Orientation towards benefit and need
- Efficient use of resources
- Use of renewable resources
- Multiple use and recycling
- Flexibility and adaptability
- Fault tolerance and risk precaution
- Securing employment, income and quality of life

For the subprogramme "Factory of Tomorrow", these guidelines have additionally been specified by defining the "Factory of Tomorrow" as a factory aiming at zero-waste and zero-emission production, producing and providing products and services of tomorrow by using materials of tomorrow to meet tomorrow's needs. Thus the

[3] www.nachhaltigwirtschaften.at

thematic priorities of the calls for projects focus on innovative development in the following fields:

- Sustainable technologies and innovations in production processes
- Use of renewable raw materials
- Products and services with consequent focus on the performance and service of the product

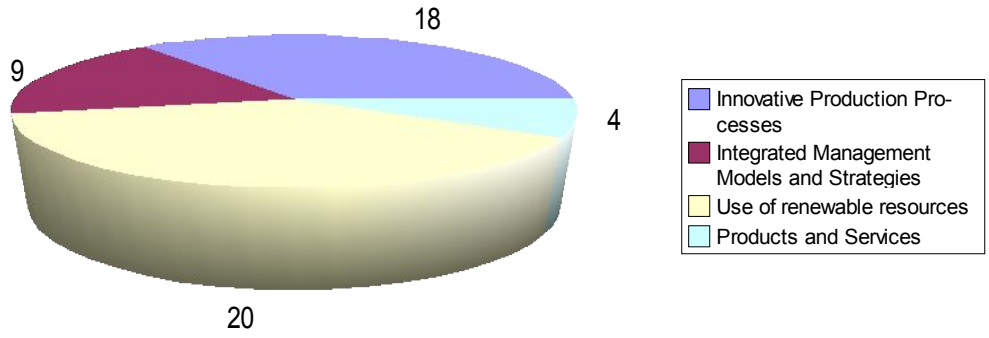
It is interesting to see, how the broader definition of sustainability as laid out in the seven guiding principles above (including social aspects, albeit in a very general way) is translated into more specific descriptions at the level of the work programme. Here one can observe a much stronger focus on technical aspects of materials and the technical organisation of production processes.

The programme "Technologies for Sustainable Development" is seen as one of several activities providing first steps to contribute to the aims of the Austrian Strategy for Sustainable Development (Federal Ministry of Agriculture, Forestry, Environment and Water Management, 2002). The subprogramme "Factory of Tomorrow" is closely related to two out of 20 key objectives of the strategy, namely *Successful Management through Eco-efficiency* and *Strengthening Sustainable Products and Services*. The Austrian Strategy for Sustainable Development aims at increasing resource efficiency by a factor of 4, while the "Factory of Tomorrow" wants to enforce "Factor 10 Technologies". Although these objectives are already challenging, other programmes or research projects on sustainability and sustainable technologies which focus on longer time horizons (e.g. Weaver et al., 2000; Partidario/Vergragt, 2002) emphasize that in the long run (20-50 years) a reduction of the environmental burden by a factor of 10 to 50 will be necessary for industrial countries.

Projects funded by the programme

Within the first two calls of "Factory of Tomorrow" (2000 and 2002) 54 projects have been funded with a total volume of about Euro 6,5 million. Apart from three accompanying measures the projects are subsumed by the programme management under the following topics:

Figure 1: Funded Projects of "Factory of Tomorrow" within the first two calls



The concept of the programme clearly states that in addition to technology development, structural and social innovations will be of great importance. In line with our earlier observation that the detailed work programme focuses on technology-oriented categories, also the funded projects tend to deal with rather specific technical issues, but also structural and management questions are addressed, especially within the project areas *Management Models and Strategies* and *Products and Services*.

A procedural aim of the programme: building networks

The Austrian programme intends to promote the development of "new partnerships", cooperations and networks within the different fields of activity. As in the first call of "Factory of Tomorrow" 71 and in the second 118 project partners (companies, institutions and organisations) have been involved in the projects, a contribution to increased cooperation can be observed at the level of the individual projects. It is however more difficult to establish links and exchange between the projects. Here again, the great heterogeneity of the domain of manufacturing compared to issues like energy systems or sustainable households comes into play. The "Factory of Tomorrow" programme is confronted with a higher diversity of groups of actors, research and policy fields. Moreover, common topics, problems or visions which provide the potential of interaction or integration are more difficult to identify. Therefore, it is much more difficult (but at the same time also very useful!) to establish a common platform and vision of the field than, for instance, in the sister programme "Buildings of Tomorrow" where a number of accompanying measures promote the interaction of the funded projects.[4]

In a way "Factory of Tomorrow" is designed with intentions which have also guided the Dutch programme *Sustainable Technology Development,* where Weaver et al., 2000, point out that policy programmes should try to shift the balance of R&D efforts of firms and technology developers toward long-term issues, focus their attention on the long-term challenge of sustainability and increase the success rate of their innovation efforts, especially by facilitating the networking process and helping network members to reach some agreement on problem definitions, visions of possible futures and expectations. However, as our short analysis of the programme structure of "Factory of Tomorrow" demonstrates, the operationalisation of long-term strategies for structural and social change (as implicated in the underlying sustainability principles) and their integration into detailed work programmes still represents a major challenge.

Managing transitions to sustainable development

The basic question of our accompanying project to the "Factory of Tomorrow" programme is, whether the concept of transition management could be of help in the process of updating and upgrading the programme and embed the projects in long-term oriented transition strategies to sustainable production-consumption systems. Before outlining our ideas to modify the transition management approach in a way that makes it more useful for the specific circumstances of the programme, let us first present some of the basic principles of transition management.

Transitions: What they are and why they are important

Over the last years the expectations with respect to the role of innovation in society have gone beyond the traditional growth objectives and now include several long-term issues which are often subsumed under the notion of sustainable development. This implies that innovation policy is increasingly required to develop capabilities that enable society to address long-term issues and challenges such as climate change, agriculture, mobility, water management, the health systems reform, etc., and to induce corresponding shifts in the technological regime that determines innovation processes.[5] Mainly originating from Dutch debates, the concept of transition manage-

[4] For example, see the OEKOinFORM project - a platform for the exchange of information, which integrates about 60 projects concerning ecological buildings.

[5] In Kemp/Schot/Hoogma (1998) a technological regime is defined as "the whole complex of scientific knowledge, engineering practices, production process technologies, product

ment has been developed as a framework for long-term strategies in innovation policy-making with a view to long-term transitions towards sustainable development.[6] The ability to manage transitions is regarded as an additional key capability that raises specific requirements with respect to innovation policy and its governance.

Several examples of transitions are known from past history. For instance, the move from a coal-based energy supply system to a gas-based system, or from an industrial to a service economy can be interpreted as transition phenomena. Usually, transitions are long-term processes that can stretch over several decades,[7] and they are characterised by a co-evolution of institutional settings, markets, technologies, cultures, behavioural patterns and policy-making and policy. Often, individual niches are at the origin of regime shifts and further on of changes in the socio-technical landscape in the wider sense.[8] The interactions and interdependencies between these different realms give rise to irreversibilities that stabilise and reinforce the transition path.

The policy perspective: From transitions to transition management

From a policy perspective, the understanding of past transitions raises two questions, namely a) in how far can comprehensive and goal-oriented transformation processes be influenced and guided in a desirable direction at all (i.e. in the direction of sustainable development), and b) what role can and should government actually play in this process.

It is well known that the uncertainty, ambiguity and complexity of future developments prevent any attempt to plan the future in a linear fashion. Consequently, transition management is not about the central planning and realisation of future development paths but implies the conscious implementation of structures and collective processes for governing long-term transitions in a goal-oriented and adaptive manner. It is a multi-level and multi-actor learning process in society that aims to integrate the distributed intelligence[9] of the actors involved in order to improve the co-ordination and coherence of their behaviour. In particular, experimentation and bottom-up learning processes are regarded as key elements of transition management in order to maintain the adaptive capacity of an innovation system. Shared problem perceptions, common guiding visions and overarching strategies contribute to orienting the decisions of the different actors towards common goals.

Policy, and innovation policy in particular, is supposed to provide the necessary framework conditions to enable such collective learning and co-ordination to happen. This requires first of all to stimulate processes of anticipating and formulating long-term perspectives that can serve as an orientation and focusing device for the range of actors involved. Secondly, there is a need to monitor continuously the policy actions taken and to adjust them to the evolving visions of the future (see Figure 2). Moreover, conflicts of interest may emerge where government action is needed to mediate between the parties involved. Finally, given the pivotal role played by experimentation, innovation policy can support a transition process by supporting socio-technical experiments that are geared towards the societal goals striven for.

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characteristics, skills and procedures, established user needs, regulatory requirements, institutions and infrastructures".

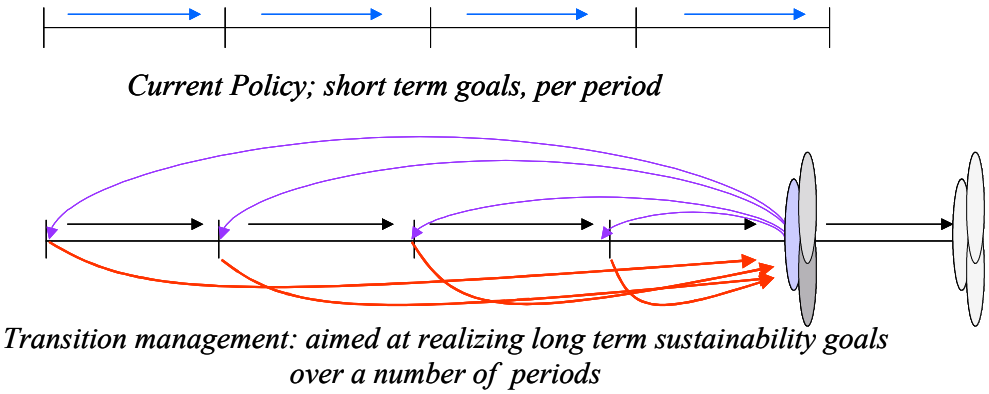
6 See Rotmans/Kemp/van Asselt (2001) and Kemp/Rotmans (2003)

7 Transition processes can thus be interpreted as comparatively smooth transformations, whereas terms like rupture, revolutions or breaks imply a rather fast and abrupt type of transformation process.

8 See for further details Geels/Kemp (2000) and for an extensive case-study Geels (2002)

9 See Kuhlmann (2001) for a detailed introduction to the concept of distributed intelligence.

Figure 2: Transition management offers a long term perspective for formulating short term policies



Three levels of transition management

The key difficulty of transition management is to ensure the link between open and collective learning and innovation processes on the one hand and the societal goals implicit in the transition concept on the other. In order to operationalise abstract goals such as sustainable development in the context of a transition management process, it is useful to differentiate three levels of action. First of all, *transition arenas* are defined on the basis of comparatively broad problem areas that reflect basic functional needs of society (e.g. energy supply, water supply, mobility, etc.). In a transition arena, government actors, knowledge institutes, businesses and NGOs/consumers interact in order to develop the visions and frameworks/paradigms necessary to guide a transition process. Below this strategic level, *innovation networks* composed of representatives from the same constituencies formulate specific transition agendas, define key projects, and mobilize and expand the network. At the level of the *testing grounds*, concrete experiments are developed, implemented and monitored in order to put the transition agendas into practice and feed the findings back to the other levels of transition management.

These three levels of transition management reflect also its main phases or elements: 1) development of long-term sustainability visions and overarching joint strategies, 2) organisation of a multi-actor network, mobilisation of actors and execution of projects and experiments, and finally 3) monitoring and evaluation as inputs to the collective learning process.

Transferring transition management to other contexts

It is still an open question in how far transition management, which has been mainly developed in the Dutch context, can actually be transferred and adapted to other countries. It is at least a matter of debate whether so-called "best practices" of policy learning in innovation and technology policy can be sensibly transferred and adapted from one country to another. Political cultures and institutional settings are recognised today as important factors determining how policy learning actually takes place and how coherent an innovation policy can actually be developed and implemented.

The challenge to adapt transition management to RTD-programmes

As outlined above, transition management is a very comprehensive approach to shaping societal transformations. It provides a number of generic building blocks for

policy strategy. However, RTD programmes, such as "Factory of Tomorrow" tend to address very specific projects and technologies. One of the crucial challenges of applying transition management approaches to such RTD programmes appears to be the identification of appropriate intermediate levels of analysis (and policy!), which link broadly defined functional transition fields with specific technologies and technological research issues. For such intermediate levels useful conceptual building blocks are still lacking in the transition management discussion.

More specifically, the adaptations suggested for the use of transition management approaches to support the "Factory of Tomorrow" programme are as follows:

- *Extending the application of the transition management concept to new thematic domains, here production-consumption systems.*
  So far transition perspectives have been applied mainly to infrastructure domains, such as energy supply, water management and transport. The domain of production is more heterogeneous than these other domains and thus poses specific difficulties. We would thus like to test the usefulness of the approach to more diverse contexts such as production.
- *Building a conceptual bridge between highly general macroscopic concepts and very concrete projects in the field of the programme.*
  Some relevant research work on the domain of production-consumption systems has focused mainly on the end-user needs, but not traced the implications back to individual production processes, which may add further difficulties.
- *Assess technologies with respect to their potential contribution to a transition path/scenarios.*
  It is very difficult to assess individual projects and technologies with respect to their potential role in wider scenarios that comprise also the needs side of production-consumption systems. Is this a promising approach to guide policy and programme development?
- *Pinpoint additional transition elements for the assessed technologies*
  Within the framework of a technology research programme, projects at a rather technical level constitute the majority of the funded projects. Therefore, necessary changes of the socio-economic context, policy strategies, changes in social practices etc. to support the diffusion of sustainable technologies in case of the two examined examples of production-consumption systems will be explored.
- *Testing and assessing the transferability of the transition management concept to other socio-cultural contexts*
  Transition management as mentioned above has been developed and tested mainly in the Dutch context, but it promises to be of great use also in other countries. However, socio-cultural contexts differ, and transition management presupposes certain conditions for governance and decision-making. In this sense, the project aims to check whether transition management as a guiding framework can actually be transferred (and if necessary adapted) to the Austrian context.

Operationalising transition management for the meso-level of production-consumption systems

When trying to break down the approach of transition management to more specific domains than "the production consumption system" as such, it is necessary to specify the transition fields that shall be addressed in more detail by a research programme. As a starting point, we take the observation that production is meant to serve certain "needs". The fulfilment of these needs is ensured by systems of production and consumption, i.e. socio-technical systems that range from the provision of raw materials (including recycling) to service concepts and products for final consumption.[10] The closer you get to the needs side of this chain, the more prominent are

[10] See for instance the EU-funded project SusHouse where final needs in the realm of the household have been analysed and explored (Vergragt, 2000; Green/Vergragt, 2002).

the social practices and routines of the users for defining this stage. In earlier phases, technical design practices are an important social component, while technical considerations play an important role throughout the entire chain.

When looking at production-consumption systems in a more differentiated way, we can thus start with the delimitation of three levels of analysis:

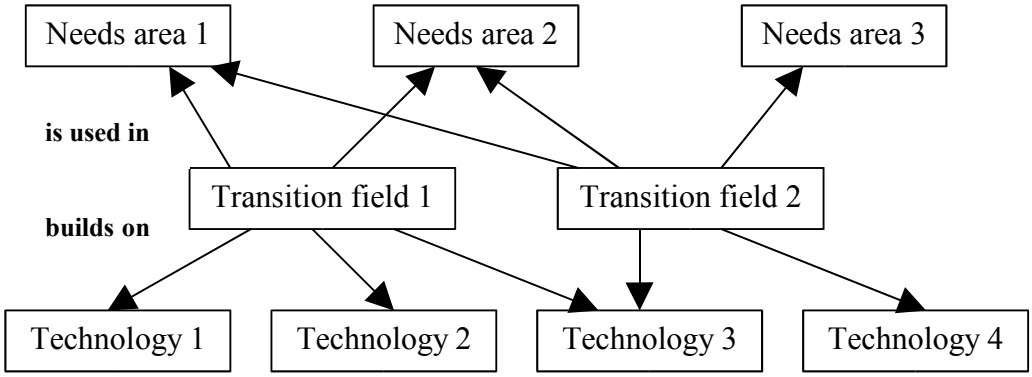
- Needs areas: Final needs of end-users or consumers can be met in different ways. By concentrating on satisfying these final needs, it is possible to overcome the conventional product orientation and think about alternative ways of meeting needs by providing the necessary services and/or products. For instance, the final need of "mobility" cannot only be met by individual car ownership, but also by means of new service approaches such as car-sharing, door-to-door mobility services, etc. Often these alternative concepts are embedded in wider "visions" or "Leitbilder" that capture both these new services and the changes in social, regulatory or organisational practices required. "Sustainable mobility", "sustainable household", "factory of the future" or "green chemistry" are examples in case, often expressed even in terms of concrete performance targets. However, these visions remain at a fairly abstract level. In general, the concept of needs areas can also be applied to other levels of a production-consumption system, i.e. also intermediate users (not only end users or consumers) can define a needs area to be addressed by a research programme.
- Transition fields: More specific than the broad-ranging needs areas, transition fields represent the areas where systemic solutions for meeting needs are developed. Transition fields are formed by technologies, actors and their objectives, and they can be interpreted as arenas, where systemic solutions for ensuring the provision of certain functionalities evolve. In other words, it is at the level of transition fields, where specific technologies are tied together with and embedded in social and organisational practices in order to offer an alternative solution for providing a functionality needed. Transition fields are thus an intermediate systemic level, at which the integration of individual technology projects into the provision of needs-oriented products and services takes place, guided by an orientation towards long-term sustainability.[11] For instance, in the case of sustainable mobility, the introduction of an intermodal and integrated mobility service is an example of a transition field. Real-time travel information could be another example, as well as on-line or mobile booking. As an example of an intermediate transition field, vehicle maintenance services could be mentioned.
- Individual technology projects: The practice of research programmes shows that the individual projects often focus on specific technologies, without particular attention to final needs or social context. In other words, they tend to be conducted in a rather isolated way and need to be integrated and adapted at the level of the transition fields. In other words, these specific technical solutions need to be contextualised at the level of transition fields in order to diffuse more widely. In principle, an individual technology can be applied in different transition fields to meet different functionalities, and correspondingly a functionality can be realised by using different individual technologies. For instance, travel information can be provided in real-time to your mobile phone using GSM, but it can also be transmitted by means of local information terminals or by phone services. Integrated

[11] In principle, transition fields can be categorised in several different ways. They can be described in terms of different functionalities they address, in terms of policy arenas or in terms of networks or industrial branches. Especially in the case of manufacturing a sectoral differentiation can be useful (at least in some cases) if this is in line with the production-consumption system under study. "Printing" is an example of a functionality that can be roughly represented by specific industry branches while "dyeing" is scattered over many industrial branches and policy arenas. Thus it should be noticed that usefully delimited transition fields can also be constructed around branches (the paper industry) or resource bases (biomass use).

intermodal services can be achieved by standardised integrated ticketing (like in urban transport "Verbünde") or by means of an electronic bidding service where prices may vary according to demand, etc. Obviously, we are particularly interested in new and innovative technologies that have the potential to contribute to a transition to sustainable development.

These three levels of analysis build on each other, thus reflecting the idea of a production-consumption chain. However, these chains should not be seen in isolation. Certain functionalities can be useful to serve different needs, just as some technologies have the potential to be applied for fulfilling different functionalities (Figure 3).

Figure 3: Three levels of analysis



An illustrative example of how transition fields can relate to visions of different needs areas on the one hand and different specific technologies on the other is given in the case of polymer coatings with special focus on the application in the automotive industry (Partidario/Vergragt, 2002). They develop long term scenarios (period up to 2050) that combine visions of new fulfilment of the function of surface protection and colouring of cars with visions of new ways of providing transport functions. Specific technological innovations in surface protection and colouring are currently under way with a scope ranging from incremental process improvements to pollution reduction at the source, improved coating fitness via a change in raw material (e.g. C to Si based resins, powder coatings, renewable materials), complete recycling opportunities and strategies to avoid surface treatment by 100% plastic or metallic cars. These technological solutions are combined with questions of integration along the supply chain and management of the product life cycle, e.g. car producers managing the whole product life cycle. As regards transport and mobility, needs visions range from business as usual with individually owned cars via multimodal transport systems, leasing and renting to public/shared transportation and the offering of transportation function instead of automotives with non-polluting alternatives. Here several technical alternatives are currently in the R&D phase that need to be combined in new organisational systems for mobility service provision.

The importance of "transition fields" as an intermediate analytical level

From the perspective of a research programme, the transition fields are clearly the most interesting level of analysis to study. It allows to bridge between needs areas and images of the future for certain fields of production and consumption on the one hand and concrete technology projects of the programme on the other hand. This bridging of need fulfilment and individual technologies makes transition fields a key

concept to define and select intermediate transition fields as the core of research programmes strategies geared towards sustainability-oriented transitions.

Abstract images of the future are available for many domains as well as individual projects and technologies that are somehow related to these visions. What tends to be lacking, however, is a useful operationalisation at an intermediate level of analysis applicable to structuring a research programme, i.e. a description that is sufficiently concrete to relate easily to individual technologies, but at the same time sufficiently general to be compatible with more abstract visions of the future at the level of needs areas. Moreover, a transition field within a research programme should be defined as a sub-field of the production system that is sufficiently coherent and limited in scope to be able to operationalise a well-defined transition process. In order to reduce the complexity of the scenario development and policy process it appears to be helpful, if a transition field does not consist of too many actor constituencies and if it relates to a limited set of needs areas and technology fields. A certain homogeneity in these areas may be an important argument to select or delimit certain functionalities when demarcating a transition field addressed by a research programme.

Whereas a transition field is characterised in terms of the technologies, organisational structures and actors, the notion of "functionalities" is a particularly useful concept to explain the role played by a transition field for the other two levels of analysis. As a result of integrating specific technology projects in a social and organisational context, socio-technical innovations emerge at the level of transition fields that allow to provide functionalities in an alternative way that serve to satisfy final or intermediate needs.

Not only for analytical reasons, the level of the transition fields is of crucial importance: Their peculiarity is of special relevance for the sustainability of the whole production-consumption chain. Changes from one way to fulfil a functionality to another way sometimes can change the overall environmental effect of the need satisfaction much faster and more radical, than changes in the needs themselves (societal needs change relatively slow) or by isolated technological developments (mainly incremental changes).

Three examples of production-consumption systems

From the broad and heterogeneous domain of production-consumption systems, three specific transition fields have been selected in order to exemplify our methodological considerations. For this selection, a number of criteria were applied, partly derived from the requirements of the transition framework and partly inspired by the clusters of ongoing projects within the programme "Factory of Tomorrow":[12]

- Significant innovation potential with respect to a regime shift towards sustainability.
- Associated to the preceding point, existence of a relevant research capacity in Austria.
- Ecological relevance and connection to the guidelines of sustainable technology development of the programme.
- Existence of a significant industrial basis or potential for its emergence and clustering. This criterion serves to ensure that the area selected is of economic relevance.
- Existence of a common "technological regime" to ensure the homogeneity of the field of investigation.

[12] These criteria cannot only be used for selecting the case examples in our project but – at least in principle - also as selection criteria for project proposal in the programme.

- Existence of other, complementary forms of research funding and support in order to be able to assess the additionality of the programme "Factory of Tomorrow" with respect to other research and technology policy measures.
- Existence of a relevant number of projects in the programme "Factory of Tomorrow", if possible for different segments of the chain.
- Potential to link up with similar transition fields in Europe in order to go beyond the limited scope of the Austrian market.
- Existence of a lead actor who could at least potentially adopt and carry ahead a transition agenda.

Moreover, the two transition fields selected should concentrate on different segments of the production-consumption chain and differ in important characteristics. The areas chosen are "wood as a structural material", a transition field largely defined from a resource-based perspective and integrated within an important industrial branch in Austria, and "dyeing with renewable materials", a transition field constituted around a specific functionality but spread over several branches and needs areas. Striving to define and demarcate these transition fields which will be the basis for further scenario development processes shall also help to develop a clearer view on the characteristics a transition field should fulfil to

Transition field 1: Renewable structural materials

Within the rather broad functionality of "providing structure" one of the main sustainability principles that can be applied is the increased shift to renewable resources. Within the potential spectrum of renewable structural materials, we will especially focus on timber. This means on the level of technologies that we will focus on technologies which make use of wood to provide structural materials. At the level of need areas, timber is increasingly used as structural material for buildings (or as a function: providing shelter). We will firstly focus on applications serving these needs, while further need areas may gain relevance within the scenario process.

The choice of this specific transition field is supported by the following arguments:

- timber as structural/constructive material has been identified by the Technology Delphi Austria (ITA, 1998) to be one of 11 potential fields for technological leadership of Austria;
- wood is identified within the Austrian Strategy for Sustainable Development to be one of the renewable materials where considerable expansion possibilities exist, since only about two thirds of the annual increase of woody biomass is used and with 47% of the federal surface covered by forest, timber production has a special importance for Austria;
- there is a significant industrial and research basis in Austria for this topic and clusters have already been established (e.g. timber clusters in the provinces of Salzburg and Lower Austria);
- the Wood Composites & Chemistry Competence Centre is one of 18 Austrian Competence Centres financed within the technology structural programme K plus by the Austrian Federal Ministry of Transport, Innovation and Technology (BMVIT);
- within the programme "Factory of Tomorrow" 6 projects relate to wood or timber (see table 1)
- Wood and wood products is also an important sector of European industry, with major application potential in a wide range of other industries (e.g. car manufacturing)

- Although the wood products industry tends to be dominated by medium-sized enterprise, cooperation with large users could be a promising model for establishing a lead actor.

Within the comparatively broad domain of wood production and use, the focus could also be put on new emerging types of technologies and functionalities, such as for instance bio-polymers where there is still a major, but unexplored potential of particular interest to a forest-rich country like Austria.

Transition field 2: Dyeing – renewable dyes

The functionality of "dyeing", meaning the colouring of fibrous materials such as textiles, paper or wood, is performed for the production of many different kinds of goods. These goods serve most different needs from the protective and social functions of clothing and home textiles to the comfort provided by textile coverings in cars.

Applying sustainability principles leads to attempts to re-establish the use of herbal dyeing substances. The aim is to substitute the common use of synthetic dyes, which contribute to the proliferation of toxic chemicals in the biosphere. Especially avoiding allergic reactions to synthetic colouring agents is a very important motivation for such efforts of substitution.

Similarly, for the surface treatment with paint and finish, bringing also colour to our lives besides protecting many product surfaces, organic substances have been used for hundreds of years, before the bulk production of synthetic coatings from mineral oil became prevalent. For the substitution of such synthetic coatings with all their ingredients (solvents, pigments and additives) changes in different production-consumption systems are needed that differ very much from the ones needed for renewable dyeing. For this reason, the two fields of transformation shall be looked at separately within this exemplary exercise.

At the level of technologies, the promoters of renewable dyes are aiming to reduce any need to change the way of application, when substituting conventional dyes with their products.

The choice of this specific transition field is supported by the following arguments:

- A study of Industriewissenschaftliches Institut on behalf of the Austrian Ministry of Agriculture, Forestry, Environment and Water Management (Industriewissenschaftliches Institut, 2001) stated the feasibility of a production of renewable dyes in Austria and promotes consolidated research activities. The report on the preparation phase of the programme "Technologies for Sustainable Development" (Katter et al., 1999) states a high potential for paint produced on a renewable basis to enter the market of printing paint. As a conclusion of an expert forum on vegetable dyes in Germany, Vetter and Biertümpfel stated in 2001, that contemporarily "in principle, nothing can get in the way of vegetable dyes being used for the colouring of textiles, leather, paper and wood. […] That the complete 'break through' has not occurred – although the production chain is complete from the producer of vegetable dyes through to the dipper, and despite of all the available applications – can be blamed only to the fact that so far no important trader of textiles has ordered naturally dyed products" (Vetter/Biertümpfel, 2001).
- Over the last seven years, a number of well established Austrian research institutions including the University of Innsbruck, the Austrian Ecology Institute and the Vienna based Universität für Bodenkultur have carried out research on wide range of issues from the selection of suitable species through to marketing aspects. They

were actively supported by the Bundesanstalt für Landtechnik Wieselburg, an agency of the Austrian department for agriculture and environment.

- The production of vegetable dyes is an attractive option for Austrian agriculture, since there exists wide experience with the production of herbs for medicinal and food applications. This is comparable in terms of high requirements of quality and comparatively small quantities.
- Research agencies and other promoters of vegetable dyes have established strong ties with some interested commercial partners. Many networks of actors concerned with the use of renewable resources in general have been established over the last years. The German Forum Färberpflanzen is regularly conveying meetings of up to 70 people concerned with the production and use of dyeing plants on a two-year basis. There exist rather mature niche markets in certain fields of application, such as hand woven carpets (Turkey) and eco-textiles (Germany).
- The EU is supporting research projects on natural dyes with up to 2,5 million Euro (Vetter/Biertümpfel 2001). Complementary activities are supported within the programme "Nachwachsende Rohstoffe" of the German government (allocating grants worth about 25 million Euro annually), including activities for market penetration.
- Within the programme "Factory of Tomorrow" two important projects relate directly to renewable dyes (see table 1). These are very interesting projects in terms of scope, aim and perspectives (strategic product development and substitution strategies with regard to different realms of society).
- Renewables dyes is a small market, also in most other European countries. However, the recent developments in Germany point to a potential for exploring a larger market. Globally, the potential is huge, at least in principle, given the size of the textile industry.
- For the moment, there is no clearly identifiable potential lead actor in Austria. There are nevertheless a number of firms that could take a lead role if adopting renewable dyes for their products.

Transition field 3: Biorefinery

A broad range functionalities can be provided by means of products from biorefineries, addressing an equally broad range of needs areas. Examples are proteine-rich components for animal feedstock, lactic acid, certain types of fibres, etc,. The underlying technologies use chemical and biochemical processes to produce a variety of products from different types of biomass (oil seeds, sugar beet, cane sugar, wood, grass, etc.).

In terms of sustainability, the main benefit of biorefineries consists of a reduction in the use of petrochemicals, entailing often the production of toxic by-products. In order to have a noteworthy effect, however, biorefinery should not be restricted to fine chemical products only, but be used also for bulk products.

The arguments for considering this transition field can be described as follows:

- Biorefineries offer the potential to produce flexibly mass products for large markets, even if production volumes are today still rather limited. Changing to biorefineries would have major impacts on the entire resource supply chain (e.g. agriculture) as well as competing non-renewable chemical production systems. The potential for system innovations and a regime shift is therefore very high.
- Biorefineries are still in an early phase of the their technological life-cycle; first pilot plants are currently being implemented and tested in order to learn more about the potential for upscaling and economic feasibility.
- In terms of ecological impacts, a positive net effect is usually expected, but as long as there are no concrete (pilot) plants in operation, it is hard to make any definitive judgements. As shown in recent study, green biorefineries can have a number of

positive impacts with respect to transport, the use of fossil resources, regional embedding and adaptation, and regional income and quality of life (Schidler 2003). However, large-scale biorefineries could also have adverse effects on local and regional agriculture.

- In economic terms, green biorefineries look quite promising already, even if the details depend on a number of framework conditions (e.g. benefits from heat and power exports) and on the market perspectives for the biorefineries' products.
- For the moment, the transition field is still quite homogeneous due to the fact that there are only a few research projects under way and a small number of plants in operation. The main actors in Austria are already cooperating at regional level, but there is still a need to establish a network at national level, involving in particular also additional actors from agricultural and structural policy..
- Apart from the projects conducted in the context of the programme „Factory of Tomorrow", research on biorefineries is also conducted at the University of Natural Resources and Applied Life Sciences in Vienna. However, overall, research capacity in Austria is very limited.
- Three main technological trajectories for biorefineries can be distinguished.
  - LCF-biorefineries (Lignocellulose Feedstock Biorefinery)
  - Cereal and corn biorefineries
  - Green Biorefineries, using humid biomass such as grass, lucerne, etc.
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- Biorefineries are an issue in several other countries of the EU, notably those with an important chemical industry and/or agricultural sector. Also the EU is considering biorefineries and bioenergy in particular as important future technologies.
- For the moment it is still hard to identify a potential lead actor given the early stage of development of the field. However, some of the industrial actors involved in the ongoing projects of the programme "Factory of Tomorrow" could in principle take on such a role,

Overall, biorefineries are a transition field in an early phase of development, but with good promises for the future.

The next steps within the project will be a more detailed analysis of the present situation with respect to the three transition domains in order to select two for which a transition scenario development process will be launched, as described in the following chapter.

Table 1: Overview of projects in "Factory of Tomorrow" related to the chosen transition fields

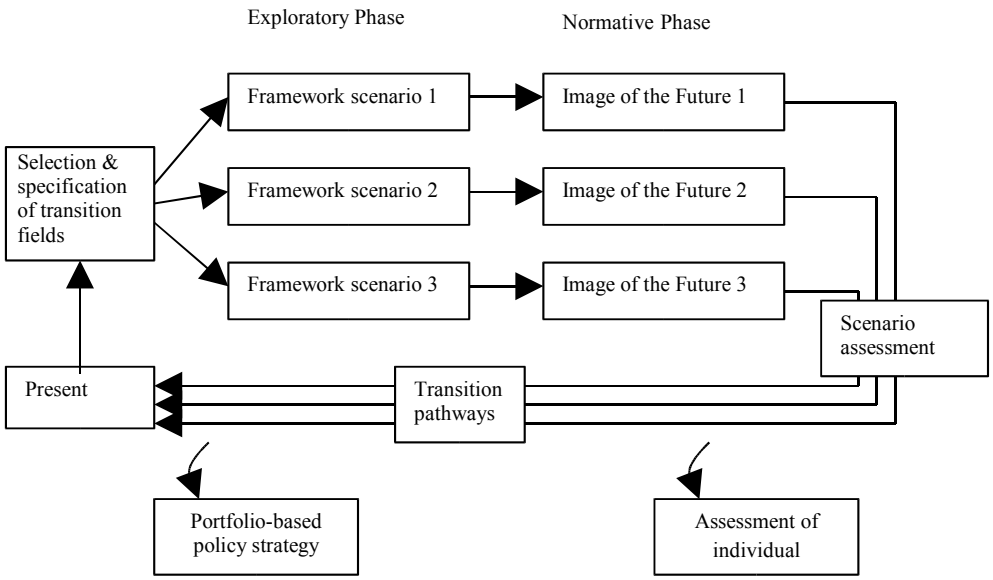
Functionality	Project Title	Synopsis
wood based structural material	Wood-processing employing a s uperimposition of ultrasonic vibrations	Development of wood-processing techniques employing high-frequency ultrasonic vibrations in terms of applications in the woodworking industry.
wood based structural material	Characterisation of material parameters as basis for innovative processing methods and products made of large dimensioned wood aiming at economically sustainable use of Austrian timber resources	Facing the problem of decreasing demand for large dimensioned timber, investigations are carried out concerning certain properties like strength and fibre characteristics. Due to the data it is possible to create a model about the variability of special properties of a stem.
wood based structural material	Sustainable outdoor use of larch wood through classification of durability by means of innovative measurement methods	In this project the utilisation of untreated larch wood is promoted by means of innovative measuring-technologies. Optic-spectroscopic measurements are linked to extractive contents and mass-decay, in order to predict the "natural durability".
wood based structural material	Wood Plastic Composites – adding value by splints	Systematic investigation of a new family of materials, which are produced of waste products of timber industry and combined with thermoplastic polymers (polyolefines, 5-40%). This materials provide characteristics similar to timber but can be manufactured by technologies of plastics industry.
wood based structural material	Wood Plastic Composite - Direct extrusion	In wood plastic composite extrusion, wood is typically palletised, compounded or agglomerated. In this project a new feeding dosing equipment is being developed to allow direct use of wood fibres, chips or powder, even combined with polymer pellets.
wood based structural material	Wood Plastic Composites - Development of an extrusion tool	Development of a new generation extrusion tool for a wood plastic composite. This material will be developed in a second project an should show a fibre content of 60 – 85%.
Dyeing	TRADEMARK Farb&Stoff From an idea to a trade product ready for marketing: Plant dyes for the textile industry.	TradeMark Farb&Stoff is about making the next and, indeed, crucial step: developing marketable plant dyes for the textile industry. In the efforts to establish a resource-efficient and economically interesting product line, residual plant material from the lumber- and food processing industries is mainly used.
Dyeing	COLOURS & TIES	New cooperations between agriculture und industry are necessary to ensure the utilization of renewable materials. The project focus is upon natural dyes and their application in textile industry. The goal of the project is to create a contact institution which connects various suppliers of diverse plant materials, takes on the processing, and standardising of the natural dyes, and makes a product that can be used by the industry.
Biorefinery	Development of foamed products based on proteins	Goal of the project is the development of a new foamed product based on by-products and waste products rich in protein. Possible applications are mounting parts for thermal insulation for building materials, parts of furniture, motor vehicle interiors and bulk good.
Biorefinery	Green Biorefinery – separation of valuable substances from grass silage juice	Juice from pressed silage grass has a high content of lactate and free amino acids. The goal of this project is to develop a technology for the separation of these valuable products.
Biorefinery	Green Biorefinery - Primary Processing and Utilization of Fibres from Green Biomass	Tests on optimisation of the essential process unit mechanical fractionation of the primary raw material "green biomass" into a liquid and a solid – fibres containing – fraction. Furthermore, lab and pilot scale tests with respect to technologies and processes for primary processing of the solid fraction (e.g. technologies for obtaining specified well defined fibre fractions, reduction of odour etc.). Finally, lab and pilot scale tests regarding manufacturing of prototype fibre products (fibreboards and adhesives & fillers for the construction sector) based on specific well defined fibre fractions from green biomass as primary raw material.

The scenario methodology

One of the main objectives of the project is to explore future trajectories of transition fields and associated needs areas in order to assess the potential role to be played by the technologies funded by the "Factory of Tomorrow" programme and to suggest possible fields for future research. For that purpose, it is first of all necessary to develop scenarios of future transition paths that capture the levels of needs areas and functionalities.

In principle, the transition management perspective lends itself to a normative approach to scenario-building, where, based on a single desirable scenario, a backcasting methodology is applied to identify a promising future pathway at the levels of needs areas, transition fields and technologies. However, while such an approach may serve as a useful orientation and guidance with respect to the direction of change that ought to be taken, it neglects the fact that the future is inherently open. A future development path, even the most desirable one, is contingent on many other factors that are outside the influence of, for instance, a small country like Austria. A fully exploratory approach would not be appropriate, either, because it is not amenable to an assessment in terms of sustainability. These considerations show that a simple and straightforward application of a normative or an exploratory scenario-building methodology would not be appropriate in our case. What is needed is instead a combined approach, allowing to take into account bottom-up exploratory elements (for instance new technology options, external driving forces) with top-down normative features implied by the sustainability-orientation of the images of the future drawn.

Figure 4: Schematic overview of the project methodology



Moreover, the project itself has a limited scope and volume. It can therefore not address all the research fields covered by the programme "Factory of Tomorrow" but has to focus on a subset of interesting and relevant transition fields. The lessons learnt from these selected fields shall nevertheless be instructive for defining research themes at programme level in the future. It should thus shed some light on the overall perspectives for the programme.

Figure 4 gives an overview of the methodology developed for the project. We suggest to apply a combined exploratory and normative approach. The initial phase serves to identify, specify and select two transition fields to be subject to the scenario development process. At this stage, also the most relevant needs areas related to these transition fields will be analysed. Then the actual scenario development process will be started, aiming to develop first a set of different possible framework scenarios at the level of needs areas. This step will follow an exploratory method. It is not unlikely to assume that this will deliver a set of framework scenarios that will differ in terms of their overall sustainability orientation. This is regarded as a very useful outcome from a policy perspective, because it allows to discuss further on how to move towards sustainability even under detrimental conditions. In fact, in view of a generalised economic slowdown it is not unlikely that the wider framework conditions for manufacturing will be geared towards other objectives than sustainability. Each of these framework scenarios will serve as a starting point for specifying at the level of transition fields the most desirable outcome possible, i.e. "best-case" images of the future for the transition fields under the conditions of the different framework scenarios.[13] These best-case images can then be characterised in terms of sustainability.[14] These most desirable, but nevertheless contingent future images then serve as a normative starting point for studying possible pathways leading to these images. Here, particular emphasis will be put on barriers, systemic effects and critical events needed to realise such a pathway. Individual projects and technologies can then be assessed with respect to their likely contribution to the different transition pathways. As a result, we get a set of possible and desirable scenarios/images together with the corresponding pathways at the level of transition fields and functionalities. They provide the foundation for a portfolio-based approach to policy-making (i.e. for foundation for developing robust and adaptive policy options that allow to deal reasonably well with different possible futures).

In practice, the methodology can be described in six steps as specified below. It will be implemented in the course of a series of workshops with participants from relevant projects of the research programme and external experts and stakeholders. In addition to the initial selection and specification workshop, three workshops are foreseen for each of the two transition fields, complemented and prepared by desk research and synthesis work using secondary sources and the results of the workshops.

1. Definition, specification and selection of transition fields: It is essential to have a clear understanding of the transition fields and how they can be systematically represented in terms of the three levels of analysis suggested above. In particular, the needs areas that are related to a transition field need to be identified.
2. Development of framework scenarios at the level of needs areas: Based on first sketches of potential framework scenarios, a workshop will be organised to further explore, modify, elaborate and refine them. These framework scenarios will be strongly based on social, economic and political "driving forces", but will also take general technological orientations in society into account. Obviously, particular emphasis will be put on user- and needs-sided aspects.
3. Development of "best possible" images of the future at the level of transition fields: The framework scenarios are based on an exploratory scenario approach, and are subsequently used as a frame for specifying "best possible" images of the future at the level of transition fields. The main difficulty is to integrate the

[13] It is still open for discussion whether we should go for several or just for one normative scenario. However, even if we develop several, there will be a best one that could serve as a basis for the transition analogy.

[14] The assessment can be conducted along the lines of one of the different approaches for sustainability assessment, for instance the approach of the Helmholtz-Society project on Sustainability "Global zukunftsfähige Entwicklung – Perspektiven für Deutschland" (Coenen/Grunwald, 2003; Grunwald et al., 2001)

framework scenarios for different needs areas into the specification of the images of the future of a transition field.

4. Assessment of the images of the futures: In terms of a predefined set of criteria, the images of the future will be characterised with respect to sustainability. This will not be an in-depth evaluation (which would go beyond the scope of the project), but it should deliver a rough assessment of the desirability of each of the images, differentiated according to key sustainability dimensions. What is particularly interesting from a transition perspective is the question in how far a scenario/image implies a potential for a major shift towards sustainability (i.e. a "regime shift").
5. Analysing transition pathways: A key question of any scenario analysis is: How do we get there? What are the requirements and systemic implications the scenario (or here better images of the future) would raise? At this stage, barriers to diffusion of new technologies will be analysed as well as missing links or elements to ensure the realisation of the pathway. This stage will have to build very strongly on inputs from the workshops.
6. Policy analysis: As part of the final stage, the role of individual technology projects with respect to the transition pathways can be assessed. Probably even more interesting will be a look at the implications of the project results for the design of research programme and policy portfolios to support a transition process. This will be the topic of a final workshop.

Conclusions

The methodology suggested builds a conceptual bridge between highly general guiding visions and very concrete projects of a research programmes. It thus allows to contextualise the projects of the research programme "Factory of the Tomorrow" under the conditions of a set of a longer-term transition perspectives. Moreover, the transition fields can be studied with respect to the potential influence of different driving forces, framework conditions and systemic effects. Two transition fields are selected to test the applicability and usefulness of the approach..

The scenario process is expected to stimulate debates about long-term perspectives for the transition fields under study. They serve as an orientation and thus as a focusing device for the strategies of the actors involved. From a policy perspective, the project is expected to result in a number of benefits, also beyond the level of an individual research programme:

- Analysing and assessing transition fields offers the opportunity to identify promising future themes for research programmes. Moreover, research themes would not only be selected on the basis of technological considerations or very general sustainability strategies (renewable materials, efficiency, etc.), but also in terms of their possible impact on transitions to a more sustainable production system.
- Transition scenarios will help identify critical socio-technical barriers and effects not yet addressed and understood by current research and thus point to new inroads for future policy.
- In principle, transition scenarios provide an orientation for staged research strategies towards sustainability, ranging from a broad range of exploratory and more ground-laying research projects to applied research pilot actions.
- Other policy areas than RTD policy often play a crucial role for the success of a technology and the evolution of a transition field. The transition perspective allows to define overarching transition strategies for the fields analysed and identify complementary .policy measures needed to enable and strengthen a transition path.

- By developing different scenarios that combine exploratory and normative elements, it is possible to underpin the formulation of robust and adaptive policy strategies, i.e. of strategies that are geared towards the objective of sustainable development, but at the same time allow to get prepared for different uncertain futures.
- The scenario building process also serves as a forum to enable interaction between the different projects of the programme (at least those related to similar transition fields) and other actors external to the programme. The process should thus facilitate networking of the programme participants and second-order learning effects by giving them an opportunity to reflect on the contribution and conditions required for success of their projects. These networking and learning processes should also lead to a better alignment of related projects and actor strategies.

In general the broader perspective provided by the transition scenarios of our project is expected to open up new perspectives for the process and the content of a next generation of the "Factory of Tomorrow" programme, based on the objective of initiating transition processes towards sustainable development. Nevertheless, at the present stage only a limited number of transition fields is dealt with in our accompanying project. It would be desirable for the further proceeding of the programme that the results of the example scenario development processes are convincing enough to trigger similar processes for other fields. As a first step this would require to draw up a more comprehensive list of transition fields covering most of the production sector. These transition fields could then be assessed according to the criteria presented above (potential contribution of the area to sustainability; relevance for the Austrian innovation system, etc.) in order to have consolidated basis for including the ones with the biggest potential impact on sustainable production as priority fields into future work programmes. Due to their socio- technical character, these transition fields could help overcome a too technical orientation in many research programmes aiming at sustainable development. With such a programme design, the consideration of integrated transition strategies would become an elements of RTD programmes and create closer links between technical development, social and organisational changes, and policy making for sustainability.

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References

CEC (ed). 2001. A sustainable Europe for a better world: A European Union Strategy for Sustainable Development. The Commission's proposal to the Gothenburg European Council. 15.5.2001, Communication from the Commission COM(2001)264, European Commission: Brussels.

Coenen R, Grunwald A (eds). 2003. Nachhaltigkeitsprobleme in Deutschland. Analyse und Strategien, sigma: Berlin.

Federal Ministry of Agriculture, Forestry, Environment and Water Management (ed). 2002. A Sustainable Future for Austria – The Austrian Strategy for Sustainable Development. Vienna.

Geels FW. 2002. Understanding the dynamics of technological transitions. PhD thesis, Enschede, Universiteit Twente.

Geels FW, Kemp R. 2000. Transities vanuit sociotechnisch perspectief (transitions from a socio-technical perspective). Research Report, MERIT: Maastricht.

Green K, Vergragt PJ. 2002. Towards sustainable households: a methodology for developing sustainable technological and social innovations. *Futures* 34(5): 381-400.

Grunwald A, Coenen R, Nitsch J, Sydow A, Wiedemann P (eds). 2001. Forschungswerkstatt Nachhaltigkeit. Wege zur Diagnose und Therapie von Nachhaltigkeitsdefiziten. sigma: Berlin.

ITA – Institut für Technikfolgenabschätzung der österreichischen Akademie der Wissenschaften. 1998. Technologie-Delphi II. Ergebnisse und Maßnahmenvorschläge, Studie im Auftrag des Bundesministeriums für Wissenschaft und Verkehr, Wien.

Industriewissenschaftliches Institut. 2001. Stoffliche Nutzung nachwachsender Rohstoffe in Österreich – Marktanalyse und Handlungsmaßnahmen. Studie im Auftrag des Bundesministeriums für Verkehr, Innovation und Technologie, Wien.

Katter R, Mackwitz H, Narodoslawsky M, Payer K, Stadlbauer W, Weiß B, Wimmer R, Wörgetter M. 1999. Nachwachsende Rohstoffe – Ergebnisse aus der Vorbereitungsphase für das Impulsprogramm Nachhaltig Wirtschaften. Studie im Auftrag des Ministeriums für Wissenschaft und Verkehr, Graz.

Kemp R, Schot J, Hoogma R. 1998. Regime Shifts to Sustainability through Processes of Niche Formation. The Approach of Strategic Niche Management. *Technology Analysis and Strategic Management* 10(2): 175-195.

Kemp R, Rotmans J. 2003. The Management of the Co-evolution of Technical, Environmental and Social Systems. In: *Towards Environmental Innovation Systems*, Weber KM, Hemmelskamp J (eds). Springer: Heidelberg (forthcoming).

Kuhlmann S. 2001. Management of Innovation Systems. The Role of Distributed Intelligence. Maklu Uitgevers: Antwerp.

Loorbach D. 2002. Transition Management: Governance for Sustainability. Paper for the Conference "Governance and Sustainability: New challenges for the state, business and civil society", Berlin 30 September - 1 October 2002.

Partidario PJ, Vergragt PJ. 2002. Planning of strategic innovation aimed at environmental sustainability: actor-networks, scenario acceptance and backcasting analysis within a polymeric coating chain. *Futures* 34: 841-861.

Rotmans J, Kemp R, van Asselt M. 2001. More evolution than revolution. Transition Management in public policy. *Foresight* 3(1): 15-31.

Schidler, S. (2003): Technikfolgenabschätzung der Grünen Bioraffinerie, Endbericht, ITA:Wien

Vergragt PJ. 2000. Strategies towards the sustainable household. The Netherlands. TBM-Delft University of technology, final report SusHouse project, EU contract no. ENV4-CT97-0446.

Vetter A, Biertümpfel A. 2001. Zusammenfassung des Veranstalters. Forum "Färberpflanzen" 2001, Gülzower Fachgespräche Vol. 18, edited by Fachagentur Nachwachsende Rohstoffe e.V. (FNR) Gülzow.

Weaver P, Jansen L, v. Grootveld G, v. Spiegel E, Vergragt PJ. 2000. Sustainable Technology Development. Greenleaf: Sheffield.

Whitelegg K, Weber KM. 2002. National Research Activities and Sustainable Development. A survey and assessment of national research initiatives in support of sustainable development. Research Report EUR 20389 EN, ESTO/ARC: Sevilla/Seibersdorf.