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Scientific and technological developments as drivers

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External drivers affecting Swedish forests and forestry

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This working report is one in a series of ten reports which focus on external drivers that have a potential of affecting the Swedish social-ecological forest systems in the future. The drivers were chosen after discussions in Future Forests' Core Team of researchers and in Future Forests' Panel of Practitioners. The reports are essential inputs to the research program's scenario analysis of possible futures for the Swedish social-ecological forest systems. Other reports on *External drivers affecting Swedish forests and forestry* are:

- Wilhelm Agrell (2009). *Geopolitics. Competition, conflicts, and wars in the future international system.* External drivers affecting Swedish forests and forestry. Future Forests Working Report
- Gustaf Egnell, Ola Rosvall & Hjalmar Laudon (2009). *Energy as a driver of change.* External drivers affecting Swedish forests and forestry. Future Forests Working Report
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- Camilla Sandström & Anna Lindkvist (2009). Competing land use associated with Sweden's forests. External drivers affecting Swedish forests and forestry. Future Forests Working Report.

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Future Forests analyzes conflicting demands on forests systems
to enable sustainable strategies under uncertainty and risk

Content

1. Introduction

Our modern world is to a great extent explained, shaped and driven by natural sciences (hereafter, science) and technology, and everything indicates that science and technology will continue to play a major role in the world of tomorrow. This is at least what the scientific community as well as politicians and educated people in general believe. When the international newsmagazine *Newsweek*, at the turn of the millennium, asked their readers what they expected from the 21st century, they outlined a future dominated by implications of advances in science and technology (Brown, Rappert & Webster 2000). Since one of the few utopias to serve the past century was that of the sciences and technologies, this result is not surprising (Shaffer 2003). Yet, in what ways new (or, for that matter, old) scientific and technological findings and inventions will operate as *drivers*, and what these drivers will be, is impossible or at least extremely difficult to foresee. The reason is quite simple. In contrast to the grand belief of the Enlightenment philosophers, the development of science and technology is not in any way a linear and naturally evolving process. And the same can be said about the *impact* of science and technology on nature and society. A research result that in one context is looked upon as strange and totally useless, may in another context become a driver for social and economic change; a research result that once was celebrated with a Nobel Prize and gave rise to new markets, may some decades later be regarded as the cause of severe environmental problems and an incarnation of a technocratic past.

Against the background of insights about the dynamics and complexities of social and ecological systems, thinking about the future has over time become less mechanistic and more reflexive. The future of science and technology is, however, not possible in all thinkable forms, hence not totally uncertain. It is rather, as Brown, Rappert and Webster (2000) put it, "actively created in the present through contested claims and counterclaims over its potential". What we as analysts can do is to examine current visions and expectations surrounding scientific and technological findings and inventions not yet implemented. From research done on the trajectories of findings and inventions in the past, it is also possible to relate such visions to challenges usually connected to implementation of new science and technology. In this paper both visions and challenges are discussed.

Before we begin some concepts need to be clarified. From a contemporary point of view, science and technology seem to be strongly connected. This relationship has, however, quite recently been formed. Technology – in the form of using tools and crafts in order to fulfil certain human needs and desires – has originated hand in hand with humankind ever since the days of the species *Homo habilis* ("the handy man"). Science – in the form of a systematic pursuit of knowledge and theories about the natural world – has a much shorter history. It began as pure natural philosophy in ancient Greece but did not develop into an empirical and organised enterprise until the "scientific revolution" in Europe during the sixteenth and seventeenth centuries. From then and until the end of the nineteenth century science and technology progressed either in partial or full isolation from each other. The present relationship between science and technology is thus a result of a historical process (McClellan & Dorn 2006).

The relationship between modern science and technology has long held the attention of historians and even been a matter of dispute (Lundgren 2004). Some scholars emphasise that technology to a high degree is a result of science, that technology, strictly speaking, is "applied science". In historiography this model, which also imply the idea that applied research, in its turn, will appear on the market as innovations, is called the "linear model". Others stress the fact that much of modern science is based on and even shaped by the technology available, an interpretation sometimes put under the label "technological determinism". Technological determinism is a model that implies that technological developments take place outside society, following an internal technical logic, and that technological change causes or determines social change (Wyatt 2008).

The linear model and the model of technological determinism are both highly idealised frameworks, which leave small space for human choice or intervention. To get rid of some confusion scholars within the field of Science and Technology Studies (STS) rather prefer to use the concept “technoscience”. Furthermore, technoscience is interpreted as an integral, context dependent part of society, as something that both shapes and is shaped by social and cultural forces. One reason behind this conceptualisation and interpretation is that there does not seem to be any practical difference between science and technology: both are skilful activities with different traditions and ideals but nevertheless products of human art and craft (Collins & Pinch 2002). Technoscience may refer to technical projects, which are heavily dependent on science (or vice versa), or to the production of scientific commodities in academic-industrial-governmental complexes. It captures the coupling between “ways of knowing” and “ways of doing” (Pickstone 2000).

Due to the focus of this paper, another distinction may be made between science and technology in general, and science and technology developed with the specific aim of shaping or improving forests and the forest sector. In the past both types have had an impact as drivers on the forest system, therefore both will be discussed in this paper.

2. Science and Technology in the Context of Sweden's Forests and Forest Sector

In the context of Sweden's forests and forest sector science and technology have an impact in many different ways. For the forest sector science and technology contribute to new methods and tools for forestry and silviculture, which aims at sustaining and intensifying the productivity of natural resources, and at the development of the forest industry, including all steps in transforming natural resources into profitable products, from mechanical harvesting to trustworthy marketing. As in many other sectors, scientific and technological innovations tend to increase this sector's competitiveness in the market place, and at the same time reduce the numbers of workers needed within the sector. As technology influences so many aspects of the forest industry McFarlane et al. (2008) define it as a "major determinant" of the competitiveness of the Canadian forest sector. This is true also for the forest sector in Sweden, at least from the forest industry's point of view.

For biodiversity and the environmental condition of the forests scientific and technological findings, innovations and systems have been a double-edged sword. On the one hand science and technology can pride itself on having been at the forefront of establishing the environmental agenda in the second part of the 20th century (Sörlin 1997). Science and technology also contribute to "eco-effectivity" within the forest sector. On the other hand, science and technology have contributed to much environmental havoc; many environmental problems of today, such as global warming, depletion of the ozone layer, acidification, eutrophication and loss of biodiversity are to some extent consequences of innovations in science and technology. Most of these problems are results of science and technology in general, but some are due to the implementation of ideas and inventions from agricultural sciences and forest engineering in particular.

In contrast to modernists' worldviews where scientific and technological developments always represented progress toward a better future, technoscience is now widely seen to be both a solution to problems and the potential source of risks and undesirable "side effects" (Yearley 1995; Lidskog, Sandstedt & Sundqvist 1997). This is not to say that all science and technology are dangerous or problematic from environmental or cultural perspectives. Both science and technology are skilful activities, and it can never be guaranteed that a skill will always be executed with precision, but just as science may enter a realm where no one questions or disputes its findings, so technology becomes more reliable as our experience grows and our abilities develop (Collins & Pinch 2002). Through a process, which may be called "cultural appropriation", much science and technology that first were regarded as deeply problematic have eventually been accepted (Hård & Jamison 2005).

As a driver on the forest system, scientific and technological developments have many links to other articulated drivers, notably the global market for forest products and energy but also land use claims, climate change, air pollution and the politics surrounding these areas. Furthermore, the development and implementation of science and technology are shaped by norms, values and attitudes. In their paper McFarlane et al. in particular highlight neo-Luddism, which they consider as a modern movement of opposition to technological development. This is a common statement in certain policy circles, but it is too simple and unilateral. First, in historical terms, technoscience seems to have never been spontaneously and universally trusted. Second, criticisms and oppositions have often been essential for the development of safer technological systems (Pestre 2007). Third, norms, values and attitudes are of course as significant for those who develop and promote technology, including the modern technocracy movement and others who believe that technology is the answer to all problems, even societal problems.

3. Methodological Considerations

The present paper is based on overviews and reviews concerning research and development in connection to forests and the forest sector, in particular documents on future scenarios composed within other research programs, such as the Canadian Sustainable Forest Management Network's project Future Forests, and the European project EFORWOOD: Sustainability Impact Assessment of the Forestry–Wood Chain. The paper also draws on findings and models from the interdisciplinary research fields Environmental history and Science and Technology Studies (STS), of which the latter includes studies in the history, philosophy and sociology of science and technology.

4. Looking Back

Science and technology have affected the Swedish forests and forest sector in numerous ways. Sometimes innovations external to the forest system have played the major role. The best example is perhaps the transformation of the industrial use of forests that took place in the middle of the 19th century: from charcoal production for the old iron industry to timber production for the new forest industry. There were of course many factors behind this transformation, including a growing competition on the international iron market and an increasing demand for wood and timber. But scientific and technological developments were also part of the story, not least innovations in steam power technology and later in combustion technology, which utilised fossil fuels and made charcoal an outdated energy source.

In the wake of this transformation the forest industry in Sweden expanded quickly; the number of forest companies and sawmills increased, the rivers were industrialised and at the turn of the century Sweden was in fact the leading exporter of timber in the world. Since then the forest industry and the manufacturing sector as a whole have gone through two major shifts – toward the production of first pulp and then paper products – partly due to innovations in chemistry and chemical technology. Of importance for the forest industry was also the invention of new wood based materials such as Masonite, an American innovation introduced as the "latest thing" at the Stockholm Exhibition in 1930. Ever since, it has been a significant design material.

Many inventions have been developed within the context of the sulphite and sulphate industries, for example technologies for producing chemicals and handling the waste. Pine and spruce contain at best only 40% cellulose, and in the beginning, the remainder was released into air and water, causing major environmental problems. In 1909, two Swedish engineers patented a method to ferment sulphite lye into alcohol, ethanol, and since then several attempts have been made to set up a large scale production of biofuels from wood. Within a couple of years three sulphite alcohol factories were established. During the First World War when import of oil decreased, the number of plants producing sulphite alcohol grew and an industry producing engines designed for this fuel emerged. A socio-technological system was about to be established but it never reached momentum, partly because cheap imported oil increased after the war (Sundin 2005). This story was more or less repeated during the Second World War, during the oil-crisis in the 1970s, and it is repeated today.

As McFarlane et al. (2008) reminds us, scientific and technological innovations external to the forest sector have contributed not only to an increasing but also a decreasing demand for forest related products. As the expansion of printed media in the 19th century created a growing need for paper, the expansion of electronic media since the late 20th century has reduced the consumption of paper, at least paper used for mediating news. The establishment of the recycling system, in

Sweden and elsewhere, is another example of an external process that clearly has affected the forest related market. In 2006, 1.8 million tons of paper and corrugated cardboard and 10.9 million tons of wood were recycled in Sweden (Naturvårdsverket 2006). Recycling has now become a business sector in its own right.

Ever since the Royal School of Forestry (1828) and the Experimental Station for Forestry Research (1902) were established, methods and tools with the specific aim of improving forestry and increasing productivity have been developed and sometimes implemented. We have in view all sorts of methods for plant breeding and silviculture, which are based on theories or experiments in fields and laboratories, as well as mechanical tools for harvesting and other innovations in forest engineering. Needless to say, this research has not developed in an intellectual vacuum but has all the time taken advantage of knowledge produced within other academic disciplines, notably plant physiology, genetics, ecology and economics. We also have in view the many technologies that have their roots in other sectors but have been adopted and transformed in order to fit the needs of the forest sector, such as decision-support systems that integrate remote sensing, GIS and visualization tools (Rosvall & Sennerby-Forsse 1997; McFarlane et al. 2008). An overview of the Swedish forest sector's productivity development 1956–2005 (including the development of tools and machines) is presented in figure 1 below.

In Sweden research and development concerning forests, forestry and forest products have to a high degree been funded by the government and conducted in academic settings, such as the Swedish University for Agricultural Sciences and the technological universities. This is not by accident since a large part of the forests is state property and important for the nation's economy and environment. But private industries within or connected to the forest sector have also been responsible for funding as well as research and development in industrial laboratories. The present research and development landscape in Sweden, including funding, is discussed in detail below.

Over the past century the implementation of scientific and technological based methods and tools in forest management has contributed to transforming the forests' ecosystems in a profound way. Today some 95 % of the Swedish forest is a cultivated and industrialized environment, dominated by planted spruce and pine in accordance with political and market demands. From the point of view of the forest industry this development has been nothing but a success, although the need for more and cheaper wood seems to be a timeless wish. Other interest groups, notably the environmental movement and the Sámi organisations, have not been as impressed by the result (Lindkvist & Nordlund, forthcoming).

Until the 1970s the introduction of new forestry methods and tools was, for good and for bad, a fairly easy business in Sweden. The main objective was to intensify forest growth and support production, and science and technology were the means to reach that goal. Changes within the sector occurred through the impact of small networks of forest scientists, forest owners and forest-related firms, and as in many other sectors of the "People's Home", consensus was the predominant norm. Since then society has become much more complex, the mediated public debate more critical and heterogeneous, and both forestry and the forest landscape as a whole have turned out to be a highly contested arena. According to the forest scientist and historian Kardell (2004) almost all modern methods and tools for intensifying forest growth – clear-cutting, spraying with phenoxy acids, fertilization, contorta plantation – have been officially criticised. In the end some of these methods have also been forbidden or regulated.

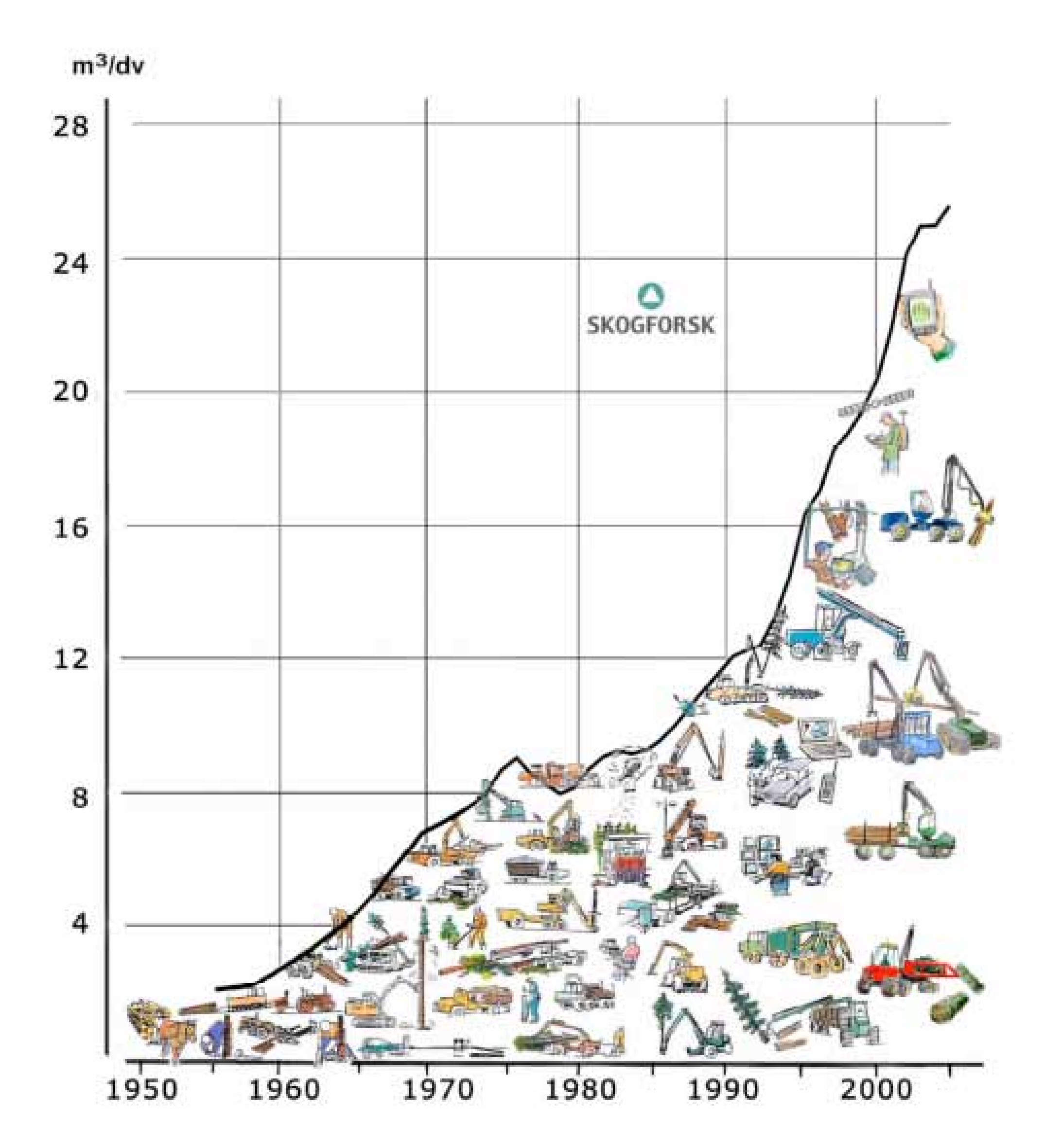


Figure 1. The Swedish forest sector's "productivity development" 1956–2005, including the development of tools and machines. The picture is published in *Nytt från Skogforsk* 3 (2007).

Models for the Dynamics of Science and Technology

McFarlane et al. correctly point out that technological development is influenced by a diverse range of drivers. But in order to work as drivers, scientific and technological findings and tools not only need to be discovered or invented. They also need to be accepted and implemented, and implemented on a fairly broad scale. How does that happen in modern liberal societies? Or to put it another way: how can we understand the dynamics of science and technology?

Sometimes agency is attributed to a particular technology itself, as if its benefits for users, the society or the environment are “self-evident”. This almost deterministic view is typically found in commentaries on the “future impacts” of new technologies. The force implied in this attribution of agency is, according to Brown, Rappert and Webster (2000), that “one can either ride the wave of advancement or drown in the waves of progress”. Powerful narratives or visions may indeed turn out to be “self-fulfilling prophecies” but science and technology do not determine cultural developments; rather they dispose our cultures to take on new possibilities (Hård & Jamison 2005). Another idea is that implementation of new technologies is only a matter of knowledge among the potential consumers and users, why dissemination of information and campaigns to foster public understanding are seen as the most critical practice. However, as will be discussed in detail in this section, introducing radically new scientific and technological innovations on a large scale is usually a very complicated business.

In the following we will present three different but partly overlapping models dealing with production, acceptance and implementation of science and technology on different scales. All models are based on empirical findings and grounded in real world problems but they are still examples of “grand theories” and as such they shall be used with cautiousness. First and foremost, they provide food for thought concerning the nature and challenges of technoscience.

Actor-Network Theory

Since the 1980s, theories about networks have played a major role in both the humanities and social sciences, first and foremost as a way to conceptualise links between individuals and structures, interests and power. The most common aim of networks is to generate, transmit, and transform information (Nettelbeck 2006), and within Science and Technology Studies (STS) network theories have been utilised in analyses of the “development”, “dissemination” and “establishment” of scientific and technological facts, artefacts and systems.

One of many approaches is the so-called Actor-Network Theory, or ANT. ANT is associated with theoretical works of the STS scholars Latour (1994) and Callon (1999) but has over time become more of an analytical tradition than a coherent theory. The original ANT and its terminology is not easy to summarise in a simple way, but it may be described as a conceptual framework for exploring collective scientific and technical processes in the making, and for explaining why certain theories and practices come to prevail and others not (Yearley 2004).

Within this framework technoscientific networks are defined as processual, built activities, performed by the actors (or “actants”) out of which they are composed, and also an actor in its own right. In contrast to theories about social networks, ANT claims that any actor, whether a person, an object, a piece of nature, or an institution, is important to the success of a network and hence the innovations proposed by it. At the same time, networks in the making are looked upon as fragile. If one or more actors within the network are removed, the network begins to break down. Like a chain, a network is not stronger than its weakest link. Another point of departure for the model is that there always exists a dynamic interplay between knowledge production and social interests. Knowledge production is shaped by social interests, for example environmental or economic concerns, but social interests are also shaped by knowledge production.

Analytically, ANT deals with the ways in which technoscientific networks come into being, overcome resistance and strengthen internally, thus gaining coherence and consistence. This is called *stabilization*. Second, ANT is interested in how networks organise and convert network elements, that is the *translation* of knowledge. This process may be explained as a chain of translations, as, for example, when a soil sample from Vindeln is translated into a representative of a soil type, which is then translated into a sketch map of soil distributions, which then can be transferred onto a formal map and circulated in scientific papers and laboratories all over the world. “Translation is a process before it is a result”. [---] “it is the mechanism by which the social and the natural worlds progressively takes form”, as Callon (1999) succinctly puts it. Third, ANT analyse how networks not only keep their actors but also *enroll* and *mobilise* allies to invest in, follow or support the proposed program. In sum, ANT deals with how networks expand, make knowledge transportable and useful, and how they eventually become functionally indispensable for others, as *obligatory points of passages*.

The success of science and technology is attributed to the ability of technoscientific networks to force entities to pass through academic settings in order to harness evidence in academic or political disputes; to translate materials, actors and texts into *inscriptions* that allow influence at a distance from the academic settings; and to organise *centres of calculations* where network elements are defined and controlled, and strategies for translation are developed and considered (Latour 1994; Crawford 2004). From the ANT perspective, results from research and development in science and technology, such as findings and inventions, are important, but they are only starting points; they do not “speak for themselves”. Networks, and hence their innovations, will gain influence when they become obligatory passage points for stakeholders.

The Swedish research network associated with the resilience concept may serve as an illustrating example. Over the years it has not only enrolled researchers from many different disciplines, but also mobilised institutions and organisations and eventually established a centre of calculation, Stockholm Resilience Centre, which is, or at least has the potential to be, an obligatory point of passage for research as well as politics and business concerning sustainable development.

To become and continue as a robust network is easier said than done since numerous networks, providing different types of knowledge and attracting different types of interests, are competing with each other all the time. Another problem has to do with the importance of enrolling more and more allies in order to gain strength and at the same time keep them within the network, since the diversity of interests also tend to increase over time. These circumstances are significant for all technoscientific networks that aspire to become “drivers” within the context of the Swedish forests and forest system.

Socio-technological Systems

Based on a historical study on electrification, which indeed may be defined as a broad network analysis, the historian of technology Hughes (1999) has developed elements of a more general theory of the evolution of large technological systems. By technological system Hughes means both a technical core of physical artefacts and organizational structures such as manufacturing firms and investment banks, where the technical core and the organizational structures are interlinked and depends on each other. Furthermore, technological systems usually incorporate scientific components, regulatory laws and nature resources. Well-known examples of this type are infrastructural networks, which stretches large geographical areas such as electricity systems, railroad networks, and telephone networks. Because of the interaction between a technological system and its surroundings, technological systems are looked upon as both socially constructed and society shaping. Hence, the concept “socio-technological” (Hughes 1999).

How do modern socio-technological systems evolve? Hughes suggests that the history of evolving, or expanding, systems can be presented as a series of partly overlapping phases conceptualised as *invention*, *development*, *innovation*, *transfer*, *growth*, *competition*, and *consolidation*. These phases are, however, not simply sequential. For example, inventions (within the framework of the system) may happen all the time. Different phases are also dominated by different "system builders", or entrepreneurs, such as inventors, managers or financiers. The model may be summarized in the following way.

To start with, technological inventions are divided into two types, "radical" and "conservative". The first type inaugurates a new system and hence occurs in the first phase, while the second type improves the first and consequently occurs in later phases of the ongoing system, typically due to competition and growth. Radical inventions are crucial for historical change, but, as is also stressed in ANT, they only represent potential for change. If an invention should be looked upon as a "breakthrough", or not, is impossible to say when the invention is new and not yet supported. Before an invention turns into an innovation, practical problems need to be solved and the idea has to be provided with the economic, political and social characteristics that it needs for continued existence in the real world. This occurs during the development phase.

In classic economics an invention turns into an innovation when it enters the market. But this is also a complex process, which implies that the innovation develops into an innovation system consisting of manufacturing, sales, service facilities and so on. Further problems tend to arise when technology is transferred in time and place; since a technology and its organization are usually designed for a particular cultural and natural environment – has a certain "style" – the total technical system has to adapt to every new cultural and natural environment where it is used (or the environments have to be made to fit the technology).

For different reasons managers of technological systems often try to expand their system as much as possible. But when technological systems grow, new troubles emerge, some of which Hughes labels "reverse salients". The concept is a metaphor connected to uneven and complex change. "A salient is a protrusion in a geometric figure, a line of battle, or in expanding weather front. As technological systems expand, reverse salients develop. Reverse salients are components in the system that have fallen behind or are out of phase with the others" (Hughes 1999). In other words, reverse salients can be defined as critical and often unexpected problems which, when solved, will expand the system, and if not solved, will lead to decline for the old system and at the same time to possibilities for new or competing systems.

Technological systems that have been consolidated, that continue to produce conservative inventions and have a stable growth never become totally autonomous, but they acquire "momentum", which make them very difficult to beat in "the battle of the systems". Momentum is also a metaphor, originally a term from physics referring to an object's quantity of motion: the higher its momentum, the more an object will continue along its trajectory. In the present context, momentum implies established social organization, technology and skills, but also certain attitudes and values – *mentalités* – that resist change (Hughes 2006).

To sum up: socio-technological systems are complicated, complex and very difficult to establish. The attempt to scale up production and use of ethanol from wood, which in Sweden has been going on for almost a century, is an illustrative example. But when they are established, and have reached momentum, they are also very difficult to change. They tend to exert influence on other systems, groups and individuals in society. In the context of the Swedish forests and forest sector, this has implications regarding for example the capacity of the production system to adapt to future challenges, such as global warming. Given that the present system has reached momentum, it will continue to produce and accept only conservative inventions as long as it is possible, while new and radical inventions – that perhaps are better suited to future challenges – will have trouble to be accepted. According to the model, a new system will not be able to break through until the present system encounters reverse salients not possible to solve.

Multilevel Perspective

From models dealing with expanding technoscientific networks and evolving socio-technological systems, we now turn to the even bigger picture offered by the model known as "Multilevel Perspective" (or "Multilevel Analysis"). This model has a strong connection to traditional research on innovation systems but has been of certain interest for research focusing on the question why so many innovations, for example innovations of possible importance for a sustainable development, get stuck in laboratories or showrooms and never make it to the market. Building upon ideas and insights from the history and sociology of technology (notably theories of networks and socio-technical systems) but also from evolutionary theory and innovation research in general, this perspective interprets innovation processes and transformations of technological systems at three heuristic levels: the local level, the sector level and the macro level. It includes analyses of structures, agency and power relations as well as social constructions of shared meanings and negotiations (see for example Geels 2007, and Markard & Truffer 2008 for overviews).

In the model, *technological niches* represent the local (or micro) level. Technological niches consist of small networks of actors who work in more or less protected domains, such as university departments or company laboratories, and support novelties on the basis of shared expectations and future visions. The point of departure is that innovations developed within these niches are always "in the making" and their challenge is to withstand pressure from the market. Niches thus act as "test-beds" for potentially radical innovations that would otherwise not survive.

The sector (or meso) level is represented by *socio-technical regimes*. In the model it includes sets of rules, laws and regulations, cognitive routines, established practices etc. common to a community of scientists, engineers and other groups belonging to a certain sector, as for example the forest sector. This level accentuates the institutional character of a regime, which creates the stability and momentum of existing socio-technical systems. The point of departure is that technological regimes typically have a resilience and adaptive capacity, which make technical systems "dynamically stable" where innovations and transitions occur cumulatively along established technical trajectories. At the same time, this clearly generates a powerful path-dependency over time, which marginalises competing or new technologies to enter into the sector.

The macro level is represented by *socio-technological landscapes*, which refer to the wider external environment of processes and factors. This level includes various heterogeneous factors, such as wars, oil prices, emigration, environmental problems as well as general political and cultural values. In addition, it includes deeper structural and material aspects of society, such as demography and spatial patterns of cities, industries and infrastructure. Furthermore, it embraces physical changes and the dynamic process of nature itself, which all the time interact with social processes causing complex long-term changes and sometimes dramatic shocks, most obviously exemplified by global warming. The point of departure is that changes on the landscape level influence both socio-technical regimes and technological niches.

Research on scientific and technological innovations sometimes attempts to explain failures in sustainable technology introduction by niche-internal reasons. Reasons of this type include a poor articulation of expectations, a lack of user and outsider involvement in the social networks involved in niche market experimentation, and a limited learning process that only focuses on techno-economic optimization and neglects user preferences, the regulatory and political environment, infrastructural constraints, power plays and other social and systematic dimensions (Ulmanen, Verbong & Raven 2009). The advantage of the multi-level framework is, however, that it emphasises the importance of taking notice of several different social and technical processes as well as the connections between all of these. The emergence of novel scientific and technological innovations at the niche level, and the rhetoric surrounding them, is only one part of the play. In accordance with the model, we also (and simultaneously) have to take into consideration both stabilization mechanisms at the regime level and destabilization forces at the landscape level.

Stability of prevailing regimes is one important part of the explanation why radical innovations have a hard time breaking through and usually remain stuck in the niches. It is important to note that, according to the model, there is nothing intrinsic to the technologies, which makes one more superior to another. To quote Brown, Rappert and Webster (2000): “The difference lies not in the technology necessarily but rather in the contingencies of socio-technical circumstances and the play of institutional interests that favour one technology over another.” However, as the history of science and technology demonstrate: nothing lasts forever. Or, as Summerton (1994) puts it: “systems and networks are dynamic entities. They can seldom be black-boxed for good”.

At some point in time new values, changed political agendas, disturbances on the market or natural disasters may emerge at the landscape level, creating pressure on the existing regimes. This makes internal technical problems – “reverse salients” – appear, leads to social protests, changes the users’ preferences, or alters the competitive conditions. Geels (2007) argues that such pressure may cause de-alignment of the existing regime, which creates a “window of opportunity” for a broader change of the socio-technical system. Important though is that actors need to be active and also take the opportunity. If scientific and technological innovations are sufficiently developed within the niches, actors who promote them may take advantage of the situation to expand their networks and start competing with existing technology.

5. Looking Forward

One might ask whether it is possible for researchers to express themselves about the consequences of their research without crossing the boundary between fact and fiction. The sociologist Mulkay (1996) does not think so, and he is right: “When speculating about the development of new science-based technologies, participants cannot rely entirely upon what they take to be the established facts. While they think and argue about the shape of things to come, they have no alternative but to create some kind of story that goes beyond these facts.” Historical studies of ideas about futures in the past indicate that “visions of tomorrow” tend to be context dependent, that is, they are extrapolations of the present and owe much to the time and place of the actors who formulate them. This is true also for our own attempt to “look forward”. It is, however, hard to envision a future which does not count on science and technology as important drivers for the design and use of forests, but it is at the same time important to respect both the difficulties connected to the implementation of innovations on a broad scale, and the possibility of undesired side effects when implementation processes became successful. We need to have the right expectations, whatever that means. Given that scientific and technological developments will continue to be a driver for the forests and the forest system, what are the trends and what will happen until 2050?

There exist today some powerful commercial, policy-related and intellectual narratives associated with the anticipated future impact of three types of technoscientific fields: Information and Communication Technology (ICTs), new materials, including nano technology, and biotechnology (Brown, Rappert & Webster 2000). In the literature these fields are said to represent a major shift, from “exotechnologies” to “endotechnologies”. In contrast to the first type, which enlarged the biologically restricted human reach in its immediate and geographically extended environment, and allowed for the mass production of artefacts as well as the construction of vast infrastructures, the endotechnologies is extending the scale of the human-built world down to that of infinitesimal living organisms and within matter itself (Nowotny 2006). As we will describe below, elements of the these narratives are of certain interest for the present discussion on sustainable development and ecological modernization, including sustainable future forests and a sustainable forest sector.

The grand visions connected to these narratives may to some extent be interpreted as forms of speculative scientific and technological (and economical) optimism; the rhetoric surrounding future technoscientific miracles is indeed hyperbolic. This makes them no less important or less interesting. As researchers within the field of technoscientific expectations have indicated, expectations, regardless of how speculative they may be, ought not to be seen as ephemeral or irrelevant but as fundamental for research and development. The simple theoretical point of departure for this approach is that visions and socially constructed futures contribute to legitimizing claims, mobilizing financial resources, forming networks and thereby urging science and technology in certain directions and away from others. In other words, they are strategic resources in political and technological agenda-setting processes (Nordlund 2007).

Visions, however, also create unease in the wider society. They have, as Nowotny (2006) puts it, given rise to anxiety equivalent to the wonder they have inspired. And as long as we live in a democratic society anxiety matter as well. To some extent this anxiety is also connected to the new regime of science production and regulation that has been established over the last decades. According to Pestre (2005), we have moved “from a system of science in society dominated by an equilibrium between science as *public good* and science as *industrial good* to a system in which a financial and market-oriented appropriation of scientific knowledge is now in the ascendant, to science as mainly a *financial good*”. This pragmatic and financial markets-driven regime, what is sometimes called the new knowledge-based economy, has most likely implications for peoples trust in technoscience, or perhaps rather, trust in the regulations of technoscience.

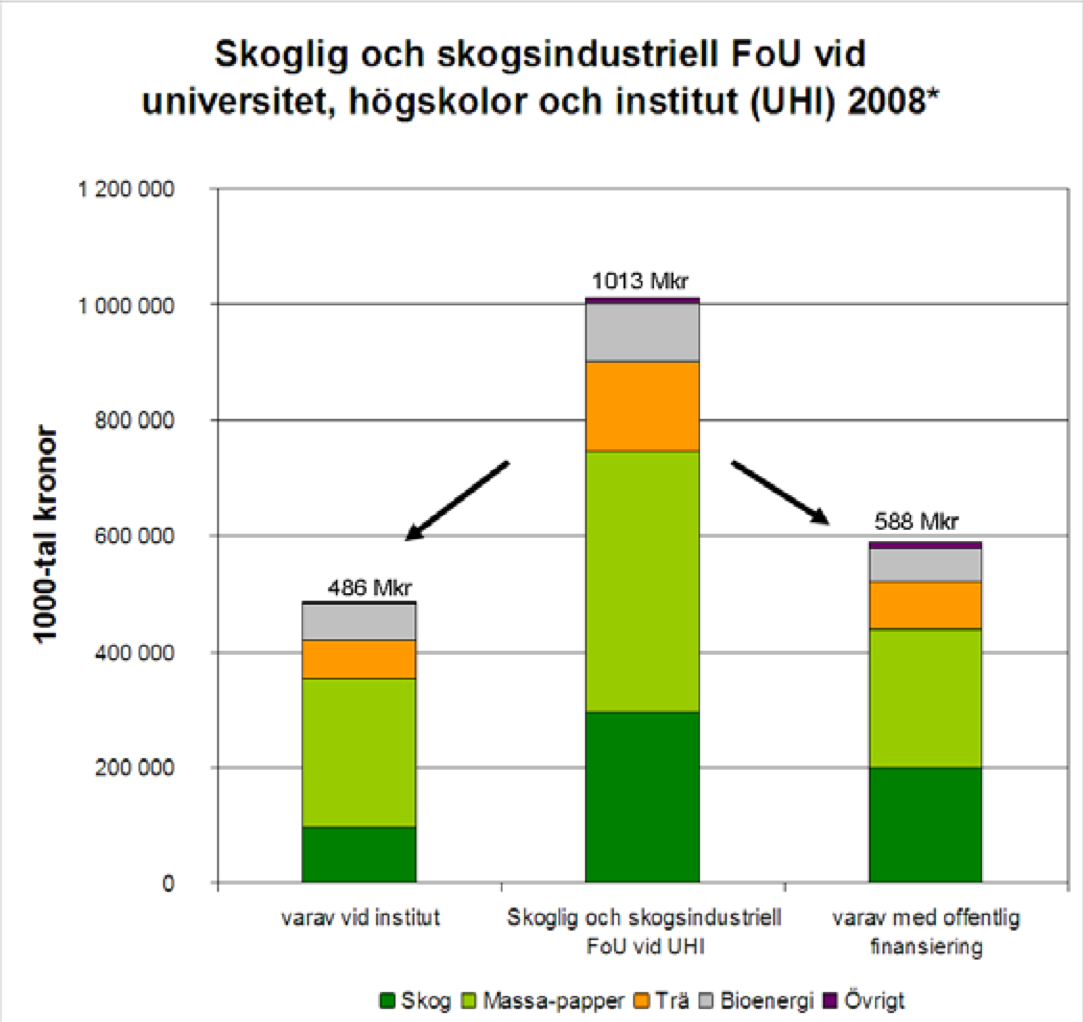
The R&D Landscape in Sweden

The value of the forest is defined by what it can be used for. Forests may, of course, be used for many different purposes, including ecosystem services. From a consumer product market perspective, however, trees are only raw materials that need to be managed, utilised and improved into products. The value of raw materials can be increased by both the development of higher valued end products and by decreased production costs. The latter include both costs for silviculture and harvesting. If the values of the products are low and the harvesting costs high the trees will not be harvested. For some time forest value has been generated by decreasing operation costs at a faster rate than the drop in wood prices. From the point of view of the forest industry it is important to contemplate about what science, technology and other developments can change this situation in the future.

In order to continue the forest industry business and meet future customer and consumer demands large private and public investments are today put into research to develop completely new products for new fields of applications both for materials and energy. The forest industry vision is no less than a new product portfolio and new technological and business partnerships with added value to products and services.

The full extent of the research basis for scientific and technological development concerning forests, forestry and forest products industry is hard to tell since this branch of business gather information and knowledge from, and depend on, the whole scientific and technological world. However, the extent of research carried out specifically on forestry and topics of relevance for the forest industry at universities, university colleges and institutes has been compiled by the Swedish Forest Industries Federation, see figure 2. Out of totally 1 013 million SEK per year 44 %, 15 % and 10 % is invested in the research fields: pulp and paper, solid wood and bioenergy respectively, i.e. totally 69 %, while the rest is invested in general forest research. Slightly less than half of all research takes place at institutes and just above half of all research is financed by public funding. The institutes have a relatively larger share of its research addressed to pulp and paper and wood technologies. Thus the main part of forest related research is conducted at universities and university colleges. An image of the forest industry research and development landscape 2008 is presented in figure 3.

In the following sections we will focus on three technoscientific topics related to future forestry and forest related business – bioenergy, modified trees and biomaterials – and briefly discuss their possible impact on the forest system. Furthermore, we will also present some ideas about possible technologies for the forest industries' production chain.



* Enligt enkät till FoU-utförarna

Figure 2. Research carried out on forestry and topics of relevance for the forest industry at universities, university colleges and institutes. (www.skogsindustrierna.org)

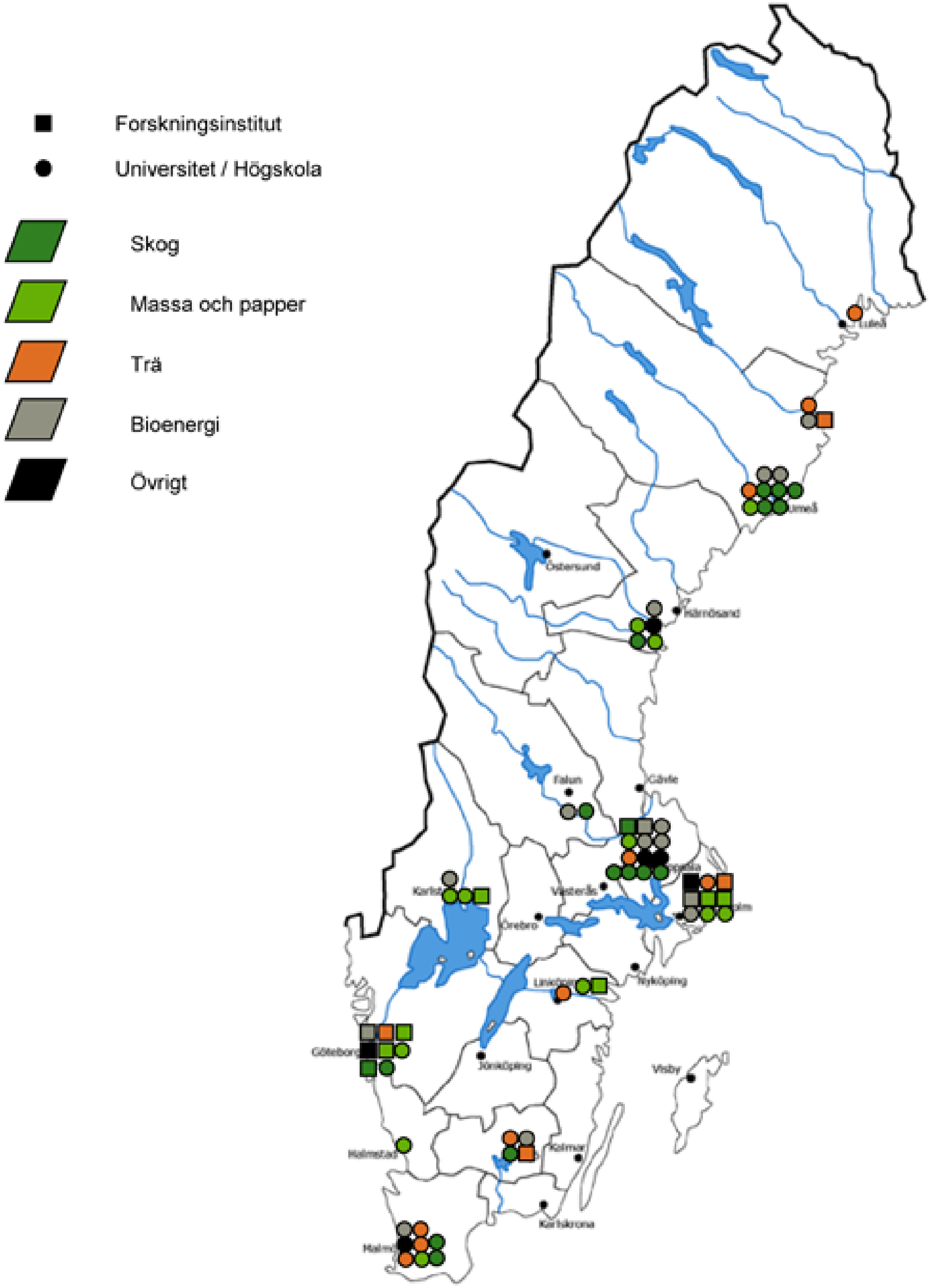


Figure 3. The forest industry research and development landscape 2008. (www.skogsindustrierna.org)

Bioenergy

Since global warming seems to be a result of the combustion of fossil fuels, a systematic replacement of these fuels is now of paramount importance. In addition to environmental considerations, oil dependency has important financial and security implications as well. From the MLP model perspective, this is a situation on the landscape level that facilitates broader changes of dominant socio-technical systems. Like the shift in energy regime from wood to coal in the 19th century, and from coal to oil in the 20th century, it is therefore most likely that we will face a shift from oil to something else and hopefully more sustainable in the 21st century (McNeill 2000). This "something else" will probably be a combination of many different energy resources such as water, wind and solar power, hydrogen power or perhaps an energy resource not yet discovered. It may also, and perhaps to a large extent, be bioenergy. No matter what, implementations of scientific and technological developments in new types of socio-technological systems are some of the most crucial factors in the replacement process.

In Europe great expectations are connected to the possibility of increasing the production of bioenergy from both agricultural and forest sources. A certain interest has been shown for the possibility of using and producing biofuels, and the European Commission has also supported many research and demonstration projects within the Union. The present (not so likely) goal is that, in 2010, biofuels shall contribute to some 6 % of the total European transport fuel consumption. So far the main biofuels produced in Europe – bioethanol and biodiesel – have been based on agricultural products, such as sugar beets, wheat and rapeseed. In Sweden, however, the century old vision of producing biofuels from domestic wood has once again been articulated and boosted. Biofuels may be ethanol from fermentation of cellulose or synthesized fuels from gasification of black liquor or residual biomass. Through torrification residual biomass can be homogenisised into a high value fuel.

In numerous Swedish reports and media articles we are said to be "on the verge of" a new industrial revolution, aimed at replacing oil by biofuels. One "driver" behind this image is the organisation BioFuel Region (BFR), which indeed may be defined as a technoscientific actor-network in advance. In the rhetoric of BFR's own marketing material, the revolution is already a fact, propelled by humanity's need to, within a few decades, transform the energy system for the transport sector as a whole. Not only are we hoping and wishing for such a future, we are also faced with the inevitability of it – in some sense it is already here. In BFR marketing as well as in newspaper reporting, convinced and engaged people, scientists, politicians, "the man on the street", bear witness to this ongoing societal transformation.

What these believers offer the readers are arguments for why industry will choose a new trajectory, and what this new trajectory will be built on. For example, in the prophesies of BFR leader Carstedt (2006), the industrialisation of cellulosic biofuels can generate over 100 000 high-quality jobs and financial investments world-wide to the amount of thousands of billions of Swedish crowns over the course of the next 20 years! BioFuel Region's "own" high-profile politician, Maud Olofsson, Minister for Enterprise and Energy but with roots in the region, declares in an interview that turning cellulose ethanol into an industrial reality constitutes a major opportunity especially for the Västernorrland-Västerbotten region. In her perspective, it is a win-win situation: "We can create new jobs at the same time as we save the environment. That is what I would like to work with the coming four years. Swedish biofuel production is very important, for the jobs as well as the environment" (Johansson 2006).

An industrial revolution towards a more pluralistic fuel system may have started. The future is, however, not here yet. In Europe and elsewhere the debate on biofuels has recently changed in a dramatic way. From being looked upon as a relatively sustainable alternative, biofuels is now seen as a technology leading to more harm than good. The critique mainly deals with the possible correlation between fuel production (for the rich) and food production (for the poor), but also comprises problems related to future deforestation and loss of biodiversity.

If the bioenergy visions became realised – with or without biofuels – many different types of natural resources must be used. In a bioenergy scenario (for the years 2005–2025) developed within the European research project EFORWOOD: Sustainability Impact Assessment of the Forestry–Wood Chain, raw material is taken both from the forest, e.g. harvest residues and stumps, and from the forest industry, e.g. sawdust, chips, bark, black liquor, rejects and downgraded assortments. But this will probably not be enough. Harvested and storm-thrown round wood needs to be used as well, which will increase the competition for raw material with pulp and paper industries. Furthermore, the scenario also includes new dendro-bioenergy plantations on former farm land (Vötter et al. 2009). Such plantations will not be traditional forest plantations. McFarlane et al. (2008) predict that new industries will be seeking cheap, low-grade fibre, thereby increasing the consumptive pressure on the forest ecosystem.

At least some of these problems would be possible to handle if the production of bioenergy was far more effective than it is at the present. For that reason research in order to develop the technologies and infrastructures needed has been supported by both funding bodies and private companies. As Ulmanen, Verbong & Raven (2009) demonstrate, many "biofuel niches" have in fact developed successfully in Sweden, and some of these are connected to BFR. For example, researchers within energy technology and thermal process chemistry are eager to contribute to an increased knowledge of the critical thermo-chemical conversion processes, and to participate in the development of new scientific ideas and process concepts. Another route is taken by plant scientists, who hope to produce genetically engineered trees, tailored to meet the demand for better-suited raw material (more of which below). This is still science and technology in the making but in 2050 current problems may be solved and a new regime established.

To sum up this technoscientific vision: new biotech applications are said to awaken a dormant domestic asset, the "green gold", and frontline chemical process technologies will – by virtue of being "second generation techniques" – set it apart from traditional forest and pulp mill industries. If the vision is fulfilled, both the forests and the forest sector will be transformed.

Modified trees

Biotechnology is one of the fastest-growing areas of scientific, technological and industrial innovation of recent times. In the agricultural field biotechnological research, including genetic engineering, have first and foremost been used to support conventional crop breeding but has also been directed towards trees. Among the goals articulated within this research are possibilities to improve growth rate, wood properties and quality (for example wood with less lignin), pest resistance, stress tolerance, herbicide resistance, and in the end to create new types of transgenic trees.

The frontier talk about this research, which typically takes place in public forums rather than within places of ordinary scientific work, has indeed been surrounded by great expectations. "In the near future genetically modified trees will enter forestry", some Swedish researchers declared in the popular science book *Genklippet* (2003). In this imagined future forest, tailor-made trees, designed in order to fit the demands of the customer, will grow; the problems concerning long generation times and effective improvement by breeding are solved. In the context of biofuel production in the future, Gustafsson, a molecular plant physiologist and coordinator of BFR's Research & Development working group, concretely envisions what role biotechnology would have, in terms of speeding up growth, for forest cultivation: "For forest growth it will have the same effect as putting in a turbo in a car motor" (Sjöstrand 2006).

Business is said to benefit from this development, but also the environment. In this win-win situation modified trees may, for example, contribute to the replacement of oil and petroleum-based materials and decrease the use of energy needed for paper production. Another common line of argument for this type of intensive forest management is that if the growth rate is increased, it will not only be possible to produce enough raw material for the bioenergy society, it will also be possible to decrease the productive area, hence leaving more space for other interests in the forest landscape, such as recreation and biodiversity. As the biotech enthusiast Fagerström (2009) writes: "Improvements in forests and silviculture based on biotechnology will open up for totally new possibilities for variations in forestry and hence a forestry in harmony with the requirements of nature protection."

Articulated visions and expectations of this kind have certainly helped research networks within this field in enrolling allies and mobilising support for their work. Several niches producing scientific and technological findings, inventions and innovations do exist in Sweden. However, so far the progress has been slow, at least in comparison to agricultural biotechnology. Complicated gene action, tissue culture, regeneration and the long generation times for the species involved are some reasons behind the fact that genetically modified organisms (GMO) still do not exist in Swedish forests (or elsewhere). The step from scientific and industrial laboratories to the real forest landscape has yet to be taken.

But, as was stressed above: the success of a technology lies not only in the technology itself but rather in the contingencies of socio-technical circumstances and the play of institutional interests that favour one technology over another. Significant reasons for the current situation have to do with public opinion at the landscape level as well as the stability of prevailing regimes, that is the traditional forest sector. Societal values have strongly influenced the development and implementation of biotechnology in both agriculture and forestry. The use of GMOs is a source of significant debate and concern within society and the environmental movement, and different nations have adopted varying responses to these issues. As Bauer & Gaskell (2002) put it: “While the biotechnology industry initially assumed that regulatory processes were the sole hurdle, it is now apparent that a second hurdle, national and international public opinion, must be reckoned with.” The Forest Stewardship Council will not yet certify any forest where GMOs are used, and the Swedish forest industries – well aware of the critical public opinion – have taken up a cautious attitude.

The niches seem to be trapped in a paradox. In order to attract allies, mobilise support and receive funding, actors conducting research in the field need to translate their ideas into great expectations, but the greater the expectations, the more critical the opposition tends to become. Nevertheless, if we are to believe the strongest supporters of tree biotechnologies, genetically designed trees will dominate future forests. Perhaps not in 2050, but maybe in 2100.

Biomaterials

A systematic replacement of oil may open a window of opportunity for a development of new materials that substitutes materials produced from petrochemicals. One possibility, which today is strongly supported by many visionary research entrepreneurs as well as companies within the Swedish forest industry, is to produce new biomaterials through converting renewable lignocellulosic materials in so-called “biorefineries” (Axegård 2009). Indeed, some foresee a revolution as important as when oil started to be utilised for producing synthetics: “In future biorefineries forest resources will be improved into products that replace virtually everything that today is produced from oil”, as it is formulated in the forest company magazine *Skog & virke*. The goal is not only to produce more or less the same product as before but also to develop “radically new creations and processes” (Thorén 2009). New products include second generation biofuels, new packing materials, cellulose composites, and bioplastics from nanocellulose, specialty chemicals, pharmaceuticals, new building and isolation materials, and resistant surface coating.

The concept of a biomass-based biorefinery is not yet well defined but has similarities with a petrochemical refinery for crude oil. The biorefinery may produce chemical platform products from cellulose, hemicelluloses, lignin and extractives that can be used as raw materials for high value industry or consumer products in a chain of industrial processes. In the first step current pulp mills can be developed into bio-refineries to produce an extended mixture of biomaterials, biochemicals and bioenergy in parallel with pulp fiber production and specialty fibers. Purified lignin can be the basis for low cost carbon fibers for car and aircraft industry and phenols for a variety of uses, and Xylan from hemicelluloses can be used in barriers by the packaging industry. Nanocellulose may be a platform for a variety of new materials and products (Axegård, Backlund & Tomani 2007).

Several niches for the development of the science and technology needed for the fulfilment of the biorefinery dream do exist in Sweden today. Biochemistry, organic chemistry and chemical engineering are probably the most important fields of research for this business. But biotechnologies, including genetic engineering, may be a driver in this field as well. One idea is to use genetic engineering in order to create trees with qualities that suit certain needs in the biorefinery process. Another idea is to modify microbes that can be used in the industrial processes. In contrast to some other visionary technoscientific narratives, the biorefinery concept also seems to be fairly well accepted within the Swedish forest sector. In other words, the industry expects the dream to come true.

As in the case regarding bioenergy, a future dominated by biomaterials will affect both the forest sector and the forests. Although resources which today are looked upon as by-products – such as black liquor and bark – may be utilised to a great extent, other forest based resources may be needed as well. Hence, the harvest will probably have to increase which will affect biodiversity and ecosystem stability.

New IT

Productivity in logging operations has improved drastically over the last decades by the implementation of new technology, but for forestry to stay competitive there is a constant need to continue this development. It is difficult to foresee any revolutionary technical changes or breakthroughs, rather many minor improvements will occur. Last but not least, information technology has the potential to influence all kinds of forest operations including forest inventory, operational planning, silviculture, harvesting and transportation. One vision is that automation will be possible by the use of robots, increasingly refined “artificial eyes”, measurement systems and IT technology, i.e. laser scanning, NIR and other spectral methods combined with image analysis. The complex forest site and all environmental concerns will make it difficult to totally exclude the operator, but new technology and automation of part of the operations can give efficient support to the operator, and in the end increase productivity.

Within the European research project EFORWOOD: Sustainability Impact Assessment of the Forestry–Wood Chain, four types of new (or improved) technologies for the Scandinavian forest industry have been articulated and analysed in a couple of future scenario cases (from 2005 to 2025). Although these technologies are more internal than external to the forest sector, and conservative rather than radical, we will briefly present them and their possible impact, according to Usenius and Laurijssen (2009).

The first type of technology proposed is based on X-ray scanning. The main idea is to use this technology in an “inspection system” that will identify internal density changes inside stems and logs, for example knots and defects, which are not visible on the wood surface. Such scanners are thought to be implemented at log sorting stations and cross cutting terminals for stems, thereby improving the data needed for optimizing sawing operations. In the second type X-ray scanning is combined with many other sensors, such as RGB-cameras, IR-cameras, microwave detectors and ultrasound detectors. The idea is to create a major “Multisensor scanning system”, which may detect all wood properties of interest, thus increasing the possibility for characterisation, grading and classification.

The third type of technology is an information system, which enables an advanced control of the wood material, from the forest to the end products. The system implies visible or non-visible markings (for example electronic tags) in the forest that can be read through the whole production chain. The vision is to link information to final products, raw materials and processing parameters, which, for example, will make it possible for customers and end users to know the source of a certain product. Finally, the project envisions new types of “flexible and adaptive manufacturing systems” that grade and select sawn timber into different classes, and contribute to upgrading and value added components.

In a future, which in the EFORWOOD scenario happen to be characterised by strong economic growth, rapid introduction of new and more efficient technologies, a substantial reduction in regional differences in per capita income, and low public awareness concerning environmental issues, these technologies – taken together – are supposed to “increase the use efficiency of raw material and produce higher quality products that are tailored to the needs of consumers, which results in less use of raw material and/or an increased value added to the products” (Usenius & Laurijssen 2009). In the end, the impact of such new technologies on forest environment as well as business depends on the demand of the final products.

6. Conclusions

Looking back there are, indeed, several occasions where scientific and technological developments have had a major impact on changes in how forests have been utilised and affected. Looking forward we can assume similar great changes over time. What scientific and technological “breakthroughs” will occur, and which of them will operate as drivers and significantly influence the development of future forest management and forest ecosystems, is impossible to foresee. What we can do is examine and speculate about current trends and visions.

In this paper some of the more or less grand technoscientific trends and visions of today concerning bioenergy, modified trees, biomaterials and IT are explored and related both to challenges usually connected to new science and technology – the problem of network stabilization and implementation at the system or sector level – and to their possible impact on the forest system. We have stressed that part of the work of successful technoscience is the construction, not only of scientific facts and technological artifacts, but also of the societies that accept, use and validate them. What is needed is “co-production” of technoscience and social order. Our conclusion is that while new goods and services from forests are likely to appear, so too will new stresses and threats.

Due to current changes and disturbances at the socio-technological landscape level – such as globalization and global warming – existing forestry regimes and sectors are now put under pressure. This situation creates a “window of opportunity” for sufficiently developed scientific and technological innovations, and hence for a broader change of socio-technical systems. Scientific and technological developments may generate new opportunities for growing, managing and harvesting trees, for developing new wood based material and energy products as well as new industrial processes and business opportunities. Development in science and technology, in particular within the fields of energy and materials, may at the same time affect the forests in many ways when the use of finite resources is to be changed to renewable ones. A future dominated by both woodbased biofuels and woodbased biomaterials may sound sustainable, but the question remains: is it?

On the other hand, alternative new energy sources, developed energy technology and other innovative technologies may also create new opportunities for non-forest based materials and energy supply – and these will compete with forest based materials and energy. In this way the development of energy saving technologies, alternative energy sources, and methods to store and distribute energy can have a major impact on demand for forest materials and energy and thus how forests will be utilised. Most probably the uses of forests will be extended as new ecosystem services are articulated and appreciated. In the end, the forests not only provide “provisioning services”, such as material and energy, but also supportive, regulatory and cultural services for human life on earth.

By way of conclusion; whatever direction scientific and technological development and forest resource demand takes, operational management will only slowly be able to change the boreal forest system in any profound way. The trees to be harvested at mature age for most of the present century are already in place. With an annual regeneration rate of about 1 % of the Swedish forestland area, it takes some 100 years to replace old forest with new. One reasonable option would be to introduce highly intensive silviculture, starting in new stands on for example 5 % of the area. Yet, due to the slow rate at which suitable land becomes available, it will take up to 50 years before the first larger harvesting can be conducted (Rosvall 2007). Since there are known limits for what can be harvested during the foreseeable future, all present expectations from society and industry simply cannot be fulfilled.

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