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Working Paper

Biotechnology as a competitive edge for the Finnish forest cluster

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No. 1076

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BIOTECHNOLOGY AS A COMPETITIVE EDGE FOR THE FINNISH FOREST CLUSTER

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Table of Content

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ABSTRACT: In this study we have collected information by interviewing all identified parties within the Finnish forest sector who might have a potential biotechnology connection: university research groups, research institutions, small and medium-sized biotechnology-companies and up to the largest forest companies. The ultimate goal was to assess how resources have been allocated and biotechnologies utilized within the value chain of the entire forest sector.

This study aimed at providing answers to the following questions:

- What are the current Finnish academic resources and projects related to forest industry biotechnology?
- How much does the Finnish forest cluster invest in biotechnology R&D activity, and what are the key application areas in the value chain?
- How well do the academic resources, company R&D investments and research needs converge to help secure the future competitiveness of the Finnish forest industries?

In order to answer the questions above, the study approached the matter in consecutive steps. First, the existing forest industry related biotechnological knowledge base within the academia on one hand, and the resource base among firms on the other hand, were mapped. Following up on that, we evaluated the sales expectations of forestry related biotechnological applications within the domestic forestry cluster itself, other potential domestic industries and global export markets. The third step assessed whether the development of forestry related biotechnological applications is justifiable in the framework of comparative advantage. This was accomplished by comparing the relevant existing knowledge and other resource bases to their sales expectations.

In order to evaluate the potential of biotechnology in the entire forest industry value chain, the study assessed four value chain modules. Module 1 represents the beginning of the value chain: forestry applications. Module 2 consists of the development of wood products, module 3 is related to the pulp and paper industry, and module 4 to utilization side streams for bioenergy, biochemicals and other food or pharmaceutical applications.

The assessment of module 1 implies that there is a constant lack of resources. Basic research conducts some relatively long projects, which often seem too time-consuming in applied research and corporate R&D. There seems to be only few active links between the academic research projects and companies. Many new technologies already exist but since the individual forest owners hardly have incentives to invest in R&D due to e.g. the long breeding cycle, collaboration with companies seems as the only potential pathway to commercialization of forestry related biotechnologies.

There were few biotechnology-based projects within the module 2. The research and product development seems to focus on physical modifications, and composite research is based on chemistry.

Module 3, paper, pulp and board industry, seems to be the most active in research and product development activity. Their products generate positive cash flows, and research projects are abundantly funded. The companies are closely involved in the research projects as financiers and collaborators. This involvement impacts on the nature of the research, which seems highly applicable and linked closely to industrial applications. Consequently, biotechnology applications are already used in the pulp and paper industry. Some biotechnology applications are adopted rapidly. They, such as enzymes in reducing paper machine runnability problems, do not affect the quality of the fibers, intermediate or end products and are thus easier to take into use in production scale.

We observed the research and product development within module 4 as a high priority for both the academia and industry. The research is anticipated to grow strongly and even more than in other modules. Biotechnologies are applied as substitutes to chemical and thermal technologies. However, all of these fields of technology are developed and applied by the industry. This provides some important implications for technology development and innovation policy. Due to the fuzziness between technology border-lines, it seems misleading to prioritize biotechnologies over some other technology; in contrast, the most efficient technology should be preferred. Accordingly, technology subsidies might be most efficient if the public technology programmes would be based on application segments instead of a specific technology.

Our assessment of international patenting activity raised some interesting notions. Finland seemed to be comparatively most specialized in plant genetic engineering, food and food additive, and waste disposal and the environment applications. However, biotechnology based biofuels are not included as a source of comparative advantage, which also stresses the importance of parallel development of biotechnologies and other technology fields.

A potential source of value creation could be the utilization of process side streams more efficiently, including refinement of by-products such as tall oil, to products with higher value added in other application areas.The paper and board making might also be strongly influenced by new packaging solutions, materials and methods; these utilize, however, only rarely or never biotechnologies as such.

Finland has a good overall and mainly publicly maintained infrastructure. If the raw material's high quality and some special features can compensate the relatively low growth rates, Finland should be able to attract the multinational pulp and paper industry also in the long term.

We conclude that the development of biotechnologies should not contain any intrinsic value per se. The commercial value of the biotechnology could be benchmarked with the value of alternative technologies; and consequently, biotechnology could become part of the technology options for companies active in established and conventional industries.

The Finnish forest cluster has financial resources to commercialize any new technology that can increase the process efficiency or provide other economic benefits in new application areas. This is a reason why we see this area exceptionally promising compared to any other high technology field without such a financial backbone.

Keywords: competitive advantage, forestry, paper and pulp industry, process side streams, value chain

JEL codes: L69, O32, O34

1 INTRODUCTION

1.1 Background

Finland does not hold an absolute advantage based on cheap mass production and economies of scale in economic activities, due to its small domestic markets and a high cost level. However, Finland does have a comparative advantage in areas where it focuses on generating technological innovations. In the 1990s, the ICT sector grew fast and became the locomotive for innovation and exports growth. With the ICT sector maturing and markets saturating fast due to harsh global competition, Finland has to map and develop new sectors that

(a) form a strong platform for technological innovation activities and
(b) are of significance on a global scale.

Biotechnology is one of the potential candidates that fit both of the above criteria. Nevertheless, it has been argued that health care-related biotechnology, the most heavily represented and discussed branch of biotechnology in Finland, is not expected to become the fourth pillar of the Finnish economy within the next ten years (Hermans and Kulvik, 2005; Hermans, Kulvik and Ylä-Anttila 2005). However, biotechnology can open new sources of comparative advantage for the presently strong and global Finnish forest industry. Although there is a widespread consensus that biotechnology is currently emerging as a competitive factor for the forest industries, the overall picture of the scale of biotechnological applications in the Finnish forest cluster has not yet been established.

1.2 Aims

In this study we have collected information by interviewing all identified parties within the Finnish forest sector: university research groups, research institutions, small and medium-sized biotechnology-companies and up to the largest forest companies. The ultimate goal was to assess how resources have been allocated with the value chain of the entire forest sector.

This study aimed at providing answers to the following questions:

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In order to answer the questions above, the study approached the matter in consecutive steps. First, the existing forest industry related biotechnological knowledge base within the academia on one hand, and the resource base among firms on the other hand, were mapped. Following up on that, we evaluated the sales expectations of forestry related biotechnological applications within the domestic forestry cluster itself, other potential domestic industries and global export markets. The third step assessed whether the development of forestry related biotechnological applications is justifiable in the framework of comparative advantage. This was accomplished by comparing the relevant existing knowledge and other resource bases to their sales expectations.

In order to evaluate the potential of biotechnology in the entire forest industry value chain, the study assessed four value chain modules. The first module covers the potential of biotechnology applied in breeding, propagation and growing of forest trees, the second module focuses on the wood product industry and the third on the pulp and paper industry. The fourth module compiles data on all material and technological inputs stemming from the Forest Cluster biotechnology but potentially applicable in any other Clusters. The scope in each module is to identify the technologies applied within the module and to identify the molecules or other materials that can be applied in other Clusters.

1.3 Definitions

The biotechnology industry does not exist as an individual branch in any official statistical classification. The OECD presents a statistical definition of biotechnology (OECD 2005a). According to the definition, biotechnology is: “The application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services.” In addition, a list-based definition specifies biotechnology processes in more detail.[1] Companies can develop biotechnologies or they can apply biotechnology processes in their production. The former can be called biotechnology research companies and the latter biotechnology using firms. FAO defines biotechnology applications as follows: “*Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use.”*

In our statistical survey we followed the OECD definition of biotechnology in order to classify the survey companies to those that develop biotechnologies and those that apply other biological technologies. For our entire sample we, however, utilized a broader [FAO] definition of biotechnology.

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[1] The following seven categories are presented by the OECD. The list is indicative (not exhaustive):

a) DNA/RNA: Genomics, pharmacogenomics, gene probes, genetic engineering, DNA/RNA sequencing/synthesis/amplification, gene expression profiling, and use of antisense technology.

b) Proteins and other molecules: Sequencing/synthesis/engineering of proteins and peptides (including large molecule hormones); improved delivery methods for large molecule drugs; proteomics, protein isolation and purification, signaling, identification of cell receptors.

c) Cell and tissue culture and engineering: Cell/tissue culture, tissue engineering (including tissue scaffolds and biomedical engineering), cellular fusion, vaccine/immune stimulants, embryo manipulation.

d) Process biotechnology techniques: Fermentation using bioreactors, bioprocessing, bioleaching, biopulping, biobleaching, biodesulphurisation, bioremediation, biofiltration and phytoremediation.

e) Gene and RNA vectors: Gene therapy, viral vectors.

f) Bioinformatics: Construction of databases on genomes, protein sequences; modelling complex biological processes, including systems biology.

g) Nanobiotechnology: Applies the tools and processes of nano/microfabrication to build devices for studying biosystems and applications in drug delivery, diagnostics etc.

2 THE FINNISH FOREST CLUSTER

The forest cluster -comprising of a variety of industries and services related to forestry and forest industry- offers still one of the most important concentrations of competence in Finland. It creates about 10% of the national GDP in Finland, 30% of the industrial production, and 40% of the net export income. The Finnish forest industry employs 70 000 people (table 2.1). The indirect effects are, however, considerably larger since the majority of the required raw material, intermediate products and services are acquired from within Finland. According to the Forest Academy Finland, the forest cluster induces a total of 170 000 workplaces, of which 70 000 are within the forest industry itself, 24 000 in agriculture, 16 000 in the engineering sector, and another 12 000 work within transportation and logistics. Supporting services such as maintenance, consultation, training and research and development employs 25 000 people, and finally 24 000 work within the chemical sector, furniture manufacturing and printing houses. The total value added is approximately 12.2 billion euros.

Table 2.1 Key figures of the forest sector (2005)
Sources: OECD STAN and ANBERD datafiles, Etla

	Forestry	Wood products	Paper and board products	Publishing and printing
Value added (million euros)	2 700	1 279	4 499	1 680
Labour (1000 persons)	24.8	28.6	37.6	32.2
Export (million euros)		2 393	9815	426
R&D expenditure		19.1	72.4	9.6

The figures above are estimates, because industries and functions associated with the forest sector are on agreement basis, and the figures thus reflect only the situation at a single point of time. Moreover, the borders of the definitions are not fixed. As an illustration, the increased foreign ownership as well as the globalisation of the companies have resulted in the forest cluster being less Finland-centred compared to the situation in the early 90´s. Additionally, the electronics, machine and chemical industry of the forest cluster is nowadays mostly in foreign ownership. The definition of a Finnish forest cluster hence refers especially to the development of intellectual capital within companies, universities and research centres situated in Finland, not to Finnish ownership *per se*.

The Finnish forest sector has had a strong international orientation during the last decades. However, there is also an increasing pressure from countries offering clearly lower production costs as compared to Finland; the operations also in Finland are under scrutiny even though the companies are successful on a global scale. Further challenges include increased competition, a broad interest for the use of renewable resources, the challenges in energy production, and the significance of forests in the provision of recreational and other services that pose restrictions concerning the use of raw material ((Ministry of Agriculture and Forestry 2006).). The production is expanding in countries with ample wood resources, low production costs and growing markets. In the long run the importance of Finnish operations might increase through domestic research and development activities that aim at refining our domestic wood raw material and its derivatives in a novel way.

The value added of the Finnish forest sector will in the future rely increasingly on the improvement of internal efficiency and new products in the later part of the value chain. Improving the efficiency will probably not be easy especially if economies of scale can not be realized. The increase in the productivity has during the last two decades impacted on the strong increase in production. With a three percent annual increase in production, the productivity has risen two percent. The future growth potential in production is estimated to be 1 – 1.5 percent annually, which corresponds to a rise in productivity of 0.75 to 1 percent (Savcor Indufor database 2006). The main portion of the growth will probably be due to incremental enhancements of the production machinery. A prerequisite for improving the productivity is a constant search for new technologies that can enable a comparatively more efficient production. As the forest industry is based on biological raw materials, it would seem logical that biosciences and biotechnology play a significant factor in sustaining overall competitiveness.

The production of competitive products and services as well as the development of a strong competence around the production and processing of wood based products is one of the major targets for the forest cluster (Ministry of Agriculture and Forestry 2006). Recent research and development strategy agendas, e.g. a European level Strategic Research Agenda for Innovations, Competitiveness and Quality of Life for forest-based sector (FTP 2006) and National Research Agenda for the Finnish Forest Cluster (FFIF 2006) as well as financing arrangements that emphasize intensive cooperation between research organizations and industry, are tools to promote research meeting the current and future needs of industry and markets. The focus areas in the recently launched National Research agenda are:

1. Smart wood and fibre products
2. Materials made from wood and its components
3. Versatile bioprocessing of wood
4. Sustainable use of forests
5. Increased value for wood biomass
6. Smart production technologies that save resources
7. Customer solutions for the future

Innovations in many other sectors contribute to the production of new technologies, expertise, products and services that could improve the competitiveness of the Finnish forest cluster within a global context; figure 2.1 presents anticipated future changes in the Forest cluster stakeholders. Maintenance of the cost and quality competitiveness in the globalized markets is identified as one of the major challenges for the Finnish forest policy (Ministry of Agriculture and Forestry 2006).

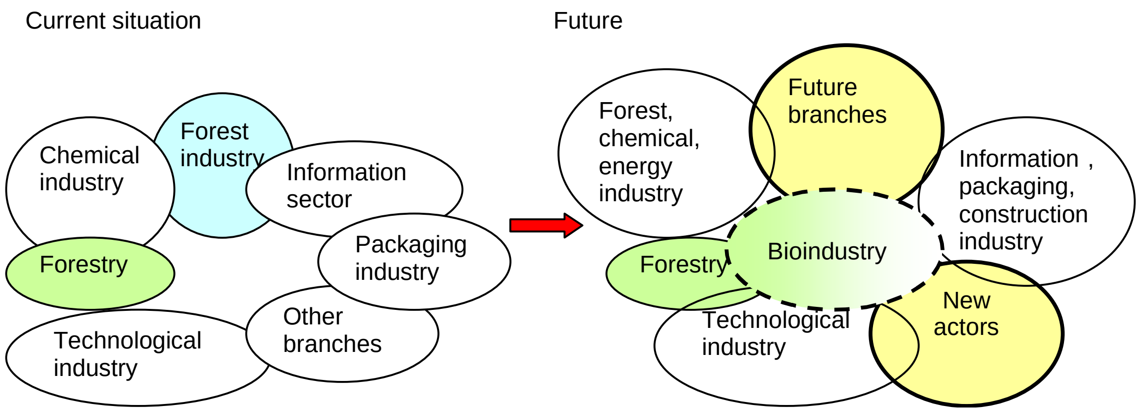

Figure 2.1 Structural Future Changes in Forest Cluster (Gädda 2006)
Modified from the presentation held by Lars Gädda, M-real Oyj at the publication of the National Research Agenda for the Finnish Forest Cluster in 5.10.2006

The value chain of the Finnish forest cluster comprises the production and processing of wood and fibers from a growing tree to the products in wood and paper industry and end use. The value chain covers all side products generated during the different phases of processing. These side products can be further processed for different uses e.g. in the wood, food, chemical or energy industry. For this study the forest cluster value chain is classified into four modules: Forestry, Wood product industry, Pulp, paper and board industry, and Side-stream utilisation.

2.1 The input-output structure

By definition, the forest cluster is focused on wood and its processing. Besides the manufacturing of basic wood-based products, the cluster has gathered around it a multitude of specialized functions. Examples thereof are machinery companies that build equipment for the forest sector, the chemical industry, and transport companies.

Figure 2.2 Input-output structure of the mechanical wood processing industry in 2005

The most important single input for the mechanical forest industry comes from the forestry sector in the form of raw material. Machines and equipment are clearly less important (figure 2.2). In paper and pulp industry the most important inputs are the work force and the capital bound to the machines and equipment, which opens up opportunities also for other potential cluster connections creating added value (figure 2.3).

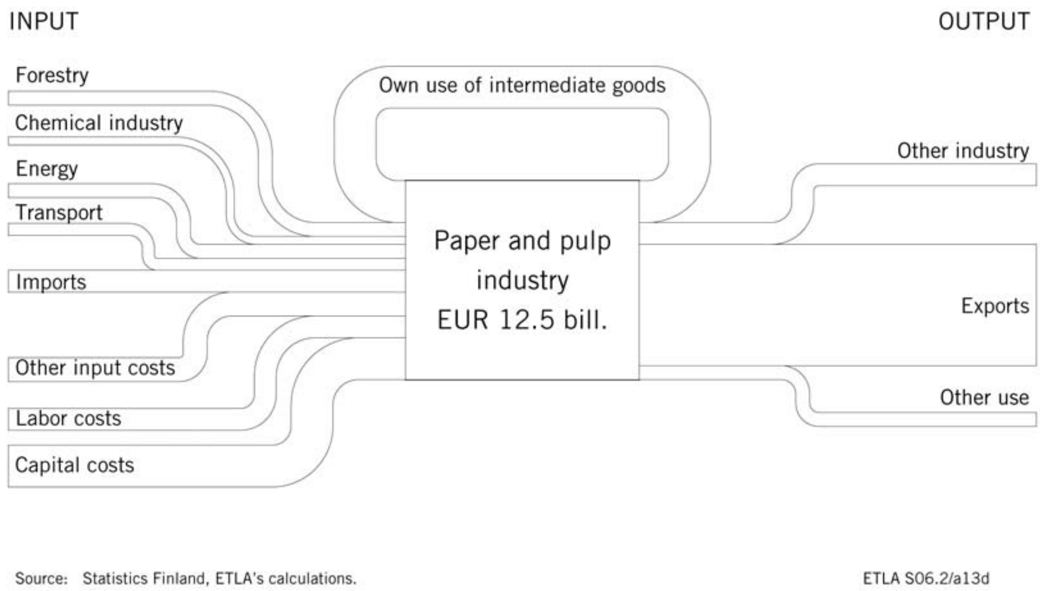

Figure 2.3 Input-output structure of the paper and pulp industry in year 2005

2.2 The international cost competitiveness

Cost competitiveness Based on Total Unit Costs

The increase of labour productivity and the reduction of relative labour costs are largely driven by a substitution of labour by other inputs, especially capital. Conceptually, the unit costs tend to rise when the increasing total factor productivity does not compensate for higher input prices.

Savcor Indufor has compared the total unit production costs of the Finnish pulp and paper industries to the pulp and paper industries in seven competing countries, which altogether account for about 57% of worldwide paper production.

The total unit costs include costs of all production factors, which are taken into account through a detailed analysis by individual input, i.e.

- raw materials,
- chemicals
- energy
- other (intermediate) inputs
- labour
- capital.

Thus, the total unit costs analysis pays regard to competitiveness due to intermediate inputs as well as the value added related efficiency of labour and capital.

The competing countries included are[2]:

[2] Japan is not included in the comparison of production costs in pulp and paper industry

- Sweden
- Germany
- Austria
- France
- USA
- Canada
- Japan

In a corresponding fashion, an international comparison was carried out for the sawmill industry including four competing countries:

- Sweden
- Germany
- Austria
- Canada

In the cost competitiveness analysis, the development of the Finnish unit production costs are related to the unit cost development of the competitors. The weighing of the competitors is based on the share of the producers in the European forest products market.

The analysis indicates that the Finnish paper industry's cost competitiveness fell very rapidly from 2000 to 2001: compared to the competitors, the unit costs in Finland increased by some 15% over twelve months. In local currency terms, there has been some recovery in the competitiveness over the past five years. However, the recovery has been clearly more limited in Euro terms due to the appreciation of the currency, and the Finnish industry is still clearly worse off as compared to year 2000. (figure 2.4)

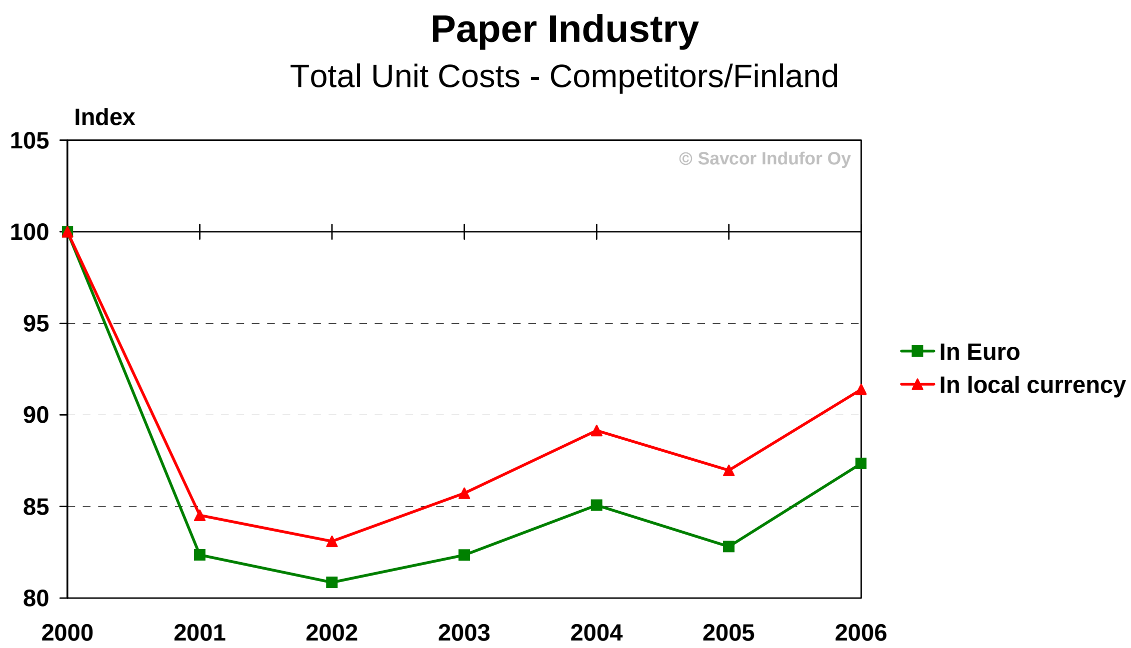

Figure 2.4 Pulp and paper Industry Competitor Countries' Total Unit Costs Compared to Finland, 2000-2006
Source: Savcor Indufor database 2006

The Finnish sawmill's cost competitiveness has decreased rather trend-wise since year 2000. With respect to competitors, the Finnish unit costs in Euro terms stand at some 12% higher in 2006 as compared to year 2000. (figure 2.5)

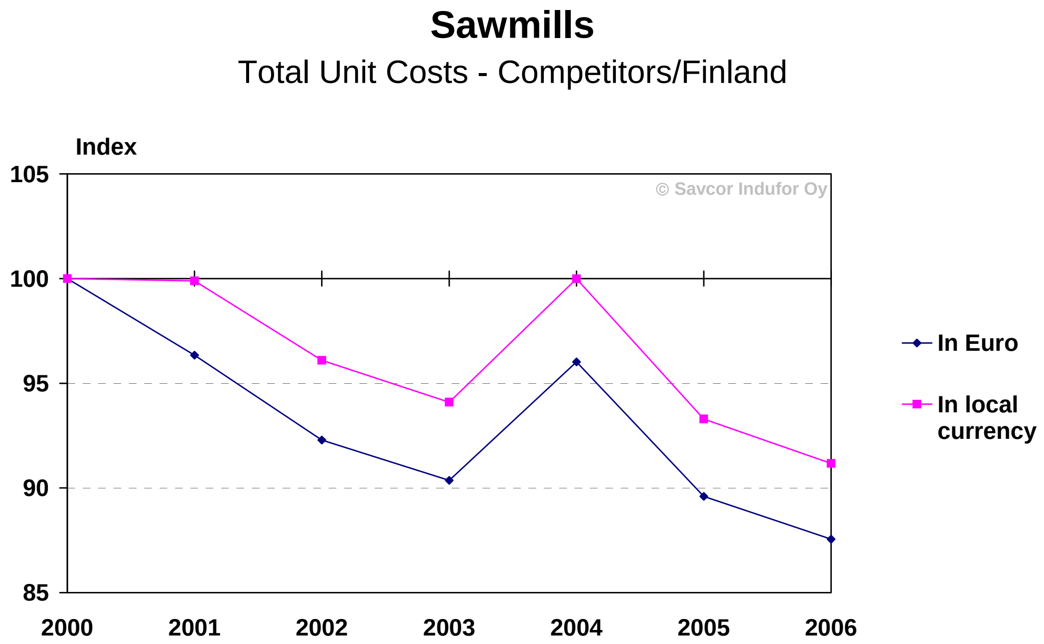

Figure 2.5 Sawmilling Industry Competitor Countries' Total Unit Costs Compared to Finland, 2000-2006
Source: Savcor Indufor database 2006

In order to compare international competitiveness in terms of value of production, that is value added, we need to conduct a comparison of the industry's ability to create the value added (output – intermediate input costs) between Finland and its competing countries. Even though Finland has had relatively costly intermediate inputs, it has been capable of producing higher value added than its competitors. This suggests an international competitiveness in terms of higher productivity, based on, for instance, process innovations.

In the following section we will assess the cost competitiveness of the paper and pulp industry as compared to competitors within the EMU-countries. For that purpose we want to stress that the impact of average labour costs have to be separated from the unit labour cost calculations because they are a part of value added figures by definition.

Cost competitiveness and value added

We divide the cost competitiveness into the effects of labour productivity, labour costs and exchange rates. The higher the value of each indicator, the higher is its positive effect on the competitiveness against competing countries.

The cost competitiveness is derived by calculating the labour costs per unit of output in Finland. The labour costs per unit of output are divided into costs of labour and the productivity of labour.[3] The unit costs of competing countries can be presented in an identical manner. The cost competitiveness of industrial sectors is compared to the cost competitiveness of competing countries, with the inclusion of currency exchange rates yielding the comparison feasible.[4]

The productivity of the paper and pulp industry increased rapidly and the labour costs per unit of output diminished during the second part of the last decade; the output grew but the labour demand remained stable or even diminished as a result of the high level of investments (figure 2.6). The labour productivity has increased steadily, with the exception of a short downturn in the middle of the 1990s: the international demand diminished but the input of labour did not show a similar decrease, which resulted in an increase in unit prices and consequently a lowering of the competitiveness.

The rise in labour costs has had a negative influence on the cost competitiveness as compared to competing countries. This has been countered by several projects aiming at savings and increased productivity, both at plant and company level; examples thereof are increased working hours and running times, as well as wage agreements.

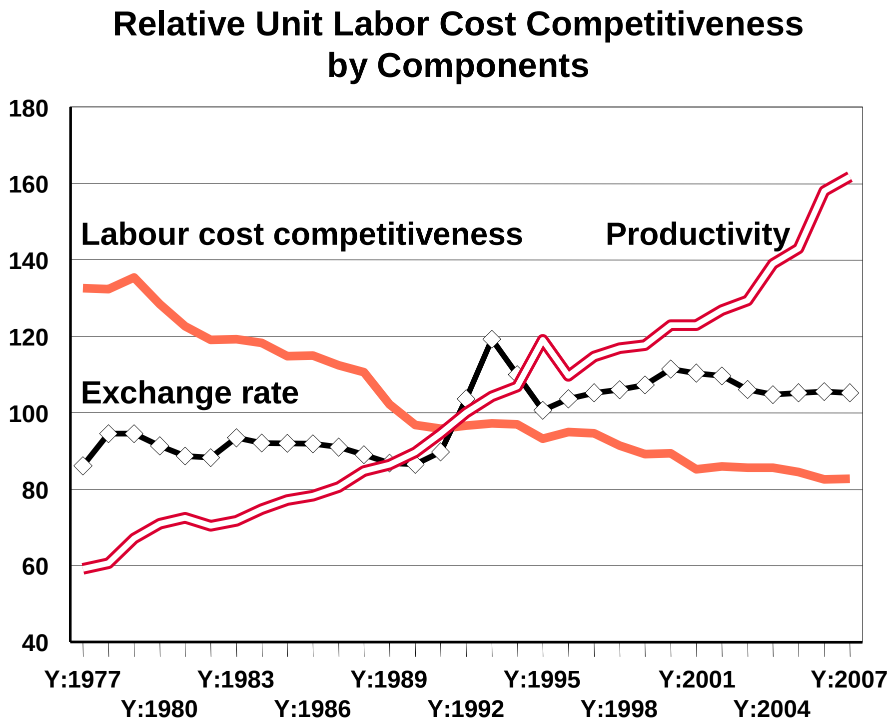

Figure 2.6 International cost competitiveness of the Finnish paper industry (Mankinen 2006)

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3 The equation below clarifies the separation of labour costs and labour productivity within cost competitiveness assessments in statistical analysis.

$\frac{W}{Q} = \frac{W}{H} \cdot \frac{H}{Q}$, that is Labour costs per unit of output= costs of labour x productivity of labour, where W corresponds to labour costs, Q denotes the production and H the required amount of labour. In line with the equation Labour costs per unit of output (W/Q) can be divided into a component describing average labour costs calculated per labour hour (W/H), and inverse of labour productivity (H/Q). These parameters are calculated for all included countries.

4 The cost competitiveness of Finland is compared to the cost competitiveness of competing countries using one currency, as follows:

$$\text{Cost competitiveness of Finland} = \frac{\text{Unit labour costs in Finland}}{\text{Unit labour costs in competing countries}} * \text{exchange rate}$$

Llabour costs per unit of outputare further divided into its components (average labour costs and labour productivity) as described in the preceding footnote.

After the devaluations in the early 90's, the export-friendly exchange rates promoted our industrial cost competitiveness. Even though these strong changes later normalized, the favourable exchange rates have induced long-standing cost competitiveness for the Finnish industry.

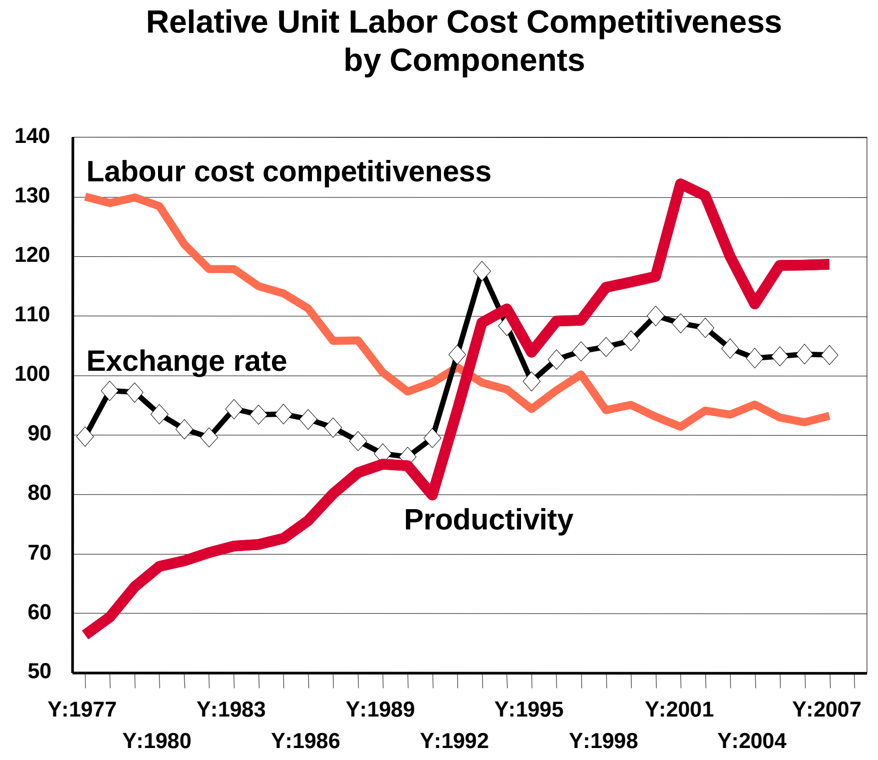

Figure 2.7 International cost competitiveness of the Finnish wood industry (Mankinen 2006)

The modern capacity and large unit sizes are typical not only for paper and pulp industry, but also for the wood sector. As a result of investments, the labour productivity has risen faster than average (Figure 2.7). However, the relatively high prices of the raw material have strained the earnings within the sector. On the other hand the unit labour costs and the exchange rates of major target countries have remained stable during this decade, which has stabilized the cost competitiveness of the Finnish wood industry.

The prices of the inputs of production, the efficacy of their processing and the exchange rates have a major impact on the international price and cost competitiveness of the paper and pulp industry[5]. The low export prices as well as market induced stoppages and the high prices of the central inputs have strained the profitability of the sector. In years 1995 – 2005 the cost competitiveness of the Finnish paper and pulp industry weakened by over 10 percent. This development is influenced by more effective operations and a faster rise in the prices of labour input as with the competitors. The EU emission trading can also have an increasing effect on the price of energy in the future.

[5] The devaluation of the Finnish Markka has historically been an often used method to support the competitiveness of exports in Finland. This option ceased to exist in the beginning of the 1990's, as the decision rights on Finland's monetary and exchange rate policy were 1999 handed over to the European Central Bank. Along with the introduction of the Euro, the potential to solve a single country's economic problems were omitted.

The internationalization of the forest cluster will require further education and research. Finns will have a leading role in management and expert positions, because Finland's share of both the industry's education and research and development is large in comparison to the size of the country. In the long run, the success of the Finnish forest cluster will probably and specifically be dependent on the cluster's intellectual capital.

3 BACKGROUND OF THE FINNISH BIOINDUSTRY

3.1 The ETLA survey from 2004

The newest comprehensive data on the Finnish Biotechnology industry is from 2004, when ETLA collected data through a telephone questionnaire (Hermans, Kulvik and Tahvanainen 2006). The data was supplemented by financial statement data from The National Board of Patents and Registration (NBPR), representing 2003 figures.

The number of biotechnology companies grew sharply until the beginning of the millennium. At the end of 2003, there were about 120 biotechnology companies in Finland, with no significant change from 2001. Despite stagnation in growth, the Finnish companies constituted almost 7 percent of the entire number of biotechnology companies in the European Union (EU). This is a considerable amount if we compare it to Finland's population of 5 million, about 1.3 percent of the EU population in 2003. Finland can be considered a biotechnology intensive country. However, Finnish companies are limited in their size and ability to exploit their market potential: about 110 of the Finnish companies are small or medium-sized.

Most of the Finnish biotechnology business activities are connected with healthcare applications, with almost 60% of the small and medium-sized biotechnology companies related to the pharmaceutical industry or pharmaceutical research. The pharmaceutical markets hold high growth expectations due to the development of medical research and the ageing of the population.

The ETLA survey of the Finnish biotechnology sector focussed primarily on small- and medium-sized biotechnology enterprises (SMEs)[6]. This narrower focus was justified as the inclusion of the handful of giants active in Finland would have distorted and eliminated effects that the numeral majority of biotechnology companies have on the analyses[7]. Furthermore, one could assume that larger and more mature companies resemble more those in other sectors in terms of firm characteristics than small and medium-sized companies, due to the more consolidated state of business. Thus, the inclusion of large-sized firms might have diluted and masked findings stemming from characteristics distinctive for biotechnology businesses.

[6] SMEs in this paper are defined according to official definitions of the EU excluding firms with over 250 employees and match additionally at least one of the following criteria: (i) Annual turnover > 50 mill. EUR, (ii) balance sheet total > 43 mill. Departing from the official EU definition, we include those daughter companies owned by large parent company in our SME sample, if they match the above definition in every other aspect.

[7] Orion Pharma alone, for example, has publicly disclosed it has over 2400 employees in Finland compared to the total employment of all Finnish biotechnology SMEs of about 2500.

3.2 Knowledge stock and collaboration patterns

As knowledge in its uncodified or tacit form is related to individuals, the total number of personnel captures and quantifies the total mass of knowledge inherent in the companies. As the biotechnology industry is knowledge-intensive in character and depends on human capital as the engine of innovation, it can be assumed that a critical mass of complementary and cohesive human capital is essential for an exceptionally high performance, or taken to the extremes, for survival. A typical Finnish small biotechnology company has 10 employees, of which one in five holds a doctoral degree (table 3.1). (Hermans, Kulvik and Tahvanainen 2006).

Table 3.1 The Finnish small and medium-sized biotechnology industry in 2003

	N	Sum	Mean	Median
Personnel	100	2,450	25	10
Number of personnel holding doctoral degree	75	273	3.6	2
Age (years)	79	870	11	7
Number of patents and patent applications	76	640	8.4	4
R&D expenditures (million euros)	81	71	0.88	0.18
Governmental financing obtained	79	76	96 %	1
Sales to a principal customer over 33% of total sales	78	34	44 %	0

A conversion of the human capital's tacit knowledge into a codified form is an important pathway to create value in the science-driven business. The number of patents and amount of R&D expenditure measures an ability to codify the knowledge. The typical Finnish biotechnology company was founded 10 years ago. The R&D expenditures of the company were 180,000 euros annually. Due to the intensive R&D activities, its patent portfolio contained 4 patents or patent applications, of which about half were officially accepted.

The external structures of a company are important in a value creation process. Owners can in many ways influence the company's business development. It is noteworthy that almost all Finnish biotechnology SMEs have obtained governmental financing. The typical small Finnish biotechnology company collaborates with universities, research institutions and other companies. Almost half of the companies have a principal customer (≥ 33 percent of the company's sales). Over one-fifth of the companies have a principal subcontractor, from whom they purchase over 33 percent of their input for their research and development and production activities.

3.3 Value Creation

The total sales of the small biotechnology industry reached 330 million euros in 2003 leaving the industry still unprofitable. Operating losses were 60 million euros during this period and the net losses 70 million euros. Revenues were highest in enzymes – one of the most traditional sectors of Finnish biotechnology- followed by drug development and food and feed (Figure 3.1). With over 150 million euros, enzymes made up almost half of all revenues of the small biotechnology industry. However, these producers were not independent, but instead subsidiaries of larger groups. Bioinformatics was last with compound revenues of less than 3 million euros.

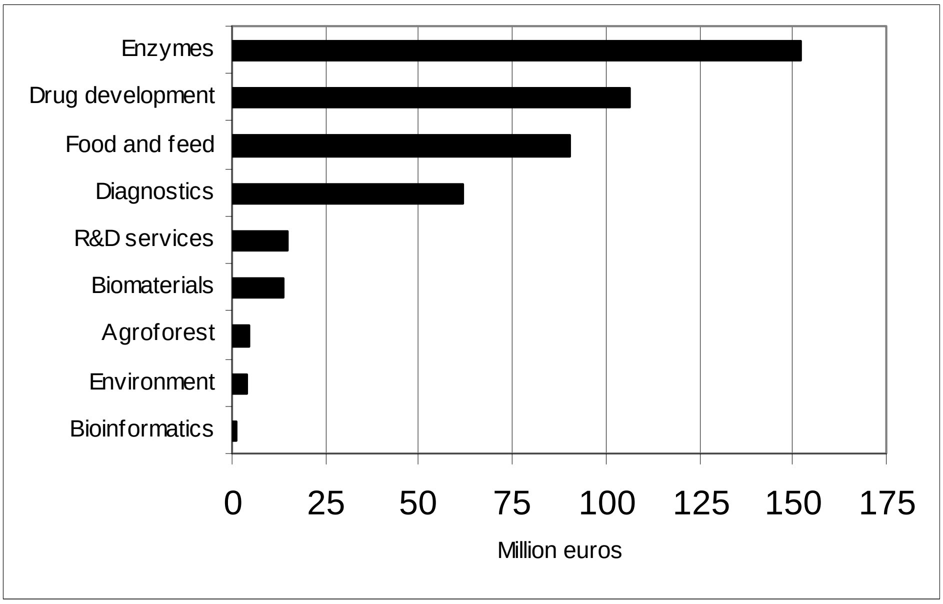

Figure 3.1 Sales of the Finnish biotechnology industry by the fields of applications in 2003

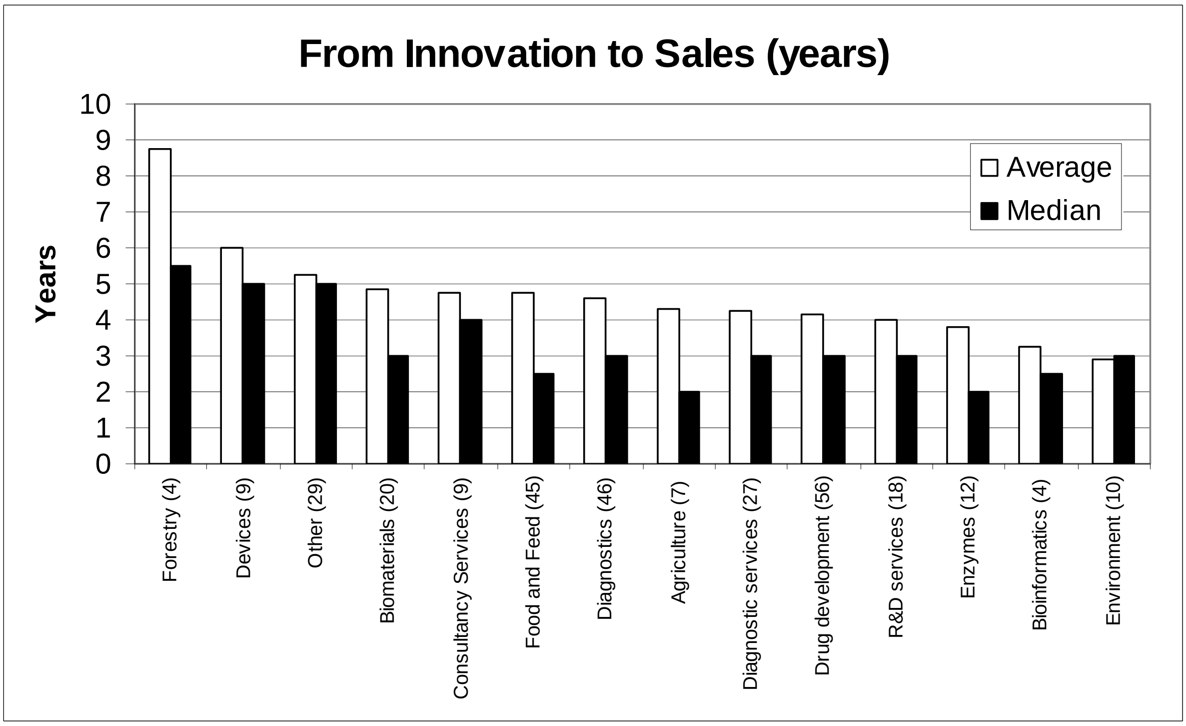

Figure 3.2 From-invention-to-sales duration in distinctive biotechnology application segments (number of product groups within the application segment in brackets).

Figure 3.2 depicts average and median durations of commercialisation within distinctive biotechnology application areas. The median and average from-invention-to-sales durations seem to range within distinctive application areas between 2-6 years and 3-9 years, respectively.

The higher numeric values of averages compared to medians indicates that there are some inventions with relatively long realised or anticipated commercialisation durations, in other words, the duration distributions have a long tails in the positive direction in all of the application areas with the exception of environmental applications. The reliability of the distributions may be questioned due to the small number of observations in some application segments (*e.g.* agriculture, bioinformatics and forestry). However, the number of these products reflects the number of companies active in that specific application segments.

The longest commercialisation durations seem to occur with the applications related to the forestry and in the development of devices. Slightly surprisingly, drug development projects seem to capture positive cash flows sooner than diagnostics and biomaterials. This indicates the importance of out-licensing strategies in the drug development sector in order to create the positive cash flows from sales at early development stages and thereby survive in their highly regulated application segment. And, for instance, despite the slacker regulation environment, developers of biomaterial often set their own goal to develop a product to the end-users, which extends the commercialisation duration. Interestingly, consultancy services take even more time to mature than other application segments zeroing in on developing more concrete products.

The economic growth effects of the biotechnology sector are assumed to increase in the future, but only a few of the Finnish biotechnology companies seek for applications within the forest industry (see *e.g.* Hermans 2004, Hermans, Kulvik and Ylä-Anttila 2004). Even though the forest industry utilizes enzymes in their production processes, the Finnish enzyme producers disclose lower estimations of their future sales than other biotechnology companies. However, nowadays the Finnish enzyme production plants are parts of large global enzyme companies, and their operations might not have as strong link to Finnish pulp and paper sector as earlier.

4 BIOTECHNOLOGY IN THE FOREST INDUSTRY

Biotechnologies are currently applied in the pulp and paper industry, where enzymes are used to enhance processes and improve the end product quality. Biological waste water purification has also been widely used for decades. Advances in research in molecular biology and gene technology have increased the potential to find beneficial biotechnological applications throughout the value chain.

In forestry the greatest benefits of biotechnological applications are foreseen in tree breeding, where the techniques to recognize the genes or molecular structures contributing to the desired qualities have improved significantly. In wood industry the greatest challenges in using biotechnology are related to wood protection against stain and decay.

Compounds extracted from wood or its metabolic processes have been in domestic industrial use for centuries. Tall oil, for example, is a raw-material for detergents, lubricants, functional foods and other industrial products. In recent years the research has focussed on innovative applications of wood-based compounds as a feedstock to biomass based refining chains, so called biorefineries. The end products from biorefinery applications vary from liquid biofuels to high-end pharma intermediates. Biotechnology is one of the key technologies in this development (Figure 4.1).

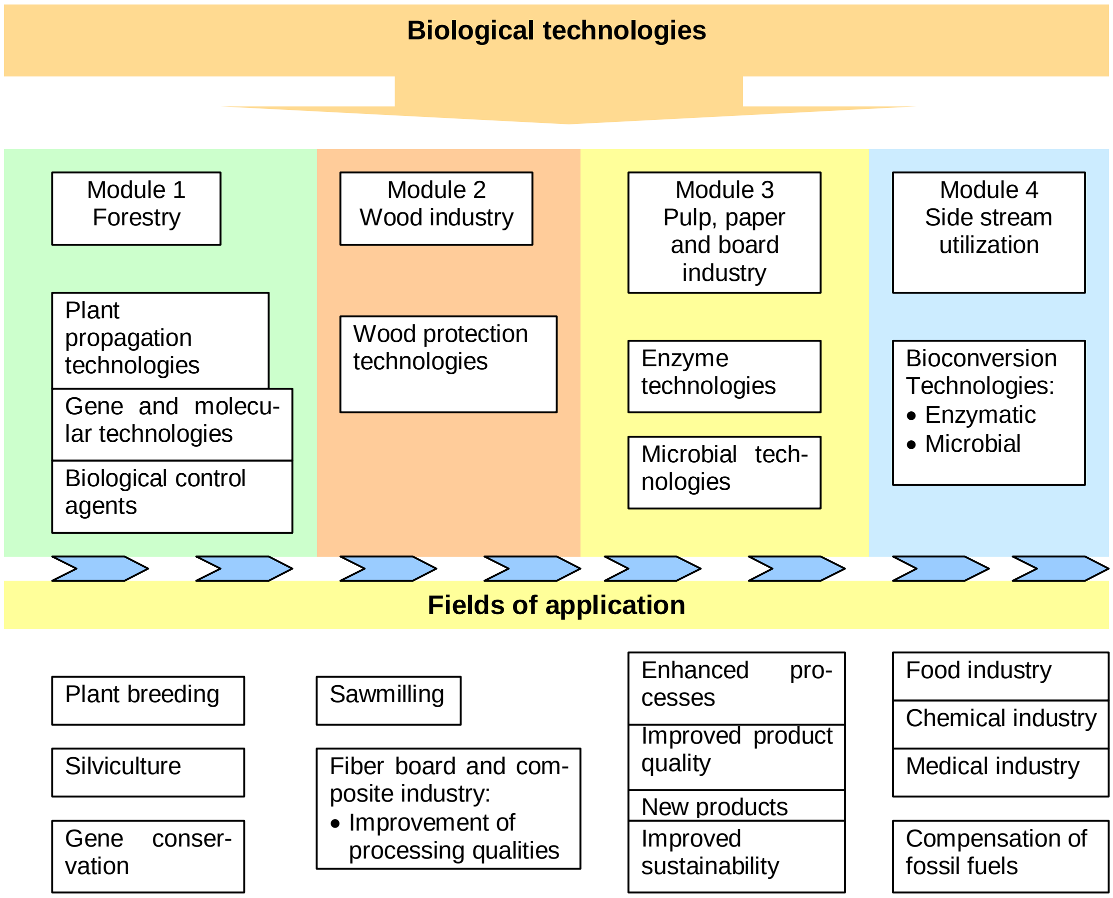

Figure 4.1 Biotechnology in the Forest Cluster Value Chain

In the following chapters we list and briefly characterize the biotechnological applications related to Modules 1, 2, 3 and 4. The activities in Forestry (Module 1) is classified into groups based on whether they involve genetic modification or not, and depending on the type of the forest-related application. The division between activities implying genetic modification and those that do not is meant to facilitate the treatment of forest biotechnological applications with different underlying ethical and legislative principles. The description on forestry related applications is based on literature survey, interviews and on the Indufor projects related to plantation forestry as listed in the list of references.

5 BIOTECHNOLOGY APPLICATIONS IN FORESTRY (MODULE 1)

Biotechnology encompasses a series of **techniques** that are combined into **applications** aimed to serve a specific end-purpose**.** In order to standardize the classification of biotechnology techniques for data collection purposes, OECD (OECD 2005b) established a list of general techniques applicable to all sectors. This classification separates biotechnology techniques into seven groups: DNA/RNA, proteins and other molecules, cell and tissue culture and engineering, process biotechnology techniques, gene and RNA vectors, bioinformatics, and nano-biotechnology.

In the case of techniques related with used in Forest Industry Biotechnology these could be classified in three different types: (1) Genetic and molecular techniques intended to increase the understanding and/or modify specific plant physiological processes (e.g. genomics, proteomics, metabolomics, MAS, recombinant DNA technology), (2) cell and tissue culture used to maintain or multiply selected genetic lines of plant material, and (3) Process biotechnology techniques, which involve the use of organisms or enzymes in specific applications. The genetic and molecular techniques as well as cell and tissue culture techniques will be reviewed in more detail in the following chapters and the process biotechnology techniques relevant for the forest cluster are discussed in more detail in Chapter 9.

Biotechnological Applications Excluding Genetic Modification

5.1 Biotechnology in Tree Breeding and Nurseries

Conventional tree improvement has started fairly recently when comparing to other crop species. Although conventional breeding and biotechnology have faster and probably higher benefits in perennial plants, trees have a great unused breeding potential as compared to agricultural plants. There are still lacunae of knowledge on processes controlling tree growth and wood quality, which provide potentials for breeding benefits. The environment of forest trees cannot be controlled to the same degree as in breeding of agricultural plants, which sets specific challenges to the propagation of forest tree species (Tapio 2006).

Conventional tree improvement is based on the use of selected seed, either from elite trees located in natural populations or from planted seed orchards intended for quality seed production. The methods are based on the phenotypic characteristics of a tree (e.g. fast growth, straight stems, branch angles), which in most cases are not visible until many years after planting. This fact implies a very slow implementation of the breeding results. The biotechnological approach consists of linking the phenotypic properties of a tree with its genotype, facilitating an early selection of the individuals with the desired qualities and efficient vegetative propagation of new plant material.

The Finnish Forest Research Institute published in 2005 a long-term breeding programme (Metla 2005) that defines the following main objectives for forest tree breeding:

1. Productivity - all breeding shall aim at high genetic gains and their transfer to forest cultivation either through seed or vegetative propagation.
2. Predictivity - breeding material shall be well adapted to the changing environmental conditions caused by the climate change, changes in breeding objectives and availability of new bio- and genetechnological applications.
3. Cost-efficiency - application of new biotechnological methods (marker assisted selection, vegetative propagation, cryopreservation, etc.) that allow the decreasing of testing populations.

Shortening the breeding cycle is the most important single issue for which biotechnology may provide a solution (Metla 2005, Tapio 2006). Shorter breeding cycle and faster materialization of the economically significant breeding benefits may increase the interest of the private sector to invest in the tree improvement (Tapio 2006). The Breeding cycle can be shortened by using biochemical molecular markers (e.g. DNA molecule) linked with a trait of interest, the information allows the early selection of individuals with the desired traits. Marker assisted selection may increase the genetic gain by 28%. Vegetative propagation through cuttings, micropropagation or somatic embryogenesis shorten the breeding cycle and allow early testing of clones (Aronen 2005).

At present, important tree properties improved through breeding include:

a. growth rate
b. resistance to diseases
c. technical and chemical quality of wood (lignin synthesis, content, fiber length)
d. new forms of timber use
e. energy
f. source of various biological compounds (extracts)
g. resistance to abnormal environmental conditions (e.g. heavy metals)
h. control of flowering patterns and seed production

Although the genetic and biotechnological research on forest tree species is advanced, and commercial applications are available, the practical applications with the slow growing boreal species are few. Biotechnologies applied in the research, aimed at a better understanding of the basis of different tree properties in tree breeding, include (Kangasjärvi 2006):

1. Cloning of superior trees with desired qualities
2. Somatic cells, protoplast fusions, haploid and doubled haploid production
3. Use of mutations
4. Conventional breeding with crosses and marker assisted selection
5. Genomics, proteomics and metabolomics
6. Transgene - technologies (discussed in section 5.4 – 5.9)

According to Tapio (2006) Biological techniques in use include

- micropropagation and DNA mapping, which is used to verify the genetic composition of seed orchads. Various hormones, e.g. auxins and gibberellins are used for controlling the flowering patterns of forest trees (Tapio 2006).

Among the techniques studies but not yet widely implemented in practice include

- vegetative propagation where desired characteristics can be transferred unaltered to the seedling material. The method provides
- marker assisted selection of plants with desired characteristics
- gene mapping to identify the individuals and populations that have the genes that influence on the breeding qualities.

Micropropagation is applied to some extent in practice to produce breeding material and special seedlings. DNA-based gene mapping is used to control the genetic composition and functionality of seed orchards (Tapio 2006). DNA-markers are also used for testing seedling material according to EU directive. Growth hormones, e.g. gibberellins and auxins are used to increase flowering and seed production. Hormones may be used also in grafting.

All these applied techniques produce non-GMO seedlings although gene manipulation might be required during the research phase, when the gene function is tested.

On the commercial scale the international forest biotechnology joint venture ArborGen focuses their priority projects on faster growing trees, lignin modification, bioenergy, environmental protection and restoration of threatened tree species, based on genomics and tissue culture techniques (www.arborgen.com).

Companies are strongly involved in the development of methods for vegetative propagation of different species and apply for patent protection for any new technologies. Canadian joint venture CellFor Inc. has a blocking proprietary position in the somatic embryogenesis of conifers with issued products and process patents. CellFor's propagation technology allows growers to preserve their elite seeds cryogenically, thereby providing for an infinite supply of copies from each selected seed for years to come. This approach known as "Clonal Forestry", is the same as using cuttings but Somatic Embryogenesis is much more efficient and flexible.

Seed production with somatic embryogenesis allows forest companies to get higher genetic gain from their tree improvement program by generating a yield gain of 30-60%, compared to 8-13% from traditional seed orchard methods used for coniferous trees. In addition to increasing yields, the trees are also more uniform, possessing more consistent grain structures and branch sizes. The available technologies allow a significant multiplication of the seed production with the desired qualities compared to traditional methods.

5.1.1 Micropropagation in Tree Breeding

Micropropagation is a key technique in tree breeding, because it accelerates the multiplication of the breeding product and it increases the fidelity of the process. Cuttings continue to be the most widespread way to propagate plants vegetatively. Stem cuttings are most commonly used in forestry, and they consist of detaching a twig from the stem and induce in it the formation of roots with hormones. However, in several tree species the rooting of the cutting, its survival, aging of the mother tree, or the high associated costs pose limitations. Most of these problems can be resolved with micropropagation, in particular with somatic embryogenesis combined with cryopreservation techniques. Cryopreservation in low temperatures is used to maintain the plant material in a juvenile state (Haines, 1994; Häggman *et al.* 1998), giving time for field testing while conserving the genetic line in case a need arises for future large scale propagation.

At present, no more than some thousand hectares have been reported to be planted with micropropagated material worldwide (FAO, 2004). Somatic micropropagation methods are in use for a broad range of broadleaved trees and also for southern pines (*Pinus taeda* and *P. radiata).* These methods, however, do not necessarily apply as such to boreal species, and *Pinus sylvestris* is especially difficult to propagate from adult somatic cells. The research on the development of successful somatic propagation methods e.g. for pine is well advanced in Finland (Häggman *et al.* 1999, 2000; Pirttilä et al. 2002, 2005). *P. sylvestris* is only little studied in other countries, emphasizing the significance of the domestic research in the provision of solutions for the forestry in Finland.

Currently, micropropagation methods are operational for spruce, silver birch and aspen, but the price is still too high for normal timber production. The method would be feasible for the production of ornamental plants or trees with special qualities. Breeding of *P.sylvestris* is still based on two phased progeny tests per generation (Metla 2005, Tapio 2006). A future breakthrough in micropropagation of *P. sylvestris* would rapidly be available for the national breeding programs in Finland, due to the close cooperation between research and practical breeding through Metla.

Internationally several biotechnology companies study and apply patent protection to somatic embryogenesis of broadleaved and conifer species. The Canadian based CellFor Inc. is managing a USD 49 million research project to develop and scale up new micropropagation methods for conifers (http://www.cellfor.com), and it is already using somatic embryos to produce planting stock (in the order of several million plants/year) of *P. taeda* (Sutton *et al.* 2004). Also, CellFor Inc, Bioforest SA, Carter Holt Harvey Forests and others are using somatic embryos for *P. radiata* in combination with a further multiplication step with stoolbed cuttings (Kellison *et al.* 2004). Several other companies are also investing heavily in forest tree biotechniology: AgriGenesis (AU), ArborGen (USA), SweTree (SWE) and ForBio (AU) which has the worlds largest facility (2005) to produce tissue cultured elite plants.

Despite the advances in research in micropropagation and its benefits in the production of breeding material, it does not yet provide a cost efficient application for conventional seedling production.

5.1.2 Genomics and Marker Assisted Selection in tree breeding

The understanding of the genetic basis of traits such as growth, wood quality or pest resistance in trees brings a new and powerful tool into tree breeding.

Gene mapping provides a basis for identification of candidate genes influencing certain tree properties, and it provides the basis for genomic studies (gene function). Due to the evolutive convergence in many plant processes, researchers are able to study processes, such as wood formation in annual plants (e.g. *Arabidopsis thaliana*) and extrapolate the results to tree species after some additional research. With *Arabidopsis* the results are obtained faster and with lower costs than with trees.

Gene mapping and genomics are highly capital consuming research areas and hence commonly undertaken as a multilateral cooperation effort. For example, the poplar genome (*Populus trichocarpa),* has recently been sequenced as a collaborative effort lead by US research groups together with research groups from Canada, France, Sweden, Belgium, Germany and Finland (Universities of Helsinki and Turku; Tuskan *et al.* 2006). Similarly, the genomes of birch (*Betula pendula)* and spruce (*Picea abies*) are under study, including Finnish and other Nordic research groups. Finnish research is part of an international network studying the genetic structure of tree species. The research focuses on studying “tree models” whose genetic maps and genomic background data are better known and available in international gene-databases (e.g. www.pinegenome.org and http://dendrome.ucdavis.edu). Gene mapping has also contributed to the development of genetic techniques, e.g. (i) EST sequencing, (ii) cDNA arrays, and oligonucleotide array development (Palva 2006).

Understanding gene functions together with the marker-assisted technique for gene selection provides a revolutionary tool to select the best populations for breeding, and attain the target without need to use genetic engineering. The genetic modification (GM) possibilities are discussed in the Section 4.4 – 4.9. At present, Finnish researchers are carrying out genomic studies on different traits of trees that could be improved through MAS:

- Resistance against abiotic stress (Vahala et al. 2003, Welling and Palva 2006)
- Lignin biosynthesis and polymerisation in Norway Spruce (Kärkönen et al. 2002, Kukkola et al. 2004)
- Phenology, tree growth and dormancy (Savolainen et al. 2004, Riihimäki et al. 2005)

The steps to assess the gene function and use the knowledge in Marker Assisted Selection (MAS) are presented in figure 5.1. The figure illustrates that genetic engineering can also be used only as a tool to test the candidate genes. Genetic modification applications are dealt with in Chapter 4.4. – 4.9.

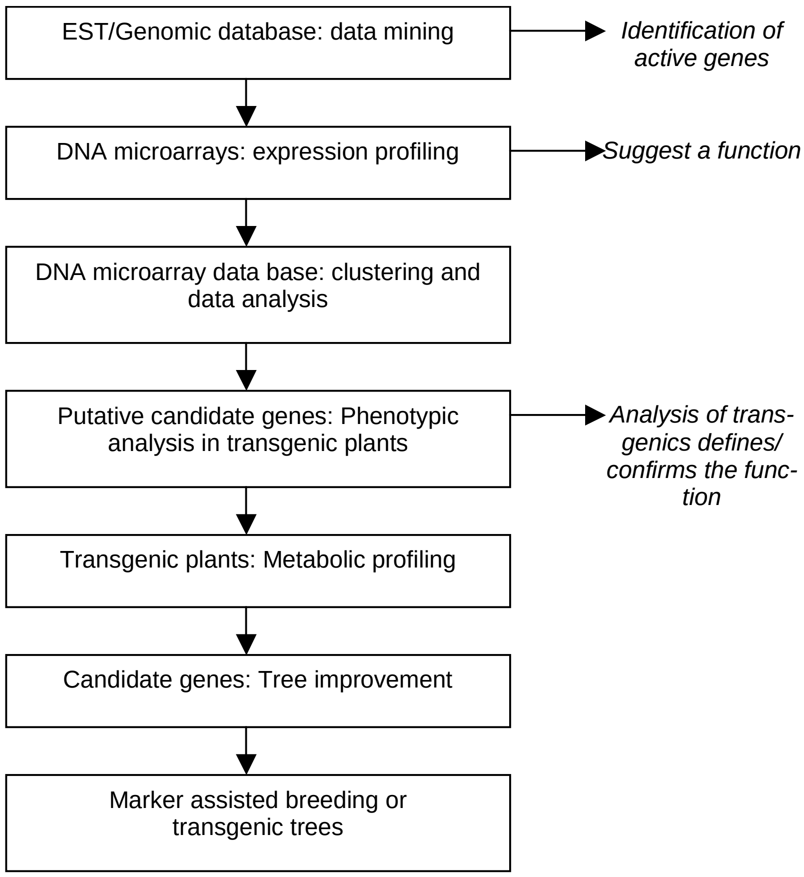

Figure 5.1 Assessing Gene Function
Adapted from Palva, T. 2006. Presentation on the Finnish Forest Biotechnology Network and Birch Genomics. Forest Biotechnology Seminar held in February 1, 2006

Practical implementation of MAS techniques in breeding programs require still better information on the gene maps of our main forest trees and on the correlation between marker genes and quantitative traits in the species. Most likely MAS will be first implemented in identifying genes in *P. Sylvestris* that promote adaptation to the climate change and those correlating with fiber quality (lignin content, composition and resistance to decay) (Metla 2005).

5.1.3 Summary on the Future Biotechnological Techniques in Tree breeding

Feasible and cost efficient methods to produce somatic embryos of broad-leaved and conifer species allow the transfer of the desired elite qualities through clone multiplication to new seedlings. Somatic reproduction can be used to produce improved seedlings for forest regeneration, or to produce breeding material. The benefits of somatic reproduction as compared to seed orchads include (i) benefits of a specific desired combination of qualities, (ii) avoidance of background pollination that decreases the breeding benefits and (iii) shorter time lap needed to proceed from early production to a larger scale profitable production.

Other biotechnological applications in forest breeding include prevention of physiological maturation of clones, marker assisted selection in the early development stage and gene transfers. Hormones can be used to regulate flowering and seed production (Tapio 2006).

The first fields of application for MAS selection would be in selection of clones (i) resistant to various environmental consequences of climate change and (ii) with desired wood qualities (e.g. resistance to decay).

5.2 Biotechnology in Silviculture (Pest Control)

Forest pests include: pathogenic microorganisms, competing vegetation, and insect pests**.** Traditionally, pest control has been done by means of chemical fungicides, herbicides and insecticides. These chemical products are not target-specific and may lead to unpredicted side effects in the ecosystem. Biotechnological alternatives consist of the use of biological control agents (BCAs), such as microbial pathogens as fungi, bacteria and viruses, and have been used for a long time. For example, the fungi *Beauveria bassiana* has been applied for insect control in Russia and China, since it has a broad action range; or the polyhedrosis virus (NPV) used to control a pest of European pine sawfly, *Neodiprion sertifer*, in Canada back in the 50s (Reddy & Retnakaran, 1998). BCAs are also used in Finland, against root-rot in spruce and pine stands (Rootstop®) and against European pine sawfly (polyhedrosis virus). In spruce seed orchards the bacteria *Bacillus thuringiensis* is used to prevent cone and seed pests. The presense of various pests in seed orchards has been detected with various pheromone-traps. In future a combined use of pheromones and BACs can efficiently reduce the cone and seed damages in seed orchards (Tapio 2006).

The limitations in the use of BCAs lie in their production, which is still costly and slow, and in their efficiency, which does not always reach the levels of chemical control agents. BCAs are often highly specific and their use requires detailed knowledge on the strains of the pathogen, which enables the control of specific strains. Moreover, since BCAs are integrated into the target population (i.e. a virus attacking an insect) their impact is not restricted exclusively to the area of application, which in some cases increases their efficiency compared to conventional chemicals.

New regulations on the use of synthetic pesticides also promote the development of BCA approaches. The current trends in forest pest control point both to the use of genetic engineering in BCAs to improve their efficiency, for example increasing the virulence of viruses, and to the application of genetic engineering in the tree species by directly enhancing their resistance to pests or herbicides (dealt in more detail in 5.4).

Some biological control agents are currently commercialized for forestry use based on fungi or natural biochemicals, e.g. StumpOut® (stump removing by rapid degradation with fungi), BioChon® (control of Stump sprouting), or ECOclear™ (weed control). There are concerns that newly introduced pathogens may affect non-target species too. However, the use of native pathogens and results from impact studies reveal also that the risks are low (Gosselin et al. 1999). In Finland the germs of *Phlebiopsis gigantea*- fungus are used to protect trees and roots from the contamination of root-rot (*Heterobasidion spp.).* The BCA product is patented and commercialized by Verdera Oy under the name Rotstop®. A commercial product of polyhedrosis virus (NPV) controlling the European pine sawfly has also been available for years. Furthermore bacterium preparations of *Bacillus thuringiensis* have been tested against spruce cone and seed pests (e.g. the moth *Dioryctria abietella*) with successful results in Sweden. The efficiency of the method is now being tested in Nordic countries in the field (summer 2006), and results will be available soon.

Prevention of wood decay, specifically the root-rot in spruce and pine stands has been a long-term priority in forest research. The current research focus is on using molecular techniques to recognize the specific pathogens, which allows prompt application of appropriate protection measures (e.g. Tuomivirta and Hantula, 2005).

Molecular marker-assisted techniques are also applied in the identification of pathogens from imported wood and thus preventing the expansion of plant diseases. The technique allows e.g. identification of specific strains of *Heterobasidion spp.* fungi causing decay, and identification of other BCAs such as natural viruses to the pathogens (e.g. Scleroderris canker (*Gremmeniella abietina*)), (Tuomivirta and Hantula, 2005).

5.3 Biotechnology in Conservation Biology

The objective of Conservation Biology is to preserve and understand the biodiversity of ecosystems both in terms of species and genes. Genetic diversity is the result of long term adaptation via natural selection. The understanding and characterisation of genetic diversity in a tree population can be used both to effectively manage and conserve biodiversity (e.g. determination of minimum population size), and to serve as a natural bank of genes for future tree breeding needs. Conservation approaches can be *in situ,* in the natural habitat, and *ex situ,* outside the natural habitat. Biotechnological tools are increasingly important in forestry for *ex situ* conservation of tree genetic resources, including *in vitro* and cryogenic storage methods (Benson, 2003). Alternatively, molecular markers can be used as a tool to study the link between taxonomy and genetics, and in the characterization of genetic diversity (e.g. Aronen, 1995).

In Finland, Metla plays the role of conductor carrying out the practical research to ensure the maintenance and management of forest biodiversity, and the conservation and utilization of its genetic diversity. Research Programs intended to evaluate and utilize the potential of the genetic variability of Finnish forests are covered through Research Programs (e.g. Forest Tree breeding Program, 2000-2001); Biodiversity in the forest ecosystem, 1995-1999).

5.3.1 Characterization of Genetic Diversity

The genetic diversity of tree populations can be seen as a natural gene bank; and characterizing the genetic diversity of other organisms such as pests or pest control agents can help in pest control and ecosystem management. For example, a recessive allele in a gene coding for a specific lignin type containing an unusual subunit composition, was identified in naturally growing loblolly pine; this lignin was more easily removed from wood during the pulping process (Merkle & Dean, 2000). Hence, the naturally existing genetic diversity occurring in natural populations can be used for our benefit once it has been mapped. Mapping or characterization of genetic diversity uses all types of molecular markers, though DNA-markers provide more information. Another potential application of DNA-markers in the context of genetic diversity is fingerprinting, where DNA-markers are used to verify the provenance of plant material or seed.

In a recent study carried out by FAO (2004), studies in the field of genetic diversity were found to be concentrated on measuring diversity (57%), tree conservation (8%), population genetics (15%), paternity analysis and fingerprinting applications (14%), and taxonomic and phylogenic applications (6%).

In Finland, current research aims at identifying the genetic diversity of a target species population (trees, fungi, viruses) for different purposes, e.g. the characterization of fungal viruses important as a pest control agent (Tuomivirta and Hantula, 2005); that of the variability in phenolic composition in birch trees, also an important pest control agent (Laitinen et al. 2005); or the genetic variability responsible of adaptative traits, such as time of flowering or growth onset (Savolainen, 2004; Riihimäki, 2005). Overall, the information obtained from studies of genetic characterization is not only the basis for conservation programs, but a link to MAS or genomic studies that can improve traits of commercial interest, or serve other biotechnological applications such as biological control agents (BCAs), dealt in more detail in section 5.4.

Genetic Modification in Forestry

Genetic engineering has opened a wide range of possibilities to improve tree performance, wood production and selected wood properties; both directly, by introducing new genes into the tree genome that confer the desired new properties; and indirectly, improving the understanding of the plant cell functioning through genomic research combined with conventional breeding.

Genomics and genetic engineering go hand in hand, since a deep understanding of the cell biology is essential before any application of genetic engineering can be attempted. In this context, forestry has greatly benefited from the wide genetic knowledge readily available from agriculture. This has accelerated the process so, that the genetic knowledge in tree genera, such as poplar, pine or eucalypts, is already as important as that for main crop species.

Current genetic modification field trials concentrate in US (48%) and Europe (32%). Field trials are mainly restricted to *Populus, Pinus, Liquidambar* and *Eucalyptus.* Half of the tests are intended to provide material for other research objectives (e.g. functional genomics), and the other half cover herbicide tolerance, biotic resistance, or wood chemistry among others. So far, only China has reported the release of commercial plantations with GMO trees (some 300-500 ha, *Populus sp.*), compared to the 81 million hectares of GM crops planted worldwide in 2004 (FAO 2004).

In Finland, GMO field experiments have been done with Scots pine, Norway spruce, birch, covering traits such as flowering (birch), resistance to fungal and insect diseases (birch), or marker system (Spruce, Pine, Birch), (JRC 2006).Furthermore, tests are also done in laboratory conditions and include other species, e.g. aspen (Seppänen et al. 2004). In order to evaluate the ecological and social impact of GMOs, the Academy of Finland, the Ministry of Agriculture and Forestry, and the Ministry of Environment are funding a Research programme on Environmental, Societal and Health Effects of Genetically Modified Organisms (University of Helsinki 2007) The program covers a total of 10 research projects in different Finnish Universities and Research Institutes. Projects include the investigation of the ecological interactions between GMO plants and their ecosystem, elaboration of models, creation of a monitoring methodology, and evaluation of the social and ethical implications of GMOs. So far, studies have not found any evidence of the impact of GMO trees to the environment (e.g. Pasonen et al. 2005, Vauramo et al. 2005).

Gene manipulation techniques are used as a research tools that provide good information on molecule level biochemical processes and their genetic background. Concerns on adverse environmental impacts of gene modified organisms have resulted in very strict precautionary measures to be implemented in research and in any potential application (Metla 2005). The commercial scale use of gene manipulated plants is not likely to be an option in Finland during the next 10 years.

5.4 Resistance to Pests and Herbicides

Pests may cause significant losses in tree growth and timber production, e.g. insect attacks resulted in 18% volume losses (at 5 years), and fungal attacks in 35% growth reductions in a poplar plantation (Haines 1994). Pests can be controlled with chemical products, but these are not always environmentally friendly. On the other hand, biological control agents (BCAs) lack sometimes the effectiveness of chemical agents. Two biotechnological approaches are: first, the use of genetic engineering to modify the tree metabolism in a way that it synthetises the control agent, with the wood remaining intrinsically protected, and second, the production of trees resistant to broad-range, or environmentally acceptable herbicides (e.g. glyphosate).

Examples of the first approach are: i) inserting a gene in the tree that encodes an endotoxine that remains in the plant tissue, and once eaten binds to the intestine of *Lepidoptera*, *Coleoptera* and *Diptera* eventually killing the insect; ii) inserting a gene that encodes an inhibitor that affects the digestion of the insect and causes its death; or iii) by a combination of methods. In contrast, herbicide resistance has been attained both i) by modifying the plant with a mutated version of the gene encoding the enzyme target for the herbicide, or more frequently ii) by introducing a gene encoding an enzyme for the detoxification of the herbicide.

A limitation in trees compared to crop species is that the effective modification is more challenging since the genotypes cannot be readily replaced as in annual crops, once and if the insect develops resistance.

In Finland gene manipulation techniques are used mainly as a part of functional genomics studies, to study specific metabolic routes. However, field tests have been done with GM birch and aspen against fungal diseases and insect pests. The results have been variable (e.g. Pasonen et al. 2004, Seppänen et al. 2004).

5.5 Production of secondary metabolites

Genetic engineering can be used to enhance the production of selected plant secondary metabolites. Secondary metabolites are naturally synthesized by plants and have important roles, such as plant defense against pests. Thereby, genetic engineering can be used as a tool to increase the production of determined secondary metabolites (natural toxins) to confer enhanced pest resistance, or to produce selected commercial biochemical compounds. For example, some plant secondary metabolites have been used for thousands of years in human medecine, e.g. the acetylsalicylic acid (later commercially known as aspirin) was originally obtained from willow bark (*Salix spp.*), or more recently, the new anti-cancer drug taxol, obtained from yew tree

(*Taxus spp.*) and the Xylitol extracted from birch, which prevents the growth of caries bacteria in the teeth and has already been commercialized world wide for years.

In Finland studies on the secondary metabolites are done in a broad sector. They focus on

1. Production, processing and preservation of acetylsalicylic produced by *Salix* spp.
2. Analysis of the various protective compounds in trees: e.g., HMR lignan that may be beneficial for medical purposes.
3. Improvement of forest berries secondary metabolites (e.g. flavonoids)

Currently the production of secondary metabolites is not based on GM and very limited knowledge is available on the genetic control of plant secondary metabolism. Current research in Finland is based on genomics and metabolomics to elucidate the genetic control of secondary metabolites production in berries (e.g. Jaakola et al. 2002), and birch (e.g. Laitinen et al. 2005). The secondary metabolites and its connection with other sectors (i.e. drug development) are discussed more in detail in section 8.1.2. (module 4).

5.6 Control of flowering

Different techniques are used to control flowering and serve opposite purposes. On the one end, flowering can be affected through the transfer of plants from juvenile to adult state. The earlier the tree reaches the mature state the earlier it will produce flowers. Understanding of the genetic basis of the juvenile to adult state transition provides the basis for genetic modification and production of early flowering trees (Egea-Cortines & Weiss 2001), which can be used to accelerate the conventional tree breeding process. On the opposite end, flowering can be annulled by modifying or silencing some of the key genes involved in the flowering process (Lännenpää et al. 2005). Research on flowering control is mainly done in model species, such as *Arabidopsis* and extrapolated then to trees. Production of sterile trees has potential applications for the control of transgenic pollution, or spread of engineered genes into the natural population. This application has had wide interest since it is in some cases seen as a pre-requisite to commercial release of GMO trees. In addition, a proposed side effect of sterility is the increase in vegetative growth due to the reallocation of resources otherwise spent in the production of reproductive structures.

Genetic ablation techniques or production of sterile trees has been studied in poplar, resulting in more than 90% of transformed lines without flowers (Confalonieri et al. 2003). In Finland the research on flowering is done on silver birch (*Betula pendula)* with the objective to find the ecological interactions and set a basis for development of non-flowering birches (Lemmentyinen et al. 2004, Lännenpää et al. 2005), and shorten the breeding cycle with early flowering birches. The studies are still doing basic research but commercial applications are potential in the future.

5.7 Increase of growth

Increase in tree growth is one of the classic aims in tree breeding. The genetic engineering approach seeks to directly influence some of the plant metabolic processes influencing growth. Some attempts have been made to improve growth through enhancing the capacity to assimilate nitrogen in *Picea* and *Populus*, (Gallardo *et al.* 1999), which is one of the main growth limiting factors; or to modify the gibberellin synthesis in *Populus*, a plant hormone controlling height growth.

In Finland the current research in relation to plant growth investigates the process of wood formation and cell differentiation. At the present, research concentrates in root development of *Arabidopsis* (Mähonen et al. 2006), but in the future the findings will be extrapolated into more commercial applications, such as wood formation in the trunk of birch (Helariutta 2006).

5.8 Altered lignin properties

Lignin is a wood component that provides support to the plant, providing a solid cell wall that strengthens the plants defense system. Lignin needs to be removed during the chemical pulping and bleaching processes. Subsequently, biotechnological approaches to reduce the lignin content in wood or to modify the lignin composition are being intensively studied. The techniques studied attempt to regulate the activity of key enzymes involved in the lignin biosynthesis pathway, resulting in decreased lignin contents or composition (i.e. production of syringyl lignin, which is easily hydrolysed). For example, in transgenic poplar a reduction of the lignin contents up to 45%, together with an increase in the growth rates, has been obtained (Merkle & Dean, 2000). Lignin modifications would serve exclusively for pulpwood, since the properties of lignin: enhancing the natural durability and structural properties of wood, or conferring a higher heat capacity, are needed for other industrial or energetic uses.

Finnish research aims at modifying the lignin content and/or its composition and study the viability of GM trees and the ecological impact of these changes in the forest ecosystem. Current studies focus on the metabolic path-ways of lignin biosynthesis in spruce (*Picea abies)*, and the identification of the genes involved in this synthesis (Koutaniemi et al. 2005). Also, different lignin structure types have been identified in cells with different developmental stages in birch and spruce (Kukkola et al. 2004), these lignin types behave differently during the Kraft pulping process. Finally, on the ecological integration of GM trees is also investigated, for example, Tiimonen et al. (2005) found no effect of GM birch with altered lignin properties on the feeding preferences of Lepidoptera.

In the future, GM trees with reduced lignin contents or altered composition might be a reality, once and if their social acceptability and ecological impacts result positive. On the other hand, the knowledge obtained through genomics on the genetic control of lignin synthesis pathways may be used in combination with studies of population genetics (genetic diversity) to produce, by means of marker-assisted selection, improved trees with the desired lignin properties, without the need to employ GM technology.

5.9 Abiotic stress

Tree species have developed a great adaptation potential during their evolution and can survive in the variable conditions of their natural environment (i.e. temperature pattern, precipitation pattern). However, in plantation forestry highly productive alien species, such as Eucalypts or pines are grown outside their natural distribution areas. In exotic growing site and under changes in climate, trees may face drastic conditions (draught, diseases, high or low temperature, different photoperiod) to which they are not adapted.

The biotechnological approach to these limitations is to study the genetic basis of the plant response to abiotic stress, such as draught, cold, or ozone, in order to produce genetically improved plants and trees with enhanced capacity. Another approach is the introduction of specific genes from other organisms, e.g. the already classic and controversial example of the introduction of gene encoding an antifreeze protein from an ocean pout into tobacco plants (Kenward, 1992).

In Finland, research on abiotic stress does not aim at producing GM trees. Instead, it uses GM technology as a part of the genomic studies to understand the genetic basis of plant adaptation to the environment. The goal is to utilize this information in breeding programs in order to select trees that are better adapted to a changing climate.

Biotechnology encompasses a series of **techniques** that are combined into **applications** aimed to serve a specific end-purpose**.** In order to standardize the classification of biotechnology techniques for data collection purposes, OECD (2005) established a list of general techniques applicable to all sectors. This classification separates biotechnology techniques into seven groups: DNA/RNA, proteins and other molecules, cell and tissue culture and engineering, process biotechnology techniques, gene and RNA vectors, bioinformatics, and nano-biotechnology.

In the case of techniques related with used in Forest Industry Biotechnology these could be classified in three different types: (1) Genetic and molecular techniques intended to increase the understanding and/or modify specific plant physiological processes (e.g. genomics, proteomics, metabolomics, MAS, recombinant DNA technology), (2) cell and tissue culture used to maintain or multiply selected genetic lines of plant material, and (3) Process biotechnology techniques, which involve the use of organisms or enzymes in specific applications. The genetic and molecular techniques as well as cell and tissue culture techniques will be reviewed in more detail in the following chapters and the process biotechnology techniques relevant for the forest cluster are discussed in more detail in Chapter 9.

5.10 Summary

In Figure 5.2. the main biotechniques used in Forestry are exemplified for a tree improvement process (see following chapters for more applications). Tree populations contain an immense natural diversity of genes, the functions of which are, in most of the cases, unknown. The role of genomics is to discover and understand the role of target genes involved in the trait of interest (e.g. wood quality, pest resistance). Once this information is ready, markers can be used to select those organisms containing the target gene or genes, making the breeding process faster and more efficient. The last step would be the use of Micropropagation techniques to multiply the elite material. Alternatively, genetic engineering can be used to introduce alien gene into the tree genome that cover a specific function.

The forest ownership structure in Finland is one of the key problems in implementation of R&D in practical forestry. Due to the small-scale ownership structure investments in R&D in wood production are not profitable. A decreasing number of forest owners also have forestry as a core business activity whereas those who consider forests as a source of occasional revenues and place for recreation is increasing. To implement ownership structure that would have a greater incentive to invest in R&D would require facilitating larger scale ownership e.g. in forest funds. Such investor driven activities could result in the development of large scale forestry business with wood production and forest conservation as a focus business and with a sufficiently long time horizon to allow investments in R&D.

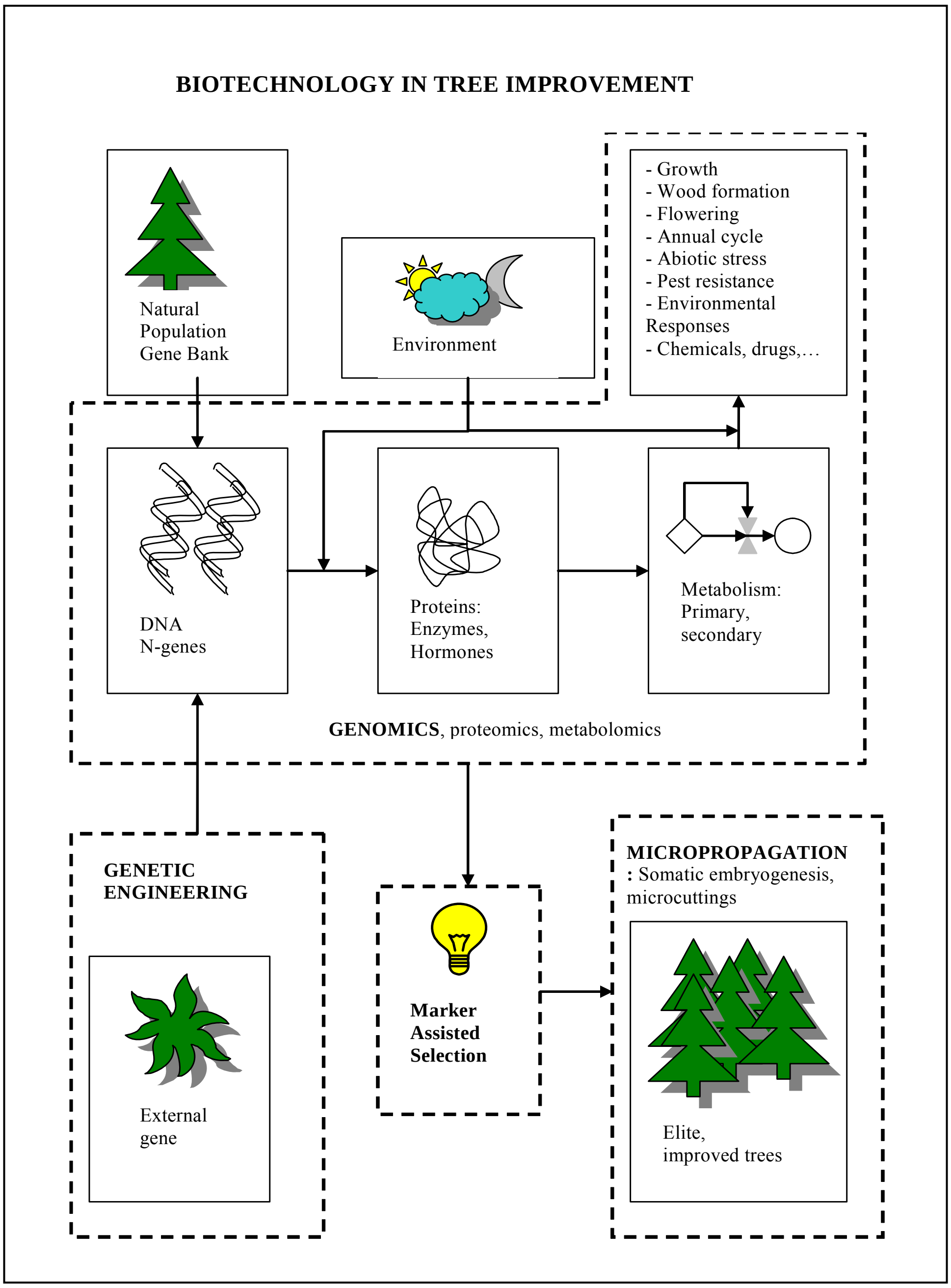

Figure 5.2 Example of Biotechnology in Tree Improvement

6 BIOTECHNOLOGY APPLICATIONS IN TIMBER PROCESSING (MODULE 2)

Applications of biotechnology in timber processing focus mainly in the optimization of wood protection against biodegradation and in the enhancement wood-based board properties.

6.1 Wood Preservation

6.1.1 Biological protection of wood before processing

After trees have been cut down, and while wood is drying in the forest or in the mill yard, wood is susceptible to the attack of fungi until it reaches a moisture content < 25%. Protection of wood after felling does not need to be long-term, and is mainly intended to last until wood is further processed. Fungal attack may affect the physical (e.g. white- or brown-rot) or aesthetical (e.g. bluestain) properties of wood. The chemical protection of wood is effective but implies health and environmental risks. In contrast, Biological Control Agents (BCAs) bring a environmentally friendly means of wood protection. One approach is the use antagonist fungi (e.g. Phlebiopsis gigantean) that competes with the unwanted fungi and have minimal side effects, or the application of bacterial isolates with fungicidal properties (e.g. Debaryomyces). A commercialised example is the use of melanin-deficient mutant (the fungal pigment causing changes in the coloration of wood) to control sapstain on the basis of the antagonism approach, the product is marketed as Cartapip 97. However, tests are still undergoing to evaluate the possible impacts of this mutant (Mai et al. 2004). The antagonism approach is valid for sapstain fungi since they do not affect the structural properties of wood. In contrast, since decay fungi degrade structural components of the wood any antagonistic application based on competition for nutrients would be futile (Bruce, 1998).

Compared to chemical agents, BCAs are biodegradable generally more specific. These characteristics limit their use since they require a much more careful handling, have more limited shelf-time, and are not efficient against a broad spectra of pathogens. Nonetheless the use of BCAs is likely to increase due to the increasing legal limitations in the use of chemical control agents.

6.1.2 Biological protection of wood in service

Once wood has been processed it needs to be functional during a variable time span (up to many decades) depending on the application. The required levels of wood protection depends on the average moisture content in the place of location (i.e. wood exposed to rain needs more protection than wood under cover), given that wood can be attacked by insects (when moisture content is >12%) and fungi (when >18%). Conventional wood preservatives, such as creosote, pentachlorophenol (PCP), or inorganic arsenicals (e.g. Chromated Copper Arsenate, CCA) are toxic. Long-term exposition to arsenic compounds has been associated with cancer pathologies in humans, thus the current trend is towards non-arsenic based preservatives, such as Alkaline Copper Quaternary (ACQ), or Copper Azole (CA) (Canadian Institute of Treated Wood: http://www.citw.org). Environment and health friendly biotechnological alternatives are under intensive research and some have been commercialized. The use of fungal antagonists (e.g. Trichoderma spp.) has been tested to prevent fungal attack. Also, fungal (e.g. Beauveria bassiana) or bacterial insecticides have proved promising for the biological control of termites, however, their efficiency needs still to be improved to reach standard protection levels (e.g. AWPA, American Wood Preservers Association). Commercial products, such as the BINAB FYT (pellets of spores and mycelial fragments of selected fungi) have shown variable results (Mai et al. 2004).

In Finland the research on the use of biotechnological applications in wood protection are still few. They focus on e.g. on identification and function of natural phenolics in wood (e.g. Venäläinen et al. 2004) Recently positive results in increased resistance to decay have been found by adding monolignol to wood and allowing it to react with internal wood peroxidases that oxidise the added monolignol and bind it stably into the cell wall matrix, which could hinder fungal decay. The results indicated lower dry weight loss and increased decay resistance compared to the control (Raiskila et al. 2006). Most new methods to increase the resistance of wood to decomposing are based on physical treatments that keep the moisture content in wood under the critical level. Tall oil also provides a biotechnological method to protect wood from decay.

6.1.3 Improvement of penetration of preservatives

Once wood is felled, the cell pits close, (cell pits are the orifices between cells that allow water transport from the roots to the leaves in a living tree) and are often incrusted by wood extractives that decrease the wood permeability. Conventional wood preservatives, such as copper, chromium and arsenic, creosotes, etc., are liquid or applied in a liquid media and need to penetrate deep and homogeneously in the wood in order to attain sufficient protection. The normal procedures are vacuum and pressure treatments, steam, or incision of the wood with needles or lasers to facilitate the impregnation of preservatives; however full protection is not attained (Mai et al, 2004).

The biotechnological alternative consists in degrading the pits with commercial enzyme preparations, such as pectinases and cellulases, in order to improve permeability and facilitate the posterior impregnation with preservatives. This has been successfully attained for example in spruce wood (Mai et al, 2004). However the process requires several weeks for sufficient enzymatic degradation. Alternatively, inoculation with selected fungi (e.g. *Trichoderma* spp., *Gliocladium* spp.) after thermal sterilisation of wood, has shown increased permeability after some weeks of incubation.

6.2 Biotechnology in the Fiberboard Industry: Biological adhesives and treatments

In the formation of wood fibre or particle boards, wood material and a binder are generally combined under heat and pressure to form the board. The common binder is urea-formaldehyde, phenol formaldehyde (PF), or isocyanate. Formaldehyde emissions from the boards have to be controlled since they are toxic and cancerogenic. Therefore, the current trend is towards low or emission-free boards. The biotechnological alternative uses an intrinsic natural binder already present in the wood: lignin, to replace the use of the previous toxic petrochemical adhesives. One alternative is the use of the fungi *Trametes versicolor* to produce enzyme (laccase) which is later combined with lignin to act as binder (Kharazipour & Hüttermann, 1998, Mai et al. 2004). Other biotechnological alternatives include the pre-treatment of the wood with enzymes to reduce the consumption of petrochemical binders and energy, or the use of the intrinsic chemical properties of the cell membranes to produce the desired binding, by reactivation of lignin with laccase (Kharazipour & Hüttermann, 1998, Mai et al. 2004). Lignin and laccase can be obtained as by-product from the pulp and paper industry, e.g. as lignosulphonate (the spent sulphite liquor), while laccase can be obtained through fungal fermentation of the spent sulphite liquor (Mai et al. 2004). Laccase is also available as a commercial product.

7 BIOTECHNOLOGY APPLICATIONS IN THE PULP AND PAPER INDUSTRY (MODULE 3)

In this chapter both commercial and R&D stage biotechnological applications relevant for the pulp and paper industry are reviewed. In general, the applications in this module involve the use of enzymes (Table 7.1) or micro-organisms to improve the process efficiency, product properties or quality or to decrease process energy or chemical consumption. Another scope for the use of biotechnology is to enable new products and reduce process problems caused by e.g. microbes.

Research on biotechnology in pulp and paper industry has been active for many decades, and several applications have already been commercialized. However, the majority of the potential applications is still in the pre-commercial stage. The current commercially available applications are shown in the table below. The main obstacles for commercialization in this field have been availability and cost-competitiveness of the enzymes and controlling the enzyme reactions and interactions with chemistry in the production processes.

Table 7.1 Commercialized applications for enzymes in the pulp and paper industry

Process stage	Application area	Enzyme
Pulping	Bleach-boosting	Xylanase
	Removal of residual hydrogen peroxide	Catalase
	Energy saving in refining	Cellulases
Paper making	Pitch degradation	Lipase
	Drainage aid, fine-tuning of fibers	Cellulases
	Control of anionic trash	Pectinase
	Deposit control, paper machine clean-up	Protease, amylase
	Deinking aid, stickies control	Cellulases Esterases Amylase
Coating	Starch modification	Amylase
Waste management	Effluent treatment	Laccase

7.1 Biotechnological treatments prior to pulping

In this chapter the biotechnological applications used for treatment of logs or wood chips prior to chemical or mechanical pulping are reviewed. Mechanical pulping is an energy demanding process and one of the main goals in the chip pre-treatments is to reduce the energy consumption in refining. Because pitch is not removed during mechanical pulping process, the other target is to reduce paper machine runnability problems caused by pitch.

Pectinase enzymes, that are commercially available, have been shown to lower energy consumption of mechanical debarking in wet conditions (Rättö et al. 1993). It is however problematic to impregnate the enzyme into the logs and moreover today debarking is in most cases carried out in dry conditions in order to have optimal heating value in bark boilers.

Penetration of the cooking chemicals could be improved by enzymatic or fungal pre-treatment.

Chips can be pre-treated with white-rot fungi, which selectively degrade lignin to facilitate mechanical pulping (biopulping). Fungal pretreatment of wood chips has been shown to decrease the need of electrical energy in mechanical pulping, improve certain strength properties of the resulting pulp, remove pitch and give environmental benefits. The scale of the biopulping experiments with *Ceriporiopsis subvermispora* have grown up to 50-ton semi-commercial scale and trial mill runs (Scott et al. 2002). A new biopulping fungus, *Physisporinus rivulosus* has been patented also In Finland (Hatakka et al. 2003). The main obstacles for full commercialization are the chip pre-treatments to obtain full colonization of the chips, the required long fungal treatment time (more than a week) and the difficulties to control the process (Kallioinen et al. 2003).

Pitch deposits cause paper quality problems, web breaks and machine stops for cleaning. Especially problematic pitch is in mechanical pulping of *Pinus* species. Pitch can be controlled by treatment of wood chips with lipolytic fungi (Farrell at al. 1993). A commercial product based on blue-staining fungus *Ophiostoma piliferum*, which requires no pretreatment of the chips for colonization, is available.

7.2 Use of enzymes in mechanical pulping

The reduction of refining energy consumption in mechanical pulping by use of enzymes, which may act on different wood polymers, has been studied for many years. Most of the studies have been conducted after primary refining because chips are not very accessible to enzymes. An effort has also been put to enhance the impregnation of enzymes into wood chips by impregnation press devices (Mansfield 2002, Pere et al. 2004). Successful mill scale trials with approximately 10-15 % energy savings in TMP reject refining have been conducted with a novel cellulase product (Pere et al. 2002). Many of the enzymes used in treatment of wood chips to reduce refining energy are commercial and the technique is more close to commercialization than biopulping, and has potential of being largely adopted (Kallioinen et al 2003).

7.3 Enzymes in bleaching

7.3.1 Hemicellulases in bleach-boosting

Xylanase-aided bleaching, which was originally a Finnish invention (Viikari et al, 1986, Viikari et al. 1991) is today widely used to enhance the bleaching of Kraft pulp. Only in North America there are at least 16 pulp lines producing over 2.4 million tonnes of pulp annually using xylanase (Hoddenbach et al 2004). The benefits of xylanase treatment are cost reduction, increased production, effluent color reduction, pulp property enhancement and production increases for ClO_2 limited mills. Apart from xylanase mannanase has also shown potential. At the same time as the price of the commercial xylanases has sank, the enzyme performance in the mill conditions, relatively high pH and temperature has improved, which has increased their usage.

7.3.2 Oxidoreductases in pulp bleaching

In the laccase-mediator concept the mediator oxidized by laccase acts on lignin and results in efficient delignification (Call and Mücke 1997). One of most promising current mediators, laccase-DiAc system, was proved efficient in a pilot scale bleaching plant trial (Paice et al. 2002). Laccase-mediator bleaching concept is not yet commercial, although laccase itself is commercially available. Research in the area is still very active and new mediators are patented constantly. Laccase -aided bleaching steps have been applied also to TMP bleaching (Petit-Conil 2002). The use of manganese peroxidase (MnP) in bleaching of chemical pulps has also been studied in semi-pilot scale (Moreira et al. 2003). The applicability of MnP into bleaching is limited by the demand of strictly controlled reaction conditions and the lack of cheap commercial enzyme product.

7.3.3 Enzymatic treatments after bleaching

Inorganic or organic compounds are released from the pulp in bleaching and accumulated on process waters of closed-loop bleaching systems. In a recent study it was shown that oxalic acid in process waters can be enzymatically degraded with oxalate decarboxylase or oxalate oxidase (Cassland et al. 2004). Catalase, which is produced commercially, breaks down hydrogen peroxide and can thus be utilized in natural removal of residual peroxide after bleaching.

7.4 Fiber modification using enzymes

Research on tailoring fiber properties for different products with enzymes is very active and is one of the growing application areas of biotechnology. The studied enzymes are various and include cellulases, hemicellulases, pectinase, lipase and laccase (Kleen and Kangas 2003).

7.4.1 Modification of chemical pulp fibers

Pulp fibrillation by cellulases to enhance strength properties was patented as early as 1959. It was then, however, principally applied to cotton linters and other non-wood pulps. After that primary finding several studies have been published on application of pure or mixed cellulases and hemicellulases to improve bonding properties of various fibers and enhance beatability of chemical pulp fibers. Today the technology is commercial, but controlling of the enzymatic pre-step to avoid excess hydrolysis and yield and strength losses is still challenging. Commercial cellulases and hemicellulases can be applied to improve the drainage by hydrolyzing the most accessible parts of the cellulose and hemicellulose present in fibers, fines and dissolved and colloidal substances. To improve drainage the enzyme treatment is carried out after refining and to prevent excess depolymerization careful optimization of dosages and treatment times is important. This technology is widely used for speciality paper grades or recycled fibers. Cellulases and hemicellulases have also been studied in modification of pulp properties, like wet strength in tissue applications.

The new non-hydrolytic enzymes including plant cell wall loosening enzymes such as XET (xyloglucan endotransglycosylase) and expansin give new possibilities to modify fiber characteristics without compromising the strength properties. XET enzyme could be utilized in adding modified xyloglucan on fiber surfaces. With this approach fibers may be given new properties, like waterproofness (Teeri and Brumer 2003).

7.4.2 Modification of mechanical pulp fibers

The effects of cellulase, hemicellulase and laccase treatments on mechanical pulp properties have been studied. Laccase has proven potential as strength additive.

The ability of laccase to create radicals on lignin has been utilized in grafting of fibers. Unbleached Kraft pulp (Chandra et al. 2004) and mechanical pulp (Yamaguchi et al. 1992, Grönqvist et al. 2006) have been used as starting material of laccase-aided grafting with various chemicals, including 4-hydroxybenzoic acid, syringic acid, vanillic acid and tannic acid. Laccase is today available commercially for industrial scale applications and the development of laccase-based fiber functionalization is very active although the application is still in the R&D scale.

7.5 Enzymes in paper and board making

In paper production enzymes give versatile possibilities to enhance runnability and process efficiency. One of the main areas biotechnological applications is the control of harmful components like anionic trash, pitch and slime. These problems have been increased by water system closure and use of recycled furnishes and there are many commercial solutions offered in addition to active ongoing research on the area. Fibers can also be treated with enzymes to enhance important papermaking parameters.

7.5.1 Enzymatic degradation of pitch

Pitch contains triglycerides which agglomerate and deposit on the paper machine surfaces. Pitch control by lipase was originally developed in the 1980s. In addition to increasing runnability, production efficiency, lipase treatment improves paper quality and strength. The technology is now in wide use in mechanical pulp production. Recently a thermostable lipase that works also at high temperature (up to 90°C) was developed (Host-Pedersen et al 2004). New pitch biocontrol solutions, like steryl esterases with wider substrate specificity have been developed. In addition to lipase, oxidative enzymes like laccase are capable to modify the composition and structure of lipophilic and hydrophilic extractives (Karlsson et al. 2001).

7.5.2 Enzymes in slime control

The process waters in paper mills present favourable conditions for microbial growth. The attachment of the microorganisms on surfaces of the paper machine to form biofilms causes slime deposits on paper which lead to product quality problems or breaks (Kolari 2003). The use of enzymes offers an environmentally friendly way to control microbial growth. There are several commercial enzyme preparations to control biofilm formation that are based on the action of enzymes such as amylases and proteases. A lot of research is currently going on to find the most efficient enzymes for biofilm degradation, including the enzymatic hydrolysis of microbial extra-cellular polysaccharides (EPS) linking the microbes together (Buchert et al 2004).

7.5.3 Enzymes in control of anionic trash

The oxidation products of wood components created in peroxide bleaching of mechanical pulps cause problems in the paper machine and form one main component of “anionic trash”, which reduces the effectiveness of papermaking chemicals. Especially pectin and its degradation components, polygalacturonic acids are harmful. Pectinases, which are commercially available, have shown to be effective aids in this problem as they degrade polygalacturonic acids to less harmful acid monomers (Thornton 1994).

7.5.4 Enzymes in coating

Starch used in coating formulations can be modified enzymatically with amylases, or amylases can be used for cleanup of starch handling systems. Commercial alpha-amylases are used today as a better alternative for reducing starch viscosity (Host Pedersen et al 2004).

7.6 Enzymatic improvement of recycled fibers

Enzymes can be utilized to improve deinking of recycled fibers and to decrease the problems caused by impurities originating from the recycled raw material. The recovery percentage of waste paper is over 70% in Finland, but because 90% of paper produced in Finland is exported, only a low amount of raw material is recycled paper (Finnish forest industry statistics, 2005).

7.6.1 Enzymatic deinking and drainage aid

Recycled fibers are increasingly used especially in Central Europe. Enzyme-aided deinking is a commercially available technology, which reduces the need for deinking chemicals (Mansfield and Esteghlalian 2003). The technology is based on the application of hydrolytic enzymes. Cellulases, hemicellulases and pectinases easen the removal of ink from fiber surfaces and esterases make the sticky compounds less adhesive. The use of cellulases and xylanases also improve the drainage of secondary fibers. The use of enzymes is limited by the pH area of the traditional deinking process which is too high for most enzymes.

7.6.2 Stickies control with lipases and esterases

Stickies are hydrophobic components that originate from adhesives and glues of recycled paper and cause problems at the paper machine. One of the main components of stickies is polyvinylacetate PVAc, which could be deacetylated by esterase enzyme to a less adhesive alcohol form which is easier to suspend in water (Host-Pedersen et al. 2004). The esterase based stickies control technology is commercially available.

7.7 Waste water management

Overall water consumption of the pulp and paper industry has decreased by the closure of the water system. Biotechnology is used by the Finnish mills in their waste water management in the active sludge process, which is based on aerobic microbial activity. The active sludge treatment markedly decreases the waste water biological and chemical oxygen demand (BOD and COD) and the amount of organic chlorinated compounds and nutrients. The phenolic compounds in waste water can be polymerized by laccase and subsequently precipitated and removed (Host-Pedersen et al. 2004). Today commercial laccases are available for waste water treatment.

7.8 New paper products

The use of biotechnology enables the manufacturing of new value-added functional paper products. By the immobilization of biomolecules like enzymes or antibodies into paper the product may be given new functionality, which can be utilized in smart packaging or bioactive paper products. For example a bioactive surface could be used to remove oxygen (oxygen scavengers) inside of a package or for antimicrobial activity. Biosensors could also be used for example in food packaging to detect package leakage or as time temperature indicators. The more value added application area is to use incorporated enzymes in pharmaceutical test sticks. The application possibilities concerning bioactive paper products were recently reviewed (Aikio et al. 2006).

8 SIDESTREAMS AS A FEEDSTOCK TO BIOREFINERY AND BIOREMEDIATION (MODULE 4)

Forest industry sidestreams form a vast source of natural raw materials that could be utilised for further refining of value-added chemicals and fuels. Already today a wide variety of chemicals are produced from pulp and paper industry sidestreams like tall oil and turpentine. However, biotechnology based refining processes have not yet been taken into commercial use in these businesses, and still today most of the sidestream material is used for energy (burning) or earth construction. These uses with relatively low value addition could be replaced in the future by biorefinery applications, where the valuable compounds are either separated for feedstock for further refining or used for energy or fuel production with new, more efficient technologies. The principle of the forest biorefinery is illustrated in figure 8.1.

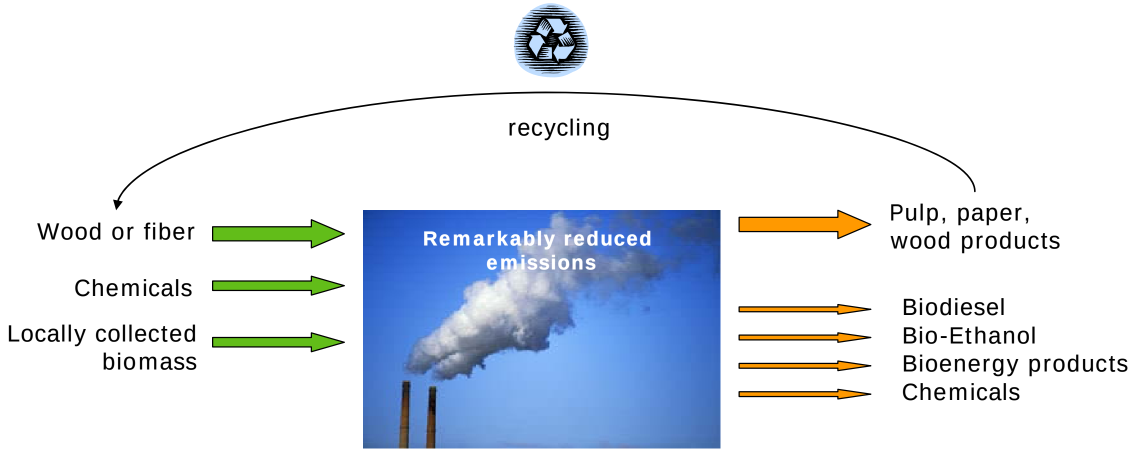

Figure 8.1 Principle of forest biorefinery

The main areas where biotechnology could be utilized in upgrading of forest industry sidestreams are:

- Enzymatic breakdown of lignocellulose feedstock to intermediate sugars to be upgraded to chemicals or fermented to ethanol to be used as a biofuel
- Enzymatic or microbial conversion of wood-based compounds to chemicals

8.1 Biorefinery

8.1.1 Ethanol

Although biotechnology is not yet commercially used for these applications, the research is active especially on enzymatic breakdown of lignocellulose feedstock to be fermented to ethanol. The drivers for this research are needs to develop CO_2 neutral biofuels and reduce oil dependency. In the future biotechnology may have an impact in the other areas as well. The challenge is to develop cost-competitive processes to break heterogenous lignocellulosic feedstock to fermentable sugars. Competing technologies include chemical and thermal processes, for example pyrolysis and Fischer-Tropsch –synthesis in biodiesel production.

Acid and enzymatic hydrolysis are two of the alternatives. The lignocellulosic material requires often a pre-treatment to decrease enzyme consumption and increase the ethanol yield (Knauf & Moniruzzaman, 2004), followed by fractionation of the main wood components: lignin, cellulose and hemicellulose, and eventually hydrolysis and fermentation of the cellulose (Saddler & Gregg, 1998). Small scale and pilot projects are testing new methods to use lignocellulosics (e.g. 2004, Iogen Canada, using wheat straw, partners: Shell/PetroCanada; 2004 Swedish Process, using soft woods, partners: Lund University/Ethanol tech) (Rogers, 2005). The current technology yields 250 liters of ethanol from 1 ton of spruce at a cost of 4 SEK/litre (Galbe & Zacchi, 2002); the yield can be compared to the theoretical 500 liters of ethanol per 1 ton of sugar cane bagasse (Knauf & Moniruzzaman, 2004). Further cost reductions could be attained by integrating ethanol production with other industries, such as pulp and paper (Galbe & Zacchi, 2002).

The potential of ethanol lies in decreasing the cost and increasing the efficiency of cellulase enzymes. Protein engineering can serve as a tool together with genomics and proteomics to enhance the cellulase enzyme. It is anticipated that in the next 5 years cost-effective biomass conversion technologies will help in the market expansion of ethanol (Knauf & Moniruzzaman, 2004).

8.1.2 Wood Chemicals

Secondary metabolites are important as medicines, adhesives, insecticides, or fungicides, among others (e.g. camphor, tall oil, or taxol). Tannins are used for example as adhesives in combination with formaldehyde for wood panels (Pizzi, 1998), and have also been used as wood preservatives. Also, extractives from heartwood in some species give fungicide and insecticide properties to the wood.

As discussed previously (chapter 4.5) genetic engineering techniques can be applied to increase the production of high value secondary metabolites, such as the anticancer diterpene taxol extracted from the yew tree (*Taxus spp*.). The use of taxol is limited by its short supply caused by the slow growth of yew trees, and biotechnological solutions to improve taxol production through genetic engineering are being studied (Han *et al.* 2000). In Finland, genomic studies are performed to understand flavonoid production in berries (Jaakola et al. 2002), or specific medical products in *Salix* spp (Laitinen et al. 2005).

Sidestream extraction of chemicals from wood is one alternative to reduce costs of production and obtain alternative value-added products, but for certain high-value forest products the production of chemicals might also become the main goal (e.g. flavonoids from berries, or medicine production from *Salix* spp.).

8.1.3 Bioenergy

Bioenergy has become a political priority and a tool to combat the climate change in the world. EU has taken several initiatives to promote the use of renewable energy sources (RES), such as the RES-Electricity Directive and the Biofuels and Transport Directive. The Biomass Action Plan (2005) sets targets for increasing the bioenergy production to 10 fold by the year 2010 as compared to 1995.

The share of wood-based fuels in primary energy consumption in Finland is currently 20%, of which 50% is solid energy wood and 50% industrial bioliquors (Kuitto 2006). The use of bioenergy is most elaborated in an integrated pulp and paper mill, where the recovered energy fuel side-streams and direct and indirect wood fuels (industrial solid wood residues, black liquor) are burned for energy.

Converting biomass to liquid fuels is a key topic in most western countries at date. Part of the bioenergy applications take advantage of biotechnology, others utilize more conventional techniques such as formation of syngas through pyrolysis and subsequent synthesis of liquid fuels through the Fischer-Tropsch –method. Wood based fibers could be processed to bio-ethanol like agricultural fibers. Converting some pulp mills to biorefineries for ethanol production has been discussed, but the global competition on ethanol markets has become fierce. However, feasibility analyses indicate that biodiesel production from domestic timber can be profitable if the production plant is in connection to a large integrated pulp and paper mill (Häggblom 2006).

8.1.4 Possible sidestream feedstock materials

The main possible sidestream feedstock materials for biotechnology based upgrading are:

- Harvest residues
- Bark
- Hemicellulose extracted from chips
- Dissolved and colloidal substances in mechanical pulping process waters
- Kraft black liquor (pulping spent liquor)
    - Kraft lignin
    - Hydroxy acids
    - Acetic and formic acids
    - Polysaccharides
    - Crude tall oil – extractives
- Sludges from pulping, papermaking and waste water treatment

The volumes of the above listed sidestreams are in most cases very large, but development of cost-effective extraction and conversion technologies limits their potential for utilization. The main compounds for utilization from these feedstock material streams are lignin, cellulose, hemicelluloses, phenolics and extractives. For further reading on forest biorefinery a recent book is recommended (Kamm et. al 2006).

8.2 Bioremediation and phytoremediation in the Forest Industry

Conventional wood preservatives, namely creosote, pentachlorophenol (PCP) or inorganic arsenicals (e.g. Chromated Copper Arsenate, CCA) are toxic and need to be properly disposed. Combustion or incineration of the wood is an effective alternative to landfills but requires special furnaces and costs are rather high (Mai *et al.* 2004). The biotechnological solution consists in the utilisation of microorganisms (mainly fungi and bacteria) able to survive in these toxic conditions and to degrade the toxic compounds into less or non toxic forms. Typically, the microorganisms are originally sought and isolated from populations naturally occurring in treated wood. For creosotes, bacteria show much higher tolerance to the toxic phenolic compounds of creosotes than fungi but they cannot degrade all phenolic compounds. Thus the combination of bacteria and fungi has shown better results (Majcherczyk & Hüttermann, 1998). White-rot fungi are specially indicated to treat wood contaminated with creosote, showing significant degradation of the toxic compounds after a short incubation period (3 weeks). White-rot fungi are very efficient producers of extracellular enzymes which oxidize aromatic compounds by generating a high redox-potential, this approach has been called enzymatic combustion (Kirk & Farrell, 1987). Generally 2-3 months incubation with white-rot fungi are enough for remediation of contaminated wood. For remediation of PCP-treated wood, some fungi have been also tested (e.g. *Trichoderma* spp.). Remediation of inorganic preservatives, such as heavy metals, is more challenging since they are more persistent, however partly success has been attained with bacteria and fungi (Mai *et al.* 2004). Also combination of chemical and microbiological remediation methods is being applied, for example in the remediaton of CCA treated wood with commercial oxalic acid followed by treatment with bacteria (*Bacillus licheniformis*) (Clausen 2004a). Litter-decomposing fungi could be applied to treat contaminated soil, as they are able to grow in soil and degrade recalcitrant compounds like lignin and PAH compounds (Steffen 2003). However, the costs of these technologies still need to decrease substantially before they can be widely adopted.

In Finland, old wooden sleepers that cannot be reused are transported to UPM-Kymmene's power plants in Rauma or Kajaani, which hold the necessary environmental permits for incinerating the contaminated wood (Otto Lehtipuu, VR, personal communication). So far, no biotechnological alternative is being used. And no research in this area was identified in Finland. One possible explanation is that conventional bioremediation technologies are already sufficiently developed to be applied. One interviewee stated that:

"…bioremediation does not have so much future in Finland, once everything is cleaned up here we will need to move to neighboring countries. On the other hand, the trend is to build industries that do not pollute, and not to bioremediate so much (maybe after 20 years there will be no more activity). Also the technology mostly developed…"

Phytoremediation, uses plants to detoxify the soil. Phytoremediation can operate removing the toxic components from the soil (phytoextraction of metals) or reducing toxic organic compounds to CO_2 and water (phytodegradation). In particular, the perennial nature of trees and their larger rooting system make them excellent candidates for phytoremediation (Séguin et al. 1998). Phytoremediation offers a much more economically sound alternative to the current technologies, needing relatively small investments. However, the technology is still under research and testing. In Finland, the molecular mechanisms of birch tolerance to heavy metals are under research (Koistinen et al. 2002, 2005).

9 THE EMPIRICAL PART

9.1 Data and Methods

Data

The objective of the interviews on the academic research was to cover all the research related to forest based biotechnology. A total of 29 research groups from universities and research institutions, and 39 companies were interviewed, which practically meets the target on the full sampling. The categorization of research groups into forestry, wood industry, process or side stream research was not always explicit because some groups provided results applicable on several fields. However, 14 groups had a main focus on questions applicable in forestry, mainly in tree breeding, seven groups studied the characteristics and use of side-stream products, seven groups focused on process related questions and one group majored in questions related to environmental protection.

The interviews were conducted as telephone and face-to-face interviews based on the detailed questionnaires sent to the interviewees beforehand. The questionnaire covered the following issues: financial figures, human capital (*e.g.* number of personnel, R&D personnel, education, business experience), structural capital (*e.g.* patents and patent applications, R&D expenditures), relational capital (*e.g.* collaboration with academia, collaboration with companies, customer-subcontractor network), and information on product development, application segments, and funding and sales anticipations.

Methods

Econometric modeling is used as our main tool as we model the linkages of the biotechnology-based application segments with both research funding and sales anticipations. Principal component and regression analyses are applied as an analysis method (as an introduction to the method, see e.g. Sharma 1996). The principal component analyses assess the profiles of R&D projects of the academia and companies. Resulting principal component scores are fed into regression analysis. The prediction of getting research funding or generate sales based on any R&D project profiles are estimated by these regression models. Hermans and Kauranen 2005 provide a close application for the two-stage in assessing high technology sales predictions.

Thus, there are two stages in the statistical procedure:
Stage 1: Principal component analysis is used to identify project profiles within the application segments and produce principal component scores for each R&D project.
Stage 2: Regression analysis is used to predict the research funding of academic projects and companies' anticipated sales in 2010. In other words, the principal component scores are used as variables in the regression model and the output of the principal component analysis is used as predictors that explain the research funding and anticipated sales of the sample of forest biotechnology R&D projects.

First, we try to find the forms of interactions between the application segments within the forest cluster's value chain and knowledge committed to the projects. The knowledge can be expressed as two overlapping roles: 1) tacit knowledge related to quality and quantity of human resources, and 2) codified knowledge related to, for instance, R&D activities and intellectual property rights (Nonaka and Takeuchi 1995). According to the knowledge management theory, the adequate tacit knowledge creates value for the business since an organization can exploit and even distribute the knowledge over its human resources and exploit it commercially. Thus, the value creation in business activities is connected to the interactions between the distinctive forms of knowledge. Meanwhile, we link these knowledge structures to distinctive application segments. In statistical terms, the interaction between the two knowledge categories and application segments is measured as the co-variation of the variables. The result shows the knowledge and application segment of the projects.

The idea in the first stage is to find the common variation between the variables and form the knowledge and application segment components discussed above. Because an orthogonal principal component method is applied, the components are uncorrelated with each other, which is an advantage in regression analysis. This lowers the risk of multicollinearity between the independent variables. Principal component scores are constructed from the components and they are used as new variables in Stage 2.

Our attempt is to relate both the research funding and anticipated sales of the R&D projects based on the knowledge management approach and value chain of the forest cluster. Regression analysis employs two separate models. Firstly, we predict the research funding of the academic R&D projects. Secondly, we predict the anticipated future sales of the R&D projects conducted by the companies in our data.

Despite the fact that we employ cross-sectional data, the analysis is dynamic in a similar sense as Bounfour (2002). We are interested in the valuation of assets and the input-output relations of forest biotechnology R&D activity.

9.1.1 Characterisation of Biotechnology know-how in Modules 1-4

The key stakeholders in both academia and companies were interviewed. The collected data was assessed through the following three steps:

Step 1 Depiction of the Finnish biotechnology sector and forest cluster – Existing knowledge and resource bases

- The areas of scientific research (e.g. areas of research, number of articles and researchers, budget). The quality of research was evaluated by the interviewed experts.
- The organisational arena of the forest-based biotechnology industry: the resources of firms in the related areas.
- The areas of competence benchmarked against economic resources.

Step 2 Sales anticipations of biotechnological applications related to forest industry

- The options, potentials and bottlenecks for the commercialisation of bio-technology derived products assessed.
- Future trends and development potentials of biotechnology products in the forest cluster in Finland and internationally.
- Overview on potential domestic and export markets for forest-based applications of biotechnology.

Step 3 Identification of comparative advantage

- A comparative advantage of forest cluster based on biotechnology is discussed.
- Current allocation of research and development resources in biotechnology sector and recommendations for future orientations are offered.
- Policy implications

9.1.2 Survey

The survey was designed to meet the demands posed by the questions presented in chapter 2.1. Face-to-face and telephone interviews were conducted. The questionnaire consisted of a structured part, where quantitative questions were asked, and a more conversational part through which more qualitative information was obtained.

The data collection covered a variety of topics, ranging from the basic characteristics of companies to the conduct of R&D to sources of financing and sales, as well as collaboration patterns and purchasing. Insights included also geographical and inter-institutional R&D-collaboration patterns, mapping of the academic science base on which the companies build their own R&D, detailed, comprehensive and reliable financial statements, and, probably most importantly, product-level data that incorporates R&D- and sales figures, forecasts thereof, collaboration patterns, product-specific science-base mapping and academic origin of the innovations.

The quantitative results of step 1 are presented using descriptive statistics as well as tools that display concentrations in knowledge and resource bases. The main areas – where biotechnological research and know-how is concentrated in distinctive modules of the value chain – are discussed together with its present application status and potential for future implementation.

9.2 Characterisation of Research Units in Forestry, Module 1

A total of 14 Research Leaders of groups studying aspects related to forest biotechnology in Module 1 were identified and interviewed.

The majority of the Research Groups were based in Universities (71.4 %), the remaining in Research Institutes (including Metla) (28.6%). This distribution explains the predominance of basic research studies compared to applied research. The groups were fairly small, in average 12.4 man years/group (std dev 8.02), including technical staff. All the groups had intensive cooperation ties with other Finnish groups and especially with Metla, and with selected Universities abroad (North America and Europe). Furthermore, 50% of the Groups had had cooperation with companies during the last three years. Only one Group cooperating with companies had two patents, and two Groups had patent applications (1-4 each).

Most researchers doing forestry related biotechnology research had a degree in biology (93%), 14% (2 persons) had a degree in forest sciences and 7% (1 person) in chemistry (one person reported 3 degrees: forestry, biology and chemistry).

The share of researchers with higher education (Licenciate or Ph.D.) was in average 4.1 persons per group, which is quite a high number. The heads of each group were experienced in their field of study as 86% of the repliers had over 10 years of experience in biotechnology, but in average only 3.67 years in applied biotechnology. This indicates that only recently the forest biotechnology research has achieved the technical and theoretical basis to move on towards applied research.

9.2.1 Research Funding (Module 1)

The total research funding received during 2005 by the Research Groups in module 1 was 2.7 million € (Table 9.1), 88.2% of which was allocated to basic and 11.8% to applied research. The interviewees estimated that the total amount of research will remain approximately the same or with a slight increase (about 5%) in 2010 until 2.83 million €, corresponding to an approximate 1% annual growth. In terms of average research budget per group this would remain approximately same, from 0.19 million € in 2005 *(std dev 0.14)* to 0,2 million € (*std dev 0.13*) in

2010. Yet, the given figures are rough estimates for the trend in financing. It was also estimated a significant movement from basic towards applied research in the future, with the share of applied research almost doubling from 11.8% in 2005 to 21.4% by 2010. However, basic research will remain the predominant research type in Module 1 with 78.6% of the research budget.

Table 9.1 Annual funding received by the universities and research institutions in module 1 in the year 2005 and the estimate of funding received in the year 2010 in M€

	Funding 2005	Estimate 2010
Basic research funding	2.38	2.23
Applied research funding	0.32	0.60
Total funding	2.70	2.83

A common view among the repliers was that the share of applied research will increase, although the total funding for the sector might not change significantly. Also, 50% of the interviewees claimed that research funding does not support the long-term requirements of most forest biotechnology research projects, or its goals. One replier stated that:

"It would help if the funding schemes would be longer or else there is no time to get results… specially when working with trees, otherwise it's easier to work with Arabidopsis…"

Another:

"TEKES and Academy exist, but we would need a financing body that would not emphasize applicability as much as TEKES and would understand applied research better than Academy. TEKES and Academy remain principal sources for financing."

In relation to contract research. Only two Research Groups in Metla (The Finnish Forest Research Institute) reported having contract research. This research consists mostly of the public services Metla is enforced to provide and is also financed from public sources. In tree-breeding and plant genetics the share of contract studies was 15% of the annual budget whereas e.g. in the research on wood decay the share is about 2%. No research group reported providing studies for individual private companies.

9.2.2 State of Applications (Module 1)

During the year 2005 the research activities of Finnish Research Groups corresponding to Module 1 were related to the following five general applications:

1. Tree improvement through Marker-assisted Selection
2. Characterization and utilization of genetic diversity
3. Micropropagation techniques
4. Biological control of pests
5. Tree improvement through genetic modification

In Figures 8.1 and 8.2 the detailed classification of the main applications under research or commercialization is presented. The 25% of the research projects (n=52) evaluated in Module 1 dealt with Marker-assisted selection, 23.1% of the projects involved or aimed at characterising the genetic diversity of a specific population of trees or other organisms relevant to the forest ecosystem, micropropagation techniques were used or developed in 17% of the identified projects, and biological control methods for wood protection after felling were researched in 10% of the projects. Finally, genetic modification is widely applied by Finnish Research Groups in biotechnology research to improve different traits of the tree. The main area under GM research aims at modifying the lignin content and structure in trees (current work with Spruce), with 21.2% of the projects. In addition 9.6% of the projects aimed at increasing the insect resistance through GM, and similarly 9.6% dealt with resistance to abiotic factors. Finally the control of flowering was dealt in 7.7% of the projects. Research projects dealing with the impact of GM on the ecosystem were included under “Other Conservation Biology” and were present in 5.8% of the Research Projects. Other applications under research can be seen in Figs. 9.1 and 9.2.

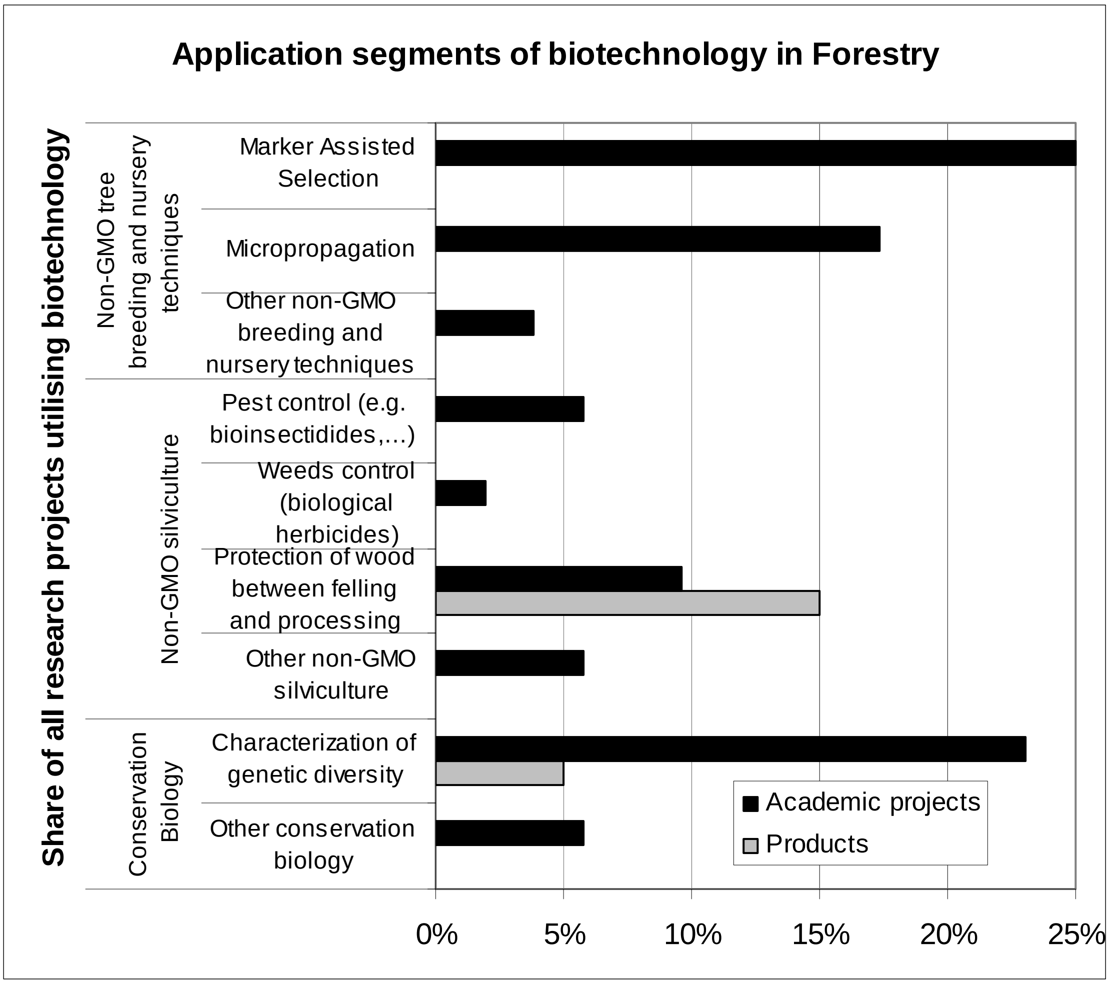

Figure 9.1 Application areas of Biotechnology in Forestry

Currently GMO-based research is used mainly to develop techniques for non-GMO biotechnology applications in forestry. Legislation on production and release of GMO plants in nature is extremely strict and currently no commercial GMO trees can be planted in EU countries. Pressure to reconsider the anticipated risks of GMO plants is growing due to the more liberal approach to research and practical implementation in US and Latin American countries with significant plantation forestry. It is likely that also EU will be more liberal towards GMOs in future which will increase the possibilities to produce GMO based products in forestry. However, precautionary approach will be taken before genetic modification of natural species (e.g. our forest tree species) is allowed in a commercial scale.

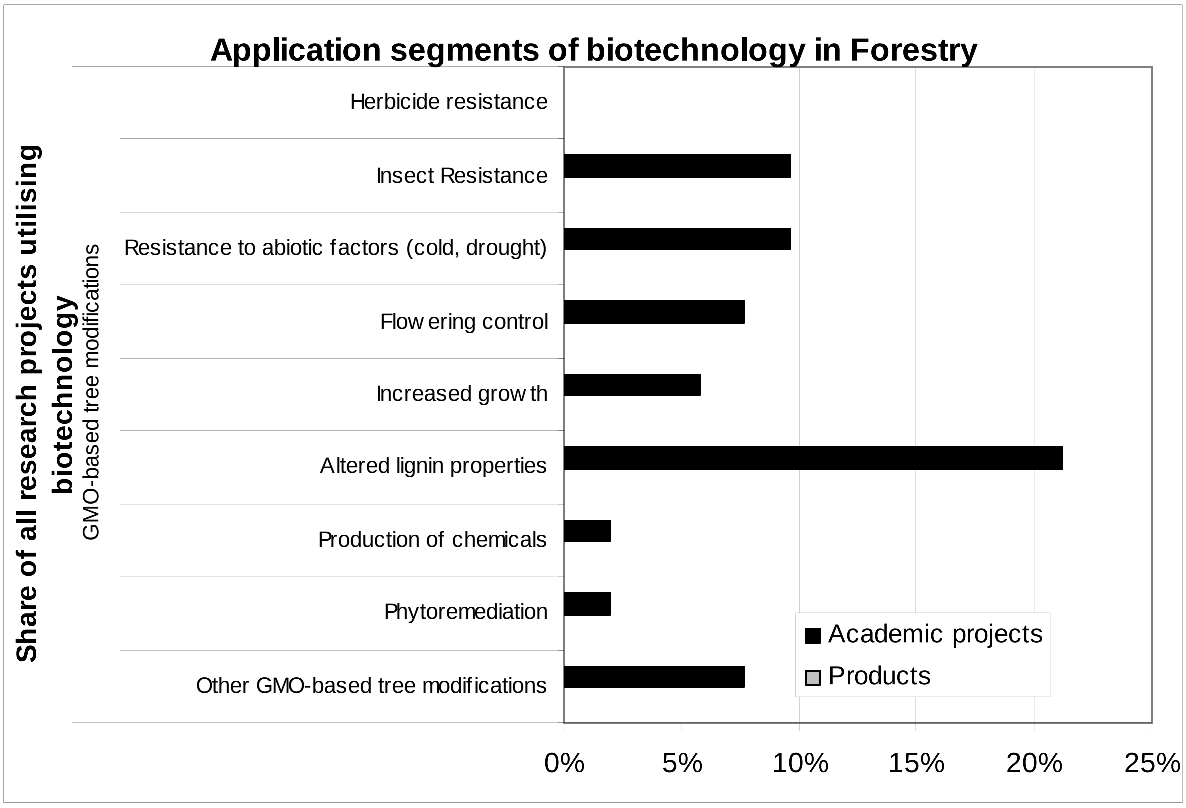

Figure 9.2 Application areas of Biotechnology in Forestry

9.2.3 Current state and future trends in Forest Biotechnology (Module 1)

The views on the future prospects of biotechnology in the Finnish forestry were optimistic, although shortage of research funding and lack of long-term research projects were considered to hamper the possibilities to stay in the world top on the sector. Funding and support to the R&D has been stronger in a number of other leading countries (e.g. Sweden, France, USA, Canada).

Currently the techniques in molecular biology and gene technology are developed to the level where a broader transfer towards applied research is possible. The great potential lies in the non-GMO based biotechnology, i.e., characterisation of genetic diversity, genomics and MAS, with applications in tree breeding and pest control: reducing of tree breeding cycles, attainment of the desired timber properties, and effective biological control methods in pest management.

The use of gene manipulated end products in forests (GMO plants) is not foreseen in the near future. The social perception towards GMOs is of reluctance and fear that new engineered genes scape to natural populations, that they end up affecting human health or the appearance of monocultures, typical of agriculture. The Biosafety Association (http://www.bioturva.org) might be the most known objector of GMO plants in Finland, but the majority of the citizens do not know the subject so well that they could show their attitude. To prevent the dispersion of foreign genes to nature, the fieldtesting of GMO trees is very brief in duration, to avoid seed production. In Finland, since 1995, 21 field experiments have been done, and there were 2 experiments on going in 2004. Because of the security provisions of GM technology, the long term following of the success, constancy and effect of the genetic modification has not been possible so far even at level of basic research (Metsänjalostus 2050, 52).The board of Gene Technology (GTLK, http://www.geenitekniikanlautakunta.fi) is the Finland's national competent authority in these affairs. GTLK acts under the Ministry of Social Affairs and Healt. The relevant current legislation is the Gene Technology Act of 1995 (377/1995) which is based on the precautionary principle, and the Government Decree on Gene Technology of 2004 (928/2004).

Both the negative social perception towards GM trees and the legislation are reflected into the financing of GM Research Projects. There are little resources even for risk assessment studies, although the ecological and social risks need to be assessed in the same conditions than the future implementation. Use of GMO in forestry based on natural forests is problematic (higher risk for gene contamination), and also the ownership structure prevents large scale investments to forestry (large plantations). However, gene manipulation techniques provide a very valuable research tool that can be applicable to study non-GMO solutions for forestry.

Short-term and limited research funding and poor structures for cooperation between the public and private sectors do not encourage feasible projects on applied research, and encourage the use of annual plants instead if testing on more slowly growing trees. Funding organizations do not support projects that study the preliminary options for practical applications and private sector on the other hand is reluctant to finance any research that does not provide direct practical benefits. Also, the high degree of confidentiality and broad patent protection were also seen to delay the access and validation of information, which is a basis for creative research.

9.3 Characterisation of Research Units in the Wood Industry, Module 2

The research activity in relation to Module 2 in Finland was very small. We did not identify any Research Group fully dedicated to research of the biotechnological applications in the wood industry. Only 5 applied research projects were connected to applications in Module 2. In Figure 9.3 the significance of these projects relative to all identified forest biotechnology research projects is estimated.

The only commercial activity in relation to Module 2 was identified in the protection of wood (BCAs). The budget figures of Module 2 are embedded in Modules 3 and 4.

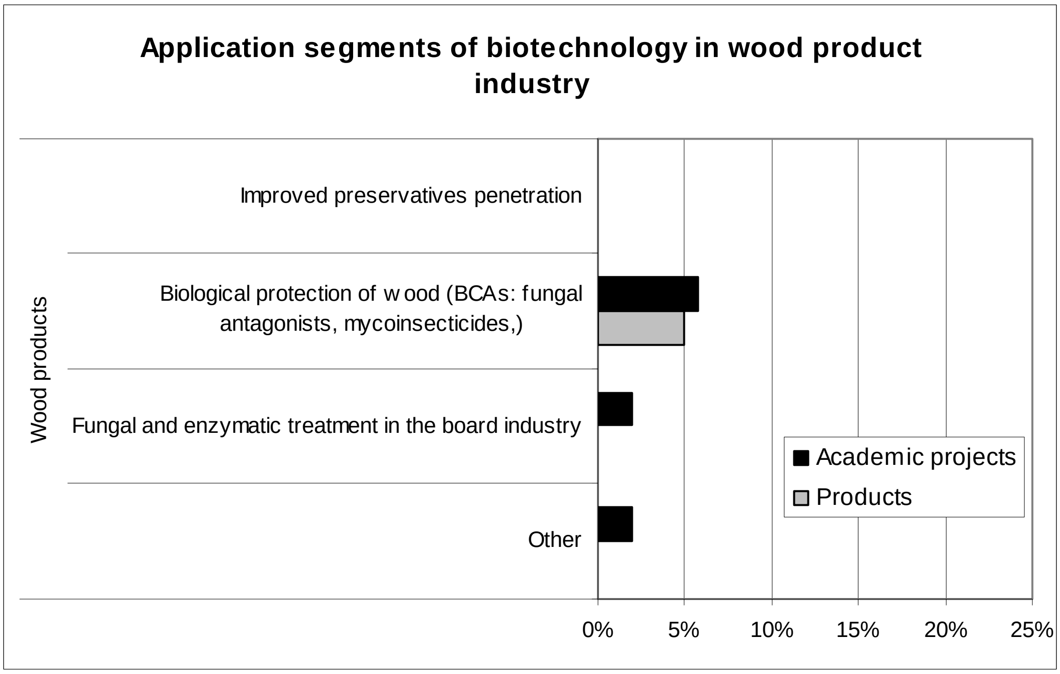

Figure 9.3 Application segments of biotechnology in wood product industry

9.4 Characterisation of the Pulp, paper and board industry, Module 3

The interviews covered a total of 17 research projects conducted by 7 research units, 5 from universities and 2 from research institutes.

The academic research in module 3 is conducted in large units together with other research, either research in biosciences not related to pulp and paper industry or research in pulp and paper applications, which do not involve the use of biotechnology. This can be seen as a low share of the total funding (less than 10% in four cases) allocated to biotechnical research aiming for applications in pulp and paper industry. The interviewees had a degree in either engineering or biosciences and many of them had a long up to 30 years experience with forest biotechnological research.

Cooperation between companies and academia is active in module 3. All of the interviewed research units had a close contact with companies and in addition all but one group conducts contract work for companies. The research units within Finland have a tight network and they collaborate actively with each other but surprisingly few mentioned collaboration with foreign parties. All of the interviewed research units have patents and most also patent applications.

9.4.1 Research funding in universities and research institutions (Module 3)

The total funding received by the universities and research institutions in module 3 in the year 2005 was 4 million € (Table 9.2). In the year 2005 57% research could be classified as basic research and 43% was applied research. According to the estimate given by the interviewees the total funding will grow by 18% during the next years to be 4.7 million € in the year 2010. The annual growth is thus approximately 3%. The increase in funding will be focused on applied research while the funding in basic research remains at the same level as in the year 2005.

Table 9.2 Funding received by the universities and research institutions in module 3 in the year 2005 and the estimate of funding received in the year 2010 in millions of euros

	Funding 2005	Estimate 2010
Basic research funding	2.28	2.16
Applied research funding	1.74	2.56
Total funding	4.02	4.72

9.4.2 Research activities and future prospects (Module 3)

In the year 2005 the research activities in module 3 addressed the four main targets (Figure 9.4):

1) Reduction of energy consumption in pulp and paper processes
2) Fiber modification to obtain novel product properties
3) Development of biotechnical tools for the detection or solving of process related problems
4) Development of enzymes or enzyme production

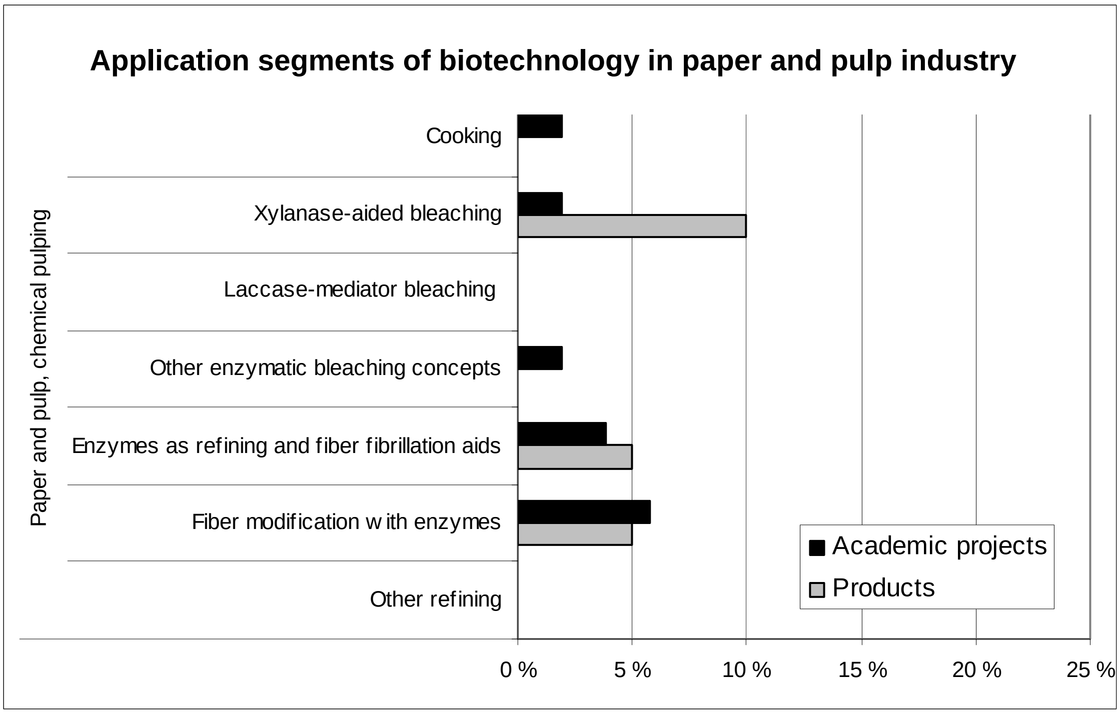

Figure 9.4 Application segments of biotechnology in paper and pulp industry

It can be seen in figure 9.4., that xylanase-aided bleaching is today in industrial use, and the academic research at that field is becoming less active. It is also the only application area within module 3 where the number of products is higher than the number of academic research projects. All in all biotechnological bleaching applications is not a focus area in the Finnish research environment at the moment. Enzymatic fiber modification is also in industrial use and it is still actively studied in the academic institutions. It may be estimated that more industrial applications on enzymatic fiber modification will be taken into use. Thus it can be concluded that xylanase-aided bleaching is further in the product life-cycle curve than the other applications, which was also noted in the literature study. There is academic research going on also aiming to improving of the existing processes or products. These projects are partly directly funded by companies and thus the results will be easily and fast taken into use.

The interviewees were asked for their opinion about the future prospects on biotechnology applications in pulp and paper industry. One of the key factors for successfull development of biotechnological applications was considered to be collaboration both between the researcers and researchers and companies. In order to implement biotechnical processes, a close cooperation is needed both between the academia and industry and between researchers in biosciences and engineering. Understanding the needs of the companies is essential and R&D work should be problem based not technology based. The research should be driven by industry needs, not the available technologies.

"The research should start from the problems and needs, not from a certain enzyme. It is problematic that the top experts in biotechnology do not always understand the realities of industry and business."

It was seen that it is sometimes difficult to compete with chemistry. However, enzymes are seen as excellent tools for modifying fiber surface, in such a way that is not possible with chemistry. It was foreseen that in short term biotechnology may have an impact in improvement of processes, but in long term also the development of new products becomes relevant. In future the implementation and cost-competitiveness of biotechnology in industrial processes needs more attention.

9.5 Characterisation of the Side Stream Utilisation, Module 4

The interviews covered a total of 10 research projects conducted by 8 research units, from universities and research institutes. The interviewees had a degree either in chemistry, engineering or biosciences and many of them had a long, up to 30 years experience with biotechnological research.

The research units in module 4 have a very active collaboration network both inside and outside of Finland. The research units have cooperation also with companies from different business sectors.

The activities in this Module 4 addressed three main targets (figure 9.5):

1) Isolation of value added products using biotechnical and other methods
2) Production of biobased fuels
3) Phytoremediation

The research and the applications in this field are not only biotechnology based. In most cases biotechnology is used together with chemical methods.

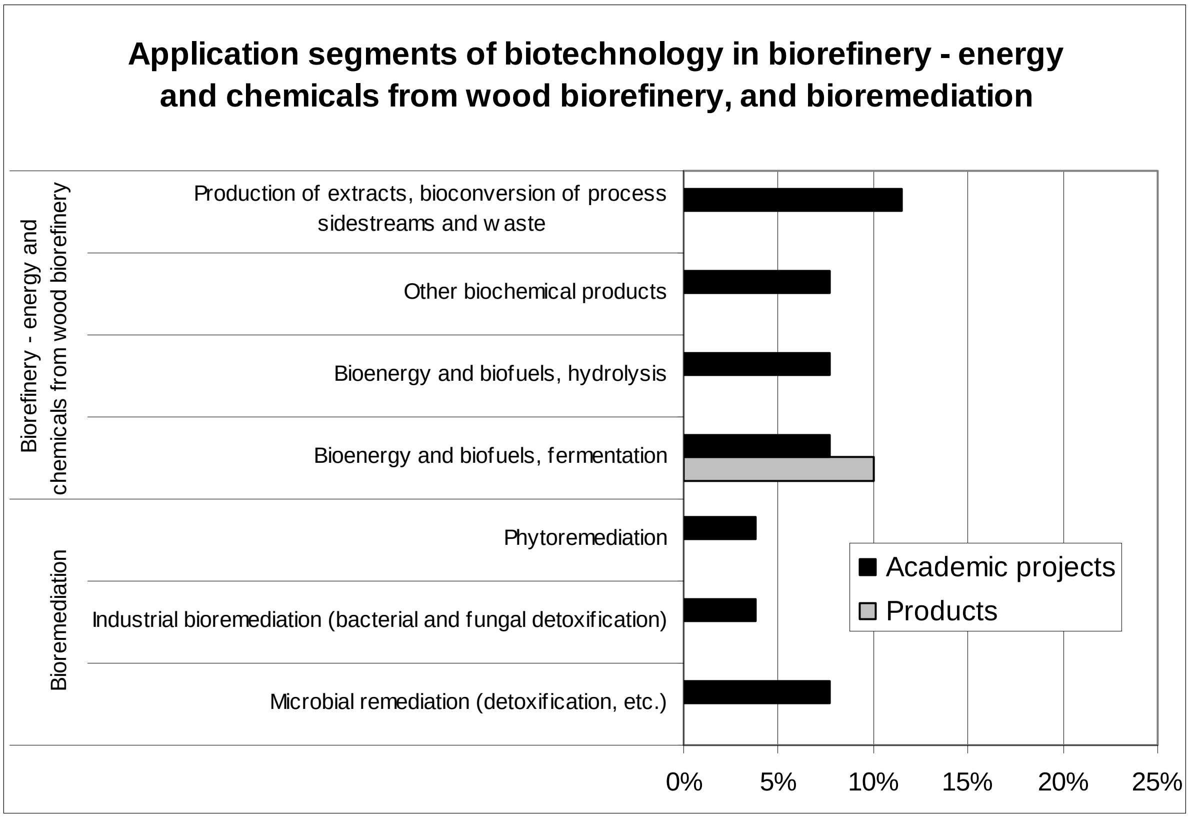

Figure 9.5 Application segments of biotechnology in biorefinery and bioremediation. Percentage of academic projects or products related to the application

The academic representatives in the module 4 were highly optimistic about their future funding and there is growing interest for the utilization of side streams. As the utilization of side streams requires expertise from several fields of science collaboration is essential for successful research.

"*Collaboration between wood chemists and researchers in medical and food sciences could catalyze new ideas and products. Finland has got world wide attention in development of functional food additives for example xylitol and sitosterols*."

Also the production of Ethanol in Europe is expected to grow rapidly. Europe produced roughly 2 billion litres in 2005 (estimation Renewable Fuels Association 2006), and the European Commission has targeted a 12 billion litres production by 2010. One of the interviewees mentioned that:

"…Energy production is going to increase not only in Finland but everywhere else. Moving towards sustainable sources of energy. Also, bioenergy production is going to be a increasing area of research, we have now good research in the field and soon it will be excellent…."

In Table 9.3 the present and future estimate funding figures are presented. The estimation shows that this research area is expected to increase rapidly during the next years, with a 66.2% increase in total budget by 2010, which corresponds to a 13.2% annual increase. The increase will be larger in applied research (73.2%) compared to basic research (56.4%).

Table 9.3 Funding received by the universities and research institutions in module 4 in the year 2005 and the estimate of funding received in the year 2010 in millions of euros

	Funding 2005	Estimate 2010
Basic research funding	1.41	2.21
Applied research funding	2.25	3.88
Total funding	3.66	6.09

9.6 Results of the company interviews (Modules 1-4)

This section describes the companies that are included in our data. We divide the companies by their size and by the nature of their R&D activity, while we here present the overall business activity of the companies, the analysis at the end of this paper deals with R&D and commercialization activity within Finland.

Table 9.4 Data description of all the companies in the sample

All the companies	Sum	N	Mean	Median
Age of the company		36	46	36
Number of personnel	119 985	37	3 243	235
Number of PhDs	447	37	12	1
Number of R&D labor	3 616	35	103	10
Total sales in 2005 (mill. euros)	45 114	36	1 253	85
Anticipated sales in 2010 (mill. euros)	58 326	36	1 620	110
Sales per labor (mill. euros)		36	0.49	0.26
R&D expenditure (mill. euros)	379. 89	37	10.27	0.67
Biotechnology R&D expenditure (mill. euros)	35.62	37	0.96	0.04

The sums in the descriptive statistics of the forest sector companies in our sample are dominated by the large multinational enterprises. Table 9.4 depict the numbers of all companies in order to draw an overall picture of the resources and business activities related to the domestic forest industry. The companies employ nearly 120,000 persons of which 3,600 are involved in research and development activity. The industry generated total sales of 45 billion euros in 2005, and it expects a 5.3% annual growth of sales in the period 2005-2010.

26 of the companies disclosed that they conduct some biotechnology R&D activity. Figure 9.6 relates the biotechnology R&D expenditure with the total sales of the forest companies in our sample. Relatively large companies, with the sales volume exceeding 50 million euros, can finance their biotechnology R&D expenditure by their own revenues. There are 8 such a high sales companies but only one small company that spend over 950 000 euros to their

biotechnology R&D activity. This indicates that the biotechnology R&D financing diverge strongly form other biotechnology industry, which seems to rely mainly on external financing.

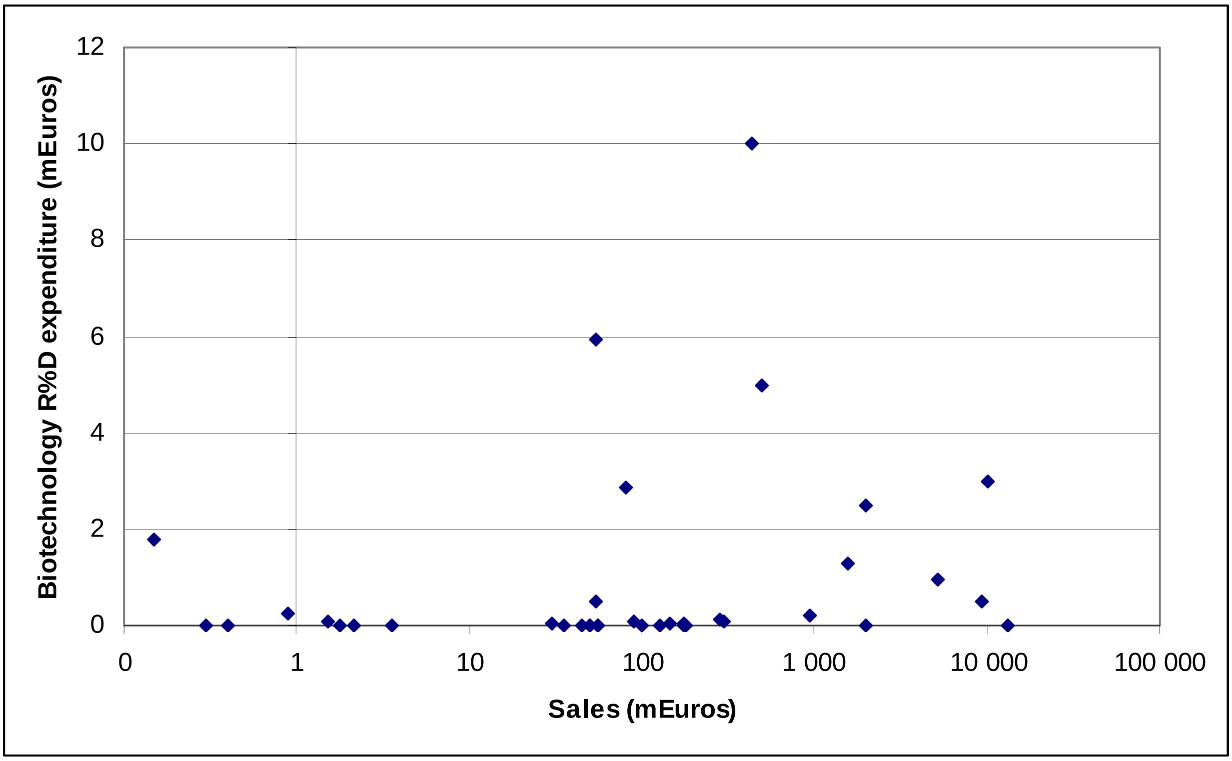

Figure 9.6 Distribution of Biotechnology R&D expenditure and sales of the forest companies utilizing biotechnologies

Table 9.5 Data description of the companies with biotechnology related R&D activity

	Sum	N	Mean	Median	% of Total Sum	% of Total N
Age of the company		24	44	28		66.7
Number of personnel	73 140	25	2 926	450	61.0	67.6
Number of PhDs	315	25	13	1	70.5	67.6
Number of R&D labor	2 966	23	129	20	82.0	65.7
Total sales in 2005 (mill. euros)	31 463	24	1 310	136	69.7	66.7
Anticipated sales in 2010 (mill. euros)	42 516	24	1 771	154	72.9	66.7
Sales per labor (mill. euros)		24	0.64	0.31		66.7
R&D expenditure (mill. euros)	285.19	25	11.41	1.80	75.1	67.6
Biotechnology R&D expenditure (mill. euros)	35.62	25	1.42	0.25	100.0	67.6

Two thirds of the companies in our sample disclosed that they do apply biotechnology based intermediate inputs but do not actively develop biotechnology applications. Table 9.5 depicts the two thirds of the sample companies having some R&D activity related to biotechnologies. Biotechnology developers seem to be more R&D intensive than appliers: they employ almost 3,000 R&D workers which is 82 percent of the R&D workers within all interviewed companies. The biotechnology developer companies anticipate a 6.2 percent annual growth of sales, which is slightly higher than the anticipations of the whole industry.

Table 9.6 Data description of the companies employing less than 250 persons

	Sum	N	Mean	Median	% of Total Sum	% of Total N
Age of the company		19	26	12		52.8
Number of personnel	1 531	19	81	35	1.3	51.4
Number of PhDs	22	19	1	0	4.8	51.4
Number of R&D labor	95	17	6	3	2.6	48.6
Total sales in 2005 (mill. euros)	529.98	18	29.44	32.50	1.2	50.0
Anticipated sales in 2010 (mill. euros)	733.10	18	40.73	36.50	1.3	50.0
Sales per labor (mill. euros)	17.78	18	0.99	0.34		50.0
R&D expenditure (mill. euros)	11.63	19	0.61	0.20	3.1	51.4
Biotechnology R&D expenditure (mill. euros)	8.98	19	0.47	0.01	25.2	51.4

About half of the sample companies are small or medium-sized in terms of labour size (less than 250 persons). These companies employ altogether approximately 1,500 persons, of which only 95 (6.3 percent of the total personnel) are related directly to R&D activity. These companies generate sales of 530 million euros in 2005, and they anticipate a growth of sales by 6.7% on annual terms.

Table 9.7 Data description of the companies employing less than 250 persons with biotechnology related R&D activity

	Sum	N	Mean	Median	% of Total Sum	% of Total N
Age of the company		11	23	10		30.6
Number of personnel	556	11	51	16	0.5	29.7
Number of PhDs	17	11	2	0	3.8	29.7
Number of R&D labor	72	9	8	5	2.0	25.7
Total sales in 2005 (mill. euros)	334.21	10	33.42	37.50	0.7	27.8
Anticipated sales in 2010 (mill. euros)	487.80	10	48.78	47.50	0.8	27.8
Sales per labor (mill. euros)	8.24	10	0.82	0.44		27.8
R&D expenditure (mill. euros)	10.63	11	0.97	0.25	2.8	29.7
Biotechnology R&D expenditure (mill. euros)	8.98	11	0.82	0.09	25.2	29.7

About 30% of the companies are small or medium-sized and actively conducting biotechnology R&D activity. Although they generate only 0.7% of the total sales of the sample companies, their R&D expenditure constitutes 2.8% and biotechnology R&D expenditure 25% of the industry total, respectively. These companies are, in other words, more R&D intensive than their larger counterparts. However, even their R&D intensity in Finland (R&D expenditure-to-sales ratio), 3.2% is relatively low in part due to the location of R&D activity overseas. This can be compared with health care biotechnology companies, which base their business model entirely on R&D activity and rely on external financing instead of positive earnings (Hermans, Kulvik and Tahvanainen 2006).

9.7 *Value Creation of Tacit and Codified Knowledge*

This chapter relates the research funding of the academic R&D projects with their knowledge profiles and value chain of the forest cluster. The actual sales and anticipated sales, as well as productivity is mirrored to the knowledge profiles of the companies. First, principal component scores present knowledge profiles and positions the projects within the value chain and generated components are used as new variables in the regression analyses. Regression analysis employs two separate models. Firstly, we predict the research funding of the academic R&D projects. Secondly, we predict the anticipated future sales of the R&D projects conducted by the companies in our data. Despite the fact that we employ cross-sectional data, the analysis is dynamic in a similar sense as Bounfour (2002). We are interested in the valuation of assets and the input-output relations of forest biotechnology R&D activity.

9.7.1 Knowledge profiles in the value chain

9.7.1.1 Academe profiles with the highest research funding

We found five knowledge and application segment profiles that were able to explain the obtained research funding of biotechnology research projects, one profile predicting sales and anticipated future sales of the corporate R&D projects, and a one project predicting sales per capita, respectively. These profiles are presented in the white boxes and related to the value chain of the forest industry. The indicators are listed by their weights in the principal components. These findings are discussed below and they are related to the value chain of the forest cluster. The detailed statistical results of the principal component and regression analyses are presented in Appendices 1 and 2.

The 1st profile depicting knowledge and application segment profiles of the academic research groups indicates that those academic R&D groups with an intensive collaboration with companies and foreign organization(s) can receive significant research funding (Figure 9.7). The projects protect their research outputs by a relatively large patent portfolio and thus rely on their codified knowledge. These projects rely on a single customer in terms of sales. In other words, this “principal customer” purchases at least one thirds of the sales budget of the contract research of the research group. This knowledge profile is related to modules 3 and 4 in the value chain. The paper and pulp processes with a link to the development of process side stream utilisation have received a relatively significant amount of funding.

1st Profile of funded research projects: "R&D collaboration with companies"

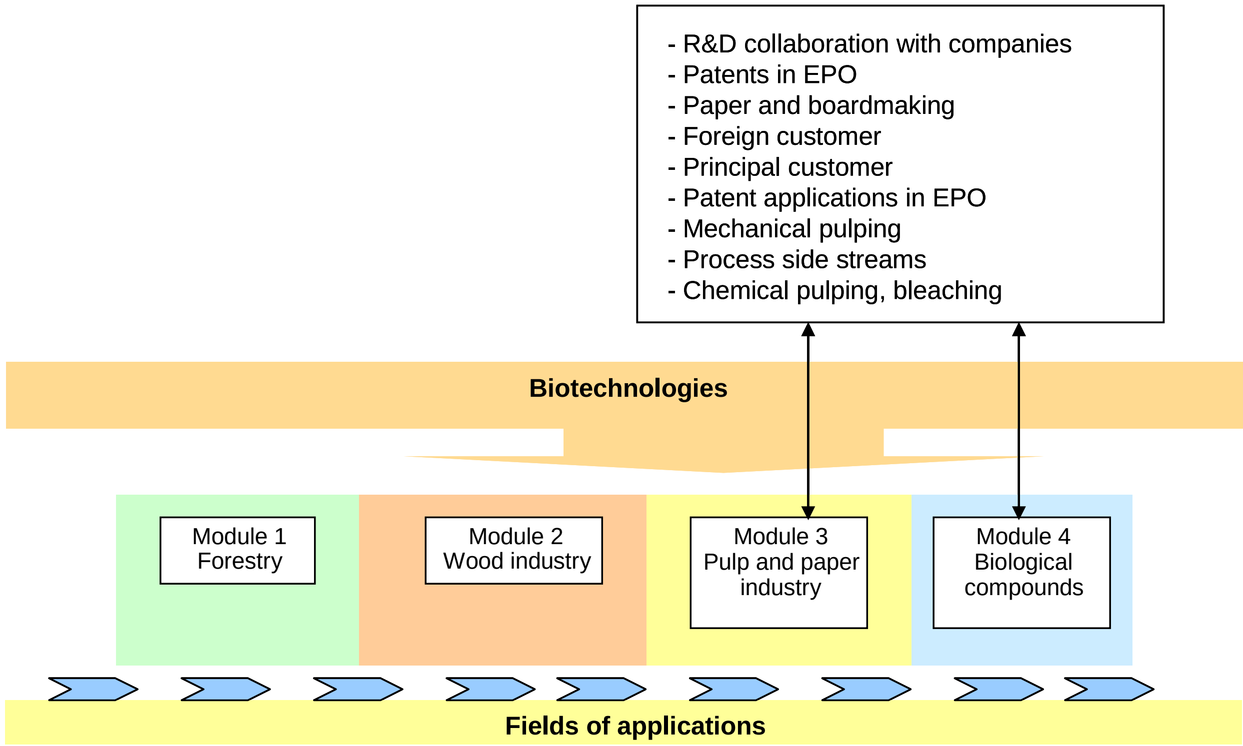

Figure 9.7 Biotechnology research project profile "R&D collaboration with companies" mirrored against the value chain of the forest cluster

2nd Profile of funded research projects: "Research institute"

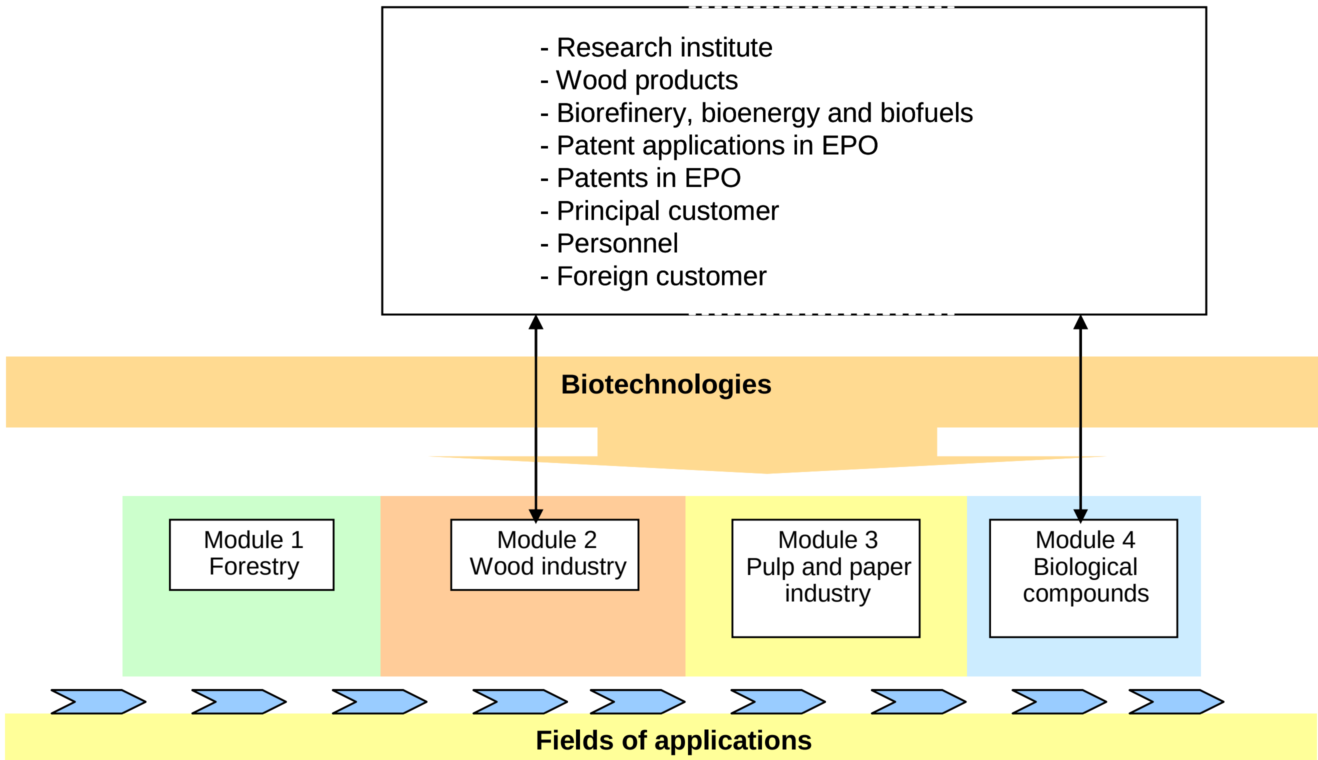

Figure 9.8 Biotechnology research project profile "Research institute" mirrored against the value chain of the forest cluster

The 2nd research project profile links wood product and biorefinery development together (Figure 9.8). The profile presents how a research institute have a large patent portfolio and relies on a principal customer and foreign customer contacts. This result can be understood in the sense that bioenergy and biofuel application use the large amount of biowaste produced as a side product of sawmilling and wood industry. However, the borderline between biotechnology and other technologies is fuzzy particularly within the companies utilising biomass. These research institute led projects carry on efficiently their knowledge management both in respect of tacit and codified forms, which have seemed to contribute to obtaining funding for the research of wood product applications and side-stream utilisation.

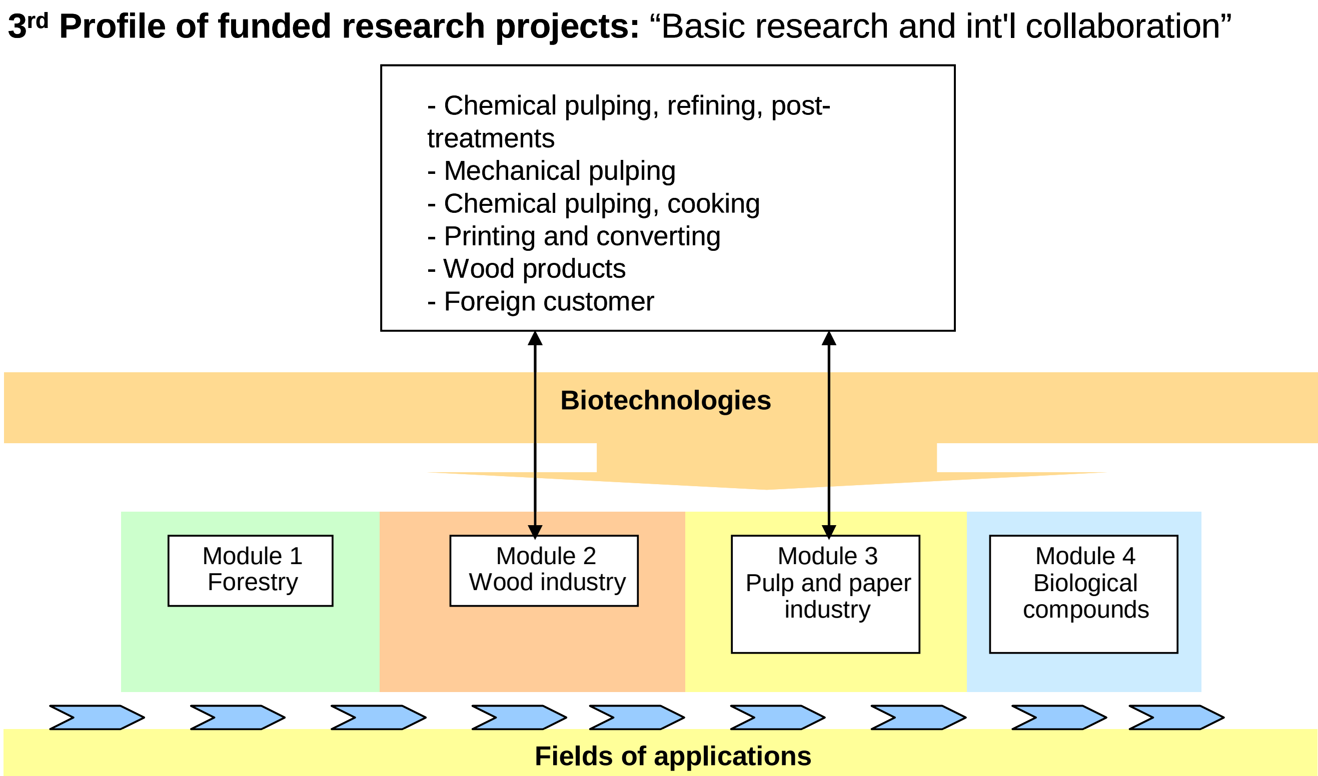

Figure 9.9 Biotechnology research project profile "Basic research and international collaboration" mirrored against the value chain of the forest cluster

The third profile relates applications of wood products and chemical and mechanical pulping together in academic research projects (Figure 9.9). Applications cover chemical pulping, refining, post-treatments, and printing and converting. It is often the case that the biowaste from the wood product refinement processes can be utilized also in the pulp and paper industry. It is noteworthy, that all three profiles above include a link to a foreign customer. The innovative activity is based on international relationships due to the multinational nature of the forest industry, which seems to be a key to raise funding for research in modules 2 and 3.

The fourth profile combines that biorefineries, including bioenergy and biofuels, biochemical products, and environmental management applications (Figure 9.10). It seems that research funding organizations appreciate these research projects linked to module 4 application segments *per se*. Biorefinery applications and environmental management go hand in hand in the academic research. Often these applications are regarded as sustainable solutions for traditional industries, which seem to make them attractive funding target without any systematic relation to specific forms of knowledge. In other words, the research projects active in module 4 have obtained significant funding despite their knowledge profiles. This indicates that the module is appreciated by the institutions providing funding to academic research.

4th Profile of funded research projects: "Biorefinery, bioenergy and biofuels"

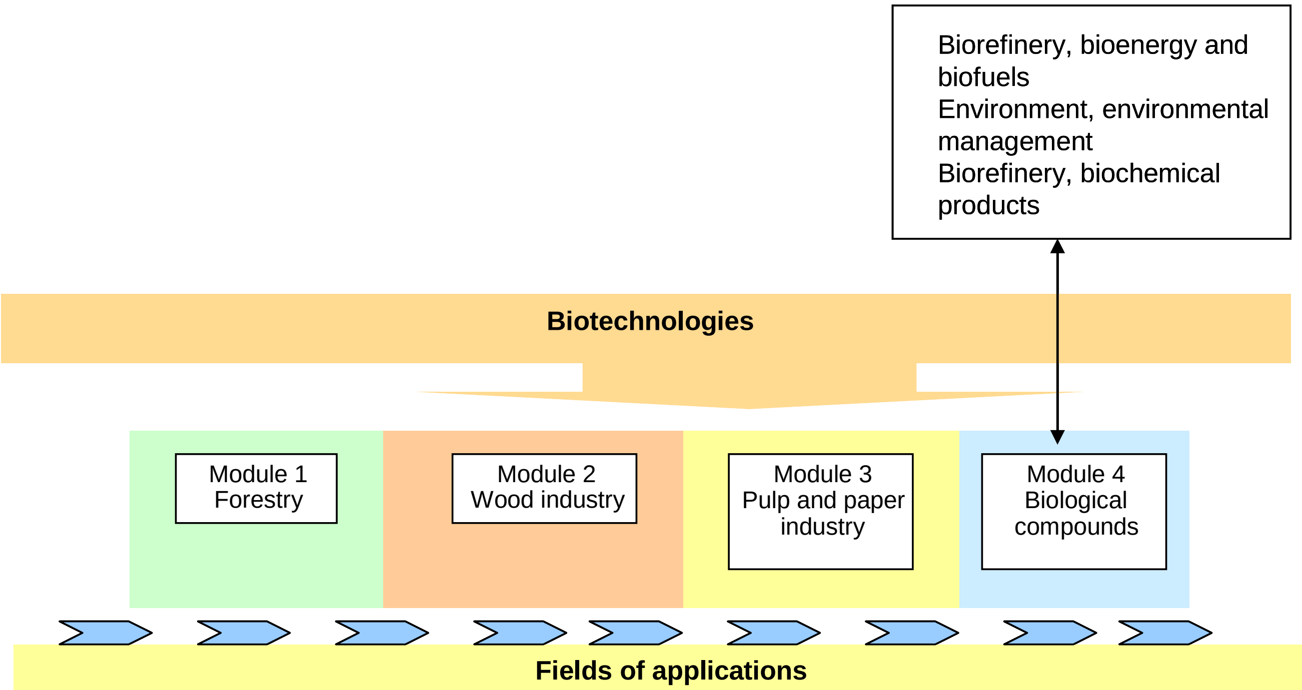

Figure 9.10 Biotechnology research project profile "Biorefinery, bioenergy and biofuels" mirrored against the value chain of the forest cluster

5th Profile of funded research projects: "Critical mass of intellectual capital"

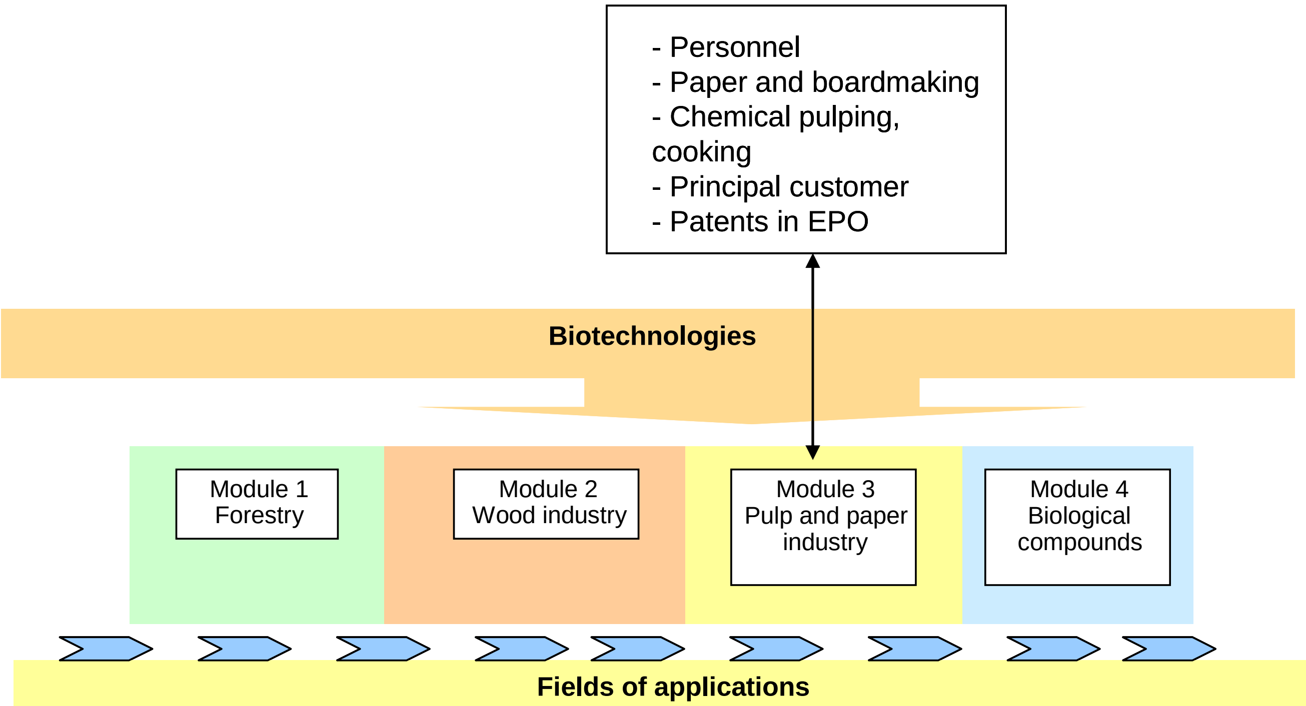

Figure 9.11 Biotechnology research project profile "Critical mass of intellectual capital" mirrored against the value chain of the forest cluster

The fifth research project profile applies biotechnologies in chemical pulping and paper and boardmaking (Figure 9.11). These research projects have a principal customer and granted patents in European patent office. They rely directly on the one Finnish industrial pillar, the pulp and paper industry. However, one might want to ask how long these applications can generate additional improvements for the highly efficient industry as a basis for international competitiveness. However, the research projects seem to rely on both tacit and codified knowledge which seems reasonable in a further exploit of commercial potential even over positive research funding. The research with a critical mass of human capital and intellectual property rights in the pulp and paper applications have received sufficient funding, partially by a principal customer.

9.7.1.2 Industry profiles with the highest sales prospects

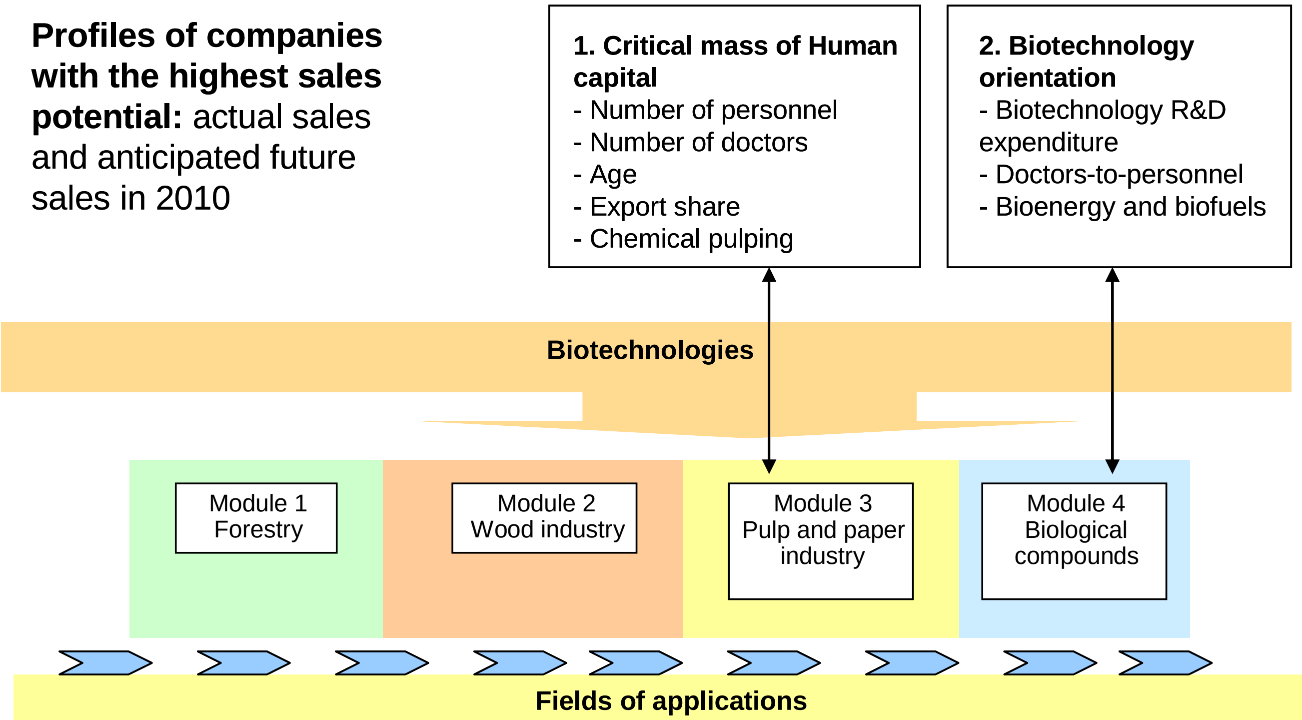

Figure 9.12 Biotechnology product development profiles "Critical mass of human capital" and "Biotechnology orientation" mirrored against the value chain of the forest cluster

The highest actual and anticipated sales can be generated by applying biotechnologies in chemical pulping and bioenergy and biofuels applications (Figure 9.12). Chemical pulping correlates with the component "critical mass of human capital". This component is characterized by large number of personnel and highly educated employees. The company relies on international trade. The critical mass of tacit knowledge (both in terms of labour and highly educated personnel) within the pulp and paper industry might have an influence to a difficult situation seen previously between the employers and employees: since the codified knowledge is not present in the profile, the labour input might be relatively difficult to be substituted at least locally.

Energy applications segment correlates with the component "biotechnology orientation". This profile reveals high biotechnology R&D expenditure and a high share of personnel have earned doctoral degree. In other words, large companies involved in R&D activity generate value in applying biotechnologies in their chemical pulping applications, as well as intensive bio-technology orientation in developing bioenergy and biofuel products create significant amount of sales.

9.7.1.3 Industry profiles with the highest output productivity

The same application segments as above, regarding sales, are related to a high productivity in terms of sales per capita (Figure 9.13). However, a size of the company does not guarantee the highest sales per capita estimates, but s strong codified knowledge management (in terms of the size of the IPR portfolio) does this in our data. Since a company allocates significant resources to a biotechnology R&D activity and protects its inventions by patenting, it seems to prosper in developing chemical pulping applications. This result does not depend on a size of the company. We can contrast this outcome with the above pulp and paper industry profile, where critical mass of tacit knowledge resided within individuals: the "productivity" is not related to a size of the company but to the codified knowledge management.

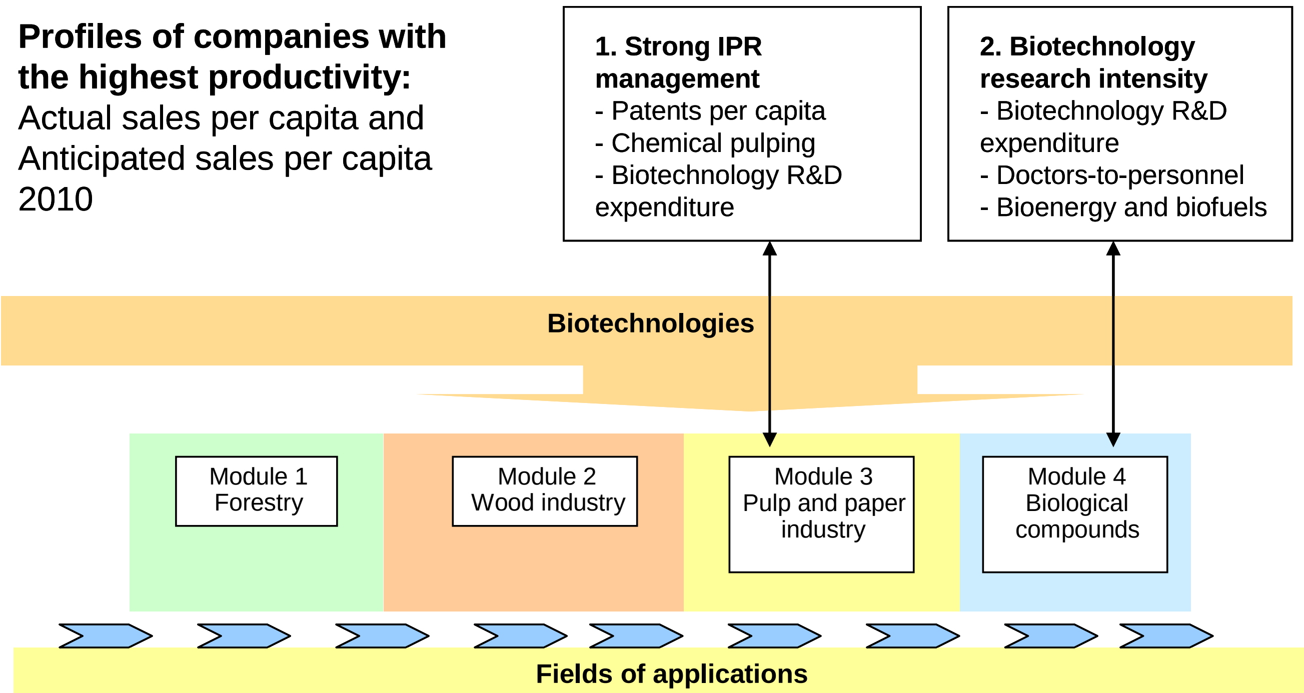

Figure 9.13 Biotechnology product development profiles "Strong IPR management" and "Biotechnology orientation" mirrored against the value chain of the forest cluster

A successful development of bioenergy and biofuel applications seems to be based on the high volume of biotechnology R&D expenditure and in addition to that, a high intensity of human capabilities and IPRs. It seems that both sales and sales per capita profiles utilise the same linkages within pulp and paper production processes and bioenergy applications.

9.7.2 Comparative advantage in commercialization of biotechnologies

This section compares the comparative advantage in commercialisation of the biotechnologies in Finland. Finland has comparative advantage having abundant forest reserves. However, the growth rates of wood material are lower than in southern hemispheres. Thus, Finland could not rely solely on this source of comparative advantage. Instead, if raw materials and other intermediate inputs production processes contain some other added value in terms of features and quality, one could expect that multinational companies might find reasons to locate their production activities in Finland. The quality aspect, in turn, is related to innovative activity. In this section, we measure the biotechnology patenting activity by geographic regions. Finland holds 0.17% of biotechnology patents granted in 2000-2003 listed in the Derwent Biotechnology Resource.

Table 9.8 Percentage shares of granted biotechnology patents by geographic regions in 2000-2003 (Derwent Biotechnology Resource)

Patent class	**USA**	**EU-15**	**Finland**
Genetic engineering and fermentation	58.7 %	22.0 %	0.16 %
Engineering - Biochemical engineering	40.9 %	34.7 %	0.21 %
Analysis - sensors and analysis	50.6 %	31.4 %	0.00 %
Pharmaceuticals	60.2 %	21.4 %	0.10 %
Agriculture	62.1 %	19.5 %	0.25 %
Food, food and food additives	36.5 %	40.2 %	0.70 %
Fuels, mining and metal recovery	25.7 %	38.6 %	0.00 %
Other chemicals	31.7 %	40.5 %	0.20 %
Cell culture	59.5 %	23.8 %	0.00 %
Biocatalysis	37.0 %	34.2 %	0.37 %
Purification - downstream processing	42.5 %	40.9 %	0.00 %
Waste disposal and the environment	21.7 %	32.9 %	0.53 %
Total	55.9 %	23.8 %	0.17 %

The bottom row in Table 9.8 indicates how large proportional share of granted patents have a priority country within the region. Accordingly, 0.17% of the patents refers to Finland as a priority country. All the patent classes that have a higher proportional share than 0.17% can be taken as a potential source of comparative advantage. These patent classes indicating comparative advantage are flagged by a yellow background. Under these assumptions, Finland seems to have a comparative advantage in biochemical engineering, agriculture, food and food additives, other chemicals, biocatalysis, and waste disposal and the environment. In agriculture the patents are particularly related to the subclasses of biological control agents and plant genetic engineering. To be noted, although genetic engineering and fermentation does remain below the critical border of comparative advantage, a subclass of fermentation would clearly be flagged with a 0.69% share of Finnish patents.

Slightly surprisingly, plant genetics, food and industrial applications seem rather prominent degrees of commercialisation. In a comparison of comparative advantage over the regions, Finland has mainly aligned profiles with the EU. However, in agriculture applications, especially in genetic plant engineering, the profile matches with the USA. These profiles could indicate some promising collaboration patterns utilising specialized capabilities.

9.8 Discussion on the profiles

The resources of academic research and outputs of product development seem to focus on latter parts of the forest cluster value chain. Consequently, the applications of forestry are not focal in developing forest biotechnologies in Finland. The Finnish forest-owners might not have incentives to invest in R&D of wood materials due to the fragmented structure of ownership. The industrial R&D activities seem to focus on the development of paper and pulp production processes and energy applications. However, if more southern locations provide an absolute advantage in terms of generate wood raw materials for the industry, the development of the quality aspects of wood materials could provide an important vehicle for the multinational paper and pulp industry to further development of their production facilities in Finland.

Forestry and many wood-derived products provide one of the most significant energy resources for a forest-abundant country, such as Finland. As an externality from conventional forestry, there remain many forms of unused residual forest biomass, such as branches, needles, stumps and small-sized trees, which could be utilised as an important resource of energy.

Development of energy innovations can draw on the international regulations restricting pollution, while it encourages the public sector to steer the development of energy technology into non-petrochemical solutions. It is also noteworthy that the Finnish refinery industry lacks its own oil reserves; thus, it does not cannibalise on its own funds but is instead encouraged to develop new technologies and conquer new business areas. This is true both for alternative ways of producing liquid fuels, as well as for the utilisation of biomass to manufacture mixtures of polymers that could serve as substitutes for the current plastics.

10 GENERAL OVERVIEW, FUTURE PROSPECTS AND CONCLUSIONS

Some general conclusion can be made from our empirical findings from the research projects and corporate product development projects. We divided the projects in four modules in line with the value chain of the whole forest cluster. Module 1 represents the beginning of the value chain: forestry applications. Module 2 consists of the development of wood products, module 3 is related to the pulp and paper industry, and module 4 to utilization side streams for bioenergy, biochemicals and other food or pharmaceutical applications. Furthermore, Hermans and Kulvik (2006) relate the biotechnology innovation clusters to global megatrends.

The assessment of module 1 implies that there is a permanent lack of resources. Basic research conducts some relatively long projects, which often seem too time-consuming in applied research and corporate R&D. There seems to be only few active links between the academic research projects and companies. Many new technologies already exist but since the individual forest owners hardly have incentives to invest in R&D due to e.g. the long breeding cycle, collaboration with companies seems as the only potential pathway to commercialization of forestry related biotechnologies.

Although there are new radical innovations aiming at shortening the breeding cycle, their implementations require relatively high sunk costs. Thus it seems probable that the research and development will be first conducted in applications related to ornamental trees. Sometimes there is also a trade-off between a preferred outcome and an unpreferred one in a technology adoption process. For instance, a decrease of lignin seems possible even today, but the increased risk of vulnerability to physical strain counteracts the adoption.

There were few biotechnology-based projects within the module 2. The research and product development seems to focus on physical modifications, and composite research is based on chemistry.

Module 3, paper, pulp and board industry, seems to be the most active in research and product development activity. Their products generate positive cash flows, and research projects are abundantly funded. The companies are closely involved in the research projects as financiers and collaborators. This involvement impacts on the nature of the research, which seems highly applicable and linked closely to industrial applications. Consequently, biotechnology applications are already used in the pulp and paper industry. Some biotechnology applications are adopted rapidly. They, such as enzymes in reducing paper machine runnability problems, do not affect the quality of the fibers, intermediate or end products and are thus easier to take into use in production scale.

We observed the research and product development within module 4 as a high priority for both the academia and industry. The research is anticipated to grow strongly and even more than in other modules. Biotechnologies are applied as substitutes to chemical and thermal technologies. However, all of these fields of technology are developed and applied by the industry. This provides some important implications for technology development and innovation policy. Due to the fuzziness between technology border-lines, it seems misleading to prioritize biotechnologies over some other technology; in contrast, the most efficient technology should be preferred. Accordingly, technology subsidies might be most efficient if the public technology programmes would be based on application segments instead of a specific technology.

Although we found good examples on practical applied research, our study raises the question of what are the highest barriers between the academic research and commercial applications.

It seems to be difficult to obtain any information regarding the utilisation of biotechnologies in industrial processes; less than half of the companies were willing to disclose that information, including most of the large pulp and paper multinationals. This reluctance might be related to the company's core competence and, thus, competitive advantage. On the other hand, the impact of biotechnology might be difficult to estimate if it is used only as one technology among all the others deeply involved in the entire production process.

Can biotechnologies create a platform that provides some comparative advantage to the Finnish economy? Our assessment of international patenting activity raised some interesting notions. Finland seemed to be comparatively most specialized in plant genetic engineering, food and food additive, and waste disposal and the environment applications. However, biotechnology based biofuels are not included as a source of comparative advantage, which also stresses the importance of parallel development of biotechnologies and other technology fields.

A potential source of value creation could be the utilization of process side streams more efficiently, including refinement of byproducts such as tall oil, to products with higher value added in other application areas. Moreover, the paper and board making might be strongly influenced by new packaging solutions, materials and methods.

The high education and long experience in the forest industry provide some comparative advantage to Finland in terms of tacit knowledge. However, large part of the experienced leaders within the modules 3-4 will retire in the near future. This could threaten the continuation of the commercial success but also provide some expectations for a turnover of the new ideas in the research and product development.

Finland has a good overall and mainly publicly maintained infrastructure. If the raw material's high quality and some special features can compensate the relatively low growth rates, Finland should be able to attract the multinational pulp and paper industry also in the long term.

We conclude that the development of biotechnologies should not contain any intrinsic value per se. The commercial value of the biotechnology could be benchmarked with the value of alternative technologies; and consequently, biotechnology could become part of the technology options for companies active in established and conventional industries.

Biotechnology funding in drug development has been based on scientific excellence. However, superior top notch science has not necessarily been a sufficient driver for solid business activity. An opposite example is found within the Finnish ICT sector where a traditional company – active in the rubber industry, and paper and pulp industry – formed a financial backbone for a development of mobile communication technologies. The latter example stresses the importance of resources other than only financial ones, such as international business experience.

The Finnish forest cluster has financial resources to commercialize any new technology that can increase the process efficiency or provide other economic benefits in new application areas. This is a reason why we see this area exceptionally promising compared to any other high technology field without such a financial backbone. Could it be that the way to the success in this field would be found in corporate spinoffs instead of academic ones?

The academic forest biotechnology research funding is mostly allocated to the same parts of the value chain as in which the industry indicates the existence of highest market potential in terms of actual and anticipated future sales and productivity. This finding indicates that commercial viability has guided the allocation of research funding. The above analysis showed that price competitiveness of the Finnish forest industry seemed to decrease during the ongoing decade in terms of prices of intermediate inputs. To increase the quality of, for instance, the wood materials might pay off some of the disadvantage raising from the high price level. However, one could ask whether there are sufficient incentives among the forest owners to invest in long-term biotechnology R&D *e.g.* aiming at sustainable development. This might provide a reason for government interventions in technology development, if the qualities or features of wood materials could provide further benefits in value adding processes to the industry of the late stage in the value chain; long-term commitment of funding bodies is crucial especially for basic research.

In the future one of the key challenges in commercializing the biotechnology related applications in forest industry is the gaps between the different stakeholders. Academic research should be driven by the needs of industry and society, and results of it should be utilized in subsequent application-oriented projects with strong industry involvement and cross-disciplinary competence. Funding schemes are crucial in filling the gaps between basic research, applied research and industry applications. The new on-going initiatives like Tekes Symbio technology program and new cluster-wide cooperation and funding structures are expected to improve the current situation.

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Appendix 1. Principal components generated from academic research project features.

Rotated Component Matrix(a)

	1	2	3	4	5	6	7	8
Non-Gmo tree breeding and nursery techniques	-0.805	0.117	-0.169	-0.121	-0.075	0.021	-0.069	0.049
GMO-based tree modifications	-0.780	-0.005	-0.131	-0.086	-0.010	0.082	-0.003	0.024
RD collaboration with companies	0.663	0.054	0.186	0.036	-0.034	-0.095	-0.017	0.176
Patents in EPO	0.646	0.373	-0.034	0.068	0.214	0.426	0.360	0.026
ForeignCust	0.573	0.333	0.387	0.103	0.199	0.367	-0.155	-0.115
Institute	-0.022	0.943	-0.082	-0.121	0.006	0.107	0.028	0.004
University	0.012	-0.938	-0.103	-0.231	0.027	-0.064	-0.004	0.004
Wood industry	0.118	0.622	0.481	0.240	0.134	-0.084	0.169	0.396
Chemical pulping, refining, post-treatments	0.139	0.075	0.846	0.151	-0.048	0.198	0.068	-0.129
Mechanical pulping	0.333	0.008	0.757	0.148	0.110	-0.141	-0.009	-0.120
Printing and converting	0.021	0.082	0.442	0.843	-0.080	-0.093	-0.055	-0.018
Process side streams	0.382	0.108	-0.113	0.767	0.065	0.339	0.031	0.025
Biorefinery, bioenergy and biofuels	0.049	0.401	0.043	-0.127	0.726	0.256	0.125	0.002
Environment, environmental management	-0.134	-0.329	-0.001	-0.068	0.719	-0.229	-0.131	-0.028
Environment, conservation biology	-0.393	-0.071	-0.162	-0.176	-0.537	0.069	-0.082	0.221
Biorefinery, biochemical products	0.176	0.104	-0.385	0.141	0.484	0.014	-0.019	0.455
Chemical pulping, bleaching	0.353	-0.085	-0.086	-0.064	0.129	-0.774	-0.019	-0.146
Patent applications in EPO	0.491	0.498	0.071	0.184	0.166	0.523	-0.040	-0.076
Personnel	0.167	0.341	0.493	-0.224	0.150	0.161	0.671	-0.042
Paper and boardmaking	0.590	-0.069	-0.084	-0.111	-0.091	-0.078	0.645	-0.063
Chemical pulping, cooking	0.256	-0.172	0.502	-0.289	-0.093	0.269	-0.535	-0.079
PrinCust	0.510	0.365	-0.122	-0.268	0.146	-0.233	-0.534	-0.088
Non-GMO silviculture	-0.021	0.006	-0.155	-0.035	-0.105	0.090	-0.007	0.924

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

Appendix 2. Principal components generated from industrial product development features.

Component

1	2	3	4	5	6	7
0.959	0.068	0.083	-0.011	-0.039	0.004	-0.055
0.956	0.099	0.108	0.004	-0.024	-0.019	-0.059
0.564	-0.126	-0.292	-0.259	0.073	0.272	0.189
0.415	-0.104	-0.040	-0.318	0.106	-0.287	0.381
-0.026	0.979	0.105	-0.071	-0.004	0.037	-0.029
0.098	0.978	-0.008	-0.068	0.028	-0.009	-0.023
-0.152	0.112	0.931	-0.013	0.006	-0.004	0.020
0.447	-0.028	0.857	-0.058	-0.037	-0.042	-0.043
-0.078	-0.124	-0.104	0.799	0.049	-0.086	-0.046
-0.031	-0.018	0.030	0.788	0.017	-0.047	0.007
0.076	0.114	0.085	0.183	0.869	0.130	0.134
0.137	0.150	0.268	0.214	-0.673	0.106	0.461
-0.119	0.016	0.378	-0.161	0.132	0.641	-0.024
-0.135	-0.152	0.233	-0.105	0.347	-0.603	-0.176
0.036	-0.045	-0.071	-0.068	0.083	0.599	-0.113
-0.069	-0.046	-0.036	-0.040	-0.021	-0.053	0.910

Rotation converged in 8 iterations.

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