The Fourth Pillar? An Assessment of the Situation of the Finnish Biotechnology

Gerd Schienstock
Pasi Tulkki

ABSTRACT. The success in constructing a flourishing information and telecommunication cluster has encouraged Finland to seek equal possibilities in other knowledge-intensive industrial branches. Presently, biotechnology is seen as an auspicious business area. Like in other parts of Europe, Finnish biotechnology concentrates mainly on pharmaceutical industries. More than 70 percent of the human resources of Finnish biotechnology industries is settled in this industrial branch. Despite large investments and financing, modern biotechnology industries are still a marginal industrial branch in the Finnish economy. Its turnover in 1999 was only one percent of the total GNP. The wide spectrum of Finnish higher education and the close relations of co-operation between universities and industries can open up promising prospects. Finland's technology-affirmative attitudinal climate works in the same direction. This progress can be delayed by a lack of highly skilled human resources, which is already a problem in the IT sector. The small size and minor experience in global markets have also limited the success of the Finnish firms.

1. Introduction

Finland is largely known as a country of forest industries. Until the end of the 1950s, about 90% of the exports of the Finnish industry came from the forest or wood processing industry. In the 1960s, this figure decreased to nearly 70%, but the forest cluster, constituted by forestry, mechanical forest industry, chemical forest industry, and several related supplier industries and customer industries was still by far the biggest exporter in Finland. The share of the metal industry at that time was about 13%. During the following decades, the metal industry improved its position as an export industry, mainly due to the increasing trade with the Soviet Union. Nowadays the share of the forest cluster in the Finnish export still is 31%, but the share of metal industry increased to 45%. Half of the metal industry's export consists of the products of the new information and telecommunication sector. During the 1990s, Finland was able to develop the IT industry as the third pillar of its exports beside the old wood processing industry and the traditional metal industry.

Indisputably, *Nokia* is the dominating company in the Finnish IT sector. The share of Nokia in the recent export boom of the Finnish industry became so conclusive that fear of the "Nokia dependence of Finland" was expressed. On the other hand, the high standard of expertise and know-how created by Nokia can also be viewed as the base of constructing other high technology clusters. Both arguments are mentioned when the need for a fourth pillar for the Finnish export industry is being discussed. In this debate, biotechnology is seen as a promising new growth area which the Finnish public attention is just now very strongly drawn to. There is great hope that the success story of the IT sector, which for a good reason can be considered as a result of a national project,[1] can be repeated in the biotech sector. The progress made in the IT branch can be explained by a close co-operation between industry, public research institutes and the education system. Business enterprises in the sector have invested heavily in R&D (Research and Development) and at the same time about half of all the national research input is used in or for the benefit of this single branch. And in higher education, about 35% of all the university and polytechnic graduates have an education in IT or neighbouring fields.

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Work Research Centre
University of Tampere
Tampere
Finland
E-mail: ytgesc@uta.fi

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Certainly, there are other industries which are also seen as possible candidates for future growth, such as the contents industry and the new media industry, for example. However, biotechnology seems to be the first choice in the political as well as public debate when the advancement of a new growth area is discussed. One indicator of the fact that biotechnology is given highest priority is the increasing financial support for research in this sector.

2. The Finnish view to biotechnology

In Finnish publications, the interpretation predominates that biotechnology represents a new type of technology. Up to now clustering of biotechnology takes place mainly within existing industries such as agro-food industry, pharmaceutical industry, and wood processing and chemical pulp industry, as well as in the debilitated waste management industry. The way Kreiner and Schoulz have described the "pre-clusterical" situation of biotechnology industries also applies to Finland:

"In a loose sense, we may talk about a biotech community, since across all differences, all the competing classifications being applied and used, they identify themselves in certain situations and contexts as working in biotech."[2]

One sign of the development of an independent biotechnology cluster, however, is the foundation of the Finnish Bioindustries (FIB) organisation. The majority of the companies in this field are nowadays members of this association (including some foreign members), which are mostly micro enterprises, but whether biotechnology will ever become an industrial cluster of its own is controversial. So far, biotechnology is *de facto* a new method used by various industries in research, development and production, and in many different industrial clusters. In this respect, it is comparable to telecommunication technologies. The complex nature of biotechnology makes it difficult to assess its economic impacts.[3] Nevertheless, it is possible to identify the focus domains of modern biotechnology.

In Finland, modern biotechnology is mainly applied in the pharmaceutical industry, biomedicine, and bioremediation. Exploitation of modern biotechnology in the agro-food industry, and the forestry and chemical pulp industry is just taking off. Research and development work with biocatalysts and enzymes seems to produce some promising results. Many of these biocatalysts can

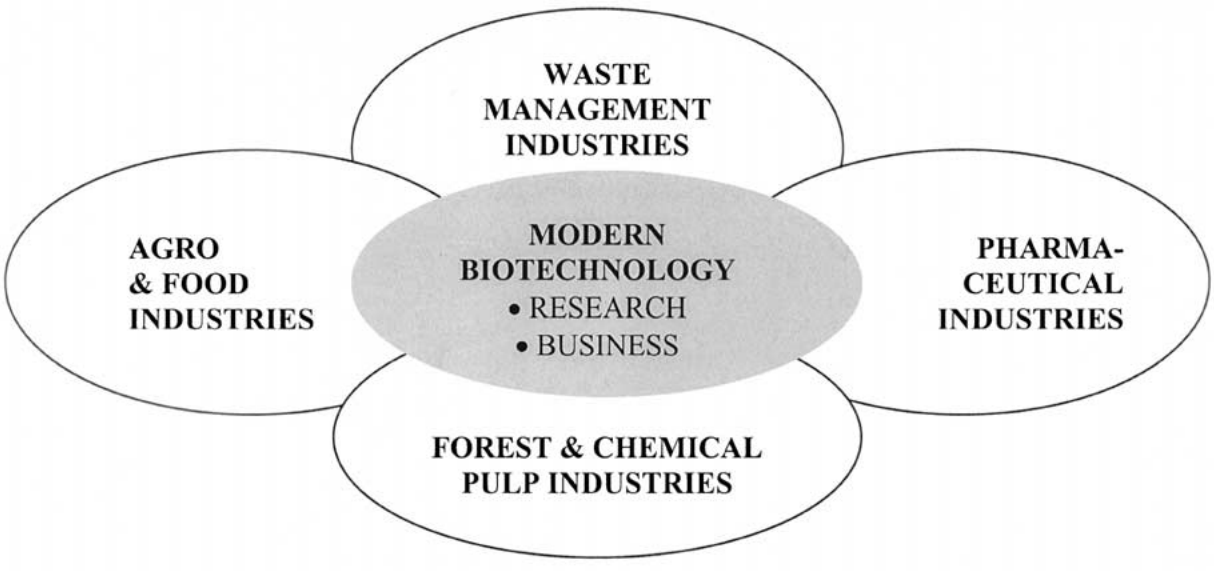


Figure 1. The focus domains of modern biotechnology (see: TEKES, 1998, 'Technology and Future (Teknologia ja tulevaisuus), p. 95).

be used in the processes of the agro-food industry and the chemical pulp industry. The waste management industry in Finland is rather underdeveloped, although some applications based on modern biotechnology are currently researched.

3. Some conceptual aspects

For a long time, the scientific debate on the development of new technologies and new industries based upon them has been dominated by the controversy between the "science or technology-push approach" and the "market-pull approach". Nowadays there is widespread agreement that both factors, newly created knowledge and the market, are important for the development of new technologies and industries. There is also, however, a third factor which must be mentioned here: the closeness of the existing knowledge stock within firms to the newly emerging knowledge.[4]

Concerning the knowledge or technology aspect, not only the amount and the quality of research plays an important role but also the co-operation of knowledge producers (mainly universities) with industries is decisive, since successful innovation processes depend upon an inclusive and rapid knowledge flow between these two parts of the idea-innovation chain. Furthermore, companies need to have an absorptive capacity to be able to use the new knowledge produced in the university. Their knowledge stock must be compatible with the newly produced knowledge, as learning in companies takes place in a cumulative way.

Regarding the market aspect, close co-operation between producers and users is crucially important for firms in order for them to be able to develop products for which market demand exists. In this respect, small countries with closely networked small and medium-sized firms may even have some advantage; but, in the long run, the development of new technologies that can become the basis for new industries depends upon the access to international markets through global players. In the following, we will discuss the extent to which the emerging biotechnology sector in Finland can rely on such favourable preconditions.

4. The importance of biotechnology for the Finnish economy

So far, the importance of modern biotechnology for the Finnish economy is still limited. In 1998, the turnover of the related industries was estimated to be FIM 7,425 million (€ 1,249 million), which is only 1.1 percent of the total GNP (Gross National Product). The employment rate of the Finnish modern biotechnology industry is also marginal. It employs 5,610 people, which is 1.3 percent of the employment in the whole industry, and 0.3 percent of total employment. About 4,000 people employed in the sector are working in the pharmaceutical industry, which is more than 70% of the workforce in this sector. Biotechnology-related employment in process industries, including agro-food industries and enzyme production industries, amounts to 1,400 people. And about one hundred people are working in knowledge-intensive business services in the field of biotechnology.[5] Also, the number of companies in the biotechnology sector is rather small in Finland. There are only about 120–140 companies in the sector,[6] while the total number of companies in the Finnish economy is about 210,000. Most of the companies in this field are very small, employing less than 10 people.

Up to now, modern biotechnology has had no significance in the Finnish export statistics. In 1997, the value of exports of high-tech pharmaceuticals was only FIM 140 million (€ 23.5

TABLE I
Total volume of modern biotechnology in Finland in the year 1998.

Branch	Number of companies	Turnover (million FIM)	Personnel
Drugs	17	4,310	2,640
Diagnostics	28	1,220	1,390
Biomaterials	8	45	60
Food and forage	10	1,410	1,060
Industrial enzymes	3	325	290
Agro	7	10	30
Biotech-KIBS	16	70	110
Others	3	35	30
Total	92[a]	7,425	5,610

[a] The member companies of FIB.
Source: Finnish Bioindustries FIB, 2000.

million), and the value of exports of high-tech chemicals was FIM 310 million (€ 52.2 million). The combined value of exports of both high-tech industries was only 1.3% of the total high-tech exports in Finland. Export of electronics and telecommunication, on the other hand, the strongest high-tech sector in Finland, had a value of FIM 22,760 million (€ 3,800 million).[7]

The number of patents can also be seen as a good indicator of competitiveness. Here we can see a dramatic increase in all patent categories. Table II also demonstrates the leading role of the pharmaceutical industry in biotechnology.

The distribution of venture capital investments represents another good indicator in addressing the importance of a particular industry. In Finland, the total value of venture capital investments in 1997 was FIM 5,850 million (€ 984 million), of which two thirds were investments from the private sector. The venture capital investments in biotechnology were FIM 25 million (€ 4.2 million), which is only 0.4% of total investments.

Despite the marginal position of modern biotechnology in the Finnish economy, there are high expectations concerning the future development of this new sector and its contribution to the Finnish economy and to Finnish exports. These expectations are supported by the results of a survey analysis conducted in Finland in 1996. According to this survey, one fifth of the Finnish population accepts the GMO (genetically modified organism) food without reservation. Finnish people also associate some advantages with modern biotechnology. In an EU survey, two thirds of the Finns were optimistic concerning the implications and consequences of modern biotechnology, while on average only 50% of the EU citizens had an optimistic view on biotechnology.[8] The share of optimistic people was biggest in Finland compared to all other EU countries, a fact that can be seen as an important supportive environmental factor which may open up great prospects to biotechnology in Finland.

We must be cautious, however, not to become too optimistic concerning the future of biotechnology in this country. A company survey conducted in 1997 shows that Finland together with other Nordic countries, Austria, Switzerland, Germany and Greece, is considered as having a less supportive environment for investments in and use of biotechnology. The following elements were considered as most important influencing factors: market conditions, consumer acceptance, intellectual property, regulatory framework, entrepreneurship, the science base, availability of equity capital, skilled staff, availability of suppliers, and fiscal policy.

5. Constructing the biotechnology competence

Biotechnology is very much dependent on formal education, as – according to Lundvall[9] – knowledge in this field is highly codified. This is reflected in the fact that Finland has certainly invested heavily in biotechnological education in the recent 15 years. Since the mid-1980s, bioengineers have been educated at the Helsinki University of Technology. In 1998, a master's pro-

TABLE II
Patents allocated in biotechnology to Finns in Finland, in Europe (EPO) and in U.S.A. 1989–1998

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Total
Total	*55*	*75*	*79*	*90*	*76*	*98*	*103*	*142*	*98*	*128*	*944*
Drug[a]	*48*	*67*	*70*	*74*	*66*	*83*	*82*	*118*	*79*	*101*	*788*
Patents allocated in Finland	31	46	39	45	32	40	42	64	24	46	409
Patents allocated in Europe	4	11	11	9	19	28	20	28	22	25	177
Patents allocated in USA	13	10	20	20	15	15	20	26	33	30	202
Other biotechnology[a]	*7*	*8*	*9*	*16*	*10*	*15*	*21*	*24*	*19*	*27*	*156*
Patents allocated in Finland	4	2	1	6	2	4	3	4	1	3	30
Patents allocated in Europe	1	1	5	7	7	10	7	12	10	10	70
Patents allocated in U.S.A.	2	5	3	3	1	1	11	8	8	14	56

Source: National Board of Patents and Registration in Finland, 1999.
[a] Vihko, R. and A. Pauli, 1999, p. 14.

gramme in biotechnology was established at the University of Turku. In 2000, sixty new students will start their studies in a new training programme in biotechnology at the University of Kuopio. In the Science Park of Viikki in Helsinki, about 3,000 students study different subjects of biotechnology and Life Sciences.[10] Finnish polytechnics too offer training programs in biotechnology. However, the number of biotech students is not yet comparable with the number of engineering students, for example. On the university level, about 500 students start their studies in biotechnology year by year, while about 3,500 start their engineering education.[11]

Furthermore, 14 graduate schools have been established at Finnish universities supporting research in various areas of Life Sciences.[12] Five of them are situated in Helsinki, four in Turku, two in Kuopio and one in Oulu, Tampere and Joensuu respectively. The location of graduate schools reveals something of the anticipated location of Finnish biotechnology industries; the appreciable regions of the future biotech industries seem to be the Helsinki and Turku regions. The graduate schools are mainly integrated in regional biotechnology centres of expertise.

6. New outlook in pharmaceutical industry

In the Finnish industrial policy discourse, biotechnology is mainly associated with the pharmaceutical industry.[13] The leading role of the pharmaceutical industry can be explained to some extent by the fact that the workforce in this sector is traditionally highly skilled with many academics, having a degree in medicine or technical sciences, working in R&D departments. The fact that private ownership is dominating in this industry while it is not in other biotechnology fields may be seen as an important factor as well.[14] Public opinion is also supportive; because of the careful clinical testing system and the regulations in medicine industries, people accept biotechnological solutions in drugs more easily than in other branches.[15]

The crisis of the pharmaceutical industry in the beginning of the 1990s may also have contributed to the dominance of medicine in Finnish biotechnology. Many companies in the industry changed their strategies and abandoned their biotechnological research and development actions and departments. As a consequence of this, many highly educated employees in companies' R&D laboratories lost their jobs and began to start their own small R&D firms. The founding of the new centres of expertise also braced the development; in these new centres there was a proper support structure available for small R&D enterprises.

Today the new university-affiliated bio centres – or the centres of biotechnological expertise – have an important role to play in the research and development activities of the pharmaceutical industry. The BioCity centre in Turku, Biocenter in Oulu and the A. I. Virtanen Institute in Kuopio

TABLE III
The graduate schools of biotechnology in Finland

University	Graduate Schools
University of Helsinki	The Biomedical Graduate School The Graduate School in Neurobiology The Finnish Graduate School on Applied Bioscience The Graduate School in Biotechnology Viikki Graduate School in Biosciences
University of Turku	The Turku Graduate School of Biomedical Sciences The Finnish Graduate School in Musculo-Skeletal Problems Biological Interactions Graduate School
Åbo Academi (Turku)	The Graduate School of Informational and Structural Biology
University of Oulu	Biocenter Oulu Graduate School
University of Joensuu	The Graduate School in Forest Sciences
University of Kuopio	A. I. Virtanen Graduate School

all work in the field of medical and diagnostical research. They have strong linkages to pharmaceutical industries, but they have also been criticized for excessive diffusion of their limited resources. These centres of expertise take in a lot of small firms, spin-offs either from universities or larger pharmaceutical companies.

The founding of the centres of biotechnological expertise has changed the structure of the Finnish pharmaceutical industry significantly. Previously, only a few large national companies having their own research units existed. Nowadays, a network of small R&D-based firms situated in the university-affiliated biotech centres of expertise has become a key actor in this biotechnology sector. These enterprises can be divided into three different types. Firms belonging to the first type are concentrating on research and development activities, while the second group of companies specialises in knowledge-intensive business services, and the third type of companies can be characterised as technology support producing enterprises. Some global pharmaceutical companies also have smaller units in Finland and in Finnish bio-centres. In addition to enterprises, the centres of expertise also host university institutes and private research institutes.

The Turku area in the south-west of Finland has attracted a remarkable number of Finnish pharmaceutical companies. To further develop this industrial agglomeration, the City of Turku has made large investments into modern biotechnology. The reason for the City's heavy investment in biotechnology is that it did not participate in the rapid development of the Finnish information and telecommunication technology. Finnish pharmaceutical corporations are small, however, which makes it difficult for them to hold their own on the global markets. Because of the limited scope of the national pharmaceutical industry, the most R&D-oriented companies in Finland look for co-operation with global corporations. After the economic crisis in the beginning of the 1990s, the Finnish pharmaceutical industry did not only restructure, but also a number of mergers and take-overs took place, and some companies went bankrupt.

Nowadays one of the leading pharmaceutical corporations in Finland is *Orion*. Two of its divisions, Orion Pharma and Orion Diacnostica, are concentrating on products based on biotechnological research and development work. Their net sales in 1998 was about FIM 2600 million, which was about half of Orion Corporation's total net sales (€ 870 million).

Orion Pharma is engaged in the research, development, production and marketing of pharmaceuticals and drug substances as well as drug-related products for the prevention and treatment of diseases. Their product portfolio encompasses all

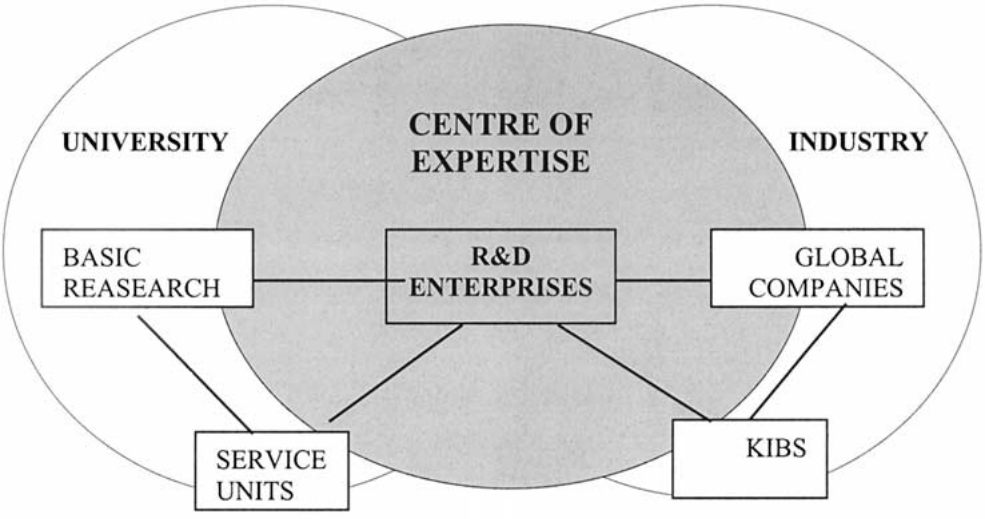


Figure 2. The basic structure of the university-industry biotechnology network in the area of pharmaceutical industries.

elementary therapy groups, including veterinary drugs. International operations account for approximately half of the total net sales (FIM 2400 million). The growth of the business is increasingly based on drugs resulting from the company's own pharmaceutical research activity. Orion has several drugs manufacturing plants in Finland, and one in Denmark.

The focus of Orion's pharmaceutical research is on neurology, asthma, menopausal disorders, cancer, and heart failure. In special fields, R&D activity comprises all phases of pharmaceutical research, from basic research in Finland to multinational clinical trials. R&D expenditure amounts to about 16% of the net sales of pharmaceutical reparations, and around 730 persons are engaged in R&D activities. Orion Pharma collaborates with bio-centres in Kuopio, Turku and Helsinki.

Orion Diagnostica is a division relying on biomedical research in its tests for diagnosing diseases. Its core competence is in infectious disease diagnostics, specific protein and hormone assays, and bone markers. International markets account for almost 80% of the operations, most important Scandinavia, Central Europe, the U.S.A., and Japan. The division also has subsidiaries in the Nordic countries. Orion Diagnostica co-operates with scientific institutes and company units in Medipolis in Oulu.

7. The agro-food industry

Conservatism and less favourable attitudes towards technological development are the main reasons for the low innovation capacity of the Finnish agro-food industry in the field of biotechnology.[16] Moreover, exaggerated expectations concerning return on investment, the fear of technological risks and the lack of skills and competence in modern biotechnology can be seen as significant factors that have hampered biotechnology-related R&D activities in the Finnish agro-food industry.

The delayed social and economical transformation contributed to the high status of farmers in Finland. In Finnish argo-food industry, the farmers, their unions and their co-operatives represent the only relevant group that has an influence on the techno-economic development. Most of the agro-food industrial mills, creameries, slaughterhouses and food factories have been owned by the farmers' production co-operatives. The share of privately owned companies in the food industry is very limited and they are rather small by size.

The co-operatives have become national monopolies. The co-operative creamery *Valio*, for example, was in the possession of 97% of the milk markets by the end of the 1970s. Correspondingly, the co-operative's market share in the meat industry was 53% and its share in the egg industry was about one third.[17] This "monopolar" structure in the Finnish agro-food industry, which prevented hard competition, has not been a supportive environment for any kind of innovative activities. Also, the fact that the industry was heavy subsidised became a hindrance for technological progress.

Before the Finnish EU membership and the opening of the markets in the 1990s, the structure of the Finnish agro-food industry can be described by the term "agro-food industrial complex".[18] This is an economic system consisting of the industries providing agriculture with material and technical equipment, the industries taking care of the agro-food raw material production, and the industries taking care of the processing and delivery of the products. In this tightly coupled structure, the state and its financing, research and educational organisations are entwined with the farmers' organisations and co-operatives. Also, privately owned companies had to adapt themselves the structure and strategies of the agro-food industrial complex. The fact that the whole education system for the agricultural sector was subordinated to the Ministry of Agriculture until the end of the 1960s is a further indicator for the closeness of the sector.[19]

The co-operative *Valio*, founded at the beginning of the century by co-operative dairies to export butter, plays an important role in the Finnish agro-food industry. Today, Valio is engaged in processing and marketing milk, dairy products and other food products over a total product range of 800 items. During the 1980s and 1990s, *Valio* has strongly invested in the research and development of functional food products. The company has been marketing products with Lactobacillus GG (LGG) in Finland under the Gefilus brand since 1990. Gefilus products include

yoghurts, cultured buttermilks, pasteurised milk, a fermented whey drink, fruit drinks, and capsules as well. Today, products containing LGG are on the market in more than 20 countries around the world, under licence agreements from *Valio*. The company is also the world leader in applying UHT technology to infant foods. The company has developed ultra-high temperature (UHT) technology in close co-operation with paediatricians. Several clinical studies have been carried out in order to improve the composition of its products. For nearly 20 years, *Valio* has also studied, experimented with and put into practice lactose hydrolysis in a highly sophisticated and intensive manner. The company has developed tailor-made and patented solutions for the removal of lactose in different milk products. These solutions include the use of many soluble enzymes; the *Valio* Hydrolysis Process using immobilised enzyme technology and the *Valio* Chromatographic Process, in which lactose is physically separated from milk.

Valio Ltd. is owned by 11 co-operative dairies and 17,000 dairy farms produce milk for the company. The Valio Group comprises the parent company Valio Ltd. and its subsidiaries in Finland and abroad. The Group employs 4,300 people. The whole Valio Group net sales in 1998 amounted to FIM 7.6 billion (€ 1.3 billion), of which exports and foreign subsidiaries made up one third. Noteworthy subsidiaries are Valio Sverige AB in Sweden and Finlandia Cheese Inc. in the U.S.A., for example.

Besides Valio's products, there are also other examples of successful R&D activities in the Finnish agro-food industry. Beer is a product with a long tradition in Finland. Lately malt-houses have focused on developing malting barley and new malting technologies. The most recent addition to barley breeding techniques uses genetic engineering. The first genetic barley in the world was made in 1993 by the research group of the Technical Research Centre of Finland (VTT) and was used in trials.

The most known case is the developing of the Benecol plant stanol ester, an ingredient that lowers serum cholesterol levels. The problem that triggered the innovation was to find an application for the surplus sitosterol of the chemical pulp industry of Kaukas Ltd. *Raisio* Ltd. developed the idea of using the surplus sitosterol in margarine and vegetable oil. In the so-called North Karelia project, researchers discovered the cholesterol-lower character of Benecol.[20] Nevertheless, Benecol, an innovation with great economic potential, demonstrates many of the problems related to the long-term economic isolation of Finnish agro-food industries. Raisio Ltd had great problems in getting access to the U.S. market, as it lacked the knowledge of the rules and procedures regulating the functionalistic food market in the U.S.A. Due to the lack of expertise, competitors were able to bypass the R&D work conducted on Benecol and develop their own products of a similar kind.

The Raisio Group was established by Finnish farmers in 1939. The first production unit was a flour mill, but the company has over the years expanded into many other areas of arable product processing, and it can claim to be ahead in this field of knowledge. The Raisio Group headquarters are in Raisio, a small town in the south-west of Finland. The Group employs nearly 2,900 people, of which about 40% are based outside Finland. Today Raisio has production units at over 40 locations in 17 countries. The Group's turnover was FIM 4,950 million (€ 833 million) in 1998. The parent company, Raisio Group plc, has been listed on Helsinki Stock Exchange since 1989, and over 50% of its shares are owned by international institutional investors and funds.

The Raisio Group export margarine products, malt products, wheat flour, pastas, cereal flakes, potato products, cat and dog food, feeds for fur animals and farm feeds. The Chemical Division is Raisio's most international division, with production plants in 15 countries. It is a specialist supplier to the pulp and paper industry throughout the world. Its exceptionally wide product range includes chemicals and equipment extending from pulp-making to the manufacture, coating, conversion, and recycling of paper.

After the opening of markets and Finland's EU membership, the Finnish agro-food industry has approached the situation of escalating change. One example of the fundamental nature of the changes is the course of events around *Cultor Ltd*. The Corporation employs 7,000 people in Finland. Cultor is the world's largest producer of functional ingredients for the international food industry and

the world's leading supplier of feed ingredients. The company is also the leading producer of emulsifiers, functional systems, locust bean gum, fat replacers, butter flavourings, and the world's second largest producer of pectin. The product range also includes other textural ingredients, flavourings, enzymes, sweeteners, antioxidants, and other protectants, in which Cultor is among the world's leading suppliers. Cultor has invested a lot in biotechnology oriented R&D activities.

The development of the sweetener xylitol is one success-story in applying biotechnology in the Finnish agro-food industry. The research done in the Faculty of Dental Surgery in the University of Turku addressed the beneficial effects of xylitol to human teeth. Cultor Ltd. placed xylitol in many of its products, which led to economic success. In 1992, the R&D and the production of xylitol got the innovation reward of the Finnish National Fund for Research and Development.[21] In March 1999, the company accepted the bid of the Danish corporation Danisco. In November 1999, Danisco listed as the first non-Finnish company on the Helsinki Stock Exchanges' Main List of blue-chip companies. Cultor continues to operate as Danisco Cultor in the ingredients sector of the Danisco Concern. Most of its products are produced using natural raw materials, such as vegetable oil, seaweed, citrus fruits, and seed from leguminous plants. The Danisco strategy is to establish production plants close to key raw materials. Danisco is also developing and testing the GMO sugar beet in collaboration with DLF-Trifolium A/S and Monsanto Company. The case of Cultor illustrates that even bigger Finnish companies in the biotechnology sector have difficulties to hold their own in a globalising market. This may be due to the fact that, in biotechnology, huge investments in R&D have to be made to be able to compete globally. Nonetheless, Danisco has cut the R&D activities in Cultor, and at least 15–20 percent of the researchers have been made redundant.

Lately, the entire agro-food sector in Finland is undergoing major changes turning into a research-based modern biotechnology industry. The Agricultural Research Centre of Finland is planning the experimental production of genetic modified cheese and it has started the research on GMO animals. According to the OECD's database of biotechnological field trials, two projects researching on streptococcus bacterium are conducted in the Valio laboratories. *Kemira Agro Ltd.* is studying the virus resistance of potatoes and *Hilleshog AB* is studying the glyphosate tolerance of the sugar beet. Altogether there were six biotechnological field trials conducted in Finland before 1997.

Other key actors in the agro-food biotechnological R&D field, besides the laboratories of the agro-food industry and the Research Centre for the Finnish Agriculture, are the new Helsinki Science Park in Viikki, which employs about 1,000 researchers, and the Kuopio Technology Centre TEKNIA Ltd. These new agro-food biotechnology centres of expertise represent the new technology policy of Finland. The new centres of expertise establish larger and tighter linkages between universities and industries. Education, university research, knowledge-based agro-food industrial small firms, and departments of larger companies all are operating in a close connection to each other in these centres.

In the near future, the only Faculty of Agriculture and Forestry in Finland will be established in Helsinki Science Park. In this park, also other research institutes are operating: the Institute of Biochemistry, the Institute of Microbiology, the Institute for Animal Physiology, the Institute for Environmental Research and the Institute for Pharmacy, for example. The Helsinki Science Park is planning to become the most extensive concentration of biosciences in Europe.

In 1995, the Development Company Foodwest in Seinäjoki was launched. It is owned by 24 agro-food companies and 32 communes and communities, among them the Central Union of Agricultural Producers and Forest Owners (MTK). A few years ago, Foodwest was elected a centre of expertise, and today it employs about 15 people. There is also a Development Company for agriculture production called Agropolis Ltd. in Jokioinen. It is owned by local communities and other public authorities.

8. The wood processing industries

In Finland, the production and export of chemical pulp has been comparatively high, which ultimately is a semi-manufactured product and raw material to paper industry. The manufacturing of

chemical pulp is a representative example of mass production. For a long time, one problem of the Finnish wood-processing industry has been the low degree of horizontal process integration. This is a result of the Finnish so-called smallholding policy; two thirds of the Finnish forests are nowadays privately owned by farmers or testamentary heirs of ex-farmers, one quarter belongs to state, and only 8 percent to corporations.

Due to this situation, some kind of a dichotomy in the production chain of wood-processing industry emerged, which has drawn a clear dividing line between corporations on one side and farmers on the other side. Both interest groups formed their own economic and commercial organisations. In the 1960s, the situation had already developed into a kind of "double-closure"[22] and opposite national cartels. Not surprisingly, the research and development interests of the two key actors also diverged into two different directions. The wood-processing industry was mainly interested in research and development of end products and processes inside the factories. Correspondingly, the farmers' or wood growers', as they are called in this connection, interest focused on the betterment of the productivity of forests. In general, biotechnologically oriented research had a larger indent on the wood growers' side, and not so much in the corporations' side. However, the wood growers' interest in intensifying forestry's yield by biotechnological applications was not very strong. Because of the fact that Finland is rich in forests, the wood growers were mainly interested in the improvement of forestry work.

The productivity of Finnish forests was already very early defined as an issue of national survival.[23] The state has – beside the Finnish wood grower organisations – been active in forestry research and development. The great interest of the state in the wood-processing industry is somehow self-evident, as some forty years ago 70% of Finnish export came from this industry. Due to the polarised situation in the Finnish wood-processing industry, the state has placed itself into a kind of an umbrella position. It established a broader vision in which both the interests of the corporations and of the farmers can be argued.

Today, there are three globally acting corporations in the Finnish forest industry. The *UPM-Kymmene Group* is, measured by turnover, the biggest, *Stora Enso* is one of the world's leading forest industry companies, and *Metsä-Serla Oyj* is the sixth largest forest industry and paper-producing company in Europe. The large forest industry companies, however, seem to be less active in promoting biotechnology innovations, while companies in the chemical pulp industries, being part of the forest cluster, seem to be much more engaged in research in modern biotechnology.

The most famous biotechnological innovation in the chemical pulp industry, developed by the Technical Research Centre of Finland VTT's biotechnological laboratory, is an enzyme-aided process for bleaching cellulose pulp.[24] In this process, hemicellulases are used in order to avoid using clorine chemicals. The first pulp mill designed for complete chlorine-free bleaching was built at OY Metsä-Rauma Ab and started in 1996. Ahlstrom is the leading company in Finland in developing new processes and machinery for pulp and paper manufactory in which the environmental aspect is considered.

The structure of the biotechnology innovation network in forest industries differs significantly from the one in the pharmaceutical industries. There are different research organisations functioning in the forepart and in the end of the production chain. The chemical pulp and paper companies and the Central Laboratory KCL co-operate in research and development of the enzymes with companies like Raisio Chemicals, Primalko and Genencor International. The latter co-operate with VTT Biotechnology, which has close linkages to university research. In the forepart of the production chain, there are actors working on improvements in productivity of forests, such as Forest Centres and The Finnish Forest Research Institute METLA.

The Finnish Forest Research Institute (METLA), established in 1917, is an independent research organisation subordinated to the Ministry of Agriculture and Forestry. This central forest research organisation has a staff of 700 people; 200 of whom are research officers in the research centres located in Helsinki and Vantaa. METLA also has 8 research units in different parts of the country. METLA has a strong tradition in research

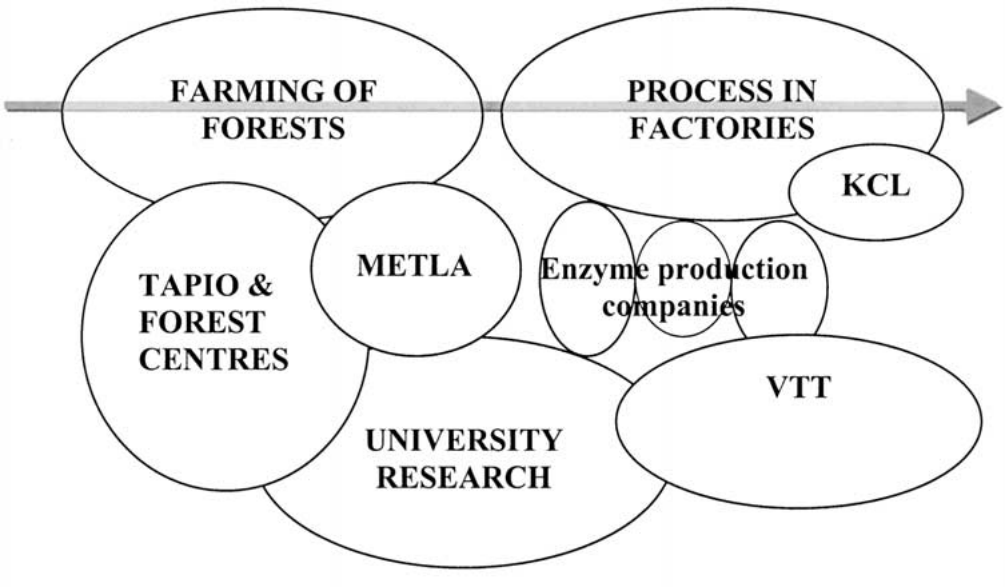


Figure 3. The biotechnology network in Finnish forest industries.

and development activities based on traditional biotechnology. Applications of modern biotechnology have often been delayed, mainly because the problematic proprietorship of Finnish forests. Wood production based on applications of modern biotechnology would be easier to realise in a large and market-oriented forest industry than under the conditions of disintegrated forest smallholding. Despite these difficulties, six modern biotechnological, forest genetic research projects are currently conducted at METLA.

As far as corporations are concerned, the most interesting institutional actor has been the above-mentioned Central Laboratory KCL, which concentrates on the quality control of the end products of chemical pulp and paper industry mills. But lately the interest of the laboratory has broadened from mere quality control to larger R&D activities, including also research in biotechnology. The state research organisation, the Technical Research Centre of Finland (VTT) with its biotechnological laboratory is another important actor that has close linkages to corporations. Although most of the biotechnology projects of METLA, VTT and other institutional actors are financed by the WoodWisdom programme, modern biotechnology is in a marginal role in the whole programme entity.

The radical changes in the beginning of 1990s broke the customary notion of the juxtaposition of wood-processing corporations and wood grower organisations. In the new atmosphere, one started to consider the wood-processing industries as an uninterrupted production chain from forestry to consumption. According to the Technology Development Centre of Finland, the greatest future challenge for the wood-processing industry is "to integrate forest economy and forest research to a constant part of the research of products of wood-processing industries. This means comprehension and governance of the linkages between the wood raw material quality and the end product quality".[25] Research in the Bio and Food Technology Unit of the Technical Research Centre of Finland goes in this direction; it applies biotechnology in the wood-processing industry in several research and development projects. The research on wood material, for example, aims at increasing biological stability and hindering the dyeing of the raw material.

9. Biotechnology supporting policies

The Finnish Ministry of Education established the first national research program on biotechnology in 1987. The aim of the programme was to develop four powerful centres of biotechnological expertise by 1992. These new centres were

planned to affiliate with the Finnish universities that were assessed as having the capacity and resources to develop the new field of scientific research. The centres of biotechnological expertise were set up in Helsinki, Turku, Kuopio and Oulu. By the end of the five-year period, the Ministry of Education made an evaluation aiming at identifying needs to further develop biotechnology and molecular biology. The Ministry decided to continue the programme until the end of 1996. Later on, the programme period was extended to 2000.[26]

Besides the Ministry of Education, also the Ministry of Trade and Industry, the Ministry of Agriculture and Forestry, and the Ministry of Social Affairs and Health took part in the financing of the biotechnological research programme. The four centres of biotechnological expertise became part of the Finnish network of "centres of expertise". Nowadays this network consists of 17 centres of expertise, of which seven are large and have an established status. Four centres have been working for some times and six are new and rather small ones.[27] The new centres of expertise in Seinäjoki, Lahti and Pori are located in regions without a local university but they are linked to large regional polytechnics or local annexes of universities.

9.1. *Basic and applied research*

As can be seen from the following table, research and development in biotechnology is nowadays also conducted in the centres of Tampere and Seinäjoki in addition to the traditional centres. In Finland, the centres of expertise programme is intended to become the core of a newly developing regional policy. The strong relationship between the state's regional financing and the centres of expertise programme has led to "excess demand" for new centres. Therefore the policy was criticised for the excessive decentralisation of limited R&D resources. The result is that, in the field of biotechnology, no new centre of expertise will be set up in the near future.[28]

Centres of expertise offer local companies business services and forge links between regional enterprises and local universities or – in some cases – local polytechnics. They are presumed to be sources of knowledge for regional economies. They also have an important role to play in the transfer of technology from high-tech centres in Finland and abroad to their own region. In addition, they are excepted to generate new forms of business and to support the foundation of new enterprises as well as to create a stimulating environment for the techno-organisational modernisation of the existing companies. The university – so the basic philosophy of the centre of expertise programme – can stimulate and support regional development in high-tech sectors. In case there is no university located close to the centre of expertise, a regional polytechnic may, as the only base and core of local industrial network, begin to imitate a university's function.

The fact that the new centres of expertise will

TABLE IV
The centres of expertise in Finland

	Large and established	Medium-sized and stable	Small and new ones
Centres of expertise	ESPOO: Otaniemi Science Park Ltd. TURKU Technology Centre, DataCity Centre Ltd. TAMPERE Technology Centre Ltd. OULU Technopolis Ltd.	KUOPIO Technology Centre Teknia Ltd. JYVÄSKYLÄ Science Park Ltd. LAPPEENRANTA: Technology Centre Kareltek Inc.	HELSINKI Science Park Ltd. VAASA: Innovation Centre Merinova Ltd. JOENSUU: Carelian Science Park Ltd. SEINÄJOKI: Foodwest Ltd. LAHTI: Neopoli Ltd. PORI: PrizzTech Ltd.
With focus on biotechnology	TURKU: BioCity Ltd. OULU: Biocenter Oulu Ltd. TAMPERE: Fin-Medi Research Ltd.	KUOPIO: A.I. Virtanen Institute	HELSINKI Science Park Ltd. SEINÄJOKI: Foodwest Ltd.

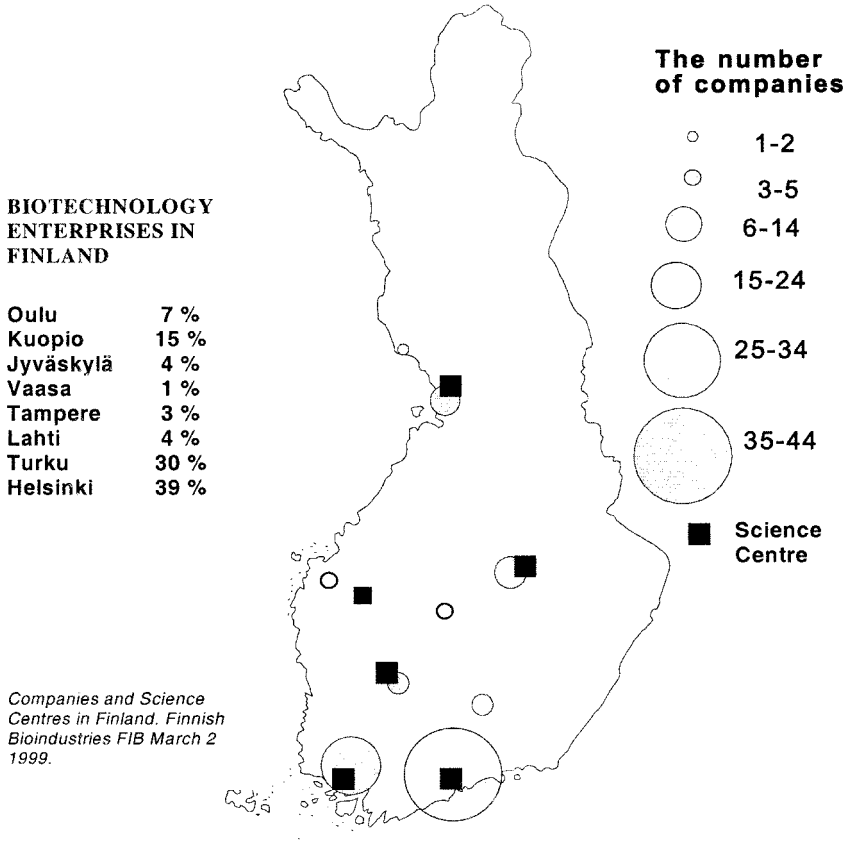


Figure 4. The centres of expertise and the location of biotechnology business firms in 1998.

be located in towns without a local university may contribute to an academic drift in polytechnics. This phenomenon, found by Pratt and Burgess, has contributed to the fact that, by the end of the 1980s, the whole polytechnic system was discharged in the U.K. and the polytechnics were transformed into universities. In regions without a local university, polytechnics may well become the base and core of local industrial networks, as was the case in the U.K.[29]

Four centres of biotechnological expertise, Oulu, Turku, Tampere and Kuopio, focus on medical research and co-operation with pharmaceutical industry. The focal area of Helsinki Science Park and Foodwest in Seinäjoki is the co-operation with the agro-food industry. The dominant status of the pharmaceutical industry in the field of Finnish biotechnology can partly be explained by the fact that this was the focus area of the old centres of expertise. As those centres that concentrate on R&D in the agro-food field have been established only lately, this area is still lacking behind in its economic development.

9.2. *Strong public financing*

Research and development in biotechnology is highly dependent on state funding. As has been mentioned earlier, only 0.4% of the private venture capital investments was directed to biotechnology in 1997. As a capital-needy country, the state and public financing plays an important role in Finnish venture capital markets. Different parts of the idea-innovation chain are financed by different institutions. The Academy of Finland is supporting scientific basic research in universities and research centres. The Technology Development Centre (Tekes) aims to applied research and product development by supporting the co-operative activities between university research

and companies. The role of the Finnish National Fund for Research and Development (Sitra) is to support promising start-up enterprises. Later on, the new knowledge-intensive companies are expected to get their financing from the capital markets.

Tekes invested FIM 535 million (€ 90 million) in the field of chemistry and biotechnology, which is 27% of its total investments. The Academy of Finland and Tekes invest about FIM 20 million (€ 3.4 million) a year in research in biosciences and biotechnology as part of the Centres of Excellence Programme. In addition, Biocentrum Helsinki, Biocenter Turku and BioCity Turku are supported with FIM 4 million (€ 0.7 million). This means that 40% of the aggregated financial support of the Academy of Finland and Tekes is directed to biotechnology. The national programme for the research on biotechnology, started in 1988, invests about FIM 80 million (€ 13.5 million) a year.[30] As state financing of Finnish biotechnology has been quite large in the 1990s, some critique has been raised about the results of this massive investment.

Presently, there are two research programmes going on within the common foundation of Tekes and the Academy of Finland. The Genome Research Programme includes gene regulation. It studies interactions between several genes and gene products, gene transfers, and knock-outs as well as gene therapy. The budget of the programme amounts to FIM 89 million (€ 15 million) in six years. The Academy of Finland financed 20 projects with FIM 37 million (€ 6.1 million) from 1995 to 1997. From 1998 to 2000, the Academy of Finland is financing 15 projects with FIM 24 million (€ 4 million). Tekes financed 5 projects with FIM 5 million (€ 0.8 million) in 1998.

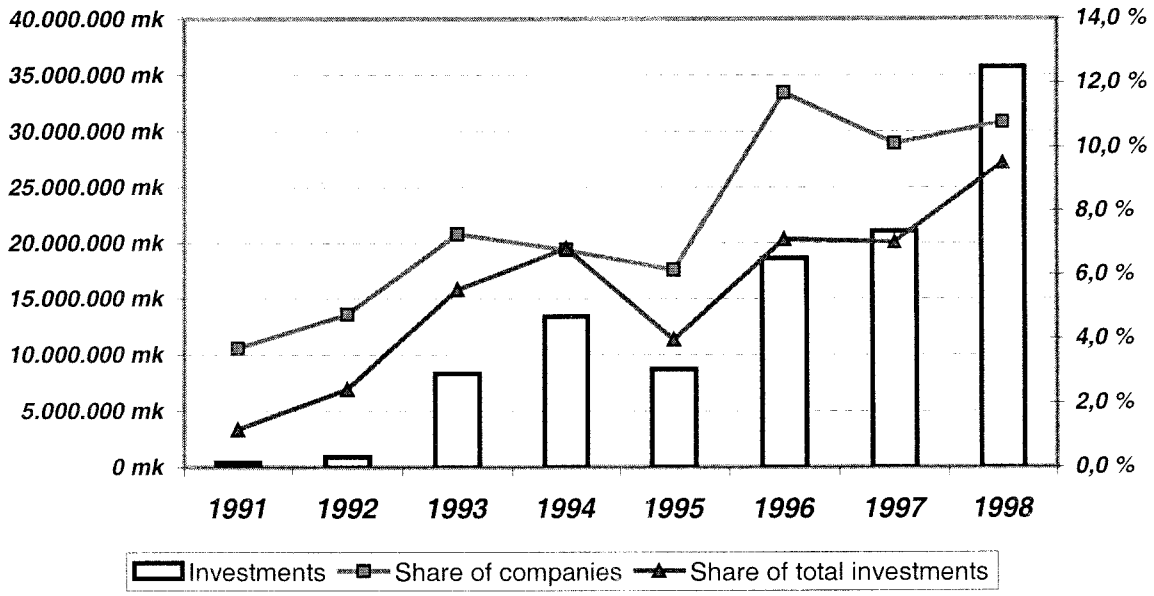
The Cell Biology Research Programme studies mechanisms of cell division and differentiation, the biogenesis of cell organelles and intracellular trafficking as well as signal transduction. The programme started in 1998 and will continue until 2001. The budget of the programme amounts to FIM 32 million (€ 5.4 million). The Academy of Finland is financing 19 projects with FIM 22 million (€ 3.6 million). Tekes financed 4 projects with FIM 5 million (€ 0.8 million) from 1998 to 1999.

In 1993, the Ministry of Education established a new centres of excellence policy by ordering the Finnish Higher Education Evaluation Council to choose ten units and institutes as "top units".[31] This policy of establishing centres of excellence has become the core of the Academy of Finland's policy.[32] It expects that the new policy can lead to a strong concentration of research and innovative activities. Currently, 6% of the Academy's funding is directed to the Centres of Excellence Programme. In 2000, a total of 26 new centres of excellence will be established. Nine of them are operating in the field of modern biotechnology and biosciences.[33] The Academy of Finland also financed research in modern biotechnology within the framework of its basic research programme. There is, for example, an ongoing programme for gene research and cell biology. In 1999, the research programme for the biology of structures started and, in 2000, a research programme for biological functions was being planned.

In addition, the Academy of Finland is financing the Research Programme in Molecular Epidemiology and Evolution. The primary areas of this programme are population genetics, concerned particularly with the evolution of genes, the adaptation of organisms to extreme conditions, genetic epidemiology and the Finnish genetic heritage, and environmental molecular genetics, including genetic factors predisposing to disease.

Tekes started a five-year Biotechnology Development Programme in 1988. It consisted of five subjects important to Finnish industry: biotechnology for the pulp and paper industries, bio-process engineering, plant biotechnology, animal cell technology, and biologically active molecules. Tekes also has an agro-food biotech programme named "The Innovation in Foods Programme". It aims at supporting the production of more competitive foods through research. The goal of the programme is to ensure the production of increasingly high quality products by improving the standards of food technology and related research in Finland. The programme started in 1997 and continued until 2000. The budget of the programme is over FIM 200 million (€ 33.7 million) covering four years. All the significant Finnish agro-food companies are participating in the programme.

In 1991, the Finnish National Fund for



Source: Sitra Annual Reports 1991–1998.

Figure 5. Investments of the Finnish National Fund for Research and Development (Sitra) in biotechnology 1991–1998.

Research and Development (Sitra), aimed at financially supporting new start-ups, invested FIM 400,000 (€ 67,000) in biotechnology, which was only 1.2 percent of its total investments. Eight years later, the investments in biotechnology amounted to FIM 35.7 million (€ 6 million). Altogether Sitra has invested in eleven biotech companies; today, the share of biotech investments is already 9.5 percent of all investments. In 1997, two special funds, Sitra Bioventures Ky and Sitra Bio Fund Management Ltd., were started with a capital of FIM 150 million (€ 25.2 million).

10. Conclusions

Biotechnology industries have only played a minor role in the Finnish industry up to now. However, the state and state-owned institutes have started to invest heavily in biotechnological research projects as well as in education and research infrastructure, as part of an extension policy of the Finnish export's industrial basis. We are entitled to use the word "massive" because only little R&D so far comes from the private sector, and only few business firms have started production of biotechnology based products.

The structure of the Finnish biotechnology sector is similar to that of European biotechnology. The pharmaceutical industry represents the leading sector, while the agro-food sector and the forest industry are lacking behind partly due to the specific "lock-ins" described in the paper. But there are signs that the industries will be able to overcome the problems caused by the lock-ins.

The further development of the biotechnology sector in Finland depends on whether the emerging research infrastructure will soon lead to the building up of a significant number of manufacturing plants. In overall terms, the business environment in Finland seems to be less supportive for investment in and use of biotechnology than in the U.S.A. and some other parts of Europe. However, there are also some supportive factors. There seems to be widespread agreement that biotechnology could become the fourth pillar of the Finnish export sector, indicated by the massive public investment in research. Furthermore, the Finns in general are very open to technological development and their attitudes to biotechnology seem to be less negative than in other European countries. And last but not least, Finnish technical universities are known for their openness to close

co-operation with industry. The centres of expertise seem to create a supportive environment for close university-industry co-operation.

There are also important factors that can hinder the further development of the biotechnology sector in Finland. First, there seems to be a serious shortage of highly qualified scientific staff in the sector, which the government is aiming to overcome by heavy investments in the education infrastructure. There is, however, huge demand for qualified engineers in the IT sector as well. Whether in the competition over human resources the biotechnology sector will be able to hold its own remains to be seen. Anyhow, there is a lack of students oriented to mathematics and natural sciences in their matriculation examination.

A major disadvantage is the small size of the Finnish market. Therefore, companies in Finland have to be globally oriented from the very beginning. However, as some examples demonstrate, the small Finnish biotechnology firms, particularly in the agro-food and pharmaceutical sector, often lack the management capacity to establish themselves on foreign and particularly on the most important U.S. market. Companies operating on the national or even on the European level may soon face serious problems because they lack sufficient awareness of and access to new biotechnological knowledge.

Concerning regulatory aspects, Finnish firms suffer the same fate as other European firms. The European regulatory framework seems to have a negative effect on the competitiveness of European firms. The greatest losers in the biotechnology age are likely to be the farmers who, for regulatory reasons, have been denied access to some products. As European farmers in general, the Finnish farmers are likely to lose global market shares to farmers from other parts of the world, who are already adopting products using biotechnology.

Still another problem is the smallness of Finnish firms particularly in the agro-food and in the pharmaceutical industry. Small companies face serious problems as product innovation and improvement in operating efficiency come to depend increasingly on the use of biotechnology. In order to be able to develop the absorptive capacity necessary for applying biotechnological knowledge, companies have to set up respective research capacity. This is a major problem for small companies, as can also be demonstrated by the small amount of private R&D investment of Finnish firms in biotechnology. However, Finnish firms start to co-operate and merge not only with European but also with U.S. companies to overcome the disadvantage of being small. As the pulp and paper industry includes some global players, the sector is not affected by this problem. As some huge mergers have already taken place in this sector, Finnish pulp and paper companies may well be able to stay on their own in the biotechnology era.

Notes

[1] Science and Technology Policy Council of Finland, 2000.
[2] Kreiner and Schoultz, 1993, pp. 189–209.
[3] Ahola, E. and M. Kuisma, 1998.
[4] Nelson and Winter, 1982; Lovio, 1993; Malerba, 2000.
[5] Miles et al., 1995.
[6] Finnish Bioindustries, 2000.
[7] White, 1998, pp. 10–11.
[8] EU, 1997.
[9] Lundvall, 1999.
[10] Halme, 1996.
[11] Yearly almost 5000 Finns reach the engineer degree in universities or in polytechnics. This is 8 percent of each age group. The number of post-graduate degrees in technical sciences was 350 in 1999.
[12] Makarov, 1999, pp. 21–23.
[13] E.g. Jalkanen, 1998.
[14] Rannikko and Tulkki, 1999, pp. 39–40.
[15] Jauho and Niva, 1999.
[16] Salo et al., 1998, pp. 36–37.
[17] MTK, 1976, pp. 55–59.
[18] Granberg, 1979, pp. 139–155.
[19] See: Bourdieu and Wacquant, 1992.
[20] Miettinen et al., 1999, p. 166.
[21] SITRA 25 Years: *Bridging the Research and the Economy* [Tutkimuksen ja talouden sillanrakentaja]. The Finnish National Fund for Research and Development 1967–1992. Helsinki, pp. 10–12.
[22] Murphy, 1988.
[23] Kuisma, 1993, pp. 104–120. See also: Michelsen, 1999; Tulkki, 1996.
[24] Miettinen et al., 1999, pp. 61–88.
[25] TEKES, 1998, pp. 115–116.
[26] Jäppinen and Pulkkinen, 1999.
[27] Saarinen, 1999.
[28] Kekkonen and Nybergh, 1999.
[29] Beck et al., 1994.
[30] Vihko and Pauli, 1999.
[31] Ketonen and Nyyssölä, 1996, pp. 68–73.
[32] Vihko, R. and A. Pauli, 1999, p. 15.
[33] Vihko, R. and A. Pauli, 1999, p. 14.

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