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INITIATIVES ON A SUSTAINABLE DEVELOPMENT STRATEGY FOR FINNISH BIOTECHNOLOGY

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ABSTRACT: The need for the strategic initiatives for biotechnology strategy emerged in interviews with 90 Finnish biotechnology leaders in the ETLA Biotechnology Survey, conducted at the end of 2004. This paper discusses on the policy implications for the project on "*The biotechnology industry as a part of the Finnish National Innovation System*" financed by Tekes, the National Technology Agency of Finland. Tekes has strongly encouraged the formation of policy implications and strategic initiatives for the biotechnology sector of Finland.

Healthcare technology has been regarded as the main application area of biotechnology, but the applications of plant and process biotechnology are gaining in importance. Irrespective of the application area, the technological interests and the market potential are global. A typical example is in the production of food, where products such as Golden rice and Bt (*bacillus thuringiensis*) wheat are discussed as a step towards balancing the global inequality of food production. However, this discussion paper focuses on the potential synergy between innovation clusters in a domestic context.

We have identified global megatrends that impose a threat on the future well-being of Finland. Our aim has been to try to take advantage of the megatrends and turn them into opportunities within the context of sustainable development[1]:

Firstly, the ageing population will induce a threat to the supply of public healthcare for everyone. Healthcare related "red" biotechnology might play an important role in the restriction of increases in healthcare costs by providing new cost-efficient healthcare applications. Additionally, some applications for functional food might offer pro-actively some positive health outcomes before there are any costs affected by an illness. In many cases, it would be more cost-efficient to create preventive mechanisms than treat those illnesses. **Secondly**, the extensive use of fossil fuels has been proclaimed as posing a major threat to the global bio-system. **Thirdly**, as oil reservoirs outside the Middle East are becoming depleted, the rising prices together with geographically skewed production will probably strain the existing economic balance. However, applications of plant "green" biotechnology and industrial "white" biotechnology could provide some solutions for producing, for example, bio-fuels instead of polluting fossil-fuels, as well as growing specified crops that take advantage of the Arctic dimension of the Finnish environment.

Based on literature and the megatrends affecting Finland as a whole, we have outlined four innovation clusters:
1. healthcare
2. food with health effects
3. energy and other biomass based applications
4. bioinformatics.

[1] In our paper, we use the term sustainable development with a specific focus on Finnish implications.

These initiatives have been presented for all of the representatives of the main stakeholders related to biotechnology: 1) the industry, 2) governmental bodies, and 3) academia, both at individual and institutional level.

The key question for the success of the Finnish biotechnology industry is to be able to take advantage of our domestic strengths, acknowledge our limited resources, and yet realize the global view of biotechnology. Our goal has been to connect our findings from the Finnish Biotechnology sector to the major trends recognized in the literature concerning international trade theory. Consequently, the following concepts form the basis of this strategy paper:

1. International Trade and the Comparative Advantage
2. Market Structure and Spatial Agglomeration
3. Infant Industry Argument, and
4. Cluster Dynamics.

As we will refer to these concepts in the text, we have included a short discussion on each of them.

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1. Analytical Background of the Strategic Initiatives

The following concepts form the basis of topical economic research within international trade theory.

1.1. Comparative Advantage

The concept of comparative advantage can be traced back to Ricardo (1817). It has formed the basis of trade analysis (Heckscher and Ohlin 1919; Samuelson 1986). There have been an extensive number of theoretical contributions and empirical investigations both to the Ricardian and the Heckscher-Ohlin-Samuelson modeling tradition up to the present day. According to the trade literature, all trading regions will gain if each region is specialized in production at a lower opportunity cost than other regions. Particularly when trade barriers get lower, according to the Heckscher-Ohlin model, a region benefits if it increases the production of goods produced from the relatively abundant factors.

A small open economy has limited and scarce resources. Therefore, it is not economically reasonable to produce all the products for domestic markets itself. In order to apply a comparative advantage, it is necessary that economies specialize in some specific application areas or areas utilizing a specific combination of relatively abundant factors of production.

> *There will be economic overall gains within a free trade area if an industry utilizes a resource combination that is domestically relatively abundant.*

1.2. Market Structure and Spatial Agglomeration

Krugman and Venables have emphasized the new economic geography approach (Krugman 1991; Krugman and Venables 1995; Venables 1996). They analyzed how the market structure is related to the location of economic activities. The modeling of the market structure was based on the concept of monopolistic competition as presented by Dixit and Stiglitz (1977) and originating from Chamberlin (1933). The basic idea of the original analysis is to show how higher sunk costs in industrial production, for example, higher M&A or R&D costs, imply more differentiated products for consumers. In one extreme, there would be only a few producers with greatly differentiated products. In the other extreme, however, there would be an infinite number of low sunk-cost producers in case the consumer prefers a very large variety of less differentiated products.

Krugman extends the model of monopolistic competition to a spatial context (Krugman 1991). In the geographic center-periphery model there are three market features affecting the spatial structures:

1. Higher increasing returns to scale (IRS) in a manufacturing sector imply higher sunk costs in the production processes. This, in turn tends to lead to a strengthening of the geographic center-periphery structure.
2. The higher the sector's usage of available production factors, the more clearly a center-periphery structure gains strength.

3. Lower trade barriers or lower trade costs imply a tendency towards the spatial agglomeration of the IRS sector. These effects imply that firms gain an advantage of the local concentration of labor [or other factors]. The firms can also subcontract with each other locally, with relatively low transport costs (Krugman and Venables 1995; Venables 1996).

> *Peripheral regions (such as Finland) can attract companies as a basis for value adding activities if there is a critical mass of location-specific but globally scarce resources available in the periphery.*

1.3. The Infant Industry Argument

Hamilton (1791) and List (1841) argued for the public support of the infant industry to achieve a leading position over OR in (depending on your meaning) other countries. The infant industry argument is often interpreted to be based on the temporary need for protection (or support) of an infant industry if the industry is unable to grow in the international context of free trade and foreign rivals. The initial excessive costs of the industry support are assumed to be compensated by the later stages' excessive profits and economic growth, not captured without the short- term governmental support.

There are some basic arguments that provide a rationale for the supporting activities, such as cumulative learning within the infant industry through the creation of positive externalities. The potential externalities over time include, for example, availability of technically competent labor, technological spillover, and diminishing transport costs due to the creation of a local cluster. If these externalities could be created only through governmental promotion, and if the long-term GDP effects exceeded the initial short-term costs of the promotion, it would be reasonable to provide a temporary support scheme for an infant industry. The infant industry argument diverges thus from the static trade restriction schemes which protect domestic industry through permanent import tariffs or quotas or by other supporting schemes.

> *A short-term injection of governmental promotion for the strengthening of some emerging critical resources within an infant industry aims at providing positive externalities and an economic upside in the long term.*

1.4. Cluster Dynamics

Porter (1990) concludes the discussion on spatial competitiveness as the industry's ability to create radical and incremental innovations. In Porter's diamond model, innovation intensity depends on the interaction among four attributes:

1. Factor conditions
2. Demand conditions
3. Related and supporting industries, and
4. Market structure.

Skilled labor and a well-developed infrastructure are critical factors of production and innovations; if there are demanding and sophisticated customers in the domestic marketplace, the companies are forced to be innovative. An internationally competitive supporting industry is a key for the availability of cost-effective inputs. Competitive domestic markets with innovative rivals intensify the innovation processes, as well as the construction of a first-mover strategy.

> *The interaction of highly specialized resources, demanding domestic customers, internationally competitive supporting industries and hard domestic competition creates an innovative and competitive industrial cluster.*

1.5. Combining the theories: the way to proceed

The biotechnology industry extends its sales to the global markets. Therefore, the strategic implications are derived from the literature of international trade. The combination of the implications can be stated as follows:

> *Create a relatively abundant, location-specific, and globally scarce interactive combination of*
> 1. *Competent factors of production and infrastructure,*
> 2. *First-class and demanding domestic customers*
> 3. *Internationally competitive supporting industries,*
> 4. *A competitive domestic environment*
>
> *by strengthening temporarily those parts of the infant industrial cluster which are critical for the long-term growth and success.*

2. Definitions

This section defines the main terms applied in this paper. Sustainable development is defined in Chapter 2.1 and biotechnology in Chapters 2.2-2.4.

Sustainable development was first set as a policy goal in the United Nations Brundtland Commission report *Our Common Future* (UN 1987). The report set as a strategic goal environmental aspects and the inequality between northern industrial countries and southern developing countries. Recently, the European Commission, has focused on the societal aspects, calling for social cohesion between distinct origin, gender, and age groups.

In particular, the ageing population will pose a threat to the supply of public healthcare for everyone. Healthcare related “red” biotechnology might play an important role in controlling the rising healthcare expenditure by providing new cost-efficient applications. Additionally, some functional food applications might pro-actively offer positive health outcomes and thus prevent charges caused by an illness. Finally, applications of plant “green” biotechnology and industrial “white” biotechnology could provide some solutions for pro-

ducing biomass-based applications instead of petrochemical-based applications. These biomass-based applications could counteract the effects of climate change and shortage of non-renewable fossil fuels.

2.1. Sustainable Development

The European Commission defines sustainable development simply as a better quality of life for everyone, now and for generations to come. It is a concept that links economic development, protection of the environment, and social justice together. The concept of Sustainable Development contains:

1. Balanced and equitable economic development
2. High levels of employment, social cohesion, and inclusiveness
3. A high level of environmental protection and responsible use of natural resources
4. Coherent policy making in an open, transparent, and accountable political system
5. Effective international cooperation to promote sustainable development globally (EC 2005).

The European Union defines as its strategy for sustainable development the following three components: First, it sets out a broad vision of what is sustainable. The strategy's basic message is that, ultimately, the economic, social, and environmental dimensions of sustainability must go hand–in-hand and mutually reinforce one another. The second component seeks to improve the way in which we make policies, focusing on improving policy coherence and making people aware of possible trade offs between contradictory objectives so that informed policy-decisions can be taken. Third, it addresses a limited number of trends that are clearly not sustainable, such as the issues of climate change and energy use, threats to public health, poverty and social exclusion, ageing societies, management of natural resources, and land use and transport (EC 2005).

2.2. Biotechnologies

The term biotechnology has been defined in several ways. Appendix 1 provides 30 examples of definitions. In this paper we, however, use the statistical definition of biotechnology as presented by the OECD: "*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*" (OECD 2005).

2.2.1. Red Biotechnology

Healthcare Biotechnology is increasingly playing a role in conventional drug discovery and diagnostics, as well as the development of tissue equivalent biomaterials. Additionally, there are hopes for healthcare -or red- biotechnology to open up new possible ways to prevent, treat, and cure so far incurable diseases using novel methods of treatment and diagnosis. Biotech medicines, such as proteins, antibodies, and enzymes, now account for 20 percent of all marketed medicines and 50 percent of those in clinical trials. Biotechnology is also increasing the number of disease targets for conventional drug therapy. Today, conventional drugs target fewer than 500 diseases, but in the future this is likely to rise to between 5, 000 and 10, 000.

Through genetic engineering, biotechnology also uses other living organisms – plant and animal cells, viruses, and yeasts - to assist in the large-scale production of medicines for human use (bio-manufacturing).

The healthcare areas in which biotechnology is currently being used include medicines, vaccines, diagnostics, and emerging cell and gene therapies. The aim is create both comprehensive and highly individualized medicines, as well as move from **treatment** towards disease **prevention** and **cure**. Europabio classifies the following categories as belonging to red biotech:

- Cell and tissues
- Stem cells
- Gene therapy
- Orphan drugs and rare diseases
- Proteomics
- Pharmacogenetics
- Diagnostics
- Genetic testing

The term **tissue engineering** was coined at a National Science Foundation –sponsored meeting in 1987, and later defined as "…the application of principles and methods of engineering and life sciences toward fundamental understanding …and development of biological substitutes to restore, maintain and improve [human] tissue functions (Sittinger, Hutmacher *et al*.; ETES 2005; NSC 2005; TESI 2005). Applications are found especially in biomaterials, but also in other areas of healthcare as well as devices.

For example, damaged joint cartilage regenerates at best only poorly; however, cell therapy offers a means of restoring defects to knee cartilage by growing a patient's own cartilage cells to repair cartilage defects. Other application areas are in the fields of regeneration and repair of bones, tendons, nerves, and ligaments. Cell-based immunotherapy is also under intensive research, with one potential result being the development of cell-based tumor vaccines for cancer patients.

Research into **stem cells** may result in important cell-based therapies to treat serious diseases and conditions like Parkinson's disease, Alzheimer's disease, spinal cord injuries, as well as diabetes, stroke, burns, skin disorders, and heart disease. Researchers work on three types of human stem cells – adult, fetal or embryonic. Embryo manipulation can be performed in embryos originating both from animals and humans, with major ethical considerations especially around [human] stem cell research.

Despite the high standard of today's medical treatments, and the number of drugs already available, many of the most debilitating human diseases have eluded efficient therapy. **Gene therapy** has entered a phase of active clinical investigation in many areas of medicine. Human clinical trials have been started for the treatment of severe immunodeficiencies, cystic fibrosis, hypercholesterolemia, hemophilia, muscular dystrophy, many types of tumors (e.g. melanoma, prostate, ovarian, brain, and lung cancer), AIDS, and cardiovascular disorders. Cellular fusion technology might also constitute a novel means for gene therapy in the future (Daley 2004)

Some 20-30 million Europeans are affected by 5,000 rare diseases. Biotechnology has been able to provide tools for the diagnosis and treatment of some of these diseases. Fabry's and Gaucher's disease are examples of orphan diseases for which **orphan drugs** have been developed.

The Committee for Orphan Medicinal Products (COMP) at the European Medicines Evaluation Agency (EMEA) has adopted opinions on 167 orphan drug designations and the Committee for Proprietary Medicinal Products (CPMP) at the EMEA has been positive towards marketing approval of 13 designated orphan drugs.

Proteins and molecules are constructed in a living cell according to information extracted from the DNA/RNA codes. **Proteomics** and glycomics are regarded as the following steps in the cascade of genetic information, exhibiting a strongly increasing complexity, and requiring a wide array of assay tools (Hirabayashi and Kasai 2000; Fields 2001). Some diseases are caused if genes do not produce the proteins (or enough proteins) the body requires or if the body produces wrongly folded proteins. Biotechnology is using recombinant (artificially created) DNA and cell cultures to produce missing or defective proteins. Lipid/protein engineering and proteomics are especially used in the healthcare-related application areas, whereas food and feed related applications do not utilize such technologies

Pharmacogenetics refers to people, with two applications that may use similar techniques but are quite distinct: a) susceptibility gene identification and b) "right medicine for right patient". Pharmacogenomics is often separated as an entity in its own right, referring to the study of how an individual's genetic inheritance affects the body's response to drugs and holds the promise that drugs might one day be tailor-made for individuals and adapted to each person's own genetic makeup. (HGPI 2004)

We can now detect many diseases and medical conditions more quickly and with greater accuracy due to the sensitivity of new, biotechnology-based **diagnostic tools**. A good example is the Polymerase Chain Reaction (PCR) technology, which imitates a cell's ability to replicate DNA by generating multiple copies of specific sequences of DNA through amplification. In this way a minimal specimen of genetic material can be repeatedly copied to provide sufficient material to detect the presence or absence of a virus, as well as to quantify its levels in the blood. PCR tests were the first that could accurately measure the amount of HIV in a patient's blood. Other examples are tests to diagnose certain cancers, such as prostate and ovarian cancer, and determine the levels of LDL cholesterol by taking a simple blood sample.

The human health benefits of biotechnology detection methodologies go beyond disease diagnosis. For example, biotechnology detection tests screen donated blood and organs for the pathogens that cause AIDS, hepatitis, and a variety of other infectious diseases.

Currently over a thousand human hereditary diseases can be identified using **genetic tests**. Most of these tests detect the presence of a mutation or mutations in a single gene which lead to monogenic (single gene) disorders, most of which are relatively rare diseases.

Finland has been very active in its research concerning monogenic diseases typical for Finns; the Finnish gene trait for disorders is among the best known in the world. It is assumed that the knowledge of the genetic predisposition can offer epoch-making changes in the development of cures for metabolic diseases like aspartylglucoseaminuria (AGU), infantile neuronal seroid lipofuscinosis (INCL), and Salla disease,

as well as growth disorders like diastrophic growth disorder, cartilage-hair-hypoplasia, and Mulibrey nanism (MUL).

However, when we move to multigenic diseases the amount of required and managed knowledge increases significantly. In many forms of cancer, there is a genetic predisposition, but also a multitude of other [environmental] factors in tumor growth and malignancy. These tests will identify patients with a propensity to diseases caused primarily by environmental factors, such as diet, giving patients an opportunity to prevent the disease by avoiding the environmental triggers. Identifying the gene for such diseases and redirecting its course is an intriguing, but also very challenging, way to cure certain diseases.

Genetic testing is also critical to the development of pharmacogenetics, which uses biotechnology-based diagnostics to better diagnose disease and provide new ways to match medicine doses and treatments to the individual.
(Eskola 2005; EuropaBio 2005)

2.2.2. White Biotechnology

The term ‘white biotechnology’ encompasses an emerging field within modern biotechnology that serves industry. It uses living cells like molds, yeasts, or bacteria, as well as enzymes, to produce goods and services. Living cells can be used as they are, or they can be improved to work as "cell factories" to produce enzymes for industry. Living cells can also be used to make antibiotics, vitamins, vaccines and proteins for medical use. Examples of applications are:

Eco-efficient enzymes can serve as alternatives to some chemical processes to make products. Enzymes offer a biological route and often cleaner solution for industry; eco-efficient, enzymes consume less water, raw materials, and energy. The environmental impact can be minimized, yet offering better products at lower cost. For example, using enzymes in washing powder allows difficult stains to be removed at lower temperatures, saving energy and reducing the impact on the environment.

Biomass like starch, cellulose, vegetable oils, and agricultural waste are used to produce chemicals, biodegradable plastics, pesticides, new fibers, and biofuels , among others. The processes manufacturing them all use enzymes, and biomass is by definition made from renewable raw materials. An example is ethanol, a renewable fuel made out of biomass. It has the potential to replace fossil fuels, which would have a neutral impact on greenhouse gas emissions, and could contribute to reducing global warming (Helynen, Flyktman *et al.* 2002; EuropaBio 2005; Söderlund 2005).

2.2.3. Green Biotechnology

Green or **plant biotechnology** is often equaled to introducing foreign genes into economically important plant species, resulting in crop improvement and the production of novel products in plants. Currently, however, green biotechnology can be regarded as encompassing three major areas: plant tissue culture, plant genetic engineering, and plant molecular marker assisted breeding.

Plant tissue culture allows whole plants to be produced from minute amounts of plant parts such as roots, leaves, or stems or even just a single plant cell under laboratory conditions. An advantage of tissue culture is the rapid production of clean plant materials.

Plant genetic engineering encompasses the selective, deliberate transfer of beneficial gene(s) from one organism to another to create new improved crops, animals, or materials. Examples of genetically engineered crops include cotton, maize, sweet potato, and soybeans.

Plant molecular marker assisted breeding is a technique that uses molecular markers to select for a particular trait, such as yield. A molecular marker is a short sequence of DNA tightly linked to the desirable trait (such as disease resistance) so that selection for its presence ends up selecting for that desirable trait. An example is maize that is tolerant to drought and maize streak virus. (EuropaBio 2005)

2.2.4. Bioinformatics

Bioinformatics uses mathematical tools to extract useful information from data produced by high-throughput biological techniques. Bioinformatics is also referred to as computational biology. Bioinformatics applies the methods from the fields of mathematics, informatics, statistics, and computer science. It processes large sets of protein or DNA data and constructs models for biological systems. In order to understand and predict biological phenomena, bioinformatics is closely related to systems biology. Bioinformatics includes the following research areas: sequence analysis, genome annotation, gene expression analysis, protein expression analysis, protein structure prediction, modeling of biological systems.

In **sequence analysis**, computer programs are used to determine genes that code for proteins, as well as regulatory sequences on DNA, on organisms, which have been decoded and stored in electronic databases. **Genome annotation** is the process of marking the genes and other biological features in a DNA sequence. This enables the genes to be found, which are places in the DNA sequence that encode a protein, the transfer RNA, and other features, and to assign functions to the genes.

Gene expression analysis is based on measuring mRNA levels with several techniques, such as microarrays or by measuring protein concentrations with high-throughput mass spectroscopy. Protein microarrays and high throughput mass spectrometry provide a scheme of the proteins present in a biological sample. **Protein structure prediction** is being developed to provide predictions on how the folding of the primary structure of the protein results secondary, tertiary, and quaternary structures for the amino acid sequence of the protein.

Systems biology simulates the functionality of cellular subsystems. **Modeling biological systems** aims at analyzing and visualizing the inter-linkages in cellular processes. Simulation also provides understanding of the evolutionary processes.

3. A Sustainable Development Strategy for Finnish Biotechnology

The threats described below can be converted to opportunities by the biotechnology based innovation clusters; the innovation clusters are inter-linked with each other. **The healthcare cluster** aims at creating a competitive red biotechnology industry designated especially to saving healthcare costs in the long run. **The cluster for health promoting food** applications could also restrict the increase in healthcare costs. The success of the cluster is additionally linked to employment within rural areas. **The cluster of energy** applications is closely linked with the last mentioned geographic aspect and also the pollution from the non-renewable fossil fuels.

3.1. Healthcare

3.1.1. Increasing Healthcare Costs

The healthcare domain in Europe is performing a balancing act between the forces of inevitable change. The combination of an ageing population, an explosion of new therapeutic technologies, and a critical shortage of clinical professionals conflict with the needs to reduce costs, improve overall quality, and further expand services. The discovery of previously unknown disease mechanisms and their treatment possibilities appears to further increase the cost pressures in healthcare (OECD 2003).

There are several national diseases in Finland, the treatment of which has considerable effects on the Finnish economy. The direct costs of healthcare constitute only a portion of the total costs as, for example, the impact of absenteeism and pensions can be even more significant from a macroeconomic standpoint.

A profound change is imminent, the signs of which have already been seen in the pharmaceutical industry: a fierce horizontal integration has produced pharmaceutical giants that act in a multinational market, and however, are sometimes regarded as reaping unethically high profits.

The gap between the public and the private sector has traditionally been wide, but there is already a partial integration, and it is probably inevitable in Europe as a whole. The impact on the healthcare industry remains so far partly obscure, although a clear horizontal integration has recently also occurred among the private healthcare providers in Finland.

3.1.2. Biotechnology as a Source of Cost Savings in Healthcare

The potential role of biotechnology is divided. On the one hand, the aging of the population and the medical chances of diagnosing and treating more illnesses than before increase the cost pressures on healthcare. On the other, biotechnology applications are expected to result in long-term cost savings by, for example, making time-consuming diagnostic methods more efficient and facilitating targeted therapy. Pardes *et.al.* have discussed the potential of medical research to control the growth of healthcare costs, and Hermans and Kulvik have investigated how the Finnish biotechnology industry could offer solutions for the cost

crisis in healthcare while at the same time spurring development of an internationally competitive industrial cluster.(Pardes, Manton *et al.* 1999; Hermans and Kulvik 2004)

It is noteworthy, that some multinational pharmaceutical companies have stated in their global commercial strategy a clear desire to reduce the overall costs in healthcare (GlaxoSmithKline 2005; Lilly 2005). Simultaneously, pharmaceutical companies have expressed their specific interest in establishing research cooperation with Finnish biotechnology companies, preferably with the support of the Finnish authorities (2005).

Inaccurate diagnoses or a lack of appropriate treatment easily leads to a prolonged illness and thus an increased use of resources such as personnel and medication. Examples of this are strokes and schizophrenia, the former is a problem of the elderly population and the latter an illness affecting one percent of the world population. If more efficient ways can be found to diagnose and treat patients who would otherwise need long-term care, even relatively expensive methods can generate considerable cost savings.

The Disconnected Loop. The public health sector offers services paid by the authorities but used by patients. The connection between the features offered and the true costs is paid via taxes by everyone, distributed by national authorities, redistributed by hospital authorities, independently re-redistributed by the clinics, and finally consumed mainly by the doctors in charge of the patient, not the patients themselves. The quality offered to patients is mainly disconnected from the local authorities; the payers can express a desire concerning the services offered at a certain price, but the content and true costs are decided mainly by the hospital authorities.

The system contains virtually no inherent and self-guiding feedback-loops, and only scarce incentives for cost-awareness. Such a set-up is vulnerable to information asymmetry. The need for control can lead to the establishment of straightforward authoritarian directions that do not sufficiently acknowledge the tacit knowledge inherent in the personnel.

Re-establishing a feedback loop. The impact of a new technology can be technical, economical, and social. The technical value is usually assessed by medical experts, based on clinical research or best estimation by leading opinion leaders in the field. The economic impacts can be assessed either proactive, for example, as pre-marketing appraisals of the economic impact of a new drug, or retrospectively, for example, as research concerning the effects of an established treatment, performed by health economists at the request of the healthcare payer. The social impact is projected against general values in society, often even reflected in the laws and statutes of the country.

The model constructed by Linnosmaa, Kulvik and Hermans (2005) combines the different aspects of the impact of a specific technology into one single framework. As an example, we have implemented the model on the impact of thrombolytic therapy in the treatment of strokes in Appendix 2.

3.1.3. The Healthcare Innovation Cluster

The Finnish Resource Base. The national diseases have to some extent steered the allocation of domestic research resources, which has led to internationally significant areas of expertise in medical science and related fields. Finland's one payer healthcare system has facilitated a comprehensive patient case record scheme, which, combined with numerous

centers of excellence –rated clinical institutes, creates a unique base for biotechnology development carried out in Finland (Eskola 2005). The research knowledge and demand for its commercial applications arising from such public healthcare needs enable the domestic market to be used as a commercial test market. Cooperation with end users of healthcare products promotes the product development of biotechnology companies and the development of service concepts, as well as prepares companies' products and services to enter the highly competitive international markets.

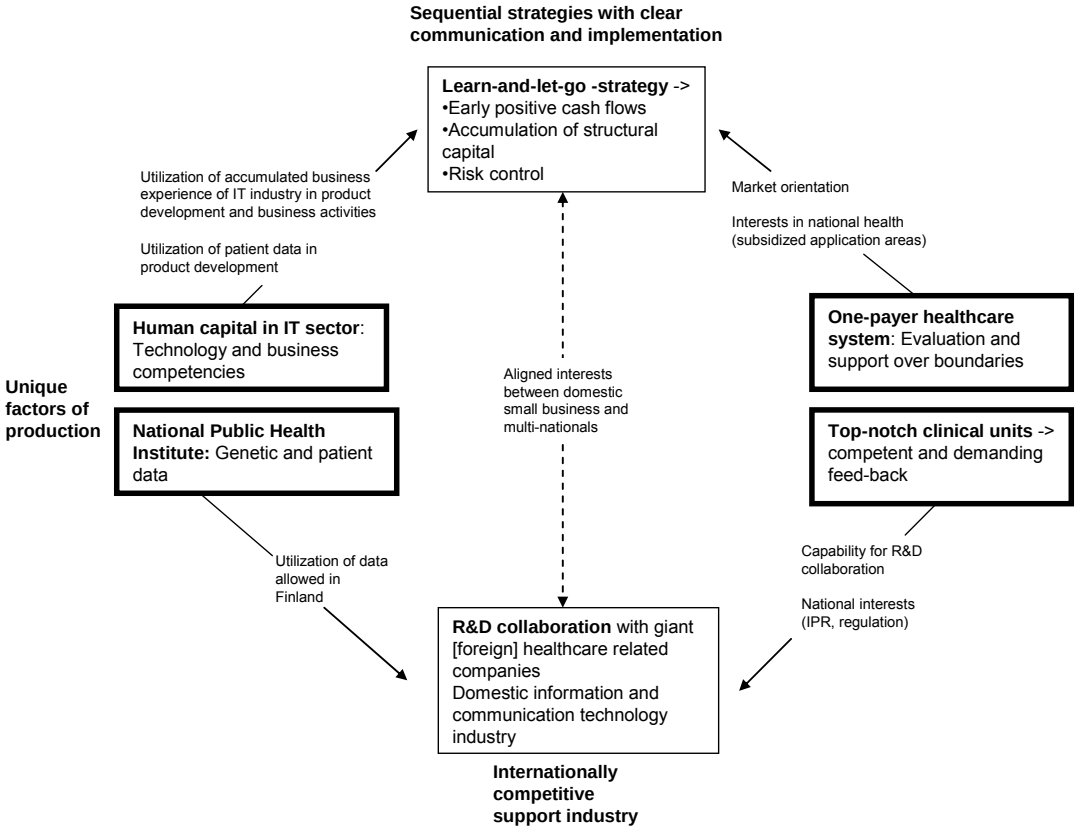

Figure 1. Sustainable Development Cluster for Healthcare Innovations.

Our suggestion is that[2]:

1. The Finnish data banks at the National Public Health Institute are utilized by offering their content to [international] pharmaceutical companies. However, the data offered is specified to cover only a clearly defined and focused application area. The original data banks remain the property of the National Public Health Institute
2. The research on the data must be performed in Finland, in collaboration with instances controlled by the National Public Health Institute. This would be secured by legislative means as it is in concordance with the original principles of the data bank collection intention: to promote and enhance the well-being of Finnish citizens. The knowledge spillovers remain the property of the National Public Health Institute.
3. If the invested data banks and knowledge are as valuable as assumed, even such a controlled opening of their data should attract international pharmaceutical compa-

[2] The main body of this strategy has been developed in discussions with Professor Juhani Eskola.

> nies to establish research collaboration with Finnish entities. The establishment of a research cluster strongly connected to the international [pharmaceutical] industry would be a strong positive sign for investors, and would also offer a means of reducing the present disadvantageous information asymmetry. (Eskola 2005)

We find it critical that the backbone of the research cluster consists of major companies, as they offer the necessary track record and knowledge of successful commercialization. Even an internationally recognized research institute without an evident track record of commercialization would not offer significant changes to the present situation *vis-á-vis* investors, risk control, and information asymmetry, but it could spur an outflow of innovations and human capital to companies abroad.

The Learn-and-Let-go strategy. The fully capitalized cost to develop a new drug, including studies conducted after receiving regulatory approval, is estimated at 897 million dollars; and only 21.5 percent of drugs that begin phase 1 human trials are eventually approved for marketing (DiMasi, Hansen *et al*. 2003). These are overwhelming data even for an established biotechnology company. Within the Finnish scope it can seem even naive to aim at becoming a full-blown drug development company, that is, to be able to follow a product from innovation to market launch.

The less regulated sector of biotechnology applications, such as equipment and diagnostic tools, does not have to face an equally long and challenging development process. However, the Finnish market is small and cannot offer a sufficient market potential for specified products. Finland can offer a domestic test laboratory for product development and market testing, but the final product launch must aim at larger markets such as the Nordic countries, Germany, or France, which requires significant experience and resources.

Both at present and in the near future the vast majority of the Finnish biotechnology companies have to show a clear strategy in order to be credible on the financial markets. Each of the following factors has been identified as obstacles to the credibility of Finnish biotechnology companies or projects (VC expert 2005):

- preponderance to overemphasize the value of basic research despite an officially disclosed goal of commercialization
- strong technology orientation
- reluctance to share knowledge concerning the innovation [to investors and evaluators]
- difficulty in accepting skills from outside own sector; typically, the need of specific expertise and experience in a commercialization process is not acknowledged
- reluctance to accept dilution of a minority position in the company
- overestimation of own managerial skills
- tendency to tamper with the set strategy

Most of these problems are typical of the high-technology and research-intensive sectors. However, due to the limited domestic potential, close collaboration with larger players in the field seems to be a necessity; any of the mentioned obstacles discourages successful cooperation.

We encourage Finnish biotechnology companies to consider the dynamic strategy of sequential learning. The main body of the strategy is to develop a product within the company only as long as the required skills are within the core competency of the company.

The next phase of development should be realized in collaboration with an experienced company in that field.

A dynamic flow of products also places stress on the company through the continuous pressure for change. The additional strain can at least partially be controlled by a well-structured and systematic approach in the execution of the strategy, with knowledge and personnel management becoming critical issues.

The tacit knowledge should be systematically converted into structural knowledge within the company from the collaboration, preparing the company to enter the next phase of development. However, when the product enters the following phase of development, the company should out-license it and focus on the next product –yet developing it in the company one step further before initiating a new collaboration. Personnel can be allowed to move with the out-licensed product to the collaborating company, as it results in an extending network of positive collaboration potential.

The aim is to create a dynamic flow of products and, when deemed beneficial, of personnel, while endowing the company with structural knowledge. The sequential out-licensing of products results in an earlier flow of income and a better control of risks inherent in biotechnological development. A concise strategy should also enhance credibility among investors and lead to better terms of outside financing.

3.1.4. Health Promoting Food Innovation Cluster

The drivers for a food innovation cluster are much the same as for the healthcare cluster: the healthcare payer has to find ways to control healthcare costs. In healthcare applications, the healthcare costs are controlled through more efficient treatment modalities, whereas in the health promoting food cluster the goal is set at preventing diseases and thus the need for costly treatments.

The health promoting food innovation cluster consists of:

1. Unique factors of production
Similar to the healthcare cluster, the unique Finnish patient data banks can be utilized in the research of health promoting foodstuffs. The relatively abundant fields are cultivated by farmers who have shown a significant ability to adapt and survive in the midst of major structural changes. The fourth potential factor lies in the Arctic dimension: an unpolluted soil that requires only minor amounts of fungicides and pesticides, and the exceptionally high concentration of beneficial nutrients in some species due to the extreme light conditions during summer.

2. The domestic market laboratory
Finnish products are perceived as clean, which puts a high standard on all new products entering the Finnish market. Additionally, it is within the interest of the healthcare payer to promote the health of the population, which aligns the interests, and also partly the criteria, with the development of healthcare applications.

3. Internationally competitive supporting industries
Several international food companies have established production in Finland. If the Finnish patient data could be utilized also in the development of health promoting foodstuffs, yet retaining the original data banks as well as spillover data in Finland through legislative measures, the international companies could cooperate with Finnish companies. This could also encourage venture capitalists' interest in Finnish biotechnology companies.

4. Sequential strategies with clear communication and implementation.
The value creation strategy can largely follow the principles described above for healthcare companies. Products tested in the domestic market laboratory can be exported to global markets in cooperation with international food giants. However, the international strategy should encompass an option of a reasonable termination of the cooperation if the planned sales are not achieved.

Health promoting food can be developed either in the form of food additives, or by enhancing the properties of the raw material. We have, however, to face the fact that transgenic plants are under intense debate, and the present customer perception is clearly controversial. This will be discussed further in Chapter 3.2.3. Revitalising the Rural Areas under Arctic Conditions. We believe that Finland should proceed in the production of transgenic food only after very careful consideration, where also the trade-off with brand perception is acknowledged.

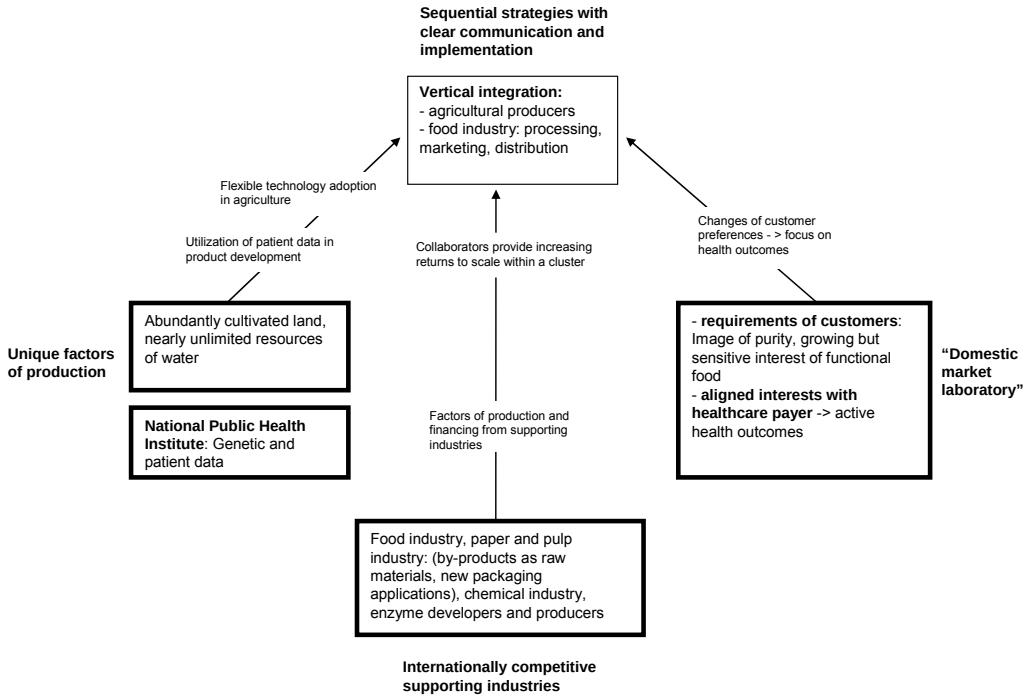

Figure 2. Sustainable Development Cluster for Food Applications.

3.2. Biomass

3.2.1. Pollution and Climate Change

The extensive use of fossil fuels has been proclaimed as posing a major threat to the global bio-system. We are faced with the fact that several of the global environmental problems will continue to worsen during the next 15 years, irrespective of even the strongest possible countermeasures. Pollution, erosion, and a warming of the climate are among the most evident changes to be encountered. As oil reservoirs outside the Middle East are becoming depleted, the rising prices together with a geographically skewed production will probably strain the existing economic balance. However, applications of plant "green" biotechnology and industrial "white" biotechnology could provide some solutions for producing, for example, bio-fuels instead of polluting fossil fuels, as well as growing specified crops that take advantage of the Arctic dimension of the Finnish environment.

3.2.2. Biotechnology as a Tool for Production of Renewable Bio-Fuels

Finland is perceived as a relatively unpolluted country, which could be used to build an image of Finland as being in the forefront of sustainable development. The Finnish plant biotechnological development could focus on plant breeding using non-transgenic solutions.

In non-food production, it is possible that the acceptance for technologies differs from food-applications. In biomass production for fuels and other forms of energy, more sophisticated technologies could be used also in the open systems. An example thereof is genetic engineering performed within the same species.

3.2.3. Revitalising the Rural Areas under Arctic Conditions

The anticipated change in climate poses threats to European agriculture. The following factors have been identified as major concerns:

- shortage of irrigation water combined with an increased need for irrigation
- higher risk of plant diseases and insect attacks
- pollution, toxic compounds in soil

Biotechnology could offer solutions to these imminent threats, and consequently the European Technology Platform has defined goals for the European agricultural research (EC 2004). However, the required characteristics of open-air plants and crops to be grown and developed in Finland differ in many respects from their southern counterparts:

Key goals for agro-biotechnology	Finnish agricultural attributes
improved resistance to drought	virtually infinite reservoirs of fresh water
improved resistance to plant diseases and pests	exceptionally low threat of plant diseases and harmful insects due to cold winters and the geographic isolation (the Arctic dimen-

	sion; remote geographical location protecting from migration of pests)
improved resistance to toxic compounds in soil	very low pollution in soil, water and air (peripheral location, low population density, scarce heavy industry, and low need for insecticides and herbicides)

Additionally, the Arctic dimension results in specific conditions typical of the Finnish climate, such as a low biodiversity and a delicate balance of species, a low yield of agricultural production which can never be competitive in terms of production volumes, as well as an exceptionally long daytime during the growth season resulting in natural enrichment of beneficial compounds in plants.

It seems inevitable that the mainstream plant biotechnological development will go in a direction not aligned with Finnish needs (EC 2004; 2005; Metzlaff 2005). The mainstream European products probably express characteristics that offer only slight advantages in the Finnish climate. Consequently, the Finnish plant biotechnology research can use the same basic technologies as the mainstream European research, but it must develop applications specific for Arctic conditions. This requires bioinformatics knowledge that enables the breeding of plants that conform to the specific conditions and needs of Finland. Due to the same Arctic dimension, the international market potential of products developed for domestic use does not lie within Europe.

In food, the research should and could take advantage of the Finnish data banks of the Finnish population. Additionally, it would seem logical to develop food and functional food compounds with positive health outcomes in the fields of common risks in the Finnish population.

Acceptability. Transgenic plants are under intense debate, and the present customer perception is clearly controversial. Additionally, the risks associated with the Arctic and its fragile nature could be seen as discouraging open-air cultivation of transgenic plants. Pharmaceutical compounds produced by plant biotechnology, as another extreme, would probably gain customer acceptability even if produced through transgenic organisms if they are cultivated in closed systems.

3.2.4. Energy Innovation Cluster

The cluster of energy Innovations can draw from 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 cannibalize 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 utilization of biomass to manufacture mixtures of polymers that could serve as substitutes for the current plastics.

The Finnish Energy Innovation Cluster consists of the following:

1. Unique Factors of Production
Finland has large forest reserves (70 percent of the total area) and relatively large areas of cultivated ground. A climate change might result in a paradoxical situation where the comparative advantage of Finland would be enhanced: growth could become stronger supported by virtually unlimited resources of fresh water and a cold winter killing most of the agricultural pests.

2. The Domestic Market Laboratory
The Arctic conditions call for fuel solutions that work faultlessly in extreme conditions.

3. Internationally Competitive Supporting Industries
The Finnish petrochemical industry has clear incentives to develop solutions offering alternatives to fossil oil as a raw material. Additionally, the side products from the Finnish forest industry offer several alternatives for energy production, as well as the manufacturing of polymer mixtures.

4. Sequential Strategies with Clear Communication and Implementation
A clearly defined and communicated strategy forms the mainframe for the successful operation of a biotechnology company. Vertical cooperation with the agricultural producers secures the optimal raw material production, and close cooperation with the distributors enables the full and rapid utilization of the domestic market laboratory.

The energy cluster can offer Finnish agriculture opportunities to adapt to market-based operations. Biotechnological solutions could be applied to enhance the cultivation of raw material suitable for energy applications. Process biotechnology can be utilized in the production of bio-fuels, and the designing and building of large-scale refineries call for a cooperation with the domestic machine industry. The Finnish Energy Innovation Cluster could later export the concept as a whole to locations with larger cultivated grounds.

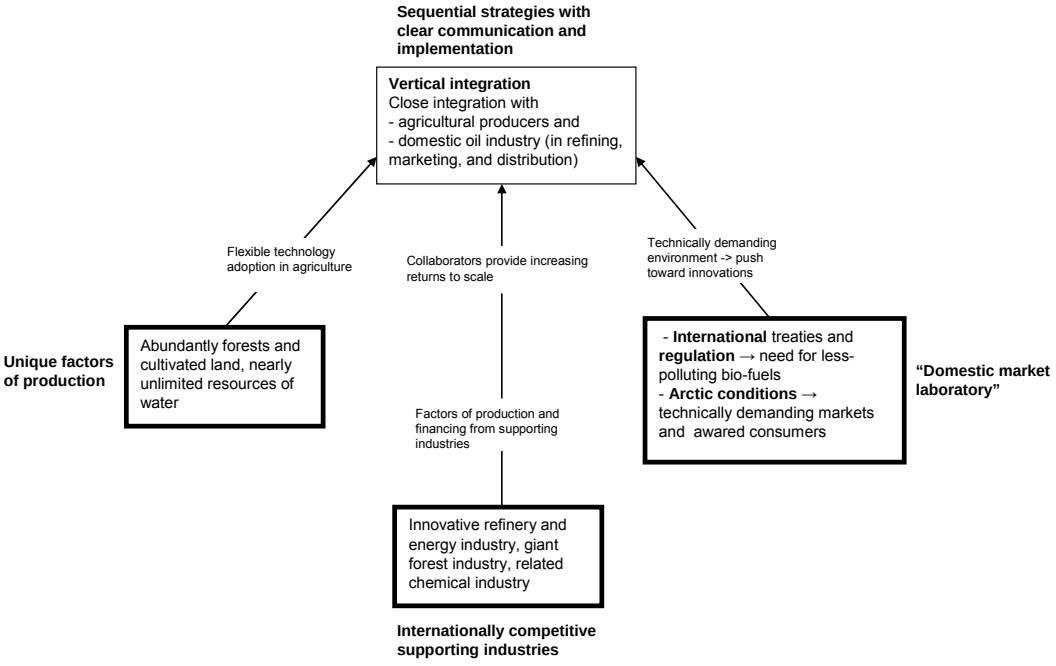

Figure 3. Sustainable Development Cluster for Energy Applications.

3.3. Solid Basis on Distinctive Innovation Clusters: Bio-Informatics

3.3.1. The Role of Bioinformatics in Finnish Healthcare

It is in the best interests of Finland to both use the data banks, and yet protect them from exploitation in an unrefined, low-value form. The value creation potential is best captured by processing the data as far as possible domestically. Bioinformatics in its wide definition is the backbone of the value creation path; sequence analysis, genome annotation, gene and protein expression analysis, structure prediction, and biological system modeling range from core DNA to the complex cellular subsystems (Eskola 2005; Wikipedia 2005).

Finland clearly has a relatively strong IT industry, and there are several research groups and companies that have been able build up significant knowledge in the field of bioinformatics, spurred by the top-notch gene research that requires efficient computational skills.

Processing the data banks domestically offers a means of protecting the data, as only the results of the data mining are delivered to the customers. The valuable raw data, as well as the valuable information processing data, remain the property of domestic entities. Through such an arrangement, the National Public Health Institute, the respective research institutes, universities, and hospitals can refine their data and thus create value both in the form of more valuable end products and the spillover-data that can be utilized for further Finnish research.

The bioinformatics companies gain from being able to not only sell top-notch processing ability, but also offer results based on proprietary data; this can result in an absolute competitive advantage. The companies can create high-value but well-protected data processing tools in close cooperation with the National Public Health Institute and research teams, offering an excellent R&D potential. Additionally, the potential is created for a dynamic flow of people from research teams to bioinformatics companies, as well as an exit possibility of bioinformatics professionals to companies that utilize the data analyzed.

From a national technological standpoint, it could be logical to strongly promote an existing and well-developed IT industry to proceed to new application areas. Due to the domestically controlled data banks, the companies could be tied to Finland, in contrast to potential biotechnology companies that seldom build on proprietary knowledge that would not be easily transferred abroad.

For the National Public Health Institute, a well-controlled utilization of the data banks would yield highest possible value creation; a utilization that offers an accumulation of new data based on the processing of existing data banks. The National Public Health Institute can guide the utilization of the patient data banks with emphasis on positive health outcomes on a national level.

For society, the setup offers a chance to steer support to domains that are aligned with the national health aspect, with the ultimate goal of promoting the well-being of its citizens and control the growth of healthcare costs. In the long term, the created cluster offers a natural way to increase cooperation with multinational pharmaceutical companies in projects that are in Finland’s interests.

3.3.2. Bioinformatics as an Innovation Cluster

The key for understanding the functions of cells and biological systems lies in a better understanding of their genetics. With the development of high throughput sequencing equipment, the collection of data has expanded exponentially. Bioinformatics has developed to extract knowledge out of the massive data collections.

The basic principles and challenges for data refinement are strikingly similar within all fields of biotechnology, and thus most of the points described in Chapter 3.3.1. also apply for white and green biotechnology. We simply conclude that bioinformatics could form the basis for a successful technology platform for and within Finnish biotechnology as a whole.

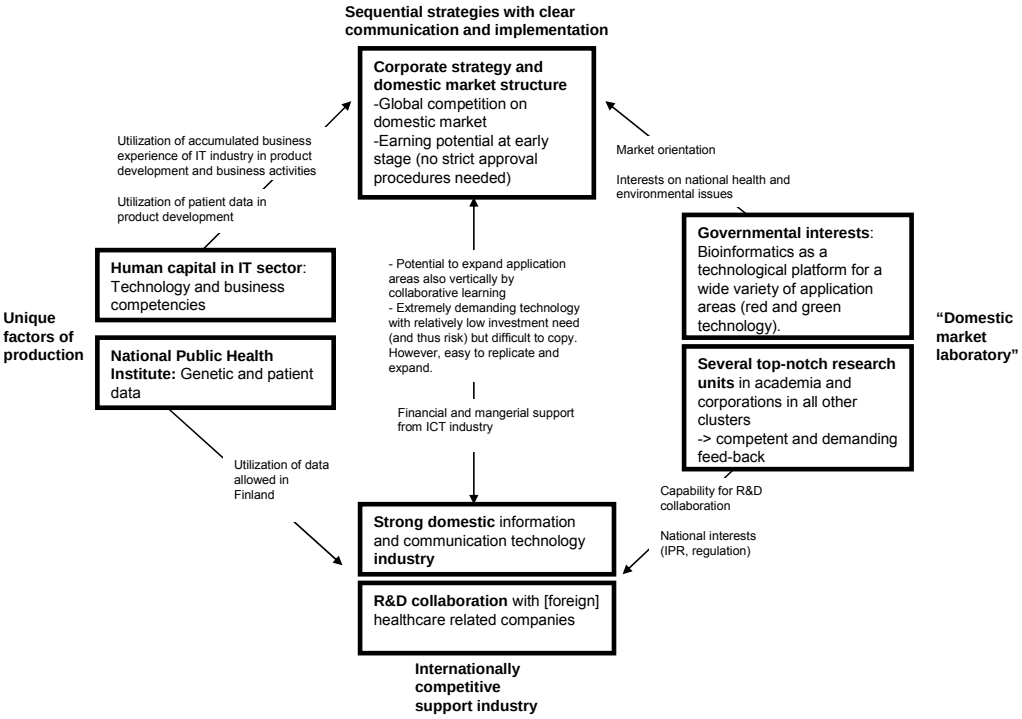

Figure 4. The Sustainable Development Cluster for Bioinformatics.

4. Discussion

Many Finnish research-oriented and technologically advanced biotechnology companies, however, lack business expertise (e.g. Hermans 2003; Tahvanainen 2004). An intensive producer-user relationship offers the companies a unique opportunity to better understand the needs and requirements of domestic but world-leading customers. By serving the demanding domestic customer, the companies accrue marketing experience that can successively be exploited on a larger scale by entering the global markets.

The thin layer of potential financiers has been regarded as a major problem for Finnish biotechnology companies, striving from innovation to commercial applications. In the following we try to evaluate the situation in more depth, with special focus on venture capital type financing.

Biotechnology is seen as a complicated investment area among venture capitalists as well as other investors. Recognized problems are the high technological risks, long product development times, and especially the risks associated with the "bio" –part of biotechnology: unpredictable outcome of development, heavy regulatory environment both in healthcare, as well as areas including genetic modification, potential liability issues, and the complex scientific base yielding only restricted insight for evaluators from outside the field.

There is an imminent risk of information asymmetry between investors and investees, and we cannot rule out the possibility that this information asymmetry is sometimes sustained by biotechnology researchers. Several biotechnology company leaders claimed that only biotechnology [research] specialists are competent to manage biotechnology companies. The view is in contrast with policies adopted by investors outside Finland.

The lack of investors in Finnish biotechnology companies suggests that the companies are not regarded as sufficiently inviting investment objects. There are no true exit opportunities, nor a developed IPR market; Finnish biotechnology companies seem in part to be isolated from international investment trends. The evident information asymmetry barrier aggravates such isolation, and should thus be broken. (VC-expert 2005)

Investors are reluctant to move alone into a new geographical or contextual area as the costs of screening and monitoring tend to rise. It is critical for Finland to lower the investment threshold by 1) offering means to diminish such costs and 2) by enhancing the credibility and transparency of the Finnish biotechnology industry.

Public sector subsidizing start-up companies. The public sector can set economically meaningful policy goals, which support sustainable development. For example, the public sector can pursue the restrictions on the increase of healthcare costs. Accordingly, a public sector financier demands the same goals from the project that it subsidizes. To this end, the public sector acts as a customer. This behavior steers the subsidized start-up company to consider the customer benefits. This, in turn, guides the pricing of the product and valuation of the company. Thus, the public sector's role as a customer accumulates the business attitude and competencies within the company.

Public sector financing biotechnology companies. The financing body of the public sector can provide external market-based financing to the companies at a more matured stage. Then the terms of financing are venture capitalist.like and conventional milestones are set according to the strategy of the biotechnology company. If R&D activities and the commercialization proceed within the milestones the governmental venture capitalist performs a sanction. Then the project can be cancelled, the related IPRs realized or the ownership of the company transferred to another party. The failure of a publicly funded project should, however, produce some spillover effects to other commercializing organizations in the society as opposed to privately funded projects.

Public sector promoting R&D programs. R&D projects of the biotechnology companies are aimed at increasing the owners' wealth even in the short run. If that is the case, sustainable development, which is focused on long-term perspectives, does not necessarily pro-

vide any incentives for the leaders of a company. The public sector could be an sole actor steering the company's R&D activities to such application areas, which are aligned with the strategic aims of the public sector related to sustainable development.

The abovementioned innovation clusters can be seen also as a proposal for the governmentally subsidized programs. At this stage of the development of the biotechnology industry, the "technology programs" should be clearly focused on distinctive application areas instead of on individual technology or bundle of technologies. This would ensure that the company would be focusing on the market place even at the initial phase of the project. Then, for instance, in the creation of novel energy applications, various potential technologies (also other than biotechnologies) would be exploited. The development of biotechnologies would not contain any intrinsic value *per se*. The commercial value of the biotechnology would be benchmarked with the value of alternative technologies in which case biotechnology could become part of the technology options for the firms active in the conventional industrial fields. Biotechnology would not then remain a separate branch funded by society with no significant societal benefits.

Society could define, in comparison with the non-biotechnological solutions, how much it would be ready to pay for the promotion of sustainable development. And the biotechnology companies could assess the opportunity costs of the societal goals on sustainable development and the terms of financing from the private sector.

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Appendix 1. Descriptions of the term 'biotechnology' as obtained from different sources

Description	Source
1. The use of biological processes to manufacture products.	www.med.nyu.edu/rcr/rcr/glossary.html
2. The application of biological research techniques to the development of products that improve human health, animal health and agriculture.	www.genencor.com/wt/gcor/glossary
3. The use of living things to make products.	ehrweb.aaas.org/ehr/books/glossary.html
4. The industrial use of living organisms or biological techniques developed through basic research.	fightaidsathome.scripps.edu/glossary.html
5. Any technique that uses living organisms, or parts of organisms, to make or modify products, improve plants or animals or to develop microorganisms for specific uses.	www.doe.mass.edu/frameworks/scitech/2001/resources/glossary.html
6. A set of biological techniques developed through basic research and now applied to research and product development. In particular, the use by industry of recombinant DNA, cell fusion, and new bioprocessing techniques.	www.bioinformatics.buffalo.edu/current_buffalo/glossary.html
7. Any technological application that uses biological systems, living organisms,or derivatives thereof, to make or modify products or processes for specific use	www.wfed.org/resources/glossary/
8. The use of living organisms or their products to make or modify a substance. Biotechnology includes recombinant DNA techniques (genetic engineering) and hybridoma technology.	thyroid.about.com/library/immune/blimm35.htm
9. A broad term generally used to describe the use of biology in industrial processes such as agriculture, brewing and baking. Recently, the word has come to refer more to the production of genetically modified organisms or the manufacture of products from genetically modified organisms.	www.biotechnology.gov.au/biotechnologyOnline/Resource/glossary.htm
10. Application to industry of advances made in the techniques and instruments of research in the biological sciences.	aerospaceschol-ars.jsc.nasa.gov/HAS/cirr/glossary.cfm
11. The scientific manipulation of living organisms, especially at the molecular genetic level, to produce useful products	www.woodrow.org/teachers/bi/1994/glossary.html
12. Techniques that use living organisms or parts of organisms to produce a variety of products (from medicines to industrial enzymes) to improve plants or animals or to develop micro-organisms to remove toxics from bodies of water, or act as pesticides.	www.nsc.org/ehc/glossary.htm
13. Term used to describe the use of any living organisms in industrial and production processes.	www.aquatext.com/list-b.htm
14. Biological science when applied especially in genetic engineering and recombinant DNA technology.	www.ventria.com/glossary.asp
15. The application of biological knowledge to practical needs. Often refers to (1) technologies for altering reproduction, or (2) technologies for locating, identifying, comparing or otherwise manipulating genes.	www.alpacas.com/AlpacaLibrary/GlossaryAC.aspx
16. A set of techniques, such as those used to make DNA in laboratories, developed through basic research that are now used by companies to make new drugs.	www.psoriasis.org/facts/glossary/
17. The integration of natural sciences and engineering sciences in order to achieve the application of organisms, cells, parts thereof and molecular analogues for products and services	www.solvo.hu/glossary.html
18. A term designating the use of genetic engineering for practical purposes, notably the production of proteins in living organisms or some of their components (bacteria, mammalian cells).	www.nccr-oncology.ch/en/glossary/glossary.htm
19. Biotechnology is a collection of technologies that capitalize on the attributes of cells, such as their manufacturing capabilities, and out biological molecules, such as DNA and proteins to work for us. Biotechnology will help improve our ability to customize therapies based on individual genomics; prevent, diagnose and treat all types of diseases rather than rely on rescue therapy and provide breakthroughs in agricultural production and food safety.	www.mayouminnesotapartnership.org/glossary.html
20. Systems biology	www7.nationalacademies.org/resdoc/Taxonomy.html
21. The industrial use of living organisms or biological methods derived through basic research; examples range from genetic engineering to making cheese or bread.	www.nigms.nih.gov/news/science_ed/chemhealth/glossary.html
22. A scientific process by which living things (usually plants or animals) are genetically engineered.	www.ecohealth101.org/glossary.html
23. The use, creation, or mutation of living organisms to make or improve industrial, agricultural, and medical products. Early examples of biotechnology include breeding plants for specific characteristics and using yeast in bread baking. A current example is genetic manipulation.	www.icons.umd.edu/resource/glossary.htm
24. Employment of biological and/or molecular processes, within the framework of technical processes and industrial production, for employment in pharmaceutical basic research and development	www.mwg-bio-tech.com/html/glossary/glossary_overview.shtml
25. The use of biological processes or organisms for the production of materials and services of benefit to humankind. Biotechnology includes the use of techniques for the improvement of the characteristics of economically important plants and animals and for the development of microorganisms to act on the environment.	www.fao.org/docrep/003/X3910E/X3910E05.htm

26. “The branch of molecular biology that studies the use of micro-organisms to perform specific industrial processes; "biotechnology produced genetically altered bacteria that solved the problem the branch of engineering science in which biological science is used to study the relation between workers and their environments.	www.cogsci.princeton.edu/cgi-bin/webwn
27. Biotechnology is technology based on biology, especially when used in agriculture, food science and medicine.	en.wikipedia.org/wiki/Biotechnology
28. The use of biological processes to manufacture products.	www.med.nyu.edu/rcr/rcr/glossary.html
29. The application of biological research techniques to the development of products that improve human health, animal health, and agriculture.	www.genencor.com/wt/gcor/glossary
30. The use of living things to make products.	ehrweb.aaas.org/her/books/glossary.html

Appendix 2. Technology Adoption and Healthcare Costs

It is evident that the different impacts are sometimes assessed by people representing rather different professions, values and cultures. Communication becomes a key issue. In an attempt to lower the communication barrier we have, as part of our project, constructed a model for assessing the influence of a new healthcare technology for society.

When implemented to a new technology, the model yields a conditional set of inequalities. The right side of the inequality gives a quantitative appraisal of the impact of the new technology, converted to a monetary value. The value is derived based on input from studies and/or experts in medicine and [health] economics, respectively. The left side of the inequality reflects non-monetary values that are at the discretion of the decision makers of society. The details of the model will be published separately.
We derive the following inequality:

$$v(q^*) - u(a^l) \geq -64375€ / \textit{patient}$$

where $v(q^*) - u(a^l)$ reflects the added value of a successful acute treatment compared to optimal long-term treatment, and -64 375€ is the monetary value above which the added value should remain in order for thrombolysis to be adopted. It is evident that the inequality is true, which is in concordance with the results obtained from plain economic analyses: treatment of stroke with recombinant DNA based alteplase not only saves lives, but also incurs significant monetary savings for society.

In Figure 1 we have extended our view to also include basic care (technology 0) and specialized care in a stroke unit (technology 1). The Figure depicts the cost-benefit barriers for acute care treatment of stroke *vs.* basic care. p_1 and p_2 represent the costs of technology 1 and 2, respectively, and T_1 and T_2 the probabilities of healing the patient with the corresponding technologies.

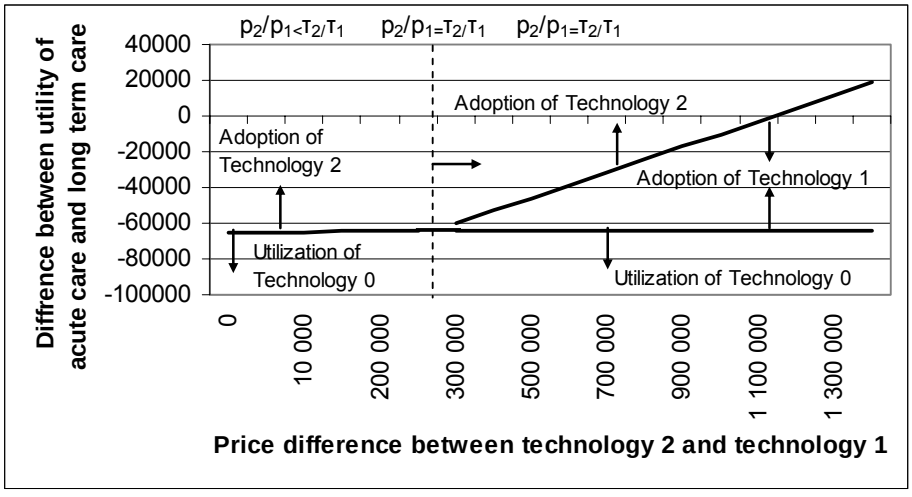

Figure 1. The cost-benefit frontiers in acute care treatment of stroke in increasing prices of thrombolysis therapy. Change long term to long-term

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