Foresight Activities in the Indian Biotechnology Firms

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CERTIFICATE

This is to certify that the dissertation entitled *"Foresight Activities in the Indian Biotechnology Firms"* submitted by Pallavi Singh in partial fulfilment of the requirement for the award of **Master of Philosophy** has not been previously submitted for any other degree of this or any other University.

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(Pallavi Singh)

DEDICATED TO...

Maa and Papa

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Chapter 1: Introduction

1.1 Significance of Technology Foresight

Technology foresight is about thinking, debating and shaping the future. As such, foresight activities play a pivotal role in today's decision-making processes within organisations that try to formulate forward planning strategies or future-orientated policies. In particular, foresight activities are an increasingly important tool in the process of developing research and innovation strategies in all the sectors of economy. It reflects the fact that decision making in the Research &Technology area is becoming more and more complex, with science and technology (i.e. scientific and technological innovation) being both a major driver of and strongly driven by social change and economic development. Innovation is now seen to take place in larger heterogeneous entities – be it within sectoral, regional, national, or even international innovation systems. Against this background, foresight has a huge potential to raise awareness and to generate better knowledge of those interdependencies among the different actors and the possible long-term challenges and opportunities arising out of this, as well as providing them with a point of entry in the process of shaping their common future.

Hence, this research work is based on foresight activities in the Indian Biotechnology sector, in the context of sectoral innovation framework. This research work also deals with the current uses, practices and impacts of Technology Foresight applied on both public and private biotechnology firms of all the major sectors of biotechnology, with a particular view to the possible contributions to innovation that foresight activities might bring in an entrepreneurial context.

1.2 Objectives of the study:

The following are the broad objectives of the present study:

- To explore and analyse the status of biotechnology foresight activities of the Indian biotech firms.
- To identify the methodologies that biotech firms are using, the extent and purpose of using those methodologies
- To analyse the differences between the methodologies and approaches adopted by the public and private biotech firms and also to analyse sector wise differences.
- The present study will seek to analyse the relationship among the firm's nature, size, the industry to which it belongs and the foresight methodology which it considers as useful.

1.3 Analytical Framework

This research work is carried out to explore the status of foresight exercise in the Indian biotechnology firms (small, medium and large scale). This has covered the different sub-sectors like health, agriculture, bioinformatics, environment and industrial biotechnology. The main purpose of this study is to enquire about different types of foresight methodologies used by the biotechnology firms of different sectors; their purpose of using these methodologies; the relationship between the firm's sizes (small, medium or large scale), sector and the foresight methodology which it considers as useful. The aim is also to find out the difference between the methodologies or approaches adopted by the public and private biotech firms. The present study is carried out in the sectoral innovation framework. In this context the contribution of foresight to innovation system is also analysed.

1. 4 The present work revolves around the following framework:

1. What are the different foresight methodologies adopted by the biotech firms?

2. Is there any difference in the methodologies adopted by the public and private companies?
3. What is the significance of foresight activity in innovation?
4. Does the adaptation of methodologies also depend upon the size of the industries (small, medium and large scale)?
5. How far foresight exercise is helping biotech firms in the strategic planning of the future?
6. What are the challenges faced by biotech firms in conducting foresight exercise?
7. What are the present approaches and trends observed in the biotechnology firms conducting foresight exercise?

1.5 Methodology

This research work is based on the primary data collected from the questionnaire e-mailed to around 400 biotechnology firms. The software used for preparing questionnaire is Infopol 7.5 designer software. The questionnaires were mailed to the heads (chairman/director) of the biotechnological firms. The list of the firms to whom the questionnaires were sent was prepared from the "Directory of Biotechnology Industries and Institutions in India" published by "Biotech Consortium India Limited (BCIL)". Its latest 5th edition of 2007 was used. Apart from the questionnaire survey, 3 Structured Interviews were also conducted with some of the technological head of the organisations namely: International Centre for Genetic Engineering and Biotechnology, National Centre for Plant Genome Research and National Institute of Immunology, New Delhi. Further, varied literature survey has also been done in the form of secondary data.

Chapter 2: Review of Literature

The present research work is based upon the conceptual approach of Technology Foresight combined with Sectoral System of Innovation, for greater understanding of biotechnology sector in India. Further, this thesis seeks to apply a model of the development of foresight as a means of understanding the roles and functions it has acquired and as a basis for evaluating its significance. Thus Greg Tegart (2003), defines foresight as, "Foresight involves systematic attempts to look into the longer-term future of science, technology, the economy, the environment and society with a view to identifying the emerging generic technologies and the underpinning areas of strategic research likely to yield the greatest economic and social benefits." There are a number of implications of this definition which are discussed as follows:

a) The attempts to look into the future must be systematic to come under the heading of 'Foresight';

b) These attempts must be concerned with the longer-term, typically 10 years and possibly 5-30 years;

c) 'Foresight' is a process rather than a set of techniques and involves consultation and interaction between the scientific community, research users and policymakers;

d) Its focus is on the prompt identification of emerging generic technologies, i.e. technologies whose exploitation will yield benefits for several sectors of the economy or society. Such technologies are still at a pre-competitive stage and can be targeted for selective funding to ensure rapid development;

e) Another focus is on strategic research, i.e. basic research carried out with the expectation that it will produce a broad base of knowledge likely to form the background to the solution of recognized current or future practical problems;

f) Attention needs to be given to the likely social benefits of new technologies and not just their impact on industry and the economy.

Hence, it is important to stress that Foresight is not the same as technology forecasting which assumes that there is a unique future. It is then the task of the forecaster to predict, as accurately as possible, what this will be. By contrast, Foresight is concerned not so much to predict the details and timing of specific developments as to outline the range of possible futures which emerge from alternative sets of assumptions about emerging trends and opportunities. Exactly which one is arrived at depends upon the choices made in the present. Foresight offers the chance to shape the future though wise decision making.

Further a critical feature of the 'Foresight process' is to define the aim since this determines the nature of the linkage with the decision-making process. Six possible aims are:

1. Direction setting - broad guidelines in science policy and the development of an agenda of options;
2. Determining priorities - perhaps the most important aim of foresight and the driving force in most of the documented country exercises against a background of resources restraint and increasing demands from researchers;
3. Anticipatory intelligence - identification of emerging trends with major implications for future policy making;
4. Consensus generation - promotion of greater agreement among scientists, funding agencies and research users on identified needs or opportunities;
5. Advocacy - promotion of policy decisions in line with preferences of specific stakeholders in the R&D system;
6. Communication and education - promotion of internal communication within the scientific community, promotion of external communications with users of research and wider education of the general public, politicians and bureaucrats (Tegart, 2003).

In addition to above specified aims, Ben R. Martin and Ron Johnston (1999) have summarized some of the functions of technology foresight which are as follows:

• It provides an approach for making choices in relation to science and technology and for identifying priorities;

• It offers a mechanism for integrating research opportunities with economic and social needs and thereby linking science and technology more closely with innovation, wealth creation, and enhanced quality of life; and

• It can help to stimulate communication and to forge partnerships between researchers, research users, and research funders. In short, foresight opens up the possibility of negotiating a new and more fruitful relationship or "social contract" between science and technology, on the one hand, and society on the other.

As the present thesis deals with technology foresight in biotechnology firms, hence in this regard, Patrick Becker (2002) has identified some of the problems in conducting foresight in firms:

1) Methodological Problems:

• Foresight needs a better/stronger methodological grounding, especially with regard quantitative analyses and economical modelling, in order to achieve a greater accurateness of its results.

2) Organisational and Managerial Problems in the Foresight Process:

• It has been analysed that there is a lack of feedback from the users of foresight data - more feedback would be helpful to trigger off leaning-effects and to make foresight predictions more accurate and more user-friendly or customer orientated.

• The positive effects of foresight-activities on the business operations are not always attributable and easy to proof. Therefore it is also important to develop ways to better measure the benefits that foresight activities have on the business success – it is much easier to communicate and promote foresight activities with clear costs & benefits indicators.

3) Overall integration of foresight activities within firms:

• A major problem with foresight is that, it is often too fragmented (i.e. there are no centralized offices/departments but a lot of lone hands) and too segmented (i.e. the activities are too specialised and to uncoordinated to give a complete picture).
• Foresight needs to be re-positioned in the firm – it mustn't be limited only with R&D-decision-making issues but could be more broadly used for corporate development and strategic planning.
• Foresight needs to be integrated more strongly in the firm's culture (via monitoring systems, future workshops, or in mission/vision statements).

4) Foresight could certainly profit from the use of more external know how, but so far there is lack of networks of (internal and external) foresight professionals.
If all the above problems are properly addressed in the firms then it might be possible that the firms could be able to conduct foresight exercise efficiently. Therefore to promote foresight in firms it is crucial for it to better communicate its use (i.e. how to use it) and its usefulness (for example, by illustrating the benefits with exemplary case studies, etc.); moreover it is important to establish a wide network of stakeholders/partners within the firm. Further there is a need for training workshops and joint foresight exercises to disseminate the knowledge for technology foresight.

Furthermore in context to the role of technology foresight in innovation Ben Martin (1999) argues that, the process benefits associated with foresight are very much concerned with fostering productive long-term partnerships—among researchers and among firms, across industrial sectors, and between industry, universities, government, and society at large. Thus technology foresight offers a means of "wiring up" and strengthening the connections within the innovation system so that knowledge can flow more freely among the constituent actors, and the system as a whole can become more effective at learning and innovating. He further states that technology foresight has a potentially important role to play in relation to innovation systems, strengthening them in terms of the capacity to learn and innovate. According to him, the concept of the innovation system has become more important as a result of transition toward the knowledge economy, and the increasing range of institutions involved in research, technological development, and innovation—institutions which need to exchange information, learn from one another, form partnerships, and so on. Central to the concept of the innovation system is the vital importance of the interactions between the actors making up the system. Hence to strengthen the innovation system, there is a need to stimulate, extend, and deepen these interactions if the system is to learn and innovate more effectively. Thus technology foresight, offers a fruitful mechanism to help achieve this.

Consequently, out of the innovation system theory, this thesis deals with sectoral system of innovation approach given by Franco Malerba (1999). He defines sectoral system of innovation as: "A sectoral system of innovation is composed by the set of heterogeneous agents carrying out market and non-market interactions for the generation, adoption and use of (new and established) technologies and for the creation, production and use of (new and established) products that pertain to a sector (sectoral products)". A sectoral system has a knowledge and a technological base, and key links and complementarities among products, knowledge and technologies, which greatly affect the creation, production and use of the "sectoral products". The agents composing the sectoral system are individuals and organizations. These organizations may be firms (such as users, producers and input suppliers) and non-firm organizations (such as universities, financial institutions, government agencies and so on), as well as organizations at lower or higher levels of aggregation (such as consumers, R-D departments or industry associations). Agents are characterized by specific learning processes, competences, structures and behaviors. They interact in a market and non market way through processes of communication, exchange cooperation, competition and command, and their interactions are shaped by institutions (rules and regulations).

According to Malerba, a sectoral system changes over time through coevolutionary processes. Further the above definition of a sectoral system highlights several points that sharply contrast with the standard definition of a sector. The industrial organization definition of a sector starts from defining sectoral boundaries as given and static. It concentrates on firms as the main actors. Accordingly, these firms use similar types of technologies, inputs and techniques, supply goods that fulfill specific functions to customers, and be engaged in market exchange, transactions and strategic decisions regarding competition, cooperation and command (vertical integration). Thus, the definition of sectoral system proposed above highlights a different set of points, which are as follows:

First, a sectoral system perspective pays attention to 'knowledge' and its structure as a key element in a sectoral system. The knowledge base may greatly differ across sectors and affects the innovative activities, organization and behavior of firms within a sector. Second, and related to the first point, it focuses on key aspects of firms such as learning processes, competences, behavior and organization. The emphasis on identifying the degree and determinants of agents' heterogeneity and behavioral and organizational variety within sectors is a characteristic of the sectoral system approach. Third, it gives importance to links and complementarities at the input and demand levels. These complementarities are both static and dynamic and include interdependencies among vertically or horizontally related sectors, the convergence of previously separated final products or the emergence of demand from the existing one. Thus interdependencies and complementarities define the real boundaries of a sectoral system. They may be at the input or at the demand level and may concern innovation, production and distribution. Fourth, it places emphasis on the role of non-firm organizations such as universities, financial institutions, government, local authorities and of institutions and rules of the games such as standards, regulations, labor markets and so on. Non-firms organizations and institutions greatly differ across sectors and affect the innovative and productive activities of firms. Fifth, it pays attention to the relationships among agents. Agents are examined as involved in processes of market and non market interactions. As a consequence, also demand is seen as composed by agents with specific attributes and knowledge that interact with suppliers in various ways. Sixth, it focuses on the dynamics and transformation of sectoral systems. In particular, it emphasizes coevolutionary processes involving firms and non-firm organisations, knowledge, technology and demand. Some methodological remarks have to be advanced with respect to the above definition of sectoral system. In addition, sectoral systems may have different levels of disaggregation, depending on the specific goal of the empirical analysis. So the sectoral products examined may be very broad. Finally, when the actors of a sectoral system are considered, this definition may run into a unit of analysis problem. The above definition, mainly talks about the firm level. However agents at a level of disaggregation lower than firm-such as a division of a firm, an R-D laboratory, or even single inventors- may be the key actors in a sectoral system.

In the above context of sectoral system of innovation approach, this thesis deals with Biotechnology as a sector and its different sub-sectors. Thus, Biotechnology is one of the so-called 'new and emerging' technologies which has crystallised only in the last two decades or so. Thus, it is necessary at the very outset to attempt a definition of biotechnology as the term has diverse connotations. "Biotechnology can be comprehensively defined as the integrated use of biochemistry, microbiology and chemical engineering for achieving the technological applications of the capabilities of micro-organisms and cultured tissue cells." More specifically it has been defined as the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services. In short biotechnology in its wider context may be understood as referring to the commercialisation of all biological processes. Implicit in the definition stated above is the fact that biotechnology is not an industry defined by products or services such as computers or machine tools. It actually refers to the use of microbial (animal or plant) cells and enzymes to synthesise, breakdown or transform materials. In short it is a process or a means of producing an existing product with properties that were hitherto not available with it (Mani, 1990).

The most distinguishing feature of biotechnology is that its domain spans an array of scientific disciplines. For instance a plant molecular biologist needs to know both plant physiology as well as molecular genetics. It thus ranges from genetic engineering and tissue culture in plants to bring about elite varieties to the production of fermented foods and chemicals such as antibiotics, enzymes, ethanol and vinegar, etc. This multi-disciplinary nature of biotechnology has extensive implications for its concentration in certain types of firms. Therefore a well diversified firm may have an inherent advantage over other firms, because technologies perfected for the production of one product (e 'g, a pharmaceutical product) can be modified and used for the manufacture of another (e g, a good additive). The second distinguishing feature of biotechnology is that it has a strong scientific foundation. This explains its concentration in certain countries. This aspect is analysed in a slightly more detailed manner below.

In order to understand the scope of biotechnology, it is also essential to delineate what exactly constitute the core of biotechnology. Central to biotechnology are three fundamental technologies. They are as follows: (i) Recombinant DNA (r-DNA) Technology: This technology involves joining the DNA from different organisms for a specific purpose. This has enabled the production of numerous compounds ranging from pharmaceuticals to industrial chemicals. (ii) Monoclonal Antibody (MAB) Technology: This involves the preparation of complex molecules. The MABs have the unique property of homogeneity, specificity and diffinity. Hence they can effectively be used in downstream purification systems for molecules, especially proteins. (iii) Bioprocess Technology. This enables the scaling up of a biological production process so that large quantities of a product can be made. This method is more popularly known as the fermentation process. The discovery of methods of immobilising enzymes and the introduction of continuous fermentation processes has opened up the possibility that biological processes might start to compete with the chemical processes used in the petrochemical industry. Another important dimension of biotechnology is that its exploration has been by and large the exclusive monopoly of advanced market economies. But these days it is widely being explored in developing nations too. For example, its major developments can be seen in Indian subcontinent.

Further, in the preceding context, S.R. Rao (2005) explains about Indian Biotechnology Developments in Public and Private Sectors. He argues that, the initiatives taken by Government of India in the field of accelerating the growth of biotechnology sector since last two decades have paid rich dividends. India has developed competence in selected biotechnology areas and come out with policies which provide the entrepreneurs an edge over other countries to set up viable and competitive biotechnology industry in certain areas. With its large resource pool of modern/molecular biologists, statisticians and software programmers, India seems well placed to capture most of the biotechnology market. Many Indian companies have introduced products of original research through technology transfer from R&D institutions of India in the field of vaccines, diagnostics and reagents. Some Indian have also teamed up with foreign collaborators for sourcing technologies and are experimenting new products produced with the help of foreign technologies with a view to introducing them into the Indian market within the framework of Indian laws. This situation is satisfactory to begin with, but there is tremendous scope to come up with innovative products that would be original and would have a cutting edge impact in the global context. Fresh investments in India could increase the turnover above the present level, that could contribute to import substitution, augmentation of local production and introduction of some new products for global marketing in the areas such as diagnostics, vaccines therapeutics, pharmacogenomics, bioinformatics, agriculture biotechnology, industrial biotechnology, and also provide inputs to the industry (hardware suppliers-instrumentation and chemicals), marine biotechnology, biodiversity and bioprospecting and environment-focused biotechnology. Thus, India is expected to emerge as a strong player in both manufacturing and consumption market of biotechnology products in the coming years.

Finally, this thesis adopts the empirical approach from R.Balachandra's paper on "Perceived Usefulness of Technological Forecasting Techniques" (1980). In this paper he states that, not all technological forecasting techniques are perceived equally useful, nor are they applicable in all situations. According to him, different forecasting objectives require different forecasting techniques. The forecasting objectives of firms differ according to the nature of the firm. Further he has analysed, the perceived usefulness of some of the common technology forecasting techniques and has catagorised techniques into different groups. In addition, he has suggested the relationship among the industry to which a firm belongs, its preference for a specific category of technology forecasting technique and its perceived level of usefulness. Hence the present research work takes it empirical grounding from the above paper of Balachandra, but instead deals with technology foresight approach.

Chapter 3: Technology Foresight, Biotechnology and Innovation

3.1 Historical Background of Technology Foresight

Thinking about the future and future events has a long history. People at all times wanted to know what lies ahead. It was mainly operations research that – for the first time explicitly formulated the fact that the future can be shaped by the actions of today. In this regard the main initial work was performed in a project called RAND (Research and Development) in 1946, which was initiated to study the broad subject of inter-continental warfare, other than surface, with the object of recommending to the US Army Air Forces preferred techniques for this purpose. These studies eventually led to the development of the Delphi method and other techniques, which came to be known as "Forecasting techniques". "Forecasting" was partly motivated by Vanevar Bush's book "Science the endless frontier", advocating the transformation of the U.S. military economy research during World War II (e.g. the Manhattan project) into long term civilian research and commercial exploitation.

In 1959 Helmer and Rescher (a RAND researcher fellow) provided a philosophical base for forecasting in "The Epistemology of the Inexact Science". In this paper, the authors argued: *"In fields that have not yet developed to the point of having scientific laws, the testimony of experts is permissible. The problem is how to use this testimony and, specifically, how to combine the testimony of a number of experts into a single useful statement."*

Then, in 1971, Japan started its 30-year Technology Forecast Survey which has been implemented every five years thereafter. The main objective of it was to provide the public and private sectors with information for use in S&T policy and Research Technology and Development investments based on 'holistic' overviews of technology developments in 14 fields i.e. materials and processing; electronics; information; life science; space; marine science and earth science; resources and energy; environment; agriculture; forestry and fisheries; production and machinery; urbanization and construction; communication; transportation; and health, medical care and welfare (For-Learn, 2007).

In order to explain further developments in future studies it becomes necessary here to define Forecasting. Forecasting is the look into the short, medium or long-term future with the means of scientific methodology, which can vary according to the areas of research or the questions posed concerning the future. Forecasting includes methods that predict future and unique future with modeling and econometric techniques, i.e. judgemental and quantitative, which use data from the past. These methods broadly include trend extrapolation, S-curves, trend curves, and patent and publication analysis. (Cuhls, 2003)

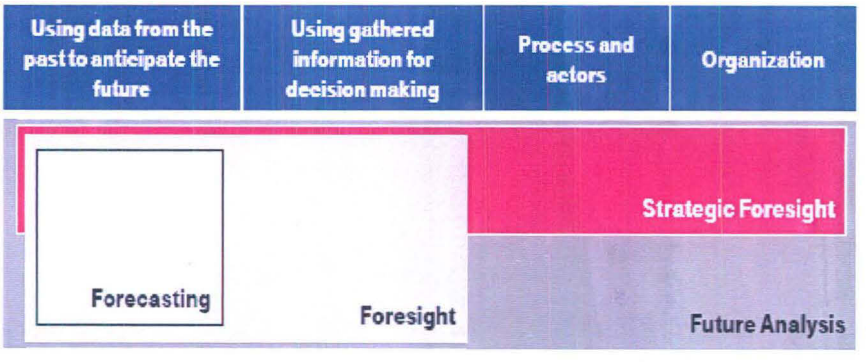
The technological forecasts cannot predict what will be learned by the research; they can identify research needs by identifying ranges of phenomena that will be encountered but for which knowledge is lacking. These knowledge "gaps" then provide the basis for research programs to make the improved product possible. Forecasting can therefore be needs-driven, too and is applied to identify not only (technological) feasibilities but also needs.

After early successes, many serious misconceptions regarding "forecasting" arose. In the sixties and early seventies, the mechanical "prognosis" or "trend prediction" type of work based on "linear", i.e. sequential, models appeared interesting and useful. Although the "linear" models of thought were discarded, some science policy communities further supported them for their legitimating power on research spending with no priorities (e.g. the project TRACES by the NSF 1968).With the advent of the new evolutionary economics, based on selection procedures and the notion of variety generation by new products, and the sociology of science working on the functions of social systems in science as opposed to technology or the economy emphasizing the "bonds of rationality" and "negotiating systems", it became clear that there may be a new, different use of forecasting methods; which in a way laid a ground for foresight. (Cuhls, Blind and

Grupp; 1998).Since 1990s national Foresight activities have proliferated in Europe and experiences have diffused to most industrialised countries and several advanced developing countries.

Foresight thus, broadened the scope of research (beyond forecasting) to incorporate methods that enable networking for information gathering, assessment and interpretation, and methods that support decision making. Furthermore, Foresight includes research on the capacity of organizations to cope with the future. Foresight is more than prognosis or prediction. Implicitly it means taking an active role in shaping the future. Both Forecasting and Foresight techniques have been investigated on industrial level and on a regional, national and supranational level. The end of the 20th century has witnessed the advent of many new foresight methods and combinations thereof. Most of the experiences in organized experiments applying various foresight initiatives concerning future issues in science, technology or society have been evaluated as very positive. Therefore, foresight is conducted in order to gain more information, collective learning and consensus building about things to come so that today's decisions are solidly based on available expertise than before. The development from Forecasting to Futures Analysis is shown in the following figure:

Figure 3.1: Development from Forecasting to Futures Analysis

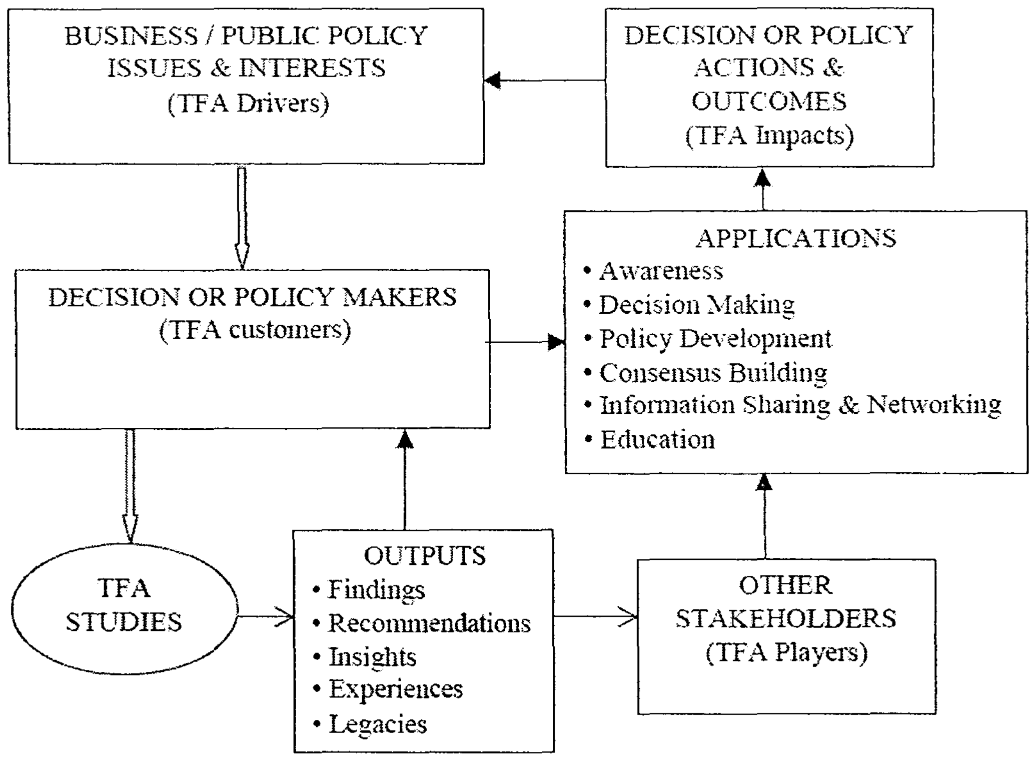


Source: Rohrbeck *et al*, 2007

3.2 Technology Futures Analysis

Recently, to integrate a wide variety of technology-oriented forecasting, foresight, road-mapping, TRIZ analysis methods and practices, an umbrella concept –Technology Futures Analysis (TFA) has been introduced. TFA represents systematic process to produce judgments about emerging technology characteristics, development pathways, and potential impacts of a technology in the future. In this sense, TFA encompasses the broad technology foresight and assessment studies and the technology forecasting and intelligence studies. It uses a wide variety of methods, both quantitative and qualitative. The choice of methods (i.e. which method to use) is inevitably affected by data availability. Despite the focus on technology, TFA requires treatment of important contextual influences on technological development, and, conversely, the impact of technological development on the socio-economic context. (Porter et al, 2004). The strategic components of TFA are given in Figure 3.2, which reveals a structured framework of the major forces and elements affecting the TFA process and arising from TFA activities.

Figure 3.2: A Framework for Technology Futures Analysis (TFA)



Source: Porter et al, 2004

3.3 TFA Process

The process of TFA is vital to facilitate its acceptance and use by the client and stakeholders. For example, the use of Foresight processes to engage previously uninvolved players may hold a higher priority than technology information products themselves. Hence, Multi-actor considerations are central to much TFA. In TFA decision-making in a multi-actor context takes place in a network where actors interact and each attempt to get the best outcome from his/her unique perspective. TFA process includes following four types of approaches namely:

1) Participative approach: Its basic theme is to involve stakeholders and others in the analytic processes, also some of the key behavioral elements are included in it. Due to it, the variety of inputs and thereby the quality of results might increase (in terms of richness of viewpoints, by

taking the expertise of stakeholders into account). It is argued that participative approach contributes to the democratic character of the process.

2) Process management: This is an approach that has originated from policy network theory. Its basic notion is that well-thought-out 'conditions and rules of the game' are needed to enhance the probability of progress in complex, multi-actor situations.

3) Negotiation-oriented approach: In this approach, analytic efforts are primarily oriented to explore possible compromises, finding solutions in which the interests of key stakeholders are intertwined.

4) Argumentative approach: This approach is also known as the dialectic approach. In this approach the focus of analysis and debate is on the argumentations (or perceptions) of stakeholders instead of on 'objective' facts. (Porter et al, 2004)

It can be argued that TFA process is an all inclusive process, as described above and it incorporates many approaches within it. There are lots of challenges in front of TFA in the present era of molecular technology and biotechnology, due to the complexities involved. But the methods developed for S&T in nanotechnology, biotechnology, and materials science will have a significant impact on TFA. Furthermore, since TFA is an umbrella concept which involves foresight also, hence a detailed description about foresight is discussed below.

3.4 Technology Foresight:

Technology Foresight (TF) or Foresight is a process whereby different stakeholders (scientists, engineers, business and industry people, government officials, civil servants and others) get together to identify areas of strategic research and the emerging technologies likely to yield the greatest economic and social benefit. In general, the Foresight process aims at participants working towards the development of a common understanding (consensus) on research priorities, and the creation of a shared vision of the future they would like to achieve. It is a useful strategic instrument and process in bringing awareness of long-term challenges and opportunities into more immediate decision-making. According to Irvine and Martin (1984):

"Technology foresight is a process which seeks to look into the longer term future of science, technology and economy and society with the aim of identifying the areas of strategic research and the emerging generic technologies likely to yield the greatest economic and social benefit."

In recent years the European Union has used a broader definition for the term Foresight which is as follows:

"Foresight is a systematic, participatory, future intelligence gathering and medium-to-long-term vision-building process aimed at present-day decisions and mobilising joint actors."

As part of the activities of the European Union funded project eForesee, a more sophisticated definition has emerged which describes foresight as:

"The foresight process involves intense iterative periods of open reflection, networking, consultation and discussion, leading to the joint refining of future visions and the common ownership of strategies, with the aim of exploiting long term opportunities opened up through the impact of science, technology and innovation on society... It is the discovery of a common space for open thinking on the future and the incubation of strategic approaches..."

Foresight is thus not a single methodology, but different methods can be and are mixed to fulfill the purpose. There is a whole range of formal and informal methods to perform the task of looking into the future such as surveys, trend analyses, Delphi etc. Most Foresight methods are not different from those used in other disciplines. People and companies conducting foresight, use to borrow and adapt methods from management, planning and social sciences. The uniqueness of "foresight methods" is the combination of:

- **Futures thinking;**
- **Networking; and**
- **Policy-making**

There are plenty of methods which are used in foresight exercises. Following table shows a variety of methods classified according to type of techniques i.e. Qualitative, Quantitative and Semi-quantitative:

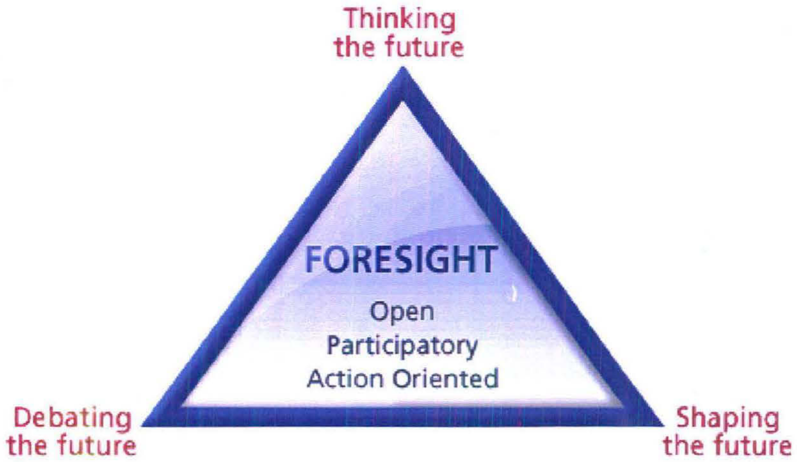
Table 3.1: Foresight methods classified by type of technique

Qualitative	Quantitative	Semi-quantitative
Methods providing meaning to events and perceptions. Such interpretations tend to be based on subjectivity or creativity often difficult to corroborate (e.g. brainstorming, interviews)	Methods measuring variables and apply statistical analyses, using or generating (hopefully) reliable and valid data (e.g. economic indicators)	Methods which apply mathematical principles to quantify subjectivity, rational judgements and viewpoints of experts and commentators (i.e. weighting opinions)
1. Backcasting 2. Brainstorming 3. Citizens panels 4. Conferences/workshops 5. Essays / Scenario writing 6. Expert panels 7. Genius forecasting 8. Interviews 9. Literature review 10. Morphological analysis 11. Relevance trees /logic charts 12. Role play / Acting 13. Scanning 14. Scenario / Scenario workshops 15. Science fictioning (SF) 16. Simulation gaming 17. Surveys 18. SWOT analysis 19. Weak signals /Wildcards	20. Benchmarking 21. Bibliometrics 22. Indicators / time series analysis 23. Modelling 24. Patent analysis 25. Trend extrapolation / impact analysis	26. Cross-impact / structural analysis 27. Delphi 28. Key / Critical technologies 29. Multi-criteria analysis 30. Polling / Voting 31. Quantitative scenarios / SMIC 32. Roadmapping 33. Stakeholder analysis

Source: Popper, 2008

The central point of foresight activities is to bring together actors from different sectors, thematic and societal backgrounds so that different ideas are introduced and assessed from different points of view. In foresight exercises, expectations of diverse actors about possible development paths are purposefully brought together to formulate strategic views about the future. Participatory methods are used to include the main regional actors and generate new ideas and innovative solutions. Stakeholder involvement is critical in order to ensure consent with the action plans developed in the course of foresight exercises (Cuhls *et al.*, 2003, p. 6). Hence, Foresight is a non-deterministic, participatory and multidisciplinary approach. It can be envisaged as a triangle combining "Thinking the Future", "Debating the Future" and "Shaping the Future", which is shown in the following figure:

Figure3.3: Components of foresight



Source: Popper, 2008

3.5 Characteristics of foresight:

There are four characteristics of foresight which distinguishes it from other kinds of future studies, therefore foresight is:

i) Action oriented: Foresight is not only about analysing or contemplating future developments but supporting actors to actively shape the future. Purely analytical studies of possible futures (i.e. "futures studies") without connection to possible actions are not considered as Foresight. Therefore, Foresight activities should only be undertaken when it is actually possible to shape the future.

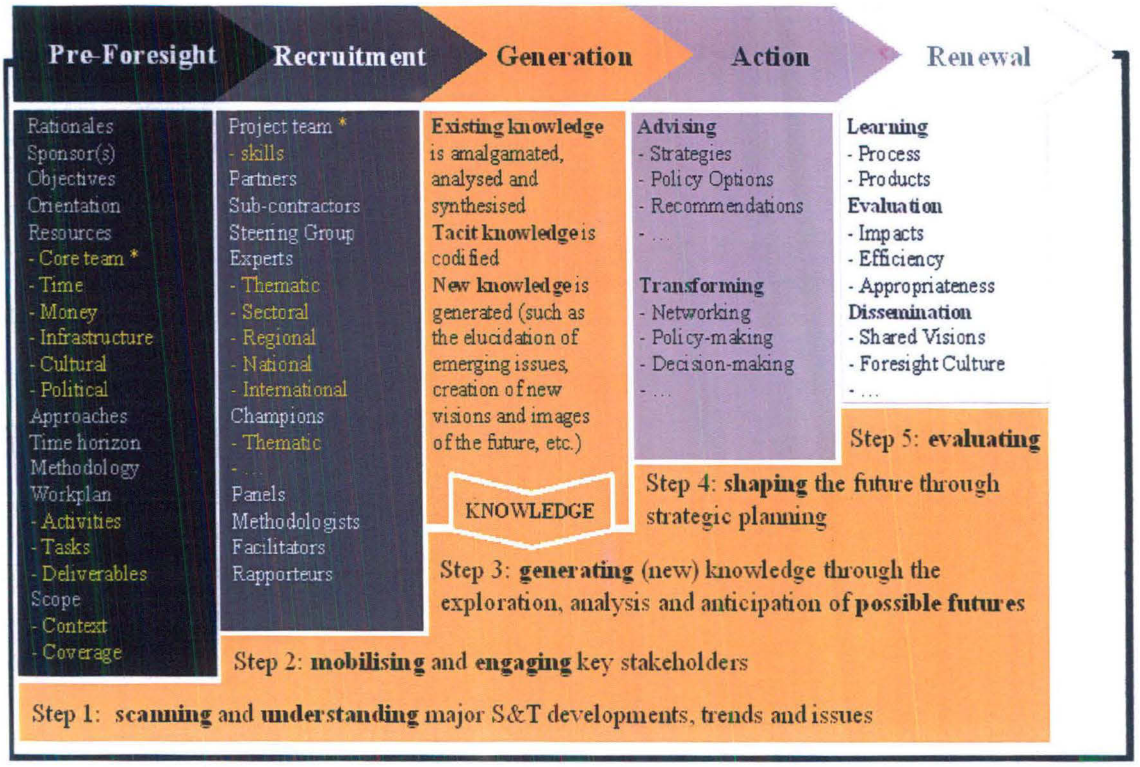
ii) Open to alternative futures: Foresight assumes that the future is not pre-determined. The future can therefore evolve in different directions, which can be shaped to some extent by the actions of various players and the decisions taken today. In other words, there is a certain degree of freedom to choose among the alternative, feasible futures, and hence increase the chance of arriving at the preferred (selected) future state.

iii) Participatory: Foresight is not done by a small group of experts or academics but involves a number of different groups of actors concerned with the issues at stake. The results of the Foresight exercise are disseminated among a large audience from which feedback is actively sought.

iv) Multidisciplinary: Foresight is based on the principle that the problems we face cannot be correctly understood if reduced to one dimension and by allowing it to fit into the perspective of the different academic disciplines. Instead, Foresight provides an approach that captures realities in their totality with all the variables influencing them, regardless of the type (quantitative and qualitative).

The above characteristics explain about the features of foresight. Hence it is needed here to discuss about the foresight process. It can be argued that quite often foresight is understood as a process with various complementary phases. Those phases are: Pre-Foresight, Recruitment, Generation, Action and Renewal. The whole Foresight process can be explained from the following diagram:

Figure3.4: The Foresight Process



Source: Popper, 2008

3.6 Objectives of Foresight:

Technology Foresight has several objectives and they must be clearly stated, internally consistent and (at least initially) avoid being too specific. Ideally, the objectives should be debated by the key players in order to ensure proper working of the foresight exercise. Typical objectives of Foresight exercise include:

i) Informing policy-making: The main purpose behind this is that decisions taken by key actors in the commissioning body are more aware of longer-term developments and are liable to interact with current policy decisions. This involves gathering intelligence on possible longer-term developments and how these may interact with the current policy decisions, or providing alerts on major future risks and opportunities.

ii) Building networks: It helps in bringing together people from different sectors and institutions involved, to shape the future of a particular topic. The purpose of bringing them together is to enable them to work on their visions and assessments of the future. This may help them to become better able to collectively understand the challenges and opportunities that they are liable to confront, and the strategies and objectives that others might pursue.

iii) Developing capabilities: Foresight involves developing capabilities widely throughout a region or an organisation in order to develop a "Foresight culture". The main aim of this is to enable people with variety of backgrounds, to define and embark upon their own Foresight activities and create their own Foresight networks.

iv) Building strategic visions: The aim of the foresight exercise is to build strategic visions and create a shared sense of commitment to these visions among Foresight participants (For-Learn, 2008).

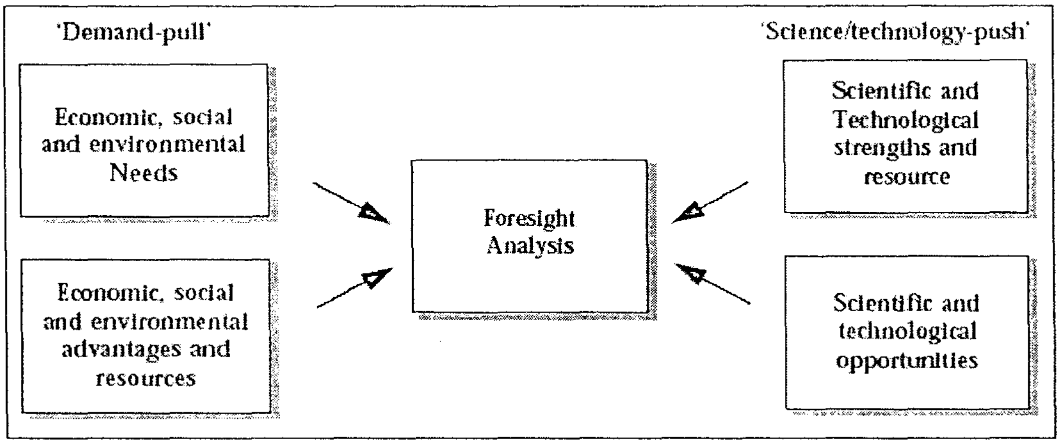
Apart from the aforesaid objectives, the ultimate objective of all foresight activities is to ensure that developments in the areas of science, technology and society that are likely to ensure future social benefits are identified promptly. To achieve its objectives Foresight facilitates a process of systematic collective reflection on the long-term future. This process of reflection has several outcomes and benefits. Thus it can be argued that, (in terms of its objectives) by providing a variety of tangible and intangible outcomes, Foresight can improve decision-making, implementation and the ability to cope with future challenges.

The essential ingredients of Foresight are shown in Figure 3.5. In conducting a 'Foresight Study' it is necessary to maintain a balanced perspective between the 'science-push' and 'demand-pull' factors that influence future developments.

i) Science-push factors include the creation of new technological or commercial opportunities by scientific research, and the strength and resources to exploit them.

ii) Developments in technology and production may create a use for existing and novel science through the mechanism of demand-pull. Demand factors include the priorities and needs of the broader community.

Figure3.5: Factors Influencing Foresight



Source: Tegart, 2003

There might be problems in communication between proponents of science-push and demand-pull, particularly due to their different time perspectives. The time horizon of those making the demands may be too short for an effective dialogue. Therefore, looking ahead together, through Foresight, can bridge this gap in many cases.

Due to the interactive nature of Foresight, the outputs of the technology foresight process might often be as important (or even more important) as the products. Hence the benefits obtained from the process are listed below as the six Cs':

i) **Communication** – it involves bringing together disparate groups of people together and providing a structure within which they can interact and communicate;

ii) **Concentration** – it is based on the longer term, so that participants look further into the future than they otherwise might;

iii) **Coordination** – it means enabling different groups to form productive R&D partnerships;

iv) **Consensus** – consensus is done so that a clear picture of alternative future directions and research priorities can be formed;

v) **Commitment** – it involves generating a sense of commitment to the results among those who will be responsible for implementing changes in light of the foresight exercise; and

vi) **Comprehension** – it helps in encouraging those involved to understand the changes happening in their business, or professions, at a global level, and to exert some control over these events (Tegart, 2003).

The success of a foresight exercise can be gauged by assessing it against the above six criteria.

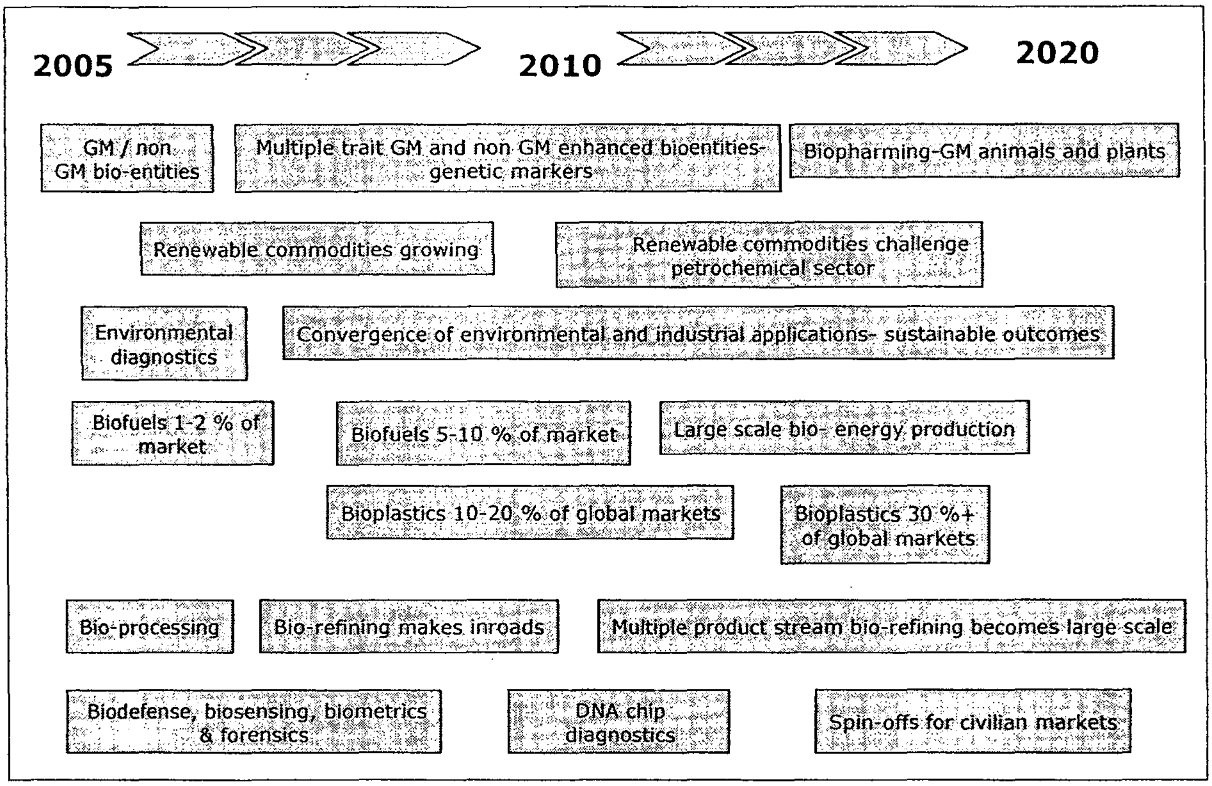
3.7 Application of Technology Foresight in Biotechnology sector

Application of Technology Foresight to Biotechnological sector leads to enormous beneficial results. Foresight identifies the biotechnological sub-sectors or areas which are growing fruitfully or which needs attention of the government bodies, different private players and other stakeholders. The areas which seek attention must be focused upon to provide them funds, or to increase research inputs in those areas.

Foresight exercise can lead us to know about the crucial need (if any) for enhancing and facilitating the development of national capacity building, to assess and manage the current and future development of biotechnology and the development of expert human resource in biotechnology. Foresight is a participatory and networking building exercise so it may lead to proper adoption of biotechnology in future. It might also help in increasing awareness among consumers, due to its involvement of all the stakeholders in the process.

Biotechnology as a sector is constituted of many other sub-sectors, for e.g. Agriculture, Industry, Environment, Health, Bio-services and Bio-informatics sector. In biotechnology sector, single type of foresight methodology may not be applicable for all sub-sectors within biotechnology sector and a combination of methodologies might be required. For example, Scenario Planning, Trend Analysis and Delphi techniques are applied in Agri-Biotech sector and other such methodologies are applied according to their suitability for other different sectors. Figure 3.6 illustrates a foresight example from the period of 2005 to 2020, of product and concept development pathways for the agricultural, industrial, environmental security and defence biotechnology sub sectors.

Figure 3.6: Foresight based development pathways in the agriculture, industry, environment, security and defence sub-sectors.



Source: Frazer and Marsh, 2006

In Biotechnological sector there are different purposes for conducting foresight exercise. Some of the most important purposes are as follows:

i) Research and Development
ii) Analysis of market scenario
iii) Consumer perceptions

3.8 Foresight shaping the Biotechnology sector over the next 10-20 years:

The way biotechnology evolves over the next 10 – 20 years can be viewed using severaldifferent tools. These include PESTE (an analysis from the Political, Economic, Social, Technological, and Environmental perspectives), SWOT Analysis (strengths and weaknesses – as seen today; opportunities and threats – in the future). Following table shows a SWOT Analysis of the biotechnology sector.

Table 3.2: Biotechnology sector SWOT analysis

Strengths	Weaknesses
Provides 'natural' solutions • Huge investor interest • Offers breakthroughs in human health and wellness • Mass customisation • Is knowledge based rather than resource based • Has application over a range of sectors	• Lack of returns for investors • Opposition to GM foods • Animal welfare • Lack of knowledge – both in people resource terms and in understanding the complexity of biological systems • Long lead times • A reliance on GM in some sub-sector areas • Long lead times
Opportunities	**Threats**
• Improved human health and wellness • Sustainable and renewable energy • Individual customisation of solutions to improve human health and nutrition • Adding value to commodities • Vastly improved diagnostics • Convergence with other sectors offers new options • Offers potentially large rewards	• Bioterrorism • Unforeseen outcomes that have negative impacts • Investors fail to gain the expected returns • Competition from non-renewable resources and affects on pricing (e.g. an oil price slump)

Source: Frazer and Marsh, 2006

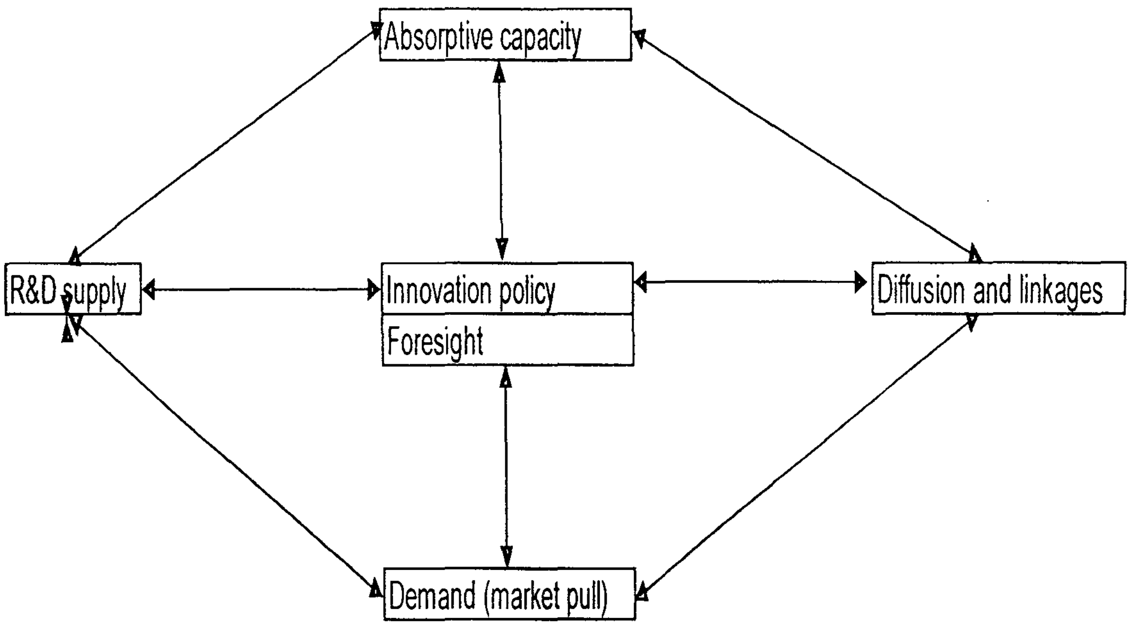
3.9 Role of Technology Foresight in Innovation system

Foresight activities have often provided support for priority-setting, networking and consensual vision-building. In the 1980's, publicly funded foresight activities were largely seen as an instrument for assisting in the development of priorities for S&T

resource allocation. Later on, stakeholder participation and networking have been regarded as increasingly essential dimensions of foresight activities for 'wiring up' the innovation system (Martin & Johnston, 1999). Reports from recent participatory foresights, in turn, have emphasized the importance of common vision-building as a step towards the synchronization of the innovation system (Cuhls, 2003). These overarching trends may be viewed as complementary dimensions of how foresight can strengthen the long-term innovative activities of the innovation system. They are also reflected in the taxonomy of Barré (2002), who distinguishes between the objectives for (i) setting S&T priorities, (ii) developing the connectivity and efficiency of the innovation system, and (iii) creating a shared awareness of future technologies.

Technology Foresight provides means to facilitate economic learning, increases knowledge distribution power and hence builds capacity for innovating. It offers means for 'wiring up' and strengthening the connections with innovation systems, so that the 'knowledge' can flow more freely among the constituent actors and the system as a whole can become more effective at learning and innovating (Martin and Johnston, 1999). Furthermore, the role of foresight in innovation system gets cleared from the following figure 3.7, which shows how Foresight helps to enhance coordination capability of innovation systems to external challenges.

Figure 3.7: Foresight: improving coordination between different elements of innovation capacity / policy



Source: Popper, 2008

Thus it can be argued that there is a close affinity between two future-oriented activities, namely foresight and innovation activities. Two reasons can be stated here for this:

i) A structural one: One main reason for the great attention given to foresight, seems to lie in the socio-economic setting under which innovation now has to be fostered: In today's knowledge-based economies, decision-making takes place under uncertainty and highly complex societal conditions, and thus explicitly demands the kind of input that are generated by foresight activities, such as:

• anticipatory intelligence

• a better understanding of and openness for the different possible futures and hence the opportunity of shaping them

• the broadening of perspectives and the encouragement of thinking outside the box

• a higher flexibility and societal embeddedness (i.e. public participation) in decision-making and implementation

ii) *A procedural one*: Foresight also has a close affinity to innovation with regard to its particular procedural requirements and success conditions. Both innovation and foresight must be considered as a process that requires good communication involving (and gaining commitment of) all those likely to be affected, if the end product is successful. Thus, besides the importance of foresight input for innovation activities, it can also give rise to very important innovation process benefits (Becker, 2002). If properly conducted, foresight can encourage the forging of better communication, collaboration, and shared commitment within and between individual companies, across different sectors, and among industry, academia and government. Such links are also essential if new innovative ideas and technologies are to be exploited to their full potential.

Since the present study deals more specifically with sectoral system of innovation, so after discussing the role of foresight in innovation, next chapter deals with sectoral system of innovation and biotechnology in detail.

Chapter 4: Biotechnology and Sectoral System of Innovation

Innovation dynamics differ across sectors. Therefore, exploring future perspectives on general innovation patterns is not enough to grasp the kinds of changes companies and other actors will need to deal with biotechnology sector hence genuinely a sectoral approach is needed. Furthermore, applying Foresight on sectoral innovation aims to integrate forward looking perspectives on sectors with a thorough understanding of the dynamics of sectoral systems of innovation.

4.1 Sectoral System of Innovation

Sectoral System of innovation aims to provide a multidimensional, integrated and dynamic view of sectors. The dynamics and transformation of sectoral systems are seen as the result of several different developments including processes of variety creation in products, technologies, firms, institutions as well as creation of new agents (both new firms and non-firm organizations) and processes of selection (Malerba 2005). Change in sectoral systems is the result of the co-evolution of various elements including technology (science and technology drivers), skills (knowledge base, learning), demand (demand side drivers), structural change (firms, non-firm organizations and institutions). The framework for examining factors that affect innovation in sectors includes the following main building blocks (Malerba 2005):

- Knowledge and technologies,
- Actors and networks,
- Institutions

In addition, two further important aspects need to be stressed:

- Demand
- Co-evolution

Whereas knowledge and technologies are at the heart of what innovation is about, actors and networks, including the demand side, represent the main types of agents influencing innovation. Institutions represent the "rules of the game" according to which these agents interact. The principle of co-evolution implies that in order for a sectoral system of innovation and production to change, these different elements need to change simultaneously and coherently. And they are therefore also the key elements to be investigated and explored in the foresight exercise.

4.2 Rationale for using Sectoral System of Innovation:

The concept of sectoral systems is a useful tool in various respects:

i) for a descriptive analysis of the differences and similarities in the structure organization and boundaries of sectors;

ii) for a full understanding of the differences and similarities in the working, dynamics and transformation of sectors;

iii) for the identification of the factors affecting innovation, commercial performance and international competitiveness of firms and countries in the different sectors; and

iv) for the development of new public policy indications (Malerba,2003).

The main the building blocks of a sectoral system of innovation are analysed as follows:

4.3 Knowledge and technologies

Within the concept of sectoral systems of innovation, sectors could be characterised by specific knowledge bases, technologies and inputs. In other words, it is the shared body of knowledge that distinguishes a sectoral innovation system from others. The focus on knowledge and technology places the issue of sectoral boundaries at the centre of analysis, as in sectors in which innovation is quite rapid, sectoral boundaries change (e.g. boundaries between the sectors of food and beverages and biotechnology). Dynamic complementarities that take into account interdependencies and feedbacks (both at the demand and at the production levels) "may set in motion virtuous cycles of innovation and change" (Malerba 2005).

Hence there is need to identify the drivers of change (science and technology drivers as well as demand side drivers) both from within the sectors and from outside. At the intersection of S&T drivers and demand-side drivers of change, innovation (product, process, organisational) takes place, and with it changes in knowledge and technology, in actor constellations, in networks, institutions and emerging demand identifying innovation themes is thus crucial for starting and accelerating the virtuous cycles of innovation and change.

Actors and Networks

A sector is composed of heterogeneous agents (organisations and individuals) that are characterised by specific learning processes, competencies, goals, organizational structures and behaviours and interact through processes of communication, exchange, cooperation, competition and command. Connected in various ways through market and non-market relationships, the relationships and networks to generate innovations and commercialize them differ between sectoral systems. From a foresight perspective there is a need to analyse issues related to organizational change, skills requirements and strategies of various agents for dealing with innovation themes in interaction with other organisations and their overall environment.

Institutions

The actions and interactions within and between the sectoral systems are shaped by institutions (including norms, established practices, rules, laws, standards, labour markets and so on) on different levels (regional, national, international). The important thing to take into account is that beyond geographically specific institutions, sectorally specific institutions also matter. The set of institutions can constrain or enable the development of innovation in specific sectors. Within the foresight exercise, potential institutional adjustments that are needed for realizing major innovation themes needs to be addressed. This includes the issues of regulation and standardization, but also issues arising from future skills requirements.

Demand

In addition to knowledge producers, the demand side is given a key role in the sectoral systems of innovation perspective. Demand is made up of heterogeneous buyers, individual consumers, firms and public agencies, each characterised by their specific knowledge, competencies and goals, and affected by emerging trends, trend-breaks, social factors and institutions. Thus, in a sectoral system demand is composed of heterogeneous agents whose interactions with producers are shaped and transformed by institutions. The emergence and transformation of demand play a major role in the dynamics and evolution of sectors and in cross-sectoral developments. The foresight exercise aims to identify potential future demand as a driver and shaping force for innovative activity within and across different sectors.

Co-evolution

Change in a sectoral system is a collective outcome of the dynamic interactions and co-evolution of its various elements. This process involves the aforementioned elements, i.e. knowledge and technology, firm and non-firm actors, their interactions and learning processes, it includes the demand side and the institutions that guide interactions. Sectoral analyses need to focus on intertwined changes in relation to these elements. From a foresight perspective, it is key to identify innovation themes and emerging markets and to focus on organisational, structural, institutional and skills-related requirements for their realization (Schaper *et al*, 2008).

4.4 From sector analysis to foresight

Studies of sectoral systems of innovation offer manly a retrospective analysis of the development and underlying dynamics of sectors. Foresight, on the contrary, aims at sketching different plausible, but challenging variants of future developments, the associated challenges, underlying driving forces and options for dealing with them. In order to achieve this, the foresight approach is looking at driving forces, captured for instance in trends and trend breaks. Such driving forces are developments that are likely to exert a major influence on the sector under study and could thus shape the evolution of the sectoral innovation system under study, in particular when interacting with other drivers in such a way that a mutually reinforcing process sets in. Foresight processes can also look at 'wildcards', i.e. at unexpected or even seemingly unlikely developments that – in case of happening - could give rise to very different future paths than any kind of "business-as-usual" assumption, or at developments that could go wrong in a possible future path. Recognizing the fact that future developments are not pre-determined, but uncertain and open to judgement and intervention, foresight covers activities to think the future, to debate the future and to shape the future. It is thus not a tool for predicting the future, but a process aiming to develop shared problem perceptions, make differences in expectations explicit and identify needs (and options) for action (European Commission 2002):

i) Thinking the future (the cognitive dimension of foresight)

Foresight exercises try to identify new trends and trend breaks to guide decision-making. Foresight activities aim at identifying today's innovation priorities on the basis of scenarios of future developments in science, technology, economy and society.

ii) Debating the future (the value based dimension of foresight)

Foresight as a participative process involves different stakeholders (e.g. industry, public authorities, research organisations, NGOs) and its activities can be organised at different levels like cross-national, national, or regional. It organises open discussion between the participants in order to create a shared understanding.

iii) Shaping the future (pragmatic and implementation-oriented dimension of foresight)

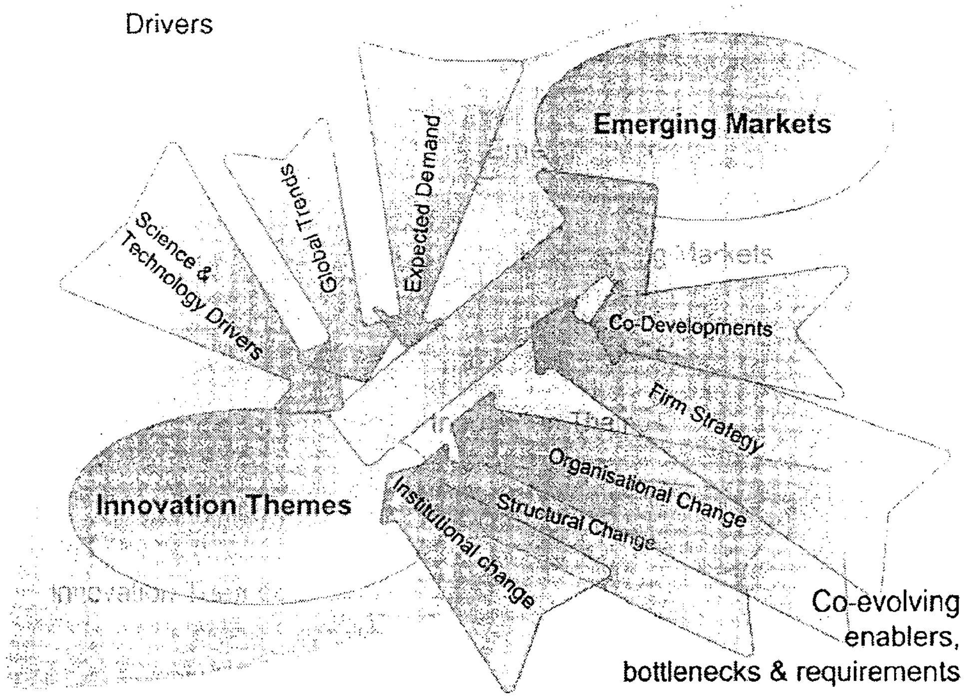
Foresight aims at identifying possible futures and future developments, imagining desirable futures, and identifying strategies that facilitate implementation. Foresight results are generally fed into public decision-making, but they also support participants to develop or adjust their strategy.

Thinking, debating and shaping the future of different but interlinked sectors is crucial today because innovation is a collectively shaped process, a distributed process, and a path dependent process. Thinking, debating and shaping the future of sectoral systems has to embed the sector developments in contextual developments.

4.5 Combining SSI and foresight

Innovation at sectoral level depends to a large extent on the developments within the innovation system, but they are also driven by developments in its context, like for instance changes in science and technology. To explore future patterns of innovation, it is thus necessary to investigate these contextual developments, as well as corresponding developments within a sectoral innovation system. Foresight activities have a limited theoretical basis and respond to practical needs of exploring the future. At present a gap can be perceived between innovation theory and foresight practice, i.e. there is not specific framework available that would combine both. For the purpose of foresight exercise, the main building blocks of sectoral systems of innovation (knowledge and technologies, actors and networks, and institutions) have to be taken into account and also integrated with the kinds of concept that are used in foresight approaches. Hence it becomes necessary here to discuss about driving forces, innovation themes and emerging markets. Thus it can be argued that in order for innovation themes to evolve into markets, the different elements of a sectoral innovation system need to co-evolve. This has led to a simple pattern of analysis, along the lines of which the sectoral foresights will be structured. The essence of this approach can be captured by the subsequent building blocks shown in Figure 4.1:

Figure 4.1: Conceptual framework – combining foresight with SSI



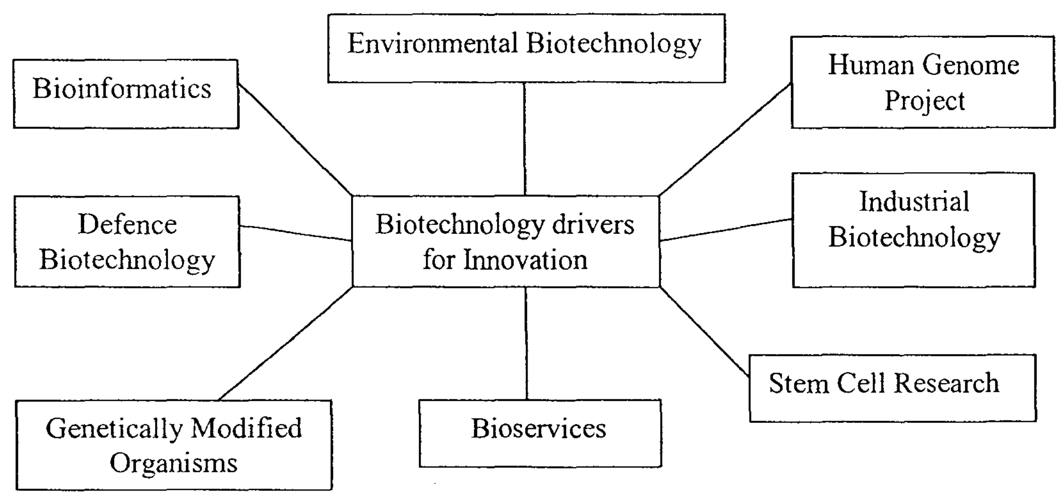
Source: Europe Innova, 2008

I) Driving forces, i.e. emerging trends and trend breaks in S&T developments, in expected demand - both internal and external – that are likely to exert a major influence on the emergence of possible innovation themes. Broader cross-cutting developments/trends (e.g. the extent to which globalization affects a sector) are needed to be taken into account. There are mainly two drivers of sectoral innovation i.e. Supply side drivers and Demand side drivers. Supply-side drivers for new innovations are mainly new insights in science and enabling technologies. From the demand side emerging societal challenges can be seen as important drivers for change.

i) S&T drivers

The amount of scientific and technological knowledge has been constantly increasing throughout human history. The use of tools and crafts by humans can be seen over 50,000 years ago. More modern technologies were the major driver for the industrialization in the 18th and 19th century (e.g. the steam technologies and manufacturing technologies). Also the chemical technologies in the late 19th and beginning of the 20th century have proven to be disruptive for our society. Recent example is mainly of biotechnology. So the question is what the major trends in biotechnologies are that will initiate the innovation of the future. The figure below gives an overview of the main areas under biotechnology that triggers innovation.

Figure 4.2: Supply side drivers for Biotechnology sector

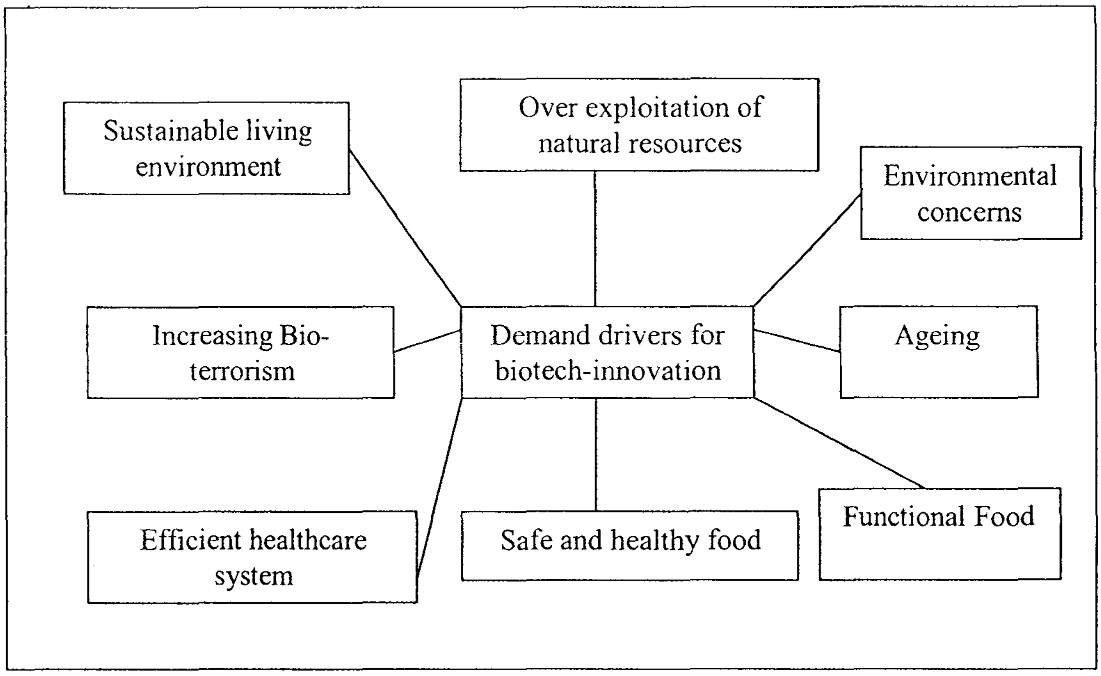


Source: Prepared by the Author

ii) Demand-related drivers

From the societal point of view, the expected changes in demand patterns and major societal challenges operate as important drivers for innovation. A clear example is Genetically Modified Organisms, which – by way of regulatory mechanisms, consumer's and farmer's pressure against its harmful effects, have played a key role in the characteristics of agricultural biotechnology innovation. Looking at today and tomorrow, there are some key societal challenges in the biotechnological sector that can be identified as important drivers for innovation. An overview is given in the figure below.

Figure 4.3: Demand drivers for Biotechnology innovation



Source: Prepared by the Author

Some major clusters as identified in above figures are:

- **Environmental sustainability**, where both the focus on climate change, as the environmental impact (local and human) are of importance;
- **Healthcare**, including the new demands for healthcare, ageing, the organisation of the healthcare system as well as issues like cloning etc.;
- **Security and defence**, including issues on terrorism, crisis and disasters and even other more defence oriented globalisation issues;
- **The organisation of food production**, including issues on animal welfare, food safety, food security;

II) Innovation themes, which are seen as the results of the interplay of S&T developments and changes in expectations regarding future developments on the demand side. In contrast to driving forces, however, innovation themes are rather specific areas on which attention and innovation effort are likely to be focused in the coming years. They can thus be interpreted as sector-specific bundles of product and/or process innovations, together with the associated technologies and organisational changes.

III) Emerging markets can achieve significance if innovation themes evolves successfully, i.e. if potential barriers can be overcome and enablers be strengthened. Initially, innovation themes have a potential to evolve into a market. However, whether this potential can actually be seized depends to a significant extent on the context conditions provided by the sectoral innovation system.

IV) Requirements and co-developments in a sectoral innovation system can operate as enablers and barriers for innovation and for markets to emerge. They can even be essential in order to allow markets to emerge at all. For instance, regulations can provide an orientation for future innovation trajectories to pursue, and the ability of firms to collaborate with research organisations may be essential for being able to exploit a new technological opportunity. Such co-developments reflect the aforementioned building blocks of sectoral innovation systems (Schaper *et al*, 2008).

4.6 SSI in context to Biotechnological sector

Biotechnology as a sector is constituted of various sub-sectors, i.e. Agricultural, Industrial, Environmental, Health and Bioinformatics. Biotechnology is characterized by major roles of science, networks, division of innovative labour, universities, venture capital and national health systems. Several actors which are the protagonists of innovation are: large firms, medium scale firms, new biotech firms (NBF), small firms, autonomous bodies, public sector organizations, research institutions etc. In this sector regulation, IPR (Intellectual Property Rights), national health systems, and demand play a major role in the innovation process. Now, a wide variety of science and engineering fields are playing important roles in renewing the search space for this sector. New biotech firms have entered into the sector, competing as well as cooperating (or being bought up) with, the established firms. More recent changes in regulation and demand are squeezing the profitability of firms and opening up new opportunities in various fields like in Stem cell research, GMOs, etc.

4.7 Challenges for Sectoral Systems of Innovation

Sectoral systems face new challenges in terms of knowledge and learning processes, actors, networks and institutions.

1) Knowledge at the base of innovative activities is changing continuously; this change is affecting the boundaries of sectoral systems:

In terms of knowledge base and learning processes, some common trends may be identified as:

- **i)** First of all, the features and sources of knowledge continue to be different from sector to sector, and show major changes.
- **ii)** Second, knowledge is relevant for an explanation of the rate and direction of technological change, the organization of innovative and production activities and the factors at the base of successful performance.
- **iii)** Third, both science and development activities are gaining importance in all sectors.
- **iv)** Fourth, the boundaries of several sectoral systems are changing over time, as a consequence of several dynamic processes related to the transformation of knowledge as well as to the convergence in demand and the changes in the type of competition (Malerba, 2003).

In the biotechnological sectoral system the advent of molecular biology since the 1980s has led to a new learning regime based on molecular genetics and rDNA technology, with two search regimes: one regarding co-specialised technologies, the other generic technologies. Nowadays no individual firm can gain control on more than a subset of the search space. Innovation increasingly depends on strong scientific capabilities and on the ability to interact with science and scientific institutions in order to explore the search space (Henderson *et al.*, 1999).

2) Changes in the knowledge base change the types of relevant actors and the structure of networks in the sectoral systems:

i) The changes in knowledge and learning processes discussed above imply major changes in the organization and characteristics of R&D. In most sectors R&D is increasingly decentralised, externalised and internationalised (Coriat & Weinstein, 2001). This is in relationship with an increasing focus on market oriented R&D, the growth of external sources in knowledge and the need to obtain access to knowledge about markets or key technological or scientific resources. (Coriat & Weinstein, 2001). The organization and the features of R&D have greatly differed across groups of sectors. While in pharmaceuticals large scale internal R&D plays major role with key links with universities, the emergence of biotechnology has lead to an increasingly role of science, to networks of R&D projects between large pharmaceutical firms, new biotechnology firms and universities.

ii) A rich, multidisciplinary and multisource knowledge base and a rapid technological change implies a great heterogeneity of actors in most sectors.

iii) Demand as composed by users and by consumers is a major factor in the redefinition of the boundaries of a sectoral system, stimulus for innovation, factor shaping the organization of innovative and production activity. In addition, the emergence of new demand or the transformation of existing demand is the major element of change in sectoral systems over time.

iv) Suppliers and users affect the boundaries of sectoral systems, by making both supply and demand an integrated part of a sectoral system and by greatly affecting sectoral linkages and interdependencies.

v) In all sectors universities play a key role in basic research and human capital formation and in some sectors (such as biotechnology) also they are a source of start ups and even innovation.

vi) In biotechnological sector new actors such as venture capital have emerged over time.

In biotechnological sector the change in the knowledge base has led to a different organization of innovative activities within and across firms and a division of labour between NBF and established companies. Networks of collaborative relations facilitated by the science base and by the abstract and codified nature of knowledge generated by the NBF have emerged in the sector. Also mergers and acquisitions has allowed established firms to obtain complementary knowledge for the development of innovative products. As of now, the biotechnological sectoral system has a structure of innovative actors which includes large firms, NBFs, small firms, and single individuals (such as scientists or NBF entrepreneurs), complemented by a very rich set of non-firm organizations and institutions, ranging from universities to the public and private research systems, the financial system and venture capital, the legal system and IPR. Demand channelled through agencies, agricultural system, health system, industrial system and institutions such as regulation play a significant role in the diffusion of new products. Nowadays no individual firm can hope to gain control of more than a subset of the search space. Even the innovativeness and competitiveness of the largest biotechnological firms depends on strong scientific capabilities and on the ability to produce and interact on one side with science and scientific institutions (in order to explore such a complex space) and on the other with specialized innovative firms (in order to develop new products) (McKelvey & Orsenigo, 2001).

3) The role of national as well as sector -specific institutions is relevant for innovation:

Institutions play a major role in affecting the rate of technological change, the organization of innovative activity and the performance of sectoral systems in all biotechnological sectors. But each sector has a different set of relevant institutions, often the outcome of the interplay between sectoral and national variables (Coriat & Weinstein, 2001). Some of these institutions are national, but with different effects on innovation and performance according to the sector or the country. Other institutions are sector specific.

There are various sub sectors within the biotechnological sector and they have different institutions. For example Agricultural sector has different institutions than Bio-Industrial or Health Biotech sector. In Indian context, for Agricultural sector there is Indian Council for Agricultural Research (ICAR), and various such other institutes. But for Health biotech sector there are different institutions such as: Indian Council of Medical Research (ICMR), All India Institute of Medical Sciences (AIIMS), etc. Furthermore, these institutions belonging to different sectors have accordingly their different effects on innovation.

In biotechnological sector, health systems, agricultural systems, industrial systems, environmental systems and various regulatory mechanisms play a major role in affecting the direction of technical change, in some cases even blocking or retarding innovation. But finally patents have played a major role in the appropriability of the returns from innovations.

4) The coexistence of global, national and local boundaries is present in sectoral systems:

In sectoral systems the national, the local and the global dimensions coexist. In the biotechnological sectoral system, there are differences in terms of national institutions, demand, networks of knowledge acquisitions, etc., and such national differences have appeared to historically affect the national firms. Over time, the markets for knowledge as well as the markets for products are becoming increasingly international, as are regulations and scientific and technological knowledge flows. Nevertheless, national institutional arrangements appear to influence not only the number and types of biotechnology firms started but also their specialization into different areas, (Casper & Soskice, 2001).

5) Co evolutionary processes are taking place in sectoral systems:

Changes in the knowledge base or in demand affect the characteristics of the actors, the organization of R&D and the innovative process, the type of networks, the structure of the market and the relevant institutions. All these variables in turn lead to further modifications in the technology and the knowledge base and demand, and so on.

In biotechnological sector, the interaction between knowledge, technology, firms, and institutions shape the evolution of the system of innovation. On the one hand, the changes in the knowledge base and in the relevant learning processes of firms induce deep transformations in the behaviour and structure of the agents and in their relationships among each other. On the other hand, the specific ways these transformations have occurred across firms are profoundly different, due to details of the institutional structure of each firm belonging to its sector (McKelvey & Orsenigo, 2001). As an example, product approval regulations has inserted an incentive towards more innovative strategies, at least for those firms which had the capabilities to invest in the new technologies.

Thus it can be argued that the biotechnology revolution, by creating new competencies and a new technological regime, has induced deep changes in the incentive structures within firms, universities, institutions etc. In the preceding context the next chapter will analyse the salient features of the Indian biotechnology sector.

Chapter 5: Salient Features of Indian Biotechnology Industry

Industrial activities based on biological processes have been used for a very long time, but biotechnology that is today the object of a very considerable policy attention is the result of a series of important advances in molecular biology, which were achieved the early 1970s. As a consequence, since the 1980s many governments started sponsoring the development of biotechnology by means of different policies. Biotechnology is generally perceived as a very pervasive technology, capable of giving rise to innovations in many different industrial sectors and fields of human activity. Many observers predict that the 21st century will be the century of biotechnology. While the scope of the future developments of biotechnology is immense, the actual rate at which they are achieved is not always comparable to the expectations of policy makers and of economic actors. This is not due to a lack of potential of the technology, but to the nature of scientific and economic evolution. First, pervasive technologies are usually constituted by many interconnected innovations, not all of which can be developed at the same time. Second, pervasive technologies do not develop in a vacuum, but co-evolve with institutions (Nelson, 1994). Thus, even if the early innovations giving rise to a new pervasive technology were to be created without any institutional innovations, the further development of the technology would require the creation of appropriate institutions. As a consequence, the full development of such a technology usually requires a long time, easily reaching a century. It is quite clear that the realizations that we have seen so far constitute only a small part of the potential of biotechnology.

An important characteristic of biotechnology is that it is both the result of a process of structural change in science and that it contributes to structural change in industry. The expression 'the biotechnology sector' is used very often in the literature, although such a sector does not appear in industrial statistics. As a consequence, it is very difficult to find accurate data about biotechnology (Senker, 2000).

5.1 Emergence of Biotechnology

The origins of biotechnology date back 10,000 years to the domestication of crops. A technique such as crop manipulation could be described as traditional biotechnology, which used natural organisms, products and processes that predate modern biotechnology methods.

Modern biotechnology derives from the creation of molecular biology, a new discipline founded in the 1930s with the objective of applying to biology the methods of physics. The discovery of the structure of DNA by Watson and Crick showed that genes contained the information required to produce proteins. Although it became immediately evident that this could have enormous potential implications for medicine as well as for many other fields of human activity, the practical realization of this potential did not begin to happen until the discovery of recombinant DNA and monoclonal antibodies in the early 1970s (McKelvey, 1997; Goujon, 2001; Eliasson, 2000). These two discoveries opened the way to industrial applications that were expected to produce economic returns within relatively short time periods. A wave of investment which gave rise to the creation of many new firms and to a new form of industrial organization followed. Thus, from its very beginning biotechnology was a very science intensive technology. Subsequent developments depended heavily on technical progress, for example on polymerase chain reaction (PCR), which allowed to magnify the quantities of DNA and of genetic material that could be available to researchers, and on the emergence of bioinformatics (Saviotti et al, 2000), a new discipline at the interface between biology and IT, which led to the automation of the sequencing of DNA and greatly accelerated the Human Genome Project. The Human Genome Project opened the door to a wide range of new potential applications. As a consequence the subsequent development of biotechnology can be characterised as a process of increasing specialisation in which particular diseases become the object of focused attention and emerging technical developments become recognised subsets of biotechnology. There is no consensus about the recognised subsets of biotechnology, although there are some commonalities between different classifications.

To understand the development of biotechnology we have to keep in mind that it is not an industrial sector, but a technology which is based on several scientific disciplines and which can affect a number of industrial sectors. Amongst the sectors that can be affected there are the pharmaceutical, agrochemical, food and chemical sectors and the environment. The adoption of biotechnology in these sectors has not been uniform. The pharmaceutical sector was and still remains dominant. Other sectors, such as agriculture and food, were considered very promising but they have not been as successful as was expected. General industrial applications developed at a slower pace but are gaining momentum. In summary, biotechnology is a component of a system which comprises scientific institutions, industrial firms, financing and regulating institutions.

The various components of this system co-evolve determining its overall dynamics. Although it is not impossible that several system configurations can achieve similar results, a country like India, wishing to develop biotechnology must make sure that all the required components perform well and are well integrated amongst themselves (Eliasson, 2000).

5.2 Defining Biotechnology

Despite its long history, there is no commonly accepted definition of biotechnology. Also known as modern biology, bioengineering or genomics, biotechnology can be described most simply as biology plus technology. However OECD defines biotechnology as "*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, 2003).

Biotechnology can be comprehensively defined as the integrated use of biochemistry, microbiology and chemical engineering for achieving the technological applications of the capabilities of micro-organisms and cultured tissue cells. More specifically it has been defined as the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services. In short biotechnology in its wider context may be understood as referring to the commercialisation of all biological processes. Implicit in the definition stated above is the fact that biotechnology is not an industry defined by products or services such as computers or machine tools. It actually refers to the use of microbial (animal or plant) cells and enzymes to synthesise, breakdown or transform materials. In short it is a process or a means of producing an existing product with properties that were hitherto not available with it (Mani, 1990).

After discussing about what is biotechnology per se and defining it, here it is necessary to discuss about the institutional setup of biotechnology in India, how it got established, its infrastructure and its present status.

5.3 Institutional development of Biotechnology in India

In the year 1982 the Government of India, in order to promote biotechnology, relevant to the needs and priorities, constituted an agency, viz. the National Biotechnology Board (NBTB) under the Ministry of Science and Technology, as an apex coordinating body to identify priorities, coordinate, oversee and plan for required manpower, integrated industrial development and large scale use of biotechnology products and processes. A unique feature of this board was that all the existing Science and Technology organizations and allied agencies participated in formulating the objectives and organization of the structure of the board as well as made financial contribution for the core funding of the Board. In terms of identification of needs and priorities in biotechnology in India, the board had a unique international interaction through the formation of Scientific Advisory Committee (North America) [SAC (N)] in 1983. Accordingly, various programmes for integrated manpower development and establishment of essential infrastructural facilities, realizing the need for capacity building through strengthening of existing laboratories, training of young scientists abroad, introducing course curriculum in biotechnology, etc. were initiated.

5.4 Establishment of Department of Biotechnology

Coinciding with the production of first transgenic farm animal and first approval of controlled experimental release of genetically engineered organism into the environment, in the year 1986 the NBTB was upgraded into a full fledged separate Department under the Ministry of Science and Technology, viz. Department of Biotechnology (DBT), in recognition of the need for having a focal point in the administrative structure of the Government of India for the purpose of planning, promotion and coordination of biotechnological programmes.

Setting up of the separate Department of Biotechnology has given a new impetus to the development in the field of modern biology and biotechnology in India and has paid rich dividends.(DBT,1985)

5.5 Biotech Infrastructure

Since 1986, concerted efforts have been made by the Government of India towards capacity building, both in terms of human resource and sophisticated infrastructure for R&D. As a result, India has world class facilities for DNA sequencing, protein engineering, bioprocessing, crystallography, molecular graphics and modelling, PL3 and PL4 level containment for work on dangerous pathogens, prescribed glass/animal houses for transgenic animal/plant research, repositories of microorganisms important in agriculture, healthcare and industry, *ex-situ* and *in-situ* gene banks for crops and endangered medicinal and aromatic plants, medium and high throughput screening facilities for drugs and pharmaceuticals, biosensors, nuclear magnetic resonance machines, different mass spectrometers for various purposes, GM testing labs and recently micro arrays, automated DNA sequencing as well as robotic plasmid isolation equipment. Most of the facilities can be shared by both the public and private research laboratories at a cost comparable to that of developed countries. There are about 200 laboratories with state of the art equipment and facilities for recombinant DNA research. Many private sector R&D facilities also have sophisticated equipment in most of these areas and some of them are paid-up service facilities for researchers. The biotechnology equipment market in India is about Rs.1500 million and is growing at the rate of 2 to 3 per cent and the demand is shifting from public research laboratories to the private sector. (Rao, 2005)

5.6 International Cooperation

India has signed several bilateral agreements for implementing joint projects and human resource development programmes. The earliest among them has been the Indo-US collaboration known as "Vaccine Action Programme" focused to develop jointly vaccines and diagnostics for communicable diseases, followed by the Indo-USSR programme on assisting manufacture of Oral Polio Vaccine (OPV) resulting in establishment of a public sector vaccines company, viz. Bharat Immunological and Biological Corporation Ltd. (BIBCOL) near New Delhi. The BIBCOL has supplied several million doses of OPV to national immunization programme. There are now several ongoing activities with both developed and developing countries, such as Germany, UK, Switzerland, Sweden, Japan, France, Israel, Sri Lanka, Myanmar, ASEAN countries and the countries from SAARC region. India also hosts one of the centers of International Center for Genetic Engineering and Biotechnology (ICGEB) at New Delhi for training and research needs of developing countries in particular.(Rao,2005) The main objective of the biotechnology international collaboration is to assist in implementation of national programmes; acquisition of knowledge in areas of specialization not available within the country; share expertise and large scale facilities; participation in joint R&D programmes; and add to the economic wellbeing of the country through private sector participation in product and process development, technology transfer and communication.

5.7 Institutional Framework

India is signatory to the WTO and the country is taking steps to enact the provisions of the WTO both in letter and spirit. More regulatory dictums within the framework of the international commitments made by India to the WTO and Convention on Biological Diversity (CBD) are in the offing. These include enactment of Plant Varieties Protection and Farmers' Rights Act and Plant Quarantine Authority of India. The Plant Varieties Protection and Farmers' Rights Act, 2001 seeks to protect, unprotected plant varieties that are novel, distinct, uniform and stable, for a period of 15 year from the date of registration. The Biological Diversity Act, 2002 has been passed with the intention of protecting India's rich bio-diversity and associated knowledge against the use by foreign individuals and organizations without sharing the benefits that arise out of such use. The Indian Patent laws were significantly amended in 2005 as part of India's commitments to the WTO. Recently, India signed Budapest Treaty and established International Depository Authority at Microbial Type Culture Collections at Chandigarh. The Department of Biotechnology has also published Ethical Document entitled "Ethical Policies on Human Genome, Genetic Research and Services" prepared by the National Bioethics Committee. The document bans any research on human cloning and germline interventions by Indian investigators (DBT, 2001).

Indian government has formulated regulatory framework for recombinant biotech products for bio-safety mechanisms so that any hazardous or unethical substance does not get commercialized in the market and reach directly to consumers. The regulatory framework is discussed below:

5.8 Regulatory Mechanisms for rDNA Products

The Indian rules and regulations as well as procedures for handling of the genetically modified organisms (GMOs) and rDNA products have been formulated under the Environment (Protection) Act (EPA) 1986. The rules enforced since 1993 cover manufacture, use/import/export and storage of hazardous micro-organisms, genetically engineered organisms or cells. However, a set of rDNA guidelines were issued in 1990 covering genetically engineered organisms, genetic transformation of plants and animals, mechanism of implementation of biosafety guidelines, containment facilities at lab level under three risk groups, etc. The guidelines have been reworked and issued as Revised Guidelines for Safety in Biotechnology matching with the newer aspects of technology. In order to provide special thrust to genetically engineered plants "Revised Guidelines for Research in Transgenic Plants and guidelines for Toxicity and Allergenicity for Evaluation of Transgenic Seeds, Plants and Plant Parts" came into force in 1998. With coming into force of the above regulatory mechanisms so far 10 r- DNA drugs have been approved for marketing, four industrial units are manufacturing recombinant hepatitis vaccine, and locally and indigenously produced erythroprotein and G-csf are also available in the market. Several novel processes to produce r-DNA vaccines and drugs are in the advance stages of development. Under plants category, cotton with insect-resistant Bt gene was given approval for commercial release in March 2002. Following the regulatory procedures, at least 165 institutions are working in r-DNA research in India, which include 55 institutions engaged in transgenic plant research, both in public sector (42) and private sector (13). A large number of private institutions engaged in r-DNA therapeutics– about 25 out of 85 are doing basic research (Biospectrum,2005).

5.9 Implementing Agencies

Government's rules and regulations are implemented by:

• Ministry of Environment and Forests
• Department of Biotechnology
• State Government

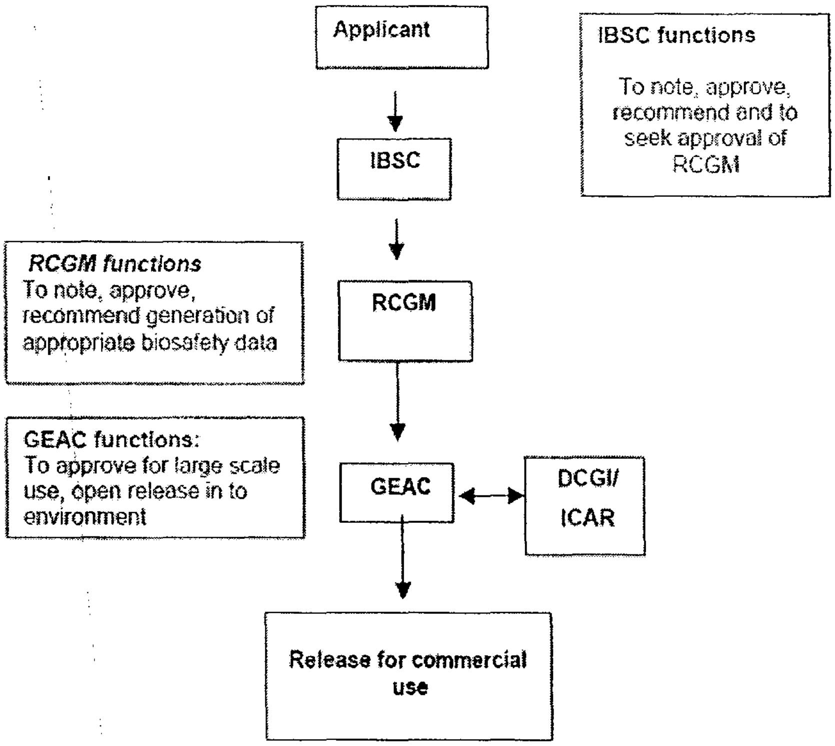
There are six competent authorities under the goverment's regulatory mechanism which are as follows:

i. Recombinant DNA Advisory Committee (RDAC)
ii. Institutional Biosafety Committees (IBSC)
iii. Review Committee on Genetic Manipulation (RCGM)
iv. Genetic Engineering Approval Committee (GEAC)
v. State Biosafety Coordination Committees (SBCC)
vi. District Level Committees (DLC).

While the RDAC is of advisory in function, the IBSC, RCGM, and GEAC are of regulatory function. SBCC and DLC are for monitoring purposes.

The procedure for approval of genetically modified organisms is shown in the following flowchart (Figure 5.1)

Figure 5.1: Procedure for approval of Genetically Modified Organisms



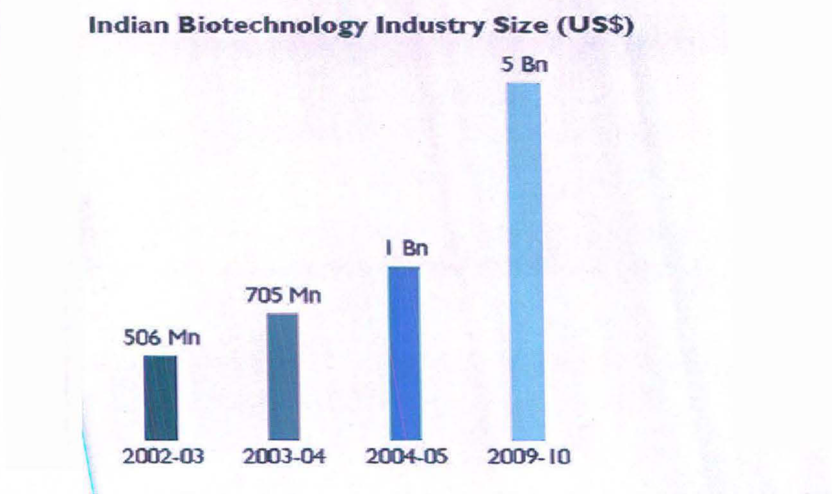
Source: Department of Biotechnology, 2001

Regulatory policies in general are compliance friendly. However, the major criticism in this respect is that at present there are too many agencies involved in giving regulatory clearances. To address the concern of both public and private sector, efforts are under way to establish a single window regulatory mechanism or to put in place a structure which could promote speedy commercialization of recombinant products and processes. Over all, the system is relatively open and transparent yet precarious in its approach. In nutshell, there is enough expertise in technology and risk assessment of GM plants and therapeutics in terms of safety to environment as well as human and animal health. Keeping up with the recent trends/public perceptions on GM foods, appropriate measures and mechanisms are being evolved to label the same within the scope of CODEX alimentaries. GM detection and analytical food safety laboratories have been established to facilitate generation of scientific data.

5.10 Significance of the Biotechnology industry

The biotechnology industry is currently dominated by major US companies as well as some European and Japanese players. Globally, the market for biotechnology products is valued at $54 billion, to which India currently contributes about 2-3%. The Indian biotechnology market, valued at INR 112.6 Billion (US$ 2.86 Billion) in 2007-08, is projected to hit a CAGR of 30% in near future. Going by a forecast in 'Bio Reality in India: Report 2008', by international real estate consultants Cushman & Wakefield, the industry is expected to cross the US$ 5 billion-mark through its products as well as services by 2010. By this time, it is estimated to occupy 140 million square feet of industrial area. According to a report by the Confederation of Indian Industry (CII) and consultancy firm KPMG, the Indian biotechnology sector is likely to become a US$ 5 billion industry by 2010. The report stated, "India is ranked among the top 12 biotech destinations in the world and is the third biggest in Asia-Pacific in terms of the number of biotech companies." The sector has been attracting major investments, which have been growing at the rate of about 38 per cent for the last three years. The following figure 5.2 shows the expected growth of the biotech industry in India.

Figure 5.2: Growth of Indian Biotechnology Industry



Source: Biospectrum, 2005

According to an industry survey, carried out by Association of Biotech Led Enterprises (ABLE), biotechnology industry in India has notched up a growth of 20 per cent during 2007–08 and the revenues earned were worth US$ 2.56 billion as against US$ 2.1 billion during the previous fiscal. Research services touched US$ 500 million and bio-IT (bioinformatics) was US$ 250 million.In 2005–06, the Indian biotechnology industry replicated the previous year's growth rates, with sales growth of 37.42 per cent, touching US$ 1.47 billion in revenues.

In the last fiscal, investments increased by 21 per cent at US$ 637,607 million with 48 per cent of the total biotech market shared between the 20 leading Indian companies. As per the findings of the survey, 56 per cent of the sector's revenue (US$ 1.44 billion) came from exports. Around 70 per cent of exports were from bio-pharma and 26 percent from bio-services segments. Further according to the findings, going by the current trend and the new biotech policy of the central government, the sector is poised to generate US$ 13–16 billion by 2015. According to the fifth survey on the industry conducted by Biospectrum and ABLE jointly in 2008, nearly 40% of the companies operate in the biopharma sector, followed by the bioservices (21 %), bioagri (19 %), bioinformatics (14 %) and lastly the bioindustrial sector (5 %).

The Indian bioinformatics market, which deals with creation and maintenance of extensive electronic databases on various biological systems, is set to double by 2010, from US$ 32 million to US$ 62 million by 2010, according to a report by research firm Value Notes Outsourcing Practice. Five major sub-sectors, bio-pharmaceuticals, bio-services, bio-agriculture, bio-industrial, and bioinformatics, have varied contributions to the biotech revenue. With revenue of US$ 1.05 billion, bio-pharmaceuticals accounted for over 72% of the total biotech revenue. Bio-services and bio-agriculture followed with $160 million and $130 billion, i.e., 11% and 9% market share, respectively. With over 80% and 69% growth rate, bio-agriculture and bio-services are the fastest growing sectors (Table 5.1).

Table 5.1: Sector wise representation of Biotechnology industry

Segment	*2005–2006 (Rs. Crore)*	*Share (%)*	*Growth rate from 2004–2005 (%)*	*Domestic rev (%)*	*Export rev (%)*
Bio-pharmaceutical	4708	72	32	47	53
Bio-services	720	11	69	5	95
Bio-agriculture	598	9	81	94	6
Bio-industrial	350	5	9	95	5
Bioinformatics	120	2	20	16	84
Total	*6521*	*100*	*37*	*49*	*51*

Source: Biospectrum, 2006

With exports forming a major chunk of the market, India is a significant exporter of bioinformatics and bioservices. The segment derives 90 per cent of its revenue from outsourcing. Since the global bioinformatics market is expected to grow at a CAGR of 16 per cent over 2007–10, it would actually be conducive to its growth in India at a rate of 25 percent.

Unlike India's Information Technology (IT) industry which has gained most of its revenue from the export, biotechnology industry presents a more even picture in terms of serving both the domestic and the international markets. The industry gained revenue from the domestic market as much as from the export. Nevertheless, different sub-sectors have its different market focus. While bio-agriculture and bio-industrial are mostly domestic market-oriented (with 94–95% revenue from the domestic market), bio-services and bio-informatics exclusively serve the international market with a mere 5–6% revenue from the domestic market. Bio-pharmaceutical, the dominant subsector, enjoys 53% revenue from the overseas market, slightly highly than its domestic share. India's biotech market has been dominated by large-size companies. In 2005–2006, India's top 20 companies accounted for 62% of the total biotech market. The four-firm and eight-firm concentration ratio are 34% and 48%, respectively. It is worth mentioning that though India is an attractive location to multinational biotech companies, its domestic companies have grown rapidly in biotech industry. In 2005–2006, 14 of the top 20 biotech companies are Indian home grown and all top six companies are domestic. The top 20 domestic companies in India contributed to 56% of the total biotech industry's turnover. They have an average annual growth rate of 45%, higher than the industrial average of 37%. Most of the leading domestic companies focus on bio-pharmaceutical and bio-agriculture sectors (Fan, 2008).

5.11 Geographical concentration of biotech firms:

Biotech firms are mainly concentrated in western and southern India. In the western India, these firms are clustered in Mumbai-Pune Industrial Region and Ahmedabad-Vadodara Industrial Belt. In south, these firms are clustered in and around Bangalore, Hyderabad and Chennai. Region wise revenue generated by the firms and their percentage share in total has been given in the table 5.2:

Table 5.2: Region wise concentration of biotech firms

Regions	Biotech Revenues (Rs.Crores)	Regions share (%)
West	3234.42	49.60
South	2367.12	36.30
North	919.46	14.10
Total biotech	6521.00	100.00

Source: Association of Biotechnology Led Enterprises

5.12 Biotechnology segments in India:

After discussing about the plan outlay it is necessary to describe about the different biotechnological segments in detail. There are mainly five segments of biotechnology namely bio-pharmaceuticals, bio-agriculture, bio-services, bio-informatics and bio-industrial which are described as follows:

Biopharmaceuticals:

The Indian pharmaceutical market is growing very fast and expected to rise from $3 billion in 1997 to $25 billion by 2010. While still small compared to the overall pharmaceuticals industry, the biopharmaceuticals sector is the single largest contributor to the Indian biotechnology industry with total revenues of $811.4M accounting for more than 70 percent of the total biotech industry (Biospectrum,2005). In recent years, this segment achieved close to 30% annual growth, primarily driven by the vaccine business. Apart from vaccines (e.g. recombinant hepatitis), the most important medical biotechnology products include diagnostics (e.g. immunology products) as well as drug development. In 2004/2005, the Indian vaccines market generated sales of about US $380M growing at an annual rate of 20%. One of the most important vaccines is recombinant (Mindbranch, 2005) Hepatitis B with a market of $22M in India, produced by companies like Shantha Biotechnics, Bharat Biotech or Wockhardt, as well as foreign producers such as Aventis, LG Chemicals or GlaxoSmithKline. With over 25 companies, the diagnostics sector generated sales of $137M with its proposition of real-time and low-cost processes through new reagents and instruments. The therapeutics segment achieved $113.64M in sales with the development and marketing of products such as Streptokinase, Granulocyte Colony Stimulating Factor (GCSF), Erythropoetin (EPO), Interferon Alpha 2b or Human Insulin of which some were released as recently as 2003 (Bhargava, 2003). In this segment the production of biogenerics plays an important role: Indian companies such as Wockhardt, Biocon or Shantha Biotech are manufacturing generic versions of biotech drugs – focusing on EPO products, Human Insulin, Interferons or G-CSF. Other fast growing areas are the bioengineering and Nanobiotechnology segments which develop new tissue engineering processes and biomaterials for therapeutics.

Bioservices

The launching of a drug costs $300-500M today, of which 25% is incurred during the research process and 75% during development. Hence, global biotechnology companies are seeking for opportunities for contract research in India as it not only offers a highly skilled labor pool, but also a diverse gene pool covering a large variety of diseases, with a well-developed R&D capability and a large patient base for clinical trials, the bioservices sector is a sector with great promise (ABLE,2008). In 2004/2005 the bioservices market generated about $97M in sales, a segment which is growing annually above 50% with expected sales reaching $1 billion by 2010. Leading global pharmaceutical companies such as GlaxoSmithKline (GSK), Pfizer or Novartis have already outsourced their clinical data management to India; GSK is building a new global center for clinical research and development. Domestic companies, such as Syngene, the subsidiary of the Indian biotech giant Biocon, carry out early state oncology drug discovery and delivery for companies like Novartis (IBEF,2005).

Agriculture Biotechnology

With declining per capita arable land in India, there is a high demand for new generations of improved crops, animals, plants, forestry and biofuels. In 2004-05 the bio-agricultural sector was the fastest growing segment of the biotechnology industry, generating $75M sales (Biospectrum,2006). India is the second largest food producer after China and therefore, offers enormous opportunities for transgenic crops. Currently, field trials are undertaken with transgenic rice, cabbage, tomato and other agricultural products. The Indian-American partnership Mahyco-Monsanto has been the first company to be granted the right to sell transgenic cotton. Other opportunities are provided in the fertilizing sector: If biofertilizers were used to substitute 25% of chemical fertilizers on 50% of India's crop the market potential would be 235k MT, compared to only 13k MT now. Similarly, biopesticides are expected to grow at an annual rate of 10-15% from their current market share of only 2.5% (DBT,2005) . To this category belongs also the emerging plant biotechnology. Indian and foreign companies are researching applications such as plant tissue cultures, bioprospecting, biofuels, as well as medicinal and aromatic plants. Lastly, the Indian nutraceuticals market is valued at about US $500-600M (Bhargava,2003). Recently, proteinenriched wheat with higher lysine content has been introduced to the fields.

In modern biotechnology new techniques such as marker-aided selection (MAS), *in vitro* regeneration, protoplast culture and fusion, androgenesis and transgenics can facilitate the development of superior hybrids and varieties resistant to biotic and abiotic stresses. Biotech crops with other attributes such as tolerance to abiotic stresses such as drought, frost and salinity as well as enhanced shelf-life and nutritional contents are at various stages of development. In India, a large number of biotech fruits and vegetables are being developed by both public and private sector institutions (Choudhary,Gaur;2009).

Presently, a number of biotech fruits, vegetables and flowers are being either field tested or commercialized in different parts of the world. These are indicated in Table 5.3.

Table 5.3: Research and development of biotech/GM fruits and vegetables in the world, 2008

Fruit/vegetable	Botanical name	Trait	Country
Apple	*Malus domestica*	AP, PQ, IR, BR, FR	USA,Sweden, Germany
Banana	*Musa spp.*	VR, DR, FR	India, USA
Blueberry	*Vaccinium corymbosum*	HT	USA
Brinjal	*Solanum melongena*	IR, DST	India, Bangladesh, the Philippines, Italy
Broccoli	*Brassica oleracea var. italica*	IR, HT	New Zealand, Japan
Cabbage	*Brassica oleracea var. capitata*	IR	India, Australia, New Zealand
Cassava	*Manihot esculenta*	PQ, MG, VR	India, USA
Carrot	*Daucus carota*	NR, PQ, HT	USA, New Zealand
Citrange	*Citrus x poncirus*	PQ	Spain
Cauliflower	*Brassica oleracea botrytis*	IR, HT	India, Japan, Australia, New Zealand
Cucumber	*Cucumis sativus*	AP, VR, HT,PQ, IR	USA, Poland, Japan
Garlic	*Allium sativum*	AP, PQ	New Zealand
Grape	*Vitis spp.*	VR, BR, FR, HT, MG, PQ	USA
Grapefruit	*Citrus x paradisi*	IR, MG, VR, BR, PQ	USA

Grapevine	*Vitis vinifera*	BR, FR, MG, PQ	USA, Australia
Lemon	*Citrus limon*	FR	Italy
Lettuce	*Lactuca sativa*	VR ,HT, FR, PQ	USA, Japan
Okra	*Abelmoschus esculentus*	IR	India
Onion	*Allium cepa*	HT, FR, DR, AP	India, New Zealand, USA
Orange	*Citrus sinensis*	PQ	Spain
Papaya	*Carcia papaya*	VR, IR	Australia, Japan, India, USA, Canada, China
Pear	*Pyrus communis*	PQ, BR	USA, Sweden
Pineapple	*Ananas comosus*	PQ, NR, VR	Australia, USA
Pea	*Pisum sativum*	OO, HT, VR, PMP, DR	USA, Germany, United Kingdom (UK)
Potato	*Solanum tuberosum*	FR, VR, OO, PQ, IR, AP, BR, HT	India, Canada, New Zealand, USA, Germany, Spain, UK, Netherlands, Czech Republic, France, Poland, Ireland, Sweden, Finland, Japan
Strawberry	*Fragiara x ananassa*	AP, FR, HT, MG, VR, IR	USA, Italy, Japan
Squash	*Cucurbita spp.*	VR	USA, Canada
Sweet Potato	*Ipomoea batatas*	HT, VR	USA
Tomato	*Solanum lycopersicum*	PQ, FR, IR, VR, AP, BR, OO, HT, NR	India, Canada, USA, Italy, Japan, China
Watermelon	*Citrullus lanatus*	AP, OO, VR	USA

(Source: GEAC and IGMORIS 2008, India)

AP-Agronomic performance, BR-Bacterial resistance, DR-Disease resistance, DST Drought and salinity tolerance, FR-Fungal resistance, IR-Insect resistance, HT-Herbicide tolerance, MG-Selectable marker, NR-Nematode resistance, OO-Cold/drought resistance, PMP-Plant manufacturing pharmaceuticals, PQ-Product quality, VR-Virus resistance.

The unprecedented adoption and success of Bt cotton in India, has proven the views of the critics to be unfounded and opened the door for crop biotechnology in India. In 2008, 5 million small farmers, (up from 3.8 million farmers in 2007) benefited from planting 7.6 million hectares of bt cotton, equivalent to a high adoption rate of 82%. Benefits vary according to varying pest infestation levels in different years and locations. However, on average, conservative estimates for small farmers indicate that yield increased by 31%, insecticide application decreased by 39%, and profitability increased by 88% equivalent to Us $250 per hectare. In addition, in contrast to the families of farmers planting conventional cotton, families of Bt cotton farmers enjoyed emerging welfare benefits including more prenatal care and assistance with at-home births for women, plus a higher school enrollment of their children, a higher percentage of whom were vaccinated (James,2008).

After the great success of Bt cotton now Bt brinjal has completed several stages of regulatory requirements and is now getting ready to be commercialised.. It assumes greater importance as it is going to be the first vegetable biotech product to be approved in India. Bt technology in brinjal is a very effective tool for mitigating damage caused by the economically important fruit and shoot borer (FSB) and has the capability to deliver substantial benefits to small and resource poor, medium and large farmers in the same way as of Bt cotton (Choudhary,Gaur;2009).

Industrial Biotechnology

The bio-industrial sector generated total revenues of $71.1M (Biospectrum, 2006). This sector is the most concentrated in the biotechnology field with 70% of India's enzyme market being controlled by Novozymes and Genencor(Palnitker,2002). Apart from the production of enzymes, innovation in the biodiesel area is heavily supported by the government in order to decrease the reliance on foreign imported fuel. A diverse set of companies such as Tata Motors, Mysore based Labland Biotech or Lurgi, Germany is involved in the development of this technology.

Bioinformatics

The bioinformatics sector is successfully creating synergies between the IT- and the biotechnology industry. In 2004/2005, this segment registered 25% growth generating $22.7M in sales (Biospectrum, 2006) and has grown to $120M sales in 20069. Certainly, the bioinformatics industry benefits from the strength of the IT industry in India. Companies like Questar Bioinformatics Ltd. or Tata Consultancy are offering services related to data mining, scientific visualization, information storage or simulation of DNA sequences (IBEF, 2005) Some companies such as LabVantge or Agaram Industries are specialized on the development of Laboratory Information Management Systems (LIMS). Naturally, other sectors such as bio-suppliers are benefiting from this growth as well and it can be expected that the biotechnology sector will have a positive impact on the growth of other more traditional industries.

There is a huge undergoing debate about the potential risks and benefits of biotechnology. Some say its a boon and for others it's a bane. The major criticism comes from the environmentalists, farmers and other stakeholders. So there is a need to manage the risks and benefits regarding biotechnology.

5.13 Managing economic risks and benefits

The major discussion about the risks of biotechnology concerns environmental and health issues. The failure to manage economic risks and benefits effectively is one of the main sources of resistance to the adoption of new technologies. There are institutions that deal with some aspects of risk and benefit management, such as antitrust legislation. But these do not address the seemingly benign cases of product displacement. Generally, such adjustments are considered to be part of the evolution of markets. However, the pace and scale at which they happen could become a threat to the diffusion of the very technology that brings about new benefits. The use of pest-resistant crops, for example, can be seen as offering a wide range of economic and health benefits. But those who rely on the chemical industry for their livelihoods are likely to be direct and indirect sources of resistance to the new technology. An early effort to identify potential winners and losers is an important part of the technology development strategy (UN Report, 2004). It is beneficial to manage both the risks and the benefits in a way that allows for relatively smooth technological transitions. Managing technological transition is not easy, partly because of the competitive nature of market behavior and the dominant view of losses as part of the institution of free markets. However, in the absence of measures that reduce radical market impacts, resistance to new technologies is likely to emerge and undermine the potential benefits to society.

5.14 Consumer perceptions about Biotechnology

It is significantly being felt these days that consumer perceptions about biotechnology are changing and consumers now are showing a positive attitude towards food biotechnology in contrast to the earlier notions developed by the consumers. The Asia region resource centre on nutrition, health and food safety has concluded that biotech foods will likely become an increasing and well accepted feature of the Asian diet in the light of the region's growing demand for high volumes of food. Currently, the only genetically modified (GM or biotech) crop grown commercially in India is Bt Cotton but the government's policy leans towards bigger use of biotech food crops in the near future. In 2008, the government has simplified, for biotech companies, the currently multi-level and complex trials made mandatory thus far before a biotech crop can come to field trials.

The AFIC survey "Consumer Perception on Acceptance of biotech Food in Asia", conducted by Nielsen across five Asian countries including India, Japan, China, Philippines and S Korea, has found that in India, a significant 95% of consumers support plant biotechnology related to sustainable food production; 84% of Indians are ready to purchase biotech food such as tastier tomato, cheaper food staples and foods/cooking oil with a healthier fat profile: more confident with food safety levels in the country, in comparison to other Asian countries surveyed. The survey also contends that 70% of Indians strongly believe that food biotechnology will bring benefits in the next few years while 68% are satisfied with the information provided on food labels. 70% of consumes surveyed, it said, had a neutral or favorable impression of biotech use in food production.

The following table shows the issues with which consumers in Asia are more concerned, within the countries of South Korea, China, India, Japan and Philippines.

Table 5.4: Level of concern with food issues (mean scores)

	South Korea	China	India	Japan	Philippines
food poisoning	4.1	4.3	4.3	4.3	4.7
pesticide residues	4.1	4.3	4.4	4.3	4.7
food from unknown source	4.4	4	4.3	4.3	4.6
additives	4.1	4.2	4	4	4.5
transferable animal disease	4.1	4.3	3.9	4.3	4.5
improper handling of food	3.9	3.9	4.3	4.1	4.7
info on packaging	3.6	4	4.3	3.9	4.6
antibiotics or hormones	4.1	4	3.8	4	4.6
nutrition level	3.8	4.1	4.2	3.7	4.6
GMO	4.3	3.8	3.8	3.7	4.1
irradiated food	3.9	3.9	3.7	3.5	4.1
calorie consumed	3.4	3.3	3.6	3.5	3.9

Source: AFIC, 2008

Figures above indicate the average score from a rating scale of 1 to 5, where 1 is 'Not Concerned at all' and 5 is' Very Concerned'.

According to AFIC survey Asian consumers, unlike EU and US consumers, ranked expiry date as the "most important" information looked for while reading food labels and that they did not perceive the presence of biotech ingredients as an additional labeling item. According to the survey "Food biotechnology is not a priority food safety concern among consumers. The important concerns are pesticide residues, food poisoning, food from unknown source and improper handling of food". (AFIC, 2008)

5.15 Ethical Issues

The Indian public is generally more open minded towards technological advances than other societies as the progress in the past decades is credited to the application of new technologies. Nevertheless, India being the birthplace of several religions is concerned with the impact of a technology that enables the physiological manipulation of living organisms.

Stem cell research is the most controversial biotechnology application. India is one of the few countries in the world that is supportive of stem cell research and there are already laboratories working on stem cells. Thus, under certain conditions and with the approval of the Department of Biotechnology,stem cell research is generally allowed. Opponents and supporters of stem cell research use Hindu mythology to support their viewpoint. Some Hindu epics as well as the Indian traditional medicine Aryuveda depict fetuses as living and conscientious creatures. However, there are other mythological stories which supporters refer to in order to advocate stem cell research. Hence, generally spoken, the Hindu religion is more flexible than the Abrahamic religions regarding the adoption of new technologies (Mishra,2005). The Indian law allows stem cell research for therapeutic cloning, but prohibits reproductive cloning. Moreover, research based on stem cells derived from adults, bone marrow or fetal cord blood can only be undertaken after the donor has given informed consent and within specific safety measures. For embryonic stem cell research, embryos are not allowed to be generated for the sole purpose of obtaining stem cells. Thus, only surplus, spare or supernumerary embryos can be used after obtaining informed consent of both spouses.

Currently, the Indian Council of Medical Research and the Department of Biotechnology are developing guidelines and rules for stem cell research. Those guidelines will later be communicated to scientists in workshops (Dureha,2006). The Indian government plans to set up an exclusive fund to support stem cell research in facilities in Hyderabad, Bangalore, Delhi and Pune. One research center, the Reliance Life Sciences Institute already ranks third among the top 10 institutes worldwide working on stem cell research. Another major concern for the Indian public is the practice of patenting DNA as indicated in the patent section on page 13 of this report. India has a very high level of biodiversity and many people feel being betrayed by foreign companies that patent organisms which have been used in India since thousand years for health or cosmetic applications(Vanguri,Rajput;2002). Moreover, as India becomes a major destination for clinical research, there are concerns that the bad economical situation of poor (and often sick) Indians is exploited by misusing those people as "Guinea pigs" for research. Bioethics is a grey area and any society needs to conduct ethical debates. However, ethical debates like in many European countries that are based on prejudices rather than facts often lead to populist legislation. Hence, there is a need for Indian government to take efforts to educate the general public about biotechnology. For that it needs to encourage inter agency communication, begin a dialogue with scientists as well as provide appropriate training for judiciary and media representatives.

While concluding it can be argued that with latest developments in the field of biotechnology, India can emerge as a global biotechnology hub. The combination of low operational costs, low-cost technologies, a skilled human resource base with proficiency in English, a large network of research laboratories and the availability of raw material such as plants, animals and human genetic diversity, with India is unique in the world.

Yet, there are many obstacles the industry is facing. Historically, due to a different patent law, the Indian Pharmaceutical and Biotechnology Industry was strong in product development and marketing, but rather weak in discovery and research. Hence, with the implementation of the new product centered patent law, many Indian biotechnology companies need to expand their IP portfolios to remain competitive. Moreover, while the system of higher education is well established, many excellent scientists move overseas where more opportunities are provided. Also, the regulatory environment is still underdeveloped and there are not sufficient people in the legal system skilled in patent practice.

Even though India is a highly entrepreneurial society, the availability of funds for young biotechnology companies is limited. Hence, in order to become a major player in the biotechnology industry, the Indian government needs to invest heavily not only into research infrastructure such as biotech parks, but also into basic infrastructure such as roads, airports, telecommunications, convention centers or primary education. The government should continue to finance large research projects and stimulate competition between the various states by providing funds to the most successful districts. It also should mediate a dialogue process between the major religious groups and the scientists in order to involve the general public in the process.

Furthermore, the domestic industry needs to build partnerships with foreign companies or acquire their assets to improve its IP portfolio. Larger companies need to invest the proceeds they gain from generics into R&D to eventually start discovering drugs themselves. While the biopharmaceutical sector will continue to dominate, smaller companies needs to look for niches such as bioinformatics where synergies with the IT industry could be leveraged and a global center for bioinformatics could be created. Moreover after discussing about the Indian biotechnology sector in detail, next chapter deals about technology foresight and its perceptions of usefulness.

Chapter 6: Technology Foresight and its Perceptions of Usefulness

Not all foresight methodologies are perceived equally useful, nor are they applicable in all situations. Different foresight objectives require different foresight methodologies (Balachandra, 1980). Also, the objectives of carrying foresight differ according to the nature of the firm and the sector to which it belongs, for example in the case of biotechnology, which is constituted of mainly five sectors namely: agricultural, industrial, health, bioinformatics and environmental. Therefore in the present study, a relationship is sought among the specific sector of biotechnology, its preference for a specific category of foresight methodology and the usefulness of the particular methodology for it.

The response to the questionnaire was quite poor as reflected in the fact that not even 10% of the total firms responded. The reasons could be partly secrecy or absence of foresight activities. Of the 400 firms, to whom the questionnaire forms were mailed, 32 responded. Out of these 32 firms, 15 have returned completed the questionnaire forms, 8 of them replied that they are not aware of Technology Foresight, while 4 replied saying they cannot participate in the survey without giving any reason, which can be articulated into the fact that they might not be aware of Foresight that's why they did not participate. Further, 5 of them mailed saying they cannot provide their confidential information. Apart from the questionnaire survey, 3 Structured Interviews were also conducted. Interviews were conducted with:

i) Technological head of International Centre for Genetic Engineering and Biotechnology, New Delhi

ii) Scientist of National Centre for Plant Genome Research, New Delhi

iii) Scientist and P.R.O. of National Institute of Immunology, New Delhi

6.1 Regional location of the firms

It is evident from the above list that most of the biotech firms are located in the southern part of India. According to BioSpectrum-ABLE survey, 2003 The North, South and the West regions are the prime ones where the activities have been concentrated. Out of the total market of Rs 2,305 crore, Southbased companies account for nearly 39 percent of the business done, while West accounts for 32 percent, and the North for 29 percent. The reasons for several companies to be based in these three regions include good support from associations, research institutes and the presence of leading companies. In the North, the fuel is Delhi and the National Capital Region (NCR). In the West, it is the commercial capital of India (Mumbai), the seed capital (Aurangabad), the IT hub (Pune) and Ahmedabad-Vadodara, regions which are driving the business. Bangalore and the pharma capital of south India, Hyderabad are the major factors for the development in South. Also the ayurvedic capital, Kerala and marine hub Tamil Nadu enrich the South.

6.2 Products / Services and their Market

Out of the total 32 respondents, 40% replied that they are engaged in production, whereas 60% said both, products and services. This means that most of them are product based firms while providing services also. But none of them replied that they provide only services. This can be analysed as: the services are not provided on a large basis as products in biotech sector. In another question, that what kind of products they produce; according to their reply it can be analysed that, their products ranges from vaccines to biopesticides mostly, showing that these two type of products are produced on a large basis.

In the next question about the market for their business product portfolio that is it national or international, 80% of firms out of 32 said both (national and international) while just 20% responded that it is international. Therefore it becomes evident that the market for the Indian biotech firms is no more confined to the national boundaries, but has expanded from national to international boundaries. In another question about the future expansion of the markets for biotech products, 86.7% out of 15 firms responded in favour of it, while 13.3% responded as they can't say. This results shows that maximum firms are hopeful for the future expansion of biotech products market, which is a bit limited at present.

6.3 Area of biotechnology

In the questionnaire, the firms were asked about their area/sector of biotechnology to which they belong. Their reply is shown in Table 6.1 below:

Table 6.1: Area of Biotechnology

Percent	Count	Answers
0.0%	0/15	Environmental
13.3%	2/15	Agricultural
53.3%	8/15	Health
6.7%	1/15	Industrial
6.7%	1/15	Bioinformatics
20.0%	3/15	Animal
100.0%	**15/15**	**Summary**

Source: Prepared by Author

From the above table it is clear that most of the firms belong to Health sector, representing 53.3% of 15. While Agricultural biotech firms clubbed with Animal biotech firms are second in terms of their number representing33.33%; whereas Industrial and Bioinformatics represent 6.7% each, none of the firms are of Environmental biotechnology sector. The above result can be coincided with the fact that in India nearly 40 percent of the companies operate in the biopharma sector, followed by bioagri (19 percent), bioinformatics (14 percent) and lastly the bioindustrial sector (5 percent), (Biospectrum and ABLE survey, 2007)

6.4 Ownership and Sector

According to the ownership criteria (i.e. Sole proprietary concern, Partnership concern, Public limited, Private limited, Autonomous body, Foreign Subsidiary), 66.7% of the firms out of 15, were private limited, 13.3% of firms were Partnership concern and Public limited each, while just 6.7% belonged to Sole proprietorship. Hence none of them were Foreign Subsidiaries. Thus it is necessary here to define all of them.

Thus it is necessary to define all of them: “A sole proprietary concern is the one which is made by an individual’s initiative to start an activity related to start a trade or commerce for his own economic benefit.” A sole proprietor is a single person who owns, maintains and manages the whole show in the business. Further, The Indian Partnership Act, 1932 defines partnership as, “the partnership between persons who have agreed to share the profits of business carried on by all, or any one of them acting for all.” In a partnership, there can be a maximum of 20 people. Because of this limit, the amount of capital that can be generated is limited. Also, because of the unlimited liability of partnerships, the partners may be discouraged from taking huge risks and further expanding their business. To overcome these problems a public or a private company may be formed. Private and public companies are much better investments because of “Limited liability”. This means that if an investor has invested Rs.1000/- in a particular company, and the company goes bankrupt, the investor only looses the money he has invested. To pay of the debt, the investor’s property, bank accounts etc. are "not" used. Because of this limited liability, many investors are interested in investing in these private or public companies. Hence, a large capital can be generated and a huge business can be run. The major disadvantage of Private and Public companies is that they have a costly and elaborate process of setting up. They are also closely regulated by the government.

These companies are also known as “joint stock companies”. The companies in India are governed by the Indian Companies Act, 1956. The Act defines a company as an artificial person created by law, having a separate legal entity, with perpetual succession and a common seal. Thus Private Limited Companies are those companies that can be formed by at least two individuals having minimum paid-up capital of not less than Rupees 1 lakh. As per the Companies Act, 1956 the total membership of these companies cannot exceed 50. The shares allotted to its members are also not freely transferable between them. These companies are not allowed to raise money from the public through open invitation. They are required to use "Private Limited" after their names.

Whereas, a minimum of seven members are required to form a public limited company. It must have minimum paid-up capital of Rs 5 lakhs. There is no restriction on maximum number of members. The shares allotted to the members are freely transferable. These companies can raise funds from general public through open invitations by selling its shares or accepting fixed deposits. These companies are required to write either 'public limited' or 'limited' after their names. On the contrary, a Foreign Subsidiary is a company that has been incorporated outside India, under the law of some other country. It is registered in that company and has set up its business in India.

Furthermore in context to the sector i.e. public or private, surprisingly 93.3% of the firms out of 15 replied that they belong to Private sector and only one firm of Mumbai replied that it belonged to public sector and hence is a public limited company. The above figure shows that in Biotechnology, most of the firms belong to private sector. Hence it can be argued that the role of public sector enterprises/ companies is rather limited, though their involvement could have been much larger.

Moreover much of the R and D activity is confined to government laboratories and universities. A general criticism against the public sector firms/enterprises under the state is their lack of commercial outlook; very little of their research output really finds its way into actual commercial production. Successive committees have expressed their reservations against this lamentable state of affairs as far as commercialisation of their research output is concerned. Thus the role of public sector enterprises/firms in research as well as in its commercialisation is very limited. The two pharmaceutical companies under the ownership of the central government, viz, IDPL and HAL are involved in some limited research. Apart from these limited instances, by and large, public sector enterprises have not yet woken up to the challenges posed to them. (Mani, 1990)

Further, in the questionnaire the firms were asked about their respective share with foreign ownership. 80% of the firms out of 15, said that they do not have any foreign ownership, while, one firm of Hyderabad replied it had between 11 to 30% of foreign ownership, one of Pondicherry said it had between 31 to 50% of foreign ownership and one more firm of Hyderabad replied it had between 51 to 100% of foreign ownership. This shows that very few of the biotech firms have foreign ownership and mainly they are domestic companies.

6.5 Size of Organisation

The size of the organisation constitutes that whether the firm if of Small, Medium or Large scale. Hence, in context to their size, none of them belongs to large scale, while 8 of 15 firms (who have returned completed questionnaire forms) out of 32 respondents are of small scale and 7 firms out of 15 are of medium scale. Thus it can be analysed that mostly biotech firms are either medium or small scale.

For long, small and medium scale enterprises were clubbed together loosely, with no clear definition of what constituted medium scale units. The government has now provided clarity on this issue with the enactment of the Micro, Small & Medium Enterprises Development Act, 2006 (MSMED Act) which came into force form 2nd October, 2006.

As per the MSMED Act 2006 (a definition exists for Micro, Small and Medium units). A Small enterprise is one which is engaged in the manufacture or production of goods, where the investment in Plant & Machinery is more than Rs. 25 lakh but does not exceed Rs. 5 crore, while a medium enterprise is one, where the investment is more than Rs. 5 crores but does not exceed Rs. 10 crore.

As per the new Act, a small enterprise engaged in providing or rendering of services is one, where the investment in Plant & Machinery is more than Rs. 10 lakh but does not exceed Rs. 2 crore, while a medium enterprise is one, where the investment is more than Rs. 2 crores but does not exceed Rs. 5 crores (DSIR,2007).

Currently, there exist around 800 companies, operating in all sectors of biotechnology, but there are only 25 companies that have gained size and are working in the modern biotech sectors. Leading companies are Reddy Laboratories, Wockhardt, Biocon, Panacea Biotech, Biocon, Nicholas-Piramal India, Reliance and Ranbaxy. The biotech sector in India is still mainly a mix of small and medium-sized companies (Biospectrum and ABLE survey, 2007). Major hurdles for Indian biotech start-ups are finding seed capital, lack of R&D focus, intellectual property rights, regulatory reforms and difficulty in competing with large companies in terms of salaries and benefits for key employees.

A large scale Indian firm is defined as one with a turnover of US$ 300 million or more. These are firms with a traditionally strong technological and marketing leadership in either the national or the international market. It is noteworthy that no public sector firm has made headline news in India despite their established production and commercial networks except for a vaccines unit which later had to be abandoned. The large Indian firms are active in human and animal diagnostics, cell and tissue culture, biopesticides, hybrid seeds, and bioremediation. They are hardly involved in radical innovations, due to the financial constraints faced by them. They are distinct from their Western counterparts in developing their technological competence in-house. To date, no systematic strategic alliances between Indian firms themselves or between firms and research institutes to develop innovations are known (Ramani, 1996).Even, links with foreign firms are for co-production of an existing product or distribution of foreign product, hardly for any pre-competitive research.

In comparison to large firms, small firms face the additional barrier that the relatively small funds they require to expand their businesses are often far less than the minimum thresholds set by international venture funds to reap an acceptable return on investment. Thus, small firms are often dependent on bank loans that would not disrupt their firm structure or overly dilute their majority shareholders' investments. A new financing model tailored to the needs of Indian small- to medium-sized enterprises is clearly needed to enable companies trying to develop innovative products to succeed. The government of India has responded to these needs by introducing several funding initiatives. For example, the Department of Science and Technology's Technology Development Board has invested over Rs 150 Crore ($34 million) in 2004–2005 in health and medicine-related projects, the most for any sector of the Indian economy. The Technology Development Board requires that their 'soft loans' be repaid with minimal interest (6%) upon successful completion of the project. Also, India's Council of Scientific and Industrial Research New Millennium Indian Technology Leadership Initiative program was set up to boost public-private partnerships between private companies, national research laboratories and academia. (Nature Biotechnology, 2007)

6.6 Venture Capital Funding

With the increased role of established private sector as well as start-up companies investing in biotechnology, several financial institutions/agencies, both in public and private sectors, have launched venture capital funding mechanism. Hence, the firms were asked about venture capital fund, that they have it or not. But 86.7% out of 15 said they don't have and just 13.3% answered in favor to it and said that they have VC funding.

The Ministry of Science & Technology created these opportunities through the establishment of Technology Development Board (TDB) in 1992 for providing financial assistance to industrial concerns and other agencies attempting development and commercialization of indigenous technology or adopting imported technology for wider domestic application. The board has been particularly helpful in promoting several new start-up companies. Since its formation, the board has signed 100 agreements with commercial enterprises/agencies with a total projects cost of Rs 15.00 billion and there is a commitment of Rs.3.58 billion financial assistance to areas of health and medicine, engineering and electronics, chemicals and lubricants, agriculture and biotechnology, waste utilization, etc. Companies such as M/s. Shanta Biotechnology and M/s. Bharat

Biotechnology, producing recombinant hepatitis vaccine, and M/s ABL biotechnology in marine biotechnology, are some known and successful beneficiaries. Venture capital (VC) funding in India for biotechnology projects picked up with success stories of the technology development board (TDB). Six or seven prominent VC firms, including ICICI (Industrial Credit and Investment Corporation of India), Morgan Stanley, and Small Industries Development Bank of India (SIDBI) are active. The venture capital is mostly available to companies whose product and market are clearly identified and research leads are already available for commercialization. During 2001, the biotechnology venture capital committed by different financial agencies other than the Technology Development Board (TDB) amounts to a total of Rs.2.80 billion during the year 2001 (Rao, 2005)

6.7 Patents

Biotechnological firms are applying for patents on a large scale. But since the procedure is complicated many of them get pending in the Indian Patent office. Regarding this in the survey, firms were asked that they have applied for patents or not. In reply 60% firms out of 15, said yes and remaining 40% said no. Then they were asked about the number of patents awarded to them. Replying to the answer some of them said that they have filed for patents but it is pending while others said that they have been awarded. The numbers of patents awarded to them were ranging from 3 to 63. This shows that the number of patents being awarded to the biotech firms is not very high.

Further, Indian firms are aiming to become more competitive by patenting their products and technologies, and they are doing so on a global basis. On a national level, India has been able to capitalize on domestic policies that emphasized process patents over product patents to build a biotech industry, with strong capabilities.

Many Indian biotechnology companies have developed proprietary processes for manufacturing "bio-generics" or "bio-similars," i.e., copies or derivative forms of first-generation biologics such as recombinant human insulin and erythropoietin. Despite their success in process development, the Indian firms are not yet filing a significant number of patent applications in India. During 2005 and 2006, they have filed only a handful of patent applications. Rather than developing novel recombinant proteins or methods of manufacturing them, for example, the bulk of India's skilled biotechnologists might remain focused on merely copying off-patent biologics. The enhanced incentives provided by India's newly strengthened patents regime might take a back seat to supplying the demand for generic biologics. The TRIPS-mandated term extension of Indian chemical (including biotechnological) process patents from seven to twenty years from filing, coupled with a shifted burden of proof for alleged infringements of process patents, is good for Indian biotechnology industry. As multiple Indian companies compete to sell the same biotechnology product, each firm's need to distinguish itself by process development increases. Therefore stronger process patent protection will facilitate competitive advantage among Indian biotechnology companies (Mueller, 2008).

6.8 Technology Foresight

80% of firms out of 32 respondents, among those 15 firms replied that they carry foresight exercise in their organisation and only 20% replied in negative.. This means that most of the firms are carrying out foresight exercise in their firms. Then they were asked that from how many years they have been conducting foresight exercise. In reply, 83.3% of 15 firms said that they have been conducting it from 5 years, while 16.7% said from 10 years. Thus it can be argued that technology foresight is new to Indian biotech firms and it has started recently only, in contrast to European nations where technology foresight is being carried out from 1990s.

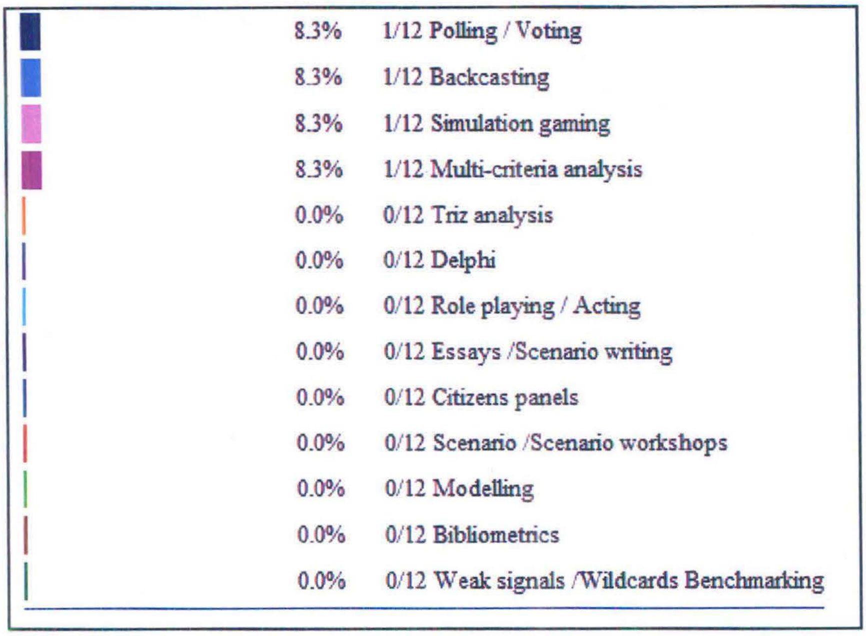
Furthermore to the questions that in how may cases, foresight exercise has helped their organisation to build real scenarios. Replying this, out of 32 respondents, 77.8% of 15 firms said that in 10 cases they have been successful, while firm of Delhi said in 20 cases and another of Mumbai said in more than 20 cases it has been successful. This show quiet a less number of success ratio among firms conducting foresight. This may be due to various reasons. Since foresight is new to them so it might be possible that they are not well equipped with the process of conducting it. In another question the firms were asked that does the size of the organisation matters in conducting foresight exercise or not. In reply 42.9% of 15 said yes, 35.7% said no, while 21.4% said they don't know. This explains that many organisations' belief is that if the firm is of large size, it will be easy for it to conduct foresight and if it is of small size then it may find certain hurdles in conducting foresight. These hurdles can be in the form of unavailability of capital, good human resources etc. Again, they were asked about their opinion about the growth of foresight in biotechnological sector. To this question 46.7% out of 15 firms replied that it is developing, 6.7% said it is developed, 20% said it is less developed, 26.7% said it is underdeveloped. While none of them said it is well developed. Thus it may be argued that most of the firms believe it is on a developing stage and it will take few years to develop it full-flegedly.

6.9 Foresight methodologies

The firms were asked about the methodologies which their organization has adopted for conducting foresight exercise.Table6.2 gives a summary of their responses.

Table 6.2: Foresight Methodologies

Percent	Count	Answers
91.7%	11/12	Literature review
75.0%	9/12	SWOT Analysis
66.7%	8/12	Brainstorming
58.3%	7/12	Conferences/workshops
50.0%	6/12	Surveys
33.3%	4/12	Patent analysis
33.3%	4/12	Interviews
33.3%	4/12	Expert panels
25.0%	3/12	Key / Critical technologies
25.0%	3/12	Cross-impact / structural analysis
25.0%	3/12	Stakeholder analysis
25.0%	3/12	Trend extrapolation / impact analysis
16.7%	2/12	Genius forecasting
16.7%	2/12	Indicators / time series analysis
16.7%	2/12	Science fictioning (SF)
8.3%	1/12	Roadmapping
8.3%	1/12	Morphological analysis
8.3%	1/12	Relevance trees /logic charts



Source: Prepared by the Author

The above response shows that in quite a number of firms, rather simple tools predominate. This becomes evident by the fact that among these firms, most commonly used methodology is Literature review which is used by 91.7% of firms. In the field of qualitative methods, this was indicated by the extensive use of cognitive methods like, SWOT Analysis, Brainstorming-exercises, Conferences/workshops, Surveys, Interviews and Expert panels. Typically, these instruments do not demand much preparation or analytical vigour, and thus can be easily employed. In the quantitative field, the same could be said for such simple statistical/econometrical methods such as patent and publication analyses, Key / Critical technologies, Cross-impact / structural analysis, Stakeholder analysis and Trend extrapolation / impact analysis. Most of the firms reported to rely on those tried and true instruments for their foresight activities - some of them even exclusively. Apart from that, however, also more elaborate and sophisticated approaches are in use in some of the companies, like Morphological analysis, Relevance trees /logic charts. Among those more complex approaches, structural methods like

Roadmapping , Morphological analysis, Backcasting ,Relevance trees /logic charts and Simulation gaming are used by very few of them.

Thus there seems to be a definitive predominance of methods that are based on the interaction between different players and which are rather person- and communication orientated. Great importance is attached to methods involving a high proportion of interviews with internal or external experts, and to teasing out ideas in common meetings or workshops. Quantitatively orientated instruments, on the other hand, are only used for certain questions, but this general "negligence" of quantitative methods could also be seen in a positive light - it certainly indicates a paradigmatic change in the general understanding of foresight: While older "forecasting" approach often dealt with probability predictions and any sort of statistical/econometrical methods in order to give a clear forecast of the future, the "foresight" –approaches of today are seen as systematic processes to identify and explore different futures, and the increasing use of cognitive methods (and their emphasis on communication and learning processes) reflect this new view (Becker, 2002).

6.10 Usefulness of Technology Foresight methodologies

Regarding usefulness of Technology Foresight methodologies, the firms were asked to rate the usefulness of all the foresight methodologies given in the questionnaire form, on a scale of 1 to 5, where 1 represents- not useful, 2- less useful, 3- moderately useful, 4- useful and 5- very useful.Table6.3 gives a summary of the responses. The numbers against each methodology represent the weighted average of the perceived degree of usefulness of the methodologies. In the subsequent columns, the numbers against each methodology represent the percentage of firms that find the methodology useful to different degrees.

Table 6.3: Frequency of use and perceived usefulness of different Foresight methodologies

Value in terms of Percentage

Ranked Average Summary	Weighted Average	Not Useful	Less Useful	Moderately useful	Useful	Very useful
SWOT analysis	4.3	0.00	0.00	20.00	30.00	50.00
Key/Critical technologies	4.14	0.00	14.29	0.00	42.86	42.86
Brainstorming	4.1	0.00	10.00	10.00	40.00	40.00
Literature review	4.08	0.00	0.00	30.77	30.77	38.46
Patent analysis	4	0.00	16.67	16.67	16.67	50.00
Interviews	4	0.00	0.00	42.86	14.29	42.86
Conferences/ Workshops	3.89	0.00	11.11	22.22	33.33	33.33
Surveys	3.88	0.00	12.50	12.50	50.00	25.00
Expert panels	3.88	12.50	0.00	12.50	37.50	37.50
Trend extrapolation/ Impact analysis	3.86	0.00	14.29	0.00	71.43	14.29
Roadmapping	3.67	0.00	0.00	33.33	66.67	0.00
Relevance trees/ Logic charts	3.4	0.00	20.00	40.00	20.00	20.00
Multi criteria analysis	3.2	0.00	20.00	40.00	40.00	0.00
Cross impact/ Structural analysis	3.14	0.00	28.57	28.57	42.86	0.00
Genius forecasting	3.14	28.57	0.00	14.29	42.86	14.29
Scenario workshops	3	0.00	50.00	0.00	50.00	0.00
Essays/Scenario writing	3	16.67	16.67	33.33	16.67	16.67
Modelling	3	0.00	25.00	50.00	25.00	0.00
Polling/ Voting	3	0.00	25.00	50.00	25.00	0.00
Morphological analysis	3	0.00	20.00	60.00	20.00	0.00
Stakeholders analysis	2.83	25.00	50.00	25.00	0.00	0.00
Bibliometrics	2.75	0.00	25.00	75.00	0.00	0.00
Role playing/ Acting	2.67	33.33	16.67	16.67	16.67	16.67
Delphi	2.6	20.00	20.00	40.00	20.00	0.00
Weak signals/ Wildcard Benchmarking	2.6	20.00	40.00	20.00	0.00	20.00
Simulation gaming	2.6	20.00	40.00	20.00	20.00	0.00
Indicators/ Time series analysis	2.5	16.67	16.67	66.67	0.00	0.00
Triz analysis	2.2	20.00	40.00	40.00	0.00	0.00
Backcasting	2.17	33.33	33.33	16.67	16.67	0.00
Science fictioning	2.17	50.00	16.67	16.67	0.00	16.67
Citizens panels	1.83	66.67	16.67	0.00	0.00	16.67

Source: Prepared by the Author

It is evident from Table 3 that "SWOT analysis" is perceived as the most useful methodology. 50% of 15 firms perceived it as "very useful" and another 30% perceived it as useful. No firm perceived it as "not useful". Key/Critical technologies, Brainstorming, Literature review, Patent analysis and Interviews are next in usefulness. It is surprising that inspite of all the developments and sophistication in Technology Foresight methodologies many firms find SWOT analysis as the most useful methodology; but the reasons for the popularity of SWOT analysis are not hard to find. First, it is quite easy to develop. Second, it does not require any special organizational set up. All that may be required is specifying the objective of the business venture, firm or project and identifying the internal and external factors that are favorable and unfavorable to achieving that objective. The SWOT analysis provides information that is helpful in matching the firm's resources and capabilities to the competitive environment in which it operates. As such it is instrumental in strategy formulation and selection, this aspect makes it important to the firm.The next two popular methodologies, Key/Critical technologies and Brainstorming require a little more effort; but they have many advantages. They produce fairly sharp and well-defined foresight which is perceived very useful.

From this cursory analysis it appears that although Technology Foresight (TF) is becoming more widespread, many firms still rely on some of the simplest methods. It is somewhat disappointing that after all the progress made in TF and its methodologies a majority of firms stake their business future on such simple methods, than on any detailed, logical and systematic analysis (Balachandra, 1980).

6.11 Perceived Usefulness of TF methodologies by Firms of different Biotechnology sectors

It is evident from the responses given by the firms that TF methodologies differ in their perceived usefulness according to the firms belonging to different biotechnology sectors. Hence, Table 6.4 shows the average weighted usefulness measure received by each TF methodology from firms of different biotechnology sectors. In the following table, low scores indicate unattractiveness.

Table 6.4: Average perceived usefulness of TF methodologies by different biotechnology sectors

Methodologies	Health	Agriculture	Industrial	Bioinformatics
Backcasting	2.2			2
Citizens panels	2			1
Essays/Scenario writing	2.6			2
Interviews	4			4
Morphological analysis	3			3
Role playing/ Acting	3			1
Science fictioning	2.8		3	1
Surveys	3.75	3.5		4
Weak signals/ Wildcard Benchmarking	2.25			3
Indicators/ Time series analysis	2.25	2		3
Genius forecasting	3.25	3	5	1
Trend extrapolation/ Impact analysis	3.6	4		5
Delphi	3			3
Multi criteria analysis	3.25			3
Roadmapping	3.6			4
Triz analysis	2			3
Brainstorming	4.28	4.5		2
Conferences/ Workshops	4.25	4	3	2
Expert panels	4.34	4	3	1
Literature review	4.71	4.67		3
Relevance trees/ Logic charts	3.75			2
Scenario workshops	3.33			2
Simulation gaming	3.2			1
SWOT analysis	4.5	4	5	3
Bibliometrics	2.67			3
Modelling	2.67			4
Patent analysis	4.2			3
Cross impact/ Structural analysis	3.4	3		2
Key/Critical technologies	4.17			4
Polling/ Voting	3			3
Stakeholders analysis	3			2

Source: Prepared by the Author

(Out of 15, one firm each from Industrial and Bioinformatics sector has responded, rest is of either Health or Agriculture sector)

From the above table it is clear that Agriculture and Industrial Biotechnology sectors use fewer methodologies. On the other hand, Health and Bioinformatics sector use more varied TF methodologies. Further, it is evident from the above table that Literature Review is the most useful methodology both for Health and Agriculture sector. Interestingly for Industrial sector, the most useful methodologies are Genius Forecasting and SWOT analysis, while for Bioinformatics it is Trend extrapolation/ Impact analysis. It may be argued that all the biotechnology sectors discussed above, consider simple methodologies as most useful for them. In other words, none of them have rated complex methodologies as very useful. Furthermore in Health sector methodologies according to their decreasing order of usefulness are as follows: Literature review, SWOT analysis, Expert panels, Brainstorming, Conferences/Workshops, Patent analysis, Key/Critical technologies and Interviews. There are many more but these are considered by health sector as more useful in comparison to others. It has even rated some complex methodologies like Roadmapping, Scenario workshops, Relevance trees/ Logic charts, Morphological analysis, Simulation gaming, etc. as moderately useful. The reason behind this may be due to the technicalities, uncertainties and complexities involved in the Health sector which is not as such with other sectors.

In Agriculture sector, methodologies according to their decreasing order of usefulness are: Literature review, Brainstorming, Trend extrapolation, SWOT analysis, Conference/Workshops, Expert panels. These are again of very simple nature. Further in Industrial sector only 5 methodologies are perceived as useful. Genius forecasting and SWOT analysis are considered as very useful while, Science fictioning, Conference workshops and Expert panels are considered as moderately useful. This is in contrast to Health and Agriculture sector who consider it as very useful. Finally, in Bioinformatics sector the most useful methodology is Trend extrapolation/Impact analysis while, Interviews, Surveys, Roadmapping, Modelling, Key/Critical technologies are considered as useful. It considers Morphological analysis, Weak signals/ Wildcard Benchmarking, Indicators/ Time series analysis, Delphi, Multi criteria analysis, Triz analysis, Literature review, SWOT analysis, Bibliometrics, Patent analysis and Polling/ Voting as moderately useful. Thus it may be argued that Bioinformatics sector perceive some complex methodologies like Roadmapping as useful while Triz analysis as moderately useful, these methodologies are considered as either less useful or not useful by other sectors.

Hence it may be analysed from the preceding discussion that firms in all the sectors perceive simpler methodologies as very useful, while Health and Bioinformatics sector consider some of the complex methodologies as atleast moderately useful. This may be due to the dynamic environment in which they operate as they have to deal with a large and rapidly changing set of variables in the environment (Balachandra, 1980). But largely all the sectors still use simpler methodologies; the reason behind it may be that they are not well trained in those methodologies.

6.12 Perceived Usefulness of TF methodologies by Biotechnology firms of Public and Private sectors and of different sizes

Out of 15 respondents, 14 are of private sector and surprisingly just one belongs to public sector. Consequently, after going through the responses, a contrast may be seen in the methodologies used by the firms of private sector and of public sector. According to the responses, firms of private sector mainly use simpler methodologies such as Literature review, SWOT Analysis, Brainstorming, Conferences/workshops, Surveys, Interviews and Expert panels. But apart from these methodologies it was found from the response of public sector firm that it uses some complex methodologies also like Morphological analysis, Backcasting, Multicriteria analysis, Relevance trees/Logic charts and Simulation gaming.

Further in terms of perception also they differ from each other. In contrast to the firms of private sector, who perceives most of the simplest methodologies as 'very useful', public sector firm perceive some of the complex and sophisticated methodologies, as 'useful'. For example (apart from the simpler methodologies like Interviews, Brainstorming, Conference-workshops, Literature review, Expert Panels which it considers as 'very useful') it perceives Science Fictioning, Essay-Scenario writing, Weak Signal-Wildcard, Citizen panel and Role playing-Acting also, as 'very useful'. However, these methodologies are perceived by 66.7% out of 6 firms (who have rated these methodologies) of the private sector, as either not useful or less useful. Some of the complex methodologies like Delphi, Relevance Trees-Logic charts etc. are perceived by public sector firm as useful while they are perceived as less or moderately useful by 60% out of 5 private firms who have rated these. Other private firms have not even rated these methodologies. Interestingly, none of the methodologies are rated by public sector firm as 'not useful'. These replies of private sector firms may be due to their non-awareness about these methodologies or may be they are not well trained in using these methodologies. Also it may be due to their reply that they carry foresight exercise from only 5 years while public sector firm conducts it from 10 years. This shows that foresight exercises are conducted in public sector firm much earlier than private biotech firms.

In context of the size of the biotechnology firms, none of the large scale biotechnology firms have responded by filling the questionnaires sent to them. The responses have manly come from small and medium size firms. Hence it may be argued that large scale firms may not have replied either due to their non-awareness of the foresight methodologies or due to confidential reasons. Further due to lack of data on account of large scale biotech firms, a relationship may not be built here between size of the firm and the methodologies perceived useful by them.

6.13 Purpose and objective of TF

The ultimate objective of all foresight activities is to ensure that developments in the areas of science, technology and society that are likely to ensure future social benefits are identified promptly. Hence, in this regard the firms were asked about the purpose of conducting foresight exercise. In reply, 86.7% of 15, said they do it for R&D Planning, while 73.3% said they do it for Marketing. This result shows that most of the firms conduct foresight for mainly R&D Planning and comparatively lesser for Marketing. This shows that R&D Planning is the dominant purpose of foresight. The firms were asked to write any other purpose if they have, apart from R&D Planning and Marketing, in the extra space provided. One firm of Mumbai replied that its other purposes are Finance and HR and one of Pune replied that its additional purpose for conducting foresight is to become number one in respective area, which is quite interesting to know.

6.14 Foresight and Innovation

There is a close affinity between two future-oriented activities, namely foresight and innovation activities. One main reason for the great attention given to foresight seems to lie in the socio-economic setting under which innovation now has to be fostered. In today's knowledge-based economies, decision-making takes place under uncertainty and highly complex societal conditions, and thus explicitly demands the kind of input that are generated by foresight activities. Foresight also has a close affinity to innovation with regard to its particular procedural requirements and success conditions: Both innovation and foresight must be considered as a process that requires good communication involving (and gaining commitment of) all those likely to be affected, for making the endproduct successful. Thus, besides the importance of foresight input for innovation activities, it can also give rise to very important innovation process benefits: If properly conducted, foresight can encourage the forging of better communication, collaboration, and shared commitment within and between individual companies, across different sectors, and among industry, academia and government. Such links are also essential if new innovative ideas and technologies are to be exploited to their full potential (Becker, 2002).

Therefore in this regard firms were asked that how foresight is helping their organisation in innovation process. In reply 84.6% of 15 said it helps as a decision making tool, 53.8% said it helps in learning new or future oriented information and just 15.4% said it helps in Network building/ Clustering. This shows that foresight is mainly helping them in taking good decisions and in learning new information, which is required for an innovation process. But another component i.e. network building does not receives much help from foresight for these firms, which is an important component for innovation process and needs more emphasis. Finally for firms that pursue an *"innovation leader"*-strategy, foresight seems inevitable, as they have to constantly monitor and react on the innovation activities of their competitors to secure their technological leadership in the market.

6.15 National and International collaborations

7 out of 11 firms who have responded to the question (about their collaboration with other organizations in research), replied that they have national collaboration while 4 replied that they have international collaborations. Further 63.6% out of 11 firms responded (for the question about the field in which they have collaborated), that they have collaborations in Basic scientific research and educational programmes, while 27.3% replied for collaboration in Seed and Venture capital, 27.3% replied for collaboration in Training programmes, again 27.3% replied for collaboration in Joint foresight exercise. Thus it may be argued that most of the collaborations are for basic and scientific research, which is needed also but very few have collaborated for joint foresight exercise. The reason behind this may be due to less awareness in firms about TF.

6.16 Importance of Biotechnology sector in Indian economy

60% out of 15 firms responded that biotechnology will be very important for Indian economy in 10-15 years, 33.3% replied that it will be important, while 6.7% responded that it will be somewhat important. This is evident from the fact that Indian biotech industry touched 11,000 crores in 2001. Of this $1.5 billion (60%) was of health biotech alone, with agricultural & veterinary accounting for 20% each. The industry is subsequently expected to reach 4, 40,000 crores in 2020.

Further, 80% out of 15 firms responded in another question, that relations between industry and universities are important for strengthening Indian biotechnology industry. While 66.7% responded in favour of 'Entrepreneur education', 60% in favour of Internationalisation, 46.7% for Basic scientific research, another 46.7% for Venture capital and 33.3% for public awareness. Hence it may be argued that better relations between academia and industries are needed for further developments of the biotechnology sector.

6.17 Strengths and weaknesses of Biotechnology firms

Following table shows the responses of the 15 firms :

Table 6.5: Strengths and weaknesses of Biotechnology firms

	Strength	Weakness
Technological competence	93.3%	6.7%
Well developed research community	66.7%	33.3%
Human Resource	73.3%	26.7%
Business development skills	46.7%	53.3%
Financial Results	40.0%	60.0%
Capital access	20.0%	80.0%
Marketing	33.3%	66.7%

Source: Prepared by the Author

It is evident from above table that most of the biotech firms are technically competent, they have well equipped research community and they have well developed human resource. But most of their weaknesses lie in the financial perspective. They are low in their business development skills, capital access; consequently their financial results get disruptive. Even their marketing strategies are also not well developed. Thus it may be argued that, as far as knowledge domain is concerned, Indian biotech firms perform well in that but in the financial scene they are not well developed. This needs to be improved in long run as for fetching more profitable results. Table 6.6 shows the responses of the firms in context to the fundings they receive:

Table 6.6: Funding of biotech firms

Percent	Count	Answers
80.0%	12/15	Self finance
46.7%	7/15	Borrowings
26.7%	4/15	Government
6.7%	1/15	Stock markets
6.7%	1/15	Foreign aid
6.7%	1/15	Venture capital

Source: Prepared by the Author

The above table shows that most of biotechnology firms are self funded, while 46.7% out of 15 firms gets their funds from borrowings, just 26.7% receives from government, this proportion is very low. Hence it is needed for government in this regard to provide more funds for biotech firms so that they can enhance their research capabilities. Also, funds received from stock markets, foreign aid and venture capital are very low. These all need to be enhanced to improve the financial results of biotech firms.

6.18 Constraints faced by biotech firms

There are a number of constraints faced by biotech firms in biotechnology research and development. Among them the most powerful constraint responded by 78.6% out of 14 firms (responding this question), is State and international regulations. Next is concerned with reducing price of the product, which is responded by 57.1% of the firms. While according to the low responses (21.4% each for consumer's negative attitude towards GM products and environmental issues, while just 14.3% for ethical constraints) it may be argued that firms are comparatively less concerned with consumer's negative attitude towards GM products, environmental and ethical issues. This is in contrast to public sector biotech firm, which considers environmental and ethical issues as more constraining, because they are not concerned with profitability but their motive is public service. While private sector firms are hardly concerned with ethics and are mostly concerned in profit maximization.

Chapter 7: Concluding observations

With the advent of the knowledge economy, decision-making in the Research and Technology area has become increasingly complex, with science and technology being both a driver of and driven by social change and economic development. Against this background, future foresight activities promise to generate a clearer picture of the possible long term challenges and opportunities arising out of these interdependencies, thus providing a crucial input for strategic planning in the area of research, technology development and innovation.

In the preceding context, after analyzing the status of biotechnology foresight of Indian biotech firms in the present study it can be argued that foresight activities in Indian biotech firms are in a nascent stage. The major lacuna is that many firms do not even know the difference between 'technology forecasting' and 'technology foresight'. After conducting the research work it was found that most of the firms still presume technology foresight to be a forecasting technique. And those firms who even know about technology foresight, they use very simplistic methods, instead of formalized processes, despite of the fact that technology foresight has become much widespread all over. It is somewhat disappointing that after all the progress made in technology foresight and its methodologies a majority of firms stake their business future on such simple methods, than on any detailed, logical and systematic analysis.

Further from the present study it may be concluded that, there is difference in use and perceptions of usefulness of different foresight methodologies, amongst public sector and private sector biotech firms. Private sector firms use mostly simplest methodologies, while public sector firm uses some of the complex methodologies also. Some of the complex foresight methodologies which are perceived as useful by public sector firm are perceived as either not or less useful by private sector firms. Moreover, public and private sector firms also differ in terms of constraints faced by them. Major constraints faced by public sector firm are Ethical and Environmental issues, but for private sector biotech firms, major constraining factors are state and international regulations and reducing price of the product. This makes it clear that public sector firms have service motive, while private sector firms are concerned with profit maximization, so are hardly concerned with environmental and ethical issues. Therefore it is necessary for government organisations to put regulations on private sector firm's R&D.

However, no conclusion could be made for the relationship between the size of the firms and their perceived usefulness of foresight methodologies, due to lack of data on part of the large scale firms. Since, all the firms who have responded are of either small or medium size, while none of the large scale firms have responded.

Again, in terms of area of biotechnology, it may be argued that, firms of different sector of biotechnology differ in their perceived usefulness of foresight methodologies. Hence, from the present research work it may be concluded that, firms of Agriculture and Industrial Biotechnology sectors use fewer methodologies. On the other hand, firms of Health and Bioinformatics sector use more varied TF methodologies. This may be due to the complexities involved in their sectors or may be that they are more developed in comparison to others.

Appendix

Questionnaire: Foresight Activities in Indian Biotechnology Firms

1. Name of the Organization

2. Address

3. Please specify the products which your organisation has launched so far.

4. Is the market for your business product portfolio mainly national or international?
   i. National
   ii. International
   iii. Both

5. Area of Biotechnology
   i. Environmental
   ii. Agricultural
   iii. Health
   iv. Industrial
   v. Bioinformatics
   vi. Animal

6. Ownership
   i. Sole proprietary concern
   ii. Partnership
   iii. Public limited
   iv. Private limited
   v. Autonomous body
   vi. Foreign Subsidiary

7. What is the share of your organisation with foreign ownership?

   i. 0
   ii. 1%-10%
   iii. 11%-30%
   iv. 31%-50%
   v. 51%-100%

8. Size of Organization

    i. Small Scale
    ii. Medium Scale
    iii. Large Scale

9. Sector
    i. Public
    ii. Private

10. What does your organisation supply?
    i. Product
    ii. Services
    iii. Both

11. Has your organisation made any venture capital fund for itself?
    i. Yes
    ii. No

12. Has your organisation applied for Patents?
    i. Yes
    ii. No

13. If yes, then please specify the number of patents awarded to your organisation.

14. Is foresight analysis carried out in your orgaanisation?
    i. Yes
    ii. No

15. What are the methodologies which your organization has adopted for conducting foresight excercise ?
    i. Backcasting
    ii. Brainstorming
    iii. Citizens panels
    iv. Conferences/workshops
    v. Essays /Scenario writing
    vi. Expert panels

vii. Interviews
viii. Literature review
ix. Morphological analysis
x. Relevance trees /logic charts
xi. Role playing / Acting
xii. Scenario /Scenario workshops
xiii. Science fictioning (SF)
xiv. Simulation gaming
xv. Surveys
xvi. SWOT Analysis
xvii. Weak signals /Wildcards Benchmarking
xviii. Bibliometrics
xix. Indicators / time series analysis
xx. Modelling
xxi. Genius forecasting
xxii. Patent analysis
xxiii. Trend extrapolation / impact analysis
xxiv. Cross-impact / structural analysis
xxv. Delphi
xxvi. Key / Critical technologies
xxvii. Multi-criteria analysis
xxviii. Polling / Voting
xxix. Roadmapping
xxx. Stakeholder analysis
xxxi. Triz analysis

16. Please rate following methodologies on a five point scale, where 1 signifies- not useful, 2- less useful, 3- moderately ueful, 4- useful, 5- very useful.

i. Backcasting
ii. Citizens panels
iii. Essays/Scenario writing
iv. Interviews
v. Morphological analysis
vi. Role playing/ Acting
vii. Science fictioning
viii. Surveys
ix. Weak signals/ Wildcard Benchmarking
x. Indicators/ Time series analysis
xi. Genius forecasting
xii. Trend extrapolation/ Impact analysis
xiii. Delphi
xiv. Multi criteria analysis

xv. Roadmapping
xvi. Triz analysis
xvii. Brainstorming
xviii. Conferences/ Workshops
xix. Expert panels
xx. Literature review
xxi. Relevance trees/ Logic charts
xxii. Scenario workshops
xxiii. Simulation gaming
xxiv. SWOT analysis
xxv. Bibliometrics
xxvi. Modelling
xxvii. Patent analysis
xxviii. Cross impact/ Structural analysis
xxix. Key/Critical technologies
xxx. Polling/ Voting
xxxi. Stakeholders analysis

17. Is your organisation using any hybrid methodology?
    i. Yes
    ii. No

18. For what purpose your organization is conducting foresight exercise?
    i. R&D Planning
    ii. Marketing

19. If there are some other purposes, please specify them.

20. For how many years your organization has started conducting foresight exercise ?
    i. 5 Years
    ii. 10 Years
    iii. More than 10 Years

21. In how may cases, foreight exercise has helped your organisation to build real scenarios?
    i. 10
    ii. 20
    iii. More than 20

22. How foresight is helping your organisation in innovation process?
    i. As a decision making tool
    ii. Helps in learning new or future oriented information
    iii. Network building/ Clustering

23. Does the size of the organisation matter in conducting foresight exercise?
    i. Yes
    ii. No
    iii. Don't Know

24. Has your organisation collaborated with any other organisation in research, please specify.
    i. National
    ii. International

25. In which of the following fields, your organisation has collaboration?
    i. Training programmes
    ii. Joint foresight exercise
    iii. Basic scientific research and educational programmes
    iv. Seed and Venture capital

26. What is your opinion about the growth of foresight in biotechnological sector?
    i. Developing
    ii. Developed
    iii. Well developed
    iv. Less developed
    v. Under developed

27. How familiar is your organisation with the government sponsored programmes from which biotechnology can benefit ?
    i. Very familiar
    ii. Familiar
    iii. Less familiar
    iv. Not familiar

28. How important will biotechnology be for the Indian economy in coming 10-15 years?

i. Very important
ii. Important
iii. Somewhat important
iv. Not important

29. For strengthening the Indian biotechnology industry, which of the following does your organisation feel, are important?
i. Internationalisation
ii. Venture capital
iii. Relations between industry and universities
iv. Basic scientific research
v. Enterpreneur education
vi. Public awareness

30. What constraints are faced by your organisation in biotechnological R&D?
i. Ethical constraints
ii. Environmental issues
iii. Consumer's negative attitude towards GM products
iv. State and international regulations
v. Reducing price of the product

31. Where does your organisation receive your funds from?
i. Government
ii. Foreign aid
iii. Self finance
iv. Venture capital
v. Borrowings
vi. Stock markets

32. What is your opinion about the market for biotechnological products, will they expand in near future or not?
i. Yes
ii. No
iii. Can't say

33. What are your organization's strengths and weaknesses ?
i) Technological competence
Choose appropriate option
- Strength

- Weakness

ii) Well developed research community
- Strength
- Weakness

iii) Human Resource
- Strength
- Weakness

iv) Business development skills
- Strength
- Weakness

v) Financial Results
- Strength
- Weakness

vi) Capital access
- Strength
- Weakness

vii) Marketing
- Strength
- Weakness

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