Technology Planning in Major Asian Countries: An Analysis of Recent Foresight Reports from China and India & Comparison with Japan and Korea

by

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for

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The Brief

To produce a report based on research into five areas:

1. Review of the two recent Chinese Technology Foresight Reports of Delphi surveys to:
    - indicate China's position compared to the rest of the world;
    - identify the fields of greatest economic and technological importance to the Chinese and when these priorities are expected to be addressed/achieved; and
    - the expected impact of technological change on China's traditional and high-technology industries, and on environmental protection and quality of life.

2. Review of Indian Technology Vision 2020, plus available updates, based on a mix of scenario planning, Delphi survey and interviews.

3. Comparison of the findings from the Chinese and Indian projects with findings from the most recent Japanese Delphi survey.

4. Comparison of the findings from the Chinese and Indian projects with findings from the recent Korean Delphi surveys.

5. Synthesis and comparative analysis of the results from Stages 1-4 into a form relevant for consideration by the PMSEIC Working Group on Asia, showing in particular:
    - any social, economic and/or environmental needs identified by the Chinese and Indians;
    - strengths of the Chinese and Indian technology/innovation sectors; and
    - capabilities identified within the Chinese and Indian technology/innovation sectors as needing development, particularly those requiring foreign assistance.

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1. Major Findings

1.1 Introduction

Industrialised and industrialising nations around the world are increasingly recognising the crucial role of investment in knowledge capacity for future economic competitiveness and social well-being. One important aspect of an effective knowledge economy is the ability to access and apply emerging technologies. These technologies provide the basis for a range of possible future commercial prospects.

There are two major types of strategies with regard to emerging technologies. The first is based on not being extensively involved in their development, by choice (ie unwillingness to invest), or by lack of capacity. Under this strategy exclusion from the embedded knowledge associated with any technology is accepted, access to the technology is via purchase when it enters the market, at the seller's price, and commercial returns are pursued by developing a range of applications appropriate to the local context.

The second is based on investment in the development of emerging technologies, and the underlying knowledge base, at a time when specific commercial outcomes cannot be confidently predicted. The objective here is to gain access to the codified tacit knowledge, in order to be able to shape the technology and develop the necessary infrastructure that would provide a position to offer future products into the market-place, from the vantage of a price-maker position.

In pursuing the latter strategy, a premium is placed on intelligence about the forces likely to shape the form and characteristics of emerging technologies, in order that investment in these capacities can be most appropriately directed. For a vibrant market economy, these decisions can be largely left to the private sector, though invariably supported by significant government investment in supporting the development of the necessary skills and infrastructure, and in informing industry of the potential of emerging technologies. For industrialising countries, with a less-developed industrial structure and limited resources, the pressure is greater to ensure that the limited resources available for technology development are directed to areas or targets likely to produce the greatest return for the nation.

Thus, in both industrialised and industrialising nations (though with considerable variation between countries), there has been substantial interest and investment in the development of capacities to better understand the forces that shape the emergence of new technologies and to establish priorities and targets for the development of technologies appropriate to local needs.

These efforts have carried various labels – technology foresight most commonly, but also critical technologies, technology vision, research priorities and futures. Both China and India have mounted major technology foresight exercises which have fed into Five-Year science and technology, and economic, planning.

Between 2002- and 2005, China conducted Delphi-based foresight surveys focused on six areas of technology: information and communication technology, biotechnology, new materials technology, energy, environment and resources, and advanced manufacturing.

These surveys examined the time of realisation of specific technologies, socio-economic and environmental consequences, the gap between China and leading countries, the R&D base in China, and impact on high-technology and traditional industries. On this basis priorities have been identified for technology research and investment.

In India, a Technology Information and Assessment Council has sought to create a long-term vision for India up to 2020 in important emerging technology areas. Seventeen technology sectors were identified as significant. The methodology involved analysis of driving forces and trends, augmented by various foresight methodologies. The Technology Vision 2020 reports were published in 1996. Since then, there has been a continuing program of updating these reports and the preparation of more detailed reports on particular sub-sectors.

As required by the brief, the findings of the Chinese and Indian foresight projects have been compared with those of recent comparable exercises in both Japan and Korea.

The first point that should be made is that both Japan and Korea, with their much greater experience of technology-based industrial development, and with technology foresight studies, are able to specify potentially significant technologies in the future in considerable detail, including objective technology and market achievements. Such a capacity, which greatly strengthens the precision and reliability of the findings of their Delphi studies, can obviously only be developed over time. Indeed, this capacity could be considered an important component of the infrastructure of a technology-supported knowledge economy.

At a general level, there is a degree of comparability between Japanese, Korean, Chinese and Indian technology priorities. All countries place a strong emphasis on new developments in IT and life sciences. There is also a shared recognition of needs and opportunities in new materials, energy and the environment.

However, the specific focus is rather different, reflecting the different capacities and stages of technology development. Whereas both China and India have a focus on further development in semi-conductors and software, Japan and Korea regard these as essentially mature technologies, where investment will produce diminishing returns as the technology increasingly takes on the form of a commodity, driven by price competition. Rather their emphasis is largely on new applications of IT to medical diagnosis and health care, and to address the challenges of resource efficiency and environmental protection.

In the same way, there is a marked difference between the Korean focus on new materials such as atomic memory and micro-sensors for artificial sensory systems, and the Chinese emphasis on new construction, and iron and steel materials, and the Indian on casting, rare earth magnets and structural ceramics.

Each study identifies energy developments as important, but for India the emphasis is on improved conventional power generation, China combines an interest in coal, nuclear and plant sources, whereas for Japan, the focus is on fuel cell technology, and the safe disposal of nuclear waste, essentially as an environmental issue.

Similarly, they all identify significant environmental concerns, but again they are tailored to the needs and interests of each country. Japan sees great impact from improved recycling of manufactured products, the Chinese focus is on water supply, wastewater treatment, and air pollution and India appears to be more focussed on resource management issues.

1.2 Chinese Findings

Strengths

Areas of Chinese R&D strength identified are:

- Chinese information processing technology
- 3G technology
- Supercomputer system design
- Information security technology
- Operating system of networked computing environment
- Plant transgenic technology
- Rapid detection and diagnosis reagent for major infectious diseases
- Low-cost high-performance advanced steel and iron materials
- High-temperature structural materials (super alloys)
- Long diameter mono-crystalline silicon wafer technology
- Million-KW advanced pressurised water reactor technology
- Security systems for large-scale electricity networks
- Super-capacitor-based long-distance transmission technology
- Rules for ore-formation in geological systems
- Design and manufacture of million-KW nuclear power units

Social, economic and environmental needs

Technologies with high **economic impact** are:

- New construction materials
- Low-cost high-performance advanced steel and iron materials
- Technology for further processing of agricultural products and manufacturing functional foods
- Reagents for fast identification and diagnosis of serious infection diseases
- Metropolitan Area Network – comprehensive business services delivery platform
- New intelligent sensor technology
- Broadband access technology
- Software technology for enterprise information management
- Computer-aided engineering

- Drug quality control and standards management.

Technologies with high **social impact** are:

- Reagents for fast identification and diagnosis of serious infection diseases
- New construction materials
- City air pollution prevention and treatment
- Treatment technology for environmental pollution
- Safe secure drinking water technology
- Infectious disease mechanisms
- Bacteria-based biotechnology pharmaceuticals
- Materials implantable in human bodies
- Drug-controlled release and organising engineering materials
- Micro-organism function genome of important disease source

Technologies with high **environmental impact** are:

- Regeneration and use of waste resources
- Technology to use renewable and waste resources
- Environmental pollution treatment technology
- Recovery and reuse of disposed home electrical appliances and cars
- Efficient agriculture water conservation equipment
- Electricity generation by large-size refuse burning equipment
- Environmentally friendly technology for high polymers
- Treatment systems for high concentrate organic industrial waste
- Electricity generation by wind-power with megawatt grid connection
- Biodegradable plastics

Capabilities in need of development

In the great majority of technology areas, China was seen as lagging the rest of the world by five or more years. Cooperation with overseas researchers and companies was seen as particularly important in the fields of ICT and, to a slightly lesser extent, biotechnology/life sciences. A more precise identification of areas needing foreign assistance for development was not possible from the available data.

Some technology areas identified as being particularly weak in China were:

- Research and manufacturing of 64-bit high-performance general-purpose CPU chips
- Biological energy and recombinant microbial fuel
- Recycling technology for waste resources
- High performance special fibres
- Protective material and invisible material
- Heavy gas turbine technology
- Deepwater oil and gas exploration and exploitation
- Manufacture of <45nm super-large scale integrated circuits.

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1.3 Indian Findings

The form of the Indian technology foresight exercises, with their production over different time periods, with different objectives, structures and formats addressing different issues, makes it very difficult to draw broad generalisations. Rather the specific Indian sectoral reports would more appropriately be treated as a resource to be interrogated with questions specific to that sector. However some conclusions have been reached.

Strengths
No overall comparative analysis of strengths or weaknesses was conducted as part of the foresight exercises. Other reports have identified strengths in the areas of software, mobile telephony, pharmaceuticals, motor vehicles and nano-technology.

Social, economic and environmental needs
The major technology sectors identified as priorities are:

- Advanced sensors
- Agro-food processing
- Chemical Process Industries
- Civil Aviation
- Food and Agriculture
- Electric Power
- Electronics and Communications
- Engineering Industries
- Healthcare
- Materials and Processing
- Life sciences and biotechnology
- Road transport
- Services
- Strategic industries
- Telecommunications
- Waterways

Capabilities in need of development

The technology priorities identified in the major sectors can be assumed to be linked to capabilities in need of development:

- Advanced sensors (inertial, SQUID, NMR-based sensors for detecting RDX explosives and narcotics, piezo-resistive, humidity, gas, enzyme, microbial, artificial noses
- hybrid variety rice production
- food technology
- membrane cell technology
- micro/nano filtration techniques
- microwave/high temperature short baking time oven
- mobile pre-cooling of fruit/vegetable harvests
- technology enhancement of catalytic hydrogenation, direct amination, conversion in diazo/coupling reactions, reverse osmosis/salt reduction
- pheromone-based pest control
- pressurised fluidised bed combustion technologies (50-60 MW)
- Integrated Gasification Combined Cycle (IGCC) technology
- cost effective high speed client server based hardware & software systems
- electronic aids for the disabled and computer education
- power conditioned motors and organic conductors

- application of super conductivity, linear motors and single chip controllers
- genetic engineering of model plants like tomato, cereals & pulses
- development of elite strains of agarophytes by genetic manipulation
- monoclonal antibodies for diagnostics
- near net shape castings
- large scale production of rare earth magnets
- surface modification technologies
- composite materials including metal matrix composites
- structural ceramics as cutting tool inserts, wear resistance parts, refractives, coatings
- advanced functional ceramics

2. Review of Recent Chinese Technology Foresight Reports

2.1 Background

In recognition of the importance to major economies of identifying emerging technologies and the range of their potential implications, and research fields with potential strategic importance, the Chinese Ministry of Science and Technology, through its National Research Center for Science and Technology for Development, and the Research Group on Technology Foresight, has recently completed two major technology foresight projects.

During 2002-2004, NCRSTD led a Delphi-based foresight surveys focused on information and communication technology (ICT), biotechnology (BIOT), and new materials technology (NMT). The project involved three stages over 21 months. The first stage addressed project design, analysis of socio-economic needs in China and S&T trends and topic selection. The latter was developed through identification of more than 1000 experts and 40 consultative seminars, leading to 218 technology topics.

The second stage involved a two-round Delphi survey. There were sixteen survey items, covering the usual items of expertise, time of realisation, and socio-economic and environmental consequences, but also issues of particular national relevance, such as the gap between China and leading countries, the R&D base in China, IP rights in the next five years, and impact on rebuilding traditional industries. The third stage involved critical technology selection and dissemination of results.

The same approach was used in a second Delphi-based project in 2004-5, this time focused on energy (EN), environment and resources (E&R), and advanced manufacturing (AMT) A total of 28 sub-fields in the three areas, and 261 technology topics were selected (from a total of 500 generated) by the 15 experts in foresight, and three area research groups, each composed of about 20 experts. For the two linked projects, some 5200 experts were surveyed, on 483 technology topics, with an overall response rate of 38%.

In analysing the results of any Delphi survey, it is important to bear in mind the inherent limitations of the methodology. It is, in the end, an opinion survey, and the opinions of people, no matter how expert, can be incorrect. However, the interest here is less in the accuracy of the findings as in the extent to which they are likely to shape Chinese investment in science, technology and innovation (STI). The significant number of people surveyed, from different sectors of the economy, also serves to reduce extreme idiosyncrasies.

In addition, it should be recognised that respondents can, with minor exceptions, only answer the questions they are asked. If a critical question is not asked, the survey will not provide any insight into that issue. Finally, there is, of course, no direct linear connection between the results of a Delphi survey leading to the identification of critical technologies, and decisions of government and industry to invest in those areas. A complementary process of review of, for example, R&D expenditure, will be necessary.

This analysis is based on a review of all English language publications of the staff of the Ministry on foresight projects, privileged access to an extended English language summary of the two projects, including a significant proportion of the original data which I have independently analysed, and regular personal communication with the key officials responsible.

2.2 China's Capacity in Technological R&D

From the 483 topics under investigation, there was only one where the Chinese respondents confidently asserted that they were leading the world – information processing technology in the Chinese language. For a further 20 topics, Chinese capability was seen as comparable with that of leading countries – 5 in IT, 7 in biotech, 6 in new materials and 2 in energy.[1] For 88% of topics, Chinese expertise was seen as lagging by up to 5 years. For 39 topic areas, predominantly in advanced manufacturing, the lag was 6-10 years.

Respondents were also asked to rate the strength of R&D capacity in China for each topic, on a standard five-point scale. Analysis of these data reveals the following areas of perceived relative strength (Table 1):

Table 1 Areas of Chinese R&D Strength (ranked within each field)

Field	Topic
ICT	- Chinese information processing technology - TD-SCDMA and enhanced 3G technology - Supercomputer system design - Information security technology - Operating system of networked computing environment
BIOT	- Plant transgenic technology - New high-quality high-yield transgenic plants - New anti-retroviral transgenic agricultural products - Rapid detection and diagnosis reagent for major infectious diseases
NMT	- Low-cost high-performance advanced steel and iron materials - High-temperature structural materials (super alloy) - Long diameter mono-crystalline silicon wafer technology
EN	- Million-KW advanced pressurised water reactor technology - Security systems for large-scale electricity networks - Super-capacitor long-distance transmission technology
R&E	- No strong areas; some significant expertise in rules for ore-formation in metallo-geological systems
AMT	- Design and manufacture of million-KW nuclear power units

[1] I am currently awaiting a response to my request for precise identification of these 20 topic areas. However, the following analysis provides some information.

In response to a question concerning the most appropriate means to overcome these lags, 63% of the topics should be pursued by national R&D and 37% by joint R&D projects with overseas partners. The latter were concentrated in ITC (59%) and BIOT (48%). Topics in ITC that strongly favoured the collaborative approach were sub-100nm reconfigurable SoC (system-on-a-chip) innovation and development platform, and SoC Design platform and SIP reuse techniques ie nanotechnology. In BIOT, the emphasis was on human functional genomics, biotic transgenic security technology, and causative micro-organism functional genomics.

2.3 Relative Importance of Technologies

A major focus of the surveys was on identifying the "degree of importance to China" of the future technologies identified in the topics. The question sought a response on a standard 5-point scale, with no apparent attempt to precisely identify the criteria of performance – economic, social, quality-of-life, research advance, learning etc. In other words, respondents were asked to make their own holistic judgment (a technique commonly used in Delphi, and follows the well-established Japanese practice).

The information available identifies the 'top 100' topics (21% of the total) in terms of importance. Within this set, 26 topics are in ICT, 22 in BIOT, 11 in NMT, 5 in EN, 20 in R&E and 16 in AMT. It is worth noting the relatively low importance of EN topics. The highest rated EN topic (No 29) is 'exploration technology for deepwater oil and gas fields'.

The concentration is even stronger in the 'top 30', with 15 from ICT (50%), 7 from BIOT (23%), 6 from AMT (20%) and only 2 from NMT, 1 from EN and 0 from E&R. Indeed, the first E&R topic is ranked 39 in the 'top 100'. However it should be noted that there are 6 R&E topics from 39th to 49th position. In the 17 topics with an importance index in excess of 90%, 10 are from ICT:

Table 2 Topics with an Importance Index greater than 90%

Field	Technology Topic	Importance Index
ICT	Information security technology	97.3
ICT	Network security technology	96.5
ICT	Super-computer system design	95.4
ICT	Research on Next Generation Network Architecture	93.9
NMT	Low-cost high-performance advanced steel and iron materials	93.7
BIOT	Rapid detective and diagnostic reagent for major and infectious diseases	93.6
ICT	Chinese information processing technology	93.5
ICT	Operating system of network computing environment	92.9
ICT	Development of new and popular integrated circuit products	92.4
ICT	Research and manufacturing of 64-bit high-performance general-purpose CPU chips	92.3
BIOT	Treatment technology of environmental pollutant	92.3
AMT	Critical technology of efficient agricultural water-conservation equipment	92.1
ICT	Research and manufacturing of embedded microprocessor	92.0

BIOT	Research technology of human functional genomics	91.0
ICT	SoC (system-on-a-chip) design platform and SIP reuse technology	90.8
NMT	Light alloy (aluminum and magnesium alloy)	90.5
AMT	Design and production technology of equipment for deepwater oil and gas exploitation	90.2

This Table, and other data, serve to reveal that in ICT and AMT, the topics are commonly quite precisely defined. In the analyst's judgment, the topics for BIOT and NMT are somewhat more general. For EN and in particular R&E, the topics seem to be not very precisely specified eg 'technology for urban wastewater treatment and recycling' or 'drinking water security technology'.

With regard to realisation, the majority of ICT and BIOT topics were seen as being realised by 2012, NMT, R&E and EN by 2013, and AMT by 2014.

2.4 Economic Benefits of Technologies

The analysis of economic benefits (Eco-*index*) is based on combining the responses to questions on prospects for industrialisation (E-*index*), effect on improving international competitiveness (C-*index*) and cost of industrialisation (100 – M-*index*) to allow for the costs of investment in achieving the outcome ie

$$\text{Eco-}index = (\text{E-}index + \text{C-}index)/100 - \text{M-}index.$$

Data are available for the 'top 10' topics in terms of economic benefits for each of the six fields. The highest economic benefits result from NMT, are also high for ICT, BIOT and AMT, medium for EN and low for R&E.

In ICT, the emphasis is on network technology, in BIOT both agricultural and medical advances are on top, while for NMT it is new materials closely related to industrial production and construction that will generate the greatest economic benefits. In EN the emphasis is on technologies related to building energy conservation, for R&E there is a wide variety of advances in environmental management and prospecting likely to produce modest economic benefits, and for AMT there is a comparable lack of clear 'winners'.

The 'top 10' overall fields, in order of economic importance are:

Table 3 Top 10 Technology Topics by Economic Importance

Field	**Technology Topic**
NMT	1. New construction materials
NMT	2. Low-cost high-performance advanced steel and iron materials
AMT	3. Technology for further processing of agricultural products and manufacturing functional foods
BIOT	4. Reagents for immediately identifying and diagnosing serious infection diseases
ICT	5. Metropolitan Area Network – comprehensive business services delivery platform
AMT	6. New intelligent sensor technology
ICT	7. Broadband access technology

ICT	8. Software technology for enterprise information management
AMT	9. Computer-aided engineering
BIOT	10. Norm on drug quality control and standards management

The most economically important topics in EN are 'environmentally natural illuminating technology' and 'energy saving optimised design for buildings', and in R&E, 'new exploration technology for solid mineral resources' and 'waste treatment technology'.

It is interesting to note the lack of correlation between technological importance and economic contribution. For ICT, only 4 of the 10 topics with greatest economic contribution were in the 'top 100' list for technological importance. The comparable figures for the other fields are BIOT – 5, NMT – 3, EN – 0, R&E – 2, and AMT – 1. The factors taken into account in determining potential economic contribution have produced a very different ranking from that of technological importance.

Respondents were also asked questions about commercial prospects and the international competitiveness of potential exports. A number of technologies were identified as having a high prospect for commercialisation within the next five years, and for the international competitiveness of exports, predominantly from the ICT and BIOT fields. The data are not presented in a way that allows comparison across fields. The major commercialisable technologies are:

Table 4 Technologies with High Prospects of Commercialisation (ranked within fields)

Field	**Technology Topic**
ICT	- Sub-100nm reconfigurable SoC (system on a chip) - SoC design platform and SIP reuse - Ipv6 critical technology and high performance router - Information security technology - Embedded microprocessors
BIOT	- High-quality high-yield transgenic agricultural products - Anti-retroviral transgenic agricultural products - Biological energy and recombinant microbial fuel - Quality control of biotech products - Plant functional genomics
NMT	- Low-cost high-performance advanced steel and iron materials

The major technologies with export potential are:

Table 5 Technologies with High Prospects of Exports (ranked within fields)

Field	**Technology Topic**
ICT	- Supercomputer system design - 64-bit high-performance general-purpose CPU chips - Information security technology
BIOT	- Human functional genomics

	- Reagents for immediately identifying and diagnosing serious infection diseases
NMT	- Low-cost high-performance advanced steel and iron materials

2.5 Impact of Technologies on High-Technology Industries

Technology topics seen as having a high impact on high-technology industries are in ICT, through network and mobile communication technologies, BIOT through bio-engineering and plant transgenic technologies, in NMT through nano-materials, and in AMT through micro-nano manufacturing technology.

Not surprisingly, it is ICT topics which are seen as having the biggest impact on high-technology industries. The ten technology topics with the highest impact on high-technology industries are:

Table 6 Top 10 Technology Topics by Impact on High-Technology Industries (ranked)

Field	Technology Topic
ICT	1. Development of new, popular integrated circuit products
ICT	2. Embedded micro-processors
ICT	3. SoC (system on a chip) design Platform and SIP re-use technology
NMT	4. Long-diameter mono-crystalline silicon and wafer technology
ICT	5. TD-SCDMA and enhanced 3G technology
AMT	6. <45nm very large scale integrated circuit
BIOT	7. Biological pharmaceuticals
BIOT	8. Human functional genomics
ICT	9. Next generation network architecture
ICT	10. 12-inch 90/65 nm micro-production line

Correlation with technological importance is high for ICT and BIOT, but low for all other fields. Again, correlation with economic importance is low – just 12 of the sixty topics identified were among top ten in their field for economic importance:

Table 7 Technology Topics with High Economic Contribution and High-Technology Industry Impact (ranked)

Field	Technology Topic
ICT	1. Next generation network architecture
BIOT	2. Reagent for immediately diagnosing serious infectious diseases
ICT	3. Operating system of network computing
AMT	4. New intelligent sensor technology
BIOT	5. Quality control of biotech products
NMT	6. Light aluminium and magnesium alloys
BIOT	7. Norm on drug quality control and standard management
NMT	8. Low-cost high-performance advanced steel and iron materials
NMT	9. Advanced magnetic materials

AMT	10. Computer-aided engineering

2.6 Impact of Technologies on Traditional Industries

Technology topics from ICT, BIOT, NMT and AMT had a high impact on traditional industries, whereas those from EN and E&R had only a moderate impact.

From ICT, integrated circuit and SoC system integration technology, and next-generation network and mobile communication technology will have the greatest impact on traditional industries. From BIOT, it is biomedicine, biological engineering and transgenic plants that will have the biggest influence. From NMT it is advanced metallic and new construction materials, and from AMT micro-nano manufacturing. A lower level of impact is expected from new coal utilisation technology (EN) and industrial and agricultural water conservation (E&R).

. The ten technology topics with the highest impact on traditional industries are:

Table 8 Top 10 Technology Topics by Impact on Traditional Industries (ranked)

Field	Technology Topic
NMT	1. Low-cost high-performance advanced steel and iron materials
ICT	2. Embedded micro-processors
ICT	3. New integrated circuit products
ICT	4. Software technology for information management
ICT	5. SoC (system on a chip) design Platform and SIP re-use technology
BIOT	6. Norm on drug quality control and standard management
AMT	7. Critical technology for <45nm VLSI circuit
BIOT	8. Biological pharmaceuticals
BIOT	9. Optimisation and processing technology for traditional bio-tech products
BIOT	10. Transgenic agricultural products

As for the impact on high-technology industries, the correlation between impact on traditional industries and technological importance is high for ICT and BIOT, but low for the other fields. Some 27 topics with high impact on traditional industries also have high economic importance. Interestingly, 7 of these 27 are from NMT.

2.7 Impact of Technologies on Environmental Protection and Resources

It should be noted that the mixing of these two categories, both as a field and an area of impact, may produce some results which fail to distinguish the different effects and needs of the two components.

Technologies with a high impact were from BIOT (environmental pollution treatment), NMT (utilisation of waste resources, environmentally friendly technology for high polymers) and AMT (environmental protection equipment and green design). A moderately high impact was expected from wind turbines and coal gasification (EN) and urban water and wastewater management, and efficient use and re-use of water for agriculture and industry (R&E). Interestingly, ICT was seen as having little impact on environmental protection.

The ten technology topics with the highest impact on environmental protection and use of resources are:

Table 9 Top 10 Technology Topics by Impact on Environmental Protection and Use of Resources (ranked)

Field	Technology Topic
NMT	1. Regeneration and use of waste resources
AMT	2. Technology to use renewable and waste resources
BIOT	3. Environmental pollution treatment technology
AMT	4. Recovery and reuse of disposed home electrical appliances and cars
AMT	5. Efficient agriculture water conservation equipment
AMT	6. Electricity generation by large-size refuse burning equipment
NMT	7. Environmentally friendly technology for high polymers
AMT	8. Treatment systems for high concentrate organic industrial waste
AMT	9. Electricity generation by wind-power with megawatt grid connection
BIOT	10. Biodegradable plastics

2.8 Impact of Technologies on Enhancing Quality of Life

High impact on quality of life was anticipated from all fields, with the exception of energy, where the impact was viewed as moderate. Key technologies are network and video technologies (ICT), disease diagnosis and infectious disease mechanisms (BIOT), new construction and human body implantable materials (NMT), water-related technologies (R&E) and environmental protection (AMT).

The ten technology topics with the highest impact quality of life are:

Table 10 Top 10 Technology Topics by Impact on Quality of Life (ranked)

Field	Technology Topic
BIOT	1. Reagent for immediately diagnosing serious infectious diseases
AMT	2. New construction materials
R&E	3. City air pollution prevention and treatment
BIOT	4. Treatment technology for environmental pollution
R&E	5. Safe secure drinking water technology
BIOT	6. Infectious disease mechanisms

BIOT	7. Bacteria-based biotechnology pharmaceuticals
NMT	8. Materials implantable in human bodies
NMT	9. Drug-controlled release and organising engineering materials
BIOT	10. Micro-organism function genome of important disease source

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3. Review of Recent Indian Technology Foresight Reports

3.1 Background

The Technology Information and Assessment Council was established under the Indian department of Science and Technology in 1988, with the mission of "providing timely and relevant S&T and information inputs into critical socio-economic areas and to facilitate and promote prioritized technology intervention."[2] It has a small professional staff which operates by drawing on the networks of technological expertise available across the country in R&D laboratories, industry and universities.

In 1993, TIFAC resolved to create a long-term vision for India up to 2020, in important emerging technology areas. Seventeen technology sectors were identified as significant, against the criteria of having major socio-economic implications, requiring or constituting major infrastructure, or being categorized as 'advanced'. In addition, more than 100 sub-areas were identified in total in the 17 sectors. An independent taskforce was established for each sector, and where appropriate, sub-panels as well.

The methodology involved analysis of driving forces and barriers, economic, social and consumer trends and global technology trends. These data and forecasts were augmented by brainstorming sessions, use of the Nominal Group technique[3], scenario construction and Delphi surveys. The outputs of these processes were analysed and priorities and action agendas formulated. The Technology Vision 2020 reports were published in 1996.

There are two distinctive features of this Indian technology planning approach. First, since the publication of the major reports in 1996, there has been a continuing program of updating and expanding these reports, and of the preparation of much more detailed reports on particular sub-sectors. Thus, the most recent reports have addressed fuel cells, microarray biochips, biodegradable plastics, advanced composite materials and transgenic plants. Hence there is an extensive and continuous body of multi-level, multi-focus reports. Some address the potential for new technologies, others are far more concerned about supplying the anticipated growing market in India, and removing barriers to this objective.

Second, as the TIFAC mission includes the promotion of prioritised technology intervention, it manages a number of schemes, and a significant budget, designed to implement the findings of the foresight analysis. For example, there is a scheme to support industries, agencies, and R&D labs interested in seeking to realise some component of the Technology Vision 2020 as a corporate strategy to diversify and compete. In addition, there are at any time a range of Vision 2020 missions. The recent list includes:

[2] http://www.tifac.org.in
[3] A simple technique for eliciting individual responses from members of a group about a particular issue, progressively forming and building a group response, and weighting the responses in terms of potential impact.

- road construction and transportation equipment
- upgrading textile machinery
- disaster management equipment, and
- fish products.

3.2 Major Findings of the Indian Technology Vision 2020

The 17 technology sectors, and the sub-sectors examined, are listed in Table 11:

Table 11 Major Technology Sectors and Sub-sectors

Sector	Sub-sector
Advanced Sensors	Mechanical sensors Chemical sensors Magnetic sensors Bio sensors Optic sensors Emerging technology scenario Demand for advanced sensors Capabilities in the area of advanced sensors
Agro Food Processing	Cereal Sector Milk Sector Fruits & Vegetables Sector
Chemical Process Industries	Petroleum & Natural Gas including Safety Petrochemicals including Polymers & Rubber Heavy Chemicals (Chlor-Alkali Chemicals) Basic Organic Chemicals Fertilizers Pesticides & Growth Regulators Drugs & Pharmaceuticals Leather Chemicals Specialty Chemicals Incl. Marine, Cosmetics, Perfumery & Flavours Coal Processing & Coal based Chemicals Chemical Processing
Civil Aviation	Airline operations Manufacturing & maintenance Pilot training Airports Opportunities Market for aircraft
Driving Forces Impedances	Education Technology Infrastructure
Food & Agriculture	• Animal Sciences and Fisheries • Agro-Industry : Agricultural Linkages • Resource Management : Soil & Water • Crop-Improvement, Bio-diversity – Agricultural • Crop Diversification • Socio-Economic Scenarios • Input Management : Seeds, Pesticides, Fertilizers, Machineries, Equipment, Energy • Medicinal Plants

	◆
Electric Power	◆Electricity ◆Policy options- private power, alternatives to capacity addition ◆Transmission and Distribution ◆Policy options- R & D ◆Instrumentation and switch gear ◆Materials ◆Policy options- renewable energy sector
Electronics & Communications	Components, Consumer Electronics Photonics / Optoelectronics, Emerging Areas & R&D Microelectronics Power Electronics, Components, SPV, Electronics in Energy Management Computers & Applications, CAD / CAM, Software Computers (Including Software) Communications Interface with Task Force on Telecommunications Telematics, Fibre Systems, Networking Computer Communication, Information Highway
Engineering Industries	Capital Goods including Foundry & Forging Transport Vehicles Textile Industry Electric machinery
Health Care	Infectious Diseases Gastro-Intestinal Diseases MCH & Nutrition Genetic, Metabolic and Degenerative Disorders Cardio-Vascular Diseases and Diabetes Cancer & Lung Disorders Renal Diseases and Hypertension Mental Disorders and Addiction Eye Disorders Injuries and Locomotion Disorders
Materials and Processing	◆Mining & Extraction of Metals ◆Metals, Alloys & Surface Engineering ◆Polymers / Plastics ◆Composite Materials ◆Nuclear Materials ◆Biomaterials & Devices ◆Photonic Materials ◆Semi conductor Materials ◆Building Materials ◆Super-Conducting Materials ◆Glass & Ceramic Materials

Life Sciences & Biotechnology	Health Care Environment Agriculture Industrial Biotechnology Marine Biotechnology Herbal Biotechnology

Road Transportation	Transportation Demand Road Construction Designs & Materials Appropriate Technologies & rural Roads Road Building machinery & Transportation Vehicles Transportation Management Systems, Traffic Management & Multimodalism National Highways & Expressways Metro Systems & Urban Systems Transportation Development & Social Interface Legal Framework
Services	Financial Services Marketing : Advertising, Media Consultancy & Infotainment Marketing Logistics & Trading HRD : Regular Education, Vocational Training, Retraining Travel & Tourism Legal Services Including IPR Technical & Management Consultancy Testing, Certification & Calibration Services Government Administration Security Services
Strategic Industries	Aircraft/Aviation Radar/Weather Survey Strategic Electronics Space Communications, Remote Sensing Critical materials & Processing Structure Advanced Sensors Industries for Strategic Technologies Robotics & Artificial Intelligence Breakthrough Technologies
Telecommunications	Access Network Transport Network Services Switching Network Management R&D Strategies Socio-Economic Impact & Vision
Waterways	Water transport scenario Current status of inland waterways and water transportation Waterways classification Technology imperatives for developing smart waterways

The identification of technology priorities and of actions appropriate to pursue these priorities varies greatly between the sectors. In some cases the reports provide a detailed analysis of the trends and prospects of the technology and of actions needed to pursue advantage for India.

A good example of this is the report on Advanced Sensors, which identifies the major technological trends as:

- development of intelligent or smart sensing devices
- emergence of integrated multifunctional sensors
- smart sensors systems capable of performing integration, self compensation and self correction
- sensors integrated with actuators, and
- development of artificial noses which can create olfactory images.

Analysis of the world market for sensors indicates that industrial control, medical and scientific instruments account for 50 % of the global market for sensors. Temperature sensors account for 36 %, pressure sensors 34 % and flow sensors 28 % of world demand.

Three major segments upon which development should focus have been identified:

- strategically important sensors
- sensors needed for industrial segment (automation, food processing, environmental control and safety) and,
- sensors which are important for social applications (health, agriculture and environmental monitoring).

The Action Plan takes the following form for the strategically important sensors:

Sensor	Key Trends	Action Needed
Inertial Sensors for Navigation & Avionics	Laser gyros Fibre optic gyro Micro accelerometer	Development of ultra-noise free and stable lasers Development of integrated optic chips Surface micro machining
Sensors for submarine detection	SQUID based systems	Development of SQUID sensor and associated noise free electronics
Sensors for detecting explosives such as RDX and narcotics	Nuclear magnetic resonance	SQUID sensors for ultra weak electro-magnetic fields nuclear quadrupole arising from NMR/NQR resonance principles
Piezoresistive microsensors	Surface micro machining of polysilicon micro structures	Development of monolithic silicon transducer including silicon conditioning and calibration

In many other cases the projections largely take the form of conventional ‘catch-up’ visions through economic development, and identification of the issues that will need to be addressed to pursue these objectives. Thus, for the Engineering Industry sector, in capital goods:

- “Capital Goods Industries will witness an average growth rate of 12-15%
- India will capitalise on the shifting of foundry and forging activities from developed countries and technological upgradation (sic) will take place to meet global demands. This will include high pressure moulding line, no bake

process, chemical bonding of sand, mechanisation of fettling, austempered SG, ductile iron, CAD, dust fume extraction.

- India will become the 5th largest producer of machine tools in the world by 2000; by 2010, 60% of the machine tools produced will be CNC; by 2020, 80%.
- By 2005 Indian industries will go in for FMS, AI applications, processing using laser, waterjet, cold forming/extrusion, near net shape manufacturing, high speed machining, intelligent manufacturing using sensors, continuous forming, reduced set-up times, virtual reality applications, hard machining.
- Boiler designs for many alternate fuels will be available by 2005. Fluidized bed combustion technology will be in wide use by 2000-2005.
- By 2000-2005 technological upgradation covering materials design, manufacturing, quality, reliability, packaging, marketing and servicing will take place. These will include new materials, CAD/CAM/FMS, ISO 9000, ISO 14000, R&D in new materials, modular design, casting and forging, mechatronics, precision manufacturing, automation and environmental issues.
- Design and development of high precision machine tools, high speed spindles, linear motor slides, diamond turning machines
- India will become a net exporter of engineering technologies by 2010.
- By 2020 India will be a leading producer of quality castings and forgings and will be a large exporter of these items. India will be self-sufficient in advanced machine tools and boilers of the state of the art technologies. Exports of these items will be on the increase."

The Action Plan involves fairly conventional initiatives:

- identification of select areas of strength: automobile parts, casting, forging, CNC machine tools.
- upgradation of processes - CAM, Robotics, Welding, near netshape manufacturing,
  Precision Manufacturing, Automation, Tooling.
- Improve quality, delivery and cost. Environmental aspects (ISO 9000, ISO 14000 implementation)
- State of the art technology adoption

In Machine tool industry

- Improvement in design, quality, reliability and reduction in cost
- Improving supplier base for components and sub assemblies
- Evolving modular designs
- Design of Flexible manufacturing and agile systems
- Availability of parts and raw materials at internationals competitive prices
- Consortium marketing and competitive prices, after sale services.

In Foundry Industries

- Control on dimension /surface finish
- Value addition - Machined castings, forgings
- Exact specification on metal compositions
- Mechanisation and automation – with increased scale of production.

In Forging

- Develop better tooling capabilities - CAD
- Adoption of cold forging and near net shape technologies
- Mechanisation and automation with large volume production.

For the purposes of this report, priorities and targets which are essentially conventional economic development have not been reported. The analyst has applied his judgment to identify substantial technology investment priorities in the major sectors, which follow:

Table 12 Technology priorities in the major sectors

Sector	Technology priorities
Advanced Sensors	• inertial sensors • SQUID sensors • NMR-based sensors for detecting RDX explosives and narcotics • piezoresistive microsensors • humidity sensors • gas sensors for process control • artificial noses • enzyme sensors • microbial sensors
Agriculture & Food	• hybrid variety rice production • food technology • new techniques of cold storage • improved long distance transport for fresh food
Agro-Food Processing	• non-conventional energy sources for primary processing • breeding according to agro climatic zones • wireless communication for veterinary services • membrane separation technology • micro/nano filtration techniques • microwave/high temperature short baking time oven • mobile pre-cooling of fruit/vegetable harvesting
Chemical Process Industries	• membrane cell technology • technology enhancement of catalytic hydrogenation, direct amination, conversion in diazo/coupling reactions, reverse osmosis/salt reduction • pheromone-based pest control
Electrical Power	• pressurised fluidised bed combustion technologies (50-60 MW) • Integrated Gasification Combined Cycle (IGCC) technology
Electronics & Communication	• cost effective high speed client server based hardware & software systems • electronic aids for the disabled and computer education
Engineering Industries	• power conditioned motors and organic conductors • application of super conductivity, linear motors and single chip controllers
Biotechnology	• genetic engineering of model plants like tomato, cereals & pulses • development of elite strains of agarophytes by genetic manipulation • monoclonal antibodies for diagnostics
Materials & Processing	• near net shape castings • large scale production of rare earth magnets • surface modification technologies • composite materials including metal matrix composites • production of structural ceramics as cutting tool inserts, wear resistance parts, refractives, coatings • advanced functional ceramics for high technology sectors

4. Review of Recent Japanese Technology Foresight Reports

4.1 Background

The Japanese National Institute of Science and Technology Policy (NISTEP) has been conducting a major Delphi survey on future technology developments and priorities every 4-5 years for some thirty years. The most recent 8th Survey was completed in 2005, but while there have been some overview presentations, the full English version of the report has not yet been released. Hence in this report, we rely on the findings of the 7th Technology Foresight Study, published in 2001, which examined future technology in Japan to 2030.

4.2 Major Findings of the Japanese Technology Foresight 2030

A total of 1065 topics were developed, arranged in 6 broad science and technology fields, and 16 sub-fields:

Table 13 Science and Technology Fields and Sub-Fields

Fields	Sub-Fields
Information Technology (IT)	Information Electronics
Life Sciences (LifeSci)	Life science Health Agriculture
Earth Science & Environment (EarthSci/Env)	Marine and Earth Space Resources Environment
Materials & Processes (Mats)	Materials
Manufacturing & Management (Mfg/Mgt)	Manufacturing Distribution Business
Social Infrastructure (Soc I/s)	Urbanisation & Construction Transportation Services

Information-related technologies, life-related technologies, and earth science and environment-related technologies are rated highest as priority fields over the next ten years. After 2010 however, the position of information-related technologies as a priority field changes significantly, with support plunging to less than half.

Many experts believe the new fields that will emerge as information-related technologies take on an increasingly base-like character and merge with other fields

will no longer fall within the framework of 'information-related technologies'. This is the main reason for the drop in responses placing importance on information-related technologies after 2010.
Life-related technologies and earth science and environment-related technologies are rated highest as priority fields after 2010. Occupying the next level were information-related technologies, material-related technologies and social infrastructure-related technologies.

With regard to international S&T capability, Japan is considered to enjoy a supremacy in the two fields of 'Resources and energy' and 'Transportation', and as being on a par with the USA in the four fields of 'Agriculture, forestry, fisheries and food', 'Marine and earth science', 'Manufacturing' and 'Urbanization and Construction'. The USA leads the world in the ten remaining fields.

An Importance Index, (out of 100) was calculated for each topic based on the respondent's ranking of 'high', 'medium', 'low', or 'unimportant'. The average index for all topics was 61.2, slightly down from the 62.1 recorded in the 6th survey. By fields, life science has the highest average Importance index with 72.6, followed by electronics (66.2), environment (65.5), and manufacturing (65.4), while the lowest was distribution with 46.6. Compared to the previous survey, increases were recorded in the importance of life science (66.1 ⇒72.6) and materials and processes topics (58.1 ⇒ 62.7), while environment (72.0 ⇒ 65.5) and transportation topics (60.3 ⇒ 55.1) both declined.

The topics with an Importance Index with 90 or more are listed below:

Table 14 Topics with an Importance Index of 90 or more

Field	Technology Topic	Importance Index	Realisation Time
EarthSci/Env	Development of technology capable of forecasting the occurrence of major earthquakes (magnitude 7 or above) several days in advance	95.0	2024
Soc I/s	Major advances in technology for disposing of disused manufactured products, leading to the emergence of commercial services capable of reducing the final disposal volume to one-tenth the current level	94.0	2015
EarthSci/Env	Practical use of technology for the safe disposal of highly radioactive solid waste	94.0	2021
LifeSci	Identification and classification by the molecular etiology of the genes related to diabetes, hypertension, and arteriosclerosis, which are typical lifestyle diseases that exhibit multiple-factor hereditary traits	93.0	2013
IT	Widespread use of highly reliable network systems capable of protecting the privacy and secrecy of individuals and groups from the intrusion of ill-intentioned network intruders	93.0	2010
LifeSci	Development of methods for surmising new functions of proteins from DNA base sequence data	93.0	2009
LifeSci	Practical use of effective means to prevent	93.0	2017

	metastasis of cancer		
IT	Realization of an environment in which the unlimited utilization of high-capacity networks (150 Mbps) for around 2,000 yen/month	92.0	2009
EarthSci/Env	Establishment of a method for evaluating the safety of the underground disposal of high-level radioactive wastes	92.0	2016
IT	Practical use of technology enabling the mass production of LSI with minimum pattern dimensions of 10nm	91.0	2015
LifeSci	Widespread use of drugs capable of preventing the occurrence of certain types of cancer	91.0	2016
Soc I/s	Practical use of technology for disposing of high-level radioactive waste	91.0	2021
LifeSci	Widespread use of medical treatment that leads dysdifferentiating carcinogenic cells into normal state by controlling the signal transduction in carcinogenesis of cells	91.0	2020
Mfg/Mgt	Widespread use of a design - manufacturing - collection - recycling system in which manufacturers are obligated by law to collect and dispose of disused products, and at least 90% of used material is recycled	90.0	2015
LifeSci	Development of technologies which dramatically improve photosynthetic functions in order to increase food production and preserve the environment	90.0	2018
LifeSci	It becomes possible to determine the entire base sequences of an individual including genetic structure and SNP (single nucleotide polymorphism) promptly and cheaply, leading to widespread use of such methods for diagnosis and tailor-made treatment	90.0	2012
EarthSci/Env	Widespread use in virtually all types of automobiles of a technique capable of meeting an emission control standard that specifies a nitrogen oxide emission limit of 0.1 to 0.2 g/km	90.0	2011
LifeSci	Practical use of a effective drug against multiple drug-resistant bacteria, including vancomycin-resistant bacteria	90.0	2011
LifeSci	Practical use of systems for the genetic diagnosis and treatment of cancer and incurable diseases based on genome analysis	90.0	2014
IT	Widespread use of a portable multimedia wireless terminal operating at about 100 Mbps which can be used throughout the world	90.0	2013
EarthSci/Env	Practical use of technology capable of reducing particulate matter emissions from diesel vehicles to 10% of current levels	90.0	2011

Respondents were asked to indicate one or more of four possible effects that could be expected from the advancement of technology for each of the topics ‘Contribution to socioeconomic development’ was highest with 51%, followed by ‘response to people’s needs’ (46%), ‘resolution of various problems of a global scale’ (27%), and ‘expansion of human intellectual resources’ (15%).

By field, business and management was rated highest in contribution to socioeconomic development with 77%, followed by electronics (76%), manufacturing (71%), and material and processes (69%), while environment field was rated lowest with 26%.

For resolution of problems of a global scale, the environment field was rated highest with 79%, followed by resources and energy (62%), marine and earth science (55%), and agriculture, forestry, fisheries and food (42%). For response to people's needs, health and medical care was especially high with 88%, followed by services (66%), information and communications (65%), and life science (62%). For expansion of human intellectual resources, the space field ranked highest with 47%, followed by life science (37%), and marine and earth science (28%).

The 'top ten' topics, in terms of contribution to socio-economic development, are shown below:

Table 15 'Top ten' Technology Contributors to Socio-Economic Development

Field	Technology Topic	Ratio	Realisation Time
IT	Widespread use of a SCM (supply chain management) system to handle data management (orders, design, manufacturing, operations, and maintenance) uniformly among related companies	98.0	2008
Soc I/s	Practical use of a shipbuilding system centering on a large-scale product database in which intelligent design production modules are dispersed over a network, leading to a reduction in shipbuilding labor requirements to about half the present level	98.0	2013
IT	Development of an optical transmission system capable of high-volume transmission of 1 Peta bps per optical fiber	97.0	2013
IT	Practical use of optical soliton transmission for intercontinental undersea cables and other long-distance fiber communications	96.0	2015
Soc I/s	Development of an integrated ship-land system for comprehensively managing ship operations in which shipping companies are connected online with their ships, shipyards, parts manufacturers, etc. using satellite communications, on-board LAN, and the Internet	96.0	2010
Mfg/Mgt	Development of semiconductor microprocessing and measuring technology of 1nm resolution for manufacturing 0.01 micron-rule LSI.	96.0	2013
IT	Practical use of technology enabling the mass production of LSI with minimum pattern dimensions of 10nm	96.0	2015
Mfg/Mgt	Production on order rather than production on estimated demand becomes the norm due to the increased sophistication of e-commerce networks and improved efficiency of business cycle times, resulting in a dramatic reduction of inventory risk for companies	95.0	2010
Mfg/Mgt	Companies are obligated to disclose more financial data to the general public	95.0	2007

Soc I/s	Practical use of high-reliability vessels that can remain in service maintenance-free for about 2 years, through improvements in the reliability of hull materials, engines and the use of a real-time monitoring system	95.0	2014

The **Realisation Year** of technology topics with a high degree of importance are listed below:

Table 16 Realisation Year of highly Important Technology Topics (to 2013)

Year	Field	Technology Topic
2007	IT	Widespread use of portable terminals capable of voice communication from anywhere in the world
2008	IT	Widespread use of systems which facilitate multimedia communication from anywhere in the world using pocketbook-size portable terminals
	LifeSci	Determination of the whole DNA sequence of crops (e.g. rice) to isolate useful genes
2009	IT	Realization of an environment in which the unlimited utilization of high-capacity networks (150 Mbps) for around 2,000 yen/month
	LifeSci	Development of methods for surmising new functions of proteins from DNA base sequence data
	LifeSci	Development of high-speed genome analysis technology and determination of the entire genome sequences of at least 50 important animal and plant species
2010	IT	Practical use of portable computers powered primarily by solar battery or fuel battery
	IT	Widespread use of highly reliable network systems capable of protecting the privacy and secrecy of individuals and groups from the intrusion of ill-intentioned network intruders
	IT	Widespread use of online seal-free (signature-free) document preparation services for various official documents such as contracts which are provided via a network based on security technology capable of achieving both privacy protection and verification
	LifeSci	Widespread use of scientific guidelines for lifestyles (nutrition, rest and exercise) to prevent lifestyle-related diseases
	Mfg/Mgt	Production on order rather than production on estimated demand becomes the norm due to the increased sophistication of e-commerce networks and improved efficiency of business cycle times, resulting in a dramatic reduction of inventory risk for companies
2011	IT	Practical use of technology that can completely automatically design high performance LSIs with several hundred kilo gates or more with required system-level specifications written in a high-level language such as C
	LifeSci	Practical use of a effective drug against multiple-drug-resistant bacteria, including vancomycin-resistant bacteria
	LifeSci	Examination of the safety of genetically modified farm products from both food and environmental perspectives and development of an evaluation method that can gain the understanding of consumers
	EarthSci/ Env	Practical use of technology capable of reducing particulate matter emissions from diesel vehicles to 10% of current levels
	Soc I/s	Widespread use of technology to reduce the harmful components of exhaust gas from large trucks to 1/10 of present levels such as diesel exhaust catalysts, particulate traps, lean-burn NOx catalysts and high precision combustion technology.
2012	IT	The number of recycled parts in new personal computers, including displays, exceeds 90% of all component parts
	IT	Practical use of card-size wireless communication instruments capable of

		changing specifications such as center frequencies, band width, modulation method, and error correction method by software operations
	LifeSci	Establishment of technologies for predicting bioactivity and functional domain of proteins from their higher-order structures
	LifeSci	It becomes possible to determine the entire base sequences of an individual including genetic structure and SNP (single nucleotide polymorphism) promptly and cheaply, leading to widespread use of such methods for diagnosis and tailor-made treatment
	LifeSci	Development of food capable of supporting a healthy aging society from a nutritional perspective by preventing a decline in anti-oxidation, brain and chewing functions
	EarthSci/ Env	Widespread use of products based on LCA (life cycle assessment) concepts that facilitate recycling and reuse
	Soc I/s	Widespread use in Japan of warning, forecasting, evacuation assistance and crowd control systems that dramatically reduce human loss in the event of a natural disaster involving rivers, roads, etc. based on localized weather forecasts
	Soc I/s	Widespread use in Japan of technology that accurately simulates the behaviors of structures or the ground at the time of a string earthquake
2013	IT	Development of an optical transmission system capable of high-volume transmission of 1 Peta bps per optical fiber
	IT	Widespread use of a portable multimedia wireless terminal operating at about 100 Mbps which can be used throughout the world
	LifeSci	Identification and classification by the molecular etiology of the genes related to diabetes, hypertension, and arteriosclerosis, which are typical lifestyle diseases that exhibit multiple-factor hereditary traits
	LifeSci	Elucidation of the arteriosclerosis contraction mechanisms
	EarthSci/ Env	Formation of a global consensus regarding international regulations on the emission of carbon dioxide and other greenhouse gases that cause global warming, including reductions in developing countries
	EarthSci/ Env	Realization of precision down to less than a centimeter in measurement of crustal movement using VLBI (very long baseline inter-ferometers), satellite lasers, inverse laser ranging, and synthetic aperture radar to contribute to earthquake forecasting
	EarthSci/ Env	Widespread use of gigabit-class global satellite communication systems
	Mats	Widespread use of signal-responsive missile drugs capable of efficiently reaching targeted parts such as tumor cells
	Mfg/Mgt	Development of semiconductor microprocessing and measuring technology of 1nm resolution for manufacturing 0.01 micron-rule LSI

4.3 Comparison of the Japanese, Chinese and Indian Technology Priorities

The first point that should be made is that Japan, with its much greater experience of technology-based industrial development, and with technology foresight studies, is able to specify potentially significant technologies in the future in considerable detail, including objective technology and market achievements. Such a capacity, which greatly strengthens the precision and reliability of the findings of their Delphi studies, can obviously only be developed over time. Indeed, this capacity could be considered an important component of the infrastructure of a technology-supported knowledge economy.

A relatively superficial comparison of the technology priorities of Japan, China and India show a range of similarities. All three countries place great importance on another generation of developments in IT and see new developments in the life sciences and biotechnology offering prospects for agricultural and human health outcomes.

Each identifies prospects for new materials, though the types and properties of the new materials are closely related to existing capabilities or needs in the cases of India and China.

Each also identifies energy developments as important, but for India the emphasis is on improved conventional power generation, China combines an interest in coal, nuclear and botanical sources, whereas for Japan, the focus is on fuel cell technology, and the safe disposal of nuclear waste, essentially as an environmental issue.

They also identify significant environmental concerns, but again they are tailored to the needs and interests of each country. Japan sees great impact from improved recycling of manufactured products, the Chinese focus is on water supply, wastewater treatment, and air pollution and India appears to be more focussed on resource management issues.

However, a closer examination of technology priorities reveals major differences. Below a comparison is made of the relative priorities at the aggregated level for Japan and China (the Indian study offered no such ranking):

Table 17 Comparison of Aggregate Technology Priorities of Japan and China

Field	Japan Ranking	China Ranking
ICT	2	1
Life Sciences/biotechnology	1	2
New Materials	3	5
Resources/Environment	4	3
Manufacturing/Management	5	4
Social Infrastructure	6	-
Energy	-	6

Theses distinctions are even more apparent when a comparison is made of the ‘Top Ten’ technology priorities, in terms of economic importance, for China (Table 3) and Japan (Table 15). The only area of overlap would appear to be in the general areas of network technologies, linked to software-based decision-support systems. Even there, not surprisingly, the Japanese priorities are expressed in much more specific terms.

5. Review of Recent Korean Technology Foresight Reports

5.1 Background

Korea has engaged extensively in foresight-based planning extensively for more that ten years, apparently driven in part by the example of, and the drive for competitiveness with, its neighbour Korea.

Major Delphi exercises were completed in 1994 and 1999, and most recently in 2004. These exercises largely followed the Japanese model, but with an independently generated series of topics. In the 1994 project, 1127 topics were assessed, and these included only a 25% correspondence with Japanese topics. These topics were arranged into 15 areas:

- ICT
- production
- materials
- fine chemicals
- life science
- agriculture, forestry and fisheries
- medical care and health
- energy
- environment and safety,
- minerals and water
- resources
- urbanization and construction
- transportation
- marine and earth science
- astronomy and space
- "ultra technology"

The results of these Delphi exercises were fed into long-term national science and technology planning. While there has been considerable discussion of the processes and methods, the detailed results have apparently never been released in English.

However, it would appear that, after the substantial reorganisation of the Korean STI system under the new President, the somewhat independent series of Delphi surveys has been replaced by a far more concerted 'whole-of-government' planning process, driven particularly by 'Vision 2025', a National Technology Roadmap, and a '21st Century Frontier R&D Program'.

5.2 Major Findings of the Korean Technology Foresight

The Long-term Vision for Science and Technology Development toward 2025 (Vision 2025) identifies 40 tasks and 20 recommendations to guide Korea's transition to an advanced and prosperous economy through the development of science and technology. The goals are grouped in three time frames spanning a 25-year period. Each time frame is defined by a unifying theme that characterizes the primary focus of activity for that period:

- *First Step* (by 2005): Place the Korean scientific and technological capabilities at competitive levels with those of the world's twelve leading countries, and ahead of other Asian nations, by mobilising resources, expanding industrialised infrastructure, and improving relevant laws and regulations.

- *Second Step* (by 2015): Stand out as the hub of research in the Asia-Pacific region, actively engaging in scientific studies and creating a new atmosphere conducive to the promotion of R&D.
- *Third Step* (by 2025): Secure a scientific and technological competitiveness in selected areas comparable to those of G-7 countries by forging ahead in specific sectors.

Five broad objectives for Korean society are set in Vision 2025:

- *Knowledge, Information, and Intelligence-based Society* - a society that provides infrastructure through which individuals, businesses and organisations can function in the most efficient way
- *Society of Healthy Life* - a society that enables its members to live healthy lives based on the development of science and technology in the areas of medicines, health and other related areas
- *Sustainable Society* - a society where human beings and the environment coexist in a mutually prosperous way
- Val*ue-creating Industrial Structure* - a society that enables conventional industries to survive and grow by helping them adapt to new technologies
- *Enhanced National Security and Prestige* - a society that can make the best use of new science and technology for national security, disaster prevention, food supply, and social integrity.

Six areas are identified for priority in spending and development: information as the basic underpinning capability, life science, mechatronics and systems, new materials, environment, and energy.

The knowledge-based society is propelled by the fusion of digital technology with individuals' ability to utilize information. Among the developments expected between 2001 and 2010 are:

- Meetings in cyberspace utilising virtual reality and large display screens
- Real-time monitoring of environmental changes through worldwide computer networks
- Electronic transactions on secure network systems protecting privacy, widespread use of pocket-book sized computers
- Computers with almost no need for a keyboard, responsive to voice and expression
- Road transportation control system monitoring the flow of transportation by detecting speed and model of vehicles, plus density of traffic
- Robots for monitoring and maintenance of nuclear facilities and other hazardous environments
- Complex drives uniting the best features of magnetic and optical drives, semi-conductors and ceramic technology
- Computer-designed medicines.

Between 2011 and 2020, the Vision identifies the following likely technological advances:

- Work, education and shopping with computers are commonplace

- Super-computers enable progress on understanding sensory perception in the human brain
- Computer technologies developed for hearing, taste, touch with capacity equivalent to humans
- Three-dimensional information stockpiling material which adapts to external Environments
- 30% of human brain functions will be understandable; neuro-computers modelling brain functions for logical thinking will be possible

During the period between 2021 and 2030, the 'Vision 2025' expects progress in the following domains:

- Availability of Artificial Intelligence chips enabling computers to understand human feelings and of computers able to read information stored in human brains
- It will be possible to understand logical inference in human brains and human cognitive mechanisms, enabling their adoption by computer science
- The gene controlling human sensitivity will be identified and interfaced directly with computers.

Telecommunications is the only sector of IT-related industry where Korea currently has a global lead. Digital content and personal digital assistants (PDAs) are regarded as a promising area for further developing this lead. Other promising industries are financial engineering based on the use of computer and telecommunication networks and advanced software engineering supporting high-tech animation, games, culture and broadcasting.

Effectively coping with the side-effects of the rapid development of a knowledge society is acknowledged as important. Examples of technologies which need to be developed for this task are those for the protection of information, ensuring security and encryption.

Essential technologies in mechatronics include:

- intelligent robots
- manufacturing systems and high-speed machining devices
- next-generation motor vehicles, aircraft, and ship systems
- wireless network sensors.

In materials processing technology, the key technologies identified include:

- high-density storage materials "in which one atom becomes a memory unit"
- intelligent micro-sensors for artificial sensory systems.

In life science and health, key technologies are:

- analysis technology
- bioinformatics
- minimally invasive surgery techniques
- medical information systems
- artificial intelligence technology

- bio-chip technology
- bio-mimetics.

Environmental pressures will place a priority on:
- technologies for the measurement and analysis of pollutants
- techniques to monitor and predict global environmental changes
- techniques to identify, predict and evaluate climate change

b

Security concerns address primarily the prevention of natural and manmade disasters, such as the impacts of climate change or earthquakes. Since Korea has plans to construct up to twelve new nuclear power plants additional to the existing 15, guaranteeing nuclear safety is an essential future task.

Korea is threatened by shortages of food, energy and water. It is currently only able to fulfil about 30% of its own food requirements. It is predicted to face a water shortage by 2006, expected to increase sharply after that date. The rate of fuel use is growing faster than the rate of economic growth.

Key technologies required include:
- R&D for mass production of food using bio-technology
- Development of core technologies for alternative energy sources and energy efficiency.

Defence is a particular priority for Korea on account of its geopolitical situation. It therefore has a high level of R&D investment on defence and speculates on the benefits of spin-offs through dual use. The country has a special "Dual-use Technology Promotion Law", enacted in 1998. Among the technologies selected by the Vision 2025 Report under the heading of civilian-military dual-use are:
- ATM (asynchronous transfer mode) with small capacity
- Satellite image analysis technology for fast sensing
- Intelligent automotive tracking with multiple targets and sensing techniques
- Quick detection systems for explosives and chemical weapons.

The National Technology Road Map has the objective of identifying promising product and core technologies essential to secure global competitiveness 10 years into the future. The key technologies identified, against the five society objectives, are:

I. Building an Information-Knowledge- Intelligence Society

Anytime, anywhere, any device communications
- Digital convergence
- Intelligent computing
- Ubiquitous network
- Mobile & wearable IT Device

Innovation in Contents and Service
- E-commerce
- Business services
- Knowledge/Information Society

Ambient Intelligence
- Intelligent man-machine interface
- Intelligent robot
- Intelligent home appliance
- Intelligent building/home
- Intelligent transport system
- Intelligent medical system.

II. Aiming at Bio-Healthpia

New drug discovery and development
- Cardiovascular
- Anticancer agent
- CNS
- Pulmonary
- Metabolism
- Immune System
- Vaccines

Innovation in disease management
- Diagnostics
- Rehabilitation systems
- Medical Imaging systems
- Cell Therapy
- Gene Therapy
- Prognostic system

III. Advancing the Environment and Energy Frontier

Pleasant and healthy life
- Reduction of environmental pollution
- Recycling system harmonising with environment
- Management of sustainable eco-system

Supplying efficient/stable and clean energy
- Efficient use of energy
- Acquisition of future energy
- Source and high value energy

IV. Upgrading the Value of Major Industries of Korea Today

Next generation transportation
- New automotive systems
- New ocean transportation systems
- New railway systems

Advancing residential building and social infrastructure
- Integrated transport system
- User-friendly advanced construction
- Sustainable natural resources and effective development of national land

Mechatronics
- Next generation manufacturing system

- Advanced precision mechanical system

Diversification of new materials

- New functional information materials/devices
- Nano materials
- Highly functional metals/ceramics/polymers/textiles

V. Improving National Safety and Prestige

Entering the aerospace age

- Satellites
- Development of launch vehicle
- Development of UAV
- Development of Helicopter

Food security and resources preservation

- Establishment of food self-sufficiency
- Establishment of bio-resources self-sufficiency.

Finally, the **21st Century Frontier R&D Program** was launched in 1999 to develop scientific and technological competitiveness in newly emerging areas. The government has invested a total of US$3.5 billion up till September 2003 in 23 projects in new frontier areas, such as bioscience, nanotechnology, and space technology. These projects are listed below:

'99	Functional analysis of human genome	'00	Plant diversity
'01	Biological modulators	'01	Crop functional genomics
'02	Proteomics technology	'02	Stem cell
'00	Tera-level nanodevices	'02	Microbial genomics & applications
'02	Nanoscale mechatronics technology	'02	Smart unmanned aerial vehicle technology
'02	Nanostructured materials technology	'01	Advanced materials processing technology
'01	Applied superconductivity technology	'99	Intelligent microsystems
'02	Proton engineering technology	'02	Advanced information display technology
'01	Sustainable water resources research	'03	Ubiquitous brain project
'00	Industrial waste recycling	'03	Ubiquitous brain project
'02	Carbon dioxide reduction and sequestration	'03	Brain research
		'03	Hydrogen energy

5.3 Comparison of the Korean, Chinese and Indian Technology Priorities

It is not surprising to discover that the technology priorities of Korea, together with their coherence and the degree of their specification, are closer to those of Japan than to either China or India. The relatively comparable stage of economic and industrial development, the strengths and experience of their STI systems, and their engagement over some years with foresight-based planning provides the basis of a comparable view of appropriate paths to establish future competitive advantage.

There are of course important differences also, which reflect the different comparative and competitive advantages of the two economies. They are also a consequence, to a significant extent, of the recent Korean commitment at the highest level of government to a holistic approach to setting, and investing in, significant STI capabilities for the future. In particular the commitment to become a substantially knowledge-, rather than a material resource-based economy, and the ambitious target of having an S&T capacity comparable with that of the G7 nations by 2015, is clearly driving a major investment program.

As noted in the comparison between Japanese, Chinese and Indian Technology priorities, at a general level, there is a degree of comparability between Korean, Chinese and Indian technology priorities. All three countries place a strong emphasis on new developments in IT and life sciences. There is also a shared recognition of needs and opportunities in new materials, energy and the environment.

However, the specific focus is rather different, reflecting the different capacities and stages of technology development. Whereas both China and India have a focus on further development in semi-conductors and software, Korea regards these as essentially mature technologies, where investment will produce diminishing returns as the technology increasingly takes on the form of a commodity, driven by price competition. Rather the emphasis is largely on new applications of IT to medical diagnosis and health care, and to address the challenges of resource efficiency and environmental protection.

In the same way, there is a marked difference between the Korean focus on new materials such as atomic memory and micro-sensors for artificial sensory systems, and the Chinese emphasis on new construction, and iron and steel materials, and the Indian on casting, rare earth magnets and structural ceramics.