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Leveraging High Technology to Drive Innovation & Competitiveness & Build the Sri Lankan Knowledge Economy

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Acronyms and Abbreviations

A*STAR	Agency for Science, Technology and Research
ACCIMT	Arthur C. Clarke Institute for Modem Technologies
AEC	Atomic Energy Council (Taiwan)
BMRC	Biomedical Research Council (Singapore)
CAGR	Compound Annual Growth Rate
CATV	Cable Television
CENTEC	Centre of Technical Excellence in Ceramics (Sri Lanka)
CLA	Council of Labor Affairs (Taiwan)
COA	Council of Agriculture (Taiwan)
CRDF	Commercialization of Research and Development (Malaysia)
CTSP	Central Taiwan Science Park
DAGS	Demonstrator Application Grant Scheme (Malaysia)
DNA	Deoxyribonucleic Acid
DOH	Department of Health (Taiwan)
EBD	Economic Development Board (Singapore)
EMS	Electronic Manufacturing Services
ENKNI	Expatriate Nationals Knowledge Network Initiative
EPA	Environmental Protection Agency (Taiwan)
EPU	Economic Planning Unit
ERC	Economic Review Committee (Malaysia)
EPZ	Export Processing Zones (Malaysia)
FDA	Food and Drug Administration
FDI	Foreign Direct Investment
FP7	Seventh Framework Programme
GDP	Gross Domestic Product
GERD	Gross Expenditure on Research & Development
GOE	Government-owned Enterprises
HIV	Human immunodeficiency virus
HRDF	Human Resource Development Fund (Malaysia)
IGS	Industry Grant Scheme (Malaysia)
ICT	Information and Communication Technology
IP	Intellectual Property
IPOS	Intellectual Property Office of Singapore
IPR	Intellectual Property Rights
IRPA	Intensification of Research Priority Areas (Malaysia)
IT	Information Technology
ITI	Industrial Technology Institute (Sri Lanka)
LCD	Liquid crystal display
MDA	
MDC	Multimedia Development Corporation
MIDA	Malaysian Industrial Development Authority
MITI	Ministry of International Trade and Industry
MNC	Multinational Corporation

MND	Ministry of National Defense (Taiwan)
MOE	Ministry of Education (Taiwan)
MOEA	Ministry of Economic Affairs (Taiwan)
MOI	Ministry of Information (Taiwan)
MoST	Ministry of Science and Technology (Sri Lanka)
MOSTI	Ministry of Science, Technology & Innovation (Malaysia)
MOTC	Ministry of Transportation and Communication (Taiwan)
MSC	Multimedia Super Corridor (Malaysia)
MSTQ	Measurements, Standards, Testing, and Quality
MTDC	Malaysian Technology Development Corporation
NASTEC	National Science and Technology Commission
NCC	National Communications Commission (Taiwan)
NEP	New Economic Policy
NERDC	National Engineering Research & Development Centre (Sri Lanka)
NGO	Nongovernmental Organization
NIC	Newly Industrialized Countries
NSC	National Science Council (Taiwan)
NSF	National Science Foundation (Sri Lanka)
NT	New Taiwan Dollar
OECD	Organisation for Economic Co-operation and Development
PC	Personal Computer
PPP	Public-Private-Partnership
R&D	Research & Development
RM	RINGGIT (Malaysian currency)
RSE	Research Scientists and Engineers
S&T	Science & Technology
SARS	Severe Acute Respiratory Syndrome
SASFP	South Asia Finance and Private Sector Development Unit
SEEDS	Startup Enterprise Development Scheme
SERC	Science and Engineering Research Council (Singapore)
SLINTec	Sri Lanka Institute of Nanotechnology
SME	Small and Medium Enterprises
STAG	Science and Technology Advisory Group
STI	Science, Technology, and Innovation
STSP	Southern Taiwan Science Park
TAF	Technology Acquisition Fund
TRIPS	Trade-related Aspects of Intellectual Property Rights
UN	United Nations
USPTO	United States Patent and Trademark Office
VSM	Vibrating Sample Magnetometer
WTO	World Trade Organization

EXECUTIVE SUMMARY

General

This study was done at an opportune time in Sri Lanka's history: With end of the war there is hope for the country's peace, prosperity, and growth. To encourage economic growth, this study examines how high technology can drive competitiveness in key export-oriented industries and help build a strong Sri Lankan knowledge economy.

The study examines global experience from economies around the world, but particularly several in Southeast Asia, to provide guidance on the role of national governments in enabling the development of a high-tech export sector and the application of high technologies in domestic production. More specifically, it reviews public policies, strategies, and investments in comparable countries that have been successful in promoting the absorption and use of high technologies for competitiveness, and applies lessons to Sri Lanka.

High Technology-led Economic Growth

The global market for high-technology goods is growing at a faster rate than for other manufactured goods. Between 1980 and 2003, high-technology production grew at an inflation-adjusted average annual rate of nearly 6.4 percent, compared with 2.4 percent for other manufactured goods.

In Asia, high-technology manufacturing has grown dramatically over the past three decades, led first by Japan in the 1980s, then by the Republic of Korea, Taiwan (China), and China in the 1990s.

In 1977, Sri Lanka became the first country in South Asia to open its economy, but it did not succeed in attracting high-technology industries. High-tech exports form only 1.5 percent of Sri Lanka's manufactured exports compared with Thailand (27 percent), Malaysia (55 percent), and Singapore (57 percent). Though high-technology driven growth is only one of the approaches it does present vast opportunities to the countries that embrace it in the current global economy. It should also be noted that though the low technologies are not subject of this report, they can be also key to development of local industries.

Implementing the Key Lessons from Good Policy Practices

Four countries were chosen for comparative country case studies on good policy practices: Korea, Malaysia, Singapore, and Taiwan. The case studies provide the following key lessons that Sri Lanka could incorporate into its policy space:

i. Adopt four elements of reform that emerged from all country case studies, namely, reduce the financial and administrative burden imposed by the government; promote competition, improve efficiency, and increase productivity in the delivery of services; stimulate private entrepreneurship and investment; and reduce the presence and size of the public sector with its monopolistic tendencies.
ii. Move from a "regulator mindset" to a "facilitator mindset," with a less direct intervention than now exists.
iii. Begin with assimilating and absorbing existing technologies—that is, import technology—and later move to developing new and innovative technologies.
iv. Finance the acquisition of strategic and relevant technology by Sri Lankan companies to enhance their technology competitiveness.

v. Introduce major reforms through ”Master Plans” for different sectors and ensure successful implementation of the plans through a strongly supported and empowered “Team Sri Lanka.”
vi. Have a new style of operations based on simplicity and marketability, rather than an obtrusive development ideology.
vii. Support industry through appropriate incentive packages, government-industry risk sharing, and the establishment of smart partnerships. Create fiscal incentives for private sector firms in the form of tax credits, tax deductions, investment allowance, and so forth.
viii. Build strong links between the public sector institutions and private sector enterprises by several means, including attractive incentives and rewards systems.
ix. Fully deregulate and liberalize the information and communication technology (ICT) sector and create successful ICT networks to enhance productivity and efficiency several-fold.
x. Greatly expand investments in higher education, research, and technology. Human resource development should emphasize demand-driven, mobile human capital. Encourage innovation in education and education in innovation.
xi. Expand primary and secondary education, which is critical to ensuring the supply of a literate workforce for the high-tech industries. Give a major role in higher education to the private sector to free up public resources for primary education.
xii. Ensure the strategic coordination and alignment between science and technology (S&T) policies and other broader economic development policies.
xiii. Make public sector R&D institutions more market driven. Create incubators and S&T parks throughout the country so that moving from concept to commercialization is well structured, sure **[[certain?]]** and swift.
xiv. Think and act as “Sri Lanka Inc.”

Higher Education and S&T in Sri Lanka: The Current Status & Challenges

Sri Lanka has not invested sufficiently in higher education with the economic relevance and quality of higher education sector at present being substantially below the level required of a middle-income country[1]. The sector’s share of gross domestic product (GDP) increased from 2.7 percent in 1980 to 3.2 percent in 1991, then fell to 2.56 percent in 1997–2000 and 2.17 percent in 2001–04, although more recently (2005–06) it increased to 2.74 percent.

The number of existing R&D personnel in Sri Lanka is low. With 237.3 researchers per 1 million residents, Sri Lanka lags behind the world average (894.0) and even the average for developing countries (374.3). Sri Lanka urgently needs approximately 18,000 research personnel—four times its present number.

Sri Lankan universities award few postgraduate research degrees, though there is a potential for non-university research institutions to do postgraduate. In Sri Lanka, investment in R&D is less than 0.13 percent of GDP. This compares poorly with, for instance, Singapore (2.7 percent) and Korea (3.1 percent). The Sri Lankan government is increasingly unable to actually fund budget allocations for R&D.

[1] The Towers of Learning, pE2, World Bank, July 2009

The intensity of research, technology, and innovation in the private business sector also has been constrained by lack of investment. In 2006, the private sector contribution to gross expenditure on R&D (GERD) was 19 percent.

S&T Policy in Sri Lanka

The National Science and Technology Commission has issued a national S&T policy with a broad vision directed at making Sri Lanka into a prosperous nation of scientifically literate and innovative people with a strong and stable economy based on highly developed scientific and technology capabilities.

Although these policies appear pragmatic and progressive, their implementation will require political will to fund the initiatives, and the institutional structure and strength to carry them out.

Sri Lankan IP System & Structure

Sri Lanka's intellectual property rights (IPR) legislation (Code of Intellectual Property, 1979; Intellectual Property Act, 2003) satisfies the requirements of the World Trade Organization's TRIPS (trade-related aspects of IPR) Agreement, although there are complaints about its enforcement.

"IP literacy" must pervade the society and government structures. Special national funds will have to be created for researchers from public institutions to patent their innovations. Skills in filing, reading, and exploiting patents will be crucial. Manpower planning for IPR protection needs to be made a priority. A number of patent training institutes will have to be set up. Judicious management of patent information will require well-structured functioning of information-creating centers, information documenters and retrievers, information users, IPR specialists, and information technology (IT) experts.

From "Brain Drain to Brain Gain"

Like most developing countries, Sri Lanka has suffered the loss of its most talented scientists, engineers, and technologists to advanced nations. However, with the war having ended, the time is right to create initiatives to induce their return.

Creation of exciting opportunities (centers of excellence such as the Sri Lankan Institute of Nanotechnology [SLINTec], attractive remuneration packages for researchers, opportunities for creating knowledge networks through establishing positions for visiting and adjunct faculty in Sri Lankan institutions, sabbaticals for Sri Lanka-based faculty and even joint appointments with foreign universities, and so forth) can begin to reverse the phenomenon of "brain drain" to one of "brain gain."

Establishing a National Innovation Ecosystem

A national innovation ecosystem comprises complex elements such as autonomy and flexibility of national higher-education, research, and technology institutions: a government that is a proactive and promotional player; progressive IP laws that are rigorously enforced; venture capital for early-stage financing; physical and intellectual infrastructure conducive to incubating new ideas, prototyping and pilot planting; and the establishment of technology incubators such as science, technology, and innovation (STI) parks.

Sri Lanka lacks such a system. A study that described in detail and draws lessons from the creation of national innovation ecosystems in other countries would be helpful to Sri Lanka.

Integrating S&T into National Planning and Development

It is important to include scientists and technologists in the national development policies and plans, and in decision making on wide ranging issues connected with economic, food, health, energy, water security as well as overall national security.

Resolving the Human Capital Deficit

The Sri Lankan government is planning a number of initiatives to meet the challenge of human talent deficit. This includes the creation of a National Cadre of Researchers (NCR) that will offer a tiered human resource structure, where promotion to and continuation in a tier will be based purely on R&D performance, an attractive remuneration package, and legislation to provide adequate, guaranteed, uninterrupted funding for R&D. These initiatives should be implemented as soon as possible.

Specific High Technologies for Value Addition to Exports and Local Manufacturing

This study shows that biotechnology, mechatronics, electronics, post-harvest technologies, and nanotechnology can have a positive impact on Sri Lanka's economy. The country has already pushed forward with nanotechnology, having set up the public-private partnership that is SLINTec.

SLINTec is the R&D incubator, while NANCO, the proposed Nanotechnology Centre and Nanoscience Park on a 50-acre land at the Homagama Industrial Park, will be the commercial or production facility.

The SLINTec initiative has attracted the participation of five leading industrial players that have 1) invested their own funds in the start-up, 2) defined specific projects on which SLINTec should focus, and 3) been given positions on SLINTec's Board, allowing the private firms to drive policy as well as project direction. All these moves augur well for SLINTec's success.

Going forward, SLINTec will require additional, more sophisticated, and more expensive equipment—and additional investment. Getting NANCO established is, therefore, a must for moving from concept to commercialization. SLINTec will require some quick wins to build confidence. For this, it will have to focus its attention on some "low hanging fruit," with rapid commercialization.

Specific Recommendations for Future Action

Assess Sri Lanka's current S&T capabilities and design a road map to direct future S&T capacity building

A team of world-class STI experts could assess the current status of the STI system of Sri Lanka. Based on the findings, the team would draw up a road map for S&T capacity building and development of capabilities in selected technologies, while at the same time addressing the question of restructuring, reforming, and repositioning of the current public R&D initiatives.

Increase the supply of researchers and scientists

This World Bank Mission proposes three initiatives that could give Sri Lanka the desired start for attracting and retaining top research talent.

National Research Cadre: Sri Lanka should push forward with its proposed NRC to attract high-caliber researchers, scientists, and technologists.

Special high-tech skill development fund: Sri Lanka has a shortage of researchers trained in high-tech areas. It needs to fund special training and skill development programs in areas such as nanotechnology and biotechnology by partnering with institutions located throughout the world.

Expatriate National Knowledge Network Initiative (ENKNI): Sri Lanka should establish and fund mechanisms for reversing the brain drain by connecting and engaging with its diaspora in a productive fashion. An ENKNI could support expatriate networks and enrich STI policies, programs, and institutional design and evaluation by bringing in international best practices.

Enhancing investments in R&D

Sri Lanka's investments in R&D remain among the lowest in Asia, around 0.15 percent of GDP. It should aim to increase this funding to at least 1 percent of GDP. There are three types of initiatives that it could adopt immediately to boost its investments in applied R&D.

Small Business Innovation (SBIR) Research Fund: For early-stage funding, a Sri Lanka-adapted version of the successful U.S. SBIR program could offer matching grants (not soft loans) to private enterprises in industrial as well as service sectors.

Technology Acquisition Fund (TAF): The TAF could provide partial funding to the private sector to acquire and enhance its high-tech capacity. The TAF could be established as a PPP (with minority public share) that would support acquisition of patents and early-stage technologies for filling gaps in Sri Lankan R&D and technology. The fund could become an important component in the technology-development value chain through technology-acquisition projects.

Leveraging S&T in socioeconomic ministries: Each of the socioeconomic ministries (health, environment, transport, and so forth) should earmark 1–2 percent of its budget to fund solutions for its specific challenges. Such directed funding, on the one hand, will help create workable technical solutions for the individual ministry, and, on the other hand, will help bolster overall S&T funding. Such progress should be closely coordinated by the Ministry of Science and Technology.

Upgrading research, technology, and innovation infrastructure

Specific elements in this component could include:

Upgrading IPR infrastructure: This initiative would involve modernization of IP offices, setting up of IP training institutes, creation of manpower for IP management, development of a capacity-building and certification program, and support for technology transfer and licensing.

Technology parks and incubators: With the formation of SLINTec, Sri Lanka has made a beginning in the nanotechnology space. SLINTec will require an additional investment of US$6–8 million to become comprehensive and competitive. The NANCO Park, estimated to cost Rs 5.6 billion, is critical to moving forward with commercialization.

Sri Lanka should expand additional technology parks (such as in biotechnology), incubators, and common research and service centers with government support and private finance and management, based on international best practices.

Measurements, standards, testing, and quality (MSTQ): In high-technology trade, the issue of MSTQ is critically important. Therefore, it is important for Sri Lanka to upgrade and increase the demand responsiveness of its MSTQ systems, such as creation of world-class metrology facilities, and strengthening of other MSTQ initiatives such as the standards institutions and accreditation boards. At the firm level, assistance should be provided on adopting MSTQ services and upgrading skills through a suitably designed matching grant program.

I. High Technology-led Economic Growth: A Global Perspective

1. General

Policies in many countries are built around a recognition that a symbiotic relationship exists between investment in science and technology (S&T) and success in the marketplace: S&T supports industry's competitiveness in international trade, and commercial success in the global marketplace provides the resources needed to support new S&T. Consequently, a nation's economic health is a performance measure for national investment in research and development (R&D) and S&T. This is true for many countries around the world.

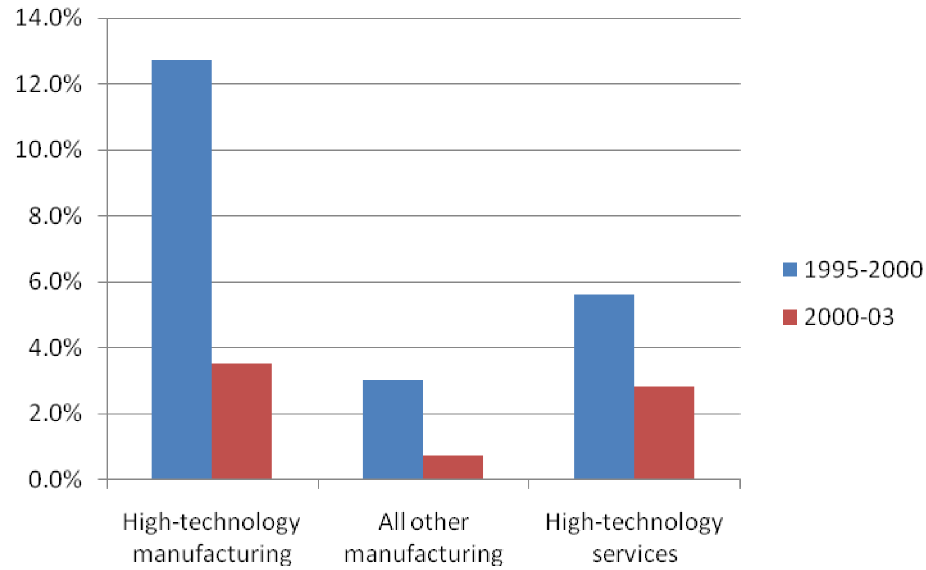
2. Global Scenario

During the last several decades of increasing globalization high-technology industries became a more prominent drivers of economic growth around the world. They are industries that utilize highly technical and technological equipment, especially complex electronic or computing devices, and employ a significant number of R&D workers. There are two levels of high-tech industry: R&D intensive, which requires the number of R&D workers to exceed the average proportion of workers in all surveyed industries by 50 percent; and R&D moderate, where the R&D worker proportion is at least equal to the average proportion of all industries. According to the Global Insight World Inc. Industry Service database (2005),[2] which provides production data for the 70 countries that account for more than 97 percent of global economic activity, the global market for high-technology goods is growing at a faster rate than for other manufactured goods. During the 24-year period examined (1980–2003), high-tech production grew at an inflation-adjusted average annual rate of nearly 6.4 percent, compared with 2.4 percent for other manufactured goods.

Global economic activity in high-technology industries was especially strong during the late 1990s (1995–2000), when high-technology industry manufacturing, led by manufacturing in those industries producing communication and computer equipment, grew at more than four times the rate of growth for all other manufacturing industries (see Figure 1).

[2] Industry Service database 2005. Global Insight World Inc. http://www.globalinsight.com/WorldIndustry

Figure 1: Global High-tech Industry Sales, Average Annual Growth Rate, by Sector, 1995–2003



High-technology industries are R&D intensive; R&D leads to innovation, and firms that innovate tend to gain market share, create new product markets, and use resources more productively. These industries tend to develop high value-added products, tend to export more, and, on average, pay higher salaries than other manufacturing industries. Moreover, industrial R&D performed by high-tech industries benefits other commercial sectors by developing new products, machinery, and processes that increase productivity and expand business activity.

Increasingly, manufacturers in countries with high standards of living and labor costs have moved manufacturing operations to locations with lower labor costs. High-technology industries and their factories are coveted by local, state, and national governments because these industries consistently show greater levels of domestic production (value added) in the final product than do other manufacturing industries.

3. Asian Scenario (The data in this section come from http://www.globalinsight.com/WorldIndustry)

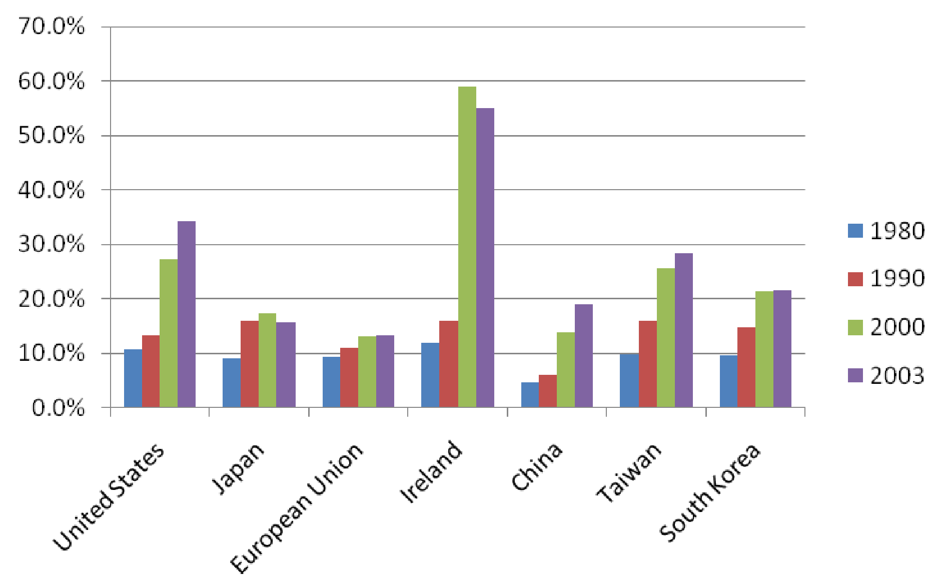
In Asia, high-technology manufacturing has grown dramatically over the past two decades, led first by Japan in the 1980s, then by the Republic of Korea, Taiwan, and China in the 1990s. The most recent data show that China's high-tech industries have surpassed those in Korea and Taiwan. If these trends continue, China's high-tech industrial sector may soon rival that of Japan in size, if not sophistication. Compared with Japan, China does not have the long record of large investments in R&D, has not produced the number of scientific articles across a broad range of technology areas, and has not been as successful patenting new inventions around the world. That may change in the near future, however, because China's investments in R&D are growing rapidly. In 2003, domestic production (value added) by China's high-technology industry accounted for an estimated 9.3 percent of global production, whereas just 23 years earlier (in

1980), domestic production in China's high-tech industry accounted for less than 1 percent of world output.[3]

China's economy is also changing and, given its size, its transformation will have a large impact on the global marketplace. China's high-technology manufacturing accounted for just 4.8 percent of total domestic output in 1980, and 6.2 percent in 1990, but soared to an estimated 19.0 percent in 2003. The value of China's domestic high-tech production in 2003 is estimated to be twice that of Germany, nearly identical to production in Japan, and nearly five times that of Ireland.

Korea and Taiwan typify how R&D-intensive industries have grown in the newly industrialized economies (NICs). In 1980, high-technology manufactures accounted for 9.6 percent of Korea's total domestic manufacturing output; this proportion jumped to 14.8 percent in 1990 and reached an estimated 21.5 percent in 2003 (see Figure 2).

Figure 2: High-technology Value Added as a Share of Total Manufacturing Value Added in Selected Countries and Regions, 1980–2003



Source: Global Insight World Inc., Industry Service database 2005,

Its high-technology ... 5.9 percent in 1990, ... economies also are ... ombine government ... ed growth in high- ... s (see Figure 2).

... facturing industries accounted for 12.4 percent of total domestic output in 1980, 20.4 percent in 1990, and for more than half its total domestic production since 1999.[4]

By 2008, led by China, Korea, and Taiwan, Asia continued to challenge the U.S. market position in S&T industries and reduce the gap on technological innovation. China has rapidly risen to become a leading producer and exporter of high-technology manufacturing goods, as measured by world market share. This rapid ascent shows signs of continuing. Korea, Taiwan, and other Asian economies have also become leading producers and exporters in S&T-intensive industries.

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[3] Industry Service database 2005. Global Insight World Inc. http://www.globalinsight.com/WorldIndustry

[4] Industry Service database 2005. Global Insight World Inc. http://www.globalinsight.com/WorldIndustry

4. Sri Lanka and High-tech Exports

In 1977, Sri Lanka became the first country in South Asia to open its economy, although its capital account was not liberalized. But Sri Lanka did not succeed in attracting high-technology industries compared with other South Asian countries that opened up their economies much later. Initial investments in Sri Lanka's free trade zones were mainly in the garment industry, where the availability of textile quotas was an important attraction to the initial investors mainly from the Far East. The garment industry has consolidated itself and managed to survive after the Multi Fibre Arrangement (also known as the Agreement on Textile and Clothing) and quotas ended in 2005, although production and exports have stagnated recently.

Only 28 percent of Sri Lanka's gross domestic product (GDP) is derived from industry and this figure is similar to that of India and Pakistan. In Thailand and Malaysia, the percentages derived from industry are 46 percent and 52 percent (Panel of the United Nations Commission on Science and Technology for Development, 2007).

High-technology exports form only 1.5 percent of Sri Lanka's manufactured exports. High-tech exports form a much higher proportion of manufactured exports in Thailand (27 percent), Malaysia (55 percent), and Singapore (57 percent). Textiles and apparel constitute over 40 percent of the value of Sri Lanka's industrial production, with food and beverages making up 23 percent. Chemicals and petroleum contribute 21 percent boosted by high prices for petroleum and rubber-based products. Pharmaceuticals, mainly tabletting, capsuling, and packaging, constitutes a quarter of these exports (Panel of the United Nations Commission on Science and Technology for Development, 2007).

These figures suggest that Sri Lanka has been less successful in its industrial development strategy and in the development of high-technology industry than Malaysia, Singapore, and Thailand. Part of the reason for this is that these countries opened their economy and their capital account long before Sri Lanka, but several other factors also have contributed, as the specific case studies in section II (and appendix) will show.

Although Sri Lanka has been a success story in telecommunication developments, with over 7 million mobile phones in the hands of its citizens, most of them are used for talking and SMS (short message service). While a few manufacturers of hardware cater to the export market, very little research or manufacturing takes place for the local market—mobile phones are almost totally imported although there are a few firms assembling computers for the local market. The growth of the software industry is impeded by the lack of human resources, and some of the firms that established in the country have moved to India. Sri Lanka, with its low labor cost and comparatively good English knowledge, has been able to attract Business Process Outsourcing business but this too could have developed on a larger scale. The use of information and communication technology (ICT) in the entertainment and media industry is still at a rudimentary level.

High technology can impact the society in multitude of ways. For example, the use of satellite and mobile technology can enhance the income levels of fishermen. Detection by satellite of the phytoplankton in the sea gives an idea about the potential fishing zones, where the catch will be much higher than normal. This communication can be sent to fishermen using the mobile technology. There are numerous such examples of improving the productivity, efficiency, and well-being of the society. Sri Lanka seems not to have realized the full potential of high technology in such contexts.

The potential of modern biotechnology as a wealth creator and differentiator is examined later in the study (pp 25-28. However, despite its huge potential impact, modern biotechnology in Sri Lanka is still in its infancy. The vast potential of agro-biotechnology, marine biotechnology, medical biotechnology, and industrial biotechnology has not been explored. The only industries are those in traditional biotechnology like beer and cheese making.

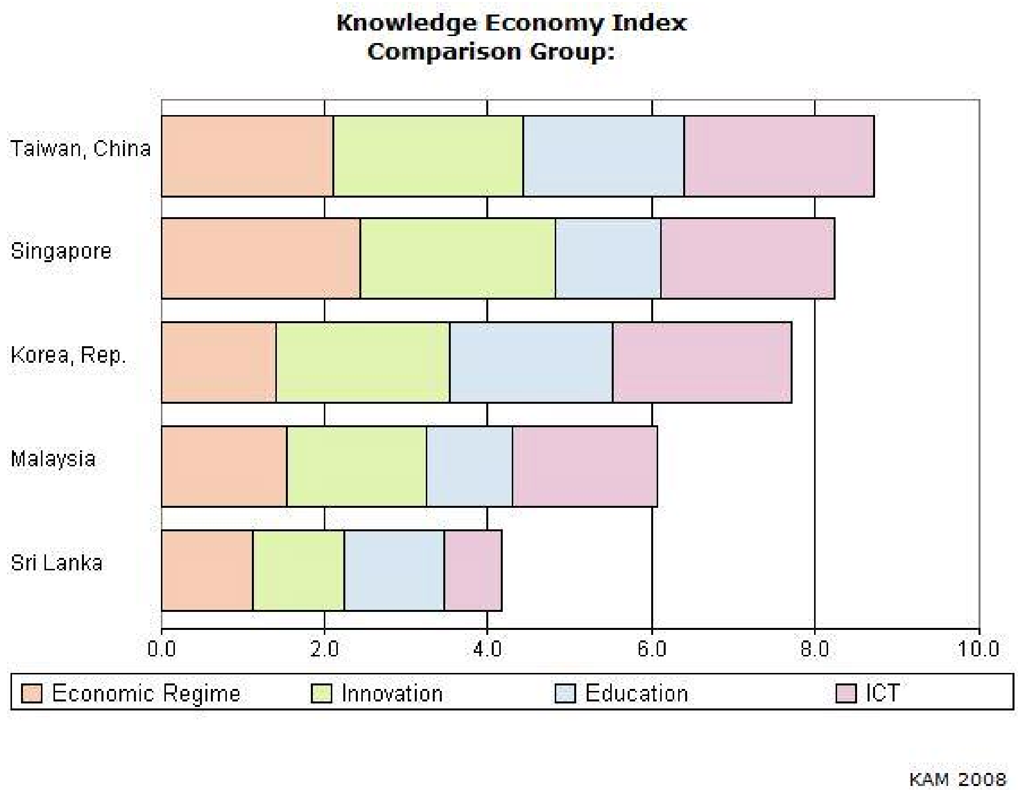
As indicated earlier, Sri Lanka has not been very successful in attracting foreign direct investment (FDI). With the exception of telecommunications, most investment in the recent past has been through privatization receipts. Sri Lanka began implementing a far-reaching privatization program in the early 1990s and has successfully privatized large parts of its state sector, including gas, telecommunications, airline, and ceramic and cement industries, and tea and rubber plantations. Privatization has now been halted as part of government policy, after attempts to privatize its petroleum refiner, power sector, and banks had repeatedly failed.

II. Lessons for Sri Lanka

This section evaluates the experiences of Korea, Malaysia, Singapore, and Taiwan in their respective attempts to make a transition toward a knowledge economy. The case of India was not selected given a vastly different size and position of its economy. The case studies provide important insights into four countries at very different stages in their transitions. A full description of the case studies is provided in the appendix. The analysis may provide Sri Lanka many insights on how it can develop its own strategies for creating a high-tech export oriented economy.

The Knowledge Economy Index of the World Bank (see Figure 3) shows where Sri Lanka stands relative to these four countries in terms of their economic regime, innovation systems, education systems, and ICT infrastructure.

Figure 3: Sri Lanka's Relative Performance in the Comparison Group



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Malaysia

Creating sound policy options for building a new economy: At independence, Malaysia was one of the poorest countries in the world. Post-independence, like many other countries, Malaysia adopted industrialization through import-substitution policies. However, rather than turning toward communism like many other countries did after independence; Malaysia took a different course, looking instead to the highly successful countries of East Asia. Its leaders pushed investments in education and technology, pursued a high savings rate, and adopted strong macroeconomic policies.

Diversifying from traditional industries to new export-based industries: Diversifying production and income away from tin and rubber was the strategic policy thrust in the light of high volatility in Malaysia's prices and anticipated decline in the long-term commodity prices, especially rubber. Malaysia's export-oriented manufacturing industries gained momentum in the early 1970s and FDI in export-oriented firms was promoted actively with the introduction of the various policies. The initial growth response to the purposeful and increased industrialization of the economy from the mid-1970s was favorable and overall growth rose to 10 percent per year in the late 1980s. FDI and manufactured exports played an important role, with the latter rising from 5 percent of total exports to more than 75 percent today.

Bringing in big reforms through the formulation of "Master Plans" and ensuring their flawless implementation: Prime Minister Mahathir Mohamad's government played a proactive role in promoting various reforms in the country. The government's Master Plan approach accelerated the pace of reforms and planning and formed an integral part of the Malaysian approach to development. Prime Minister Mahathir noted that much experience had been gained by the government and that it had been "augmented by studying methods of other countries which have adopted this approach." One of the most important beneficiaries and a relevant one in this case, has been the electronics and electrical products industry.

Strategic use of available resources for developing high-technology export-oriented industries: The promotion of the electronics industry began in 1970 with the initial companies employing fewer than 600 workers. By 2008, this sector was employing around 297,000 people and was valued at US$53.9 billion. The industry focused on making semiconductors, printed circuit boards, and industrial products such as telecom equipment, office equipment, and multimedia products. However, to achieve this, Malaysia used its existing ample, young, educated labor force, a market-oriented economy, and robust infrastructure.

Raising the bar for making a transition to knowledge-based economy: Recognizing that the quality of human resources will be the single most important factor that will determine the pace and success of the transition toward the knowledge-based economy, in 2001, Prime Minister Mahathir laid out the Knowledge-based Economy Master Plan of Malaysia. The seven strategic thrusts of the plan focused on all the important aspects of making this transition: cultivating and securing the necessary human resources; establishing the necessary institutions to champion this cause; ensuring the infrastructure and infostructure necessary to prosper in this endeavor; developing the private sector; developing governance mechanism to support this plan; and bridging the knowledge and digital divides.

Institutionalizing innovative technology development tools such as the Multimedia Super Corridor (MSC). To continue the good work that had gone into encouraging the development of the private sector, Malaysia took another bold step, that of setting up the MSC, often termed by the government as the future “Silicon Valley of East.” The motivation for moving into ICT was fairly straightforward. Malaysia was concerned about the narrow industrial base of the country and about a possible economic slowdown in the late 1990s. The clearest manifestation of this policy shift was the launching of the MSC in 1996, promoting pictorial, moving images, and sound and text technology development and marketing.

Financing the acquisition of strategic and relevant technology by Malaysian companies to enhance their technology competitiveness. Malaysia’s Technology Acquisition Fund (TAF) was a highly important and strategic tool in helping the Malaysian government achieve its high-technology development goals. TAF provided means for small firms that required new technologies to compete globally. The program allowed partial funding to companies to acquire high-tech equipment and machinery, technology licensing, acquisition of patent rights, prototypes, and design placement of Malaysians in foreign technology-based companies and technology institutes.

What can Sri Lanka learn from Malaysia’s experience?

Formulating and executing a strategic framework for developing high-technology industry. Malaysia is an excellent example of a growing economy, one that pursued relentless development in high-tech industries and created powerful incentives and sound policies for achieving its goals. However, it wouldn’t have been possible but for the active, and at times, proactive involvement of the political leadership. The same could be said in the case of any other country that has achieved rapid growth in their economy. However, in Malaysia’s case, the policies were made clear in the master plans and the execution of such plans was flawless. It is recommended that Sri Lanka should develop similar strategic frameworks outlining the changes to the fundamentals of the economy and align its governance, fiscal, human resources, and S&T policies to develop a “national innovation system”—a system of interconnected institutions to create, store, and transfer the knowledge and skills that define emerging technology areas such as nanotechnology.

Powerful tax and other incentives handed out to companies to flourish in high-technology development. For Sri Lanka, the fiscal and nonfiscal incentives package for the MSC status companies in Malaysia is worth an examination, as it illustrates both the old-style industrial policy instruments used throughout Malaysia’s push toward higher industrialization as well as a new style of operation based on simplicity and marketability, rather than an obtrusive development ideology. The fiscal incentives for MSC status companies included a five-year exemption from income tax, renewable to 10 years, or a 100 percent Investment Tax Allowance on new investments made in MSC cyber cities. The nonfiscal incentives granted to MSC-status companies allow them to employ foreign knowledge workers without restriction, to be wholly foreign owned, and to source capital globally and receive exemptions from exchange control requirements from the Controller of Foreign Exchange. However, companies were made to specify how they would transfer technology and knowledge to Malaysia, or otherwise contribute to the development of the MSC and the Malaysian economy.

Singapore

Singapore’s commitment to efficiency has attracted FDI that has allowed it to grow rapidly. Singapore’s government had always been committed to the concept of efficiency, recognizing early on that, to compensate for the country’s natural “comparative disadvantage” associated with being a small economy with a limited domestic market and population size, Singapore would need to develop a highly efficient and productive infrastructure system to help reduce production costs and attract foreign investors. This commitment to efficiency, along with an honest government that adopted proactive growth strategies and a highly educated, English-speaking workforce, has made Singapore a choice production base for multinational corporations (MNCs). There are currently over 5,000 foreign companies located in Singapore, and many more MNCs and foreign financial institutions have established operating and manufacturing bases in the country.

Like other Asian countries, Singapore reevaluated its growth strategies after the 1997 crisis. Following a period of impressive growth, the 1997 Asian economic crisis led the country to reevaluate its development strategies. Singapore has since recognized that efficiency alone will no longer guarantee sustained growth in the future and that it will need to formulate alternative strategies for growth.

What can Sri Lanka learn from Singapore's experience?

Sri Lanka should strengthen its R&D system and cultivate innovation in its universities. Singapore recognized, early on, that it needed to develop a powerful innovation sector to remain competitive in the knowledge-based economy. The country moved quickly to address the needs of building a knowledge economy and brought in international experience and funding wherever possible. Sri Lanka could acquire some of these strategies by encouraging a culture of innovation and more stringent protection of property rights.

The country should also invest more heavily in university and private sector R&D. At the moment, the country's education system does not encourage innovation. Students are generally not encouraged to conduct or promote research and even children in school are not encouraged to ask questions. Singapore has been able to combat a demotivating research environment by creating an innovation culture through attracting the right type of people. Sri Lanka could devote more effort to creating stronger research communities on a smaller scale, and encouraging researchers to interact with each other and get excited about the prospects of innovation and commercialization by building links with the private sector.

Sri Lanka could set up an intellectual property (IP) academy. The academy could have a mandate to rapidly build both the quantity and quality of IP manpower capabilities, through partnerships with leading teaching and research centers, IP thought-leaders, researchers, and industry players, both in Sri Lanka and abroad. Such an academy could also conduct leading-edge research projects and research collaborations with internationally renowned IP institutes and IP organizations. Such projects conducted by both local and eminent foreign IP researchers would allow Sri Lanka to be exposed to the latest developments in the global IP arena.

Korea

Korea's sustained rapid growth rate is due to its strategic use of knowledge for development. The Republic of Korea has had consistent growth over the past four decades, which has enabled it to overcome the economic and social damage caused by World War II and the Korean War. Korea's past left many with the notion that it would take decades to recover and rebuild from these events. However, after 45 years, Korea's GDP per capita has increased to more than US$12,000. Its growth is said to be significantly attributable to its ability to use knowledge effectively in all sectors of the economy.

Korea began with investments in education and the use of licensed technology. In the 1960s, Korea began investing in both export and import substituting industries, starting with subsistence agriculture and labor-intensive light manufacturing sectors such as textiles and bicycles. To meet the industry's current needs, considerable amounts of capital were invested in primary education. And the use of technologies, obtained through foreign licensing, were adapted for domestic production, allowing for a gradual shift up the value-added chain toward more sophisticated products.

Moving up the value chain required investments in technical and vocational training. In the mid- 1970s, Korea began the development of its heavy industries such as chemicals and shipbuilding and policies were subsequently enacted to improve the technological capabilities of the country. This transition was further facilitated and supported by Korea's incentive to improve access to and quality of technical and vocational training.

Deregulation and further investments in higher education continued to spur growth. In the 1980s, Korea attempted to ensure a market-conducive environment by deregulating various sectors and liberalizing trade. The government also expanded higher education while investing in indigenous research and development through the establishment of an R&D program. The country continued to pursue high value-added manufacturing through the 1990s by promoting indigenous high-technology innovation.

Government coordination was the key to Korea's early growth. Korea's early growth was a direct result of the country's ability to coordinate government policies and investment in education and innovation with market needs, but there came a time when the government's mechanism of resource allocation that had been effective when the economy was growing quickly was no longer effective. When the economy became larger and more complex, this approach no longer produced stellar growth outcomes.

The Asian crisis of 1997 prodded government into undertaking widespread economic reforms. The old policy framework and institutions that had led Korea in the early high-growth era turned out to be liabilities for sustained economic growth in the new economic environment. In response, Korea began undertaking reforms in the public and labor markets to overcome the crisis and ensure rapid economic recovery. Following the crisis, in 1998, Korea launched a national campaign to make the transition to an advanced knowledge-based economy in which domestic innovation would thrive. By using the framework developed by the Knowledge for Development program of the World Bank, Korea has since evolved into a mature knowledge-based economy by assigning priority to and investing in knowledge inputs, rather than in physical capital.

Korea's education system was nurtured and expanded according to the manpower needs of the economy. In the 1950s and 1960s, education policies focused on the expansion of primary and secondary education, which was critical to supply at least a literate workforce to the soft manufacturing industries. Vocational high schools were also established and developed in the 1960s to provide training in craft skills for the growing labor-intensive light manufacturing industries. Junior vocational colleges were set up in the 1970s to supply technicians for the heavy and chemical industries.

In the 1980s, the higher education expansion policies adopted by the government were instrumental in supplying high-quality professional workers and R&D personnel that were required as Korea began developing its domestic innovation system. Each level and entity within Korea's education system has been strengthened. It shows that enrollment is extremely high at the tertiary and secondary levels, and achievements in math and science subjects are even more remarkable. Korea has also been able to advance quality inputs with high levels of Internet access in schools and high-quality science and math education.

Korea's excellent ICT infrastructure has been developed by a competitive private sector telecommunications industry. In the early 1970s, Korea's information infrastructure was inadequate. To improve its efficiency, the Korean government focused in the 1980s and 1990s on introducing competition into the ICT sector by deregulating and liberalizing the sector and privatizing the government-owned telecom operators. From 1995 to 2003, the proportion of Koreans with cell phones increased to 70 percent, while the proportion of Internet users increased to 60 percent. Korea is now among the leading countries in the world in terms of proportion of broadband Internet subscribers, largely due to its successful construction of ICT networks connecting all areas of the country.

What can Sri Lanka learn from Korea's experience?

Sri Lanka should strive to formulate a strategy for development that is centered on coordination and private sector involvement. Korea's most significant development attribute was its ability to develop its skill and innovation base according the needs of the industry. Government played a major role by effectively making a transition from regulator to architect that makes strategic decisions to guide the country toward strengthening different sectors when needed for the country's development, that is, by taking a less direct interventionist approach.

Sri Lanka, which is beginning a transition toward becoming a major services industry, should begin investing in knowledge inputs that strengthen all relevant sectors of the economy. In terms of innovation, Korea invested heavily in R&D, but only after it had built up the knowledge capacity and technical base that it received from years of outward-looking assimilation and imitation of technologies.

Sri Lanka should begin investing in developing a research base geared to the process of imitation and assimilation. This will help to increase the value added of exports and begin the process of domestic innovation. Research as a discipline should be given greater funding within universities and R&D institutes, as they form the backbone of a research base. In the education system, Korea encouraged the private sector to finance a large portion of primary and secondary levels, leaving the country to focus its investment on higher education.

Taiwan

Taiwan made a successful transition from an agricultural economy to knowledge and high-technology economy. Having gone from an agricultural economic base to an industrial one, Taiwan used its local scientific and technological advantages to create economic value and improve the welfare of its people. Taiwan was quick to respond to high-technology challenges posed by the world, which included the facial masks and protective clothing that were developed to prevent the spread of the severe acute respiratory syndrome (SARS) epidemic in 2003.

Taiwan rewarded and promoted S&T professionals. Taiwan established various prizes and awards to recognize the contribution of its S&T professionals at the national level. For example, the Presidential Science Prize and Outstanding Achievement in Science and Technology Award were established to recognize outstanding performance by scientists and researchers.

Taiwan used IP to provide a competitive advantage in high-technology exports. Taiwan's high-tech export-oriented economy created pressure on the country to develop strong IP capabilities. In 2008, Taiwan ranked fourth in terms of the number of patents granted in the U.S. Patent and Trademark Office (USPTO).

Taiwan promoted and improved its high-technology industrial capacity through science parks. For more than two decades, the science parks have continually raised the bar for technological progress in Taiwan. With a wealth of experience in successful production and technology dissemination, the parks have not only improved the nation's industrial structure and economic prosperity, but also made a name for Taiwan's technology around the globe. The other advantage was having these science parks distributed across the country, the Hsinchu Science Park in the north, the Central Taiwan Science Park in the center, and the Southern Taiwan Science Park in the south. These parks are intended to form a corridor of technology and help transform Taiwan into a "Green Silicon Island."

Taiwan's science parks not only created an influx of professionals into the mainstream S&T, but also enabled the creation of lifestyle-oriented communities in Taiwan. The science parks went beyond creating office spaces for companies to operate, but focused more on combining R&D, production, working, living, and recreational facilities to establish a congenial environment for professionals and enterprises to thrive in.

What can Sri Lanka learn from Taiwan's experience?

Sri Lanka should emulate the "Taiwan Miracle." Taiwan's transformation from poverty to prosperity and from backwardness to a modern nation has been termed as the "Taiwan Miracle." The achievement is quite remarkable especially when considering that Taiwan was primarily an agriculture-based economy up to the early 1960s. Taiwan teaches an important lesson in how to create employment opportunities for a huge labor force when transiting from an agricultural economy to a high-technology one. Taiwan encouraged the development of labor-intensive export industries and capitalized on the island's inexpensive labor.

Sri Lanka should develop high-technology clusters for high-tech applications by drawing on local industry expertise. Taiwan, through the Central Taiwan Science Park, developed a high-tech cluster for nanotechnology applications by drawing on central Taiwan's precision machinery industry and attracting companies in integrated circuits, optoelectronics, and biotechnology. However, developing high-technology clusters requires bringing together the resources of academic and research institutes in various parts of the country to build a high-tech science park specializing in innovative research and development. With the creation of the Sri Lanka Institute for Nanotechnology (SLINTec), Sri Lanka has just begun this process. But there are many lessons in moving forward that Sri Lanka can learn from the strategies adopted by Taiwan.

III. Specific High Technologies for Value Addition to Exports and Local Manufacturing

High-technology manufacturing exports provide an indication of a country's ability to produce high-technology goods that can compete in the international marketplace. High technologies help to support competitiveness in international trade and to generate revenues needed for further investments in economic development. This section provides an overview of some key technology areas such as biotechnology, mechatronics, electronics, post-harvest technologies, and nanotechnology, and their potential impact on economic growth.

Biotechnology

1. General

The biotechnology field emerged in the 1970s, based largely on a new recombinant DNA technique whose details were published in 1973 by Stanley Cohen of Stanford University and Herbert Boyer of the University of California, San Francisco. Since then, the field has grown by leaps and bounds with more than 200 new therapies and vaccines, including products to treat cancer, diabetes, HIV/AIDS, and autoimmune diseases. More than 400 biotech drug products and vaccines currently are in clinical trials, targeting more than 200 diseases, including various cancers, Alzheimer's disease, heart disease, diabetes, multiple sclerosis, HIV, and arthritis. (See Table 1 for biotech market size.)[5]

Biotechnology is responsible for hundreds of medical diagnostic tests that keep the blood supply safe from HIV and detect other conditions early enough to be successfully treated. Home pregnancy tests are also biotechnology diagnostic products. Agricultural biotechnology benefits farmers, consumers, and the environment by increasing yields and farm income, decreasing pesticide applications and improving soil and water quality, and providing healthful foods for consumers. Environmental biotech products make it possible to clean up hazardous waste more efficiently by harnessing pollution-eating microbes. Industrial biotech applications have led to cleaner processes that produce less waste and use less energy and water in such industrial sectors as chemicals, pulp and paper, textiles, food, energy, and metals and minerals. For example, most laundry detergents produced in the United States contain biotechnology-based enzymes.

In terms of the current status of the global biotech market, the revenues of global publicly traded biotech companies grew 12 percent to US$89.7 billion in 2008. In that year, the revenues of U.S. public biotech firms alone grew by 8.4 percent, those of European public biotech companies increased 17 percent to EUR 11.2 billion, and those of Asia-Pacific biotech firms grew by 25 percent, led by strong growth in Australia (Ernst & Young, 2009).

Table 1: Global Market Size of the Leading Therapeutic Categories in Biotechnology

Leading Categories	Protein	Market size (US$ billion)		
		2006	2007	2008
Cancer, arthritis	Monoclonal antibodies	20	27	33

[5] Biotechnology Industry Organisation, www.bio.org

Infections	Vaccines	15	19	25
Anemia	Erythropoietin	12	11.8	9.5
Autoimmune inflammatory disease	TNF Blockers	10.6	13.5	18
Diabetes	Insulin	9	11	12.5
Multiple sclerosis and hepatitis C	Interferon	6.7	7.6	8
Growth, fertility	Hormones	6.5	7.4	8
Source: Maggon ([[**Date**?]]).				

Despite the recent global financial meltdown, the biotech industry has delivered superior performance. This is partially due to the industry's creativity in finding new and more durable models for funding innovation as this field requires continuous pumping of large capital until a biotech drug actually enters the market. In the United States and Europe, companies raised close to US$16 billion in capital, and biotech venture financing remained relatively strong, at about US$6 billion (Ernst & Young, 2009).

2. Lessons from Indian Biotechnology

The Indian government had the foresight to recognize the importance of biotechnology by establishing its National Biotechnology Board in its Department of Science and Technology, and then later converting it into a full-fledged Department of Biotechnology, as early as in 1983. This move has paid rich dividends for India in the subsequent decades.

Although the biotech industry is well spread across India, the western and southern regions of the country continue to account for 85 percent of the total revenues generated by companies headquartered in biotech clusters. In 2008, both of the regions generated more than US$1 billion in revenues. With revenues of US$1.07 billion and a 43.35 percent share, the western region exceeded that of the southern region. The western region's contribution was led by SERUM. Institute of India, and Biocon and Panacea led the revenue contributions from the south and the north, respectively (Biospectrum, 2009).

Much of the biotech boom in India was facilitated by the 13 biotech parks (see Table 2) and clusters that were developed throughout the country.

Table 2: Biotech Parks in India

Name of the Park	Area	Number of Companies	Specification
Shapoorji Pallonji Biotech Park, Hyderabad, Andhra Pradesh	300 acres	16 companies in phase I and 10 companies in phase II	Life sciences, health care, and pharmaceuticals
ICICI Knowledge Park, Hyderabad, Andhra Pradesh	200 acres	35 R&D companies	Life sciences
Agri-Science Park, Hyderabad, Andhra Pradesh	3,000 sft. lab space and 25-acre R&D centers	108 ventures have already been incubated	Agri-biotechnology and agri-business R&D
Bangalore Helix, Bangalore, Karnataka	14 acres	8 biotech incubators	Sector-specific Special Economic Zone Biotech Park
Biotech Park, Lucknow, Uttar Pradesh	8 acres	15 enterprises	Health care, agriculture, environment, industrial application, and energy
Kinfra Biotech Park, Cochin, Kerala	50 acres	Expected to house 15 to 20 biotech units	Bioinformatics, biotechnology with focus on marine, herbal, and agri-biotechnology
Golden Jubilee Biotech Park for Women Society, Kanchipuram, Tamil Nadu	25 acres	10 enterprises	Agriculture, food and nutrition, medical and health care, and environment and energy
Kinfra Biotech Park, Thiruvananthapuram, Kerala	25 acres	Developing stage	Agriculture, health care, diagnostic, and industrial enzyme
Inspira Infrastructure Biotech Park, Aurangabad, Maharashtra	25 acres	Developing stage	The biotech park is designed for biopharma and agri-biotechnology companies that do manufacturing and R&D
InternationaBbiotech Park, Pune, Maharashtra	100 acres	12 enterprises	Medical and pharmaceutical biotechnology
Savli Biotech Park, Vadodara, Gujarat	99 acres in phase I, 125 acres in phase II, 500 acres in phase III	11 companies have been recommended for land allotment in phase I	All major sectors of biotechnology
Ticel Biotech Park, Chennai, Tamil Nadu	5 acres	12 enterprises	Medical biotechnology, nutraceuticals, agriculture biotechnology, and bioinformatics
Agri Biotechnology Park, Jalna, Maharashtra	124 acres	Information not available	Bio-agriculture industry

Source: Biospectrum (2009)

As mentioned earlier, in India, the government took key steps to encourage entrepreneurs to set up biotechnology companies. India formulated a separate biotechnology policy for the states in recognition of the importance of the sector as a key growth area. The government further set up task forces in each state led by experts to attract biotech companies. The opportunities provided by the biotech parks were extended to a broad range of business areas within the biotech industry. Opportunities were identified in vaccines, bioactive therapeutic proteins, contract research, clinical trials and outsourcing, bioinformatics, infrastructure support institutions, and agriculture.

Within agriculture, hybrid seeds, including genetically modified seeds, represent new business opportunities based on yield improvement, and development of a production base in biopesticides and biofertilizers is expected to facilitate India's entry into the growing organic or natural foods market. The genetically modified crops like corn, cotton, millet, mustard, and other nutritionally improved vegetables also provide good potential in the agriculture sector. About eight of the 13 biotech parks listed in Table 2 have a focus on R&D in the agri-biotechnology field. Agricultural biotechnology is an immense global sector, boosting production of food crops and enhancing nutritional qualities. In the future, agri-biotechnology will become a top agenda item in governments and corporate research budgets, and it is anticipated that the global consumer acceptance of genetically modified food products will grow rapidly.

3. The Status of Biotechnology in Sri Lanka

It is surprising that, despite Sri Lanka's obvious advantages in creating value addition in biotechnology based on its rich biodiversity, strong agricultural base, and island status giving it an opportunity to explore and exploit marine resources, the country has missed the modern biotechnology revolution.

A 2008 U.S. Department of Agriculture (USDA) report (USDA Foreign Agricultural Service, 2008) noted that biotechnology is not widely practiced in Sri Lankan agriculture, with tissue culture being the major feature of biotechnology in local agriculture. Advancing biotechnology in agriculture is discussed at various agricultural scientific forums. However, there is little implementation of programs in the field.

This World Bank Mission was given the impression that the advent of modern biotechnology was halted by a strong campaign of opposition by nongovernmental organizations (NGOs). Sri Lanka will not benefit from the advances in modern agri-biotechnology, such as crop varieties that are genetically modified to be disease resistant, if it does not adopt a balanced "promotional and precautionary" approach, in contrast to a totally "permissive" approach or a totally "preventive" approach, as in some countries.

As a signatory to the Convention on Biological Diversity and Cartegana Protocol on Biosafety, Sri Lanka has released a National Biosafety Framework, a system of legal, technical, and administrative mechanisms under the Ministry of Environment and Natural Resources. A National Policy on Biosafety (National Sub-Committee on Biosafety) is an important element of this framework and will provide for safe application of "modern" biotechnology and ensure that there are no adverse effects on the country's conservation and sustainable use of biological diversity in the country, nor on human health and the environment.

The Council for Agriculture Research Policy and the National Science Foundation (NSF) have identified biotechnology as a means to improve the domestic agricultural sector's productivity and profitability, and to lessen the harmful environmental effects of chemical fertilizers currently in use.

The NSF is looking to partner with universities to train local scientists on biotechnology and facilitate technology transfer.

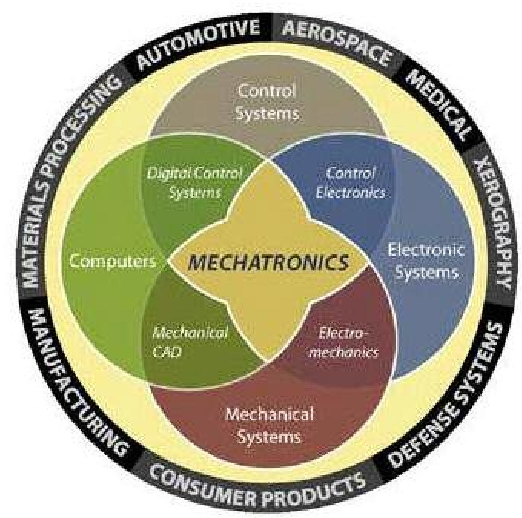
Mechatronics

1. General

Mechatronics, or "intelligent mechanical systems," is the foundation of many 21st-century enabling technologies. Mechatronics involves the integration of mechanical and electrical systems with control systems and information technology (IT). (See Figure 4 for a graphical description of mechatronics.)

The genesis of mechatronics occurred in 1969 in Japan when Tetsura Mori, a senior engineer for Yaskawa Electric Corp., coined the term. At that time mechatronics was viewed strictly as electromechanical systems or control and automation engineering. During the 1970s, mechatronics focused on sophisticated control methods, such as automatic door openers and auto-focus cameras.

Figure 4: Various Fields that Constitute Mechatronics



***Source*: Rensselaer Polytechnic**

…ed with IT whereby microprocessors were embedded into …nce, such as antilock brakes and electric seats. Finally, in … communication technologies to connect products into large … other related technologies.

…ated with the use of mechatronics in the design of physical systen… not only the ability to replace many mechanical systems with electronic systems, which introduces greater reliability and flexibility into the system, but also the ability to monitor and change the operation of a system based on information collected during its use. For example, the Toyota Prius Hybrid automobile optimizes gas mileage using mechatronics automation techniques.

Mechatronic products and processes are increasingly pervasive across a broad range of industries, the top three of which are industrial controls/automation and instrumentation (38 percent), robotic systems (25 percent), and aerospace/defense (24 percent), according to a survey carried out by Reed Business Information.

Within mechatronics, there has been a huge surge in demand in the vehicle controls and automation segment. The ever-increasing demand for "intelligent" safety features (anti-lock braking systems) and heightened comfort (power seats and automatic climate control) in vehicles has led to a corresponding boom in mechatronics. In 2004, the EU projected the mechatronics market to grow from EUR 5.2 billion to EUR 6.8 billion by the end of 2009. In the United States, mechatronics systems are proving to be a growth segment for electronic manufacturing services (EMS) providers.

While there are no market figures available for the U.S. mechatronics systems, they are included in the industrial segment along with medical equipment, defense, and aerospace. This segment of the EMS industry will post nearly 12 percent compound annual growth as it rises from US$19.2 billion in 2006 to US$29.2 billion in 2013.[6]

Various countries are taking definitive steps toward building human resources for catering to the mechatronics industry. For example, to meet the demand of Singapore's manufacturing- and electronics-related industries, four polytechnics offer mechatronics at the diploma level. Singapore has identified mechatronics as a relevant discipline to help its industries achieve sustained competitiveness. By developing talent in mechatronics, Singapore aims to achieve strong technological capability in the design of high value-added products and to support the semiconductor and wafer fabrication industries.

2. Sri Lankan Initiatives in Mechatronics

In Sri Lanka, mechatronics can play a huge role in transforming the small and medium enterprise (SME) sector by integrating mechatronics as an essential discipline in the automation of industrial processes. The SME sector represents a bulk of the local manufacturing industry and is the largest employment provider in the manufacturing sector in Sri Lanka. Its continued expansion and survival are both economically and socially important. However, the influx of foreign goods has increased the competition in the local market as well as in Sri Lanka's export markets. In the absence of industrial automation technology inputs, the local SME sector faces a huge challenge in tackling this competition.

With this challenge in mind, the National Engineering Research and Development Centre (NERDC) plans to establish a mechatronics center that will provide the institutional mechanism necessary for spearheading industrial automation in Sri Lanka with specific focus on the SME sector (MoST, 2009).

Broadly, the program will involve the following:

- Establish a mechatronics laboratory capable of experimenting, demonstrating, training, and undertaking the country's R&D on industrial automation needs.
- Build capacity and acquire know-how in the development of frontier technology in industrial automation through manpower training.
- Conduct regular professional training programs for industrialists on the industry trends and advanced technology in industrial automation.
- Train and develop the critical mass on mechatronics to be able to provide the technological inputs for industrial automation in the country.
- Establish and manage an updated data bank on technology trends, industry norms, standards, and a list of accredited service providers on industrial automation, especially on mechatronics.
- Undertake research on developing indigenous industrial process automation and adapting imported industrial automation technology to local needs.

NERDC has already taken steps toward ensuring development of the proposed mechatronics center. A few mechatronics trainer kits have been purchased and installed. These items will be transferred to the new facility once it has been established. Floor space of 1,600 square feet. has been allocated for

[6] Motion Control Association, www.motioncontrolonline.org

the laboratory. Three engineers have been currently assigned to the mechatronics work; two of them are pursuing postgraduate studies in mechatronics. In addition, the following activities are planned:

- A study tour by an expert panel to two centers of excellence in mechatronics in Asian NICs.
- Hiring an international consultant to prepare a detailed project proposal for establishing a national mechatronics center in Sri Lanka.
- Acquiring a five-acre parcel of land in either Malable or Homagama (MoST, 2009).
- Building the physical infrastructure: buildings, roads, etc.
- Building capacity for the center.
- Acquiring training kits, software, books, and equipment.

These are important first steps, but there needs to be a great thrust on using mechatronics as a transformation tool for the SME sector in Sri Lanka.

Electronics

1. General

The global electrical and electronics industry has been growing at a rapid pace, with innovative technologies and an ever-increasing customer uptake of electronic goods and services. The industry is highly fragmented, with various auxiliary sectors, namely, electronic components, computer and office equipment, telecommunications, consumer appliances, and industrial electronics.

A vital electronics industry can boost a country's economic growth, provide jobs for skilled workers, and accelerate development in other sectors. The transformation of Japan, Singapore, Taiwan, and other NICs since the 1960s is recognized as one of the great development achievements of the 20th century.

In Japan, the 1973 oil crisis induced a shift from heavy industry to less energy- and material-intensive sectors. The information industry, led by electronics, replaced heavy industry as the economy's leading sector. Between 1975 and 1985, the share of electronics in total manufacturing output rose from 9.3 percent to 17.5 percent, the biggest increase in the proportion of electronics in output of any major economy (Hanna et al. 1996).

Groups of companies—the *Keiretsu*—led the development of IT, with government as a catalyst. Since the 1970s the Ministry of International Trade and Industry (MITI) has pushed a consensus with industry and academia to promote the information industry. MITI strategy guided the formulation of direct and indirect programs, from technology parks and research consortia to tax incentives and procurement standards.

In the mid-1960s, Korea was a low-cost exporter of labor-intensive products such as apparel. A decade later, it had moved up to construction services and capital-intensive production of ships and steel. By the 1980s, the country had established a strong global position in knowledge-intensive products, particularly semiconductors and computers. Since 1969, government has spurred the technological learning of large industrial companies, the *Chaebols*. In the mid-1980s, the government supported the Chaebols joint ventures in computers with global technology leaders. Its information industry promotion plan has helped develop software, communications, semiconductors, and computers and diffused IT across society.

The extraordinarily rapid rise of the IT industry in Taiwan has been focused on the manufacture of computer products for world markets by its many small entrepreneurial firms. Similarly, Singapore has gone from a poor entrepot center to a global hub for high-value IT production and use.

In all these countries, government helped unleash the private sector response, promote the industry, diffuse technology, and develop the information infrastructure. It played several roles in developing the electronics industry: coach and coordinator for the private sector (Japan), creator of private conglomerates to compete abroad (Korea), incubator and supporter of SMEs (Taiwan), integrator and strategist (Singapore), and infrastructure provider (Hong Kong).

Government responded to evolving local technological capabilities, global environment and competitive conditions, new opportunities arising from technological change, and its own development. Export orientation and active private sector participation in policy-setting reduced the dangers of rent-seeking that often arise from interventions.

Today, the global electronics market—in particular, the consumer electronics sector—is witnessing phenomenal growth. The Consumer Electronics Association reported (2008) that global revenue from the consumer electronics industry alone was expected to reach US$700 billion by the end of 2009. Consumers will spend US$42 billion more on consumer electronics products in 2009 than in 2008. Countries with fast-growing economies and large emerging middle classes, such as the BRIC countries (Brazil, Russia, India, and China), will lead the way in new consumer electronics revenue growth. In 2008, Asia (not including Japan) will account for 30 percent of the entire global consumer electronics expenditure, followed by North America (22 percent) and Western Europe (19 percent) (Consumer Electronics Association, 2008). This growth is led by electronic products such as mobile phones, portable navigation systems, laptop computers, LCD and plasma television sets, DVD players, video game consoles, and so forth.

It is expected that this growth in the electronics industry will continue in the future and that Asian countries will play a dominant role in the future growth.

2. Current Status of the Electronics Industry in Sri Lanka

While the electronics industry is a major economic activity in most Southeast Asian countries, in Sri Lanka, only a handful of industries are engaged in an activity related to electronics. In the early 1980s, U.S.-based MNCs Motorola and Harris Semiconductors entered into agreements with the Sri Lankan government to venture into this sector but abandoned their plans almost immediately after the 1983 riots.

There is little local product and process innovation in electronics, except in a few, essentially low-end products. This is unfortunate, because local product development, especially low-cost equipment, could help greatly in increasing product penetration.

Three research institutes are involved in electronics: the aforementioned NERDC, and the Arthur C. Clarke Institute for Modem Technologies (ACCIMT). However, insufficient funding for meaningful electronics R&D, and high demand and lucrative opportunities for qualified and experienced electronics and telecommunications engineering researchers both within the country and abroad has made it very challenging for the institutes to attract and retain talent.

NERCD, ITI, and ACCIMT do have a few R&D programs in electronics. In addition, they repair electronic instruments and systems, especially where there are no commercial organizations that do repairs. The same institute staff do both repair and R&D work.

Another interesting feature is that the institutes' engineer-to-technical assistant ratio is rather high: Several engineers share each assistant. This requires engineers to do most of the work, including materials preparation, fabrication, and testing, making the cost of development high.[7]

[7] Department of Electronic and Telecommunication Engineering, University of Moratuwa, Sri Lanka.

In short, the current situation is far from satisfactory, and Sri Lanka needs to make a major, focused development effort in electronics if it wishes to share in the benefits of this high-tech revolution.

Post-harvest Technologies

1. General

Widespread urbanization and rising incomes in developing countries have been the most important determinants of how and how much food, especially fresh fruits and vegetables, is consumed. This has increased the importance of post-harvest handling of fresh horticultural commodities. Both conventional and new technologies have to be mobilized to get these commodities to markets and to consumers.

Over the past few decades, countries throughout the world, including in developing countries, have made significant progress in developing a diversity of appropriate post-harvest technologies that have improved the handling and quality of food crops. These technologies include harvesting indices, harvesting methods, pre-cooling methods and applications, storage techniques, packing and packaging, quarantine systems, transport systems especially by road and sea, and modified and controlled atmospheres. Nevertheless, significant quantities of perishable foods are lost every year in much of the world, especially in many developing countries. Quantitative and qualitative post-harvest losses of horticultural crops in developing countries are estimated to be 2-3 times those in developed countries (see Table 3).

Table 3: Estimated Post-harvest Losses of Fresh Horticultural Crops in Developing Countries

Location	Range (%)	Mean (%)
From production to retail sites	5-50	22
At retail, food service, consumer sites	2-20	10
Cumulative total	7-70	32

Source: Yahia

This loss is appreciable considering that the food industry in developing countries has tremendous growth potential due to increasing demand from both local and export markets. These countries dominate the world's fresh fruits and vegetables production, producing almost three-quarters of the world supply. China is the largest fruit and vegetable producer, with 36 percent of world production, followed by India with 9.4 percent. Other important producers are Brazil (fruits), Mexico (fruits), Turkey (vegetables), and Egypt (vegetables); together they produce almost 55 percent of the world's fresh fruits and vegetables (Yahia). Reducing post-harvest losses could presumably add a sizeable quantity to the global food supply, thus reducing the need to intensify production.

High post-harvest losses are primarily the result of a lack of inadequate post-harvest technologies and of trained capacity in those technologies; deficient post-harvest-specific facilities; inadequate marketing systems; lack of information, government regulations, and laws; and limited investment in this sector.

Temperature control and fluctuation remains the major problem facing the handling of foods in general and fresh horticultural crops in particular in developing countries. Other technical problems include packing safety, packaging, transport, markets and marketing, quality control and assurance, and hygiene and food safety.

Modified atmospheres and controlled atmospheres are used in different forms in developing countries. Both are used for marine transport of various commodities such as cantaloupe, limes, grapefruit, banana, mango, avocado, and stone fruits. Controlled atmospheres are used for storage of apples, pears, and kiwi fruit in some countries including Argentina, Brazil, Chile, Jordan, Mexico, and Uruguay.

Similarly, some countries such as China, Iran, Pakistan, and Turkey use natural cooling. Crops that exhibit comparably low perishability are sometimes stored on-farm without refrigeration. Natural cooling processes are very simple and involve piling produce in an open space (covered with polyethylene sheets and straw), open sheds, rooms in houses, and adobe or brick structures of various types.

However, significant advances have taken place in the last few decades in R&D in post-harvest technologies. Some of these advances include gas monitoring and control, transport in controlled atmospheres, packages and packaging, controlled atmosphere storage, modified or controlled atmosphere packaging, physical quarantine treatments, minimal processing, and ethylene control.

Developing country governments have begun to focus on developing diverse post-harvest systems and solutions. To encourage innovation, they are advancing research in post-harvest technologies, doing post-harvest education, transferring technology from more advanced nations, increasing private sector participation, linking farmers directly to markets, involving more researchers in post-harvest technologies, and building collaboration between these researchers at a regional level.

2. Sri Lankan Initiatives and Challenges in Post-harvest Technology

Sri Lanka is blessed with a year-round tropical climate, which is conducive to producing very high-quality fruit. Yet, its reported post-harvest loss of fruits and vegetables is estimated at more than Rs 9 billion per year—almost 40 percent of the total fruit and vegetable output—due to the absence of proper value-added methods and technologies. A loss assessment study by the Institute of Post Harvest Technology (part of MoST), put the losses at 30–40 percent with about 25 percent due to improper packaging systems and transportation methods.

MoST has taken steps to address the needs of fruit harvesting, especially export-quality fruit. For example, certain waxes made with locally found ingredients extend the storage life of fruit like papaya, pineapple, mangoes, bananas, and even export-quality king coconuts during long-distance transport. Use of this wax would encourage exporters to use sea transport, which transports more cargo at a lesser cost. In addition to being cost effective for exporters, more fruit exported at a lesser expense will translate to increased income for local fruit farmers and traders.

ITI research led to the discovery of a successful method for using *chitosan*, extracted from the head and shell waste of prawns, which works as an antifungal against the fungi of *Colletotrichum* species, a common cause of post-harvest diseases. Use of chitosan can extend the storage life of papaya and as well as some other fruits.

In addition, MoST has set up the "*Vidhata* Centres" for transferring technology and technology know-how to a large number of small-scale entrepreneurs throughout the country. The program allows the entrepreneurs to borrow up to Rs 1, 00,000 at 8 percent annual interest from the People's Bank of Sri Lanka.[8]

[8] MoST, http://www.most.gov.lk/edit_news_events.php?id=3

Nanotechnology

1. General

Nanotechnology is widely seen to have huge potential to bring benefits to many areas of research and application and is attracting rapidly increasing investments from governments and businesses in many parts of the world. Because of the Sri Lankan vision of it becoming "a regional nanotechnology hub," this study looked closely at the potential of this frontier technology.

From a scientific perspective, a nanometer (nm) is one thousand millionth of a meter. For comparison, a single human hair is about 80,000 nm wide, a red blood cell 7,000 nm wide, and a water molecule 0.3 nm across. People are interested in the nano scale (defined to be from 100 nm down to the size of atoms, approximately 0.2 nm) (Burgi and Pradeep, 2006) because it is at this scale that the properties of materials can be very different from those at a larger scale.

Nanotechnology is thus the study of phenomena and manipulation of materials at atomic, molecular, and macromolecular scales. In some sense, nanotechnologies are not new. Chemists have been making polymers, which are large molecules made up of nano-scale subunits, for many decades and nanotechnologies have been used to create the tiny features on computer chips for the past 25 years. However, advances that now allow atoms and molecules to be examined and probed with great precision have enabled the expansion and development of nanotechnologies.

The properties of materials can be different at the nano-scale for two main reasons. First, nanomaterials have a relatively larger surface area when compared with the same mass of material produced in a larger form. This can make materials more chemically reactive (in some cases, materials that are inert in their larger form are reactive when produced in their nano-scale form), and affect their strength or electrical properties.

Second, quantum effects can begin to dominate the behavior of matter at the nano-scale—particularly at the lower end - affecting the optical, electrical, and magnetic behavior of materials. Materials can be produced that are nano-scale in one dimension (for example, nano-wires and nanotubes) or in all three dimensions (for example, nanoparticles).

The wide-ranging definitions cut across many traditional scientific disciplines. The only feature common to the diverse activities characterized as nanotechnology is the tiny dimensions on which they operate. Therefore, it is found more appropriate to refer to the activities as "nanotechnologies."

2. Emerging Nanotechnology Applications and Global Markets

A recent report, "Nanotechnology Market Forecast to 2013," by international publishing firm M2 Communications, predicts the global market to grow from an estimated US$14.5 billion in 2009 to more than US$30 billion by 2013, representing a compound annual growth rate (CAGR) of around 20 percent during the period. The report also projects that the market for nanotechnology incorporated into manufactured goods will be worth US$1.6 trillion, representing a CAGR of more than 49 percent in the forecast period (2009-2013).[9]

Several initiatives undertaken by the European Union as part of its Seventh Framework Programme (FP7) will help the region emerge as a large player on the global nanotechnology map by 2013. The FP7 will contribute approximately EUR 600 million per year toward nanotechnology until 2013. Also, the presence of Japan, Korea, China, and India will foster the highest growth in the Asia-Pacific region over the forecast period.

[9] http://www.m2.com/m2/web/page.php/newspublishing **Accessed, June 2009.**

However, the M2 report predicts that the nanotechnology market will remain dominated by the United States. Examples of notable U.S.-based nanotechnology companies are cited below:

i. NanoComp Technologies Inc., in New Hampshire, is making MWCNT (multi-wall carbon nanotubes) rope for conductors for military applications. NanoComp's vision is to leverage its proprietary and fundamental advancements in the production of long carbon nanotubes together with a unique ability to fabricate them into physically strong, lightweight, electro-thermally conductive spun yarns and sheets.
ii. Nantero, in Massachusetts, is a nanotechnology company using carbon nanotubes for the development of next-generation semiconductor devices. These devices include memory, logic, and other semiconductor products. In the field of memory, Nantero is developing NRAM, a high-density nonvolatile Random Access Memory. The company's objective is to deliver a product that will replace all existing forms of memory, such as DRAM, SRAM, and flash memory, with NRAM serving as universal memory. Nantero is also making radiation-hardened memory for space applications. This company was acquired by Lockheed Martin in 2008.
iii. A123 Systems' proprietary nanophosphate technology is built on a new nanoscale material initially developed at the Massachusetts Institute of Technology. A123Systems is now one of the world's leading suppliers of high-power lithium ion batteries using their patented nanophosphate technology designed to deliver a new combination of power, safety, and life. A123Systems' batteries are now used for virtually all power tools.
iv. Quantumsphere, from California, makes catalyst materials, high-performance electrode systems, and has IP for licensing in multiple portable power and clean technology applications. Quantumsphere is currently making Zinc Air with nanomaterials in collaboration with major battery producers.
v. ZettaCore is a Colorado-based company that is focused on molecular materials applications. Their technology will lead to advances in many different electronic applications, playing a key role in new generations of electronic devices, both large and small. The company is currently is making Molecular Imprints nano-imprint lithography in electronics.
vi. Nanosphere, from Illinois, is a notechnology-based health care company offering proprietary technologies that provide a solution to simplify diagnostic testing. Nanosphere's molecular diagnostics (Verigene) system is now U.S. Food and Drug Administration (FDA) approved, and the company had a successful IPO last year.

There are many other interesting nano-cancer-based therapeutic delivery technologies, such as those made by Tempo, Kereos, Nanospectra, and BIND Biosciences. These technologies are in the development stage and have yet to go through the FDA approval process. Transparent conductors are on the horizon, whether they be CNT based (Unidym, Eikos), or nanosilver based (CIMA Nanotech). Other key IT applications are the read-write GMR-based technologies developed by IBM, Seagate, and others, which are based on nanolayers of magnetic alloys separated by antiferromagnetic-coupled layers.

3. Current and Potential Uses of Nanotechnologies

To be successful, technology needs to be designed to the needs of the target group and be suited for the socioeconomic context. Nano-scale science and its derived technologies can enhance the lives of nearly everyone, rich and poor, because of their pervasive benefits and suitability in resource-limited

settings. They have potential to provide most innovative tools and strategies in fighting poverty-related issues.
Five billion people live in the developing world and their living conditions could be enhanced by the diffusion of applications of discoveries made in this area. To substantiate this view with concrete examples, seven core areas have been identified where nanotechnologies can make a significant difference in the developing world.

Economic development

Nanobiotechnology, involving the biological production and utilization of nanomaterials, is a promising new field, especially in the developing world with its unparalleled biodiversity. This asset of the developing world can be harnessed through nanomaterials synthesis using microorganisms, including bacteria, viruses, and fungi as well as plant- and animal-based products. Several examples of nanomaterials synthesis using biology have been reported. Techniques related to nanobiotechnology do not require large investments and infrastructure and can therefore be developed on the site of application itself. The green and cost-effective solution to nanomaterials manufacturing is one example that proves that, with the necessary knowledge and skills, nanotechnology can be developed and diffused in the developing world. This approach has been applied to the synthesis of nanoparticles and nanotriangles of gold as well as various other inorganic nanoparticles such as those of CdS and $CaCO_3$. These methodologies can be suitably adapted for the large-scale synthesis of materials for applications such as cancer therapy, and infrared (IR) absorbing coatings. Synthesis of nanoparticles in human cells added a new dimension to this research.
It is also likely that an understanding of the underlying processes may permit us to alter the chemistry such that shape and size control of nanomaterials becomes possible. The biochemical events may be transplanted to other organisms so that processes similar to the bulk production of enzymes become feasible. All of these could happen in the very foreseeable future, with lower investment than that necessary for chemical or physical routes.

Safe drinking water

Among the numerous applications of nanotechnology visualized, the most widespread impact as far as the developing world is concerned is perhaps in the area of water purification. Access to safe drinking water is one of the major concerns in the developing world, since almost half of the world population has no access to safe drinking water and basic sanitation.
Water purification systems, equipped with nanomaterials and using new kinds of membrane technologies with variable pore sizes as filters, could provide people in any area with safe drinking water. These are easy in application and maintenance and already available in the market; the forward-osmosis membrane technology of Hydration Technologies is one technique utilizing nanotechnology.
Thus, a combination of nanotechnologies will be useful in providing cost-effective and safe drinking water, which also will have less dependence on energy. Although the product is currently marketed for emergency water supply, large-scale water purification is indeed feasible. To substantiate the validity of these suggestions, the carbon nanotube-based filters could be developed for water purification and development of a filter that can separate petroleum hydrocarbons from crude oil has been already demonstrated. In addition, filters can also remove bacteria from water. The nanotubes, with smart sensors, could be incorporated into the filter as several nanotube-based sensors are known already.

Nanoparticles have been shown to degrade pesticides and pollutants. Several nanomaterials are known to be antibacterial and they can be incorporated on various kinds of substrates.

Improving food security

Nutrient deficiency is a widespread phenomenon throughout the developing world and challenges the physical and mental health of over one billion people. Food starvation can be, but not always is related to crop failure. Novel techniques using nanotechnology can be applied in agriculture for breeding crops with higher levels of micronutrients, enhanced pest detection and control and improved food processing. Besides crop failure, the lack of adequate storage facilities is one of the major reasons for food shortages in the developing world, in particular in remote areas.

In India alone, huge quantities of wheat and rice rot in the open. Especially in the tropical belt, food spoils easily because elevated temperatures favor the growth of microorganisms, which reduce food's quality or render it inedible. Oxygen accelerates the degeneration process because it enables growth of microorganisms. It is known that carbon dioxide inhibits the growth of microbes. Carbon nanotubes could be used in food processing and preservation as an oxygen scavenger and prevent packed food from deteriorating. Another application of one of the recent nano-scale innovations involves atomically modified food; this marks the beginning of a radically new paradigm for food production, which has the potential to sidestep the controversial genetically modified food and increase the yield of agricultural produce.

In Thailand, researchers at Chiang Mai University have modified local rice varieties to develop a variant that grows throughout the year by applying nanotechnology. This particular technique involves the perforation of the wall and membrane of a rice cell through a particle beam for introducing one nitrogen atom into the cell, which triggers the rearrangement of rice DNA. Novel techniques applying nanotechnology could contribute to improving the current food supply, which in many parts of the globe is alarming.

Health diagnosis, monitoring, and screening

Nano-scale techniques have the potential to revolutionize health care, in particular the diagnosis, screening, and monitoring of diseases and health conditions. A wide range of novel applications using nano-scale techniques in health care is possibly the beginning of a new paradigm. Standard diagnostic tests for diseases that are widespread in the developing world are costly, complex, and poorly suited to resource-limited settings. Lack of accurate, affordable, and accessible diagnostic tests impedes global health efforts, especially in remote regions and among poor populations. Widespread communicable diseases like HIV, malaria, and tuberculosis could be diagnosed with screening devices using nanotechnology.

A radically new approach to health diagnosis has been developed in India by the Central Scientific Instruments Organisation (CSIO). Theoretical simulation and design parameters for a microdiagnostic kit using nano-sized biosensors were completed in 2004 and the kit is ready for clinical trials. The techniques are based on highly selective and specific biosensors and receptors like antibodies, antigens, and DNA, which enable early and precise diagnosis of various diseases. The diagnostic kit Bio-MEMS (microelectro- mechanical-system) has the size of about 1 cm^2, costs around Rs 30 per piece, and is easy to apply (Burgi and Pradeep, 2006).

Testing time is rapid and only requires a tiny amount of blood. This novel diagnostic tool could also find application in the detection of other diseases and pollutants in the environment, including water and food. To develop therapeutics to combat malaria caused by the parasite *Plasmodium falciparum*,

a common disease in many parts of the developing world, Professor Subra Suresh, Dean of the School of Engineering at the Massachusetts Institute of Technology, and his team are using nanotechnology to systematically measure mechanical properties of biological systems in response to the onset and progression of the disease.
Innovative drug delivery systems are another area to which nanotechnology can be applied. Cancer, as widely diffused in the developing world as elsewhere, is a big challenge to human health. Latest results obtained in cancer detection and treatment with nano-scale techniques provide hope that nanotechnology could be heading for a breakthrough in defeating this disease. A way to detect cancer safely and economically is by the injection of "molecular beacons" into the body.
Britton Chance and his colleagues at the University of Pennsylvania developed tiny capsules that use the specific biochemical activity associated to a tumor to detect breast cancer. In regard to cancer treatment, Jennifer West and her team at Rice University, Houston, developed gold "nano bullets" that can destroy inoperable human cancers. The nano-shells consist of tiny silica particles plated with gold; when these are heated with infrared light, the cancer cells die. Carbon nanotubes have been transported into the cell nucleus and continuous near infrared radiation absorption of nanotubes causes cell death. This methodology has been used for cancer cell destruction.

Environmental pollution

Environmental degradation due to unsustainable methods of production and other human activities exposes the entire world population to increased risks. Innovative techniques using nanoengineered materials and devices can be deployed for the removal of polluting molecules in air, water, and soil. Cleaner manufacturing processes and methods, applying nano-scale techniques, could also contribute to lesser environmental pollution, especially in the developing world where international standards are often not safeguarded.
For instance, arsenic in soil and water is a widespread problem in the developing world. A simple, cheap, but effective nano-scale technique to remove arsenic involves TiO2 nanoparticles. Nanomaterials have been shown to be effective in removing metal ion contamination. A wider application of such technologies harnessing discoveries in nanotechnology could have a positive and wider impact on the health conditions and natural habitat of millions of people.

Energy storage, production, and conversion

The chronic power shortage and increased need for energy resources of the rapidly growing population and economies of the developing world are challenging the energy market. Since almost all sources of energy are not renewable, soon the world will face a global energy supply problem.
Solar energy is an interesting and valid alternative, especially in the sun-rich South. Scientific studies have demonstrated that nano-scale techniques involving nanotubes and nanoparticles lead to increased conversion efficiencies. Semiconducting particles of titanium dioxide coated with light-absorbing dyes bathed in an electrolyte and embedded in plastic films are cheap and easy to manufacture and offer an alternative to conventional energy production and storage. Because of their low cost-structure, photovoltaics using nanotechnology are a valid alternative to overcome the problem of power shortage, especially in the developing world. Researchers at Nanosolar, a venture capital start-up based in Palo Alto, California, are developing cheaper methods for producing photovoltaic solar cells using nanotechnology.
The idea is to boost the power output of nano solar cells and make them easier to deploy by spraying them directly on the surfaces. The approach is simple and could be easily replicated in the

developing world. These highly efficient solar cells can be made with a mix of alcohol surfactants and titanium compounds sprayed on a metal foil. Within 30 s a block of titanium oxide perforated with holes of nanometer size rises from the foil. Solar cells are formed when the holes are filled with conductive polymer and electrodes are added and then covered with a transparent plastic. These are concrete examples that nanotechnology is suited for energy storage, production, and conversion in the developing world.

Global partnerships

The inclusion of the South in the nano-dialogue creates new platforms and alliances between the North and South and strengthens their ties. Allocation of some of the large public scientific funding of nano-science and nanotechnology could be directed to developing countries in order to foster development, diffusion, and dissemination of nano-science, engineering, and nanotechnology in the developing world.

Global research networks of excellence enhance the value of the international scientific community. Encouraging international partnerships between the North and South, similar to the first North–South expert group meeting of nano-scientists and nanotechnologists in Trieste, Italy, in February 2005 are certainly important, but also scientific exchange and alliances between countries of the developing world are becoming a necessity in view of the ongoing regionalization trends in politics and economics. Global research networks, including scientific cooperation and collaboration, are needed to find joint solutions for the most pressing problems of the world community but partnerships at the regional level will, in the long term, gain importance and therefore South–South nano-networks need to be envisaged.

The development of nano-components that imitate or emulate natural processes can find many applications in myriad sectors. Protection and preservation of species in the tropical belt has become a new dimension because of bionanotechnology and its potential applications. The scientific exploration of the nano-bio interface becomes interesting in view of developing synthetic life forms, manufactured organs, and bio-nano-devices.

Availability of the necessary research infrastructure provides the developing countries with a strategic advantage relative to the industrialized world, because the biodiversity is much larger in the tropical and subtropical belt than in other geographical and climatic zones. It lies in the hands of the developing countries to make use of this distinctive asset and to discover the secrets of its yet unexplored biodiversity and the particular physical properties of its living organisms.

The Lotus effect, discovered by Wilhelm Barthlott and his student Christoph Neinhuis at the University of Bonn, illustrates how knowledge of what happens at the bio-nano interface can be made fruitful. Lotusan, a dirt-repellent paint is the commercialized form of the scientific discovery of the Lotus effect. Discovering the richness of the flora and fauna present in the developing world by the developing world itself with regard to bio-nanotechnology is of crucial importance.

The rich cultural heritage, including the millennia-old traditional knowledge in homeopathic, ayurvedic and herbal medicine, together with the large biodiversity provide developing countries with a strategic advantage that the North lacks. It lies in the hands of these countries, especially those that have already adopted nanotechnology initiatives within the bounds of their national technology development policies, to make use of the unique assets for a better positioning in the emerging global nano world.

Sri Lankan Initiatives in Nanotechnology

Sri Lanka aspires to become a nanotechnology hub and has begun initiatives to realize that aspiration (see section V).

IV. Higher Education and S&T in Sri Lanka: Current Status and Challenges

1. General

The Sri Lankan ambition of leveraging high technology to drive innovation and competitiveness in key export industries and building the Sri Lankan knowledge economy will have to be based on a strong foundation of higher education and STI. Therefore it is important to examine the soundness of this foundation.

The ability of a nation to profit from advances in science, its own scientific research output, and its process in technology cannot be overemphasized. A nation's readiness to exploit S&T for national development is determined by several factors. GERD and business (or private) expenditure on R&D (BERD) as a proportion of GDP are also considered to be important criteria in determining the strength of a country's innovation system. Expenditure on tertiary education in science and engineering and the number of scientists and researchers as a percentage of the population's principal national innovation system also are important. Other factors include the proportion of high-technology exports as a percentage of industrial exports, publications, patents granted, and royalty and license fee payments and receipts.

Table 4 provides the details of some of the key S&T competitiveness indicators for Sri Lanka in comparison with the four nations (Korea, Malaysia, Singapore, Taiwan) that were chosen for studying the best practices in high-tech export-led growth countries. Comparison has been made also with China and India, which enjoy the advantage of scale. Further, a scientifically and technologically advanced nation, the United States, also has been included. It is clear from the table that Sri Lanka lags on most of the key indicators and will have to make rapid strides to catch up, especially if it wishes to "ride the wave" of high technology for its growth and competitiveness.

After giving this relative evaluation, it will be important to reflect on some specific areas of critical importance. This analysis is based on the data that were available in the public domain, the most recent publications by the World Bank on higher education[10], as well as other information that were provided during the field work, personal assessments arrived at during field-work interactions have been also included

[10] Source: The Towers of Learning, World Bank, July 2009

Key Technology Competitiveness Indicators	Sri Lanka	Malaysia	Singapore	Korea	Taiwan	India	China	United States
IP protection (1-7), 2007	3.8	5.1	6.2	5.4	4.9	4	3.4	5.4
Researchers in R&D / mil. pop., 2006	137.65	508.93	5,479.14	3,723.28	3,839.12	n/a	714.61	4,628.20
Total expenditure for R&D as % of GDP, 2006	0.19	0.63	2.36	2.99	n/a	0.61	1.34	2.68
Manuf. trade as % of GDP, 2005	44.7	151	290.4	53	89.9	17.1	53.5	16
University-company research collaboration (1-7), 2007	3.6	4.9	5.3	5.4	5.1	3.5	4.1	5.6
S&T journal articles, 2005	136	615	3,609	16,396	10,841	14,608	41,596	205,320
S&T journal articles / mil. pop., 2005	6.91	23.97	831.22	339.5	476.95	13.35	31.89	692.46
Availability of venture capital (1-7), 2007	3.5	4.5	4.6	4.5	4.3	4.1	3	5.3
Patents granted by USPTO, avg 2002-2006	5.2	74.4	409.4	4,233	6,630	316.4	448.2	94,216
Patents granted by USPTO / mil. pop., avg 2002–6	0.27	3.03	97.01	88.44	293.44	0.3	0.35	324.12
High-tech exports as % of manuf. exports, 2005	1.5	54.7	56.6	32.3	42.6	4.9	30.6	31.8
Private sector spending on R&D (1-7), 2007	3.8	5	5.1	5.6	4.8	4.2	3.9	5.8
Firm-level technology absorption (1-7), 2007	4.7	5.8	6	6	6	5.6	5	6.1
Gross secondary enrollment rate, 2006	87.18	69.07	63.18	97.5	99.15	54.02	75.51	93.89
Gross tertiary enrollment rate, 2006	n/a	28.58	55.9	92.6	83.58	11.85	21.58	81.77
Internet access in schools (1-7), 2007	3.2	5	6.1	6.3	5.7	3.7	4	5.8
Public spending on education as % of GDP, 2006	3.1	6.2	3.7	4.6	n/a	3.8	n/a	5.9
Prof. and tech. workers as % of labor force, 2004	9.93	17.73	28.88	17.98	24.44	n/a	n/a	20.32
Quality of science and math education (1-7), 2007	4.4	5.4	6.3	5.5	5.6	5.4	4.4	4.5
Brain drain (1-7), 2007	3.2	4.7	5	4.8	4.7	3.8	3.9	6
Main telephone lines per 1,000 pop., 2006	90	170	410	550	640	40	280	570
Mobile phones per 1,000 pop., 2006	270	750	1,070	830	1,020	150	350	780
Computers per 1,000 pop., 2005	40	220	680	530	580	20	40	760
Internet users per 1000 pop., 2006	20	430	380	700	640	50	100	690
ICT expenditure as % of GDP, 2006"	5.4	6.8	9.3	6.6	6.3	6.1	5.3	8.7

Table 4: Key Technology Competitiveness Indicators

Source:, www.worldbank.org/kam. The Knowledge Assessment Methodology (World Bank, 2009) consists of 83 structural and qualitative variables for 140 countries to measure their performance on the four knowledge economy pillars

2. Higher Education and Supply of R&D Personnel in Sri Lanka

Governments play a crucial role in building national innovation ecosystems, of which creating talented human capital is the most important pillar. Sri Lanka is no exception. Indeed, the Sri Lankan S&T Development Act of 1994 explicitly states that the MoST is "to ensure that institutions of higher education and technical education and research institutions produce scientists, technologists and technicians of high caliber and competence and to secure the provision of incentives to them with a view to ensuring their retention in Sri Lanka." Conclusions about how far this mandate has been fulfilled follow (Fernando, 2009).

- Sri Lanka has not done particularly well on investment in education, which increased from 2.7 percent in 1980 to 3.2 percent of GDP in 1991, then fell to 2.56 percent in 1997–2000 and 2.17 percent in 2001–04, although more recently (2004–06), it has increased to 2.8 percent[11].
- Sri Lanka is one of a few countries in the world that still provides education free of charge up to the tertiary level. However, the shortage of private tertiary education institutions has placed limitations on the number of university places, with gross higher education enrollment rate between 2005-07 being 21% enrolled in higher education in Sri Lanka compared with 43 percent for Thailand (The Towers of Learning, World Bank, July 2009).
- Science and engineering have ceased to be popular among the youth; many are opting for business and management studies. Indeed, the long-standing dominance by public sector technology institutes and the limited development of innovative activity in private enterprises has been a common feature of South Asian economies that has severely limited the effectiveness and coherence of their research systems.

There are two issues of immediate concern:

- Compared with both the world average of researchers per million inhabitants (894.0) and the average for developing countries (374.3), existing R&D personnel in Sri Lanka is low, only 237.3 per million. Further, only 21 percent of the R&D personnel are in the engineering discipline. Sri Lanka needs approximately 18,000 research personnel, four times the present number, thus calling for a rapid expansion.
- Few postgraduate research degrees are awarded by Sri Lankan universities; they focus instead on undergraduate education. Very low numbers of university academics are engaged in R&D (5– 20 percent of the total of 2,161). Whereas postgraduate degrees are currently awarded only by the universities, the potential for postgraduate training exists in non-university research institutions, which account for almost 50 percent of research facilities in Sri Lanka.

3. Investments in R&D

Investments in research infrastructure in Sri Lanka continue to be comparatively low. The present investment in R&D is less than 0.13 percent of GDP, in comparison with Singapore (2.7 percent) and Korea (3.1 percent). Further, only 16 percent of GERD is spent on engineering-related R&D.

[11] The Towers of Learning, p. 84, World Bank, July 09

Most (28 percent) of R&D establishments in Sri Lanka are dedicated to agriculture, followed by social sciences and humanities (22 percent) and applied sciences (18 percent). Less than 11 percent of research facilities are dedicated to industry-oriented research (Fernando, 2009).

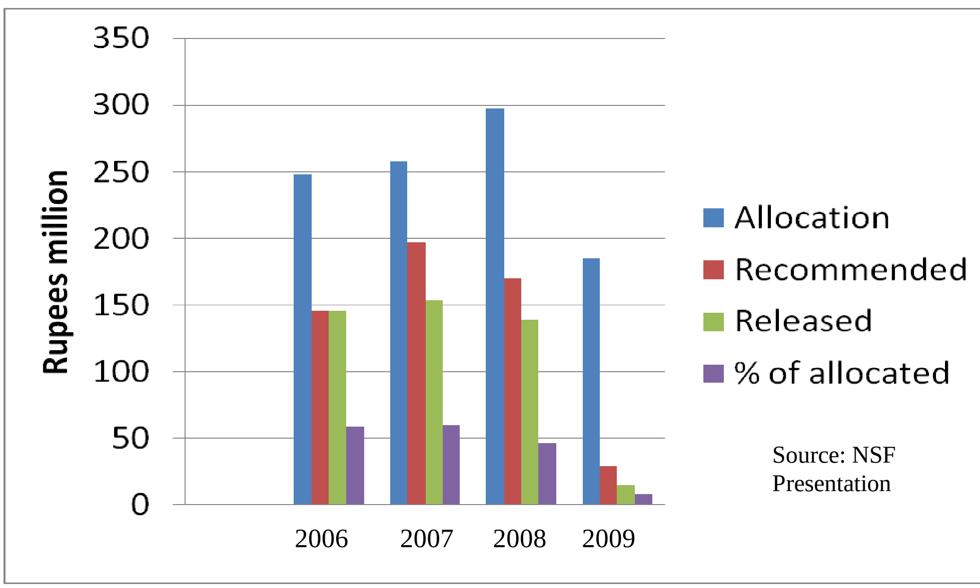
The intensity of research, technology, and innovation in private business sector enterprises has been low and so have the investments. The latest data available in the "Sri Lanka Science & Technology Statistical Handbook" (NSF, 2006) shows, however, that the contribution to GERD has risen from 0.6 percent in 2004 to 19 percent in 2006. This trend is satisfying, although the private sector investments need to be raised to a much higher level.

In contrast, foreign contributions to R&D in Sri Lanka have declined from a high of 22.6 percent of GERD in 2004 to 4.8 percent in 2006. This trend causes concern, since Sri Lanka needs the financial support of bilateral donors, foundations, and development agencies, at this critical time.

The government proposed to increase GERD to 1 percent the five-year period 2006–11. However, GERD fell in past year a result of the escalation of the war in the Northeast of the country and the associated increase in military expenditure, to 4 percent of GDP (Panel of the United Nations Commission on Science and Technology for Development, 2007).

In the past few years, the government has not been able to match the promised allocation with actual grants (see Figure 5). In particular, expenditure on the war and, more recently, on post-war settlements and rehabilitation have caused a sharp decline in 2009 budget allocations to R&D.

Figure 5: Sri Lanka's R&D Investments: Allocation Relative to Actual Released



(NASTEC) in 1998 and
ng body responsible for
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Lanka into a prosperous
able economy based on
highly developed S&T capabilities. The policy comprises the following 10 objectives:

i. Foster a STI culture that effectively reaches all citizens of the country.
ii. Enhance S&T capability for national development, make use of S&T expertise in the national planning process, and strengthen governance and policy implementation mechanisms.
iii. Build, and progressively expand and improve the resource base of scientists and technologists needed to respond to the developmental needs of the country.
iv. Promote basic, applied, and developmental research, particularly in areas of national importance and priority.

v. Develop, or acquire and adapt, scientific knowledge and technologies to achieve progressive modernization of all sectors and to enhance the country's competitiveness in the world economy.
vi. Ensure sustainable use of natural resources for development while protecting the environment.
vii. Document research into the scientific basis of, and promote indigenous knowledge-based technologies.
viii. Develop a culture of innovation and IP and ensure the protection of IPR.
ix. Ensure quality standards of S&T institutions, products, and services to achieve national and international recognition.
x. Promote the application of S&T to human welfare, disaster management, adaptation to climate change, law enforcement and defense, and human and national security.

These policies appear pragmatic and progressive. The key challenge, however, is their implementation, which will require, on the one hand, both the political will to fund the initiatives arising from the policies and, on the other hand, the institutional structure and capacity to implement the policies.

5. Implementation Agencies for S&T Policy

MOST is responsible for implementing of the S&T Act and the S&T policy. There are 8 institutions under MOST that implement the S&T policy. Though there are no institutions in Sri Lanka dedicated to the promotion of the commercialization of research. A few attempts have been made to set up business incubators, but none has spun off into independent enterprises.

The following broad conclusions about the four S&T institutions are based on interviews with NASTEC and the four institutions.

i. ITI (formerly Ceylon Institute of Scientific and Industrial Research) undertakes R&D and provides testing and analytical services in food technology, herbal technology, materials technology, environmental technology, and other disciplines.
ii. ITI's Centre of Technical Excellence in Ceramics (CENTEC) has shown significant involvement in high technologies. CENTEC was set up to enhance the competitiveness of the Sri Lankan ceramic industry, including development of self-cleaning Lanka tiles with nano-coatings. Its other activities appeared to be low-tech, such as the use of polyester waste in boiler feed, rice crackers, virgin coconut oil, health foods, coir, and bamboo-shoot processing.
iii. ITI derives its main revenues from testing and analytical services, and very little from technology transfer and licensing fees. The generation of new IP in the form of national patents was in single digits, and none was international.
iv. ITI has many staff vacancies—it is unable to draw the best human talent due to the competitive salaries elsewhere. ITI's requests for quality graduates, foreign training for human capital development, and attractive remuneration packages remain unfulfilled because of budget constraints.
v. Interactions with NERDC showed that it was involved in some useful development projects such as cost-effective buildings, municipal garbage treatment plants, and waste water treatment. It also demonstrated involvement in the high-tech field with its plans to use mechatronics for improving the quality of products from and performance in SMEs. NERDC appeared have a problems getting high-quality human talent. The fact that its core staff of 35

engineers is saddled with 350 support people with low technical qualifications raises concerns about its future viability. This problem is exacerbated by the fact that NERDC is not able to retain the best engineers, as they leave for more attractive remuneration packages in the private sector, or in universities.

vi. ITI and NERDC need to be reviewed in terms of inducing reforms, restructuring, and repositioning. For example, ITI's testing and analytical services, its main revenue earner, could be made a private sector entity, bringing professional and efficient service delivery to the customer.

6. Sri Lankan IP System & Structure

In the national innovation ecosystem, there is a critical role that IP protection plays. IP-savvy industrial researchers and academicians (such as those in the United States) form the backbone of the knowledge economy. Strong IP offices and robust legislation with strict enforcement create a powerful foundation for innovative research that leads to rapid commercialization and wealth creation. In Asia, the strong IPR efforts of Korea, Singapore, Taiwan, and others have paid rich dividends.

The initial discussions with industry leaders and heads of public R&D institutions revealed that the Sri Lankan IP system can be improved. IP awareness and IP filing appear to be at a low level. Table 5 substantiates this with quantitative data on IP generation in Sri Lanka.

It must be emphasized that IPR legislation in many developing countries has been claimed to be a disincentive to innovative research. Sri Lanka's IPR legislation (Code of Intellectual Property, 1979; Intellectual Property Act, 2003) has satisfied the requirements of TRIPS (trade related aspects of IPR) although complaints have been made regarding the effectiveness of enforcement.

Table 5: IP Generation in Sri Lanka

	Resident	**Non-resident**	**Total**
Applications in Sri Lanka (2008)	209	241	450
Registrations in Sri Lanka (2008)	89	70	159
Total utility patents granted in USPTO (all years)	-	-	30

Sources: National Intellectual Property Office of Sri Lanka, http://www.nipo.lk/; USPTO, http://www.uspto.gov/

Sri Lanka may want to use Singapore's IP Academy as a model to rapidly build Sri Lankan IP manpower capability through international partnerships (see section II). Special national funds will have to be created for researchers from public institutions to patent their innovations. Skills in filing, reading, and exploiting patents will be most crucial. Manpower planning for IPR protection needs priority. A number of patent training institutes will have to be set up. Judicious management of patent information will require well-structured functioning of information-creating centers, information documenters and retrievers, information users, IPR specialists, and IT experts. It is important to create awareness about IP among scientists and technologists, but equally important among even school and college students. IP literacy must pervade the entire society and government structures.

It is important to develop and implement institutional policies and guidelines regarding IPR. In the United States, the introduction of the Bayh-Dole Act in 1980, which set the rules of the exploitation of IP generated by U.S. academic institutions, went a long way in economic growth and job creation around university campuses, especially in high-tech areas. China (2008) and India (2009) have adopted similar legislation.

7. From Brain Drain to Brain Gain: The New Sri Lankan Opportunity

Like most developing countries, Sri Lanka has suffered from the loss of its most talented scientists, engineers, and technologists to advanced nations. This study estimated that 300,000–400,000 Sri Lankans currently reside outside Sri Lanka. However, with the end of the war, there is hope for peace, prosperity, and growth, and the time is right to create aggressive initiatives to induce the return of talented expatriate nationals.

Creation of exciting opportunities (centers of excellence such as SLINTec, attractive remuneration packages, opportunities for creating knowledge networks through visiting and adjunct faculty positions, sabbaticals, and even joint appointments with foreign universities) can begin to reverse the phenomenon of "brain drain" to "brain gain."

8. Establishing a National Innovation Ecosystem

The seamless integration of STI is extremely critical so that the nation can reap the benefits of innovation-led growth.

The national innovation ecosystem comprises several complex elements such as autonomy and flexibility of national higher education, research, and technology initiatives; a government that makes judicious investments in R&D and is a proactive and promotional player; IP laws and their enforcement; rigorous venture capital to fund the outcomes of applied R&D, especially pertaining to early-stage financing; physical and intellectual infrastructure that is conducive to incubating new ideas; prototyping, piloting and establishing technology incubators, STI parks; and so on.

This Bank Mission got an overall impression that the Sri Lankan innovation system lacked the presence of strong, dynamic, and sustainable structures pertaining to the elements enumerated above. This issue needs the government's urgent attention. It might be advisable to undertake a systematic study specifically on the creation of national innovation ecosystems in other countries and draw lessons from them, although the current study has addressed some of the issues.

9. Integrating S&T into National Planning and Development

To make rapid progress, it is important to include scientists and technologists in the national development policies and plans, in decision making on wide-ranging issues connected with economic, food, health, energy, water security, and on overall national security. Unfortunately, as the Mission learned, scientists play no role in these issues. This situation needs an urgent change.

10. The "Proposed Strategy" to Meet the Challenges of Human Capital Deficit

MoST has proposed to the government measures to address the above-mentioned challenges to the education and training, and hiring and retention of human capital, discussed above. MoST recommendations are the following:

- Move forward with creation of the proposed National Cadre of Researchers (NCR) that will offer a tiered structure, where promotion to and continuation in a tier will be based purely on the R&D performance. A very attractive remuneration package is being proposed to encourage the existing researchers.

- Attract new NCR researchers from within Sri Lanka and from abroad. Develop specific schemes to provide attractive incentives for career researchers.
- Train more graduates and scientists for research careers. Recruit senior researchers as supervisors and promote human resource development among R&D personnel.
- Create an enabling environment to achieve all these objectives. This will be done by developing world-class research infrastructure in centers of excellence for research. Most significantly, ensure sustainability of the operational framework through legislation that also provides adequate, guaranteed, and uninterrupted funding.

These are laudable objectives. However, their implementation has financial implications. With government resources truly stretched, it is not clear how the initiatives will come to fruition.

Notwithstanding, there should be strong endorsement of the initiatives, because they will provide a strong foundation for the Sri Lankan R&D infrastructure. For that reason, the government should look at the expenditure involved in implementing these initiatives as an investment in the future of Sri Lanka.

V. Sri Lanka Institute of Nanotechnology

1. General

The Sri Lankan government recently established SLINTec in a PPP framework. SLINTec is in the Biyagama Free Trade Zone, about 20 kms east of Colombo. It aims to produce nanotechnology-based competitive products that will benefit the Sri Lankan economy; it also is attempting to create original patents.

The World Bank mission was able to examine the SLINTec initiative in depth with a visit to the SLINTec site and dialogue with the key stakeholders.

2. SLINTec Structure and Programs

The SLINTec initiative is a unique PPP. Its first-year budget is Rs 450 million. The government, through the NSF (part of the MoST) has contributed Rs 250 million, and owns a 50 percent share. Five leading private sector companies—Brandix, Dialog, Hayleys, Loadstar, and MAS Holdings—have each contributed Rs 40 million each, and own 10 percent each. Separately, the government has committed to an investment of Rs 5.6 billion over five years. The companies have assigned two projects each to the institute to carry out research and development leading to innovative nanotechnology that is hoped will help them create value-added niche products, to give them a competitive advantage.

SLINTec will be the R&D arm or incubator, while NANCO, the proposed Nanotechnology Centre and the Nanoscience Park, will be the commercial or production facility. NANCO is planned to be established at a 50-acre parcel of land at the Homagama Industrial Park in about three years. SLINTec, now temporarily housed at the Silueta premises (part of MAS Holdings) in the Biyagama zone, is also expected to move to the park.

SLINTec has drawn on the international expertise of Sri Lankan expatriates who are leading figures in the nanotechnology field. They make up a core team and a panel of advisors to help achieve the goals of the initiative.

Two of its advisory team members—Professors Gehan Amaratunga and Ravi Silva—hold doctorate degrees from Cambridge University. Mr. Ravi Fernando, CEO of SLINTec, is a post-graduate in Sustainable Business, also from Cambridge University. Recruitment of another 10–15 scientists is underway; the plan is to eventually employ around 40 scientists. The staff structure is project based, meaning that the scientists will be recruited for specific projects. Most staff will come from universities and also work on a contractual basis. Apart from this team, SLINTec hopes to leverage the competencies of 70 Sri Lankan scientists working in the nanotechnology field around the world.

3. Evaluation of the SLINTec Initiative

i. The initiative was driven by the realization of the Minister of Science and Technology that, while Sri Lanka had missed out on earlier opportunities to develop its high-technology sector, it should not do so with nanotechnology. It was also based on the conviction that even developing countries have an equal opportunity to take advantage of the potential of emerging technology, such as nanotechnology, provided they made an early start and wise, proactive investments. This conclusion is very reasonable. For example, India entered space and nuclear technology in the 1940s and 1950s even as it struggled with challenges common to a poor, newly independent nation. That developing countries can be competitive is illustrated by China, which was a late entrant into the field of nanotechnology but now ranks second in the number of research papers published in international peer-reviewed journals, trailing only the United States. Thailand too has made major investments in nanotechnology in recent years.

ii. The SLINTec model recognizes that success in high technology requires the very best intellectual capital. Because that is currently not available in Sri Lanka, SLINTec is looking to draw from the international talent pool. The top leadership and personnel at SLINTec is highly competent and committed to make the initiative successful.

iii. In contrast to most new public institutions, which pay low salaries and are constrained by bureaucratic procedures, the PPP nature of SLINTec has enabled the creation of a competitive salary structure, with salaries up to four times those of purely public institutions.

iv. The developing world traditionally has had difficulty in moving from concept to commercialization. It is therefore promising that five leading private firms have 1) invested their own funds in the SLINTec start-up, 2) have clearly defined the projects on which SLINTec should focus, and 3) sit on the SLINTec board, thus driving its policy as well as program direction.

v. In-depth discussions with SLINTec's private sector partners focused on the potential marketable value-added nanotechnology products that they hope to develop and produce. They demonstrated a clear understanding of the scope, scale, and way forward needed. Brandix, a leading exporter of textiles and apparel, wishes to research special niche apparel with functional properties such as self-cleaning. MAS Holdings also hopes to produce next-generation clothing. Loadstar, one of the largest solid-rubber tire maker globally looks to create long-lasting solid rubber tires with enhanced properties such as abrasion resistance. Hayleys, a leader in activated carbon production for export, wishes to create nanoporous carbons for hydrogen and energy storage as well as superior supercapacitors. With this clearly business-driven research agenda, it is feasible to think that SLINTec will help all these companies gain and retain a competitive advantage.

4. Challenges to Moving Forward the SLINTec Initiative

A number of challenges remain for SLINTec to overcome. These include the following:

i. SLINTec has acquired approximately US$3 million of equipment for the basic needs of existing projects. To remain competitive, it will need to procure more sophisticated, and more expensive equipment such as a transmission electron microscope, optical tweezers, nano-indentors, scanning tunnel microscope, matrix-assisted laser desorption time of flight mass spectrometer, and SQID/VSM magnetometer (Quantum Design). This will require an additional investment of at least US$6–8 million.

ii. After SLINTec has demonstrated the feasibility of proof of concept, it must be made into a commercial reality. This calls for the establishment of NANCO, with an estimated investment of US$50 million. This amount will cover set-up costs, lab and other equipment, the first-year recurrent costs, human resource development, and acquisition of land. Currently, the government is expected to finance these costs. However, in light of the large sum needed, the government's budget constraints, and its inability to fully fund S&T in the past, it is doubtful that the US$50 million will be obligated. Alternative sources of funding must be sought, including new PPPs with nanotechnology parks in advanced nations.

iii. SLINTec's private sector partners appear to have in-house capacity on pilot planting and prototyping. However, further investments will be needed to ensure the establishment of a final production line. For example, Thailand's National Nanotechnology Center has set up a pilot plant for production of textile fibers at the cost of US$9.5 million. Such investment planning must become an integral part of SLINTec's concept–to-commercialization strategy.

iv. To build confidence, SLINTec will require some quick wins. To get these, it should focus initially on pursuing "low-hanging fruit" rather than on long-term research.

VI. Conclusions and Recommendations

1. General

The World Bank Mission was able to make conclusions and recommendations based on its preliminary desk research on Sri Lanka and international best practices in high-technology sectors and later interaction with stakeholders from government, academia, research institutes and private sector during the field work.

Sri Lanka has an urgent need and a clear opportunity to increase the high-technology development efforts and to improve, expand, and scale-up ongoing public R&D initiatives as well as introduce some new initiatives that will make its key export-oriented industries more competitive and build a knowledge economy. This would be best done through collaborating with the private sector and creating incentives for commercialization of R&D.

The following recommendations could serve as the basis for further dialogue with MoST, the private sector, academic and R&D institutions, S&T policy institutions, and think tanks, and the design of a road map for building the country's S&T capacity to develop and apply technology and create a knowledge economy.

2. Recommendations

Assessing Sri Lanka's current S&T capabilities and designing a road map to build S&T capacity

A team of world-class experts could visit Sri Lanka to study the current status of innovationist STI system. Ideally the team would include an eminent and well-respected Sri Lankan expatriate. The team should thoroughly review the proposed policies of the government, its ability to implement these policies, based on its political will and capacity of existing institutional structures and systems. The team would draw up a road map for S&T capacity building and development of selected technologies, as well as restructuring, reforming, and repositioning of the current public R&D institutions that would be needed to meet the capacity-building objectives.

Increasing the supply of researchers and scientists

In 2006, Sri Lanka had only 237 researchers and scientists in R&D per million residents compared with other developing countries (374 per million) and the world average (894 per million). Therefore, an urgent priority of the government should be to attract and retain high caliber researchers, scientists, and technologists. This Mission proposes three initiatives to start this process.

National Research Cadre: The NRC, the purpose of which is to attract high-caliber scientific and research talent, has been proposed. The government should move forward on the proposal with alacrity.

Special high-tech skill development fund. Sri Lanka lacks researchers trained in high-tech areas. It needs to undertake special training and skill development programs in areas such as nanotechnology and biotechnology by partnering with institutions throughout the world. India is a prime country from which to seek training, given its vast experience in high-tech areas, its cost effectiveness, and its proximity and close relations with Sri Lanka.

Expatriate National Knowledge Network Initiative (ENKNI): Sri Lanka would benefit from connecting and engaging with its diaspora in scientific and managerial disciplines. The expertise of high-caliber expatriates should be recruited to contribute to STI, in particular by enriching linkages between scientific and educational institutions, applied research institutions, and the private sector. Specific initiatives could include support to an expatriate network to enrich the STI policies, programs, and institutional design and evaluation by introducing international best practices in management of scientific institutions and programs, and providing teaching, consultancy, and mentoring resources for the Sri Lankan researchers and techno-preneurs. To do this, Sri Lanka should establish and fund an ENKNI.

Enhancing investments in R&D

Sri Lankan investments in R&D are among the lowest in Asia, around 0.15 percent of GDP over the past several years. Sri Lanka should aim to increase this to at least 1 percent of GDP to position itself with other peer-group countries.

There are three specific initiatives that Sri Lanka could take up immediately to increase its investments in applied R&D.

Small Business Innovation Research (SBIR) Fund: In the new economic and innovation environment, which is increasingly driven by industry and the private sector, the time is right to adopt new models and interventions using international best practices. These models and interventions should recognize that the funding instrument needs to match the nature of the project. In particular, the earlier the technology is positioned in the technology cycle, the greater is the intensity of innovation, and the bigger the risk; therefore public funds in the form of matching grants might support a greater percentage of the project costs. As the technology advances toward commercialization, the degree of risk-sharing (co-financing) might change, and eventually the funding instrument itself might move from a grant to equity or debt financing.

For early-stage funding, one approach is to adapt the successful U.S. SBIR program. Matching grants (not soft loans) could be offered to private enterprises in industrial and service sectors. A smaller short-term grant to explore the technical merit or feasibility of an idea could be followed by a larger award to evaluate commercialization potential. Project preparation would include examination of the feasibility of expanding the program to spur commercialization of public R&D and provide additional matching grant preferences for collaborative consortia between private firms and research institutes.

Technology Acquisition Fund: A TAF could provide partial funding to the private sector to acquire and enhance their high-technological capacity. The TAF could be established as a PPP (with minority public share) that would support acquisition of patents and early-stage technologies for filling gaps in Sri Lankan R&D and technology. This would accelerate commercialization, reduce costs, or create a better (and cheaper) product for the global markets. A TAF would provide Sri Lanka with a high-return vehicle to create niches and fill critical high-technology gaps in the technological advances for the strategically commercial areas. It could support the purchase of high-tech equipment and machinery; payment for licensing of high-tech projects: acquisition of unencumbered patent rights, prototypes, and proprietary design; placement of Sri Lankans in foreign technology-based companies and institutes, and so forth. Through technology acquisition projects, the fund could become an important component in the technology development value chain.

Leveraging S&T in socioeconomic ministries: Currently, S&T budgets are allocated to MoST, which, through a variety of institutions, supports the S&T needs of industry and society at large. It is important that each of the socioeconomic ministries (health, environment, transport, and others) earmarks 1–2 percent of its budget to fund solutions to its specific challenges. Such directed funding will help create workable technical solutions for the individual ministry and for overall S&T funding. MoST should monitor, mentor, and partner with such programs.

Upgrading Research, Technology, and Innovation Infrastructure

Specific elements in this component could include:

Upgrading IPR infrastructure: The government should invest in strengthening the IPR infrastructure. This would involve modernization of IP offices, setting up of IP training institutes, creation of manpower for IP management, development of capacity-building and certification programs, and support of technology transfer and licensing. Singapore's IP academy would be a good model for Sri Lanka to use to rapidly build its IP capacity.

Technology parks and incubators: With the formation of SLINTec, Sri Lanka has made a beginning, but this effort needs a further boost.

i. The PPP SLINTec has already got funding of about $3 million for acquiring basic equipment. However, to remain competitive, it must expand its scope, which will require an additional investment—US$6-8 million is anticipated—for additional sophisticated equipment.
ii. The NANCO park, to be established at the cost of Rs 5.6 billion, is critical to move forward with commercialization of nanotechnology projects undertaken by SLINTec.
iii. Sri Lanka should consider creating PPP technology parks in other disciplines (for example, biotechnology), incubators, and common research and service centers, with government support and private finance and management, based on international best practices.

Measurements, standards, testing, and quality (MSTQ): In high-technology trade, MSTQ is critically important. Therefore, Sri Lanka must upgrade and increase the demand responsiveness of its MSTQ systems, such as creation of world-class metrology facilities and strengthening of other MSTQ initiatives such as the Sri Lankan standards institutions and accreditation boards. At the firm level, assistance should be provided on adopting MSTQ services and upgrading skills through a suitably designed matching grant program.

Implementing the Key Lessons from Good Policy Practices

Four countries were chosen for comparative country case studies on good policy practices: Korea, Malaysia, Singapore, and Taiwan. The case studies provide the following key lessons that Sri Lanka could incorporate into its policy space:

i. Adopt four elements of reform that emerged from all country case studies, namely, reduce the financial and administrative burden imposed by the government; promote competition, improve efficiency, and increase productivity in the delivery of services; stimulate private entrepreneurship and investment; and reduce the presence and size of the public sector with its monopolistic tendencies.
ii. Move from a "regulator mindset" to a "facilitator mindset," with a less direct intervention than now exists.
iii. Begin with assimilating and absorbing existing technologies—that is, import technology—and later move to developing new and innovative technologies.
iv. Finance the acquisition of strategic and relevant technology by Sri Lankan companies to enhance their technology competitiveness.
v. Introduce major reforms through "Master Plans" for different sectors and ensure successful implementation of the plans through a strongly supported and empowered "Team Sri Lanka."

vi. Have a new style of operations based on simplicity and marketability, rather than an obtrusive development ideology.
vii. Support industry through appropriate incentive packages, government-industry risk sharing, and the establishment of smart partnerships. Create fiscal incentives for private sector firms in the form of tax credits, tax deductions, investment allowance, and so forth.
viii. Build strong links between the public sector institutions and private sector enterprises by several means, including attractive incentives and rewards systems.
ix. Fully deregulate and liberalize the information and communication technology (ICT) sector and create successful ICT networks to enhance productivity and efficiency several-fold.
x. Greatly expand investments in higher education, research, and technology. Human resource development should emphasize demand-driven, mobile human capital. Encourage innovation in education and education in innovation.
xi. Expand primary and secondary education, which is critical to ensuring the supply of a literate workforce for the high-tech industries. Give a major role in higher education to the private sector to free up public resources for primary education.
xii. Ensure the strategic coordination and alignment between science and technology (S&T) policies and other broader economic development policies.
xiii. Make public sector R&D institutions more market driven. Create incubators and S&T parks throughout the country so that moving from concept to commercialization is well structured, certain and swift.
xiv. Think and act as “Sri Lanka Inc.”

Appendix. Case Studies: Good Policy Practices

Malaysia

1. Overview

After more than 400 years of colonialism, Malaysia received its independence on August 31, 1947. What Malaysia has accomplished since then is impressive and many comparable countries can learn from it important lessons both about policy-led economic development and about how to construct a vibrant multi-ethnic and multi-cultural society.

In 1947, agriculture employed more than two-thirds of the labor force and this remained largely unchanged until independence. During the colonial period, agricultural processing was the main manufacturing activity of the economy. At independence, the native Malays, who accounted for 52 percent of the population, dominated politics, but were relatively poor, being involved mostly in low-productive agricultural activities. The ethnic Chinese, which were 37 percent of the population, enjoyed greater economic power and dominated modern-sector activities, but lacked the ethnic solidarity or political power of the Malays (Athukorala and Menon).

Economic policy making in post-independence Malaysia therefore became a continuing struggle to promote development while preserving communal harmony and political stability. Malaysia also faced a communist insurgency. The "hearts and minds" of those in the countryside had to be won, and that meant bringing economic benefits and minimizing "collateral" damage to civilians.

At independence, Malaysia was one of the poorest countries in the world. Its GDP (in purchasing power parity terms) was comparable to that of Honduras and some 5 percent below that of Ghana (Stiglitz, 2007). Today, Malaysia's GDP is more than 11 times that of Ghana, and more than 11.5 times that of Honduras.[12]

During the first decade of independence, the government continued the colonial open-door policy stance to trade and industry, while attempting to redress the ethnic and regional economic imbalances through rural development schemes and the provision of social and physical infrastructure.

Like many other developing countries at this time, Malaysia sought industrialization through import-substitution policies. However, unlike other countries, Malaysia abstained from forced industrialization through high tariffs and quantitative import restrictions and the establishment of state-owned industrial enterprises. In the 1960s and 1970s, newer industries such as beverages, textiles, chemicals and chemical products, and transport equipment began to emerge, almost entirely in the private sector.

Foreign investment was welcomed during this period. By the late 1960s, it was clear that future industrial development depended upon the expansion of export-oriented industries. Incentives offered to export-oriented ventures under the Industrial Incentives Act 1968 included exemptions from company tax and duty on imported inputs, relief from payroll tax, investment tax credits, and accelerated depreciation allowances on investments.

Since then, Malaysia has continued to enjoy relative prosperity, initially as a commodity exporter (rubber and tin, then palm oil and petroleum), with total income rising at 6–7 percent each year from 1970 until 2000. As a result, the number of poor persons (that is, those consuming less than the

[12] CIA World Factbook: Malaysia, Ghana and Honduras Country Profiles. https://www.cia.gov/library/publications/the-world-factbook/

purchasing power parity US$1 per day metric) has fallen to fewer than a million, or 3.9 percent of the population of 26.2 million people (compared with about half of the population in 1970) (Yosuf and Bhattasali, 2008).

With a GDP per capita estimated at US$15,300 in 2008, Malaysia is a rising economy in the world. The share of agriculture has fallen from more than 30 percent of GDP to less than 10 percent, and that of industry (manufacturing) has risen from 27 to about 50 percent.

The initial growth response to the purposeful and increased industrialization of the economy from the mid-1970s was favorable, with volatility declining and the overall rate of growth rising toward 10 percent per year in the late 1980s. FDI and manufactured exports (especially high-technology products) played an important role, with the latter rising from 5 percent of total exports to above 75 percent today (Yosuf and Bhattasali, 2008).

Economically, Malaysia learned from its neighbors. Many of the ex-colonies, rejecting their colonial heritage, turned to Russia and communism. Malaysia took different course, looking instead to the highly successful countries of East Asia. It invested in education and technology, pushed a high savings rate, enacted a strong and effective affirmative action program, and adopted sound macroeconomic policies.

2. Role of Leadership and Public Policies

Diversifying production and incomes away from tin and rubber was the fundamental strategic policy thrust in the light of high volatility in their prices and an anticipated decline in long-term commodity prices, especially rubber. The period between 1971 and 1990 consisted of defining events and strategies that fundamentally restructured the economy, and may be called the distributional epoch in modern Malaysian economic history.

The race riots of May 1969 were a turning point and led to the introduction of the New Economic Policy (NEP) in 1971, the publication of the Second Malaysia Plan (1971–75), and the Outline Perspective Plan (1971–90). The 1970s ushered in a new phase of economic growth, marked by the rapid rise of construction and manufacturing and a strong strategic emphasis on equitable or fair distribution, specifically through affirmative-action policies.

Export-oriented manufacturing industries gained momentum in the early 1970s. FDI in export-oriented firms was promoted actively with the introduction of the Investment Incentives Act of 1968, Free Trade Zone Act of 1971, and the Promotion of Incentives Act of 1986. Prior to these investment promotion instruments, industrial growth was driven by an import substitution strategy with the introduction of the Pioneer Industry Ordinance, 1958. The establishment of the Malaysian Industrial Development Authority (MIDA) in the mid-1960s was a landmark in the drive toward industrialization.

The 1991–2000 growth phase traversed the difficult years of the Asian financial crisis and the period of exchange controls. By 1990, the economy was more industrialized, despite being buffeted by massive shocks such as the oil crises of 1973–74 and 1978–79 and the global slowdown in demand for electronics and primary commodities in 1985–86.

Government policies on industrial promotion in Malaysia can be grouped into four phases: a first round of import substitution, a first round of export orientation, a second round of import substitution, and a second round of export orientation. Table A.1 highlights the years in which these phases took place and the policy instruments that were implemented to achieve these phases.

Table A.1: Policy Instruments Used by Malaysian Government for Industrial Development

Phase	Trade Orientation	Period of Dominance	Policy Instruments
1	Import substitution	1958–72	Pioneer Industries Ordinance, 1958
2	Export orientation	1972–80	Investment Incentives Act, 1968; Free Trade Zone Act, 1971
3	Import substitution	1981–85	Heavy Industries Corporation of Malaysia (HICOM), 1980
4	Export orientation	1986–2005	Industrial Master Plan, 1985; Promotion of Investment Act, 1986; Action Plan for Industrial Technology Development (APITD), 1990; Industrial Master Plan, 1996

The change in leadership from the administration of Tun Hussein Onn to that of Mahathir Mohamad marked an important political and economic milestone. Prime Minister Mahathir's 22-year rule witnessed the introduction of several new policies, and privatization was a primary example.

Prime Minister Mahatir Mohamad first articulated Malaysia's privatization policy in 1983, together with the "Malaysia Incorporated" approach to development. In essence, Malaysia Inc., inspired by Japan Inc., viewed the country as a single corporation, with the government providing and enabling a stable business environment for business and private enterprise. The main idea was that with the growth of private enterprise, the tax revenues of the government would rise, enabling further financing of development projects.

It is interesting to see the way in which Prime Minister Mahathir implemented privatization in Malaysia. To begin with in 1985, The Economic Planning Unit (EPU) in the Prime Minister's office issued the Guidelines on Privatization, outlining the rationale and approach to privatization. The guidelines detailed the five objectives of privatization: 1) reduce the financial and administrative burden of the government; 2) promote competition, improve efficiency, and increase productivity in the delivery of services; 3) stimulate private entrepreneurship and investment; 4) reduce the presence and size of the public sector with its monopolistic tendencies and bureaucratic support; and 5) assist in achieving the NEP objectives, especially *Bumiputera* entrepreneurship.

In 1991, the government published the Privatization Master Plan with the aim of expanding and accelerating the pace of privatization. Planning and the preparation of sectoral master plans have always formed an integral part of the Malaysian approach to development. The master plan, incorporating a Privatization Action Plan, was prepared around 1987 by a team of consultants. In the

Foreword to the Privatization Master Plan, [13] Prime Minister Mahathir noted that much experience had been gained and that it had been "augmented by studying the methods of privatization in other countries which have adopted this approach." An important point made in the Foreword was the change in the approach to privatization and that:

> Where, before, it was up to the interested parties to propose the privatization of Government services and corporations, now the Master Plan has identified the services and the bodies that are open to privatization proposals by the private sector. This will enable interested parties to study and make offers that will be considered on comparative merit. Only in certain cases will exclusivity be granted. Even then conditions will be attached which will prevent such exclusivity from being misused.

The master plan also reported that the necessary actions had been taken to remove bottlenecks. Laws had been amended to allow the passage of privatization and measures had been taken to prevent abuses by privatized monopolies. Apart from expanding on the policy of privatization, the master plan focused on specific issues related to methods, valuation, personnel, legislation changes, regulatory framework, capital markets, Bumiputera, foreign participation, and a privatization fund. It also reported on the progress made in the privatized projects up to 1990. A key part of the master plan was the listing of privatizable government-owned enterprises (GOEs) and the Action Plan for 1991–1992.

According to the Action Plan, 424 GOEs under federal, state, and local government were assessed, and 246 were considered to be privatizable. Out of the 246 GOEs, it was determined that 69 could be privatized within two years, 107 within two to five years, and the remaining beyond five years. The 246 identified projects were classified as "government-initiated privatization projects" and were to be subjected to competitive bidding. The private sector was allowed to submit privatization proposals, and on occasion a "first-come-first served" basis and exclusivity could be entertained.

During this early phase, privatization progressed fairly well in terms of numbers. By 1990, according to the master plan, some 37 projects were privatized. The list excludes the 30 government companies that were divested to Permodalan Nasional Berhad and 120 companies that were sold to the private sector before 1983. The sale of government interests in companies generated revenues of RM100 million.

Prime Minister Mahathir took special interest in privatization, heavy industries, and the MSC, and was closely involved with the implementation of these policies and programs. The personal

[13] http://www.epu.jpm.my/Bi/publi/Private/Forewd.htm

involvement of the Prime Minister ensured that the policies were implemented. Strong leadership by of MITI lead by Rafidah Aziz, was also instrumental in implementing trade and industrial policies. MIDA, which reports to the MITI, has played a key role in the implementation of the various industrial policies and in the implementation of the past two industrial master plans and the current third industrial master plan.

The involvement of private sector entities in policy implementation is vital, because they provide important feedback on the unexpected problems that are encountered when the policies are implemented and need to be refined. Private sector feedback is useful, especially when incentive measures are to be implemented. The MITI and MIDA usually take the lead when the private sector is involved in implementation issues.

It would also be important to analyze the role of leadership in promoting a specific industry. For example, the electronics and electrical products industry is the single most important manufacturing sector, making a considerable contribution to the industrialization of the economy. It maintains a preeminent position despite being pressured by recent events—for example, the semiconductor recession in 2001 and the emergence of China as a destination for electronics-related FDI.

3. Moving Toward High-technology Industries

Electrical and electronics products, which together account for about 30 percent of value added, form the largest subsector of manufacturing (also in terms of export earnings, investments, output, and employment), and have long been considered to be the spearhead of Malaysia's industrialization drive. As shown in *Economic Growth and Development in Malaysia: Policy Making and Leadership* (Yosuf and Bhattasali, 2008), electronic components (for example, semiconductors and printed circuit boards) and industrial products (for example, telecoms equipment, office equipment, and multimedia products) have a much larger share of investment and gross exports than consumer electronics (for example, audio and video products). However, electrical products, although a smaller share of the investment and trade picture, have recorded the fastest growth in gross exports.

The promotion of the electronics industry began in 1970, with the initial companies employing fewer than 600 workers. By 2008 total employment had increased to about 297,000. The Malaysian leadership courted foreign investors, and the latter were responsible for the initial growth of the electronics industry (dominated by American and Japanese MNCs) (Yosuf and Bhattasali, 2008).

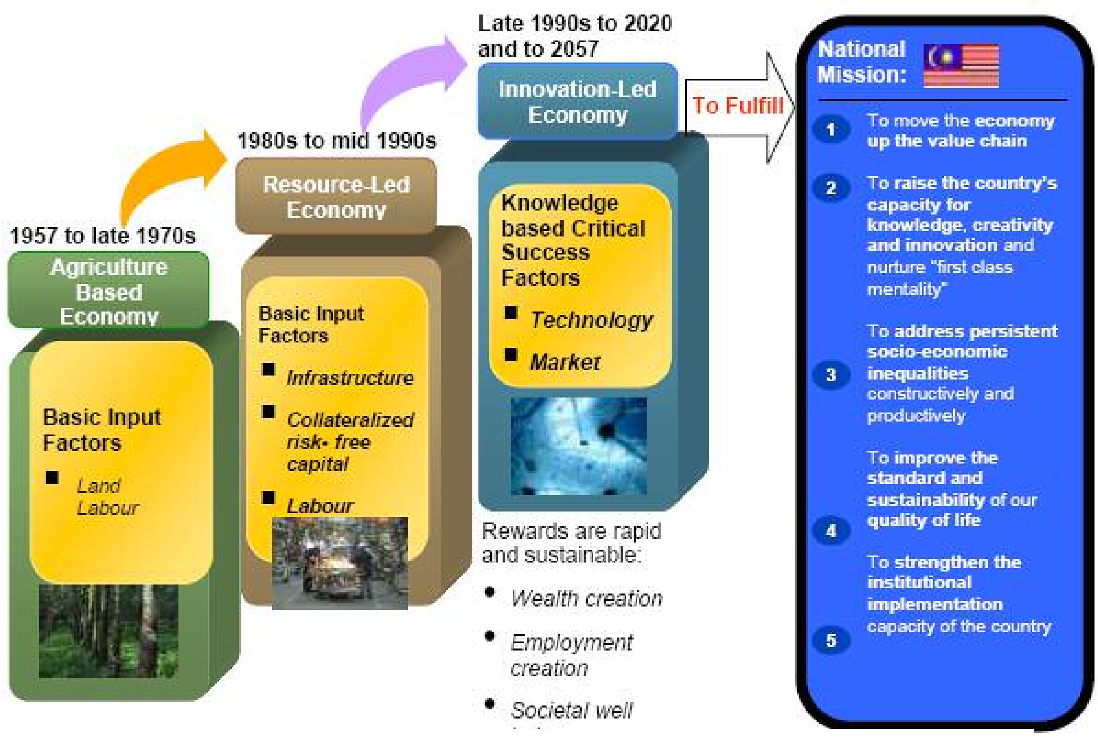
Ample labor, a market-oriented economy, a young, educated labor force, and good infrastructure provided strong attractions. Over the 1990s, the outsourcing of manufacturing activities and the development of Malaysia as a regional products and distribution center for high-end electronics products has contributed to the structural transformation of the electronics industry.

Structural change in the electronics industry has, since 1999, led to industrial electronics overtaking electronics components. Some 901 new companies entered the industry between 1996 and 2005. The increasing importance of industrial electronics has been due to the expanding manufacture of high value-added products such as computers, computer peripherals, and telecommunications equipment (Ministry of Trade and Industry, 2006). New high-end products include fabricated wafers, mobile phones, telecommunications equipment, computer notebooks, and servers. New services, including the design of integrated circuits, prototyping, testing, and failure analysis have also grown and expanded.

4. Human Resource and Institutional Capacity-building Strategies

Recognizing that the quality of human resources will be the single most important factor determining the pace and success of the transition toward the knowledge-based economy, in 2001, Prime Minister Mahathir laid out the Knowledge-based Economy Master Plan of Malaysia (see Figure A.1).[14]

Figure A.1: Malaysia's Systematic Plan for Becoming a Knowledge-based Economy



Source: The National Innovation Model, www.mosti.gov.my/mosti/images/pdf/innovation%20model%20jtpin.pdf

The master plan [illegible] onomy vision of the country and boost the transition of Malaysia into a knowledge-based economy.

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[14] http://www.epu.jpm.my/new%20folder/publication/knoweco.htm

Following were the seven strategic thrust areas of the master plan:
Strategic Thrust One: Cultivate and secure the necessary human resources.
Strategic Thrust Two: Establish the institutions necessary to champion, mobilize, and drive the transition to a knowledge-based economy.
Strategic Thrust Three: Ensure the incentives, infrastructure, and infostructure necessary to prosper the optimal and ever-increasing application of knowledge in all sectors of the economy and the flourishing of knowledge-enabling, knowledge-empowering, and knowledge-intensive industries.
Strategic Thrust Four: Dramatically increase capacity for the acquisition and application of S&T (including ICT) in all areas.
Strategic Thrust Five: Ensure that the private sector is the vanguard of the knowledge-based economy's development.
Strategic Thrust Six: Develop the public sector into a knowledge-based Civil Service.
Strategic Thrust Seven: Bridge the knowledge and digital divides.
The master plan provided a strategic framework outlining the changes to the fundamentals of the economy. It articulated a vision and mission besides prescribing the seven critical areas, with a total of 136 recommendations that need to be addressed in moving forward to the knowledge-based economy. The recommendations were laid out in three phases:
Phase I – (2001-2003)
Phase II – (2004-2006)
Phase III – (2007-2010)
Each phase had numerous recommendations that also identified the agency responsible for its implementation.
Interestingly, in building S&T capability and capacity, Malaysia had cited Finland as an exemplary knowledge-based economy in its master plan and had noted that "Finland's small population of five million people produces an economic value pie 4.3 times the size of Malaysia. The Finns, while keeping their vast forest reserves as a natural resource, aggressively enhanced their technological capabilities." **[[Pls reference/cite quote in ref list.]]**
In drawing up the Knowledge-based Economy Master Plan, consideration was given to the *Report on the Science and Technology Policy II*. The report had made recommendations on a number of strategies and the actions that need to be considered, and include the following: intensification of knowledge generation and acquisition; development and promotion of S&T capability for embracing the knowledge-based economy; building capacity and capabilities for tomorrow; building competitiveness in the industry; S&T for society; promoting a stronger S&T and innovative culture; international collaboration and cooperation; promotion of international S&T linkages, infostructure for S&T; strengthening of S&T information gathering; financing for R&D and innovation, and strengthening of S&T institutions and mechanisms for governance.

i. One of the key challenges is the mechanism to ensure the strategic coordination and alignment between S&T policies and broader economic development policies. The proposed target is a National Innovation System—a system of interconnected institutions to create, store, and transfer the knowledge, skills, and artifacts that define new technologies.
ii. Strategic knowledge-based industries should be supported by appropriate packages of incentives, government-industry risk sharing, and the establishment of smart partnerships.
iii. To exploit the potential of the knowledge-based economy, enabling and platform technologies should be developed, knowledge-contents should be intensified in all sectors, and knowledge-based industries should be developed.

iv. R&D investment should be intensified, with the private sector taking the lead in a smart partnership mode. The public sector R&D institutions should be more market-driven.
v. The enhancement of technology development, acquisition and commercialization can be brought about through science-based R&D done at universities, research institutions and incubation centers, through the generation of local technology and reverse engineering of known technologies, or through technology importation.
vi. Human resource development should emphasize demand-driven human capital that is mobile.
vii. The establishment of a national fund for R&D is essential.

Through the Knowledge-based Economy Master Plan and Science and Technology Policy II, Malaysia laid out a plan to build a strong S&T capacity. These policies put in place necessary institutional structures and governance mechanisms for promoting S&T in the country.

5. R&D in Universities

Today, the bulk of the public sector R&D funding is managed by the Ministry of Science, Technology and Innovation (MOSTI), which funds research for the public sector, namely the Institutes of Higher Learning and Government Research Institutes.

Malaysia has 17 public and 20 private universities. The universities are the training ground for the S&T human resource base for the country. The older, more established universities are University of Malaya, University Kebangsaan Malaysia, University Putra Malaysia, and University Sains Malaysia.

Private universities are growing in importance, as these institutions are being established to cater to the growing needs of the industrial and institutional sector. Among the more recently founded universities are the Multimedia University, which focuses on multimedia and ICT-based courses, the University Tenaga National, which focuses on engineering, IT, business management, and related courses, University Teknologi Petronas, which focuses on engineering and S&T, and, most recently, the Malaysian University of Science and Technology, which focuses on S&T courses. Various private colleges in Malaysia offer degree programs on a twinning basis with overseas institutions of higher learning, while foreign universities have set up branch campuses in the country.

As a result, Malaysia's number of researchers rose, from 15,022 in 2000 to 27,500 in 2005, and the number of researchers per 10,000 labor force had increased from 15.6 in 2000 to 25.0 in 2005.[15]

The S&T policy continued to lay the foundation for the attainment of a scientific and technologically advanced society and support for the transition to a knowledge-based economy.

6. Infrastructure for Development of High-tech Industries

Semiconductor cluster

There are three electronics clusters, with Penang in the north occupying a preeminent position. The government established export processing zones (EPZs) in all three clusters to attract FDI. Incentives were granted to the foreign-owned companies that were operating in the EPZs, such as pioneer status, labor utilization relief, investment tax credits, accelerated depreciation allowances, and export refinancing facilities. The semiconductor cluster around Penang and adjacent areas, especially the

[15] The Science and Technology System of Malaysia, portal.unesco.org.

Kulim High Technology Park, has been hosting major companies and manufacturers of components and parts, engineering support industries, and dedicated services, including logistics.

Training centers and higher learning institutions supporting R&D activities grew around the electronics cluster in the north. The Klang Valley and Johore, in the south, became the other two important clusters. To some extent, the MNCs located in the EPZs transfer technology to the host economy. They helped enhance skills and employees of MNCs, which have been able to set up new firms that are linked to the electronics industry. In Penang, technology transfers increased specialization and helped to create a network of second- and third-tier components suppliers. Some of the supplier firms have developed their own process engineering and original equipment manufacturing capabilities by supplying to the MNCs.

Multimedia Super Corridor: Developing ICT capabilities

The MSC is another powerful instrument that Malaysia has been using to achieve rapid transition to a knowledge economy.

As in earlier periods, concerns about the narrow industrial base of the country combined with concerns about a possible economic slowdown encouraged policymakers to consider new sources of growth. A policy shift in growth became apparent in the early 1990s with emphasis given to ICT. The clearest manifestation of this policy shift was the launching of the MSC in 1996, promoting pictorial, moving images, sound, and text technology development and marketing. Increased attention was given to developing a knowledge-based economy and, subsequently, to services, including ICT services, as a new source of economic growth.

A key objective of the MSC is to lay the foundation for Malaysia to become a global and regional leader in ICT development and applications. Envisaged as a "multimedia utopia," the MSC is located in a corridor of 75 square kilometers leading to Kuala Lumpur International Airport in Sepang, and containing the two new cities of Putrajaya (the administrative center of the federal government) and Cyberjaya (which houses ICT companies, with intelligent buildings and urban systems). The MSC's focus is on the conceptualization, design, testing, production, and distribution of advanced ICT applications.

To attract international companies into the enclave, the MSC contains hard infrastructure (such as fiber-optic telecommunications networks and modern transportation networks) and soft infrastructure, packaged with incentives and a conducive legal and regulatory environment. Again, as an example of the "cluster of reforms" approach, four cyberlaws were enacted in 1997: the Digital Signature Act, the Copyright Act (Amendment), the Computer Crimes Act, and the Telemedicine

Act. They are an integral part of the new policy, which facilitated their passage through the legislature.

The fiscal and nonfiscal incentives package for MSC companies is worth an examination, as it illustrates both the old-style industrial policy instruments used throughout Malaysia's push toward higher industrialization as well as a new style of operation based on simplicity and marketability, rather than an obtrusive development ideology. Given Malaysia's generally low taxes, it is not clear what correctives are being applied through granting extraordinarily favorable fiscal incentives; they may simply reflect a race to the bottom in a tough neighborhood.

In terms of fiscal incentives, the MSC-status companies are granted a 5-year exemption from income tax, renewable to 10 years, or a 100 percent Investment Tax Allowance (ITA) on new investments made in MSC cybercities. Imports of multimedia equipment are duty free. R&D grants are granted to local SMEs. MSC-status companies exporting multimedia products manufactured in Malaysia using dutiable components are eligible for a refund on the duty paid on the re-exported components.

The nonfinancial incentives granted to MSC-status companies allow them to employ foreign knowledge workers without restriction, to be wholly foreign owned, and to source capital globally and receive exemptions from exchange control requirements from the Controller of Foreign Exchange. In return, to enjoy MSC status, companies have to meet criteria: they must be providers or heavy users of multimedia products and services, employ a substantial number of knowledge workers, and specify how they will transfer technology and knowledge to Malaysia, or otherwise contribute to the development of the MSC and the Malaysian economy.

Products and services can be from anywhere in the multimedia value chain—that is, content, distribution, or user environment. In addition, several institutions support the MSC. A Multimedia Development Corporation (MDC) was established in 1996. The MDC implements and monitors the MSC program, processes the applications for MSC status, and advises the government on MSC laws and policies. A MSC International Advisory Panel, made up of experts and corporate leaders from the global community and Malaysia, was instituted to provide advice on the MSC.

Progress in attracting investment in the MSC and in developing the flagship applications is noticeable. By the end of 2000, 429 companies had been granted MSC status, of which 274 were Malaysian owned. Most companies were involved in software development for engineering and specialized applications (70). Others were involved in e-commerce services/solutions (44), software development for business applications (56), and Internet-based business application services (37). Europe (50 companies), the United States (27 companies), and Singapore were the top three countries invested in the MSC.

A fiber-optic backbone network, covering 360 kilometers, was completed over the 1996–2000 period. More than 27,000 new jobs were created in the MSC by 2005, and about RM 5.11 billion was invested. According to the EPU in 2005, the number of MSC-status companies increased to 1,421 firms. Investment by the end of 2004 had reached RM 5.11 billion. There were 349 foreign-owned companies. The MSC entered its second phase over the 2001–05 period, and cybercity status was granted to Bayan Lepas in Penang and the Kulim Hi-Tech Park in Kedah in the north (Yosuf and Bhattasali, 2008).

However, in the Knowledge-based Economy Master Plan, which was unveiled in 2001, it was acknowledged that the MSC initiative does not cover all the attributes that will be necessary for developing the economy toward a knowledge-based economy. However, the MSC provided a strong foundation for continuing Malaysia's transition toward a knowledge-based economy.

SIRIM

SIRIM, the national organization of standardization and quality is an institute for industrial research and development. SIRIM's role is 1) to promote and undertake scientific industrial research, 2) to boost industrial efficiency and development, 3) to provide technology transfer and consultancy services, and 4) to develop Malaysian standards and to promote standardization and quality assurance for greater competitiveness. SIRIM's clients comprising mostly SMEs are given technical assistance to upgrade their businesses and to stay competitive.

The National Biotechnology Directorate

The National Biotechnology Directorate was set up to spearhead the development of biotechnology in Malaysia through research and related activities directed at the commercialization of biotechnology and establish Malaysia as the leading center for biotechnology center for biotechnology industry with a view to commercialize R&D outputs and to create spin-off commercial activities. In collaboration with universities and research agencies locally and internationally, the National Biotechnology Directorate also identifies focal points for specific areas of biotechnology for collaboration among institutes of higher learning to enhance national capabilities through training of scientists, technologists, and related personnel.

Incubation and technology parks

The Malaysian Technology Development Corporation (MTDC) is a venture capital-based company established by the government and the private sector. MTDC's objectives were established by taking into consideration the need to improve the level of technologies of Malaysian companies. Thus, MTDC's objective is to spearhead technology development in Malaysia through:

- Commercialization of research results;
- Development of technology-based companies; and
- Providing venture capital.

MTDC also collaborates with local institutions to set up incubation parks near the institutions to assist their start up ventures such as Serdang–UPM–MTDC Technology Incubation Centre, UTM–MTDC Technology Incubation Centre and UUM–MTDC–Advanced Electronic Centre.

The MDC was set up to promote the development of the ICT sector, focusing on ensuring the success of the MSC and the companies operating in it. This one-stop center was set up to ensure that the necessary infrastructure (hard and soft) is in place to create a vibrant ICT industry with the necessary linkages. The MDC also advises the Malaysian government on legislation and policies, development of MSC-specific practices, and setting breakthrough standards for multimedia operations. MDC promotes the MSC locally and globally, as well as support companies, which are locating within the MSC.

The Technology Park, Malaysia was set up to provide infrastructure and services for technological innovation and R&D to enable knowledge-based enterprises to grow and compete in the global

marketplace and to facilitate government and private sector smart partnerships in technology development.
The Technology Park, located within the MSC, provides entrepreneurs with services on a one-stop basis, and enables tenants to reduce their overhead costs by sharing facilities. Such parks are able to significantly improve the survival and growth prospects of new start-ups. As part of the national agenda to promote biotechnology, BioNexus Malaysia, essentially a nationwide network of centers of excellence comprising companies and institutions that specialize in specific biotech subsectors, has been established.

7. Investments: R&D, Centers of Excellence, International Linkages and Learning Opportunities

By 2005, the national gross expenditure on R&D had gone from RM 1,671 million to RM 4,300 million marking a 0.4 percent growth in gross R&D expenditure as a percentage of GDP of the country.[16] In Malaysia, MOSTI is charged with the responsibility of managing the funding and the implementation of S&T and R&D programs. Some of the important funding institutions and schemes are as follows (also see Table A.2 for detailed funding provided through various funding mechanisms).

Table A.2: Malaysia's investments in science, technology and innovation

Sr.	Funds / Grants	Allocation 9th Malaysian Plan (RM million)	Cumulative expenses (RM million as of March 2008)	Balance allocation in 9th Malaysian Plan (RM million as of March 2008)	Allocation 2008 (RM million)
1	Science Fund	966.5	362.72	603.78	210.0
2	Techno Fund	1075.8	334.48	741.32	270.0
3	Inno Fund	200.0	11.98	188.02	30.0
4	Demonstrator Application Grants Scheme (DAGS) roll-out	100.0	5.23	94.77	18.3
5	E-Content Fund	150.0	21.54	128.46	15.0
6	Technology Acquisition Fund (TAF)	142.5	11.38	131.12	25.0
7	Commercialization of R&D Fund (CRDF)	115.0	25.54	89.46	20.0
8	MSC Grant Scheme (MGS)	120.0	4.74	115.26	18.0
9	Human Capital Development Fund (HCDF)	500.0	141.51	358.49	74.0
Source: MOSTI Facts & Figures 2008, www.mosti.gov.my					

Intensification of Research in Priority Areas (IRPA)

This fund was introduced in 1988 with the purpose of focusing R&D activities on areas that have the potential for enhancing the national socioeconomic position. This is largest of the grants managed by

[16] Ministry of Science, Technology & Innovation; www.mosti.gov.my

MOSTI. It is mainly utilized by the public sector universities and research institutes; however, of late, a small proportion has also been given to the private sector. IRPA is considered a key program to catalyze the generation of new products, processes, services, and solutions. A large portion of IRPA funding is allocated to activities that will lead to commercialization. In allocating grants for R&D projects, the granting agency adheres to several principles such as to:

- Fund projects that are of high national priority and can be commercialized,
- Fund projects that address the needs of Malaysian industry,
- Encourage collaborative efforts among research institutions, and
- Enhance R&D linkages between the public and private sectors.

Industry R&D Grant Scheme (IGS)

This scheme has been administered by the MOSTI since 1996 to mobilize Malaysian companies toward enhancing their technological capabilities and innovation. This scheme is restricted to mainly Malaysian companies. The other objective of this scheme is to foster PPPs including universities. Between 1998 and 2003, 102 projects were approved worth RM 243 million. Most of the projects funded under the this grant scheme relate to high-technology and advance science sectors.

MGS R&D Grant Scheme

This scheme was launched in 1997 mainly to promote the development of R&D clusters. During the period 2002–03, 29 projects worth RM 66.71 million were approved. In all, more than 52 projects worth RM 114 million have been sanctioned. In 2003, some changes were made to make more companies eligible for seeking funding.[17] In the 9th Malaysian plan, the scheme received an allocation of RM 500 million.

Technology Acquisition Fund

The TAF was introduced in 1997 and is operated by the MTDC. The TAF was established by the government to facilitate the acquisition of strategic and relevant technology by Malaysian companies to enhance their technology level and production processes. The TAF provides partial funding to private sectors to acquire and enhance their technological capacity. Under TAF, these included the purchase of high-tech equipment and machinery, technology licensing, acquisition of patent rights, prototypes, and design placement of Malaysians in foreign technology-based companies and institutes. The TAF program is an important component in the technology development value chain as it provides the means for companies to undertake technology acquisition projects. In general, the TAF program has benefited many SMEs that have recognized the need to keep abreast of new technologies in order to compete globally. In the 9th Malaysian plan, the TAF received an allocation of RM 142.5 million.

Demonstrator Application Grant Scheme (DAGS)

The DAGS is managed by the Malaysian Institute of Microelectronics, an ICT-related R&D organization that functions as an advisor to the Malaysian government on technologies, policies, and strategies relating to ICT development. The DAGS funds focused and short-term projects (not exceeding 12 months) for the benefit of the community and focuses on content and people

[17] Multimedia Super Corridor R&D Grant Scheme - www.mscmalaysia.my

development. This scheme requires a partnership of private sector with a public research organization or institution. Priority is given to IT and multimedia technology-based proposals that have local content. In the 9th Malaysian plan, DAGS received an allocation of RM 100 million.

Commercialization of R&D Fund (CRDF)

The CRDF also came into operation in 1997, like other schemes managed by the MTDC to commercialize results of R&D. It provides three types of grants: market survey and research; product and process design including designs, prototypes, and pilot plants; and standardization measures including IPR.
Employers in the manufacturing and service sectors that contribute to this fund are eligible to apply for grants to defray or subsidize the costs incurred in training and retraining their workforce. The National Vocational Training Council under the Ministry of Human Resources coordinates the planning and development of a comprehensive system of vocational and industrial training programs for all public training agencies. It also develops the National Occupational Skills Standards on a continuous basis. In the 9th Malaysian plan, the CRDF received a funding allocation of RM 115 million.

Human Resource Development Fund (HRDF)

In 1993, the HRDF was launched by the government to encourage training, retraining, and upgrading skills in the private sector. The HRDF Programme in S&T is another effort by the government to strengthen the human capacity and capability for the enhancement of S&T in Malaysia. Among the objectives of this program is to increase the critical mass of scientists and researchers of the country. It also aims at further strengthening the R&D functions in institutions of higher learning and public research institutions and to enhance the country's competitiveness through the development of trained, innovative, and creative human resources. The HRDF provides scholarships for in-service training, as well as students wishing to earn postgraduate degrees.

Tax incentives

The involvement of private companies in R&D activities is crucial to the nation's industrialization drive. To further encourage the involvement of the private sector in carrying out R&D, the government of Malaysia has made available various types of incentives for R&D activities. Most of the R&D deductions and allowances are provided for under the Income Tax Act, 1967.

The category of incentives by way of Pioneer Status and Investment Tax Allowance are provided under the Promotion of Investments Act 1986. These incentives allow for technology acquisition and double deduction for R&D.

Programs such as TAF provide partial funding to private sectors to acquire and enhance their technological capacity. The TAF program has enabled recipient companies to undertake various acquisition activities to shorten technology development time and providing them with a competitive edge.

Loans and venture capital

Over the years, the Malaysian government, through various ministries and agencies has helped the small and medium industries succeed from start-up through the many stages of growth. Financial assistance is offered to help start or expand these businesses and achieve success through business loans to entrepreneurs and business owners of specialized industries. These loans are made available through various financial institutions to enable entrepreneurs to obtain up to 100 percent loan and credit facilities to support their business aspirations.

Venture capital is an alternative form of financing. The government has proven itself in the past to be supportive of the venture capital industry and has continued to be so, providing adequate liquidity to meet the industry's needs.

Singapore

1. Overview

Between 1965 and 1997, Singapore's economy grew at an average annual rate of over 8.5 percent. (Yue, **DATE**). This growth lasted till the onset of the regional financial and economic crisis of 1997–98. Having recovered from the crisis, Singapore resumed its growth and made a successful transition to a knowledge-based economy.

Because Singapore is small and lacks a natural resource base like Taiwan and Malaysia, rapid economic development brought labor shortages and rising costs. It had to face the challenge of continually upgrading into higher value-added manufacturing and services and move up the value chain.

Singapore's government had always been committed to the concept of efficiency, recognizing early on that, to compensate for the country's natural "comparative disadvantage" associated with being a small economy with a limited domestic market and population size, Singapore would need to develop a highly efficient and productive infrastructure system to help reduce production costs and attract foreign investors. This commitment to efficiency, along with an honest government, which adopted proactive growth strategies and a highly educated, English-speaking workforce, has made Singapore a choice production base for multinational corporations. There are currently over 5,000 foreign companies located in Singapore and many more MNCs and foreign financial institutions that have established operating and manufacturing bases on the island.

Approximately 19 percent of the population of Singapore is made up of foreign nationals. As a result of this ability to attract foreign capital and skilled foreign workers, the Singaporean economy has grown at 8.5 percent per annum in recent years and per capita income has grown at 6.6 percent, roughly doubling every decade. Over the years, the economy has gradually moved into more technology-related fields. Labor-intensive industries such as textiles, once important to the island's economy, are no longer part of Singapore's economic landscape (Yue).

Following a period of impressive growth, the 1997 Asia economic crisis led the country to reevaluate its development strategies. Singapore has since recognized that efficiency alone will no longer guarantee sustained growth in the future and that it will need to formulate alternative strategies for growth.

2. Public Policy and Regulatory Enablers

In 2002, a high-level Economic Review Committee (ERC) was organized by the government to assist the country in formulating a new development strategy. The ERC focused on enhancing the economy's innovative capacity, with the aim of making Singapore an innovation hub for Asia. The government has since devoted more resources to R&D and innovation.

Previous five-year plans implemented by the National Science and Technology Board, starting from the early 1990s, sought to target mainly short-term applied technological innovations, with few attempts to deepen the culture and practice of innovation across the whole economy. Singapore's new innovation strategy, however, seeks to accomplish these goals by developing basic innovation and cultivating a scientific culture. At the 2002 Knowledge Economy conference in Sydney, Ko Kheng Hwa, MD, of the Singapore Economic Development Board (EDB) discussed the country's strategy in making the transition to the knowledge economy without abandoning its powerful presence in manufacturing. He emphasized that Singapore is looking to reform its innovation system

to focus on “the broad and the basic,” from drug discovery, all the way to clinical development, clinical trials, process development and manufacturing, and the provision of health care services.
It aims not only to promote innovations in manufacturing, services, and creative content, but also to do so at different levels of firm size, from giant MNCs to local SMEs. To pursue these strategies, the government allocated $S7 billion over five years to support public sector R&D, which would, in turn, stimulate private sector R&D.

3. Singapore’s Strategy for Future Development (2003)

Singapore’s 2003 Strategy for Future Development had four main parts:
Strategy 1: Build bridges through a web of free trade agreements. These free trade area agreements, both multilateral and bilateral, will be a crucial part of Singapore’s strategy to build bridges to key economies to the world, and to increase market accessibility of companies based in Singapore.
Strategy 2: Broaden the industry base and develop new growth clusters. The country will focus on new industry clusters such as biomedical and nanotechnology in manufacturing, as well as a portfolio of internationally salable services with high growth potential, such as educational services, professional services, and IP management.
Strategy 3: Whether in services or manufacturing, the country will build new capabilities to move up the value chain in three particular areas. The first will be lifting the value added of production activities, for example, into highly automated manufacturing. The second is moving upstream into R&D, innovation, and tax baits for new ideas. The third is moving downstream into regional electronics supply chain management into market development, brand management in the Asia Pacific region, IP management in the region, and enlarging the regional headquarter operations.
Strategy 4: Creating a vibrant enterprise ecosystem by developing the venture capital industry, increasing tax incentives for new ideas, and provisions of new users to try out the country’s new inventions.
The new plan was intended to shift the focus of innovation to developing technology within small firms in the services sector. More resources were being devoted toward long-term, basic research. There was also an increased awareness that a significant part of innovation actually comes from small firms. The untapped innovative energy within the services sector had become a high priority. In addition to traditional service industries that thrive in Singapore such as financial, tourism, entrepot trade, health care, transport, and logistics, the government was also actively promoting the country as a regional hub in other service industries like education, legal services, and creative industries.
To make these transitions, the Singaporean government planned to invest heavily in innovation infrastructure, rather than efficiency infrastructure, deemed necessary to build a critical mass of innovative people and innovative activities, with the immediate objective of attracting the right type of workers rather than the right type of firms. There were also efforts planned to change the “mindset” of Singaporeans, to bring out the enterprising and adventurous spirit in them, by increasing the availability of innovation-enabling infrastructure such as R&D facilities, well-defined IP laws, and venture capital.

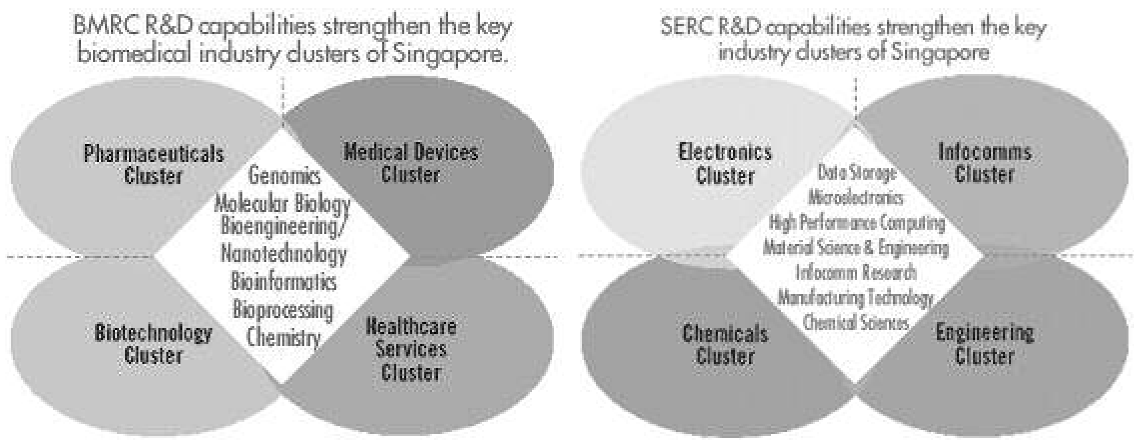
4. Government’s Role in Promoting S&T

In 1991, the government of Singapore established the National Science and Technology Board, with the primary mission of raising the level of S&T in Singapore. The board was later renamed the Agency for Science, Technology and Research (A*STAR).

Since its formation, A*STAR implemented two five-year plans, the National Technology Plan (S$2 billion from 1991 to 1995) and the National Science & Technology Plan (S$4 billion from 1996 to 2000). A*STAR is the lead agency in implementing the National Science and Technology 2005 Plan with a budget of S$7 billion from 2001 to 2005.[18]

A*STAR has an unconventional mode of operations. It functions in what it calls a "luminous constellation" comprising the Biomedical Research Council (BMRC) and the Science and Engineering Research Council (SERC). Both BMRC and SERC promote, support, and oversee the public sector R&D research activities in Singapore. Both fund the A*STAR public research institutes, which conduct cutting-edge research in specific niche areas in science, engineering, and biomedical science. The R&D Capability Diamonds in Figure A.2 show clearly how the research capabilities of A*STAR research institutes strengthen the key industries in Singapore.

Figure A.2: Singapore's Innovation Model



Source: A*STAR, www.a-**star**.edu.sg

[18] A*STAR, www.a-**star**.edu.sg

The Biomedical Research Council

Established in October 2000, the BMRC supports, oversees and coordinates public sector biomedical research and development activities in Singapore. The BMRC:

- Oversees the development of core research capabilities within A*STAR research units specializing in bioprocessing, chemical synthesis, genomics and proteomics, molecular and cell biology, bioengineering, and nanotechnology and computational biology.
- Actively promotes translational medicine and cross-disciplinary research as part of its efforts to advance human health care.
- Supports biomedical research in the wider scientific community, such as public universities and hospitals.
- Engages in human capital development in the biomedical sciences and promotes societal awareness of biomedical research through outreach programs.

BMRC works in close partnership with the Singapore Economic Development Board's (EDB) Biomedical Sciences Group and Bio*One Capital in spearheading the Biomedical Sciences Initiative to develop Singapore into the Biopolis of Asia—an international biomedical sciences hub advancing human health care, through the pursuit of excellence in R&D, manufacturing, and health care delivery.

The Biomedical Sciences (BMS) International Advisory Council, comprising eminent international scientists and visionaries in the biomedical field, shares their perspectives and insights, advises Singapore on major global trends in biomedical research and industry, and critiques and advises Singapore on BMS initiatives.

There are seven research institutes under BMRC:

1. Bioinformatics Institute (BII)
2. Bioprocessing Technology Institute (BTI)
3. Genome Institute of Singapore (GIS)
4. Institute of Bioengineering and Nanotechnology (IBN)
5. Institute for Medical Biology (IMB)
6. Institute of Molecular and Cell Biology (IMCB)
7. Singapore Institute for Clinical Sciences (SICS)

In addition, BMRC has established the following research consortia to focus on developing capabilities in translational research:

- Singapore Cancer Syndicate (SCS)
- Singapore Bioimaging Consortium (SBIC)
- Singapore Stem Cell Consortium (SSCC)
- Singapore Immunology Network (SIgN)
- Singapore Consortium for Cohort Studies (SCCS)

Science & Engineering Research Council

SERC promotes public sector research and development in science and engineering with a focus on fields essential to Singapore's manufacturing industry, especially electronics, infocomms, chemicals, and precision engineering.

SERC's objectives are:

- To develop a foundation of high-quality research in key disciplines;
- To nurture human capital for research; and

- To promote information dissemination and technology transfer.

Exploit Technologies

Exploit Technologies commercializes the R&D and IP generated by A*STAR. A*STAR's research institutes have researchers and scientists developing technologies and IPs across multiple science and engineering disciplines and biomedical research areas. Exploit Technologies manages and consolidates all research institutes' IPs under one roof as a one-stop center for research institutes, industries, and enterprises.

Through licensing deals and spin-offs with industry partners, Exploit Technologies enhances the research output of its scientists by translating their inventions into marketable products or processes. In so doing, IP becomes relevant to industry. Exploit Technologies generates a value-added edge and jobs for the Singapore economy.

As the strategic marketing and commercialization arm of A*STAR, Exploit Technologies is a key driver of technology transfer in Singapore. It actively engages industry leaders and players to commercialize A*STAR's technologies and capabilities, bridging the gap from "mind to market."

Working closely with industry players, Exploit Technologies Pte Ltd (ETPL) identifies viable commercial avenues for inventions created by A*STAR's researchers and transforms them into new products, processes and therapies to benefit mankind.

ETPL provides access to Singapore's large pool of IP and knowledge generated by over 2,000 researchers at A*STAR's research institutes, as well as the following institutes:

- Data Storage Institute
- Institute for Infocomm Research
- Institute of Chemical & Engineering Sciences
- Institute of High Performance Computing
- Institute of Materials Research & Engineering
- Institute of Microelectronics and
- Singapore Institute of Manufacturing Technology.

5. Singapore's Thrust on IP Protection and Commercialization

It is widely recognized that knowledge and innovation have played a critical role in the recent growth of world economies. IP, as an asset, is acknowledged as a key value driver for business growth, economic productivity, and wealth creation. Thus, there is increasing awareness among nations and businesses of the need to put in place management mechanisms and policies to identify, protect, develop and commercialize the intellectual assets arising from innovations.

Singapore recognizes that to stay competitive and prosperous, a small resource-scarce country like itself must embrace the knowledge-based economy and build innovation into its economic development strategies. To remain globally relevant, the country has to develop both capabilities and capacities for innovation-driven and IP-intensive activities that will fuel future economic growth. As a result, Singapore has committed significant efforts and investments to build a conducive environment where IP-related activities can thrive, with the eventual goal of establishing a self-sustaining IP life cycle (IP creation, IP protection, and IP exploitation) to power the economy further into the knowledge era.

Nevertheless, IP challenges are relatively new to a newly developed nation like Singapore. Strategies have been put in place to accelerate development particularly in the infrastructure and human resource capital areas.

6. Human Resource and Capacity-building Strategies

Singapore's ability to innovate and create IPs is dependent on the availability of quality research scientists and engineers (RSEs), who will create the competitive advantage for businesses and enhance the human intellectual capital of the nation.

Singapore's strategy is to build a local pool of quality RSEs and supplement it with talent from abroad. The research institutes were established to help accomplish this goal, by growing and hosting a critical mass of RSEs, with strong capabilities. Besides serving the MNCs and local customers in terms of contract R&D, technology transfer, high-level problem-solving, and manpower training, the research institutes also help the local universities to attract local and foreign students to their postgraduate programs.

In addition, experienced RSEs in the research institutes have contributed to graduate education programs, by becoming co-teachers or co-supervisors for academic programs, as well as instructors in professional short courses that aim to upgrade the practicing RSEs in industry.

By early 2000, it became apparent that the IP manpower capabilities in Singapore lacked both breadth and depth. The IP Academy was set up in January 2003 precisely to address this issue. It was given the mandate to rapidly build both the quantity and quality of IP manpower capabilities, through partnerships with leading teaching and research centers and IP thought leaders, researchers, and industry players, both in Singapore and abroad. As a key IP education institute, the academy develops and delivers a comprehensive suite of IP-related training programs. These range from short executive workshops to full-fledged certification programs that target a variety of audiences including IP professionals (such as patent attorneys), senior management executives, entrepreneurs, scientists, and engineers.

Other IP-related programs are conducted by organizations such as the Centre for Management of Science and Technology (CMOST) at the National University of Singapore and Exploit Technologies, which is the technology transfer arm of A*STAR. CMOST conducts structured programs that aim to provide scientists and engineers with a formal technology management education. Exploit Technologies runs in-house IP training for A*STAR researchers (Chieh and Ng).

The IP Academy has also been tasked to promote research in IP-related fields, with the intent of helping Singapore gain thought leadership in selected IP fields. The academy conducts leading-edge research projects and research collaborations with internationally renowned IP institutes and IP organizations. These projects are conducted by both local and eminent foreign IP researchers and allow Singapore to be exposed to the latest developments in the global IP arena. They also represent opportunities for Singapore IP researchers to learn from renowned experts and strengthen Singapore's indigenous IP research capabilities. Thus, there is a growing availability of IP-related research and education programs that will help Singapore create a large pool of highly qualified and, hopefully over time, experienced IP professionals with the necessary IP skill sets.

7. R&D Infrastructure

Singapore has established a strong R&D infrastructure to support both public and private sector research activities. Since the early 1990s, A*STAR has set up a number of public research institutes to support the growth and development of specific technology sectors.

These research institutes play critical industry support roles that include the training of RSEs and providing R&D support to industry. In addition to the benefits of research manpower training and core capability development, publicly funded research activities have also created commercializable

IPs. As in other developed countries, the universities and research institutes have strengthened their technology-transfer offices to protect, aggregate, and exploit the commercializable knowledge.

These offices have become additional key components of Singapore's R&D infrastructure. In the private sector, Singapore plays host to a number of R&D operations belonging to well-known research-based companies. Philips, Seagate, and Novartis have all set up multi-million dollar research centers that conduct high-value R&D activities.

These centers have become part of Singapore's R&D infrastructure and help enhance the nation's R&D capabilities. Various government agencies have also committed significant efforts and investments to build IP capabilities in the industry that complement the IP infrastructure. For instance, the IP Strategic Business Unit of the EDB actively promotes Singapore to overseas IP service providers, with the aim of attracting these companies to set up operations here, thereby completing the value chain of IP activities.

The Intellectual Property Office of Singapore (IPOS) has developed a number of very useful IP resources that augment Singapore's R&D infrastructure. The Intellectual Property Education and Resource Centre is an education and training unit that offers a range of resources including IP information, IP clinics, IP talks and conferences, IP publications, and IP roundtables. There is also an online portal that delivers a complete range of IP management services to businesses and individuals via the Internet. IPOS' SNIPS (Singapore Network of IP Service Providers) provides a directory listing of IP expertise located in Singapore. These are useful resources that the industry can tap upon.

Soft infrastructure plays a role equally important to that of hard infrastructure. A robust IP infrastructure is vital for the promotion of innovation and the growth of IP-related activities. Singapore recognizes that strong IP protection is critical to attracting foreign investment, as well as recruiting and retaining world-class research talent. Thus, it has built a comprehensive set of IP laws that meet international norms (in particular, the standards set by the World Trade Organization (WTO) TRIPS Agreement); in fact, Singapore's IP laws have attracted much attention in the international IP community because of the state-of-the-art protection it will soon provide as a result of the ground-breaking Free Trade Agreement that was signed with the United States in May 2008.

Having a strong legal framework on paper is not sufficient; an effective administration has to be put in place and strict IP enforcement policies have to be developed. In this area, the responsible ministries work closely with the relevant government agencies, in particular IPOS, as well as the business community. They ensure that policies shaping Singapore's IP infrastructure are sound and consistent with the development needs of the industry and the nation.

In addition to investing in infrastructure, Singapore is nurturing a pro-enterprise environment that will stimulate creativity and innovation in both existing and new companies. These businesses will be able to utilize the infrastructure and tap available resources to fully exploit their IP assets. To create such an environment, the government has taken a broad multiagency approach to promote awareness and appreciation of the various components of the IP life cycle and their importance to Singapore's economy development.

For instance, IPOS, A*STAR, EDB, IE Singapore, and Media Development Authority (MDA), have come together on occasion to organize programs and events that aim to promote greater awareness about IP. Industry groups like business associations and chambers of commerce are often invited to participate as well. This allows the pooling of resources and extends the reach of the promotional efforts.

Agencies like MDA, IE Singapore, and SPRING Singapore are also developing specialized programs, to raise awareness of IP and enhance the IP know-how of the industries under their charge. For example, MDA, with the support of the IP Academy, organized a customized IP workshop in April 2004 to equip media professionals with the knowledge needed to handle media-related IP issues. The interest in the media industry was initiated through large-scale seminars providing industry-sharing and smaller clinics to address specific concerns coordinated by MDA, IPOS, and IP.

8. Investments – R&D, Centers of Excellence, International Linkages, and Learning Opportunities

Singapore has used incentives to promote investment, innovation, manpower development, and enterprise development. For instance, to attract inward investments, the EDB provides tax incentives and R&D grants to MNCs setting up significant research operations in Singapore. In return, these companies create jobs, develop local capabilities, and help boost the status of Singapore as a preferred location for R&D investments.

To encourage innovation among Singapore-based companies, agencies including EDB, A*STAR, and IDA support the R&D activities of these companies in a number of ways. The incentive may come in the form of R&D grants, tax deductions for R&D expenditures, or financial incentives for manpower training, such as the Initiatives in New Technology (INTECH). Furthermore, to encourage companies to protect their IP assets, the EDB has a Patent Application Fund (PAF) scheme that helps companies defray some of the cost associated with patent application.

Complementing the general financial incentive for manpower training in S&T, both IPOS and EDB offer incentives for local companies to build in-house IP capabilities. These incentive schemes provide assistance to help reduce the burden on companies and promote the growth of a pool of local IP professionals.

To encourage the commercialization of innovations and the creation of new enterprises, programs such as the Proof of Concept (POC) program and Startup Enterprise Development Scheme (SEEDS) were developed. Under the SEEDS program, the government will provide start-up funding to companies, matching the amount that the companies are able to raise from third-party investors. SEEDS was administered by the EDB and focused predominantly on technology start-ups.

Singapore has committed itself to create a pro-enterprise environment, where start-ups can thrive and businesses can tap on readily available resources, to continually upgrade themselves to compete globally. The intent is to create a sizeable pool of local enterprises that can both innovate, and transform their innovations into viable global products or services.

To help existing businesses strengthen their competitiveness, there are a range of initiatives and resources, to assist companies build specific capabilities. For instance, to help local firms build their technology capabilities, A*STAR started the Growing Enterprises with Technology Upgrade (GET-UP) program, which provides local enterprises with technical and human capital assistance to help them compete globally.

Through the program, A*STAR researchers may be "borrowed" by the local enterprises to take on specific critical R&D projects. Taking a different approach, agencies like EDB and IDA have created the Local Industry Upgrading Programme (LIUP), which aims to bring together MNCs and their local supporting companies in mutually beneficial collaborations.

Similarly, to help businesses establish or build their capabilities in the area of IP and commercialization, IPOS created the "IP-Creation, Exploitation and Protection" program (IP-CEP), a collaborative effort with other economic agencies, business chambers, and industry groups. The program aims to raise awareness of IP in the industry, and make available IP information and resources, as well as to encourage better IP management practices in the industry. More recently, IPOS has taken the next step and developed an “Intellectual Asset Management” program (IAM) to help promising IP enterprises upgrade their IP management capabilities.

Korea

1. Overview

The Republic of Korea started as a low-income country. Korea’s sustained economic growth was an outcome of the knowledge economy approach. Between 1950 and 1997, Korea’s economic development hinged on the important interactions among the four pillars of the knowledge economy, which have evolved together with the various stages of economic development.

The development strategies focused on achieving sustained productivity growth through value-added output. The emphasis was on technological capacity building and corresponding human capital creation, which complemented this capacity building. The Korean government played a crucial role in providing proactive leadership in supporting the market and providing a conducive environment to foster the transformation.

In the 1960s, Korea promoted both export- and import-substitution industries. They started with subsistence agriculture (rice) and labor-intensive light manufacturing sectors (textiles and bicycles). Considerable capital accumulation and investment in primary education during this period allowed a gradual shift up the value-added chain toward more sophisticated commodities. Emphasis was on technology acquisition through foreign licensing and its adaptation for domestic production.

In the mid-1970s, the government made a major shift to the development of heavy industries (for example, chemicals and shipbuilding). Along with industrial targeting, policies were enacted to further improve technological capabilities, together with improving access to and quality of technical and vocational training.

In the 1980s, the Korean government moved toward the creation of a market-conducive environment by deregulating various sectors and liberalizing trade. Concurrently, it expanded higher education while investing in indigenous research and development. This was done through a well-articulated and -executed National Research and Development Program. Korea continued to pursue high value-added manufacturing in the 1990s by promoting indigenous high-technology innovation. Domestic wage hikes and the appreciation of the Korean won had resulted in chronic current account deficits, which sparked a series of reforms, including the reform of the financial market.

Together with the setting up of a modern and accessible information infrastructure, there was continued expansion of R&D capabilities in Korean industries, which drew on the skilled labor force that had resulted from the government’s aggressive expansion of the higher education system.

2. The Financial Crisis of 1997

The mechanism of resource allocation that the government used to wield discretionary power over the market had been effective when the economy was beginning to develop. However, it approached its limits as the economy developed and became larger and more complex. The financial crisis of 1997 manifested the limitations of discretionary resource allocation and underscored the urgent need for widespread economic reform.

The old policy framework and institutions that had led Korea in the early high-growth era turned out to be bottlenecks for sustained economic growth in the new economic environment. As such, Korea, with a clear national consensus, implemented a comprehensive restructuring of ailing corporate and financial sectors and undertook reforms in the public sector and the labor market, all of which contributed to overcoming the crisis and ensuring a rapid economic recovery.

3. Role of Political Leadership and Government

In the aftermath of the financial crisis in 1998, Korea officially launched a national campaign to make the transition to an advanced knowledge-based economy in which innovation would thrive, thereby enhancing overall productivity and sustaining economic growth. The initial impetus came from the *Maeil Business Newspaper,* which presented in 1996 a more coherent vision of the future for the Korean economy.

Subsequently, economy-wide action plans were drawn up and implemented through the coordinated efforts of a number of government agencies. Key to the success of the national knowledge-economy strategy was the strong political leadership from the Kim Dae-jung government and the national consensus with the private sector and civil society. Korea's new knowledge-based development strategy was based on the Knowledge Economy Framework developed by the Knowledge for Development Program of the World Bank. Korea's transition toward a knowledge economy has been relatively successful.

The OECD has documented Korea's active investment in knowledge, which in 2002 was 5.8 percent of GDP, the fourth highest among the OECD countries. Moreover, Korea's investment pattern has been changing significantly in recent years, from investment in physical capital such as machinery and equipment to knowledge inputs. Among the OECD countries in 2002, Korea still had the highest ratio of spending on machinery and equipment to GDP, but the ratio is rapidly decreasing. From 1995 to 2002 the ratio decreased by 3.7 percentage points. For the same period, in contrast, Korea's investment in knowledge increased by 1 percentage point (World Bank, 2006).

The role of the government in the efforts of developing indigenous innovation capabilities evolved together with the phases of industrial development. For example, to enable firms to finance the massive importing of capital goods and the building of turnkey plants in line with its technological assimilation strategy in the 1960s, the Korean government brought in large-scale, long-term foreign loans and allocated them to selected industries. In the 1970s, as the economy had developed and was moving into heavy industries, the government created government research institutes in the fields of heavy machinery and chemicals to compensate domestic industries for their technological weakness. These government research institutes, such as the Korea Institute of Machinery and Metals and the Electronics and Telecommunications Research Institute, worked with private industry to some extent to enhance technological capabilities for further industrial development.

The Korean government has also contributed significantly to the rapid rise in private sector investments in research and development. First, the government's outward-looking or export-driven development strategy forced domestic industries into international markets, exposing them to intense global competition. For these firms to remain competitive, they had to keep pace with technological changes by investing heavily in R&D. Second, the government's industrial policy that favored large firms gave birth to a unique business organization in Korea, the chaebol.

Chaebols enjoy greater financial affluence owing to the economies of both scale and scope of their business operations. Chaebols, which are usually big multinational firms, were able to engage in risky and expensive R&D projects. The top-20 firms account for about 57 percent of the total industrial R&D investments in Korea (World Bank, 2006).

Most important, Korea has been able to increase R&D investments at such a rapid rate because it has an abundant pool of highly educated manpower that could meet the increasing demand for R&D services in both private and public sectors. However, Korea's efforts to build an indigenous innovative service base are not without challenges. For instance, most of the R&D is being performed by the chaebols, and little is being conducted by the universities. This disproportionate distribution of R&D investment is not sustainable for the economy as a whole as insufficient resources are being devoted to R&D in basic sciences, which is necessary for the long-term development of S&T.

4. Human Resource and Institutional Capacity-building Strategies

Education and human resources have been key factors in Korea's rapid economic growth over the past four decades.

Expanding enrollment rates

Korea's educational system has expanded rapidly over the past 40 years. Universal primary education was adopted as early as the 1950s, which was instrumental for full-fledged industrialization in subsequent years. The secondary enrollment rate was relatively low in 1970, at less than 40 percent.

However, subsequent sharp increases led to secondary enrollment being more than 90 percent in 2004. Similarly, enrollment in higher education has experienced steep increases since 1990 and surpassed 60 percent in 2004, the highest level among the OECD countries.

Enhancing educational quality

Korea's education system has achieved qualitative improvement in tandem with quantitative expansion. Korea ranks very high in various international tests administered in recent years. For example, it ranked third in mathematics and fourth in science out of 40 countries included in the OECD's Programme for International Student Assessment (PISA) 2003 survey.

Expanding the education system in tandem with economic development

Since the 1950s, Korea's educational policy and planning have complemented the government-led economic development plans. Specifically, the education system was nurtured and expanded according to the manpower needs of the economy.

Hence, in the 1950s and 1960s education policies focused on the expansion of primary and secondary education, which was critical to supply at least a literate workforce to the industries. Vocational high schools were also established in the 1960s to provide training in craft skills for the growing labor-intensive light manufacturing industries. Junior vocational colleges were set up in the 1970s to supply technicians for the heavy and chemical industries. In the 1980s, the higher-education expansion policies adopted by the government were effective in supplying high-quality white-collar workers and R&D personnel that were required as Korea began enhancing domestic innovation.

Public and private expenditure on education

Korea's emphasis on education and developing a skilled workforce can be seen from the economy's total expenditure on education. In 2002, 7.1 percent of GDP was spent on education, a level much higher than the OECD average of 5.8 percent.

The government's priority on education can be seen from the growth rates of the public education budget, which have outpaced those of GDP over the past four decades. In particular, for the period 1963–95, government spending on education increased more than 27-fold in real terms, whereas GDP increased only 14-fold and the government's overall budget has increased only 15-fold.

Another characteristic of the Korean education system is the unusually large component of private financing. Private expenditures on education account for 2.9 percent of GDP, which is the highest among the OECD countries and far above the OECD average of 0.7 percent (World Bank, 2006).

The Korean government has been successful in encouraging the private sector, either households or private foundations, to bear a significant portion of total education costs. In particular, private foundations have established a number of secondary schools and higher-education institutions, in which expenses are paid for by user fees. At the secondary level, enrollment at private institutions accounts for more than 40 percent of total secondary enrollment, whereas private enrollment for tertiary education is over 70 percent. On the other hand, primary education in Korea has been treated as a public good and has been mostly publicly funded, with about 99 percent of primary school students in 2005 being enrolled in public schools.

The heavy reliance on private funding in secondary and higher education has important policy implications. Inducing the private sector to play a more active role in providing secondary and higher-education services has had a leveraging effect where scarce government resources have been spent on key priority areas. More specifically, by leaving higher education to the private sector and targeting public resources for primary education, Korea was able to address one of the main equity issues, basic education for all.

The cultural factor

One factor that is contributing to the high propensity for private spending in education is the intrinsic social values that literacy and education have in Korean culture. Indeed, educating children has always been the overriding family task for Korean parents. Coupled with the rising demand for a more educated workforce, a natural consequence of the industrialization process, this cultural factor has greatly contributed to Korean families' willingness to pay for educating their children, and consequently to the rapid increases in school enrollment rates.

5. Investments: R&D, Centers of Excellence, International Linkages and Learning Opportunities

Rapid development of indigenous R&D capabilities

Korea has recognized the importance of developing indigenous capabilities in S&T for successful industrialization and therefore has made building such capabilities one of the key priority policy areas over the past four decades. Korea's GERD has grown both in size and as a share of GDP, which increased from 0.25 percent in 1963 to 2.84 percent in 2004. Along with the rapid increase in R&D investment, the number of researchers has also increased more than 100-fold during the same period, from 1,900 to 209,979 (World Bank, 2006). The rapid increases in total R&D expenditure have been possible because of active expansion of investment by the private sector.

During the earlier years of industrialization, private sector R&D spending was negligible, but rapid economic growth has called for commensurate investment in technology development, resulting in continuous increases in R&D spending by private enterprises over the past four decades. Consequently, the funding sources have also greatly changed: the government's share of GERD has been continuously reduced, with only one-fourth of GERD coming from the government in recent years.

The rapid increase in R&D investments has led to a corresponding increase in indigenous innovation and adoption of foreign technologies. This can be seen from Korea's improve performance in various international indicators of innovation and technology adoption, such as the number of scientific and technical journal articles written and published by Korean authors, the number of USPTO patents granted to Korean inventors, and the amount of royalties and license fees paid and received by Korea. According to the World Bank Knowledge Assessment Methodology, Korea is currently on par with a typically high-income country in many aspects related to innovation and technological adoption.

Evolution of technological assimilation and domestic innovation capabilities

When Korea launched its industrialization drive in the early 1960s, it had to rely almost completely on imported foreign technologies. By doing so, it pursued two key objectives. The first was to promote the inward transfer of foreign technologies, the second was to develop domestic absorptive capacity to digest, assimilate, and improve upon the transferred technologies and to adapt them to domestic production. The second objective required a relatively skilled labor force, which Korea had because of its concurrent aggressive educational policies.

The technology-assimilation strategy used various channels, such as original equipment manufacturing, foreign licensing-based production, reverse engineering of imported capital goods, and learning from the building of turnkey plants. These channels of informal technology assimilation enabled Korea to minimize its dependence on FDI, which had become more prominent since the 1997 financial crisis, and to maintain independence from MNCs.

The strategy proved to be a success and Korean firms were able to assimilate technologies rapidly enough to undertake subsequent expansion and improvement with little assistance from foreign suppliers. Changes in economic environments in the early 1980s induced Korea to embark on serious investments in indigenous R&D. On the one hand, Korean industrial development had reached the stage at which domestic industries found it more difficult to be competitive in the international market because they were reliant on imported technologies and employed domestic labor that was becoming more and more expensive. On the other hand, Korean industries had grown to become potential competitors in the international market, making foreign companies increasingly reluctant to transfer technologies to Korea; thus, it was inevitable that Korea would have to develop an indigenous base for research and innovation. Meeting the challenge required highly trained scientists and engineers as well as financial resources to support R&D activities, which are by nature uncertain and risky.

Nurturing entrepreneurship and cultivating venture businesses

The development of venture businesses requires a stable supply of concomitant risky capital, which was absent from Korea until the early 1980s. Accordingly, the government actively promoted the formation of a venture capital market, which has grown rapidly since the late 1990s. Korea is now among the leading OECD countries in terms of venture capital investment as a share of GDP.

The government recently revised its venture business policy to avoid any direct intervention into the market and thus to improve the self-sustaining capability of venture business. The government now focuses more on the establishment of regulations to maintain a level playing field and on monitoring and supervision to make sure the regulations are observed.

6. Infrastructure: High Bandwidth Connectivity

In the early 1970s, Korea’s information infrastructure was inadequate and the provision of ICT services was insufficient and too inefficient to meet the telecommunication demands associated with rapid economic growth. In 1975, only 3 percent of Koreans had a telephone (World Bank, 2006).

To improve efficiency in the provision of telecommunication services, the Korean government decided to rely on the invisible hands of the price mechanism and thus focused on introducing competition into the ICT infrastructure sector. As such, a series of sequential but rapid policy measures were implemented for the deregulation and liberalization of the ICT services sector, along with privatizing the government-owned telecom operators. The Korea Telecommunication Authority was established in 1981 to spearhead this effort.

The reform of the ICT infrastructure sector resulted in tremendous improvements in terms of ICT penetration rates. Most noteworthy are the recent penetration rates of cell phones and the Internet. From 1995 to 2003, the proportion of Koreans having a cell phone increased by nearly 20 times, to 70 percent, while the proportion of Internet users increased by a whopping 75 times, to 60 percent

Similarly, Korea is currently among the leading countries in the world in terms of the proportion of broadband Internet subscribers.

Korea constructed ICT networks connecting all 114 areas of the country, and ICTs are used extensively in numerous economic and social activities. The number of individuals using ICT-related services is also constantly rising: the number of subscribers to Internet banking services reached 22.58 million as of March 2005, and e-commerce has rapidly increased from 50 billion won in 1998 to 314 billion won in 2004, which is equivalent to 40 percent of GDP. Led by an e-government initiative, the public sector is also extensively using ICTs. In 2004, about 97 percent of documents were dealt with through the e-approval system in the government agencies, compared with only 21 percent in 1998 (World Bank, 2006).

The rapid development of the Korean information infrastructure hinged on key government organizations that were responsible for the informatization strategy. These organizations were restructured in the 1990s. They included the Informatization Promotion Committee, chaired by the prime minister; the Informatization Strategy Meeting, chaired by the president; and the Ministry of Information and Communication. Concurrently, the Korean government established three master plans for the development of the information society. In 1995, the Informatization Promotion Act was enacted, and the first master plan for promoting informatization was formulated a year later. In 1998, in the second master plan, Cyber Korea 21 was established to cope with the changing environment that resulted from the Asian financial crisis. And in 2002, when most of the policy goals set up by Cyber Korea 21 had been achieved ahead of the original schedule, the third blueprint, e- Korea Vision 2007 was laid out.

To build the infrastructure efficiently and economically while actively responding to the technological development and changing demands, diverse implementation methods have been used. Networks in commercial and densely populated areas have been built with optical cables; networks that extend to subscriber premises have been built partly with optical cables and partly by digitizing and enhancing the speed of existing telephone lines or CATV networks or by building new wireless local loops.

To finance the investment for the rapid deployment of Korea’s information infrastructure, the Informatization Promotion Fund was established as a special vehicle to overcome short-term budgetary constraints. From 1993 to 2002, the fund reached a total of US$7.78 billion. About 40 percent of that was from government budgetary contributions, 46 percent came from private enterprises (of which licensing fees for new communication services composed major portions), and the remaining 14 percent came from miscellaneous profits and interests. The funds were allocated in a way that would balance development in ICT-related activities: 38 percent for technology development programs (the best known is CDMA wireless technology), 18 percent for human resources development, and the remaining 44 percent for building of infrastructure and diffusion, including standardization (World Bank, 2006).

A particularly important purpose of the fund was to narrow the digital divide. Socially alienated groups, such as aged and rural villagers, have continuously received various supports and assistance, including computer-literacy education.

Taiwan

1. Overview

Taiwan's rapid economic growth, its transformation from poverty to prosperity and from backwardness to modern nation has been termed as the "Taiwan Miracle" by Westerners. In 2008, Taiwan ranked 17th among the 140 countries covered in the World Bank's Knowledge Economy Index. Within Asia, Taiwan surpassed Japan to take the No. 1 spot on the list. Of the four major items that make the Knowledge Economy Index, Taiwan performed very well in national innovation systems with a score of 9.24, outpacing Japan, Korea, and Hong Kong. This reflects the success of the R&D and innovation policy that the government has implemented in recent years, advocating industrial-academic interchange and promoting the establishment of innovation R&D centers, and the reinforcement of patent protection (Council for Economic Planning and Development of Taiwan. Taiwan's score of 9.07 in the information infrastructure item surpassed the United States, the United Kingdom, Germany, and Korea. The Council for Economic Planning and Development of Taiwan attributed this high score to the government's vigorous promotion of the information and broadband Internet infrastructure as well as its strengthening of innovation and application services. Taiwan's mobile phone penetration reached 105.9 percent in 2007, there were 492.1 computers for every 1,000 people, and the ratio of household broadband connections was 59 percent.

The achievement is quite remarkable especially when considering that Taiwan was primarily an agriculture-based economy up to early 1960s. The government commanded a great influence in the national economy and had adopted protectionist measures. Between 1952 and 1961, more agricultural products and processed agricultural products were exported than industrial products, which demonstrated just how important the farming sector was in generating foreign exchange reserves.

By 1962, industrial production value began to exceed that of agriculture. This period has been generally referred to as Taiwan's "industrial era." However, during Taiwan's transformation from an agriculture-based into an industrial-based economy, it encountered a number of socioeconomic problems. The principal issue was the employment of labor no longer needed in the rural areas. Because providing employment opportunities for the huge labor force was a matter of great importance, the government encouraged the development of labor-intensive export industries. As a result, foreign investment poured in to capitalize on the island's inexpensive labor.

To encourage such industrial growth, the government promulgated the Nineteen Financial and Economic Reform Measures in 1959 and the Statutes for the Encouragement of Investment in 1960. The former eased trade restrictions, promoted exports and encouraged savings and thrifty consumer spending, thereby greatly increasing investments in factories. The latter helped improve the investment environment, attract foreign capital, and encourage the development of export-oriented industries.

Industrial growth (1981–95)

The greatest changes in the structure of Taiwan's industrial sector took place in the 1980s. Labor-intensive industries were no longer the mainstay of the industrial sector and were slowly being replaced by technology and capital-intensive industries. This transformation of Taiwan's industrial structure stemmed in part from the global economic trends at that time.

In 1984, the government announced plans for the liberalization and globalization of the economy as well as the privatization of government-run enterprises. In addition, interest-rate controls were abolished, tariff rates were slashed, and the central exchange rate was abandoned. To boost industrial development, the government established the Hsinchu Science-based Industrial Park in 1981.

Such science-based industrial parks were established to introduce high-tech industries and attract talent to Taiwan, promote the upgrading of Taiwanese industries, balance regional development, and drive national economic development.

Using innovation to create economic value and improve the wellbeing of citizens

Since achieving globalization, Taiwan has been using its local scientific and technological advantages to create economic value and improve the welfare of its people. Many successful cases have been produced over the past few years. For instance, the government's S&T programs have integrated upstream and downstream textile businesses and developed key technologies for different types of high value-added textiles.

During the 2003 SARS outbreak, Taiwan immediately developed facial masks and protective clothing to significantly prevent the spread of the epidemic. In addition, Taiwan is combining textile technology with tradition, culture, and art by using digital inkjet fabric printing technology to imprint local artwork onto clothing and designs. This integration of technology and creativity into textile production has sustained Taiwan's textile output value at more than NT$500 billion each year[19], and businesses continue to thrive. Another example of innovative success comes from ergonomics of the arm: oval-shaped gears fitted onto fishing reels are a great success among world fishing enthusiasts and can be sold at nearly twice the price; this may appear to be a small innovation but has already made great contributions.

As Taiwan's high-tech businesses continue to improve their manufacturing technologies, many low-priced electronic products have quickly spread to lower-income countries. For instance, inexpensive cell phones make it possible for developing countries to enjoy the same conveniences as advanced countries. Also, Taiwan is the world's leading center for computer-making. Taiwanese notebook PC firms are cooperating with the United Nations and other nonprofit organizations to make inexpensive notebook PCs for children in poorer regions of Asia, Africa, and South America, to link them to the world.

These examples describe how Taiwan is using innovation to create economic value and raise the quality of life, at the same time narrowing the digital divide of third-world nations, improving the well-being of their people, and giving back to the international community.

2. Public Policies

In 1959, the Executive Yuan established the National Council on Science Development (predecessor to the National Science Council, or NSC) to be in charge of promoting scientific and technological

[19] White paper on Science and Technology (2007-2010); Meeting of the Executive Yuan; Jan 17, 2007 [[**Who is author/issuer (e.g.government). Once citation is complete, pls insert reference into text, citation into reference list. Please also fix remaining footnotes in this section.]]**

development. Over many years, the organization has undergone restructuring and change while establishing and refining Taiwan's S&T development framework and mechanisms for policymaking. In 1999, the government enacted the Fundamental Science and Technology Act, which lays out the directions and principles for promoting S&T in Taiwan and has become an important reference for S&T development.

The responsibilities for promotion of scientific and technological development in Taiwan are delegated among various government agencies: Academia Sinica under the Office of the President, and various agencies under the Executive Yuan including the Ministry of the Interior (MOI), Ministry of National Defense (MND), Ministry of Education (MOE), Ministry of Economic Affairs (MOEA), Ministry of Transportation and Communications (MOTC), Department of Health (DOH), Environmental Protection Administration (EPA), Atomic Energy Council (AEC), National Science Council (NSC), Council of Agriculture (COA), Council of Labor Affairs (CLA), and National Communications Commission (NCC). The government guides and implements policies on scientific and technological development though budget planning and execution at each agency.

Additionally, the Minister-without-Portfolio in charge of S&T affairs is responsible for coordinating efforts across different agencies. The first Executive Yuan agencies to designate specialized S&T administrative units were the MOE, MOEA, MOTC, and MND. In 1979, the Science and Technology Advisory Group (STAG) was established separately, and agencies thereafter began designating their own S&T promotion units such as the EPA's Office of Science and Technology Advisors, DOH's Science and Technology Unit, AEC's Department of Planning, and COA's Department of Science and Technology. Each is responsible for coordinating and integrating programs within their respective organization.

As for agencies that have not yet designated S&T units, the work of S&T development is undertaken by different units depending on the nature of the operation. Responsibilities for actual implementation of S&T development are shared by the research units of universities, research organizations, nonprofit organizations, and public and private enterprises.

Scientific and technological development can be divided according to the level of research into basic research, applied research, experimental development, and commercialization. Apart from playing the key role in directing S&T policy, the government also serves an important function in conducting upstream and midstream research in S&T development. Upstream research consists primarily of basic research conducted by Academia Sinica and colleges and universities under the MOE; midstream research mainly consists of applied research and experimental development conducted by the research units of government agencies under the Executive Yuan, the R&D departments of state-run businesses, and specially commissioned nonprofit research institutes; downstream research consists of experimental development and commercialization as conducted by private enterprises.

Currently in Taiwan, S&T policies are mainly formulated through important conferences such as the Science and Technology Meetings of the Executive Yuan, NSC Council Meetings, National Science and Technology Conferences, Science and Technology Advisory Board Meetings of the Executive Yuan, and the Industry Technology Strategy Review Board Meetings. The consensus reached at these meetings are used to guide the formation of S&T policies.

3. Regulatory Enablers

The government enacted the Fundamental Science and Technology Act to lay down fundamental guidelines and principles for promoting scientific and technological development. Portions of this

Act have been amended twice since enactment in 1999, primarily in response to evolving needs in S&T development and to remove restrictions no longer deemed necessary.

- Article 6 of the Fundamental Science and Technology Act originally provided that a juristic person or entity receiving government subsidies to perform procurement for S&T development shall not be subject to the regulations of the Government Procurement Act. After the Fundamental Science and Technology Act was implemented, however, it was discovered that more than two-fifths of the public agency R&D units conducting government S&T projects were unable to qualify for this exemption. To uphold the spirit of the Act, this provision has been amended to include public universities, public research agencies (organizations), state-owned businesses, and juristic persons or entities. Moreover, all S&T procurements by these entities are now exempt from the Government Procurement Act, regardless of the size of procurement.[20]
- Article 17 of the Fundamental Science and Technology Act originally specified that, to recruit outstanding scientific and technological personnel from abroad, necessary measures shall be taken to ensure the quality of living and working conditions for an appropriate period of time. But because these provisions did not cover education benefits for the children of foreign professionals, many were still reluctant to relocate to Taiwan. Therefore, the article was amended allowing the MOE to pass regulations and create suitable education environments for these children, thereby providing more attractive incentives for outstanding foreign scientists and professionals to work in Taiwan.[21]

To protect the nation's sensitive scientific technologies while ensuring national security and industrial development, the NSC drafted the "Sensitive Scientific Technologies Protection" bill, currently in review at the Legislative Yuan. After ratification, this law will be able to guard national security and public interest while maintaining Taiwan's competitive advantages in S&T. Under this bill, information on sensitive scientific technologies that are critical to national security and public interest shall be managed by the competent authorities, and may be publicly disclosed after approval by the Executive Yuan. And in case of unlawful infringement on sensitive scientific technologies, the rights owner may report the matter to appropriate authorities for assistance.

In order to achieve the full spirit of the Fundamental Science and Technology Act, the regulatory environment still needs to overcome various bottlenecks. For instance, Taiwan needs to loosen the personnel affairs system at colleges and universities, create regulations to oversee researchers at government research institutes working concurrent jobs, transform government sector research institutes into administrative corporations, and build more flexibility into the S&T personnel hiring system. Breaking through these barriers will help improve the flow of S&T talent among industry, government, academia, and the research community.

4. Human Resource and Institutional Capacity-building Strategies

The NSC employs the following approaches in cultivating scientific and technological talent:

- The NSC provides financial funding for principal investigators to hire research assistants and nurture basic research skills.
- Each year, personnel from local universities or research institutions are selected to go abroad and participate in foreign research projects or to train in S&T.

[20] White paper on Science and Technology (2007-2010); Meeting of the Executive Yuan; Jan 17, 2007
[21] White paper on Science and Technology (2007-2010); Meeting of the Executive Yuan; Jan 17, 2007

- The Post-Doctoral Research Program encourages recent doctoral degree recipients with demonstrated potential to participate in research projects and cultivate skills and experience.

Recruiting S&T personnel

Funding is given to colleges, universities, academic institutions, and government agencies to recruit specialized experts or research teams in Taiwan or from abroad. These personnel participate in research projects, teach in specialized fields, or assist in R&D or management work.

Rewarding S&T personnel

In 2001, the Office of the President established the Presidential Science Prize to recognize innovative scholars who have made significant contributions at international levels in mathematics, physical sciences, life sciences, applied science, and social sciences. This award is the nation's highest academic honor and conferred once every two years upon scientists who make outstanding contributions to Taiwan society. The NSC organizes the nomination and selection process for this award.

In addition, the NSC recognizes individuals with special contributions in S&T innovation with the Executive Yuan's Outstanding Achievement in Science and Technology Award. To encourage scientific and technological personnel with outstanding research results, promote long-term participation in academic research, and enhance the country's academic standards and international standing, the NSC established the Outstanding Research Award. The NSC also grants the Ta-You Wu Memorial Award to encourage new researchers entering the field. In 2004, the NSC established the Outstanding Industry-University Cooperation Award to recognize outstanding principal investigators of industry-university research projects.

5. Promoting S&T Interchange and Cooperation

To encourage scientific interchange between S&T personnel on both sides of the Taiwan Strait, the NSC has taken the following steps: fund key researchers from the Mainland for short-term visits to Taiwan, recruit Mainland Chinese scientists to conduct research in Taiwan, provide funding for Taiwanese scholars and specialists to visit the Mainland for short-term scientific research, and sponsor S&T conferences for participants from both sides of the Taiwan Strait.

The NSC has signed 69 cooperation agreements with top S&T organizations in 37 countries to foster interchange among researchers, organize joint conferences, and conduct cooperative research projects. The NSC has also established practical channels for exchange through high-level visits and trade conferences. These efforts support the government's foreign policies and help promote S&T diplomacy.

To stay abreast of international cooperation trends and to enhance Taiwan's foreign relations, the NSC also participates in the activities of international S&T organizations, global cooperative programs, and major national or international laboratories.

Additionally, the NSC established the Tsungming Tu Award in 2006 as the highest academic award granted to foreigners. This award is established in conjunction with reputable academic organizations in other countries and conferred in a reciprocal manner. The first such award was granted in 2007 in cooperation with the Alexander von Humboldt Foundation of Germany.

To increase the depth and range of Taiwan's international S&T cooperation and to promote its academic achievements to the world, the NSC actively encourages Taiwan research teams to participate in the activities of international S&T and academic organizations. Funding is provided for teams to participate in the meetings of international organizations, for scholars or graduate students to attend international conferences, for groups to hold international seminars, and for overseas professionals to visit Taiwan.

Additionally, the NSC also provides subsidies for S&T personnel to conduct research at overseas universities or research organizations; this is intended to enhance the capabilities of Taiwan's education and research personnel as well as to broaden their global perspectives.

The NSC's overseas S&T divisions serve as Taiwan's gateway for scientific exchange with the world. In recent years, the NSC has been establishing more divisions and building closer networks for S&T exchange. Currently, the NSC oversees 16 S&T divisions in 12 countries around the world, all of which contribute significantly to Taiwan's overseas S&T cooperation and foreign diplomacy efforts.

Apart from establishing broader international cooperation and collecting technological information from host nations, the S&T divisions also maintain contact with overseas scientists. Responding to domestic development needs, the divisions are actively recruiting overseas professionals to meet the nation's demands for S&T manpower.

In 2005, the NSC launched the Taiwan Tech Trek program for youths of Taiwanese ancestry living around the world. The program provides summer internship opportunities at national laboratories, research institutes, science park companies, and universities all across the island. The aim of the program is to build a strategic liaison with new generations of overseas Taiwanese and increase their understanding and support for Taiwan.

6. Infrastructure: Science Parks, Intellectual Infrastructure and Connectivity

Perhaps Taiwan's greatest strength today is the infrastructure it built to promote the development of S&T. According to the IMD *World Competitiveness Yearbook* released in May 2006, Taiwan placed 18th in the overall ranking and 20th in Infrastructure.[22] Under the Infrastructure factor, Taiwan ranked fourth in Technological infrastructure and fifth in Scientific infrastructure, two indicators of the nation's true scientific and technological capabilities.

The Hsinchu Science Park and the Science and Technology Advisory Group (STAG) provided the foundation for Taiwan's S&T infrastructure development. STAG institutionalized linkages between the state, industry, education, and advisers. From the early 1980s, virtually all state ministries and institutions were held accountable to STAG. The Hsinchu Science Park became a resounding success as a single location within which both state-owned institutes and foreign- and domestic-owned private enterprises shared technologies and worked together to improve Taiwan's high-tech industrial capacity (see Table A.3). Hsinchu, in fact, became a model that Taiwan tried to replicate in other locations in the 1990s.

Table A.3: Growth of Science Parks in Taiwan

Item	2001	2002	2003	2004	2005
R&D Expenditure (NT $ million)	46,000	46,530	50,404	57,090	71,002
Sales (NT $ million)	711,583	807,300	1,011,658	1,343,874	1,398,919
R&D expenditure / sales %					
Among science parks firms	6.5	5.8	5.0	4.2	5.1
Among all manufacturers nationwide	1.26	1.30	1.28	1.24	1.33
Employees	105,782	113,105	122,004	146,613	159,048

22 http://www.imd.ch/research/publications/wcy/index.cfm

Source: Taiwan National Science Council (**DATE**)

Science parks

Taiwan’s science parks combine R&D, production, working, living, and recreational facilities into life-style oriented communities. As magnets for high-tech industries and manpower, the science parks build technological expertise, balance regional development, and advance Taiwan's industry.

For more than two decades, the science parks have continually raised the bar for technological progress in Taiwan. With a wealth of experiences in successful production and technology dissemination, the parks have not only improved the nation’s industrial structure and economic prosperity, but also made a name for Taiwan's technology around the globe.

Taiwan currently has three core science parks located in northern, central, and southern Taiwan.

The Hsinchu Science Park

The Hsinchu Science Park was established in 1981 as the first of Taiwan’s science parks. Since its inception, the government has invested heavily in its facilities and infrastructure. The park has expanded swiftly thanks to convenient transportation, attractive working environments, and its proximity to National Chiao Tung University, National Tsing Hua University, and the Industrial Technology Research Institute.

As land use in Hsinchu Science Park is currently close to saturation, the government is working quickly to develop sites in Tungluo, Longtan, and Ilan, and constructing the Hsinchu Biomedical Park to accommodate the needs of growing industries.

Companies in the Hsinchu and Chunan parks are mostly concentrated in the six main industries of integrated circuits, computers and peripherals, telecommunications, optoelectronics, precision machinery, and biotechnology. The Tungluo site will focus on developing the integrated circuit design, advanced packaging and testing, digital living, avionics and aerospace, and biotech pharmaceutical industries, as well as establishing a Hakka cultural park.

The Longtan site is expected to focus on the optoelectronic industry. The Hsinchu Biomedical Park will concentrate on pharmaceuticals and high-end medical equipment. This site will also house an epidemic control center, an innovation incubation center, biotech factory buildings, and a zone for private corporations. The Ilan site will be the first park in Taiwan devoted to telecommunication and knowledge services, with companies providing services in cultural innovation, digital content, information software, telecommunications, financial services, and medical insurance. The Ilan Park is expected to become an important base for the next industrial revolution in Taiwan.

The Hsinchu Science Park experienced negative growth for the first time in 2001, primarily due to the global economic slowdown and broader impacts from the events of September 11, 2001, in the United States.

Southern Taiwan Science Park

The NSC began developing the Southern Taiwan Science Park (STSP) in 1997 as the second science park in Taiwan after Hsinchu. STSP has been designed to complement the unique characteristics of southern Taiwan while merging working, living, and environmental facilities into a high-quality science park. After several years of development, STSP now includes the Tainan Science Park and the Kaohsiung Science Park.

Tainan Science Park’s main industries include optoelectronics, integrated circuits, precision machinery, biotechnology, telecommunications, and computers and peripherals. This park is currently the most comprehensive location for the vertical integration of Taiwan’s optoelectronics industry, providing a full range of parts and services from upstream components to midstream panels and downstream applications.

Within the integrated circuit industry, this park offers the most sophisticated 12" wafer fab nanometer copper processing technology on the island. Kaohsiung Science Park has planned a biotech medical devices and equipment zone that will draw on the R&D resources of Academia Sinica, National Cheng Kung University, National Chung-Cheng University, and the National Laboratory Animal Center. And with the advantage of being near to Kaohsiung's precision machinery industry, the park is forming an industrial cluster for orthodontic, orthopedic, and microelectromechanical medical devices. The park will also form a telecommunications cluster by attracting telecom companies and harnessing the R&D capabilities of the MOTC Telecom Technology Center, the Industrial Technology Research Institute, and local universities. And with the R&D capabilities of the Institute of Nuclear Energy Research and the Metal Industries Research and Development Center, this science park will promote green energy industries and drive the growth of another trillion-dollar industry.

Central Taiwan Science Park

The Executive Yuan approved the development of the Central Taiwan Science Park (CTSP) in 2002 as the third science park after Hsinchu and Southern Taiwan. During the development process, companies were allowed to build their own facilities at the same time as the government's construction of the park.

As a result, companies were able to move in as early as July 2003, setting a new record for efficiency in science park development. Currently, CTSP includes the Taichung Park, Huwei Park, and Houli Park.

CTSP is in the process of developing a high-tech cluster for nanotechnology applications by drawing on central Taiwan's precision machinery industry and attracting companies in integrated circuits, optoelectronics, and biotechnology. The Taichung and Houli Parks focus on integrated circuits, optoelectronics, and precision machinery in the hopes of forming a major world hub for 12" wafer fabs and building an advanced center for optoelectronics and precision machinery. Meanwhile, the Huwei Park is focusing on biotechnology and aiming to generate a trillion dollars in production value after the park's completion in 2012. Looking ahead, CTSP plans to bring together the resources of academic and research institutes in central Taiwan to build a high-tech science park specializing in innovative research and development.

7. High Bandwidth Connectivity

Taiwan has rapidly become a significant player in broadband Internet access. The government has successfully promoted the benefits of broadband and has committed to being on a par with the United States by 2010.

In May 2002, the Taiwan government had announced its Challenge 2008, a Six-year National Development Plan to transform itself into a high-tech service island. The plan involves a budget of NT$2.6 trillion (approximately US$75 billion) (National Science Council of Taiwan, 2008). One of the objectives of this plan was to develop a "Digital Taiwan." To this end, there were five goals that had been set for achieving this, with one of the most important aspects of the plan being to install broadband Internet in every household, with a view to reaching 6 million households by 2008.

The four fixed networks had planned to invest a total of NT$364.4 billion (US$10.5 billion) in broadband deployment between 2002 and 2007.[23] The Directorate General of Telecommunications (DGT) had been asked to play an active role in opening up the telecommunications market, deregulating the unnecessary rules and controls, lowering the entry barriers, maintaining market order, providing a stable and competitive environment, and removing the obstacles to the broadband infrastructure.

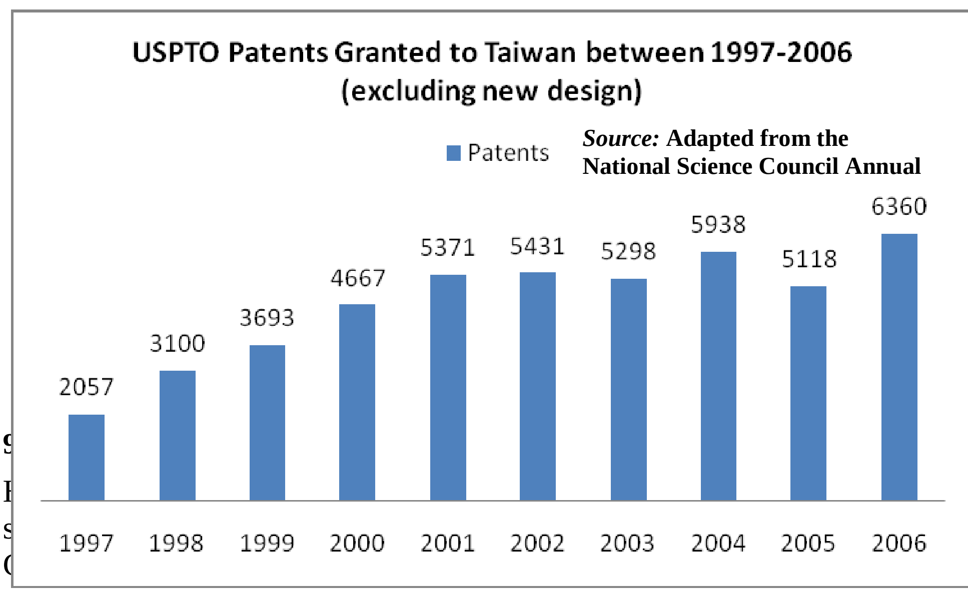
By end of 2008, Taiwan had 7.1 million broadband connections and 15.1 million dial-up Internet connections. The number of mobile Internet subscribers also grew from a non-existent base in 2001 to almost 15.3 million in 2008.[24]

8. Intellectual Property

In a 2000 Trade Commission report, Taiwan was listed as one of the largest sources of pirated copyright material in the United States and in the 1990s labeled as a "Pirate Kingdom." Yet today, it stands in fifth place in terms of the number of patents granted by USPTO (see Figure A.3). How did this transition happen? What were the critical interventions made by the government that led to such a transformation in the country's IP profile?

Taiwan's government has played a key role in the development of Taiwan's IP. Entry into the WTO, demanded by Taiwan's economy, spurned great changes in its IP creation and litigation laws to meet WTO's TRIPS requirements. Taiwan's recent IP legislation centers around the Taiwan Science and Technology Basic Act, produced in 1999 and enforced in the early 2000s. An attempt to copy the U.S. Bayh-Doyle Act, it allows R&D labs and research universities to commercialize their R&D results. It has been successful in creating a physical IP marketplace, centered on technology licensing and sales. Much of this has been exercised through the Industrial Technology Research Institute's new Technology Transfer Center, created partly as a result of this reform.

Figure A.3: Taiwan's Growth in Patents



9 … arning Opportunities

F … ne business enterprise s … sector (see Table A.4). C … activities.

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23 National Communications Commission

24 National Communications Commission

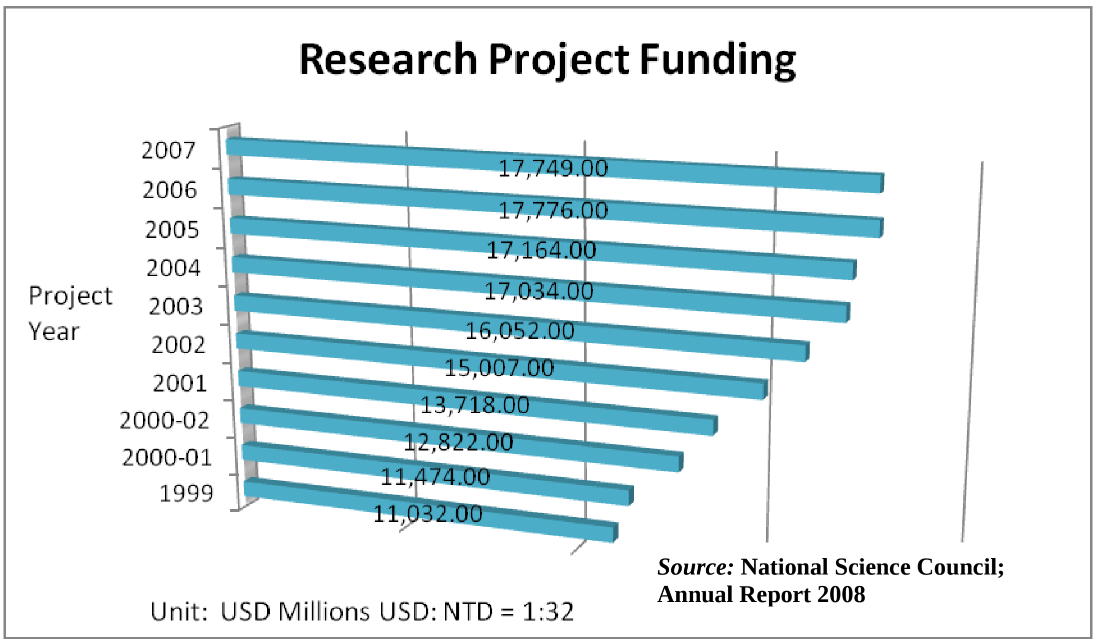
Table A.4: Growth in R&D Investment as % of GDP

Item	2001	2002	2003	2004	2005
Gross domestic expenditure on R&D	204,974	224,428	242,942	263,271	280,980
Growth rate%	3.7%	9.5%	8.2%	8.4%	6.7%
As a percentage of GDP (%)	2.08	2.20	2.35	2.44	2.52
Sector of performance					
Business enterprise sector	130,296	139,569	152,614	170,293	188,390
Government sector	47,732	55,693	59,928	61,144	59,143
Higher-education sector	25,521	27,637	28,890	30,350	32,092
Private nonprofit sector	1,425	1,530	1,510	1,484	1,355

Source: NSC (2006)
Note: Defense R&D expenditures were added beginning 2002, and other new industries were added starting 2003.

Within business enterprise expenditure on R&D, Taiwan's high-tech and ICT industries expenditures on R&D have grown steadily from 2001 to 2007 (see Figure A.4). As a percentage of business enterprises expenditure on R&D, spending by the high-tech and ICT industries accounted for 72.35 percent (NSC, 2006).

Figure A.4: Growth in Research Project Funding as a Result of Growth in ICT Industry



Source: **National Science Council; Annual Report 2008**

****Note***: In accordance with government conversion from fiscal-year to calendar-year accounting, budget year 2000 covered the second half of 1999 and all of 2000. During this time, the NSC approved projects for two full academic years (shown as 2000/1 and 2000/2) and adjusted project start and end dates accordingly.

Government funding for S&T Programs: National Science Council (NSC)

NSC support for domestic S&T research primarily takes the form of grants for educational and research institutions to conduct research projects. Proposed research projects must pass through two stringent rounds of review; if approved, projects can receive NSC financing for research personnel, equipment and facilities, books and references, consumable materials, and overseas travel expenses.

Individual research projects

An individual research project is submitted by a single researcher according to his or her field of expertise, or in line with the NSC's planned research topics.

Integrated research projects

An integrated research project consists of one main project and several subprojects, and focuses on the NSC's research topics. A chief investigator may propose a multidisciplinary or interuniversity project, or form a group of integrated projects around a specific topic.

In addition to financial funding, the NSC provides other assistance to encourage researchers to form teams and establish centers of excellence, thereby drawing the maximum benefit from available resources.

National S&T programs

Since 1997, the NSC has been promoting national S&T programs to address major socioeconomic and livelihood issues in Taiwan. Currently, the national S&T programs cover telecommunications, agricultural biotechnology, biotechnology and pharmaceuticals, system-on-chips, e-learning and digital archives, nanotechnology, and genomic medicine. These programs combine the efforts of multiple government agencies for the purposes of training S&T personnel in key areas and boosting national competitiveness.

Program for Promoting Academic Excellence of Universities-Phase II

To further develop research results from the MOE Program for Promoting Academic Excellence of Universities, the NSC began promoting the second phase of this program in 2003. With US$93.8 million in funding for 2004 through 2009, Phase II will encourage cooperation and exchange among domestic researchers, integrate national resources, and reinforce areas of academic strength.[25]

Industry-university cooperative research projects

In 1991, the NSC began promoting industry-university cooperative research projects for the purposes of harnessing the abundant R&D resources of universities, helping companies raise innovative design capabilities and improve manufacturing processes, and training more S&T personnel with practical experiences. Aside from NSC subsidies to encourage academic involvement, the participating companies also contribute a fixed percentage of research expenditures, provide facilities, or send personnel to implement the projects.

This mutually cooperative model has not only raised Taiwanese companies' capabilities to develop cutting-edge technologies, but also strengthened the management of R&D results and intellectual properties, thereby raising the overall competitiveness of Taiwan's industries.

Application of R&D results

In principle, research results arising from an NSC-funded project belong to the project-implementing organization, which also manages and promotes the results. The NSC also provides awards, grants, and other incentives to help educational and research institutes build R&D results promotion and application mechanisms so that they can quickly disseminate their new technologies.

[25] National Science Council of Taiwan - Annual Report 2008

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