Technology and engineering in India: The past and the way ahead*

V. K. Aatre

India has turned 50 and this is the time for looking back on the fifty years. Though history indicates that migration of certain medical, architectural, textile and engineering science and technology took place to the West, today's technological scenario in India leaves a lot to be desired. We are much below the world average in several parameters. Our S&T vision and push is yet to yield commensurate results. This paper analyses the reason through our performance figures in several areas of engineering and technology. Our strengths, weaknesses and educational standards are also presented. Finally, the paper stresses the need for identifying core competencies for our industries and sets forth the future ambitions of bringing welfare, workforce and wealth to the nation.

INDIA is blessed with some of the best intellectual might, rich natural resources (some of its resources are yet to be tapped fully) and proud heritage of cultivating science and technology. We have been traditionally strong, from ages past, in the areas of concept, analysis, logic, and validation (*Tharka Shastra*). The people of this country have been taught the ways of life through Vedas, governance by Kautilya's *Arthashastra*, surgery by Shushrutha, and have had the tradition of excellent teachers (and teaching methodologies) be it in philosophy, literature, wargaming, medicine, applied sciences or architecture. Our temples and monuments speak immensely of our skills in metallurgy and architecture as is evidenced by techniques that helped us build such gigantic monuments like the temple of Konark, monolithic statue at Shravanabelagola and rustless iron pillar at Delhi. Remains of such marvels of engineering are still around reminding us of our glorious past.

Yet, as we trace the growth of technology and engineering (T&E) since the Industrial Revolution, we seem to have missed several of the revolutions. As we survey the developments based on science, technology and engineering that have taken place over the last fifty years of independent India, it leaves a lot to be desired; we keep hearing that the growth in our infrastructure has been slow and not keeping pace with the requirements, industrial production and product quality are not in league with the imported ones and so on. No doubt we possess excellent workforce of highly-skilled and technically-competent personnel capable of delivering the best, if we choose to perform. We have done creditably in textiles, steel and chemical industries and more recently ventured into petroleum, electronics, communication and information technologies. On the education front, we have good institutions in science, technology and engineering – training graduates, in substantial numbers, who are sought-after by the West and the East. Notwithstanding these, we have still not reached a level to consider ourselves a developed country. As we celebrate the Golden Jubilee of our independence, it is good to look back and evaluate where we are and what we have to do in the coming decades to become a developed country. In this article we present certain aspects of technology and engineering, our standing and achievements and our way ahead.

Our standing

Science and technology lead to development, and all round development leads to progress in the quality of life and national stature. Clearly, technology and engineering of a country serve as barometers of its wealth, which, to a great extent, influence the human development. While technology constitutes the intellectual assets, the ultimate engineering effort, which translates the former to the real world through structures, manufactured goods and the like has direct bearing on the wealth of a country and the quality of its life. The Human Development Index (HDI), as defined by UN, measures this development. This index is estimated on three major parameters: life expectancy, literacy and GDP of a nation. India at present is registering a value of 0.436 (against 0.609 for China and the world average of 0.746), ranking 135th place on the world map. While

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we compare favourably on the life expectancy and literacy scales with China, we lose out to China in the GDP, almost by a factor of two.

Independent India's economy started out basically as agro-based; but, from mid-1975 onwards there is definitely a shift towards greater industrial output. Table 1 and Figure 1 give some indications of our industrial production. Industrial growth in 1997–98 has declined and presently the figure stands at about 4.7% (April–Sept. 97). While we have made great progress over the last fifty years, there is certainly a lag in industrial-based growth. A glance at our weakness in policies, resources and people is essential to learn the lessons that history has taught us these last fifty years.

Our weakness

Some of the technology gaps that existed at the dawn of independence were bridged mainly by importing technology through technology transfer and licensed production. This resulted in mainly acquiring product-oriented knowledge and process know-how rather than 'know-why'. This has contributed minimally to our technology base. During this period, imitative and reverse engineering processes were the order of the day. No real attempt in inventing new technologies or innovating on the technologies imported, was carried out. Government being the major operator in the capital-intensive industrial sector, there were no viable partners from the private entrepreneurs. Any serious R&D work related to technology was institutionalized under the Government, with scope and applications not necessarily being governed by commercial propositions. Also, we witnessed a lengthy period of protective market economy and noncompetitive environment which led to complacency and dormancy in our attitudes. With consumers not having many choices in the selection of products, quality and standardization were given a go-by. Productivity in the industrial sector was low with social priorities in the labour sector being more compelling. With diminishing opportunities for challenging work in home-grown technologies, we found it hard to retain our intellectual and trained manpower. Our top universities became the training grounds for feeding manpower to the technologically-advanced western societies.

This era also witnessed global transition from 'steel age' to 'silicon age' and we were technologically left behind to a large degree. Our inadequate research base in material technology prevented us from venturing in to the development of new silicon devices thrown up by this transition. We are even today largely dependent on import of sophisticated electronic devices and the prediction for 2000 AD and beyond is not very encouraging.

When we evaluate the first 50 years of our independence, there are many other factors to be considered. Our economic growth has been mostly urban-based which has increased the disparity between the urban and the rural population. Exodus into city has created problems of unemployment, housing, hygiene and crowding. Infrastructure growth is not sufficient to keep pace with the demands of our cities and that of the modern world. Our service sectors are rather poorly organized. As a result, industrial developments are mostly seen to be confined to urban areas instead of spreading over the length and breadth of the country. The result is a steady increase in the input costs to all industrial ventures.

Yet another serious lacuna is the absence of knowledge base regarding our core technology strength. From experience elsewhere in the world, for an industry to succeed it is essential that it attaches itself to a clearly defined core competence. We have not seriously evolved any formal process for evaluation of such strengths or consolidation of our strengths to reach excellence at the international level.

Table 1. Industrial production index (1980–81 = 100%)

	1960	1970	1980	1990	1997
Mining	48	68.5	100	221.2	258.8
Manufacturing	42	69.7	100	207.8	299.4
Electricity	17	52.1	100	236.8	356.6
Others	40	67.9	100	121.6	292.5

Source: *India's Industrial Sector*, CMIE, Jan. 1996 and *Hindustan Times*, 5 October 1997.

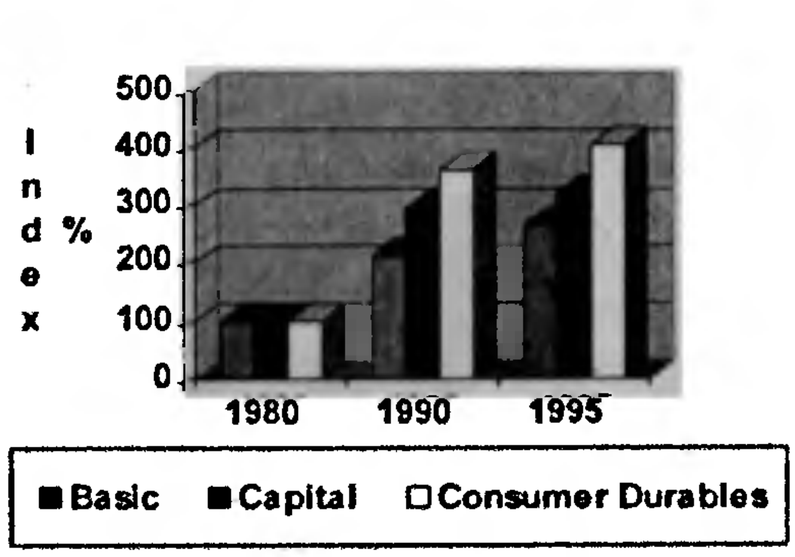

Figure 1. Production index (manufacturing) (1980–81 = 100%). Source: *India's Industrial Sector*, CMIE, January 1996.

Our progress

In spite of the enumerated weaknesses and problems, we have made commendable progress in several sectors which have helped India improve its GDP and the recent liberalization and other Government policies are bound to have positive impact in further improving our HDI index. Let us ascertain now our performance in a few of the major sectors as: energy, steel, electronics, related

infrastructure, service industries and education which are important from the point of view of T&E:

Energy

India has limited natural resources in oil and natural gas; but has only exploited 18% of its hydro power resources and 10% of coal reserves so far. Electricity generation growth rate is presently around 7% with a large gap between demand and supply. Eco-friendly energy generation with sufficient capital investment and efficient distribution of power can change the industrial scenario in the country. Economic development and per capita energy consumption are linked rather closely. For comparison, if we consider per capita energy consumption in India as unity, then the consumption in USA is 33 units, in Japan 11 units, in China 2.5 units and in Indonesia 1.3 units. Our energy sources are appx. 60% coal-based, 10% crude-based and about 27% are based on hydro power. Nuclear power generation accounts for less than 3%. Industrial consumption of power is around 42%–46% and this has remained so for the last 6 years.

Steel

The industrial age has stressed the development, production and consumption of steel as a bench mark of progress. In 1996, out of 96 steel-producing companies (of capacity 2 MT/year or more), SAIL, TISCO and RINL occupied 7th, 64th and 85th positions, respectively. But out of the first 10 companies in the world, five are from Asia. We occupy 10th place as a steel-producing country with China at the top position. Though labour cost is comparatively low (0.34 times the cost in USA), the input cost of steel industry is driven high by energy charges (1.4 times the cost in USA). India's consumption of steel is at a level of about 43% of that of China and pegged at a level of 17% of the world average. Annual growth rate in consumption in India has been only 4.4% between 1989–1995. Our construction industry consumes about 25%, automobile 20%, mechanical industry 20%. Recently the automobile industry with reduced content of steel has increased the demand for various kinds of advanced alloys and composites. Nevertheless in India, construction and automobile industries are the two major consumers of finished steel. Still our position as 'steel consumer' is not very good (as per the 1990 statistics our per capita consumption is 26 kg compared to 802 of Japan, 506 of South Korea, 60 of China and a world average of 149 kg).

Electronics

This is one of the world's largest and fastest growing industries. For quite some time, the industry was the exclusive province of advanced western economies. But since about 1965 with Japan's emergence in the field, there has been a shift in this tendency. Today Hong Kong, South Korea, Taiwan, Singapore, China and also India claim share in this industry. Our initial thrust in this sector was mostly defence electronics. With the Electronics Commission being set up in 1971, a planned development was seen in the country. During the initial phase, public sector units were set up to meet the primary need of the country and at the same time to limit the influence of the multinationals in this sector. Now, the electronics industry is influencing almost all areas – mass communication, telecommunication, transport, oil, power, service sectors – a never-ending list. Electronic industries received a boost in the VII Plan period (during this plan period the entertainment electronics exceeded the target by 170%). But still in the context of global share, our output was only 22% of China's. Most of the R&D effort was supported by and centred around the Government while no real attempt was made to become self-reliant in components and devices. As for semiconductor devices, it is estimated that even at the turn of the century the gap between demand and supply within the country will be of the order of 70%.

There are broadly seven major electronic industry sectors: consumer electronics, communications, industrial, strategic, components and computer H/W and S/W. (defence electronics is considered as a part of strategic electronics). Our growth rates in these fields are shown in Figure 2.

In the field of semiconductor processing, national effort has established 1 μ capability in silicon technology. Presently we have embarked on GaAs technology for fabricating MMICs. Adequate design capability in VLSI/ASICs and access to indigenous foundries exist to meet some of the domestic requirements. However, to graduate to the latest semiconductor technology and make our foundries economically viable, we have also

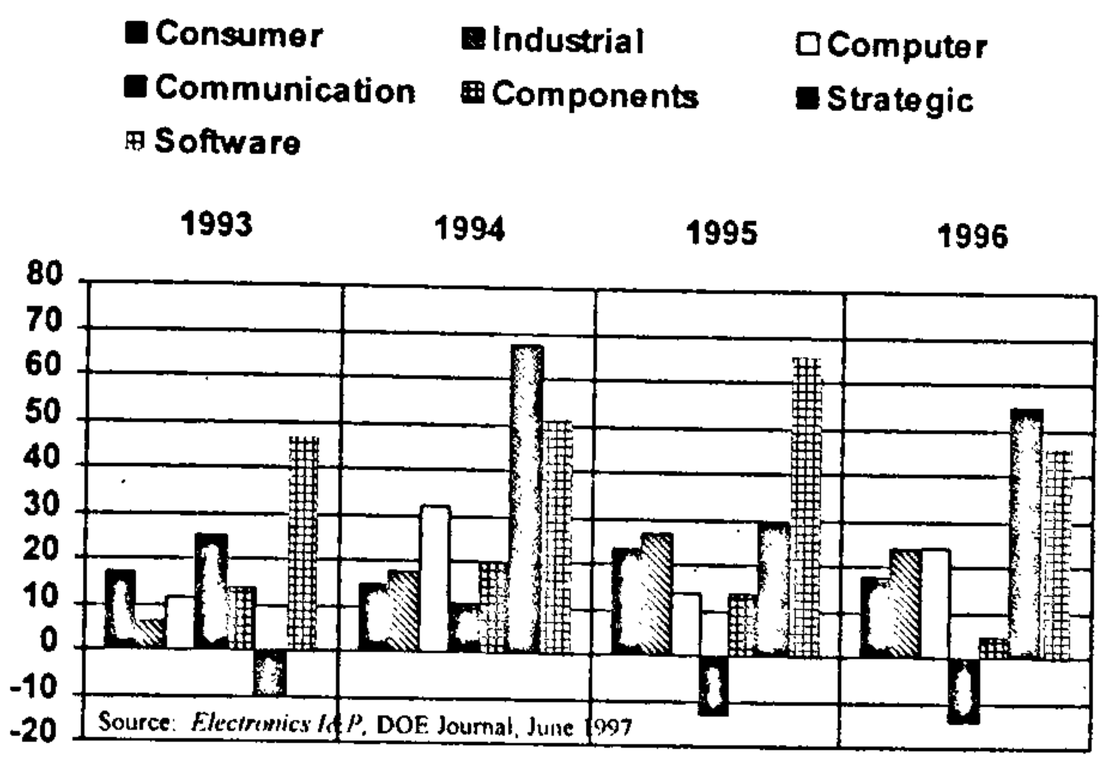

Figure 2. Electronics production growth (%).

to look for international markets in VLSIs.

In the field of mass communication through TV networks (thanks to the Indian space programme), and radio, we have done very well with television and radio, reaching far corners of the country. In the telephone and personal communication field, the recent spurt in growth is certainly going to be helped by the more recent liberal policies of the Government. Various kinds of other services like E-mail, FAX, Internet and ISDN services (limited) are on the increase.

The technological breakthrough which has influenced almost every corner of the society is the introduction of IBM computing machines (and compatibles) – so-called PCs. During the last decade we have seen a tremendous growth in networking and inter networking these computers, thereby bringing in the concept of 'home office'. The Internet and the fast-spreading World Wide Web are becoming the major facets of the IT revolution across the globe. Fortunately we seem to be almost in synchronism with the happenings elsewhere in the world in these areas. In the third area which is spreading like wild fire, viz. the software industry, the picture is very promising. S/W exports have grown from Rs 430 crores in 1991–92 to Rs 2550 crores in 1995–96 period. Technology parks set up at Pune, Bangalore, Hyderabad, etc. have tremendously helped in getting some of the world best companies to invest in India. Such an industrial growth is a good sign and we can hope to cash in on our software potential to become one of the market leaders.

Support structure for T&E in India

During the initial decades of independent India, the Government which was the major developer of infrastructure, concentrated mainly on the agricultural front: building dams, canals, major/minor irrigation systems, food processing, preservation and storage. Foundations for other infrastructures like railways, roads and bridges, ports and air ways were indeed laid during the days of 'British Raj'. Though these have received considerable attention ever since, the progress made in several of these, due to paucity of funds for such capital-intensive activities, is inadequate. Coupled with not-so-adequate availability of power, electronic communication systems, the insufficiency of infrastructure development has been the main factor in the slow growth of technology and national wealth induced by such technology. In the absence of any significant participation by the private sectors and Government's other priorities, the growth in infrastructure may well impede major advancements in T&E.

Services

A considerable part of the recent developments that are taking place in S&T, like in information technology, have elevated the service sector to a dominant position. Most of the services in India today like postal, banking, insurance, health, communication, electricity, etc. are controlled by the Government. As such there is neither competition nor consumer awareness in this sector, resulting in lack of cost effectiveness of the services rendered. For instance, India's energy cost per unit continues to be one of the highest in the world (with poor availability). The slow progress and quality in the service sector does reflect adversely on the T&E progress otherwise made in our country. Table 2 indicates our comparative positions in socio-technological areas with some of the advanced countries:

It is interesting to note that 41.5% of India's GDP (*India Today*, 9 December 1997) is contributed by the service sector consisting of hotels, banking, communication and public administration where the impact of modern technology in terms of electronics and communication and IT are not yet fully felt and the quality of service expected from these sectors has not been fully realized. Our service-oriented industries, both in Government and public/private sectors, are in the process of establishing quality through ISO certifications. But the overall awareness among the Indian population to pay for the product and service quality is yet to be felt and appreciated.

Education

Besides the requirements of infrastructure, funding, etc. progress in T&E requires one other critical resource – qualified and trained manpower. India has an unique asset – a large number of trained technicians, well-qualified scientists, technologists and engineers. Our strength in scientific and engineering manpower has grown substantially from 0.05% (1958) to 0.68% (1996) of population (Figure 3).

With our society valuing academic qualifications as proof of intellectual attainment and also as a gateway for better employment and social status, there are over 204 universities, including deemed universities, and 8613 technical institutions (1994 estimate) spread all over the country providing quality education and hands-on training to more than 6 million students. Growth of enrolment

Table 2. Position in socio-technological areas

Factor	Rank for India	1st	2nd	3rd
Infrastructure	48	Hongkong	Singapore	USA
Technology	36	Singapore	USA	Finland
Management	38	USA	Sweden	Canada
Labour	30	Hongkong	Singapore	Taiwan
Overall competitiveness	45	Singapore	Hongkong	USA

Source: *Business Today*, 7-21 August 1997

in science, engineering and technology (higher education) itself is about 85% (Figure 4). Beside 300 universities granting engineering degrees, there are six Indian Institutes of Technology (five of them founded between 1950 and 1961) and Indian Institute of Science imparting internationally recognized education in T&E. Unfortunately West-ward exodus of such graduates, the problem of brain drain, has somewhat diluted the impact of these institutions on Indian T&E fraternity.

However, compared to the IITs and IISc, a large number of universities and engineering colleges are not so comfortable with the quantum of financial resources, leading to certain frustration in academic life in India. Added to this, our present society does not recognize the importance of competent and professional teachers and of maintaining well-equipped technological institutions. We also suffer from poor recognition (hence, of low esteem) of scientists and T&E personnel in the context of national stature.

Our way ahead

Our Nation is beset with some peculiar problems – a large and fast-growing uneducated population (our literacy rate is pathetically low) with diversity in many aspects of religion, customs, languages, food habits, etc. While during the initial years of freedom, the country tackled the problem of food and agriculture to feed the underfed and undernourished millions, we are now forging ahead to solve other problems with thrust in science, technology and engineering. Any technology in India has to necessarily cater to its diverse requirements – large rural population (which is going to remain so, for some decades to come) with great propensity for urbanization, cohabitation of luxury cars with bullock carts, large population with not even primary education to a large pool of world-class scientists and technologists, cottage industries with almost pre-industrial revolution technology to sophisticated computer and IT-driven technologies, remote areas with apologies for basic infrastructure to cellular phone-based urban centres, thatched huts with little water, electricity and other facilities to 'five star' and 'intelligent buildings'.

Clearly selection of technologies to cope with such diversities has to be done wisely, chosen not by mimicking western technologies (it is true that technology is like a steam roller); but, by identifying appropriate technologies which generate wealth for the country (thus pushing up the GDP and the resulting HDI), and improve the quality of life. At the same time, these technologies should be socially relevant like being eco-friendly, labour intensive, etc. For instance, on the critical infrastructural front of energy, we may have to ponder over non-conventional energy sources like biogas (suitable for rural areas and small communities), solar/wind (for remote areas), nuclear for industrial and urban energy hungry regions.

Though the productivity in our industries is growing, there is a crying need for us to identify 'core competencies'. Today there is no clearly defined core competence for most industrial houses resulting in India not being able to identify a product which is a world beater. Of course, the choice of and 'building' on such competence needs leaders with vision (at least technological vision) and managers who can groom and motivate the vital human resource needed to achieve excellence (it should be clear to all of us that there is no dearth of competent S&T personnel in India).

We have to once and for all accept that we cannot be global players and strong contenders on the 'technological front' by continued import of technology. Our strength has to be built on either home-grown technologies or innovations on 'once imported' technologies. Thus there is an imminent need for investments on in-house R&D by the industrial houses. At present the R&D scenario in India is not very good as only 0.81% of GNP is spent on R&D (*Economic Survey*, 1995–96

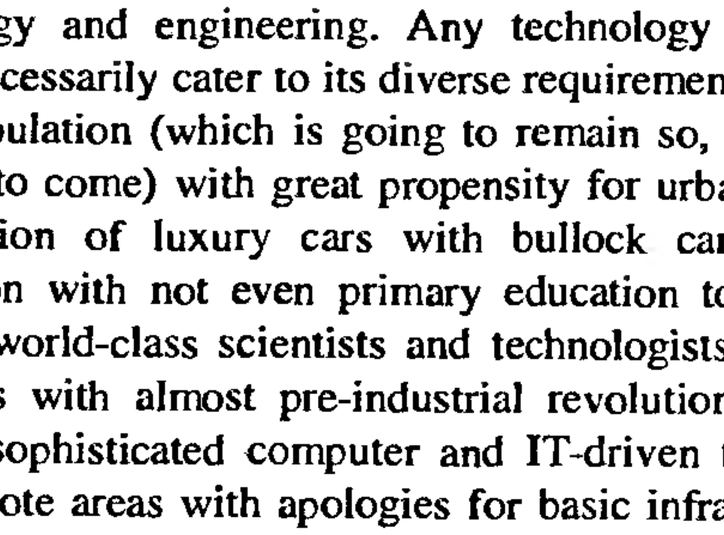

Figure 3. Science and engineering. Manpower growth. Source: *S&T Data Book*, 1995.

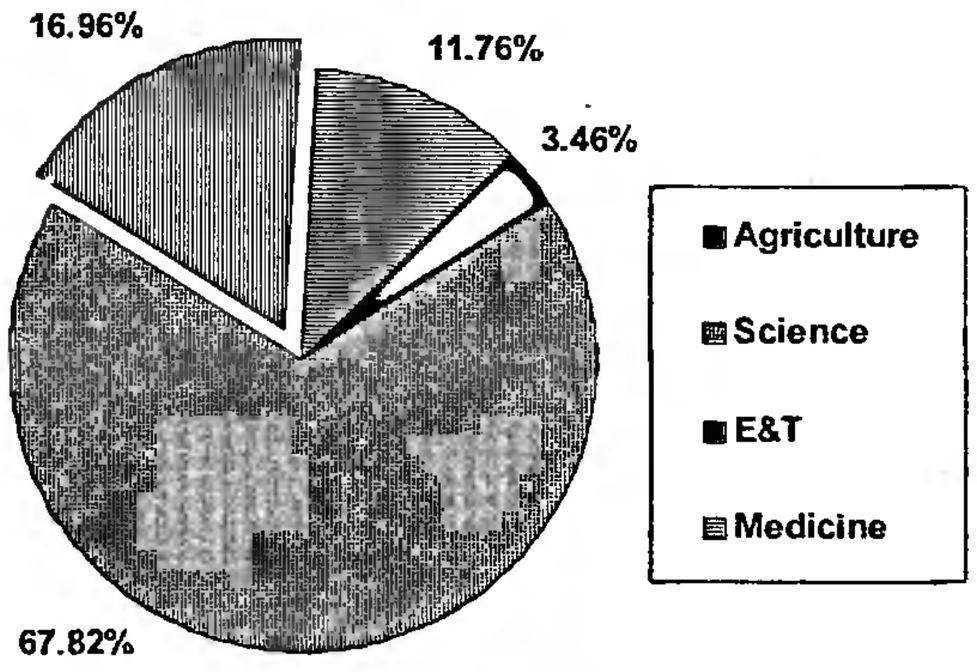

Figure 4. Growth of enrolment in higher education (1994–95). Source: *R&D Statistics*, DST Report, 1994–95.

and *DST Data Book*, 1995) and that too is dominated by the Government funding (most of the R&D being done by Government-controlled laboratories). Our industry participation is less than 20% of the overall R&D investments in the country. Share of private industries directly towards R&D in socio-economic areas of the country is very marginal (Figure 5). Government agencies are again the main players.

No doubt Government has to play a key role (funding or otherwise) in R&D on upcoming and risk technologies. But domination by Government-funded R&D is not very conducive to the future technological growth in India. Fortunately, we already witness a trend towards industrial R&D, though it is too early to categorically state that we have turned round the corner.

Our industrial productivity is still low in comparison with others. Socialistic attitudes in dealing with welfare and labour-related issues are good for the soul, but not for productivity. A major change in work culture and ethics is absolutely essential without which all other efforts are bound to fail. We must at the same time build in quality, standardization, customer satisfaction as true attributes in our industrial sectors. Though we mimic West in several aspects, this is one aspect which is generally given a go-by. Again 'motivating managers and leaders' who understand human behaviour and developmental aspects is the need of the day.

We must also convince ourselves that mega industries and multinational companies do not necessarily imply that our goals would be achieved. We should recognize that the small-scale industries in the 'silicon valley' are leading the way in the major technological revolution that is sweeping us. We have done well in several industrial fronts. Of late, we keep hearing about our strength, if not brilliance, in the world of software, which is turning out to be a core competency of India as a whole. We should capitalize on such achievements to-date and spare no efforts to further push this.

Several of the issues raised here require changes in our mind-set and the governmental policies. We need to effectively interact amongst ourselves to bring out cohesive thoughts and inputs to influence nation's progress through plans and policies. That changes are required in policies has already been accepted and, indeed, things are afoot. It is fervently hoped that this will gather momentum.

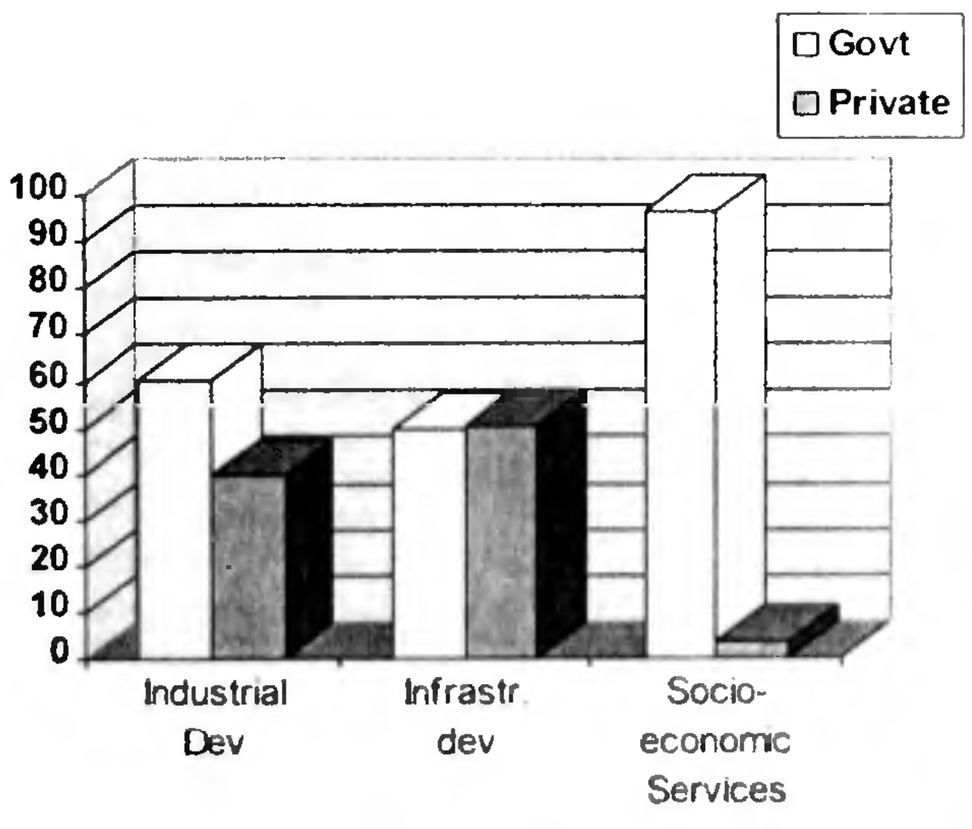

Figure 5. Share of R&D (Govt vs private). Source: *Data Book*, S&T, 1995.

Imperatives

Our ambition since independence as articulated by Pandit Jawaharlal Nehru was towards overall development of the people of the nation by the application of science and technology, boldly standing on our own as a nation and being self-sufficient on the basic needs. We were aspiring to bring in the three W's – welfare, workforce and wealth – to the nation. There has been a gap, even after 50 years, between our ambitious 'vision' and the reality. With the overall view that a large part of our population is still below the poverty line and not happy, comfortable and contended, there have been endless debates on the pursuit of science, on the appropriate and affordable T&E; this often culminates in blaming S&T itself for our present status and predicament. Notwithstanding criticisms and inquisitions, Nehru's vision of S&T being the way to fulfil our ambition is still relevant. With S&T driving us all towards 'global village', we have to reorient ourselves to local and global perspectives, to be innovative and competitive in 'technology', and to relentlessly pursue excellence to take India from a underdeveloped/developing nation to a developed nation. What is needed is certain amount of introspection, certain changes in our attitude towards work (and change in our work culture), certain changes in government policies and a clear national goal. Specifically we need:

- Team work, commitment and integrity
- Sense of professional pride
- Improved work culture
- Enhanced infrastructure
- Tap and utilize natural resources wisely and efficiently
- Identify our core competence and build on them
- R&D for 'home grown' technologies
- Linking S&T education with national development and goals
- Provide prestige and recognition to teachers and T&E professionals
- Policies conducive to the growth of S&T and its personnel
- Involve S&T personnel in national policy-making
- Provide export capability for T&E products.

As we come to the end of a momentous century, which saw spectacular progress of science, technology and engineering, we have just celebrated the centenary of discovery of electrons and the golden jubilee of transistor which coincides with the golden jubilee of our country. With Second World War acting as a trigger, the West, led by the United States, has dominated the field of S&T (&E); the coming century would surely belong to Asia and we should (and could) – with our heritage, strength and ambitions – elevate ourselves to be the leaders in science and technology. There is the intent, the talent and guiding spirit as put in beautifully by the Nobel Laureate Rabindranath Tagore:

'... Whoever wishes,
May he sit in meditation
With eyes closed
To verify if the universe be true or false.

I, in the meanwhile,
Shall sit with insatiate eyes
To see the universe
While the light lasts.'

—Our Universe

MEETINGS/SYMPOSIA/SEMINARS

Brain Storming Workshop on Geoelectromagnetism

Date: 17–18 August 1998
Place: IIT Kanpur

The workshop objectives are to review the work carried out by electromagnetic community in India in broad band electromagnetic spectrum and to decide priority application areas for future in the exploitation of Earth, Ocean and Snow resources.

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Training Course in Geological Mapping of Quaternary Formations

Duration: About three weeks from 24 November 1998
Place: Digha

Contact: Deputy Director General
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International Symposium on Multifaceted Aspects of Tree-Ring Analysis

Date: 15–19 November 1999
Place: Birbal Sahni Institute of Palaeobotany, Lucknow, India
(An autonomous Institute under Department of Science & Technology, Government of India)

A five-day symposium (including a field excursion) covering various aspects of tree-ring analysis is proposed. It will focus on the recent trends and developments in tree-ring analysis. It is also planned to hold plenary lectures on different themes of the symposium before each technical session. The themes include: Tree growth/climate relationship and climate reconstruction; Isotope studies on tree rings; Application of tree-ring studies in forest monitoring; Assessment of natural disturbances on tree growth; Dating of natural hazards; Dating of archaeological and historical structures.

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