Perspectives on energy R&D and next generation technologies*

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Energy and environment challenges during the next two decades will to a large degree determine sustainable development, environmental quality and energy security. Energy strategy usually embodies various aspects of policy and technology pathways. The challenge is to focus R, D & D on technologies that seek to achieve higher levels of efficiency covering all forms of energy conversion as well as those that seek to improve the efficiency of energy conversion at the end use stage. The paper presents the technology pathways highlighting those that are needed for a secure energy future, at the same time managing the environmental impacts including the global climate change concerns.

ENERGY and environmental issues are no longer peripheral among the aims of a national technology policy. We are on the threshold of entering a new millennium facing even greater challenges than before. The way we address the energy and environmental challenges of the next two decades will, to a large degree, determine sustainable growth, environmental quality, and national security. Energy research and development have received scant attention in the discussions of a national technology policy over the last decade and a relatively small share of the national R&D budget. It is therefore not surprising that the performance of our country's energy sector has been rather poor resulting, among others, in unreliable quality and unsatisfactory power supply situation.

Admittedly, energy sector reforms are urgently needed to rectify the supply–demand imbalances, inefficiencies and inequities in the urban and rural energy systems. Nevertheless, I believe that as a nation we have some critical choices to make with respect to our long-term strategy for inducting the next generation of energy technologies.

Population growth, economic and industrial development, and technological change drive energy needs. To examine the energy technology pathways, one needs to consider perspectives on energy that take into account the inter-connections between global and national actions on the one hand and between different economic sectors at the national level on the other. Exciting technological developments are taking place as a result of growing concerns about the environment and sustainability. Successful application of new technologies can fundamentally change the way energy is produced and utilized.

In today's world, perceptions about the crisis that engulfed the energy sector in the seventies and eighties have considerably changed. What was once a major concern that oil resources will get depleted in the near future and prices would drastically increase was belied by the changed situation in global oil supply and demand and new discoveries. The oil prices have been relatively stable since mid-eighties and, in fact, oil price in real terms is perhaps even lower than what it was before the oil crisis. This rather anomalous situation has lulled many economists and energy industry leaders into a sense of complacency. I strongly believe that we can ill-afford this complacency as also the lack of concern for the long-term outlook. I will revert to this issue later.

In the last two decades, despite soft conditions in the oil front, profound changes have taken place worldwide in terms of wide-ranging reforms in the energy sector, especially in the electric power sector, including privatization, deregulation, pricing policies, environmental regulations etc.

In India too, economic liberalization and opening the doors for private sector participation were expected to attract investments in energy, but the impact of private sector on energy sector development has not been significant so far. As a matter of fact, energy sector investments from both public and private sector have been woefully inadequate, as evidenced in major shortfall in capacity addition especially in the power sector. One of the consequences of this situation is that the thrust of R&D has lost its edge and whatever momentum existed earlier has slackened. If the demand for increasing the

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quantity and quality of energy services in our economy is to be managed, it is imperative to ensure strong support to R&D so that the critically needed high rate of innovation takes place.

Worldwide, economic growth has largely been associated with increased energy consumption, and increased use of energy has led to more urban air pollution, contaminated water, social disruption, and massive emission of greenhouse gases. Recent events in some countries indicate that the link between economic growth and energy consumption can be broken by pursuing efficient production processes and by reducing waste. At the same time the link between energy consumption and pollution can also be broken by relying more on renewable energy as well as efficiently using fossil energy. Only by doing so can we expect to have less energy intensive growth as well as growth with less pollution. Of course, there is almost always a trade-off to be made on the basis of how costs and benefits are assessed to arrive at rational choices.

The energy debate at the global level is replete with a variety of contentions and differing viewpoints. By and large, the issues involved relate to climate change concerns and energy for sustainable development. Discussions at various global forums promise to open the door for agreements on what is called Clean Development Mechanisms (CDM). Without going into details of the positions taken by different groups of countries, suffice it to say that global agreements being forged will have a profound impact on the future technological pathways for all countries. A defining challenge for the next century is how to effect a progressive shift toward an economically, environmentally, and socially more sustainable course.

Historically, transition from one generation of energy technologies to the next has been taking place at intervals extending over 4–5 decades. In this context, an interesting observation made by IIASA some time ago concerns the progression of the world energy system during the last two centuries towards fuels having higher hydrogen to carbon ratio. For instance, in 1800, the global primary energy consumption had a H/C ratio of about 0.2 (note than H/C ratio of wood is about 0.1). By 1900, this had increased to 0.8 with progressive inroads made by coal (H/C ratio approximately 1). By 1950, this had further increased to 1.3 with oil (which has a H/C ratio of approximately 2) forming a significant part of the energy mix. By 2000, the H/C ratio will be closer to 4, indicating the increasing role of natural gas (methane H/C = 4). Beyond 2050, the likelihood of a hydrogen economy taking roots is strongly indicated. In line with this trend by the 22nd century we may witness a non-fossil fuel hydrogen economy. In each era, new sources never completely replaced the earlier ones. Therefore one can say that the future mix of energy technologies is likely to reflect this trend.

In India, energy has remained a major constraint for our country's socioeconomic development. The challenge that we face today is twofold, while one is concerned with what we can and should do in the near term to improve the poor state of energy services available to industry, agriculture, household and commercial sectors through policy and institutional reforms and efficiency measures, the other concerns the issue of deciding on what investments are needed to build our scientific and technological capacity so as to induct the next generation of energy technologies.

India is the fifth largest energy consuming country of the world. It imports 60% of its oil needs and is the third largest oil importing country in Asia, after Japan and Korea, with an annual volume of around 40 million tonnes and this amount is increasing inexorably. The oil crisis of 1973, 1979 and the Gulf crisis of 1991 did have an adverse affect on our economy. If we are truly strategic in our approach, we should build and maintain emergency oil stocks, taking advantage of low oil prices of the kind that occurred during this year when oil prices dipped below $10 per barrel. Needless to say that this will require political will of a high order.

Our country has the largest unsatisfied demand for natural gas in the world. The demand is to supply ratio based on present reserves is of the order of 2.5 to 1 for the year 1999 which is expected to increase to 4 to 1 in 2010 (from 143 to 58 MMSCMD in 1990 to 265 to 68 MMSCMD in 2010). Domestic availability can be increased by intensifying exploration, improving R/F, and using unconventional gas resources namely, coal bed methane, hydrates and coal gasification.

The need for gas imports appears inevitable. In the medium term import from Myanmar (28–42 MMSCMD) and in the long term from Oman (56 MMSCMD), Iran (50–75 MMSCMD) and Central Asia (30 MMSCMD) through pipelines must be initiated. LNG imports from Oman, Qatar, Indonesia, Malaysia, and Australia totaling over 40 MM TPA are envisaged during the next five years. Increased use of natural gas in combined cycle power plant deserves serious consideration, as this is one of the most efficient technologies for power generation with greatly reduced emission of carbon dioxide.

We have in the country huge reserves of coal and lignite, of the order of 230 billion tonnes (80 billion tonnes proven) of which 300 million tonnes were mined last year. However, a vast majority of our coal reserves are of very low grade, with more than 40% mineral matter (ash) content which results in difficulties in handling, transporting, and using coal for power generation. This disadvantage is mitigated to a considerable extent by the fact that the sulphur content of coal is generally less than half per cent resulting in lower amounts of sulphur dioxide emission to the environment. The challenge that this coal poses to clean thermal power generation is through modifications and improvements in the conventional technologies, development and adoption of new technologies; with efficiency and environment being controlling factors.

There has been no dearth of studies on how to deal with India's energy problems. Studies by various committees – Energy Survey Committee (1965), Fuel Policy Committee (1973), Energy Policy Committee (1979), Advisory Board on Energy (1984), and other studies by the Planning Commission, TERI, CII, FICCI, ASSOCHM, TIFAC – have all analysed the evolution of energy demand and supply, the situation of energy in rural areas, energy resources, investment requirements and policy options. Regardless of the deviation between projections made in these studies and actual reality, it is clear that the issues involved are quite complex and that policy and technology choices will have to be made keeping in view both short- and long-term perspectives.

Energy strategy usually embodies various aspects of policy and technology pathways and therefore it seems appropriate to revisit the strategy for effecting improvements and for charting new pathways, wherever possible. The challenges to be faced in our energy strategy are how to reconcile energy supply with increase in its demand, finance the power sector expansion, increase domestic oil and natural gas production, develop alternative sources of energy and manage the environmental impacts including the global climate change. Improving the environmental conditions in both urban and rural areas has become a dire necessity when we look at our continuously deteriorating environmental quality. Measures such as fuel switching, energy conservation and deployment of energy-efficient and environmentally sound technologies must receive much greater attention than heretofore. Prices must reflect full economic costs and only then will there be necessary signals to producers and consumers alike to use energy more efficiently.

I wish to focus attention here mainly on the technology dimensions of our energy strategy.

Attempts to chart technology pathways for the country indeed started as far back as 1973 when the erstwhile NCST undertook assessments of technologies and recommended R&D efforts in the short, medium and long term periods. The NCST played a useful role in catalyzing the establishment of new programmes in the then Department of Science and Technology like New Energy Sources, Ocean Science and Technology, Environment, Biotechnology, NRSA, NISSAT, TIFAC etc. which were subsequently spun off into new institutional arrangements including new government departments and ministries. The scientific and other professional communities have made notable contributions in all these areas.

Our scientific and technical communities have amply demonstrated their abilities to produce results when the nation sets clear goals and backs them with sustained support. The country can meet much of its growing demand for energy services in a less capital-intensive and less environmentally harmful manner by making bold and imaginative choices out of the vast array of cost-effective and energy-efficient technologies. In examining technological pathways and in making choices, it is important that a distinction be made about what is feasible in the short term and what lies in our long-term interest.

India's existing energy sector technology base is vast and varied. Some of its capital stock are old and replacements have not taken place. One of the dilemmas faced with regard to introducing new technologies is that life times of in-use energy capital stock are usually long and therefore this becomes a major consideration in replacing them in an economical way. Therefore, in the short term, one has to look for technology pathways that can improve the existing technologies. Costs can be minimized if efficient and cleaner technology replaces less environmentally friendly technologies at the time of capital stock turnover than through early turnover of stock. We have to keep in mind that other factors like market dynamics and user preferences also affect the extent to which this approach becomes feasible.

The challenge before the nation is to focus R&D on technologies that seek to achieve progressively higher levels of efficiency covering all the different stages and forms of energy conversion, as well as those that seek to improve the efficiency at the end use stage. Let me now briefly discuss technology pathways, highlighting those that I consider important for our energy future.

First, a word about government's role in supporting R&D. Given that large investments are needed to develop energy technologies which also usually require long gestation periods, government's facilitating role as well as support for R&D remains critically important. This is so despite structural changes in the energy sector with increasing private sector participation as well as competition and diversification of energy resources. From the long-term point of view, ensuring that sustained inputs become available for building the necessary scientific and technological capabilities, remains crucial.

A range of views exists regarding the future share of fossil fuels in primary energy supply. What seems indisputable however is that for the next couple of decades fossil fuels will continue to be a major player, coal will continue to be dominant in power generation, petroleum in transport, and natural gas will be gaining increasing share because of its inherent advantage as a clean fuel. Some long-term scenarios (for example, Shell International, IPCC etc.) postulate a rapidly increasing share of renewable technologies reaching up to 50% of the total by the middle of the 21st century.

Technology pathways must encompass the entire fuel cycle – exploration, extraction, refining, transport, conversion, transmission, distribution, and end use.

Technology opportunities in resource exploration have expanded with advent of new and advanced geophysical techniques that provide more precise information along with three-dimensional mapping, especially of oil and gas resources. Likewise in mining of coal or in drilling for oil, techniques involving inclined and horizontal drilling are proving to be more effective; other technologies of interest include deep drilling for onshore and offshore oil resources; reservoir modelling; enhanced oil recovery etc.

Coal will continue to remain as a major energy resource for our country. Technology opportunities in efficient utilization of our relatively low-grade coals must be pursued vigorously including beneficiation, coal briquetting, fluidized bed combustion systems, gasification including *in situ* gasification routes etc.

The issue of whether or not our coals should be beneficiated has remained unresolved for too long. It has taken almost 20 years for us to come to grips with the application of coal beneficiation technology whereas in other parts of the world it is almost a standard practice for a long time. Even now there are no clear guidelines or agreement among all concerned entities in the country on technological approaches to beneficiation. It is true that there are problems connected with the disposal of middlings and other environmental aspects. We must reach quick resolution of this issue and make appropriate technological choices. Transporting coal with 40% ash over long distances is an unnecessary wastage of energy. Moreover serious problems encountered in boilers, especially tube rupture, are attributable to the use of high-ash coals with high silica content. The technology of coal washing is well developed and therefore it must be introduced expeditiously. R&D in this area must focus on specific aspects of Indian coals. Research must also investigate dry and wet grinding of coal and transportation of coal water slurry. The technique of firing coal water slurry to substitute for oil firing must be established and inducted rapidly.

In all countries with significant use of coal, attention is increasingly turning to clean coal technologies. Despite its environmental limitations, coal will continue to be a major source of energy well into the next century. The importance of clean coal technologies for our country can hardly be overemphasized as nearly 70% of power generation is from coal.

It is imperative that R&D efforts be intensified for clean coal utilization technologies. Technology collaborations and joint R&D must be sought with outside partners wherever considered necessary in order to speed up their development and utilization in the foreseeable future. A variety of clean coal technologies for power generation are at various stages of development and deployment. Let me mention in passing, technologies that are commercially available and proven that we can rely on in the short term. These are, pulverized coal firing plant with flue gas desulphurization, NO_x and particulate emission control; atmospheric fluidized bed (AFBC) and circulating fluidized bed combustion (CFBC) plants.

The installed power generation capacity in the country has now crossed 90,000 MW and demand is growing at the rate of about 9% per annum. We must pay more attention to technological pathways for modernizing thermal power generation as it constitutes a major part of this capacity.

Pulverized coal technology is currently the mainstay of our thermal power generation. For large plants, this technology will continue for at least the next ten years. Currently, efficiency of coal power plants in our country is relatively low – in the range of 31–38%. The aim should be to progressively move towards a higher efficiency regime with proper choice of technologies. The successful experience with ultra-supercritical power plants in Europe with efficiency in the range of 45–47% at steam temperatures of 560–580°C, without reduction in availability, indicates the trend that need to be considered over the next 5–10 years. The main challenge in this case to overcome is the material problem. The most recently built pulverized-coal-fired power plant in Denmark uses special steels. In future plants, nickel base super alloys are likely to be used. The target steam temperature is 700°C and net efficiency between 52 and 55%. At least for the next 10–15 years, ultra-supercritical PF power plants will remain prominent.

Let me now turn to the next generation technologies for power generation which all aim at attaining higher efficiencies and lower emissions of CO_2 and other pollutants. These include: coal gasification and combustion of the synthesis gas in combined cycle gas turbine (integrated coal gasification and combined cycle – IGCC); pressurized fluid bed (PFB) in combined cycle; direct and indirect coal-fired turbines; fuel and pure oxygen gas turbines; magnetohydrodynamic generators; carboniferous fuel cells (molten carbonate, solid oxide); and separation of hydrogen from coal (hydrocarb process).

IGCC technologies have been developed in the United States and Europe, starting with a 30 MW gasification unit and subsequently upscaling it to 80 MW. Demonstration plants have helped to validate design features and to improve designs. The technology has reached a stage of technical readiness and is poised for commercialization. It is likely that this technology will take roots beyond 2005. PFB has also gone beyond pilot stage and is rapidly approaching the stage of commercial availability.

Our own efforts with regard to these technologies have been lacking in sustained support and commitment. For nearly two decades both BHEL, Trichy, and the Institute of Chemical Technology, Hyderabad, have been working on the development of coal gasification technology (fixed and moving fluidized bed) for power plant applications. BHEL has successfully operated a 6 MWe IGCC power plant. Presently a 150 tons/day plant is being operated for demonstration as well as for obtaining engineering data. Keeping in view the international developments as well as our own national experiences, efforts were made nearly a decade ago for setting up a 100 MWe IGCC plant. A detailed feasibility study was carried with the involvement of Bechtel and PDIL, Ranchi, and relevant technological plant engineering inputs were identified. It seems that the project has been languishing ever since, but recently another committee has recommended the establishment of a 250 MWe IGCC facility. Much time seems to have been lost in deciding on plant size, technology choice, location, and implementation arrangements. We need to be bold and decisive in moving fast on IGCC, as this will surely be one of the prominent next generation technologies for power generation.

In the seventies, spurred by the developments in the former Soviet Union, attempts were made to develop a coal-based MHD power plant. A 5 MWth MHD pilot plant was set up at BHEL, Trichy, in collaboration with Institute of High Temperature Physics, Moscow. While the feasibility was demonstrated, full-scale commercial plants proved elusive both due to anticipated technical problems as well as investment risks. Furthermore, the advent of natural gas combined cycle plants with comparable efficiencies but much lower investment cost has pushed the MHD technology out of contest at least in the foreseeable future. It is somewhat unfortunate that a number of spin-off technologies that resulted from MHD research have also remained unexploited even though many technologies such as high temperature air heaters, high temperature regenerative heat exchangers, oxygen-fuel combustion systems including combustion plasma systems, showed great promise.

In the long run, fuel cell technology for power generation seems to be the most attractive as it involves conversion of the chemical energy in the fuel directly into electricity. When it comes to very high net efficiency and minimum emission, the use of coal gas in fuel cells is particularly attractive, provided the exhaust gas of a high temperature cell is put to additional use in a downstream combined gas/steam cycle. Molten carbonate and solid oxide fuel cells are under development. Because these fuel cells operate at high temperatures (550 to 650°C for molten carbonate and approximately 1000°C for solid oxide) applications are likely to be mainly in industrial combined heat and power systems that require high-temperature heat for process use and in central station configurations. Very high efficiencies of the order of 75% are expected in such systems. Following the development of a molten carbonate fuel cell (MCFC) at the beginning of this decade, MITI in Japan is targeting at a 1000 MW pilot plant to be commissioned in early part of the next decade. However a breakthrough will have to be made with respect to service life and further cost reductions if the planning and construction of a MCFC demonstration plant is to be commenced in 2010.

Regarding other technologies, let me mention in passing that direct coal fired systems are in the prototype development stage and the Hydrocarb process is still at the proof-of-concept stage. Both hold considerable promise in the longer-term future.

In less than a decade, natural gas has emerged as an important fuel source for power generation. Natural-gas-based combined cycle power plant technology is not only readily available but is also proving to be attractive for quick capacity additions and at the same time is capable of meeting cost and environmental goals. Given the increasing availability of natural gas within the country as well as prospects of trans-boundary pipelines and LNG, we must intensify our effort on natural gas combined cycle plants as it is one of the most economical and environmentally attractive fossil fuel technologies. Its application is increasing because of its inherent advantages in terms of low capital costs and low emission. The most efficient units on the market achieve availability of 95% and 52% net efficiency. Further efficiency improvements by a few percentage points are expected in the next few years. Its attractiveness also stems from the fact that project gestation period is relatively short – about two years – and what is more is that plants can switch to fuel oil if it becomes necessary thereby giving considerable flexibility in fuel switching. From environmental standpoint it is surely a winner. Obviously this attractiveness is dependent on fuel availability and its price.

See Table 1 for comparison of various clean coal technologies.

All the different clean coal technology pathways have the common objective of utilizing the vast coal resources in an efficient, environmentally and economically acceptable manner as may be possible at any given time. We must keep our options open with regard to different clean coal technologies and prepare the ground for smooth transitions as and when it becomes expedient for achieving higher levels of efficiency, reliability, and environmental goals.

In order that we may develop our technological capabilities in these areas, we must have an action plan and mobilize support for its implementation. I shall now propose the outlines of such an action plan.

(i) Encourage the establishment of AFBC and CFBC power plants of commercially available unit sizes.

(ii) Facilitate the establishment of a PFBC power plant of 70–120 MWe for demonstration purposes as well as to advance development of high temperature and high pressure particulate control system.

Table 1. Characteristics of clean fossil electricity generating technologies (Nakicenovic[a], 1993) (all costs are in 1990 US dollars)

System	Units	Conventional coal	PFBC coal	IGCC coal	DCFT coal	ICFT coal	Combined cycle natural gas
Power	MW	400	400	1250	200	200	400
Capital cost	$/kW	1300	1750	1350	2100	1430	650
Fixed O&M cost	$/kW/yr	36.4	56	37.8	71.4	30	16.3
Variable O&M cost	kW/yr_e$	42.9	26.3	27.2	30.7	25.4	5.9
Efficiency	%	38.8	45	44.3	43.2	51.7	52.6
Fuel use	BTU/kWh$_e$	8800	7600	7700	7900	6600	6490
Fuel cost	$/GJ	2.05	2.05	2.05	2.05	2.05	2.4
Life time	years	35	30	35	30	35	35
Load factor	%/yr	80	80	80	70	75	80
Cost (excl. fuel)	$/kWh$_e$	0.0229	0.0291	0.0218	0.04	0.0196	0.0094
Total ac electricity generating cost	$/kWh$_e$	0.0468	0.0486	0.0415	0.0608	0.0368	0.0265
Carbon emissions	kgC/kWh$_e$	0.232	0.2	0.203	0.208	0.174	0.109

System	Units	MHD coal	MCFC coal	MCFC natural gas	SOFC coal	SOFC natural gas
Power	MW	150	650	200	165	165
Capital cost	$/kW	2600	1650	1150	1240	860
Fixed O&M cost	$/kW/yr	78	16.5	15	12.4	11.2
Variable O&M cost	kW/yr_e$	87.6	92	87.6	78.8	74.5
Efficiency	%	55	50.5	52.9	49.7	54.2
Fuel use	BTU/kWh$_e$	6200	6750	6450	6860	6300
Fuel cost	$/GJ	2.05	2.05	2.4	2.05	2.4
Life time	years	30	30	30	30	30
Load factor	%/yr	70	75	75	75	75
Cost (excl. fuel)	$/kWh$_e$	0.0535	0.0313	0.025	0.0246	0.0197
Total ac electricity generating cost	$/kWh$_e$	0.0769	0.0564	0.0153	0.0484	0.0442
Carbon emissions	kgC/kWh$_e$	0.163	0.178	0.108	0.181	0.106

PFBC, pressurized fluid bed combustion; IGCC, integrated gasification combined cycle; DCFT, direct coal-fueled turbines; ICFT, indirect coal-fired turbines; MHD, magneto-hydrodynamic; MCFC, molten carbonate fuel cells; SOFC, solid oxide fuel cells.
[a]Nakicenovie, N. *et al.*, *Energy*, 1993, **18**, 401–609.

(iii) Facilitate establishment of an IGCC power plant of suitable capacity (70–120 MW) based on fluidized bed gasifier technology for technology validation purposes and to obtain data on technical and economic parameters for design upscaling.
(iv) Encourage development of detailed designs for a large-scale power plant and IGCC technologies for implementation in the 5–10 year period.
(v) Encourage adoption of supercritical boilers.

On the R&D front, support must be considered for technology development covering pilot-scale studies on pressurized circulating bed combustion to obtain technical data on high ash Indian coals for design purposes, and for a facility for pressurized fluidized bed gasifier to study suitability of Indian coals for IGCC application. Design studies that need to be undertaken for large scale PFBC and for advanced IGCC technologies also deserve support. In the Indian context, further R&D work is needed in the areas of fly ash utilization, DENOX and HTHP particulate control technologies. BHEL had earlier worked on the development of slagging cyclone coal combustor technology. We need to pursue technology development efforts of this kind and bring them to the stage of practical applications instead of abandoning such efforts without proper evaluation. Basic research studies in gasification, combustion, and modelling must also receive attention.

It must, however, be recognized that basic and applied research, technology development and demonstration, and implementation of the best available technology must progress concurrently. In such an endeavour, it is essential to have active participation and mutual support among industries, academia, R&D labs and the Government in a well-focused and well-defined manner for finding optimal solutions to the dire energy situation that we face today.

Nuclear energy for power generation is gaining greater attention in many parts of the world in the context of climate change concerns as it offers significant potential for reduction of CO_2 emission. France derives 75% of its electricity from nuclear power. Japan and Korea are adding significant capacity. Opposition to nuclear power in countries, notably USA and Europe, has been strong due to various factors including safety considerations. For our country with a very low per capita energy resource endowment, all sources of energy including nuclear energy assume importance. Based on our modest uranium reserves of 70,000 tons and thorium reserves of 300,000 tons, the maximum capacity that can be built is about 10,000 MW of PHWR and with breeder technology it is about 300,000 MW. Apart from technical and economic considerations, public acceptance of nuclear power generation is essential for sustained effort in order to realize the share of nuclear power in our total energy mix projected at about 20,000 MW by 2020. In this effort, greater attention must be given to taking public into confidence of our capability with regard to nuclear safety, waste disposal, and decommissioning of nuclear power plants.

Considerable scope exists for introducing more efficient technologies in the transmission, distribution, and end use of electricity. Efforts are already underway in the country to introduce EHV and HVDC technologies in our electricity transmission systems. Continuation of R&D efforts to upgrade these technologies, to develop component technologies, and to ensure reliability should receive priority attention.

Improving the energy efficiency of end use devices is vital, as it tends to reduce the primary energy requirements. It must be stressed that the main purpose of conversion of primary energy to its final energy forms is to facilitate higher efficiency, convenience, and environmental compatibility of energy end use. End-use efficiency can be more important for the overall efficiency of the full fuel cycle than the upstream efficiencies themselves. End-use technologies are linked to particular forms of energy. For example motor vehicles and light bulbs are linked to different forms of energy, and often these technologies limit the flexibility for switching between different sources of primary energy and fuel forms.

In considering technology pathways, it is necessary to examine the combination of end-use technologies and associated fossil fuel cycles that could provide a full range of required energy services in the future with the highest overall efficiencies, economically and with minimal environmental impacts. For a variety of stationary end-use technologies, electricity is the final energy choice in combination with different fossil fuels. Motor fuels are the final forms of choice for combining (crude oil) with different mobile end-use technologies. This link between different fossil energy fuel cycles and characteristics of energy end use is what makes so important to improve performance of end use devices. Thus, demand side management (DSM) and other measures to improve the efficiency and reduce costs of energy end-use are as important as supply side improvements. In general, energy end use technologies require relatively modest investments in R&D.

Let me now turn to specific economic sectors of our economy. Technology aspects concerning energy consumption in agriculture and rural activities must receive much greater attention than before as there has been an accelerated growth of energy consumption in recent years reaching almost 30% of total energy. New and efficient technologies can have positive impact not only on energy consumption but also on increasing agricultural productivity. Potential energy savings can be found through changes in the use and design of irrigation pumps, tractors, post-harvest technologies (drying and storage technologies), improved silvicultural practices etc. Use of renewable energy technologies can also contribute to savings in fossil energy used in agriculture. Examples are solar and wind energy and energy from biomass residues or products from energy cropping for heat and power production, wind as direct source for irrigation and solar as direct source for drying. R&D activities must be directed to practical aspects of these opportunities.

Industry accounts for nearly 50% of total energy use. Within the industry, the largest energy users are the basic materials processing industries: steel, paper, cement, nonferrous metals, glass, chemicals etc. Major innovations are taking place elsewhere in the world focused on reducing the materials intensity in manufacturing processes and end-use equipment. The net effect of all these is a reduction of overall energy consumption and emission of pollutants and greenhouse gases. It must be recognized that many of the technologies used in basic materials production in the country today are relatively inefficient and outdated.

Many component technologies used in basic materials production can be made more efficient by proper choice of technologies. Much of the potential for improvement in technical energy efficiencies in industrial processes depends on how closely such processes have approached their thermodynamic limit. In industrial processes that require moderate temperatures and pressures, there is the prospect of introducing technologies for combined heat and power so as to achieve higher overall efficiencies. Fundamentally, new process schemes and substitution of materials, changes in design and manufacture of products resulting in less material use and increased recycling, can lead to substantial reduction in energy intensity. Take the case of electric motor drive system, which accounts for the largest share of electricity use in industry. Use of more efficient motors and variable speed drive systems can make a significant contribution to reduction of energy intensity of basic materials production in industry. Major effort will be needed to bring about process changes as these often yield even more substantial benefits than upgrading equipment piecemeal; and the benefits will go beyond energy alone.

Technology opportunities have expanded for improving the efficiency of end-use devices such as lighting systems, motors, domestic appliances, space conditioning systems etc. Our efforts must be intensified in introducing efficient technologies that are available with suitable adaptations as may be necessary.

Developments in emerging technologies must be closely tracked and necessary scientific capabilities must be built up. Let me mention by way of example certain new electrotechnologies that are being introduced that can impact strongly on efficiency of energy use. These span a wide range from microwave processing, electroseparation, and electrochemical synthesis in chemical industry to ultrasound processing, ozone disinfection, and radiofrequency drying technologies in textiles and carpet industries. Elsewhere, in pulp and paper industry use of membrane separation and biofiltration are being introduced. New energy technologies of interest in the food processing industries include ozonation and ultraviolet light for sterilization, electron beam processing and electronic pasteurization for meat and poultry. These have the potential to improve energy and environmental performance as well as industrial productivity.

Yet another technology pathway is the superconducting power equipment. Recent advances in high temperature superconducting (HTSC) materials – materials that can be cooled with liquid nitrogen. The long-standing promise of zero-resistance superconductors for utility applications is poised for practical realization in the next 10 years. Some applications of HTSC have already started to emerge. For example, the telecommunications industry is using chip-size HTSC signal filters in telephone repeater stations to reduce noise. For power industry, the new superconductor's projected benefits are indeed great. HTSC power cables will be capable of transmitting 3–5 times more current than comparable underground conduits. The new HTSC materials will also bring dramatic reductions in the size and weight of large motors, generators and power transformers.

In some advanced countries, several full-scale HTSC devices have already been, or are soon to be, tested on utility power systems. Superconducting motors of 200 HP have been built and operated; 1000 HP motors are next. Superconducting power cables that can carry 2000 A, 115 kV could be ready for commercial application in the early part of the next decade.

In our country as well, several research institutions have been engaged in HTSC research. Although the zeal with which a technology mission was started for HTSC is no longer visible; the importance of gaining ground on the scientific and technology aspects of HTSC remains undiminished. The effort that BHEL has been making in translating research results into practical applications in motors and generators deserves further support. Our scientists and technologists must reach out for strategic collaborations for introducing HTSC technology so as to take advantage of a technology of great potential that is still at an early stage of its application.

The rapid increase in the population of motor vehicles is a matter of concern not only because of their impact on demand for imported petroleum fuels but also because of serious problems of urban air pollution and public health in addition to greenhouse gas emission. In 1994, there were about 600 million motor vehicles on the road worldwide including commercial vehicles. At the present time, motor vehicles account for 15% of world CO_2 emission, and this share is increasing with increasing population of vehicles expected to reach about one billion by 2030. Given projected massive increases in motor vehicles from current level of about 5–6 million including two wheelers in our country, nothing less than a transcendental change will be required to protect our urban areas from dangerous levels of pollution.

Broad-based technological strategies will be required to address the challenges that lie ahead in transport sector. More efficient engine vehicle systems, alternate and cleaner fuels (CNG, ethanol, methanol, hydrogen), electric vehicle and fuel cell technologies, and better overall management of transportation sector demand and other measures will be needed.

In the short term, the technological pathway evidently is in the direction of increasing fuel efficiency through improved engine designs, electronic controls, continuously variable transmission as these are relatively easy to integrate into the current vehicle fleet. But in the medium and long term the solution lies in technological pathways that minimize emissions and ultimately to zero-emission vehicles powered by hydrogen.

Technology options based on ethanol and methanol as well as CNG must be pursued consistent with the availability of these fuels in different parts of the country. Alcohol blending is relatively simple and engine modifications required for this are minor, making its implementation easier. CNG is particularly well suited for use in trucks, buses and boats, provided filling stations can be set up rapidly. Safety aspects need special attention.

In the medium- and long-term electric vehicle (EV) technology can serve as one of the technology pathways for passenger cars, commercial vans, buses, and even motor cycles and scooters. All of the world's major automobile manufacturers are developing electric or hybrid electric vehicles for commercial production in the next decade. Toyota has already introduced a hybrid vehicle in the market. The major problem requiring attention is the storage battery that can give a range of 100–200 miles per charge with acceptable weight, service life and cost. A variety of battery and storage technologies are being investigated including batteries such as advanced lead acid, nickel hydride, sodium sulfur lithium ion, metal air and other devices such as fuel cells, ultracapacitors, flywheels, etc. The race is to apply leading edge technologies in advanced electric vehicles to reach performance, and price goals that can match conventional vehicles.

R&D for development of battery-powered vehicle technology in our country started as far back as 1974 with the involvement of CECRI, Karaikudi; BHEL, VRDE, Ahmedabad; and RDSO, Lucknow. Over a period of 5 years several prototypes were built and tested, notably by BHEL. Further development of battery powered vans by BHEL, and testing under actual user conditions in Delhi have yielded valuable information. Many technical challenges still remain, mainly concerning storage batteries. Some attempts by private sector to commercialize electric vehicles have not been successful. Our achievements in battery technology in terms of energy density and the number of charge-discharge cycles are still much below international results. Much remains to be done on vehicle technology to bring the application to the commercial stage.

There is a great deal of hope and expectation about fuel cell technology for automobiles. At present only the phosphoric acid fuel cell is being marketed commercially – largely for stationary combined heat and power markets in commercial and residential apartment buildings. Over 200 units in the range of 200 kW have been installed worldwide. Power densities achievable with this technology are low and as such are not suitable for cars.

The technology that is currently getting the most attention is the proton exchange membrane (PEM) fuel cell. This operates at a low temperature of around 80°C and offers both high power density (suitable for use in automobiles) and a prospective cost in mass production that might enable PEM cell electric vehicle to compete with internal combustion engine vehicle for automotive applications. Over the next 5 years, this technology is expected to be commercially available for transit bus, and building combined heat and power applications.

Most major automobile manufacturers abroad are developing fuel cell electric vehicles. Costs are currently high and many technology and engineering challenges still remain to be resolved. In the longer term, use of PEM fuel cells in automobiles will require a hydrogen production and delivery system. Until then, onboard fuel processors for use with either gasoline or methanol will be needed. For stationary applications, natural-gas-based fuel processors can be used. Progress in this area has been rapid. The proof-of-concept hydrogen-PEM fuel cell bus with compressed hydrogen storage was introduced by Ballard Power Systems only in 1993. By 1997, Ballard had sold and introduced several hydrogen-PEM fuel cell buses in Chicago and Vancouver. During 1998 Ballard and Daimler Benz, Toyota, Ford, GM and Chrysler have all announced plans to develop production-ready fuel cell cars by 2004.

Our efforts in this field in collaboration with BHU, IITs, and other institutions have been rather meager. Keeping these developments in mind, we must quickly expand our R&D capabilities in this field even if we perceive that benefits of this technology for our country can only be realized in the longer term.

Let me now turn to renewable energy technology pathways. Renewable sources of energy currently supply somewhere between 15 and 20% of the total world energy demand – mostly hydropower and biomass. There is growing realization that renewable energy technologies will play an increasing role in the future. The main challenge is to improve the cost-effectiveness of currently available technologies and to develop new ones. This is where increased thrust needs to be given to support well-defined R&D programmes with clear goals and practical orientation.

Recent major international studies indicate significant growth potential for renewable energy applications, particularly in scenario studies where environmental constraints are imposed. For example, the IEA study forecasts a 7.5 to 8.5 % growth in commercial use of energy from 'new renewables' by 2010. The WEC's ecologically-driven scenario forecasts a growth from 18% to 30% of the world's needs by 2020. The United Nations scenario forecasts a growth of up to 30% of world's needs met by renewables by 2025 and up to 45% by 2050.

To achieve substantial contribution from renewables to energy supplies at national and global levels would require:

- achieving rapid growth of renewable energy industry, thereby bringing with it significant employment opportunities;
- introducing market incentive to change the patterns of energy supply and use; and
- enhancing research, development, and demonstration to introduce innovations, reduce costs, improve performance, and establish market confidence.

India has built up an impressive record in the development and application of renewable sources of energy. Starting as a programme in the New Energy Division of the Department of Science and Technology in the mid-seventies, renewable energy development is now under the charge of a full-fledged ministry, supported by state-level agencies, a separate financial institution, research centers, university departments, and NGOs. A variety of industries – big and small are engaged in manufacturing activities covering a vast array of renewable energy systems from improved wood stoves and biogas plants to solar collectors and hot water systems, solar cells, modules and systems, biomass gasifiers, wind electric generators, small hydro systems etc. In addition, a variety of financing mechanisms have been introduced, and commercial banks are being associated with these financing mechanisms.

The overall strategy for the development and application of renewable energy involves support for R&D, demonstration projects and dissemination programmes through fiscal subsidies, incentives, and soft loans. All these actions have resulted in making India's renewable energy programme as one of the largest and wide ranging programmes in the world. The budgetary outlay stands at about Rs 400 crores per year. In terms of numbers of renewable energy devices or installations, the figures look impressive. Nearly a 1000 MW of wind power capacity has been established. A variety of solar thermal applications, such as water heaters and air heaters, have used more than 400,000 sq m of collectors. Over 150,000 solar PV systems aggregating 32 MW have been supplied. With an annual production of more than 11 MW of PV panels, India ranks among the top five countries in the world. Biomass and small hydropower capacities exceed 150 MW and 130 MW respectively. Biogas plants number about 2.5 million and improved wood stoves 25 million.

Despite all these achievements the overall impact on the energy sector is still relatively small. The time has come to refocus renewable energy development and redirect science and technology inputs in ways that can provide a new thrust and help in mainstreaming renewable energy into the overall energy sector activities. It is quite conceivable that renewable energy can contribute a respectable share of 10% of grid power by 2012 and about 29% by 2020. For this to become a reality, a whole range of actions will have to be taken with strong leadership provided from both policy and technical levels.

As I said before, there is widespread recognition that the country has made significant strides in the development and utilization of renewable sources of energy. We have a long way to go before renewable energy starts impacting on the energy scene in any significant manner. Our renewable energy R&D capabilities remain rather fragmented. We should bring greater coherence to our national programmes and more focus on our efforts. We should also establish greater cohesiveness among the academia, R&D labs, industry and business. Let me now outline some key areas where we need a major thrust.

Our strengths in solar technologies, both thermal and photovoltaics, must now be harnessed to increase substantially the industrial and commercialization activities. We must vigorously explore the solar thermal options (parabolic trough, dish and power tower) for grid power applications. In this connection, the proposals for solar power plants in Rajasthan and other states must receive serious and expeditious consideration. Other solar thermal technologies such as solar-assisted heat pumps, solar cooling and drying and dehumidification technologies must be brought out of the lab into the stage of practical applications.

We are among the top five countries in the world in solar photovoltaics. We have established capabilities in the production of silicon material, solar cells, modules and a variety of systems. Both crystalline and thin-film technologies are witnessing tremendous improvements in efficiency and reduction of costs. International prices of PV modules have reached $4 per peak watt. Further reductions are anticipated in the next 5 years. We must participate even more vigorously in the international effort to achieve a breakthrough in this revolutionary technology.

We need to modernize our crystalline silicon PV industry for which we need to increase our support for R&D. We need to enhance our capabilities in thin-film PV technologies, both amorphous and polycrystalline thin-film technologies. Past efforts in building momentum for developing amorphous silicon thin-film technology went as far as establishing a pilot plant. This momentum seems to have been lost in the last couple of years. We must reinforce earlier efforts and help in upgrading the pilot plant to enable it to develop multijunction thin-film technology. Plans must be laid out to establish commercial production of thin-film PV with the participation of public and private sectors.

One of the key actions that the Ministry of Nonconventional Energy Sources has recently taken is establishing a national institute called the SSS National Institute of Renewable Energy to draw together our country's national research, development and demonstration efforts within one organization and direct the national efforts in a focussed manner. To the best of my knowledge, the institute will not engage itself in all R&D activities but will coordinate and support the various R&D centres in academia, national R&D labs, demonstration centres, and industry. The priority areas for this Institute to address are: upgrading the amorphous silicon plant; strengthening the solar energy centre at Gwal Pahari to serve as a national center for testing, standardization, training and market demonstrations with its own regional test centres; facilitating the development of wind energy test and certification facility; updating wind data/map; coordination of the work of biomass centres and industrial activity in bio fuels; development of coordinated programmes in areas of energy storage including hydrogen, fuel cells, battery systems, power conditioning systems; software development; alternate fuels and vehicle systems; promotion of development of hybrid energy systems; economic and policy analysis; and education and training.

In conclusion, let me say that energy is critically important as it has a pervasive role in modern life. Securing energy for sustainable development is not only challenging but is also full of opportunities. The challenges and tasks that lie ahead in modernizing our energy industry, introducing new and more efficient technologies, and infusing necessary dynamism in the energy sector as a whole, can be managed in an effective manner provided that our scientists, engineers, technologists, managers, planners, entrepreneurs, and administrators all work in concert with dedication, commitment and common purpose.

Public policy measures such as taxes and incentives, market forces, and new technologies influence the way energy use will evolve in the country. These factors are in a way interdependent. Both markets and technology can be affected by policy. The three factors must be used to accomplish energy sector objectives namely, providing secure energy supply at reasonable price in an environmentally acceptable manner.

The arguments for a coherent national energy R&D policy are derived from the linkages among energy and economic, environmental and national security considerations on the one hand, and from the potentially serious inadequacies of the current mix of fuels and energy options, on the other.

It is gratifying to note that TIFAC in its Technology Vision 2020 on power sector has addressed some of the challenges and has set up an action team for developing a few mission-oriented proposals in the energy sector. Debates on the energy sector will continue in various forums in the country. A principal lacuna that exists in articulating the agenda for energy R&D, after a critical examination of merits and limitations of various options, is the absence of a standing group of energy R&D professionals in the country. If initiatives are forthcoming to establish such a group, the composition of such a group should consist of representatives of all key actors in the energy sector and must share a common understanding of technological pathways and bring objectivity into evaluating options for making rational choices. Advocates of each class of energy options (for example, nuclear fission, fossil fuels, renewables, and end-use efficiency) tend to disparage the prospects of the other class of options; these tendencies are exacerbated by the zero sum characteristics of energy R&D funding. In this way, the energy community itself comes up with divergent arguments such as – 'renewables are too costly', 'fossil fuels are dirty', 'nuclear fission is too unforgiving', 'fusion will never work', 'efficiency means belt tightening and sacrifice or is too much work for consumers' – that the budget cutters cheerfully employ to cut energy R&D budget one at a time and render it subcritical.

While this scenario may sound all too familiar to most of us, it is time that we reachout beyond narrow considerations and accept the niche for each source of energy. We need all sources of energy and no single source will displace all others. Support for R&D must reach out for a reasonable balance among the different technology options. I wish that DST publishes comparative data and analysis on energy R&D budget for the last twenty years for each category namely, fossil, renewables, fission, fusion, conservation, Bio/environment and basic energy sciences. This will reveal the wide budget disparities among the different categories and hopefully prompt a more rational allocation of R&D for them during the next two decades.