

INDIA'S ENERGY AND ENERGY-R&D LANDSCAPE:
A BRIEF OVERVIEW

Ambuj D. Sagar
Energy Technology Innovation Project
Belfer Center for Science and International Affairs
John F. Kennedy School of Government
Harvard University

February 2002

CITATION

This document appears as discussion paper 2002-08 of the Belfer Center for Science and International Affairs. Comments are welcome and may be directed to Ambuj D. Sagar at the Kennedy School of Government, Harvard University, Cambridge, MA 02138.

This paper may be cited as Sagar, Ambuj D., “India’s Energy and Energy R&D Landscape: A Brief Overview”, BCSIA Discussion Paper 2002-08, Energy Technology Innovation Project, Kennedy School of Government, Harvard University.

The views expressed within this paper are the author’s and do not necessarily reflect those of the Science, Technology and Public Policy program, the Belfer Center for Science and International Affairs, or Harvard University. Reproduction of this paper is not permitted without permission of the Energy Technology Innovation Project. To order copies or to request permission for reproduction, contact: Vicki Norberg-Bohm, Kennedy School of Government, Harvard University, 79 JFK Street, Cambridge, MA 02138 (617-496-3250; vicki_norberg-bohm@ksg.harvard.edu).

ACKNOWLEDGMENTS

Part of the research for this paper was carried out while the author was a visiting researcher at the Tate Energy Research Institute (TERI). The author would like to thank Dr. R.K. Pachauri for hosting him at the Institute. He would also like to thank Dr. Rajendra Pachauri, Dr. Ajay Mathur and many other colleagues at TERI for wide-ranging and stimulating discussions during his stay. This paper also draws upon discussions and interviews with researchers and officials – too numerous to name individually here – in the government, firms and other organizations in India who freely shared information as well as their views and insights. The author is grateful to all of them. Of course, the final responsibility for the paper, and the interpretations offered therein, lies with the author.

TABLE OF CONTENTS

<i>Abstract</i>	<i>v</i>
<i>Acronym List</i>	<i>vii</i>
1 INTRODUCTION	1
2 INDIA'S ENERGY SECTOR	3
3 ENERGY OUTLOOK AND POLICIES	8
3.1 COAL	8
3.2 PETROLEUM AND NATURAL GAS	10
3.3 ELECTRIC POWER	11
3.4 RENEWABLES.....	13
3.5 ATOMIC ENERGY	14
4 INDIA'S R&D: CURRENT STATE AND TRENDS	15
5 INDIAN ENERGY R&D LANDSCAPE	19
5.1 ENERGY SUPPLY	20
5.1.1 Coal	20
5.1.2 Petroleum and Natural Gas.....	25
5.1.3 Electric Power	28
5.1.4 Renewables.....	33
5.1.5 Atomic Energy.....	36
5.2 ENERGY USE.....	37
5.2.1 Transport	37
5.2.2 Steel Industry.....	41
5.2.3 Cement.....	45
6 INTERNATIONAL COOPERATION ON ENERGY	47
6.1 THE WORLD BANK	47
6.2 ASIAN DEVELOPMENT BANK (ADB).....	49
6.3 GLOBAL ENVIRONMENTAL FACILITY (GEF).....	50
6.4 JAPAN.....	51
6.5 UNITED KINGDOM	51
6.6 GERMANY	52
6.7 UNITED STATES	52
6.8 RUSSIA	56
7 WHAT SHAPES THE INDIAN ER&D LANDSCAPE?	57
REFERENCES	62
APPENDIX I	66
APPENDIX II	67

ABSTRACT

The main challenge facing India's energy sector is to increase and improve the delivery of energy services to various sections of the citizenry and the economy in an environmentally and socially acceptable manner. New and improved technologies will play a central role in meeting this challenge and from a long-term perspective, it will be in India's benefit to strengthen the technological capabilities that can help it meet its energy and environmental goals. This is the motivation for this examination of the status of the country's energy technology research and development (ER&D) efforts. Indian ER&D institutions and their activities are characterized by the dominance of the public sector in most areas, although some private firms also have sizable R&D efforts. The size (in absolute terms) and intensity (R&D normalized by sales) of ER&D efforts across the board are much smaller than in industrialized countries. There is also a remarkable imbalance between the pattern of energy supply/use and of ER&D spending: for example, biomass and coal, the mainstays of the Indian energy system, receive disproportionately little attention. While the government has been preoccupied with reforming the energy sector, the historical lack of focus on ER&D (that partly results from the division of various aspects of energy amongst various ministries) has continued in recent years. The lack of policy attention to this issue also results in the absence of any strategic plan for technology development in relation to the challenges facing India's energy sector. Given all this, a substantial and concerted effort will be required to appropriately reorient and strengthen India's ER&D capabilities to meet the energy and environmental challenges facing the country.

ACRONYM LIST

ADB	Asian Development Bank
ARAI	Automotive Research Association of India
BAL	Bajaj Auto Ltd.
BCCL	Bharat Coking Coal Ltd.
BHEL	Bharat Heavy Electricals Ltd.
CDM	Clean Development Mechanism
CECRI	Central Electrochemical Research Institute
CFRI	Central Fuel Research Institute
CHT	Center for High Technology
CIL	Coal India Ltd.
CMPDIL	Central Mining Planning and Design Institute Ltd.
CMRI	Central Mining Research Institute
CPRI	Central Power Research Institute
CSIR	Council for Scientific and Industrial Research
CWET	Center for Wind Energy Technologies
DAE	Department of Atomic Energy
DST	Department of Science and Technology
ER&D	Energy Research and Development
GAIL	Gas Authority of India Ltd.
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GHG	Greenhouse Gas
GOI	Government of India
IGCC	Integrated Gasification Combined Cycle
ICT	Indian Institute of Chemical Technology
IIP	Indian Institute of Petroleum
IISc	Indian Institute of Science
IOCL	Indian Oil Corporation Ltd.
IREDA	Indian Renewables Energy Development Agency
kgoe	Kilograms of oil equivalent
kWh	Kilowatt-hour
LCV	Light commercial vehicles
M&HCV	Medium and heavy commercial vehicles
MNES	Ministry of Non-conventional Energy Sources
MoP	Ministry of Power
MoPNG	Ministry of Petroleum and Natural Gas
MT	Million tons
mtoe	Million tones of oil equivalent
MUL	Maruti Udyog Ltd.

MW	Megawatt
NCL	National Chemical Laboratory
NIRE	National Institute of Renewable Energy
NLC	Neyveli Lignite Corporation
NTPC	National Thermal Power Corporation Limited
ODA	Overseas Development Aid
OECD	Organization for Economic Cooperation and Development
OIL	Oil India Ltd.
ONGC	Oil and Natural Gas Commission
PCRA	The Petroleum Conservation Research Association
PGCIL	Power Grid Corporation of India
PPP	Purchasing Power Parity
PSUs	Public Sector Undertakings
RDSO	Research, Design and Standards Organization
RPL	Reliance Petrochemicals Ltd.
SAIL	Steel Authority of India Ltd.
SEBs	State Electricity Boards
SEC	Solar Energy Centre
T&D	Transmission and Distribution
TCES	Total Commercial Energy Supply
Telco	Tata Engineering and Locomotive Company
TERI	Tata Energy Research Institute
TFCE	Total Final Consumption of Energy
TISCO	Tata Iron and Steel Company
TPES	Total Primary Energy Supply

1 INTRODUCTION

It is well recognized that energy services play a critical role in enhancing human and economic development and accordingly in the years since India's independence in 1947, the Indian government has undertaken considerable efforts to augment its energy system. As a result of significant planning and investment (mainly by the government), there has been a substantial expansion of, and shift in, the country's energy sector. Over the last decade, though, the rate of growth and improvement in energy supply has slower than anticipated, contrary to the optimistic beliefs of the government and many analysts at the launch of India's economic reform and liberalization programs now over ten years ago. The situation in the energy sector is increasingly viewed as a substantial bottleneck to India's industrial growth that in turn is seen as critical to stimulating the country's economic and social development. (Appendix I presents some basic data about the Indian economy.)

Provision of various energy services has also led to significant environmental and social impacts in India, as in most other parts of the world. For example, activities such as extracting coal and harnessing hydropower have led to substantial environmental impacts and displacement of large numbers of people, the ongoing controversy over the Narmada hydroelectric project being a case in point. The local air pollution issue has also been focus of increasing concern, this attention being spurred on by the rapidly deteriorating air quality in not only large, but also many smaller, cities. This has already led to major policy initiatives such as the introduction of Euro-II norms for acceptable pollutant emissions from automobiles and the mandated replacement of diesel buses in Delhi by natural-gas-powered buses. Still substantial progress in reducing emissions from transport, households, industries and power plants will be required to improve air quality to acceptable levels. A related issue, air pollution within rural households resulting from the use of inefficient cook-stoves, has not yet received the attention that it deserves. This is a major human health issue that affects a large part of India's rural population, and energy utilization once again underlies this problem.

On the global climate front, while developing countries are not obliged to cut back their greenhouse gas (GHG) emissions (a major fraction of which are energy-related) at this phase of the implementation of the United Nations Climate Convention, they will likely do so in a limited way through their participation in the Clean Development Mechanism (CDM) of the Kyoto Protocol. Furthermore, the pressure already on them to show "meaningful participation" is likely to only intensify in the continuing negotiations, making it quite likely that they will have to take

on some commitments to reduce their greenhouse gas emissions in the post-Kyoto phase. India is the fifth-largest emitter of fossil-fuel-derived CO₂, and its total emissions grew at an annual average rate of almost 6% in the 1990s (Marland et al. 2001). Even though its annual per-capita emissions for 1998 of 0.3 tons of carbon are well below the global average of 1.1 tons per capita, the size of its aggregate emissions makes its participation in any future developing country commitment regime a foregone conclusion. This will require reductions of GHG emissions from energy use in transport, industry, power generation and other sectors of the economy.

Given this background, the main challenge facing India's energy sector is to expand and improve the delivery of energy services to various sections of the citizenry and economy in an environmentally and socially acceptable manner. New and improved energy supply technologies, including those that utilize renewable sources of energy, will doubtless play a central role in meeting this challenge. In a related vein, the use of more efficient end-use technologies can assist India in its effort to better utilize its current energy supplies.

Hence development and deployment of innovative technologies will continue to be of importance to the Indian energy sector. Activities that will be undertaken through the CDM will in all likelihood bring about technological change in some energy-intensive sectors. But the CDM, given its time frame of implementation, is likely to encourage deployment of technologies that are already well established in industrialized countries rather than promote the development of new ones. Thus, from a long-term perspective, it is in India's benefit to strengthen its technological capabilities in the energy area so that it can be an innovator as well as adopter of cleaner and more efficient energy technologies.

This paper examines the status of energy technology research and development (ER&D) efforts in India. It also discusses government policies and other factors that have shaped and influenced the development of these ER&D efforts. The paper begins with a brief overview of the present state and evolution of India's energy sector as well as relevant government policies. It then presents a broad review of R&D in India followed by a survey of ER&D efforts. This appraisal includes major funding as well as performing institutions in the public and private sectors. The article also describes activities of the major international and bilateral aid agencies that assist in the development of India's energy sector. The paper ends with a discussion of some of the key policies and factors that have shaped, historically as well as more recently, the Indian science and technology enterprise and, more specifically, the country's ER&D efforts.

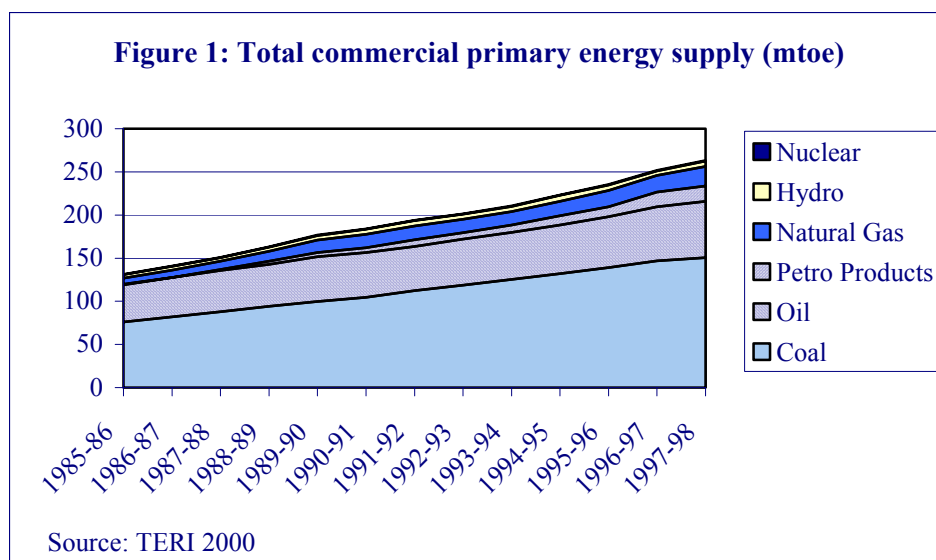
2 INDIA'S ENERGY SECTOR

Overall, there has been a more than tenfold increase in India's commercial energy supply in the fifty years since 1947. In 1997-98, the total commercial energy supply (TCES) was 263 million tones of oil equivalent (mtoe) (TERI 2000) while the corresponding figure for 1953-54 was about 25 mtoe (Planning Commission 1997a). Traditional sources of energy also continue to play a significant role in satisfying India's energy demand. Although reliable data on the supply and consumption of non-commercial energy sources is scarce,¹ it is estimated that over a third of India's energy supply is derived from traditional fuels. For example, the IEA indicates that about 41% of India's total primary energy supply (TPES) is derived from combustible renewables and waste (IEA 2000) while the Indian Planning Commission estimates put this portion at 34% (Planning Commission 1997a). Still, the country's dependence on non-commercial fuels has reduced substantially over the years – it is estimated that such sources of energy accounted for about three-quarters of the country's energy supply in 1950-51 (Planning Commission 1997a).

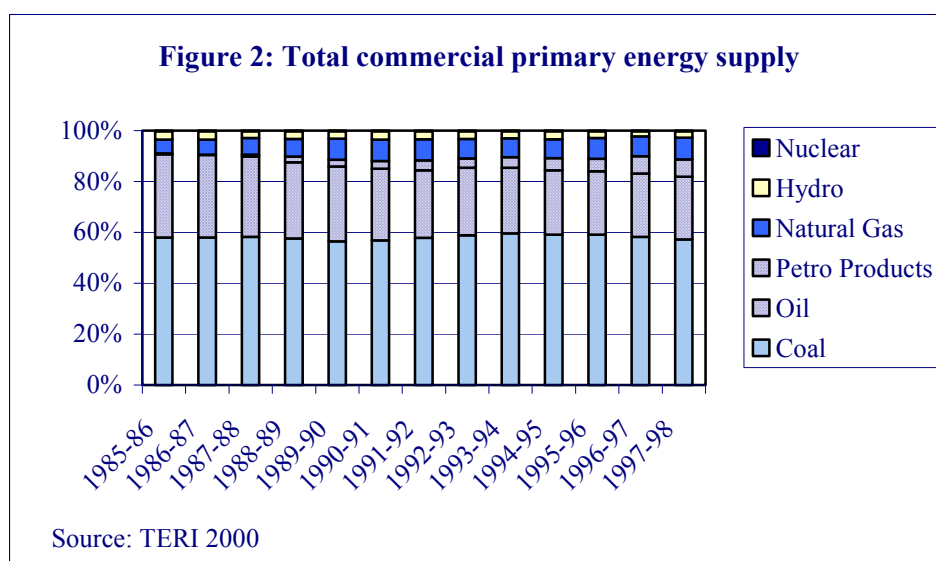
Taking non-commercial sources (mainly combustible renewables and waste) into account, India's TPES rose by two and half times between 1973 and 1997, with the IEA estimating the 1997 levels to be about 465 mtoe and the Indian Planning Commission, about 390 mtoe (IEA 2000, Planning Commission 1997a). The country's TPES per capita has increased by 50% in this period to about 480 kilograms of oil equivalent (kgoe), but still this number is less than a third of the global average, and only about a tenth of the Organization for Economic Cooperation and Development (OECD) average (IEA 2000). India's TPES per unit GDP (Gross Domestic Product) on a purchasing-power-parity (PPP) basis reduced by about 30% during the same period, although it was still above the average for the world (by about 15%) and the OECD (by 23%).

Coal and oil account for most of India's commercial energy. In 1997-98, they contributed 57.2% and 24.7% respectively of the total of 263 mtoe (TERI 2000). While the TCES went up about two-fold between 1985-86 and 1997-98 (Figure 1), the contributions of coal and petroleum products have pretty much stayed constant over that period (see Figure 2).

¹ Data on commercial energy in India also vary somewhat between different sources. In this paper, I mainly draw upon four sources for macro-level energy data – the Planning Commission, the Tata Energy Research Institute, the International Energy Agency, and the Center for Monitoring the Indian Economy – to try and present a consistent picture of energy use patterns in the country. It should be noted that even though there may be some variation across these sources, the general trends portrayed by them are very similar.



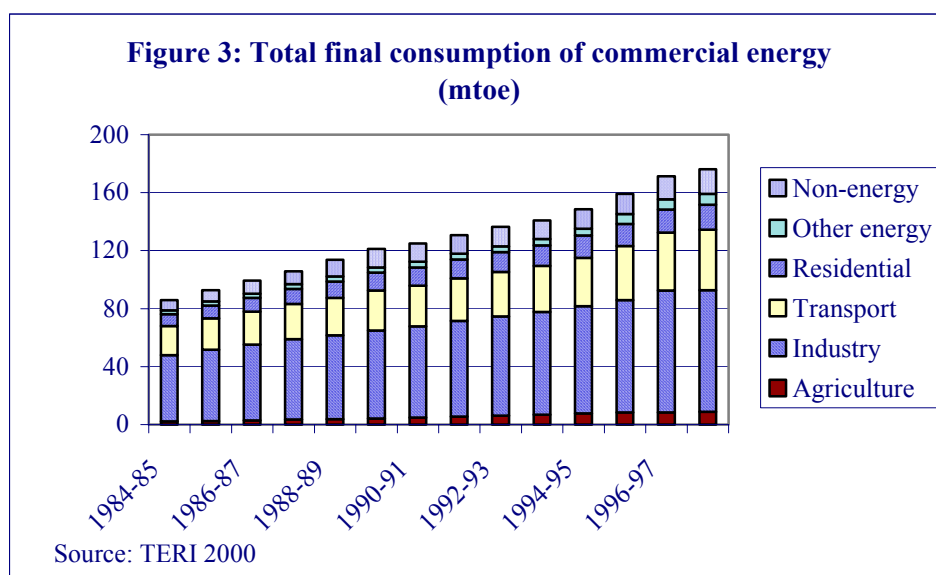
The share of natural gas, although still much smaller than these two, has increased rapidly in the last decade and half and by 1997-98, it contributed 8.6% of India's total commercial energy supply.



India is not self-sufficient in energy. Its imports (mainly crude oil and petroleum products but also high-quality coal for the steel industry) accounted for over 25% of the TCES in 1997-98 (TERI 2000), up from 8.6% in 1953-54 and 17.9% in 1990-91 (Planning Commission 1997a). Energy imports were expected to rise further to 28% by early 2002 (Planning Commission

1997a). Oil, gas and petroleum products accounted for about 87% of the imports while coal accounted for most of the rest.

The total final consumption of commercial energy (TFCE) in 1997-98 was 176 mtoe, almost double of the number for 1984-85. The share of coal in the TFCE has been steadily declining while that of oil and gas has been increasing. In 1997-98, petroleum products and gas accounted for over 50% of the TFCE while coal contributed about 30% (considering only direct use of these energy sources and not their use in electric power generation since electricity is a separate category in the TFCE tally). About half of the total petroleum consumption in the country went to the transport sector, and almost all of the coal consumption



was in industry. Overall, industry and transport are the two largest consumers of commercial energy (see Figure 3), accounting for 47.8% and 23.6%, respectively, of the total in 1997-98 (TERI 2000)². The agricultural and residential sectors consume 5.0% and 9.8% of the final commercial energy in the country (TERI 2000). While these data may seem to suggest that households consume only a small portion of the energy in the country, it should be noted that in reality households are the largest consumers of energy but the bulk of their energy comes from traditional fuels such as firewood, animal dung, and agricultural residues.

² The data for industry includes feedstocks.

On the electric power front, the total installed electric generation capacity in Indian utilities was over 101,660 MW in early 2001. This consists of 25,142 MW hydro, 71,518 MW thermal, 2,860 MW nuclear and 1,270 MW wind power (Planning Commission 2001). As Table 1 shows, 59.9% of this total capacity is within state electricity boards and electricity departments, 30.4% in the central sector and 9.7% in the private sector (Planning Commission 2001). The gross generation by utilities was 480 billion kWh in 1999-00 of which thermal generation accounted for 80.5%, hydro 17.9%, and nuclear 2.8% (GOI 2001). In addition, the capacity in captive power plants was estimated to be about 15,000 MW (Powerline 2000, CMIE 2001).

The major consumers of electricity from utilities are industry (24.5%), agriculture/irrigation (31.2%), residential (16.8%), commercial (4.8%), and railways (2.3%) (figures in parentheses are for 1998-99) (Planning Commission 2001). Average per capita consumption has grown from 15.6 kWh in 1950 to about 330 kWh currently, but this is still much lower than consumption standards prevailing in developed economies. Furthermore, according to 1991 data, 57% of the households inhabiting 54% of the population did not have facilities for electricity - nearly 25% of the urban households and 70% of the rural households were bereft of any electricity connection.³

Table 1: Power generation capacity in utilities by ownership and generation mode, 2001

	Central	State	Private	Total	% of total
Coal	20918	35817	4291	60655	60.0
Gas	4449	2428	3615	10487	10.4
Diesel	0	540	331	764	0.8
Total Thermal	24978	38659	8270	71906	71.1
Hydro	2644	22021	477	25220	24.9
Nuclear	2860	0	0	2758	2.7
Wind	0	57	1212	1270	1.3
TOTAL	30870	60863	9927	101660	100

Source: Planning Commission 2001

The substantial power capacity addition of the early 1980s combined with a slowdown in the industrial activity in the early 1990s led to a decline in the deficit between power demand and supply from well above 10% in the early 1980s to 7.1% during 1994-95, although it rose again

³ According to official figures, over 90% of the villages had been electrified by the mid-1990s (Planning Commission 2001c), but a village is officially declared “electrified” even if a single connection is provided there.

subsequently. In 1996-7, the power deficit was 11.5%, and peaking shortage was 18% (Planning Commission 2000). The situation has improved somewhat since then, although only marginally – energy and peak shortages in early 2001 were 7.8 and 13% respectively (Planning Commission 2001).⁴ The Indian power generation capacity increased at a rate of 8.4% p.a. in the 1980s, at about 5% p.a. in the early 1990s and dropped to almost half this since 1995. The capacity addition during the 8th 5-year Plan (1992-97) was well below target (16,423 MW expected vs. 30,538 MW planned) (Planning Commission 1997b).

Given the importance of the energy sector for advancing India's human and economic condition, a sizable fraction of government expenditures have been targeted towards its development. For example, from the 4th five-year Plan onwards, the energy sector has accounted for more than 20% of the total expenditures/outlay in the Plans (see Table 2). In the 9th Plan (1997-2002) it was allocated almost 26% of the public sector outlay, amounting to Rs. 2216 billion.

Table 2: Share of Energy Sector in Plan Expenditure

Plan and period	Plan Expenditure [†] (billion rupees)	Share of energy sector (%)				
		Power	Oil/Gas	Coal	NRSE [§]	Total
1 st (1951-56)	19.6	---	---	---	---	19.7
2 nd (1956-61)	46.7	9.7	0.8	1.9	---	12.4
3 rd (1961-66)	85.8	14.6	2.6	1.3	---	18.5
4 th (1969-74)	157.8	18.6	1.9	0.7	---	21.2
5 th (1974-79)	394.3	18.7	3.6	2.9	---	25.2
6 th (1980-85)	1092.9	16.7	7.8	3.5	0.1	28.1
7 th (1985-90)	2202.2	17.4	7.3	3.2	0.3	28.2
8 th (1992-97)	4854.6	15.8	8.3	2.3	0.2	26.6
9 th (1997-2002)	8592.0*	14.5	8.6	2.3	0.4	25.8

[§] New and renewable sources of energy

[†] Expenditure at current price at base year of the respective Plans.

* Plan outlay

Source: Planning Commission 1997, 2001a.

⁴ These numbers do not adequately capture the shortcomings of the Indian power system. The constant overload and stress on it leads to large numbers of unplanned power outages as well as low voltage and frequency excursions that are not only deleterious to all kinds of power equipment and devices but also make the system's operation more difficult.

3 ENERGY OUTLOOK AND POLICIES

The Indian energy sector, like the rest of India's economy, is undergoing large changes as a result of the economic reform and liberalization programs undertaken by the Indian government beginning in 1991. This sector has been the focus of much attention since it is central to economic development, as shortfalls in energy availability are seen as bottlenecks to rapid industrial growth.

Projections suggest that by 2011-2012, the demand for primary commercial energy will increase to 770 mtoe representing almost a 3-fold increase since 1996-1997. The per-capita commercial energy consumption at this time is expected to be almost 650 kgoe, which is still much lower than the current international average of about 1500 kgoe/capita and the levels in industrialized countries of 5000 kgoe/capita (Planning Commission 1997c).

Meeting the challenge of the future commercial energy demand will require development of indigenous resources (coal, oil and gas), additions to downstream processing capabilities for these energy sources, and setting up of thermal and hydroelectric power stations. At the same time, the infrastructure for transport and handling facilities, i.e., railways, roads and ports, needs to be expanded substantially. Indian government energy policies have been driven in large part by the perceived need to rapidly increase the availability of energy in the country. In the context of limited funds available to the government, foreign investment has been deemed crucial. Therefore many of the policies have involved loosening the strict controls that the Indian government traditionally placed on foreign investment in the energy sector. At the same time, efforts to improve the efficiency of public sector institutions have included moves towards restructuring and/or privatization. At a broader level, the government is also grappling with issues such as the export strategy that needs to be adopted so that the growing requirement of imported energy is met without adversely affecting the national balance of payments. This issue is likely to take on increasing urgency as the hydrocarbon reserves of the country begin to run out by 2015-2020 as projections suggest (see Table 3).

3.1 Coal

India has large reserves of coal — at the present rate of coal extraction of 0.8 million tons/day, the reserves are likely to last over 200 years (see Table 3). Thus coal forms a central pillar of India's energy future. Power utilities are the major consumers of coal in the country, accounting for over 70 percent of the total coal offtake. India annually imports about 8-10 million tons of

low-ash coking coal principally for use in steel plants. The demand for coal is expected to increase significantly in the next decade or so due to the completion of on-going coal-based power projects as well as future additions to the power generation capacity. According to the 9th Plan document, the demand for coal was estimated to rise to 410 million tons (MTs) per year in 2001-02 to 545 MTs in 2006-07 and 775 MTs in 2011-2012 (Planning Commission 1997d). Augmenting coal resources and production, while minimizing environmental impact, is thus accorded a high priority in government planning.

Table 3: Proven reserves of fossil fuels and reserve-production (R/P) ratios

	Reserves	R/P (at 1999 production rates)
Coal	70 billion tons	212 years
Oil	600 million tons	15.6 years
Natural gas	490 billion cubic meters	22.9 years

Source: TERI 2000

CIL (Coal India Limited, the national coal company) and its subsidiaries alone will not be able to meet future demand. The investment needed to bridge the gap of 400 MTs between the 1996-97 level of production (290 MTs per year) in the public sector and the projected demand over the next decade and a half was estimated to be US\$ 18 billion (GOI 1996). Public sector corporations are expected to increase their production by about 250 MTs by 2009-10, subject to their making an additional investment of US\$ 8-10 billion. This would still leave a gap of 150 MTs, which will have to be met by imports in the short run and by new investments in the long run. Accordingly, the Indian government is taking steps to allow an increase in coal imports and deregulate the coal industry. The Government of India has also announced the new Integrated Coal Policy with a view to encourage private sector participation and invite foreign investment in the coal sector. This policy allows private sector companies to carry out coal mining in the country in new coal blocks without the existing restriction of captive power consumption, as well as engage in exploration of coal reserves in the country.

Indian coal has high ash content ranging generally between 15 and 45 percent. India has 19 coal washeries with a total capacity of 27.2 MTs per annum, although capacity utilization has consistently stayed below 45 percent over the years. In addition, these washeries have mainly been utilized for coking coal in preference to coal for power plants. Therefore, the transport of

coal to power plants is often inefficient since a large portion of the moved mass is ash. Thus coal beneficiation is another high-priority area, as is setting up pit-head power stations. The government is also encouraging the adoption of clean coal technologies.

3.2 Petroleum and Natural Gas

The share of petroleum products and natural gas in the total final energy consumption has been increasing over the years, reaching 51% in 1998-99. About two-thirds of the domestic oil requirements are currently imported (mainly from the Middle East). The demand for petroleum products is expected to almost double from the 1996-97 levels of 80 MTs to 155 MTs by 2006-2007 and increase further to 200 MTs (Planning Commission 1997d). It is estimated that by then the domestic production will provide only about 25% of the requirements.

The demand for natural gas is being driven by its emergence as a preferred fuel for power generation, although the long-term demand will depend on availability of other energy sources as well as the price competitiveness of gas, given that most of it will be need to be imported since the domestic production is expected to peak by 2002. India is exploring pipeline gas and LNG imports from Western and Central Asia as well Southeast Asia. At the same time, possible utilization of coal bed methane, gas hydrates and in-situ coal gasification are being considered. The infrastructure to handle and transport gas also needs to be augmented.

According to the Government of India's estimates in the mid-1990s (GOI 1996):

- An investment of US\$ 100 billion will be needed over the next 10 to 15 years to meet the projected early-21st-century demand,
- Additional refining capacity of 110 million tons per annum is required by the year 2010 for domestic consumption, and
- Development of extensive oil and gas distribution infrastructure such as cross-country pipelines, port terminals, tanks, and strategic reserves build-up are needed to meet projected requirements.

Hence the recent policy initiatives of the Indian government aim to attract investors into the exploration and production of oil and natural gas and to enable private companies, both domestic and foreign, to explore new oil and gas reserves, develop proven reserves, and establish petroleum refineries and pipelines.

The entire Indian petroleum sector has been opened to the private sector, both domestic and foreign, for investments through joint ventures and strategic alliances. Under the New Exploration Licensing Policy, Indian oil and natural gas fields have been opened up for exploration and production to the private sector as well as to foreign participation under production sharing contracts. Under this new policy, India awarded 25 oil blocks for exploration in 2000 and another 25 blocks in 2001 through an international bidding process. Although none of the oil “super majors” participated in these bids, a number of other international companies, in partnership with Indian firms or independently, did so successfully. The refining sector has been opened to the joint ventures and the private sector. In addition, the private sector is now permitted to import most petroleum products. While retail gasoline sales are still controlled by public sector undertakings (PSUs), many multinational firms are now in the lubricants market.

3.3 Electric Power

The generating capacity to meet the projected demand for electricity by the end of 9th Plan period (2001-02) was estimated to be 137,063 MW. The Plan estimated that the feasible capacity addition to the 1997 levels would be 40,245 MW which would still leave a 1.4% electricity shortage and 11.6% peak shortage in relation to the projected demands (Planning Commission 1997b). The mid-term review of the 9th Plan indicated that power additions were likely to be only 60% of the envisaged goals (Planning Commission 2000a). Based on demand projections of the 15th Electric Power Survey (CEA 1995), the future planned capacity additions for the 10th and 11th Plans were 57,000 and 59,000 MW (Planning Commission), although recent estimates from the 16th Electric Power Survey scaled down the projected requirements by about 10% (TERI 2000).

Accordingly, India has been making ambitious efforts to increase its electricity generation capacity. Due to the paucity of the resources available to the Central and State PSUs and the state electricity boards (SEBs) for developing the additions needed, the Indian Government opened up India’s power sector in 1991, making a series of major changes in its policies at that time, and subsequently, in order to attract private investment. For example, proposals for projects of Rs. 15 billion or less with a foreign equity component up to 100% are now approved automatically. As a result of these policy changes, both domestic and foreign developers evinced keen interest in the Indian power sector, yet the implementation of power projects has been beset with numerous problems. By late 2000, only nine IPPs with a combined capacity of 2700 MW had been commissioned, and only three of the original eight “fast-track” projects had been commissioned (Powerline 2000b). Foreign investors have continued to withdraw from the country or lower their

exposure as a result of a number of bureaucratic and other hurdles faced by project developers. The controversy over Enron's Dabhol project further dampened IPP investor interest.

Current wisdom holds that failure to tackle the central issue – the poor finances of the state electricity boards (SEBs) – and starting instead with private projects, was a major reason for this unsuccessful attempt to promote private participation in India's power sector. Hence, restructuring and privatizing SEBs and implementing regulatory reform has become a major focus of the government policies. A number of states (Orissa, Andhra Pradesh, Haryana, Uttar Pradesh and others) have since embarked on restructuring programs with the hope that this will improve the financial viability of the SEBs and enhance the performance of the power sector. The Government has also created the Central Electricity Regulatory Commission under the Electricity Regulatory Commissions Act of 1998 and some states have set up counterpart bodies. The Electricity Bill 2001, introduced in the Indian Parliament in late 2001, seeks to further address and facilitate power sector reform.

While over 60% of the capacity of the utilities has been added since 1980, it has been assessed that about 34,000 MW of capacity (24,400 thermal, and 9,600 hydro) are in need of renovation and modernization (R&M). In fact, almost 15,000 MW of thermal power plants operate at plant load factor (PLF) below 45%. Estimates suggest that appropriate R&M measures could increase the output by an equivalent of 5,000 MW of new capacity. Accordingly, the Government is also making efforts to improve the performance of existing power plants.

In addition, the transmission and distribution (T&D) losses of the Indian power system have consistently been high. While there was some decline in T&D losses in the early 1990s, with the loss levels dropping to 21.8% in 1992-93, since 1995-96, these losses have risen again. The estimated T&D losses for 1997-98, 1998-99 and 199-00 were estimated to be about 24.8%, 25% and 23.7% respectively.⁵ (Planning Commission 2001). This has been an area of much concern and the 9th Plan suggested a target of reduction of T&D losses at the rate of 1% per year.

⁵ T&D figures include technical losses as well as theft and losses due to administrative negligence. The available data, although an indication of the magnitude of the problem, are a source of much debate. Many experts contend that the accuracy of these figures is highly doubtful, and that the total losses are higher (due, among other things, to agricultural sector consuming less power than suggested by official figures). For example, when T&D losses were calculated in Orissa as part of the restructuring exercise, the loss that was reported as 23.8% for 1994-95 was re-estimated as 50.4% in 1996-97 (Planning Commission 2000a).

Recent estimates have suggested that country will require an investment of about \$170 billion for generation and transmission projects to meet power on demand by 2012 (OBP 2000). About \$100 billion will be required for power generation projects summing up to about 100,000 MW and the rest will be required to set up transmission and distribution networks. Of this total requirement, the Indian government suggests that it could take care of about 30 per cent, while the rest would have to come from the private sector.

There is also a need to improve end-use efficiency in various parts of the economy. The Energy Efficiency Bill that has recently been passed by the Parliament aims to reinvigorate and institutionalize conservation efforts in the energy sector since there is also a large potential for savings through energy end-use efficiency improvements.

3.4 Renewables

India has one of the largest programs in the world on non-conventional energy covering a range of renewables. The two main aims of this program are to supplement the power generation from conventional fossil fuels utilizing domestic energy resources, and to help better meet rural energy requirements. The expectation is that India's substantial renewable energy potential (see Table 4) could be suitably exploited for meeting these goals. In this context, the government has actively promoted the development of renewable resources (wind, hydro, biomass, and solar PV) for electricity generation. It also has programs for exploring the potential of chemical sources, geothermal energy and ocean energy.

Table 4: Renewable Energy Potential and Achievement

	Potential	Status (1999 end)
Biogas plants	12 million	2.9 million
Improved cookstoves	120 million	31 million
Biomass-based power	16,000 MW	256 MW*
Solar power	20MW /km ²	42 MW
Wind	45,000 MW	1080 MW
Small hydro	10,000 MW	210 MW
Energy from waste	1700 MW	3.75 MW

* biomass-based cogeneration 222MW, biomass gasifiers 34 MW

Source: MNES 2000

The Ministry of Non-conventional Energy Sources (MNES) also has socially oriented programs such as the National Project on Biogas Development, the National Programme on Improved Chulhas (cookstoves), and the Integrated Rural Energy Programme. While efforts to develop non-conventional energy sources have until recently heavily relied on subsidies provided by the Central government (either through the Indian Renewable Energy Development Agency or through state agencies), there is an attempt to move the emphasis towards private entrepreneurship and community participation.

The Cabinet is likely to approve a proposed new national policy for renewable energy development, which, according to official claims, will help add about 12,000 MW by the end of the eleventh Plan (i.e., the year 2012). Almost half the capacity is expected to be generated using wind power, about 3,500 MW from biomass and the remaining 2,000 MW from small hydropower units below 25 MW. This capacity addition is likely to require funds in the tune of Rs 700 billion. One-eighth of this amount (about Rs 58 billion) is expected to be provided from the Central Government budget. Some funding will also be raised through the tax to be imposed on coal and fossil fuels. The bulk of the money, however, will be raised through loans (Powerline 2000a).

3.5 Atomic Energy

While atomic energy accounts for just under 2.5% of the country's generating capacity, and just over 2.5% of the power generation, it occupies an exalted place in the country's energy landscape. Nuclear power development is felt by the government to be a critical element of any strategy to avoid excessive dependence on energy imports in the coming decades. The government also feels that the full benefits of this long-term technology will not be available to the country unless its growth is adequately supported in the near term as a matter of policy. The 9th Plan (Planning Commission 1997c) suggested that the rate of growth of nuclear power is currently limited by financial constraints while it is technologically poised for higher rates of growth. According to the Plan document, the nuclear power program should grow to a minimum size of 20,000 MW in the course of the next 25 years,⁶ and be largely based on indigenous designs of Pressurised Heavy Water Reactors and Fast Breeder Reactors. Some imported Light Water Reactors may be introduced as a supplementary line to increase the nuclear power capacity

⁶ Dr. Abdul Kalam had suggested last year, when he was still Chief Scientific Adviser to the Central Government, that this target be revised to 40,000 MW.

at a faster pace, subject to such systems being available on political and commercial conditions acceptable to the country. It was anticipated that 880 MW of nuclear power would be added in the 9th Plan (1997-2002) (Planning Commission 1997b).

Given the above-stated perspective of the government on nuclear power, and the limited financial resources that can be raised by the Nuclear Power Corporation of India Ltd (NPCIL), the 9th Plan felt that there was a need to explore the possibility of private sector participation in the nuclear power program. To this end, the DAE is preparing proposals to amend the Atomic Energy Act of 1962 to allow private sector participation and joint ventures (Moorthy 2001).

4 INDIA'S R&D: CURRENT STATE AND TRENDS

India's national expenditure on research and development was Rs. 83.4 billion in 1996-97 (DST 1999). This was equivalent to US\$ 2.34 billion at market exchange rates (MER) and 11.5 billion international dollars in purchasing power parity (PPP) terms⁷ (see Appendix I for recent rupee-dollar exchange rates). Not surprisingly, this is much smaller in comparison to the national R&D budgets of major industrialized countries (see Table 5).

Table 5: Comparison of selected national R&D budgets (1996 data)

	Total (Billion US\$)	Percent of GDP	Per Capita (US\$)
India (MER)	2.34	0.59	2.5
India (PPP \$)	11.5	0.59	12.1
United States	195.9	2.57	739
Japan	85.1	2.83	676
Germany	39.7	2.30	485
France	27.7	2.32	475
United Kingdom	22.3	1.95	380
Italy	12.0	1.02	209
Canada	10.8	1.60	365

Source: DST 1999, NSF 1998

⁷ PPP estimates are the preferred international standard for calculating cross-country R&D comparisons, and are used in official OECD R&D tabulations – R&D costs such as wages of scientists, engineers and other support personnel are better represented by such a conversion (NSF 1998, pg. 4-36). Yet costs of buying capital equipment as well as many other costs of R&D are governed by market exchange terms. Hence the conversion parameter that would best represent magnitude of R&D efforts across countries would probably lie somewhere between the PPP and the market exchange rates.

Even on a per-unit GDP basis, India spends only about 0.6% on R&D whereas the United States and Japan spend over 2.5%. As Table 6 shows, Indian R&D spending did not grow much between 1990 and 1996 in real terms – by only about 3% per year on average – although it increased at a higher average annual rate in the 1970s as well as the 1980s. Recently, though, the Government has made a decision to raise the allocation for research and development to 2 percent of GDP.

Table 6: Indian R&D expenditures, Billion 1993 Rupees

<i>Year</i>	Total R&D	Central Govt.	State Govt.	Private Sector
1970-71	10.0	8.0	0.9	1.0
1975-76	16.1	13.0	1.2	1.9
1980-81	23.2	17.7	1.8	3.7
1985-86	42.4	33.9	3.3	5.2
1990-91	54.3	41.8	5.0	7.5
1991-91	53.7	41.3	4.9	7.6
1992-93	54.9	40.2	5.5	9.2
1993-94	60.7	45.3	5.6	9.8
1994-95	60.3	42.9	5.4	12.0
1995-96	62.7	43.6	5.5	13.6
1996-97	64.8	45.2	5.6	14.0

Source: DST 1999

In India, the government has historically dominated R&D spending (see Table 6). In 1996-97, the shares of the central government, state governments and the private sector were 69.8%,⁸ 8.7% and 21.5% respectively (DST 1999). Although the current situation in India is a distinct improvement over the past – until as recently as 1990, the private sector contribution was generally less than 15% – such a share of the private sector is small in comparison to major industrialized countries where its contribution is generally between 50 and 75% (for example, the private sector contributes over 70% of the national R&D expenditures in Japan and the United States (NSF 1998)).

⁸ This includes public sector undertakings (PSUs) that account for 6.4% of the national total.

Most of the Central Government's (non-PSU) R&D expenditures are through its scientific agencies (Table 7), and many of these fund and/or perform energy relevant R&D. For example, some of the Council for Scientific and Industrial Research's (CSIR's) 40 laboratories have R&D programs in coal mining and utilization, petroleum processing, and renewables. The Department of Atomic Energy is engaged in basic and applied research, technology development and its translation to industrial applications, including nuclear power. The Department of Science and Technology (DST), whose main objective is to organize, coordinate and promote S&T activities, identifies and supports front-line and priority areas of research and development through the Science and Engineering Research Council. It also provides funding for basic research in 13 autonomous institutes under it, some of which do energy-relevant research. DST also supports, through the Technology Development Board, development and commercial application of indigenous technology or adapting imported technology for wider domestic applications. The remote sensing programs of the Department of Space play a role in natural resource exploration.

Table 7: R&D expenditures by major scientific agencies, 1996-97

	Billion Rupees	Billion US\$	Billion PPP\$
Central Govt. R&D Spending	58.2	1.64	8.04
<i>Major Govt. Scientific Agencies</i>	<i>47.6</i>	<i>1.34</i>	<i>6.57</i>
Defence Research and Dev. Org.	14.62	0.41	2.02
Department of Space	10.62	0.30	1.47
Department of Atomic Energy	5.30	0.15	0.73
Indian Council of Ag. Research	4.62	0.13	0.64
Council for Sci. and Ind. Research	4.44	0.13	0.61
Department of Sci. and Tech.	2.50	0.070	0.35
Department of Biotech.	0.74	0.021	0.10
Indian Council of Med. Research	0.54	0.015	0.07
Ministry of Non-conv. Energy Sources	0.05	0.0014	0.01

Source: DST 1999

An examination of the Indian R&D budget on the basis of socio-economic objectives (following the UNESCO classification) reveals that defense and civilian space sectors account for almost a third of the expenditure; agriculture, forestry and fishing and industrial development for another thirty percent or so; and the remaining sectors share the rest among themselves (Table 8).

Table 8: Distribution of Indian R&D budget by socioeconomic objective, 1996-97

	Billion Rs.	% of total	Billion PPP\$
TOTAL	83.4		11.5
Defense	15.67	19.2	2.16
Agriculture, forestry, and fishing	13.90	17	1.92
Industrial development	11.36	13.9	1.57
Civil space	10.93	13.4	1.51
<i>Energy</i>	<i>6.19</i>	<i>7.6</i>	<i>0.85</i>
Health	6.15	7.5	0.85
Transport and telecommunications	6.09	7.5	0.84
Advancement of knowledge	3.97	4.9	0.55
Environmental protection	3.38	4.1	0.47
Earth and atmosphere	1.87	2.3	0.26
Social development and services	0.17	0.2	0.02

Source: DST 1999

Production, conservation and distribution of energy received about 7.6% of the national total R&D expenditure.⁹ This category received 8.4% of the central government R&D spending (and within this, almost 30% of the R&D expenditure by PSUs), 0.5% of the state governments', and

Table 9: Research and development expenditures for production, distribution and conservation of energy (million current Rupees and PPP\$)

	1994-95		1995-96		1996-97	
	Rupees	PPP\$	Rupees	PPP\$	Rupees	PPP\$
Central	3416	532.1	3650	536.8	3908	539.8
State	39	6.1	52	7.6	38	5.2
Public Sector	414	64.5	621	91.3	1586	219.1
Private Sector	614	95.6	605	89.0	661	91.3
TOTAL	4483	698.3	4928	724.7	6193	855.4

Source: DST 1999, World Bank 2001

⁹ This number probably underestimates the total energy-related R&D expenditures because research efforts in other categories – such as industrial development, development of transport, as well as environmental protection – may also eventually have significant influences on patterns of energy utilization.

3.7% of the private sector's R&D efforts (see Table 9 for energy-related R&D expenditures by these groups).

The proportion of Indian government R&D expenditure directed towards the energy sector falls well in the middle of the range for major industrial countries; this allocation varies from about 1% in the case of the United Kingdom to about 20% for Japan (Table 10).

Table 10: Distribution of govt. R&D budgets by selected socioeconomic objectives (% of total)

Objective	India (1996)	US (1996)	Japan (1996)	Germany (1995)	France (1996)	UK (1995)	Italy (1995)	Canada (1995)
<i>Energy</i>	8.5	3.7	19.8	3.5	4.7	0.9	3.1	8.2
Advancement of knowledge	6.0	4.1	52.1	52.8	35.2	24.8	52.8	33.4
Ag., forestry, and fishing	19.0	2.4	3.4	2.6	3.6	4.6	2.7	13.8
Civil space	16.7	11.4	7.0	5.1	10.9	2.9	8.7	7.5
Defense	23.9	54.7	6.2	9.1	29.0	40.8	4.7	4.8
Earth and atmosphere	2.9	1.2	1.3	2.4	0.8	2.2	1.4	1.6
Environmental protection	5.1	0.7	0.6	3.5	2.0	2.1	2.4	2.5
Health	3.8	17.6	2.8	3.1	5.2	7.7	8.8	8.9
Industrial development	8.9	0.6	3.8	13.2	4.8	9.3	8.8	10.4
Social devt. and services	0.2	1.0	1.1	2.4	0.9	2.5	2.8	3.7
Transport and telecomm.	3.0	2.6	1.7	0.5	N/A	0.3	N/A	3.9

Source: NSF 1998, DST 1999

5 INDIAN ENERGY R&D LANDSCAPE

This section will discuss in some detail the major public and private sector institutions that are engaged in energy-related R&D in India, the magnitude and nature of their R&D efforts, and to the extent possible, trends in such expenditures.

Figure 4 presents a broad overview of the main public-sector ER&D players and their organization under different ministries. Table 11 lists the major public agencies, private firms and research organizations that fund and/or perform research in various energy sectors. Table 12 reviews the R&D expenditures, as well as recent trends in such spending if available, of selected major ER&D-performing organizations in the country.

5.1 Energy Supply

5.1.1 Coal

Ministry of Coal

Under the 1973 Coal Mines (Nationalisation) Act, coal mining was mostly reserved for the public sector. This act was amended in 1993 to allow private sector participation in coal mining for captive power generation, washing of coal obtained from mines, and other possible end uses. Still, at present, public sector firms account for 98% of India's coal production and distribution. The Ministry of Coal administers the coal sector. The total R&D funding in 1996-97 under this Ministry was Rs. 201 million (DST 1999).

Coal India Ltd. (CIL), which is under the administrative control of the Department of Coal, is the largest coal producing company in the world and accounts for 88% of coal production in India. CIL has 8 subsidiaries, of which seven are coal producing companies while the eighth, the Central Mining Planning and Design Institute Ltd. (CMPDIL), is an engineering, design and exploration company set up for preparing perspective plans, rendering consultancy services, undertaking exploration and drilling work to establish coal reserves in the country, and collection of detailed data for preparation of projects for actual mining.

R&D activities in the coal sector are administered through the Standing Scientific Research Committee under the Ministry of Coal, with the four major areas of research being: production, productivity and safety; coal beneficiation; coal utilization; and environment and ecology. CMPDIL, the CIL subsidiary, acts as the nodal agency for coordination of research activities in the coal sector. CMPDIL, along with other CIL subsidiaries such as Bharat Coking Coal Ltd. (BCCL), Central Coalfields Ltd. (CCL), Eastern Coalfields Ltd. (ECL) and Western Coalfields Ltd. (WCL) also performs R&D. The R&D expenditures of CMPDIL in 1996-97 was Rs. 23 million, and of BCCL, Rs. 10 million. The Singrauli Collieries Company Ltd., another PSU, which produces 10% of India's coal, spent Rs. 0.2 million on R&D in 1996-97 (DST 1999). In the 9th Plan, the emphasis has been laid on development of in-house R&D in coal companies. The Neyveli Lignite Corporation (NLC), also under the Ministry of Coal, also has in-house R&D facilities in the Centre for Applied Research and Development (CARD). (CARD is being upgraded through a financial grant from UNIDO and will be known as Lignite Energy Research Institute). R&D activities include studies of lignite combustion and gasification. CARD has also taken up various joint projects in association with CSIR laboratories, universities, other

Figure 4: Main Indian public-sector ER&D organizations

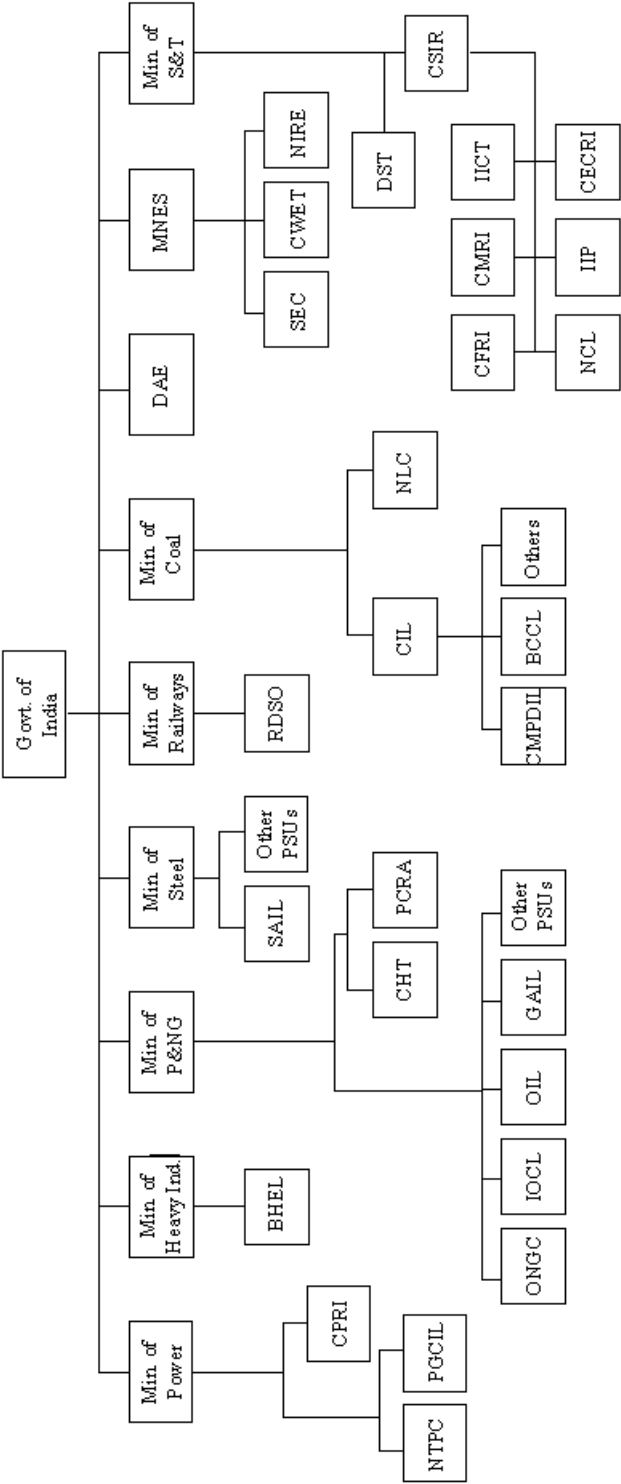


Table 11: Major Indian ER&D Funding and Performing Organizations by Sector[‡]

COAL

Ministry of Coal

Coal India Limited
Central Mining Planning and Design Institute
Bharat Coking Coal Ltd.
Neyveli Lignite Corporation

Ministry of S&T

Council for Scientific and Industrial Research
Central Fuel Research Institute
Central Mining Research Institute
Indian Institute of Chemical Technology

PETROLEUM AND NATURAL GAS

Ministry of Petroleum and Natural Gas

Oil and Natural Gas Commission
Oil India Limited
Indian Oil Corporation Ltd.
Gas Authority of India Ltd.
Petroleum Conservation Research Association
Center for High Technology

Ministry of S&T

Council for Scientific and Industrial Research
National Chemical Laboratories
Indian Institute of Chemical Technology
Indian Institute of Petroleum

Private Sector

Reliance Petroleum Limited

ELECTRIC POWER

Ministry of Power

National Thermal Power Corporation
Power Grid Corporation of India
Central Power Research Institute

Ministry of Heavy Industries

Bharat Heavy Electricals Ltd.

Private Sector

Asea Brown Boveri India
Siemens India
Cummins
Thermax

RENEWABLES

Ministry of Non-conventional Energy Sources

Center for Wind Energy Technologies
Solar Energy Center
National Institute of Renewable Energy

Ministry of S&T

Council for Scientific and Industrial Research
Central Electrochemical Research Institute

Research Orgns.

Indian Institute of Science, Bangalore
Tata Energy Research Institute
Indian Association for the Cultivation of Science

ATOMIC ENERGY

Department of Atomic Energy

Bhabha Atomic Research Center
Indira Gandhi Center for Atomic Research
Atomic Minerals Directorate

TRANSPORT

Road Transport

Private Sector

Tata Engineering and Locomotive Company
Bajaj Auto Ltd.
Mahindra & Mahindra

Research Orgns.

Automotive Research Association of India

Railways

Ministry of Railways

Research Development and Standards Orgn.

STEEL

Ministry of Steel

Steel Authority of India Ltd.

Private Sector

Tata Iron and Steel Co.

CEMENT

Private Sector

Associated Cement Companies Ltd.

Research Orgns.

National Council for Cement and Building Materials

[‡] Note that this is not a comprehensive list.

Table 12: R&D Spending of Selected Indian ER&D Performers

	R&D spending [†] (million Rupees)	R&D Intensity (% of sales)	R&D spending trend [§]
COAL			
CMPDIL	23 ^a	2.50	
BCCL	10 ^a	0.06	
Neyveli Lignite	36 ^a	0.27	
PETROLEUM AND NATURAL GAS			
ONGC	577 ^b	0.39	+
Indian Oil	780 ^c	0.07	+
Oil India	110 ^a	1.14	
GAIL	21 ^c	0.03	=
Reliance Petroleum	451 ^d	0.50	
<i>Major Multinationals</i>		0.3-0.6 ^e	
POWER			
NTPC	45 ^a	0.05	
BHEL	808 ^d	1.30	+
ABB	51 ^e	0.63	-
Cummins	100 ^c	1.15	=
Thermax	35 ^d	0.80	=
<i>Major Multinationals</i>		~ 3 ^e	
Dept. of Atomic Energy	5300 ^a		
Min. of Non-conventional Energy Sources	46 ^a		
ROAD TRANSPORT			
Ashok Leyland	231 ^d	0.89	+
Bajaj	610 ^d	2.20	+
Mahindra & Mahindra	882 ^d	2.00	+
Maruti Udyog	51 ^a	0.12	
TELCO	905 ^d	1.10	-
<i>Major Multinationals</i>		3-4 ^e	
RAILWAYS	364 ^a	0.1	
STEEL			
SAIL	518 ^d	0.32	+
TISCO	135 ^d	0.20	-
<i>Major Multinationals</i>		0.5-2 ^e	

[†]Superscript demotes year of R&D expenditure: a: 1996-97; b: 1998-99; c: 1999-00; d: 2000-01; e: 2000

[§] Organizations with recent annual R&D budgets displaying an increasing trend marked as '+', decreasing trends as '-', and little or no change as '='. Cells left blank where sufficient data not available.

educational institutions and other PSUs. The joint projects are funded by Ministry of Coal. The 1996-97 R&D expenditure of the Neyveli Lignite Corporation was Rs. 36 million (DST 1999).

Foreign collaboration in the coal sector has been targeted at bringing in new mining technologies in underground and opencast mines as well as providing financial assistance for importing equipment and investments for development of the coal sector. With these objectives in mind, India had set up joint working groups with Australia, Canada, France, Germany, Russia and China. While cooperation with Australia, Canada and France has declined in recent years, joint efforts with Russia and Germany are still ongoing. The Russians are cooperating with India on master planning of a few coalfields as well as improving coal production in other existing coalfields. The Germans have been active in providing financial assistance for a number of projects of the Neyveli Lignite Corporation. The World Bank and the Japanese have funded 25 projects (total about \$1.06 billion) in various subsidiaries of CIL to improve investment and production capacity. The United Nations Development Program (UNDP) and the Global Environmental Facility (GEF) are also funding a coal-bed methane R&D effort.

Geological Survey of India (GSI)

The GSI introduced geophysical techniques for coal exploration in India in the late 1940s, and has played a major role in the exploration of coal and lignite deposits in the country. It has a core group of geo-scientists engaged in the assessment of different mineral deposits. It also has facilities for drilling geophysical as well as analytical testing to back up its exploration activities.

National Remote Sensing Agency (NRSA)

The NRSA, an autonomous agency under the Department of Space, has utilized its remote sensing capabilities for the exploration of minerals, including coal and petroleum. The NRSA has a ground station to acquire data from Indian, as well as foreign, remote-sensing satellites. It also has the in-house capability to process this data.

Other Organizations

Other major coal R&D performing organizations include CSIR laboratories such as Central Fuel Research Institute (CFRI), Central Mining Research Institute (CMRI), and the Indian Institute of Chemical Technology (IICT) as well as academic institutions such as the Indian Institute of Science, Bangalore.

5.1.2 Petroleum and Natural Gas

Exploration, production, processing and distribution of petroleum and natural gas is also dominated by the public sector – at present, there is only one major private player in the petroleum exploration and refining segments. With equity participation in commercial and industrial ventures in various activities of the petroleum sector being freed from restrictions, as mentioned earlier, the shape of the petroleum and gas sector may well change substantially in the future. Currently, though, petroleum and gas R&D is dominated by public sector enterprises.

Ministry of Petroleum and Natural Gas

The Ministry of Petroleum and Natural Gas (MoPNG) has 14 PSUs under it. Of these, two are involved in exploration and distribution, ten in downstream processing, and two in engineering and technical services. The MoPNG, and the enterprises under it, spent Rs. 1.32 billion on R&D in 1996-97 (up from 1.14 billion in 1994-95) (DST 1999). Of this, the PSUs of the ministry accounted for Rs. 1.12 billion. Three of these PSUs – Oil and Natural Gas Commission (ONGC), Oil India Ltd. (OIL) and Indian Oil Corp. Ltd. (IOCL) – accounted for over 75% of the MoPNG's R&D expenditure. The first two of these, ONGC and OIL, are engaged in the exploration for and production of oil and natural gas in the country, while the third, IOCL, is a downstream processing company.

ONGC is a horizontally integrated upstream petroleum company with in-house capabilities and infrastructure in the entire range of exploration & production activities for oil and gas as well as related oil field & engineering services. It is India's largest producer of crude oil, natural gas and liquefied petroleum gas. ONGC has institutionalized research and development in the oil sector and established separate institutions to undertake specific activities in key areas of exploration, drilling, reservoir management, production technology, ocean engineering and safety and environment protection in the form of 7 independently managed R&D centers. Among other things, ONGC has recently undertaken R&D projects in West Bengal and Bihar for coal bed methane operations, a topic that is receiving increasing attention in India. ONGC spent Rs. 0.39 billion in 1997-98 on R&D (0.25% of turnover) and Rs. 0.58 billion (0.39% of turnover) in 1998-99 (ONGC 1999).

OIL is an Indian national oil company under the administrative control of MoPNG and is engaged in the business of exploration, production and transportation of crude oil and natural gas. OIL spent about Rs. 0.11 billion on R&D in 1996-97 (1.14% of turnover) (DST 1999).

IOCL is India's largest commercial enterprise (by sales) and the only Indian company to find a place in Fortune's "Global 500" of the world's largest industries (ranked 209 in 2000). It is the 18th largest (by sales) petroleum refining company globally. IOCL owns and operates 7 of the country's 15 refineries that gives it a total capacity of 35.6 MMTPA – this is over 33% of the country's total refining capacity. Indian Oil's marketing network is spread throughout the country with over 19,000 sales points (the largest in the country). IOCL's refinery throughput was 33.22 MMT and its domestic sales, 47.80 MMT in 2000-01 (Indian Oil 2001). It meets about 55% of the country's requirement of petroleum products. IOCL's products include liquefied petroleum gas, gasoline, aviation turbine fuel, kerosene, high-speed diesel, other energy fuels and feedstock, lubricants and greases, and petrochemicals and specialties. The Indian Oil R&D Centre, established in 1972 for the development of lubricants as well as refining process technologies, now has a range of activities in the downstream areas of lubricants, pipelines and refining processes. Some areas of R&D at IOCL are performance evaluation of fuels; lubricants and greases; lubricants formulation technology; fluidized catalytic cracker (FCC) catalyst evaluation; FCC and hydrocracker modulation software for plant simulation and optimization; material failure analysis and remaining life assessment of refineries and pipelines; and marketing equipment and installations. Its expenditures have risen substantially in the last few years. In 1996-97, it spent about Rs. 0.47 billion on R&D (0.11% of turnover); by 1999-00, this had gone up to Rs. 0.78 billion (but only 0.07% of turnover) (IOCL 2001). The firm's R&D investments are expected to continue to rise further (IOCL 2000).

The Gas Authority of India Ltd. (GAIL), one of India's leading public sector enterprises, is the largest gas transmission and marketing company in the country. The various activities of the company range from gas marketing and distribution through trunk and regional systems to gas processing for production and marketing of liquefied petroleum gas (LPG), liquid hydrocarbons and petrochemicals. The company owns and operates over 4000 km of pipeline and has about 95% market share in the natural gas business in India. GAIL has also recently set up the Gas Technology Institute. This is the result of a 1992 agreement between GAIL and Dansk Olie Og Naturgas A/S to set up such an institute. A Rs. 250 million joint project of GAIL and DANIDA (the Danish Development Agency), the Gas Technology Institute focuses on research and technology development relating to effective processing, transmission and utilization of natural gas. It also has a collaborative arrangement with the U.S. Gas Technology Institute. Some of its main focus areas of R&D are the development of high efficiency gas use technologies as well as development of gas uses to help in environmental management. GAIL spent Rs. 20 million

(0.03% of turnover) on R&D in 1999-2000, about the same in absolute terms as in 1998-99 (GAIL 2000).

The Petroleum Conservation Research Association (PCRA) was set up in 1976 under the MoPNG, as a part of the Government's response to the oil crisis of early seventies, to undertake studies for identifying the potential and to make recommendations for achieving conservation of petroleum products in various sectors of the economy. PCRA was also entrusted with the task of sponsoring R&D activities for the development of fuel-efficient equipment and running a multimedia campaign for creating mass awareness for the conservation of petroleum products. Oil marketing companies in India have also been making efforts to promote conservation and provide support to the PCRA. A Conservation Cell was established in the MoPNG in July 1989.

The Center for High Technology (CHT), also under the MoPNG, acts as a focal point for coordinating and funding petroleum-related research work in refining and marketing, exchange of information and experiences, assessing technology requirements and getting them developed indigenously. Among its other activities, the CHT advises and implements the scientific and technological programs of the Ministry and acts as its executive wing for co-ordination, import, acquisition and upgradation of technology. Its is also responsible for recognizing gaps in R&D in refining processes and products, identifying the organization which can take up that work, and then funding relevant project work. CHT's total funding for projects until March 1999 was Rs. 68 million. Its current portfolio of projects has a funding of Rs. 450 million.

Reliance Petroleum (RPL)

The Reliance Group has recently become a major player in the petroleum refining and marketing¹⁰ with the completion of RPL's new integrated petrochemicals complex at Jamnagar, which includes the world's largest grassroots refinery project with capacity of 27 million tons per annum. This is India's only private sector refinery so far. R&D efforts at Reliance Petroleum focus on various aspects of the refining process including feedstock sourcing, asset optimization, quality and reliability assurance as well as product management and development. Reliance Petroleum's R&D expenditure for 2000-2001 was Rs. 451 million, which is approximately 0.15% of sales (RPL 2001).

¹⁰ Reliance Industries, another firm of the Reliance Group, has been awarded a total of 14 offshore oil and gas exploration blocks by the Government of India, including both, deep water and shallow blocks. This has made Reliance Industries the leading (oil and gas) exploration and production player in the private sector in India.

The R&D spending (normalized by sales) of the major Indian oil and natural gas firms is somewhat lower than the major international counterparts. In the year 2000, large oil companies spent on average 0.35% of their net sales on R&D (0.3-0.6%) and exploration companies, Schlumberger and Halliburton, spent 5.6 and 1.9% of their sales on R&D (FT 2001). Osaka Gas, a gas distribution company spent 2.1% of its turnover on R&D in 1999 (FT 2000).

Other organizations

A number of other academic and research institutions also perform petroleum-related R&D. Prominent among these are National Chemical Laboratories (NCL), Indian Institute of Chemical Technology (IICT) and the Indian Institute of Petroleum (IIP) (all three are CSIR laboratories) that carry out R&D on various aspects of petroleum processing, for example, in areas of catalysis.

5.1.3 Electric Power

About 60 percent of the national generation assets are owned and operated by states, and 30 per cent by corporations set up by the central government (this includes the Nuclear Power Corporation Ltd. that accounts for just over 2.5% of the national total). Twenty-eight private corporations and various privately owned wind farms account for the remaining 10% or so of the national installed capacity in utilities.

Ministry of Power

The Ministry of Power (MoP) has a number of enterprises under it that are involved in generation and distribution of power as well as financial institutions that assist in the development of generation and transmission assets. The MoP spent a total of Rs. 54 million on R&D in 1996-97 (DST 1999). In early 2001, the MoP put together a standing committee on Research & Development with members from various power sector organizations in the country with a mandate to frame a perspective R&D plan for the next 15 years for the country.

The National Thermal Power Corporation Limited (NTPC) is a public sector company wholly owned by Govt. of India, its main objective being to assist in the planning, promotion and organization of integrated development of thermal power in the country. It is the largest thermal power generating company of India with 12 coal and 7 gas/liquid-fuel combined cycle power plants, totaling up to about three-fourths (over 19,400 MW in 2001) of the total capacity of central government undertakings. It accounted for over 26% of the total generation by the country's utilities in 2000-01 (NTPC 2001). The efforts of the R&D laboratory of NTPC focus

on maintaining its plants through prevention of failure of equipment. For example, non-destructive testing of materials is a major area of research. In addition, the Center for Power Efficiency and Environmental Protection (CenPEEP), set up in association with US Agency for International Development (USAID) and the US Department of Energy (USDOE), serves as a center of excellence for efficient resource utilization and improved environmental management at existing thermal power stations. CenPEEP acts as a resource center for assimilation, dissemination, and demonstration of technical know-how to realize environmental improvements in the Indian power sector. The Center has also initiated efficiency improvement activities at a number of major power plants. This involves developing an understanding of the operations of power plant components such as boilers, turbines, condensers and ESPs, as well designing systems for predictive maintenance. NTPC spent Rs. 45 million on R&D in 1996-97 (DST 1999), approximately 0.05% of sales.

The Power Grid Corporation of India (PGCIL) is a PSU under the Ministry of Power that manages the national transmission grid. This transmission utility transfers more than 30% of country's power generation through its network and constructs, owns, operates and maintains transmission lines and sub-station facilities. PGCIL focuses on development and adoption of new transmission technologies through in-house R&D efforts, as well as by bringing together research organizations, academic institutions, manufacturers and PGCIL together for utilization of academia and R&D facilities for application research. The main objectives of its R&D efforts are to enhance transmission capability of existing transmission lines, optimize design of substation and transmission lines, and develop technologies for the future. also consciously focuses on disseminating its experience and expertise in various facets of transmission system management to various SEBs and other utilities.

The Central Power Research Institute (CPRI), an autonomous center under the aegis of the Ministry of Power, focuses on applied research in electrical power engineering to assist the electrical industry in product development and quality assurance. CPRI also serves as an independent authority for testing and certification of power equipment and components to ensure reliability and improve, innovate and develop new products.

Ministry of Water Resources

The Central Water and Power Research Station under this Ministry has an effort on hydrological modeling, pump design, pump and turbines testing as well as analyses and modeling of foundations, soils, structures and other elements of dams.

Bharat Heavy Electricals Ltd. (BHEL)

BHEL, a PSU under the Department of Heavy Industries (Ministry of Heavy Industries and Public Enterprises), is an engineering enterprise that manufactures and offers a wide spectrum of equipment, systems and services in the field of power, transmission, industry, transportation, oil & gas, non-conventional energy sources and telecommunications. It is the largest engineering enterprise of its kind in India and is one of the major power plant equipment manufacturers in the world.

BHEL's activities are classified in two categories. Its power sector operations are comprised of coal, gas and hydropower plant businesses. As of the year 2000, BHEL-supplied utility sets accounted for 62,460 MW or 64.4% of the total installed capacity of the country. It possesses the technology and capability to produce thermal power plant equipment up to 1000 MW rating and gas turbine generator sets up to a unit rating of 240 MW. It has also introduced cogeneration and combined cycle plants to achieve higher plant efficiencies. To make efficient use of the high ash content coal available in India, BHEL supplies circulating fluidized bed boilers (CFBC) to both thermal and combined cycle power plants. BHEL also engineers and manufactures hydro turbine sets of Francis, Kaplan and Pelton type. It also has expertise in power plant improvement through renovation and modernization of variety of power plant equipment as well as know-how for residual life assessment, health diagnostics and life extension of plants.

BHEL's industrial sector operations have the capability to produce a variety of electrical, electronic and mechanical equipment to meet the demands of a host of industries such as fertilizers, petro-chemicals, refineries, coal, steel, aluminum, paper, sugar, rubber, and cement and mining. To date, BHEL has supplied systems and individual products, including a large number of captive power plants, gas turbine generator sets, steam turbine generator sets, steam generators (coal, oil, and gas fired), FBC/CFBC boilers, industrial turbo-sets, electrical drives and controls, centrifugal compressors, heat exchangers, castings and forgings, seamless steel tubes and other industrial equipment.

BHEL has major R&D operations across a range of areas. These include power engineering (electrical machines, high voltage engineering, transmission systems, switchgear and insulation technology), electronics (power electronics, control systems, simulators and power plant automation), mechanical engineering (turbomachinery, design analysis, stress and failure analysis, fluid dynamics and manufacturing automation), residual life assessment and life extension of power plants, coal utilization technologies such as Integrated Gasification Combined Cycle (IGCC), non-conventional energy systems (photovoltaic and wind technologies), superconducting generators and fuel cells. BHEL spent Rs. 808 million on R&D in 2000-01 (1.5% of sales) (BHEL 2001). This is an increase from the Rs. 612 million spent in 1999-00, and about the same in 1998-99 (BHEL 2000). These levels in turn marked a substantial (almost 50%) increase from the 1996-97 spending (DST 1999).

Asea Brown Boveri (ABB) India

ABB India, a subsidiary of ABB, operates in the areas of power transmission and distribution, oil, gas & petrochemicals, industrial automation as well as building technologies. Its T&D businesses supply high voltage and distribution sub-stations, capacitors, transformers and switchgears. ABB India's industry and building systems segment offers products and services for process control, automation, drives, robotics etc. for a range of industries. It has transferred and eventually divested its power generation business to what is now Alstom Power India Ltd. (in keeping with the decision of the parent company to transfer and then divest its power generation business to Alstom Power, a 50-50 joint venture with Alstom S.A.). ABB India spent Rs. 50 million on R&D in 2000 (0.63% of sales) (ABB 2000). Its R&D expenditures have seen a large drop over the past few years – for example, it spent Rs. 215 million in 1996 and Rs. 144 million in 1998 (the latter figure corresponding to 1.7% of sales for that year) (WIS 2001).

Alstom India

Alstom India is a 67% subsidiary of Alstom France S.A. Alstom India's two main businesses areas are T&D systems and industrial equipment. In the former segment, it provides protection and control equipment, switchgear, and transformers and also undertakes turnkey T&D projects. In the latter business area, it supplies rotating machinery, motors and energy meters. Alstom India (or to be more accurate, its precursor GEC Alsthom) spent Rs. 28 million on R&D (about 0.5% of sales) in 1996-97 (DST 1999a).

Siemens India

Siemens India is a leading electrical and electronics engineering company in India, with 51% of its equity held by Siemens AG. It is a diversified industrial like its parent company, and has a presence in the energy, industry, health care, transportation, information, and communications. It is a major private sector player in the India power scene and is involved in generation, transmission and distribution, industrial electronics and systems, and transportation. In the area of power generation, it is involved in thermal and hydroelectric generation projects as well as servicing existing power plants, providing automation services for power plants, and offering turbines and cogeneration plants for industrial applications. In power T&D, Siemens India provides switchgears, transformers, sub-stations, and relay and control systems. It spent a total of Rs. 23 million on R&D in 2000 (0.3% of sales) down from Rs. 55 million in 1999 (Siemens 2000).

Cummins

Cummins, a subsidiary of Cummins Engine Co., USA, is India's largest manufacturer of diesel engines catering to the non-automotive segment. Its engines are used in power generation, construction, industrial equipment, and marine & locomotive applications. Its Indian operations are also used as a worldwide sourcing base. Cummins' R&D efforts focus on development of environment-friendly engines, indigenization of components for achieving import substitution and development of electronic control and systems for improving fuel efficiency. Cummins spent Rs. 95 million in 1999-00 and Rs. 100 million in 1998-99 (1.15% of sales in both years) (Cummins 2001). It also receives R&D support from the parent company.

Wartsila NSD

Wartsila NSD, subsidiary of Wartsila OY of Finland, manufactures diesel engines, diesel generating sets and other equipment. It is the market leader in diesel generating sets in India. While it manufactures smaller engines in-house, it imports the larger sets from its parent company in Finland. The R&D expenditures of Wartsila are negligible – the parent company prefers to carry out its R&D in Finland and then supply the technology or products to its Indian subsidiary, although recently it has been considering using India as a base for corporate R&D (Capital Market 2000).

Crompton Greaves

Crompton Greaves' two main lines of business are in power and industrial systems and consumer products. It manufactures and markets a diversified range of electrical products in these two categories such as transformers, switchgears, generators, electric motors, pumpsets, alternators, fans, and light sources and luminaries. It carries out R&D in a number of areas including low-voltage high-power electrical equipment, and electrical equipment test systems. It spent Rs. 74 million on R&D in 1996-97 (DST 1999a).

Thermax

Thermax has operations in energy as well as environmental areas. It manufactures and distributes a range of industrial equipment including packaged boilers and heaters, heat recovery systems, chilling and air-conditioning systems and water treatment systems as well as offering turnkey project execution services for cogeneration plants. Thermax is a market leader in small and medium boilers. It has an R&D effort that focuses on combustion, boiler systems and heat transfer. Thermax spent approximately Rs. 35 million on R&D in 2000-01 (about 0.8% of sales) (Thermax 2001).

In comparison, major international energy equipment manufacturers such as ABB and Alstom spend much higher fraction of their sales, about 3%, on R&D (FT 2001).

The State Electricity Boards (SEBs) do negligible R&D. For example, the Kerala SEB spent Rs. 1.8 million on R&D in 1996-97, which was about 0.02% of its turnover, and the Tamil Nadu SEB spent about Rs. 16.9 million in that same year (DST 1999). Once again, utilities such as the Tokyo Electric Power Co and Korea Electric Power spent 1.4% and 2.3% of their sales, respectively, on R&D in the year 2000 (FT 2001).

5.1.4 Renewables

Ministry of Non-Conventional Energy Sources (MNES)

MNES is the implementing agency for India's renewables efforts. MNES is involved in the implementation of programs across a large number of areas. These include resource assessment, R&D, as well as development, demonstration and utilization of various renewable energy technologies: solar thermal; solar photovoltaics; wind power; small, mini, & micro hydro power; utilization of biomass (co-generation, gasifiers, briquetting, biogas, improved cookstoves); and power generation and energy recovery from urban, municipal and industrial wastes. MNES also

deals with other emerging new technologies, such as fuel cells, alternative fuel for surface transportation, hydrogen energy, geothermal energy and tidal power generation.

MNES funds R&D efforts that are directly related to its activities/programs and hold promise for commercialization in the near future. Thrust areas include solar photovoltaic, solar thermal power, biomass gasifiers, improved cookstoves, windpower and windmill-based water pumping systems, hydrogen energy and fuel cells. A large number of academic and other research institutions receive funding from MNES to carry out renewables research. The Ministry spent Rs. 46 million on R&D in 1996-97 (down from Rs. 92 million and Rs. 62 million the previous two years) (DST 1999).

MNES also has some specialized technical institutions to provide services for testing and standardization of renewable energy devices and components as well as improve their production, technology as well as operational efficiency:

- The Center for Wind Energy Technologies (CWET), established in 1999 with Danish assistance, serves as a technical focal point for wind power development in India with the objective of promoting and accelerating the utilization of wind power. It will carry out research and development on wind energy technologies, wind resource assessment at macro and micro levels, development of standards and certifying procedures, testing and according type approval, monitoring and evaluation of performance and information dissemination. It is also expected to improve, through technology development in collaboration with industry, the price-performance ratio and hence the competitiveness of indigenous wind turbine equipment;
- The Solar Energy Centre (SEC) is involved in solar thermal testing and standardization, testing of solar PV systems and components, materials testing and solar passive architecture. It is also carrying out R&D in the area of low temperature applications of solar thermal energy. A Memorandum of Understanding (MoU) was signed between the SEC and the National Renewable Energy Laboratory (NREL) of the US Department of Energy during President Clinton's 1999 visit to India. The MoU envisages cooperation between the SEC and the NREL to promote scientific and technological cooperation in the field of renewable energy and also envisages cooperation with other institutions of both countries. The activities proposed to be undertaken under this MoU include strengthening of capacities for energy technology innovation as well as promoting technologies for energy conservation and for a cleaner energy supply. The forms of

- cooperation under this MoU include exchange of technical information and experience, exchange of technical and managerial personnel, and joint testing of equipment and holding of conferences and seminars; and
- National Institute of Renewable Energy (NIRE), set up recently, is meant to focus on technical aspects of non-conventional/renewable energy sources. It will also focus on R&D, commercialization, human resource development, training and international cooperation.

The Indian Renewables Development Agency (IREDA), administratively under the MNES, was incorporated in 1987 for the promotion and commercialization of new and renewable sources of energy technologies. It does this by providing financial support to manufacturers and users as well as by acting as a financial intermediary. It also promotes energy efficiency. By the end of the 1999-00 financial year, the cumulative projects sanctioned by IREDA exceeded Rs. 35 billion. IREDA's activities have received substantial international support from The World Bank/GEF (US\$ 145 million), Asian Development Bank (US \$100 million), KfW, Germany (120 million DM), DANIDA, Denmark (US\$ 15 million) and the Govt. of Netherlands (18 million Guilders).

Other Organizations

A number of institutions perform research relevant to renewable resources utilization. For example, the Indian Institute of Science, Bangalore (IISc) has a major R&D program on biomass utilization. Biomass gasifiers developed by IISc have undergone extensive testing in the laboratory and the field and have been installed in a number of locations for electric power generation as well as industrial drying applications. The Tata Energy Research Institute (TERI) also has a research program to develop biomass gasifiers for thermal and electrical applications. Its gasifier technology has been utilized in the field for thermal applications. TERI also has a research program on chemical and hydrogen energy that includes an effort focusing on the development of fuel cells. BHEL also has a program on fuel cells. The Indian Association for the Cultivation of Science (IACS) has a research effort concentrating on materials and fabrication technology for silicon based thin film solar cells. In the area of multijunction amorphous-Silicon solar cell, its technology has reached the level of commercialization. The Central Electrochemical Research Laboratory (CECRI), part of the CSIR, carries out research on materials for advanced battery technologies.

5.1.5 Atomic Energy

Department of Atomic Energy

India's nuclear power program has fourteen operating reactors including 2 Boiling Water Reactors (BWRs) and 12 Pressurized Heavy Water Reactors (PHWR) one of which (Rajasthan unit-4) attained criticality recently. Two PHWRs of 500 MW capacity each are under construction. Nuclear Power Corporation Ltd. (NPCIL), a public sector company, owns, constructs, operates and maintains nuclear power plants in India. The R&D that supports the Indian nuclear power program is funded and mostly carried out by the Department of Atomic Energy (DAE). Notably, Indian government plans stress R&D on nuclear power in order to consolidate, upgrade and utilize the high degree of self-reliance that has been achieved in the nuclear power generation in order to obtain higher capacity additions (Planning Commission 1997b).

There are five research centers under the DAE, including:

- Bhabha Atomic Research Center (BARC), which is India's premier nuclear research center, focuses on a wide range of areas under nuclear science and engineering. BARC, working in close collaboration with NPCIL, has been responsible for attaining self-reliance in nuclear reactor technology. Extensive work carried out in the area of reactor technology has accelerated the process of indigenization of equipment and components and has led to the development of a number of technologies for operation and maintenance of power reactors;
- Indira Gandhi Centre for Atomic Research has scientific research and advanced engineering efforts directed towards the development of fast breeder reactor technology; and
- Atomic Minerals Directorate focuses on exploration and evaluation of the country's uranium resources, evaluation and recovery of rare metal and rare earth minerals, geological investigations and guidance of nuclear material mining plans and activities.

The DAE also supports seven grant-in-aid institutions, including the Tata Institute of Fundamental Research and the Saha Institute of Nuclear Physics. In addition to this, DAE supports extramural research and development activities in nuclear and allied sciences, engineering and technology through its nodal funding agency – the Board of Research in Nuclear Sciences. DAE's total R&D budget was Rs. 5.3 billion in 1996-97, up from Rs. 4.87 billion in 1995-6 and Rs. 4.45 billion in 1994-95 (DST 1999).

5.2 Energy Use

This section will focus on transport, steel and the cement sectors that are major consumers of energy and emitters of GHGs in India. These three sectors together account for almost 40% of the country's total final commercial energy consumption (IEA 2000) and for almost a quarter of its GHG emissions (Garg 2000).

5.2.1 Transport

The transport sector accounts for almost a quarter of the final commercial energy consumption at present (TERI 2000, IEA 2000), with the road sector accounting for a dominant share. India's transport sector is a major contributor to India's GHG emissions – it is estimated that this sector was responsible for about 9.5% of the country's total GHG emissions in 1995, about 120 million CO₂-equivalent tons (Garg 2000). Commercial energy consumption in this sector is also growing rapidly – between 1980-81 and 1990-91, it grew at 4.9% annually, and in the 90s, it has been growing at an annual average rate of 5.6%.

Road Transport

Road transport is becoming increasingly dominant in the movement of goods and passengers. The share of the road transport in freight traffic is estimated to have increased from 11% in 1951 to 60% in 1996; the share in passenger traffic has gone up from 32% to 80% during the same period (Planning Commission 1997e). Ministry of Surface Transport also estimated that road traffic would account for 87% and 65% of the passenger and freight traffic respectively by the year 2000 (Sriraman 1998). Road vehicles also account for a dominant fraction of the energy use in the transport sector and for a significant fraction of many important air pollutants: 90 to 95% of lead and CO, 60 to 70% of NO_x and hydrocarbons, and a major share of particulate matter (Shukla et al. 2000). Since much of the road vehicle use is in cities, vehicular emissions are a significant contributor to urban air pollution, an issue that recently has been receiving substantial attention in India.

The number of vehicles in India has been increasing at a rapid pace in the last couple of decades – the total number of vehicles rose from 4.5 million in 1980 to 37.2 million in 1997, with the largest rise coming in two wheelers and cars. In 1997, India had 25.7 million two wheelers and 4.7 million cars (TERI 2000). It should be noted, though, that while more than 80% of the Indian vehicle fleet uses gasoline, vehicular diesel use (in buses, trucks, diesel cars, tractors etc.) exceeds gasoline use by more than a factor of four (Agrawal 1997).

While Indian vehicle manufacturers historically did not pay much attention to technological change, both increasing competition in the market starting in the mid-1980s and the newly imposed stringent emission norms have spurred a significant change in designs and technologies in most segments of the industry. While many of the indigenous manufacturers have their own R&D efforts, the introduction of most new and more efficient technologies has been a result of foreign collaboration and joint ventures.

At the firm level, R&D efforts in the automobile sector have focused on entering into technological collaboration with multinationals and absorbing foreign technology. The effort in indigenous R&D has been limited to a few firms, and most of their efforts are much smaller in comparison to the substantial R&D programs of firms in industrialized countries. With increased growth prospects both for the vehicle and auto component sector and the entry of global automobile companies, the investment in R&D is expected to gain momentum (SIA 2000).

Tax at the rate of 1/8% *ad valorem* is levied on all automotive vehicles (including tractors) to finance R&D activities in the automobile industry, and collected by the Department of Revenue as an excise duty. The present collection of tax is around Rs.320 million per annum (SIA 2000). These funds are distributed through the Development Council for Automobile and Allied Industry annually, and provided to various institutes serving the automobile industry for R&D and for setting up of testing facilities. For example, the testing facilities at the Automotive Research Association of India have been upgraded as per EEC standards with the assistance of such funds.

Tata Engineering and Locomotive Company (Telco)

Telco is the flagship company of the Tata Group, a major Indian industrial house. Telco is the leader in the commercial vehicle segment with approximately two thirds of the market share for the light commercial vehicles (LCV) and medium and heavy commercial vehicles (M&HCV) markets. In addition, it also has a fourth of the utility vehicle segment as well as about 10% of the passenger car market. Telco started manufacturing automotive vehicles in 1954 in collaboration with Daimler Benz, and successfully absorbed the technology for making light, medium and heavy commercial vehicles. Its Engineering Research Center – a major automobile and heavy vehicle R&D center in the country – has assisted Telco in absorbing technology from other collaborations as well as allowed in-house advances, which have included much of the design of India's first indigenously developed car. Telco's R&D expenditures in 1996-97 were

about Rs. 1.6 billion (DST 1999a), falling down to about Rs. 1.07 billion by 1999-00 and 0.91 billion in 2000-01 (about 1.25 and 1.15 % of sales respectively) (Telco 2001).

Ashok Leyland Ltd.

Ashok Leyland Ltd. is one of the leading firms in the medium and heavy commercial vehicle segment with about a third of the domestic market. The company has been paying increasing attention to its in-house R&D capabilities and has introduced new products, including CNG-based buses. It has also been upgrading its engine families to meet the new emission norms in India. In 2000-01, Ashok Leyland spent Rs. 231 million on R&D (0.89% of sales), close to the Rs. 232 million it spent in 1999-00 (0.89% of sales) (AL 2001; AL 2000).

Bajaj Auto Ltd. (BAL)

BAL, a manufacturer of two and three wheelers, dominates the Indian market – in 1999, it had 60% of the scooter, 27% of the motorcycle and 86% of the three-wheeler market. BAL scooters incorporate Piaggio technology (technical collaboration from 1961 to 1971) as upgraded by in-house R&D. Bajaj also entered into a technical collaboration with Kawasaki in the mid 1980s. BAL has also entered into an agreement with Kubota of Japan for the development of diesel engines for three-wheelers. With further strengthening of its relationship with Kawasaki, Kubota and Tokyo R&D of Japan, and Cagiva of Italy, Bajaj has enhanced its R&D and product development capabilities. It has released India's first 4-stroke scooter in 1998, which is also the world's first 4-stroke geared scooter. It has also developed, through international collaborations, catalytic converters for its entire range of 2-stroke two and three wheelers. BAL's R&D expenses have shown a sharp rise recently; it spent Rs. 0.61 billion (2% of sales) in 2000-01 up from Rs. 0.34 billion (1.1% of sales) in 1999-00 (BAL 2001).

Hero Honda

Hero Honda is the leading motorcycle manufacturer in India, with over 40% of the market in this segment. This is a joint venture between the Hero Group of India and Honda Corporation. Hero Honda has extremely limited in-house R&D. It accesses technology from Honda for which it pays a royalty. Its R&D expenses in the year 2000 were about 0.2% of sales.

Maruti Udyog Ltd. (MUL)

MUL, a joint venture with Suzuki of Japan, is India's largest automobile company. The company had a share of over 70% of the automobile market in India, although recently its market has been

falling. MUL spends comparatively little on R&D. In 1996-97, it spent Rs. 50 million on R&D (approx. 0.6% of sales) (DST 1999). Mostly it relies on technology acquired from Suzuki of Japan.

Daewoo Motors India

Daewoo Motors India is a part of the Daewoo Group of South Korea. It commenced operations in India in 1995. The company has invested Rs. 40 billion in setting up a state-of-the-art manufacturing plant and research & development facilities. In 1996-97, Daewoo India invested Rs. 708 million on R&D (DST 1999a).

Mahindra and Mahindra (M&M)

M&M is a leading manufacturer of utility vehicles and tractors in India – it has 58% and 27%, respectively, of the market shares of these segments. M&M has also recently entered into a joint venture with Ford to manufacture automobiles. R&D expenditures in 2000-01 were Rs. 0.89 billion (2 % of turnover) up from the Rs. 0.65 billion in 1999-00 (1.4% of turnover) (M&M 2001; M&M 2000).

Fiat

Fiat, which sells cars under its own label in India, has recently decided to invest US\$4 million (approx. Rs. 190 million) in a full-fledged research and development center in India.

Automotive Research Association of India (ARAI)

ARAI was incorporated in 1966 as a research organization formed by the Indian automotive industry and affiliated to the Ministry of Industry. Its focus areas include vehicle engineering, spark ignition and compression ignition engines, automotive electronics, and engine testing and development. Apart from facilities for testing, evaluation and test approval of vehicles, it has vehicle engineering groups and test laboratories in the field of fatigue testing, automotive emissions, safety and homologation, materials, metrology and electronics & control systems. Total industry-sponsored R&D in 1999-00 was Rs. 63 million (ARAI 2000).

Indian automobile manufacturers invest far less in R&D than major global automobile firms that spent, on average, about 3-4% of their sales on R&D in the year 2000 (FT 2001).

Railways

Although Indian Railways has lost the dominant position that it occupied in the 1950s, it is still a major mover of people and freight. In 1998-99, railways accounted for freight traffic of 280 billion ton-kms and 404 billion passenger-kms (GOI 2000). Indian Railways has the largest railway system in the world under single management. Its routes span almost 63,000 kms. and it has more than 7,400 locomotives, 31,000 passenger carriages and 253,000 wagons. Between 1990 and 1999, the length of electrified routes rose from 9,100 to 13,765 kms., and the fraction of diesel and electric locomotives in use rose from 42% and 19%, respectively, in 1990 to 62% and 37% in 1999.

Chittaranjan Locomotive Works (CLW) and Diesel Locomotive Works (DLW) currently manufacture the Indian Railway's locomotives in India, but these are based on imported designs. A few electric locomotives, again based on imported designs, are also manufactured by BHEL. Most of the passenger coaches are manufactured in Integral Coach Factory (ICF) and Rail Coach Factory (RCF). ICF and Jessops and Co., Ltd. produce Electric Multiple Units (EMUs). Firms in the public and the private sector along with the Indian Railways' workshops meet the country's requirement of wagons.

The Research, Design and Standards Organization (RDSO) is the R&D unit of the Indian Railways, providing direction to technological developments in almost all fields of railway activity. It focuses on development and design, testing and trials, reliability and safety as well as energy conservation measures. The UNDP has funded a project to upgrade the R&D facilities at RDSO. With a view to engendering closer interaction between RDSO and academic/research institutions and industries, Indian Railways is setting up a Railway Technology Cell at the Indian Institute of Technology, Kanpur. In 1996-97, Indian Railways spent Rs. 0.36 billion on R&D (DST 1999) that was just over 0.1% of its turnover.

BHEL also carries out some R&D relevant to railway transportation.

5.2.2 Steel Industry

India is the 10th largest steel producer in the world. In 1998-99, finished steel production was 23.8 million tons, pig iron production was 3.0 million tons and sponge iron production was 5.2 million tons. About a third of this finished steel production in India was by public sector enterprises and the rest by private sector firms; about 45% of finished steel in the country was

produced by integrated steel plants (ISPs) and 55% from secondary producers (electric arc furnaces, induction furnaces and rerollers.). There are seven ISPs in the country – six owned by the government and one by a private group – which use the blast furnace & LD/basic oxygen furnace (BF-LD/BOF) process. There were also 188 electric arc furnaces (EAF) in the country with an aggregate capacity of 12.1 MTPA, but of these about 148 units (accounting for half of this capacity) were closed in 1998-99. The remainder produced about 3.9 million tons of finished steel in that period. In addition, there were 934 induction furnace (IF) units with a capacity of 9.4 MTPA, of which 273 (with capacity of 2.2 MTPA) were closed in 1998-99. The production of the IF units was around 3.6 million tons (Min. of Steel 2000). The steel industry consumes over 10% of India's commercial energy (IEA 2000) and energy costs constitute almost 30% of the total production costs in this sector (Shukla et al. 2000). The steel industry is also a major emitter of GHGs, accounting for almost 9% of the country's emissions in 1995 (Garg 2000).

Although a steel output of almost 24 million tons placed India among the top ten producers of steel in the world in 1998-99, the per capita steel production of only 24 Kg/person was much below the world average of 150 Kg. But demand for steel is growing rapidly. It was estimated that by 2001-02, this is likely to be 31 million tons, and over 66 million tons by 2011-12 (up from 22.2 million tons in 1991-92) (Planning Commission 1997d).

The economic reforms initiated by the Government since 1991 have added new dimensions to industrial growth in general and the steel industry in particular. The licensing requirement for capacity creation has been abolished, except for certain locational restrictions. The steel industry has also been removed from the list of industries reserved for the public sector, and automatic approval of foreign equity investment up to 74% is now available. Price and distribution controls were also removed to make the steel industry efficient and competitive. Restrictions on external trade, both in import and export have been removed. And other macroeconomic policy measures such as reduction in import duty of capital goods, convertibility of rupee on the trade account, permission to mobilize resources from overseas financial markets and rationalization of existing tax structure for a period of time have also benefited the Indian steel industry. The impact of these policy reforms on the steel industry in India has been tremendous. The total crude steel capacity of Indian steel industry increased to almost 33 million tons in 1997-98, registering a growth of almost 50% since 1991-92. The increasing role of the private sector in total production can be seen from the fact that its share has increased from 51.4% in 1991-92 to approximately two thirds in 1997-98. This trend is continuing.

The technological performance of many Indian steel plants is considerably lower than existing international standards. This is due to the inefficient use of facilities, obsolete technology, incompatibility of Indian input materials with imported technology and general lack of technical discipline. Even as late as 1997, India produced 15% of its steel through the energy-inefficient open-hearth process (compared to a global average of 6.2%) and 55% of its steel through the ingot-casting route (in comparison to a world average of 22%) (India Infoline 2001)

Some of the integrated steel plants are already undergoing a process of modernization and are adopting more energy efficient practices. BOFs are replacing the open-hearth-based method of steel production and continuous casting (CC) is replacing traditional ingot casting. For example, the Steel Authority of India Ltd. (SAIL), a public sector enterprise that is India's largest steel firm, already produces 70% of steel through the BOF and 20% through the CC route. It is expected that after SAIL's recent modernization, about 80% of its steel will be produced through BOF and 55% by the CC route. The share of steel production from electric-arc furnaces has also increased. However there still exists a wide gap in Indian technological efficiency levels and those achieved in developed countries.

The Ministry of Steel estimates that the major Indian iron & steel plants and related industries spent almost Rs. 700 million on R&D in the year 1997-98, almost 80% of this being spent in the public sector. SAIL and the Tata Iron and Steel Company (TISCO), a private sector firm belonging to the Tata group of companies, accounted for over 80% of the total steel R&D expenditure.

The Indian government has taken a cabinet decision to invest up to Rs.1.5 billion per annum for research & development efforts in the iron and steel sector. The government has set up an Empowered Committee on R&D to approve scientific research programs and to provide overall direction to the research efforts on the iron and steel in the country. This committee will sanction research and technology development projects with the money available from the interest proceeds of the Steel Development Fund. Twenty projects have been approved, for which Rs. 139 million had been disbursed by end of 1999 (total value of these projects is Rs. 1.49 billion out of which the Steel Development Fund contribution is expected to be Rs.790 million and industry contribution will be Rs.700 million) (Min. of Steel 2000). The research areas cover mining and beneficiation of minerals, improvement of properties of coal, reduction in energy consumption,

reduction of refractory consumption, improvement in productivity, utilization and treatment of wastes, control of pollution, improvement of product quality, etc.

Steel Authority of India Ltd. (SAIL)

SAIL, the 13th largest steel maker in the world, is the largest integrated iron and steel producer in India contributing over 44 percent of the country's total crude steel output. This PSU's vertically integrated production facilities produce a wide range of saleable steel products. Recent modernization of the integrated steel plants of SAIL, costing about US\$3 billion, has led to significant improvements in product quality as well as productivity. SAIL has an extensive R&D program, focusing on development of new and improved technologies, processes and products as well as on energy conservation. It has a major R&D unit, the R&D Center for Iron & Steel (RDCIS), established in 1972, that is involved in research projects spanning the entire spectrum of iron and steel production. RDCIS has specialized divisions such as Application Engineering Centre, the Technology Dissemination Centre and the Technology Marketing Cell. RDCIS also undertakes domestic and international consultancy and service assignments. SAIL spent Rs. 518 million on R&D in 2000-01 (0.32% of sales) (SAIL 2001), continuing with its trend of increasing R&D. It spent Rs. 445 million on R&D in 1999-00 (0.26% of sales) (SAIL 2000).

Tata Iron and Steel Co. (TISCO)

TISCO is the country's oldest and largest integrated steel works in the private sector, and the second largest steel firm in the country, with a domestic market share of about 13 per cent. TISCO has the second-lowest cost of steel production in the world (after the Pohang Iron and Steel Company (POSCO) of South Korea) following its recent expansion and modernization. The aim of TISCO's R&D is to make it a world-class player in the iron & steel industry by lowering production costs, improving production quality, and developing new products and processes. Its R&D efforts focus on the areas of raw materials including coal, coke, energy conservation, waste utilization, sintering, blast furnace productivity and phosphorous reduction, steel melting and finishing areas, product development and improvement in life of plant and machinery. TISCO spent Rs. 104 million on R&D in the year 2000-01 (0.13% of sales), down from 131 million in the year 1999-00 (0.24% of sales) (TISCO 2001; TISCO 2001). It spent Rs. 143 million in 1996-97 (DST 1999a).

In comparison, POSCO, the most efficient producer of steel in the world, invests about 1.5-2% of its sales in R&D annually (FT 2001; FT 2000), whereas the year 2000 figure for NKK Japan was 1.2% (FT 2001) and for Bethlehem Steel about 0.5% (Bethlehem Steel 2000).

5.2.3 Cement

Cement, an important infrastructure core industry, is one of the most advanced industries in the country. Until about a decade ago, the country did not produce enough cement to meet the demand and it had to resort to imports in order to fill the gap. After the recent liberalization and globalization of Indian economy, the cement industry has been growing rapidly at an average rate of 8 percent per annum except for a short period in 1991-92 when the industry faced a recession in demand. India is the fourth largest producer of cement in the world with 118 large plants (i.e., capacity > 0.2 MTPA) with installed capacity of 119 Mt/yr belonging to 53 companies, and 300 mini-cement plants (i.e., capacity < 0.2 MTPA) with installed capacity of 9 Mt/yr. Total cement production in 1999-00 was 100 MTs (approx. 94 MTs and 6 MTs respectively from large and mini-plants) (CMA 2000). The projected installed capacity of the cement industry is about 135 million tons by 2002.

The cement industry made rapid strides both in increasing capacity and production as well improving production and process technology after cement price and distribution were decontrolled partially in 1982 and fully in 1989. In 1997-98, 89 per cent of the capacity was based on energy-efficient dry process technology. About 9 per cent of the capacity is based on old wet process technology and the remaining 2 per cent on semi-dry process technology. As a result, India's cement sector is relatively modern and energy-efficient, although there is a wide variation in the energy consumption patterns of different plants. While the Indian cement industry is, on average, more efficient than that of the United States and China, it is less efficient than countries such as Japan and South Korea.

In India, energy cost accounts for about 40-45 per cent of the total production cost of cement. The industry uses both thermal and electrical energy in its manufacturing process. Coal is an important input, both for fuel and as a feedstock. The cement industry consumed over 18 million tons of coal in 1997-98, which made it the third largest user of coal after power and steel. It also accounts for about 2% of the country's total power consumption (TERI 1999). The cement industry also emits about 5% of the country's GHG emissions (Garg 2000), making it one of the key sectors from the climate change perspective.

In the 1990's, a number of large cement manufacturers developed in-house R&D capabilities. About 12 such R&D units have been recognized and registered with the Ministry of Science & Technology, although only six of these reported R&D expenditures in the DST survey. Their combined expenditure was Rs. 122 million in 1996-97 (DST 1999). One public sector organization also reported cement and gypsum-related R&D expenditures of Rs. 2.1 million.

The National Council for Cement and Building Materials (NCB)

The NCB was established in 1962 (as Cement Research Institute of India) by the cement industry. It is affiliated to the Department for Industrial Development and dedicated to research, technology development and transfer, as well as education and industrial services for the cement and building material industries. It is the largest industrial support organization of its kind in India and is funded through the levy of a tax on industry as well as grants from the government. Its activities cover, among other things, research and development of innovative technologies, transfer and implementation of such technologies in partnership with cement and construction industries so as to enhance quality, productivity and cost-effectiveness and to improve the management of materials, energy and environmental resources in the cement industry. NCB's R&D efforts include cement and silicate research (design and optimization of raw mixes, improved refractory materials, development of newer cement and building material products and processes) and productivity enhancement (technical support for process optimization, energy conservation, plant maintenance etc.). It also carries out energy audits of cement plants on a continuing basis. NCB, in association with Ministry of Power, has also been giving awards annually to those cement plants, which have achieved the best energy performance.

The Associated Cement Companies Ltd. (ACC)

ACC is presently the largest cement company in India with an annual cement capacity of 16 million tons and an annual turnover of more than Rs. 30 billion. (But ACC is not the top producer of cement in India – the Birla group (an industrial conglomerate) and L&T (a diversified firm) produce more cement than ACC). ACC's 2000-01 cement production was 10.2 million tons. The R&D division of ACC – the Research and Consultancy Directorate – focuses on a range of issues relevant to the inorganic materials processing industry, including development of new processes, technologies, products and applications. Areas of research include cement and concrete, cementitious systems, refractory products, catalysts and advanced ceramics. In addition to its in-house services, the RCD offers a variety of specialized services – consultancy, contract and

collaborative research, and trial manufacture and supply – to a range of industrial clients. In 1999-00, RCD's revenues from technical consultancy services were Rs. 0.71 billion. Although figures for ACC's R&D expenditure for that year are not available, it spent Rs. 77 million in 1996-97 (DST 1999a).

6 INTERNATIONAL COOPERATION ON ENERGY

Seven multilateral and 13 bilateral donors provide assistance to India. The United States is the seventh largest donor after the World Bank, the Asian Development Bank, the European Union, Japan, Germany and the United Kingdom. On the energy front, most of the donors have re-oriented their efforts mainly to bring about institutional reforms, and therefore most of their funding is targeted towards loosening government controls on the functioning of the energy sector and restructuring its various segments.

6.1 The World Bank

The World Bank is by far the largest provider of external financial assistance to India's power sector. Between 1970 and 1999, it provided loans and credits for over \$13 billion worth of projects. Until 1993, World Bank energy sector lending largely followed the government's lead, focusing on expanding productive capacity through large-scale projects, implemented by Central or state monopolies. Institutional strengthening focused on improving financial performance by raising prices and studying ways to improve technical performance. The World Bank provided loans and credits to help the National Thermal Power Corporation rapidly expand generation capacity and become the largest power generator in India. In the 1980s, it began supporting state electricity board generation expansions, with the goal of improved efficiency of operation. In the coal sector, lending in the 1980s focused on increasing the proportion of coal produced through large, low-cost open-pit mines. Oil and gas projects focused almost exclusively on the physical infrastructure needed to expand production. India's economic crisis of 1990-91 led the World Bank to reevaluate the relevance of its sector objectives, and eventually shift its lending strategy to focus on the sector's institutional, financial, and environmental sustainability.

The World Bank's current assistance to the power sector focuses on supporting reforms at the state level. Orissa was the first state to launch a major overhaul of its power sector. To support the over haul of Orissa's power sector, the World Bank provided a \$350 million loan in 1996. In January 1998, it approved a US\$60 million Adaptable Program Loan (APL, a new lending

instrument that involves a series of loans to provide phased and sustained support for a borrower's long-term reform program) to support the first phase of the Haryana's ongoing program to restructure its power sector. The loan is the first of a series of APLs totaling US\$600 million that the World Bank plans to provide over the next eight to ten years to support the program in Haryana. It has also approved a US\$210 million APL for Andhra Pradesh in February 1999, the first in a series of APLs totaling up to US\$1 billion that the Bank plans to provide to this state over the next eight years. It is supporting Uttar Pradesh through a US\$150 million loan approved in April 2000 to transform the state's power sector from being a major drain on the state's budget into a source of revenue for priority sectors. Rajasthan is seeking similar assistance under the Rajasthan Power Restructuring Project, and a \$180 million loan was approved in January 2001. The World Bank expects that other states will also be inspired to undertake meaningful power sector reforms.

The World Bank has been closely involved in Powergrid's development from the beginning of its operations, funding its power systems coordination and control facilities; transmission lines and substations; and various institutional development activities. Following up on the US\$350 million Powergrid System Development Project in 1993, another project, Powergrid II, with a \$450 million loan, was approved in May 2001. With this support, Powergrid is modernizing its system facilities (including load dispatch systems for state utilities) and regional power pools. These facilities and the emerging regional electricity markets will enable generators and utilities emerging from state power reforms to trade power and improve the efficiency of system operations.

The World Bank is helping Coal India, Ltd., the leading coal producer, to carry out high-priority environmental and social mitigation programs and strengthen its capacity to deal more effectively with environmental, resettlement, and rehabilitation issues through a \$63 million Coal Sector Environmental and Social Mitigation Project. The World Bank-financed Coal Sector Rehabilitation Project (\$530 million) is financing a time-slice of Coal India's investments in 24 mines to improve the efficiency of mining operations and thereby assisting Coal India to meet the additional demand for coal. This project supports the liberalization of the coal sector and the development of a new regulatory regime. To complement the World Bank's ongoing support for coal sector reforms, its private sector arm, the International Finance Corporation, has invested in one of the first private coal mines in India.

Together with the Global Environment Facility, the World Bank is supporting renewable energy using solar photovoltaics, mini-hydropower, and windpower through an ongoing Renewable Resources Project (\$75 million loan, \$115 million grant). A follow-up \$130 million Renewable Energy project (\$ 80 million loan, \$50 million grant) was processed in June 2000.

It is also helping fund the Nathpa Jhakri Power Project, the main objective of this project being to assist in meeting electricity demand in the northern region of India through the addition of 1500 MW of hydro capacity.

6.2 Asian Development Bank (ADB)

The ADB's lending program to India was initiated in 1986. By the end of 2000, its cumulative lending totaled \$9.2 billion through 65 loans. The energy sector accounted for 37 percent of this. ADB's ongoing portfolio in India in mid-2001 consisted of 29 projects for a total net loan amount of \$4.7 billion – of this, 6 loans worth \$1.1 billion were energy related.

ADB's current strategy in the power sector is to leverage its assistance to support comprehensive reform of the institutional and regulatory frameworks at the state level, within an appropriate national power policy, by emphasizing restructuring and commercialization of the state electricity boards; rationalization of power tariffs; establishment of independent regulatory commissions; and improvement in demand management and efficiency. To this end, the projects in the pipeline include loans and technical assistance efforts for policy reform and development in Gujarat, Madhya Pradesh and Kerala, as well as to the Power Finance Corporation for reforms in other states. Within the hydrocarbon sector, ADB assistance will focus on the catalytic role for private sector investment in natural gas as well as cross-border initiatives for hydrocarbons in a sub-regional context. ADB is also planning a project on industrial energy efficiency, following up on its previous successful project.

Some of ADBs' recent and ongoing energy-related projects include a focus on:

- power generation and transmission: 4 projects, of which 2 focus on enhancing thermal power generation (\$210 million), 1 on power transmission (\$275 million to upgrade transmission grid), and 1 on renewable energy (\$100 million for assistance to the Indian Renewable Energy Development Agency for developing renewable energy projects);

- development of oil and gas: 1 project (\$136.5 million) on an LPG pipeline, as well as hydrocarbon sector deregulation and tariff setting (technical assistance on hydrocarbon exploration and production database and archive system); and
- improving energy efficiency: \$150 million for a line of credit through the Industrial Development Bank of India to support investments contributing to industrial energy efficiency.
- power sector restructuring: \$350 million for power sector reform and development in Gujarat.

6.3 Global Environmental Facility (GEF)

The overall strategic thrust of GEF-financed climate change activities is to support sustainable measures that minimize climate change damage by reducing the risk, or the adverse effects, of climate change. The GEF finances eligible enabling, mitigation, and adaptation activities in recipient countries.

At present, there are 9 GEF projects under implementation in India that are climate-change related (total project costs: \$673 million, GEF component \$143 million). Among these are:

- a \$245 million project (GEF grant \$49 million) to construct and operate, by the private sector, a grid-connected 140 MW solar-thermal fossil-fuel hybrid power plant in Rajasthan, incorporating a parabolic solar thermal field of about 35-40 MW;
- a \$186 million alternate energy project (GEF allocation \$26 million) that promotes investment in wind farms and solar PV power systems through provisions of below market loans to investors, mainly from the private sector;
- a \$37 million project (GEF component \$5 million), which is a component of the Renewable Energy II, to help overcome barriers to private investment in energy efficiency by catalyzing, supporting and funding private energy efficiency service companies;
- a \$120 million (GEF allocation \$30 million) photovoltaic market transformation initiative (PVMTI), which provides strategic interventions to accelerate the sustainable commercialization and financial viability of PV technology, especially for rural electrification;
- a \$19.23 million project (GEF allocation \$9.19 million) focusing on coal bed methane capture and commercial utilization by demonstrating the technical and economic viability of harnessing CBM and building national capacity in its recovery and utilization; and

- a \$8.82 million project (GEF allocation \$4.21 million) to develop and implement a bioenergy technology package for rural, decentralized applications.

Projects in the pipeline include efficient technology packages for the steel re-rolling sector, improvement of energy efficiency in agricultural pumpsets, and removal of barriers to biomass power generation.

6.4 Japan

Japan has been the largest bilateral donor to India since 1986. Japan's net ODA disbursements to India between 1993 and 1997 were \$5.9 billion in the form of grants, technical cooperation and loans (the last component accounting for almost 90% of the total). While Japan does not formally coordinate its programs with other bilateral donors, it has been an important source of official co-financing for ADB projects. Japan froze fresh ODA commitments in response to India's nuclear tests in May 1998 – these sanctions were lifted in October 2001.

Before the sanctions were imposed, the power sector accounted for a majority of the portfolio of Japanese ODA activities, accounting for about 60% of the annual commitments in the mid-1990s. Within this, it has emphasized increased and improved generation, transmission and distribution, as well as systems improvement. In the context of the international environment in the mid-1990s, Japan started shifting the focus of its development assistance to India. Under this shift, the activities of the Japan Bank for International Cooperation (JBIC)¹¹ were being directed mainly towards basic human need projects and selected, high visibility infrastructure projects.

6.5 United Kingdom

The United Kingdom, through its Department for International Development (DFID), has an aid program to India – its largest target – focusing primarily on poverty reduction through support for social sector initiatives. The program also seeks to support sustainable economic growth through support for economic reforms, particularly in fiscal policy and the power sector. This is a shift from its earlier policies of supporting infrastructure development through a mix of aid and trade. DFID is concentrating its assistance to selected states, mainly Haryana, Madhya Pradesh, Andhra Pradesh, and West Bengal.

¹¹ JBIC, the agency in charge of implementing Yen loans, was established in October 1999 through the merger of OECF (Overseas Economic Cooperation Fund) and JEXIM (The Export Import Bank of Japan).

The energy sector accounts for about a fifth of DFID's India program expenditures that were just over 100 million Pounds (approx. \$160 million) in 1999-2000. These efforts are aimed at assisting power sector reforms. Orissa has been a major recipient of DFID funding in this regard, getting about \$112 million over 5 years. DFID also provided about \$45 million for the Andhra Pradesh and Haryana restructuring programs. These technical assistance programs provided early support for reforms in these states, and the World Bank then provided funds for the later stages.

DFID funds a collaborative modeling effort (approx. \$1 million per year) between the Indian Meteorological Dept and the Hadlee Center to estimate impacts on India that may result from various climate scenarios.

6.6 Germany

As of mid-2000, KfW, the German Development Bank, had total commitments in India of around 2.2 billion DM. Of this, power sector exposure was roughly 44%. Projects include:

- Energy Investment Program, which provides credit line for financing rehabilitation of plants in Madhya Pradesh & Orissa (project partner is the Power Finance Corp.; funding DM 46.5 million)
- Renovation of Power Plant in Maharashtra (Funding DM 29.74 million)
- Promotion of Renewable Energy, which provides a credit line of DM 120 million for IREDA (DM 60 million is for windpower, DM 45 million for cogeneration and DM 15 million for solar).

Projects in the pipeline include the power sector reforms program in Andhra Pradesh and Rajasthan) (DM 550 million) and assistance for the financing of the integrated combined cycle solar-thermal power plant in Rajasthan (DM 250 million). The development co-operation between Germany and India, suspended after India's 1998 nuclear tests, is now back on track with the first government negotiations on development co-operation since 1997 being held in Bonn in November 2001. This resulted in, among other things, the finalization of the loan for the Rajasthan solar-thermal project.

6.7 United States

U.S economic assistance to India began in 1951 with emergency food aid. In the 1960s, the U.S. Agency for International Development (USAID) assistance supported India's Green Revolution. Economic assistance was suspended in 1971 during the India-Pakistan war, except for food aid,

but was resumed in 1978. It was suspended again after India's nuclear tests in May 1998 and resumed again in September 2001.

In the 1980s, USAID's program began to emphasize science and technology transfer, which resulted in scientific collaborations to develop sophisticated satellites for monsoon forecasting, communications systems, biomedicine, and renewable sources of energy. United States loan guarantees also supported India's development of private sector financing systems and water and sanitation services. USAID's programs in the 1990s focused on economic liberalization and the global issues of population growth, HIV/AIDS, climate change, and the status of women.

Based on the Agency's overall strategy and goals, USAID and the Government of India have mutually agreed on projects in the following focus areas: enhancing child survival; stabilizing population growth; preventing the spread of infectious diseases, particularly HIV/AIDS; improving the status of women; and protecting the environment. The last area has accounted for under 20% of the cumulative development assistance spending over the last few years (Table 13).

Table 13: USAID-India Budget (million \$)

	FY 1998	FY 1999	FY 2000	FY 2001 (planned)
Focus area:				
Environmental Protection in Energy, Industry and Cities	0.6	12.5	11.9	8.5
Development Assistance Subtotal	31.3	53.3*	53.0	70.0
PL-480 Title II Food Assistance	90.5	105.5	91.3	100.4
TOTAL	121.8	158.8	144.3	171.4

*Includes carryover funding from FY98

Source: USAID 2001

USAID has been engaged in a number of major activities focused on achieving increased financial and environmental sustainability in the energy sector. In the past, for example, the Program for Acceleration of Commercial Energy Research (PACER) (mid-to-late 1980s) worked through a major Indian development financial institution to provide conditional grants for market driven research to develop energy efficient and renewable energy technologies, which had potential for near-term commercial success.

At present, USAID has four programs focusing on energy and environment.

- The \$27 million Energy Management Consultation and Training (EMCAT) project, initiated in 1991, aims to improve India's technological and management capabilities for the efficient supply and end-use of energy by all sectors of the economy, including agriculture. It provides a combination of technical assistance and training to Indian financial and other institutions to help them address the critical issues affecting the Indian power sector: identifying and supporting policy reforms related to power sector regulation and restructuring, increasing investments in energy efficiency and demand-side management, and promoting innovative financing of energy efficiency projects.
- The Trade in Environmental Services & Technologies project started in 1992 to help Indian industries adopt environmentally sound practices. The Clean Technology Initiative being currently implemented by the ten-year, \$30 million project aims to strengthen incentives for the voluntary adoption of environmental management systems by industry to enhance their capacity to evaluate and incorporate such technologies and practices into their operations. The effort is focused primarily on selected, rapidly growing and major polluting industrial sectors (including textiles, automobiles, steel, cement, paper and pulp, and chemicals). The program also provides financial support for the demonstration of environment-friendly clean technologies and outreach and awareness activities with industry participation. CTI provides four types of assistance to industry (a) environmental information, (b) advisory and technical services, (c) business exchanges and (d) financing mechanisms for demonstration projects
- The Greenhouse Gas Pollution Prevention Project (GEP) project was launched in 1995 "to reduce the volume of emissions of greenhouse gases by increasing energy productivity and encouraging switching to biomass fuels in selected utilities." The project has concentrated on improving coal conversion to increase efficiency in coal-fired power plants and on the use of alternative bagasse co-generation for year-round cogeneration of power using biomass as fuel in the sugar industry. The scope of the \$19 million project was enlarged in September 1999 with the addition of a \$20 million climate change supplement that added new climate-related elements to the project and expanded the earlier coal program to include efficient power generation.
- The Energy Conservation and Commercialization (ECO) project promotes commercialization of energy efficiency technologies and services in India. The project began in January 2000 and will provide an assistance of \$25 million to support the development of policy and market interventions to enhance the capabilities of the private,

financial, and government sectors for deploying market-based mechanisms for end-use efficiency investments. ECO project activities are designed to address the market, technical, economic, financial, regulatory, policy and institutional barriers that have thus far inhibited investments in end-use energy efficiency practices and technologies in India.

All of these programs are consistent with USAID India's Global Climate Change strategy, which focuses on influencing the Government of India to take a more active role in international negotiations and promotes Indian participation in flexible instruments for GHG emissions reduction, especially the Clean Development Mechanism. A third objective is to help develop a better understanding of the term "meaningful participation", both by the US and by key developing countries on climate change issue. The climate change supplement of the GEP project and the ECO project were both announced during President Clinton's 1999 visit to India.

Other outcomes from Clinton's India visit include:

- Joint Statement on Cooperation in Energy and Environment, that among other things, announced the creation of a bi-national Joint Consultative Group on Clean Energy and the Environment that will focus on clean energy projects and policy, commercial development of clean energy, and, enhanced cooperation on global climate change. (Full statement is attached in Appendix II.)
- South Asia Regional Initiative (SARI) Energy Program: The SARI Energy Program is a new \$50 million USAID program designed to accelerate investment and trade in clean energy among South Asian nations, including India, Bangladesh and Nepal. Program support will help countries foster regional cooperation and develop the appropriate policy, regulatory, and investment environments to encourage private investment. The program will promote the use of clean energy technologies to reduce greenhouse gas emissions and help stimulate economic growth.
- U.S. Export-Import Bank Line of Credit: The Ex-Im Bank will provide a \$200 million specialized line of credit targeted for clean energy development projects through a Memorandum of Understanding with the Indian Power Finance Corporation.
- Clean Energy Trade Mission: To further the goals of President Clinton's International Clean Energy initiative, the Department of Commerce led a trade mission in late 2000 that focused on clean energy.
- Resumption of Bilateral Energy Consultations and Technical Assistance: DOE was to resume its cooperative efforts on non-nuclear power sector policy reforms, and on public

and private collaborative projects related to clean energy, renewable energy and energy efficiency. DOE programs were suspended in 1998 in the context of policy-based restrictions on U.S. assistance to India.

- Resumption of EPA Technical Assistance: EPA was to re-establish its environmental cooperation program in India with proposals to address air quality management, strengthening implementation of environmental policies and regulations, risk assessment and management of priority pollutants, and greenhouse gas reduction projects. EPA programs were suspended in 1998 in the context of policy-based restrictions on U.S. assistance to India.
- India-US Renewable Energy Memorandum of Understanding: A Memorandum of Understanding in the field of renewable energy was signed between the Solar Energy Center of the Ministry of Non-Conventional Energy Sources and the National Renewable Energy Laboratory of the United States Department of Energy.
- Science and Technology Agreement: India and the United States signed an agreement to establish an Indo-U.S. science and technology forum to facilitate and promote the interaction, of government, academia, and industry in science, technology and other related areas.

Primer Minister Vajpayee's September 2000 visit to the United States resulted in a further strengthening of energy-related cooperation with the signing of a Protocol of Intent between the Ministry of Power, India and the USAID for an IGCC demonstration power plant project.

6.8 Russia

The Russians are providing the technical and financial assistance for a 2000 MW nuclear power project (two Russian-designed 1,000 MW VVER light-water reactors) in Tamil Nadu. Russia will supply fuel and spare parts for the plant. Also, the declaration of strategic partnership signed by Prime Minister Atal Bihari Vajpayee and Russian President Vladimir Putin, during the latter's visit to India in October 2000, explicitly mentions cooperation in the peaceful use of nuclear energy. Thus it seems reasonable to expect further linkages and cooperation in the nuclear power arena between the two countries.

Table 14 provides an overview of the authorization of external assistance by selected multilateral and bilateral sources over the latter part of the 1990s.

Table 14: Authorization of external assistance to India by source

SOURCE	Average annual authorization, million \$		Energy component (% of recent activities) [§]
	1994-95 to 1996-97	1997-98 to 1999-00	
Multilateral sources			
World Bank	1719	1508	15%
Asian Development Bank	462	471	23%
Bilateral sources			
Japan	1307	411	60%
Germany	281	124	44%
United Kingdom	131	172	20%
United States	19	32	< 20%
Total assistance from all sources	4259	3766	

Source: GOI 2001, donor agency publications

[§] Approximate estimates based on publicly available data

7 WHAT SHAPES THE INDIAN ER&D LANDSCAPE?

The landscape of Indian ER&D institutions and their activities discussed above is characterized by a number of features:

- A multitude and diversity of organizations – govt., public sector, and private sector – are involved in energy-related R&D in India. This rather rich diversity of organization and the range of their activities separates India from most other developing countries.
- Public sector institutions clearly dominate ER&D efforts in India with private sector firms playing a significant role in a few sectors. Notably, though, the role of academic institutions seems relatively marginal (although to some extent this perception is a function of the extremely limited data available). To be fair, this should not be too surprising since many of these academic institutions focus on basic research, as is the case in other countries. Some academic R&D programs are highly applied, though, and have shown much success, such as the biomass gasifier program at the Indian Institute of Science discussed earlier.
- India has energy-related R&D across an enormous range of areas such as solar photovoltaic modules, fuel cells, biomass gasification, advanced coal technologies,

automotive technologies, railway engines, petroleum exploration and refining, nuclear energy, etc.

- A small number of organizations dominate the national ER&D landscape, accounting for a substantial portion of energy-relevant R&D spending. This includes BHEL, IOCL, ONGC, and SAIL in the public sector, DAE and CSIR among the government agencies, and TELCO and BAL within the private sector
- Generally the total ER&D expenditures in India are quite low compared to expenditures in industrialized countries, which is to be expected given India's limited financial resources.
- Indian enterprises generally have lower R&D spending levels (as percent of turnover) compared to their major industrialized country counterparts. Notably many of the joint ventures have minimal R&D expenditures in India – their focus is more on manufacturing, while often technology is simply acquired from the parent firm.
- Although in many cases, India's ER&D efforts are rather fragmented, there exist some concerted attempts to promote institutional linkages in R&D planning as well as performance.
- Much of the ER&D effort in India could be characterized as development or technology acquisition and upgrading, i.e., mostly targeted towards incremental product innovation and improved manufacturing or plant operations and performance. There are some exceptions, though - the nuclear program, for example, stands out for its range of indigenous technological development (that was necessitated due to the lack of access to technology after India's 1974 nuclear explosion).
- The overall landscape of ER&D, when compared with the pattern of energy supply and use shows a remarkable skew. For example, the coal sector that is regarded in all Indian Plan documents as a mainstay of the country's energy future receives only limited attention through the Ministry of Coal (although BHEL does have a sizable effort on coal utilization technologies). Nuclear energy on the other hand receives a not insubstantial share of the government's R&D expenditure even though it contributes only about 2.5% to the country's power supply. Within the transport sector, R&D on railway technologies does not seem, once again, commensurate with the concern expressed about this mode of transportation, and its importance for the transport sector, in recent 5-year Plan documents. And non-commercial energy sources such as biomass that support the majority of the country's population have a minor presence on the country's ER&D landscape – it is left to MNES to fund R&D on this.

While it is impossible to identify or separate out all the factors that have helped shape India's ER&D landscape, to a large extent it is possible to understand the current state of Indian ER&D and its evolution by viewing it as a result of the interactions between India's energy policies and S&T policies.

On the energy policy front, India planners have been driven since independence by a vision of rapid large-scale industrialization as the path to development and hence naturally the focus of energy planners has been electric power since this is considered central to industrial activity. Thus to a large extent, energy has been equated with electric power, and energy policy with power policy. Furthermore, the historical shortage of electricity, and the often-ambitious projections of future needs (based in large part on optimistic economic growth assumptions) additionally created the perceived need for rapid addition in the power supply, which generally translated, to a focus on increasing electricity generation.

Such a perspective, combined with the closed nature of the Indian economy (before the policy changes that began in the mid-1980s and accelerated in the early 1990s), led to "self-sufficiency" as being the tenet underlying Indian energy policy, both in terms of energy sources but perhaps more importantly, also conversion and utilization technologies. Thus the focus of most organizations was, more than anything else, on the absorption and utilization of technology. The absence of international technology vendors within the country, and the lack of any strong innovation-spurring incentives, provided little motivation to most actors to engage in cutting-edge energy technology research. Thus, even though the importance and relevance of R&D to the Indian energy system had been pointed out in many government documents, this did not translate into any kind of systematic ER&D policy.

Currently the policy emphasis is on reducing government controls in, and restructuring, various segments of the energy sector to allow market forces to improve the overall performance of the sector and to induce private sector participation. At the same time, there is also a renewed emphasis on increasing access to energy sources through domestic as well as regional and other international cooperation. Once again, there is little emphasis on energy technology development.

Another reason for the lack of coherent focus in India on the energy sector *per se* is the division of various aspects of energy amongst individual ministries – coal, petroleum and natural gas,

power, non-conventional energy, and atomic energy on the generation side and steel, chemicals and fertilizers, surface transport, railways, agriculture, commerce and industry on the user side. As a result, there has been extremely limited attention paid to end-use efficiency – only recently has this picture begun to change, driven in part by the liberalization of the Indian economy whereby competitiveness concerns are now focusing firms to improve the efficiency of their operations. While the importance of transmission and distribution in improving system efficiency has been noted in Indian Plan documents as well as various expert reports all along, it is only the experience of the last decade that has forced a hard look at the T&D issue. The government has also passed recently an Energy Efficiency bill that, through its standard-setting provisions, may provide some impetus to R&D on, or at least deployment of, improved end-use technologies.

On the S&T front, India's policies have been dominated by a few major concerns: national security, import substitution, and self-reliance (which includes modification of technologies for local conditions), the latter once again being a result of the closed-economy model followed by India until the mid-1980s.¹² This, combined with the focus of the leading Indian scientists who helped establish much of the foundation of India's S&T system, led to a initial emphasis on defense, space and nuclear technologies, a situation that continues until the present as reflected in the government's S&T expenditures (see Table 7). The 9th Plan document prioritization of S&T and thrust areas also mentions that strategic areas such as atomic energy and space should continue to receive increasing investments.

There has also been little private sector participation in S&T efforts since historically the government took on the responsibility of funding areas that were deemed to be of importance to the national economy. The private sector generally had little incentive to engage in R&D, or even upgrade its technologies to any reasonable degree because of lack of international competition. Its R&D focus was more on solving production problems through incremental efforts rather than new process/product development, and there was little interaction with the national and international S&T community. The opening up of the Indian economy, and the entry of MNCs into the market, has forced the private sector to pay more attention to technology research and development. Even as recently as 1985, public sector and private sector enterprises were

¹² The Government's Technology Policy Statement was formulated in 1983 with the basic objective of developing indigenous technology and ensuring efficient absorption and adaptation of imported technology appropriate to national priorities and availability of resources. It is aimed at attaining technical competence and self-reliance, reducing vulnerability particularly in strategic and critical areas and making maximum use of indigenous resources.

spending about equal amounts for R&D, although now private sector firms outspend their public sector counterparts by a factor of four (DST 1999).

There has been, recently, increasing attention within the S&T establishment on policies to support technological innovation, but these have focused mainly on two sectors – biotechnology and information technology, both being seen as new drivers of the Indian economy. There has also been a spate of international investment directed towards setting up R&D laboratories in India, although these efforts are directed almost exclusively at the IT sector. Notably, though, General Electric is setting up a \$100 million multi-disciplinary research center in India that focuses on a range of technologies.

In sum, the energy sector has received only marginal attention within the S&T establishment in India, especially in the planning process. Energy-relevant R&D is often funded in a number of institutions, but without explicit consideration of how a particular project fits into India's energy future. In fact, the country does not have a strategic plan for technology development in relation to India's energy future, leading to piecemeal efforts that do not necessarily have synergy between them. Thus, a substantial and concerted effort will be required to appropriately reorient and strengthen India's ER&D capabilities to meet the energy and environmental challenges facing the country.

REFERENCES

- ABB 2000. Asea Brown Boveri India 2000. *Annual Report 2000*.
- ARAI 2000. Automotive Research Association of India 2000. ARAI 1999-00 income statement accessed at http://www.araiindia.com/operational_income.htm
- AL 2001. Ashok Leyland 2001. *Annual Report 2000-01*.
- AL 2000. Ashok Leyland 2000. *Annual Report 1999-00*.
- BAL 2001. Bajaj Auto Ltd. 2001. *Annual Report 2000-01*.
- Bethlehem Steel 2000. Bethlehem Steel 2000. 10-K Filings for the year 2000.
- BHEL 2001. Bharat Heavy Electricals Ltd. 2001. *Annual Report 2000-01*.
- BHEL 2001. Bharat Heavy Electricals Ltd. 2000. *Annual Report 1999-00*.
- CEA 1995. Central Electricity Authority, Ministry of Power, 1995. *Fifteenth Electric Power Survey of India*.
- CMA 2000. Cement Manufacturers Association, 2000. Industry overview at www.cmaindia.org
- CMIE 2001. Centre for Monitoring the Indian Economy, 2001. *Economic Intelligence Service: Energy*.
- Capital Market 2000. <http://www.cmots.com/capitalmarket/results/june2000/wartsila.htm> accessed January 16, 2001.
- Cummins 2001. Cummins India 2001. *Annual Report 2001*.
- DST 1999. Department of Science and Technology, Government of India, 1999. *Research and Development Statistics 1996-97*.
- DST 1999a. Department of Science and Technology, Government of India, 1999. *Research and Development in Industry 1996-97*.
- IEA 2000. International Energy Agency, 2000. *Energy Balances of non-OECD Countries, 1997-98*.
- FT 2001. Financial Times, 27 September 2001. *R&D Scoreboard*.
- FT 2000. Financial Times, 15 September 2000. *R&D Scoreboard*.
- Garg 2000. Garg, A. and Shukla P.R., 2000. *Greenhouse Gases Inventories for India: Status and Concerns*.
- GAIL 2000. Gas Authority of India Ltd., 2000. *Annual Report 1999-00*.
- GOI 2001. Government of India, 2001. *Indian Economic Survey 2000-01*.

- GOI 2000. Government of India, 2000. *Indian Economic Survey 1999-00*.
- GOI 1996. Government of India, 1996. *India Infrastructure Report*.
- IEA 2000. International Energy Agency 2000. *Energy Balances of non-OECD Countries 1997-98*.
- India Infoline 2001. India Infoline 2001. Over view of the Indian Steel Industry. Accessed at <http://www.indiainfoline.com/sect/stee/ch03.html>
- IOCL 2000. Personal conversations with IOCL personnel, May 2000.
- IOCL 2001. Indian Oil Corporation Ltd. 2001. *Annual Report 2000-01*.
- M&M 2001. Mahindra & Mahindra 2001. *Annual Report 2000-01*.
- M&M 2000. Mahindra & Mahindra 2000. *Annual Report 1999-00*.
- Marland 2000. Marland, G, Boden, TA, Andres, RJ, 2000. *Global, Regional, and National CO2 Emissions*, in “Trends: A Compendium of Data on Global Change,” Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy.
- Min. of Steel 2000. Ministry of Steel 2000. *Annual Report 1999-00*.
- MNES 2000. Ministry of Non-Conventional Energy Sources, 2000. *Annual Report 1999-00*.
- Moorty 2001. Moorty, DN 2001. Amendment of Atomic Energy Act to Permit Joint Ventures for Nuclear Power on Anvil – Chaturvedi. *Indian Express*, Feb. 12.
- NSF 1998. National Science Foundation, 1998. *Science and Engineering Indicators 1998*.
- NTPC 2001. National Thermal Power Corporation 2001.
- OBP 2000. The Observer of Business and Politics, Oct. 4, 2000. *Comprehensive policy framework for doubling power generation*.
- ONGC 1999. Oil and Natural Gas Commission 1999. *Annual Report 1998-99*.
- Planning Commission 1997. Planning Commission, Government of India, 1997. *Ninth Five-Year Plan 1997-2002, Vol. I, Ch. 3: Public Sector Plan: Resources and Allocation*.
- Planning Commission 1997a. Planning Commission, Government of India, 1997. *Ninth Five-Year Plan 1997-2002, Vol. II, Ch. 6.1: Energy*.
- Planning Commission 1997b. Planning Commission, Government of India, 1997. *Ninth Five-Year Plan 1997-2002, Vol. II, Ch. 6.2: Power Sector*.
- Planning Commission 1997c. Planning Commission, Government of India, 1997. *Ninth Five-Year Plan 1997-2002, Vol. I, Ch. 1: Perspectives, Objectives and Strategy of Development*.

- Planning Commission 1997d. Planning Commission, Government of India, 1997. *Ninth Five-Year Plan 1997-2002, Vol. I, Ch. 2: Macroeconomic Dimensions and Policy Framework*.
- Planning Commission 1997e. Planning Commission, Government of India, 1997. *Ninth Five-Year Plan 1997-2002, Vol. 2, Ch. 7: Transport and Communication*.
- Planning Commission 2000. Planning Commission, Government of India, 2000. *Annual report on the Working of State Electricity Boards and Electricity Departments*.
- Planning Commission 2000a. Planning Commission, Government of India, 2000. *Mid-term Appraisal of the Ninth Five Year Plan*.
- Planning Commission 2001. Planning Commission, Government of India, 2001. *Annual Report of the Working of State Electricity Boards and Electricity Departments*.
- Planning Commission 2001a. Planning Commission, Government of India, 2001. Personal communication with Planning Commission staff, August 2001.
- Planning Commission 2001b. Planning Commission, Government of India, 2001. *Annual Plan 2001-2002 (Ch 8.1.2: Coal and Lignite)*.
- Planning Commission 2001c. Planning Commission, Government of India, 2001. *Indian Planning Experience: A Statistical Profile*.
- Powerline 2000. Powerline, March 2000. *Existing Captive Capacity*.
- Powerline 2000a. Powerline, May 2000. *National renewable energy policy planned*.
- Powerline 2000b. Powerline, Sept. 2000. *Power Sector Reforms: What went wrong?*
- RPL 2001. Reliance Petroleum Limited 2001. *Annual Report 2000-01*.
- SAIL 2001. Steel Authority of India Limited 2001. *Annual Report 2000-01*.
- SAIL 2000. Steel Authority of India Limited 2000. *Annual Report 1999-00*.
- Shukla 2000. Shukla, PR, Garg, A, Ghosh, D and Rao, S, 2000. *Energy and Environment Technology Inventory of Indian Industry*.
- SIA 2000. Secretariat for Industrial Assistance, Ministry of Industry, 2000. The Indian Automobile Industry. Accessed at indmin.nic.in/vsindmin/publicat/auto.html.
- Siemens 2000. Siemens India 2000. *Annual Report 1999-00*.
- Sreesankar 2000. Interview posted at <http://www.capitalideasonline.com/mm/sreeshankar/14aug2000/herohonda.html> (accessed Oct. 10, 2000).
- Sriraman 1998. Sriraman, S. Road Transport Development in India. *Current Science* 75(8): 785-790 (1998).
- Telco 2001. Tata Engineering and Locomotive Co. *Annual Report 2000-01*.

TERI 1999. Tata Energy Research Institute, 1999. *Survey of Industrial Environment: Report on Cement Industry*

TERI 2000. Tata Energy Research Institute, 2000. *Tata Energy Data Directory & Yearbook 1999-00*.

Thermax 2001. Thermax Limited 2001. *Annual Report 2000-01*.

TISCO 2000. Tata Iron and Steel Co. 2000. *Annual Report 1999-00*.

TISCO 2001. Tata Iron and Steel Co. 2001. *Annual Report 2000-01*.

USAID 2001. United States Agency for International Development 2001. USAID-India budget data accessed at <http://www.usaid.gov/in/aboutusaid/budget.htm>

WIS 2001. Wright's Investor Service 2001. Asea Brown Boveri Company Research Report accessed on August 11, 2001 at <http://profiles.wisi.com>.

World Bank 2001. World Bank 2001. *World Development Indicators 2001*.

APPENDIX I

Trends in Indian GDP, population and structure of economy

	1980	1990	1995	1997	1998	1999
GDP (current Rs., billions)	1441	5675	11819	15156	17626	19386
<i>Rupee-dollar exchange rate</i>	<i>7.9</i>	<i>17.9</i>	<i>33.5</i>	<i>37.2</i>	<i>42.1</i>	<i>43.3</i>
GDP (current US\$, billions)	182.6	316.2	353.2	407.9	419.1	447.3
GDP, PPP (intl. \$, billions)	461.8	1202.7	1739.0	1962.3	2067.4	2242.0
Population (millions)	687.3	849.5	929.3	962.4	979.7	997.5
Sectoral contribution to GDP, (%)						
Agriculture	38.7	31.5	28.4	28.0	29.1	27.7
Industry	24.2	27.6	27.9	27.1	25.7	26.3
Manufacturing	16.2	17.2	17.8	16.6	15.6	15.9
Services	37.1	40.9	43.7	44.9	45.2	46.0

Source: World Bank 2001

APPENDIX II

JOINT STATEMENT ON COOPERATION IN ENERGY AND ENVIRONMENT BETWEEN THE UNITED STATES AND INDIA

1. The United States and India share a relationship founded on a common and deep commitment to democratic values and bound by growing engagement in diverse fields of human endeavor. During the current visit of President Clinton to India, President Clinton and Prime Minister Vajpayee have outlined their vision for a new relationship in the new century. Cooperation between the two countries in promoting energy and protecting the environment is an important part of their vision for the future.
2. The two countries agree that meeting energy needs in a sustainable manner is one of the most important challenges of the 21st century. They underscore the central role energy plays in economic development, as well as the human health and environmental risks associated with unsustainable energy use. They note that the development of cleaner and more efficient energy technologies will contribute significantly to improving the air quality and protecting the global environment. As leaders in the forefront of the new high technology economy, they recognize that countries can achieve robust economic growth while protecting the environment and taking action to combat climate change.
3. The United States and India note that their common desire to promote clean energy and protect the environment has guided past cooperation and joint initiatives. They accord high importance to this aspect of their bilateral energy cooperation. They intend to activate related mechanisms established in the past, including ministerial meetings under the Indo-U.S. Bilateral Energy Consultations, and to intensify further their cooperation in the fields of clean energy and environmental protection, including the impacts of air and water pollution on human health.
4. The two countries are taking many initiatives on their own to mitigate the impact of energy production and use on the environment. India, which was the first country to establish a full-fledged Ministry for Non-conventional Energy Sources, is working to make renewable energy sources a viable and significant part of India's energy supply. India is one of the largest users of wind energy and solar energy in the world and has also made impressive advances in generating energy from wastes. India intends to achieve by 2012 a 10% share for renewable energy in the capacity-additions of electricity nationwide. In the field of conventional energy, India is increasingly making fossil fuel energy cleaner and more efficient. India intends to improve energy efficiency in the electric power sector by focusing on renovation and modernization including re-powering of old power plants to improve Plant Load Factor, upgrading/strengthening of sub-transmission and distribution to reduce Transmission and Distribution losses and introduction of legislation on energy conservation for promoting end-use energy efficiency. The proposed Bureau of Energy Efficiency will act as the focal point for affecting end-use energy efficiency and formulating goals and objectives in this area. By implementing the above activities, India intends to achieve approximately a 15% improvement in energy efficiency by 2007-08.
5. The United States is committed to a clean energy future and to the goal of reducing greenhouse gas emissions. To this end, the United States pursues a program of research and development, public education, promotion of energy efficient products and practices, and targeted tax incentives. Specific actions during the past year include issuance by the President of an Executive Order mandating reduction in energy use in federal buildings by 30% below 1990 levels by the year 2010; issuance by the President of a directive that sets a target to triple the use

of bio-energy in the U.S. over the next decade - a result that would lead to a reduction of 100 million metric tons of carbon; and establishment by the Department of Energy of a goal of increasing to 5% the share of U.S. electricity generated by wind power by 2020.

6. The two countries believe that close bilateral cooperation is needed to promote clean energy initiatives. They also intend to cooperate multilaterally in the appropriate fora for addressing climate change issues. The United States is committed to working cooperatively with India and other developing countries to address clean energy and climate change. Examples of such cooperation include: President Clinton's International Clean Energy Initiative, a program designed to accelerate clean energy technology transfer to developing countries, and promote trade and investment with them; and, a broad range of technical assistance and commercial development programs through the U.S. Agency for International Development, the Department of Energy, the Department of Commerce, the Environmental Protection Agency, the Export-Import Bank of the United States, and other federal agencies.

7. The United States and India reaffirm their strong support for international efforts to combat global climate change under the UN Framework Convention on Climate Change and its Kyoto Protocol. They reaffirm the urgent need for international dialogue on ways in which developed and developing countries could participate in actions to Combat climate change, in accordance with the principle of common but differentiated responsibilities, and in a manner consistent with sustained economic growth and social development. They recognize that, under the United Nations Framework Convention on Climate Change, the developed country Parties shall take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to the developing country Parties to enable them to implement the provisions of the Convention. The two countries intend to work together and with other countries in appropriate multilateral fora toward early agreement on the elements of the Kyoto mechanisms, including the Clean Development Mechanism, which could offer opportunity for mutually beneficial partnership between developed and developing countries. They recognize, in particular, that the Clean Development Mechanism could provide important opportunities for economic growth and environmental protection.

8. The United States and India recall their Joint Statement on Cooperation in Energy and Related Environmental Aspects signed in New Delhi by US Energy Secretary Bill Richardson, and Shri Jaswant Singh, Minister of External Affairs of India, on October 26th 1999. The Joint Statement articulated the desire of the two countries to increase cooperation in energy and environment.

9. In pursuit of the collaborative goals set forth in this statement and in the Joint Statement of 26th October 1999, the United States and India intend to create a Joint Consultative Group on Clean Energy and Environment to foster greater bilateral cooperation, Government to Government dialogue and further encourage public and private sector cooperation in these sectors. This represents another important step that the two countries have taken in expanding mutually beneficial relations. The Joint Consultative Group will ensure an institutional framework between the two countries to (a) identify, initiate and monitor public and private collaborative projects in research, development, transfer, demonstration and deployment of appropriate technologies, and review policies in the areas of clean energy, renewable energy, energy efficiency and power sector reform, (b) explore and expand opportunities for commercial development and cooperation in clean energy, and (c) enhance cooperation on climate change issues that arise in the context of the United Nations Framework Convention on Climate.

10. The co-conveners of the Group will be the Department of State of the United States and Ministry of External Affairs of India, respectively, with participation by all concerned

Agencies/Ministries as determined by either side. Focal points of contacts may be established directly between concerned Ministries and Agencies, with ministerial or other high-level involvement, as considered desirable and appropriate on specific issues.

11. The two countries believe that their strong scientific and technological resources provide a sound basis for intensifying collaborative efforts, especially between the agencies of the two Governments, in research, development, demonstration and transfers of clean energy and renewable energy technologies and for improving efficiency in production and consumption of energy from conventional resources. Progress in these areas can enhance availability of energy and increase productivity and efficiency in the economy, while protecting the environment, reducing impact on the climate and preserving the bio-diversity and natural resources.

12. The two countries emphasize the considerable mutual benefit of expanded private sector cooperation in the energy sector. They welcome the United States Energy Association/Confederation of Indian Industry-Private Sector Trade and Investment Working Group on Clean Energy and the Environment, and the creation of a Green Business Centre at Hyderabad. The Centre, a joint initiative of the Government of Andhra Pradesh, USEA and CII, is a commendable example of international private sector as well as Government -- industry collaboration in the area of environment. The two governments expect that their bilateral discussions will benefit from this and other private initiatives. For example, they welcome the joint efforts of the United States Agency for International Development, Federation of Indian Chambers of Commerce and Industry and Industrial Credit and Investment Corporation of India.

13. The United States and India believe that energy and environment could be one of the most important areas of cooperation between the two countries. The joint initiatives taken by the two sides will give practical shape to that vision. By making clean energy widely available through development and application of new technologies and strengthening efforts to protect our environment and this planet's biodiversity, Indo-US cooperation will contribute in significant measure towards further securing the welfare and quality of life of the peoples of the two countries. It will also be a vital contribution towards preserving the riches of our planet for future generations of this world.