Renewable energy sources and technologies

Introduction

The RETs (renewable energy technologies) offer a viable option to meet the challenge of achieving higher growth while conserving the natural resource base. This base has considerably deteriorated due to the rapid growth in population, urbanization, and fossil fuel consumption.

The potential for the effective use of RETs is very high in India. Recognizing the importance of the renewable sources of energy, CASE (Commission for Additional Sources of Energy) was set up in 1981 with the objective to develop and demonstrate RETs. Subsequently, in 1982, the Department for Non-conventional Energy Sources was created, which was later upgraded to the MNES (Ministry of Non-conventional Energy Sources) in 1992.

One of the key barriers in promotion of RETs is the high initial cost. In addition, there is high perceived risk associated with financing new technologies. To overcome these, IREDA (Indian Renewable Energy Development Agency Limited) was established in March 1987 as a public sector enterprise to finance renewable and energy-efficient technologies.

As on 31 March 2002, IREDA had cumulatively sanctioned 52 879 million rupees and disbursed 27 369 million rupees (IREDA 2002). Concomitantly, this was accompanied by financial and technical assistance from the World Bank, UNDP (United Nations Development Programme), GEF (Global Environment Facility), and ADB (Asian Development Bank).

As on 31 December 2002, the contribution by renewables had reached 3700 MW, which is 3.5% of the total grid capacity in India (MNES 2003). The potential of RETs, with cumulative achievements till 2003, are given in Table 1.101. The applications of various RETs are discussed below.

At a glance

- About 3700 MW of power generating capacity based on renewable energy sources has been installed. This is about 3.5% of the installed capacity in the country.
- India has the world's largest deployment of solar PV (photovoltaic), consisting of 10 30 000 PV systems, aggregating 107 MW and encompassing 40 different applications.
- With over 3.4 million biogas plants installed, India is second in the world, China being the first.
- The solar PV annual production capacity in India reached 20 MW.
- With 1702 MW of installed wind power capacity, India ranks fifth in the world.
- Over 680 000 m^2 of solar collector area installed against re-assessed gross potential of 140 million m^2.
- Gross wind power potential has been re-assessed at 45 000 MW.
- 42 156 potential sites with an aggregate capacity of 10 279 MW for small hydropower projects (up to 25 MW) have already been identified.
- There exists a potential of 3500 MW of bagasse-based power from 453 sugar mills in India.
- It is proposed to electrify 18 000 uncertified remote villages through renewable energy sources by 2012.

Power from renewables

Bagasse-based cogeneration

India is the largest producer of sugar in the world, producing an estimated 12 MT (million tonnes) of sugar. Thus, the sugar industry offers a vast potential for bagasse cogeneration. The total potential for bagasse-based cogeneration from over 430 sugar mills is estimated to be approximately 3500 MW (Table 1.102). As on December 2002, cogeneration projects with an aggregate capacity of 304 MW have been commissioned. New cogeneration projects designed at 87 kg/cm^2 pressure and 515 °C are under implementation in the states of Andhra Pradesh, Karnataka, and Tamil Nadu. Cogeneration projects with boiler pressure of 105 kg/cm^2 boiler pressure have also been prepared in Maharashtra and Karnataka. There are around 31 projects under implementation with a total capacity of 312 MW. The statewise break-up of the bagasse cogeneration and installed capacity is given in Table 1.103.

The major constraints in setting-up cogeneration projects are high costs, lack of policies, and power purchase costs. In addition to this, the high requirement of working capital to run the biomass power plant is also considered as one of the limiting factor. Off-seasonal operation of cogeneration projects is a critical issue affecting the viability of the bagasse cogeneration plant.

Box 1 Renewable energy strategy in the Tenth Plan

The Tenth Plan has laid out the strategy to enhance the use of RETs (renewable energy technologies) for various applications, with review and modifications of the existing schemes. A number of steps have been identified that will help achieving the targets. These include

- identifying remote areas where power supply from the conventional grid will be prohibitively expensive and make it a priority to provide off-grid supply from renewable sources to these areas. Create provisions for integrated generation and distribution of off-grid energy supply.
- clarifying the framework for supply to the main grid by providing regulatory certainty on tariff, off-take agreements, and direct/contracted sale to bulk users.
- encouraging private sector investments in renewable energy sources by promoting a bidding process for available subsidies. Award contracts to private entrepreneurs who provide maximum benefit with the lowest amount of subsidies.
- promoting local/private sector management of both generation and distribution for off-grid supply from renewable sources.
- integrating RETs in all buildings.
- optimizing energy plantation by raising plants on degraded forest and community land.

It is proposed that around 18 000 villages located in remote and difficult areas will be electrified through decentralized and non-conventional energy sources. A time frame has been set to complete the electrification of all the remote villages by the end of the Eleventh Plan, that is by 2012. Accordingly, the Tenth Plan would accord top priority to this activity.

A physical target of 3075 MW of power generation capacity from renewables has been set for the Tenth Plan, as per the following details.

Wind	1500 MW
SHP	600 MW
Biomass power/cogeneration	700 MW
Biomass gasification	50 MW
Waste to energy	80 MW
Solar photovoltaic power	5 MW
Solar thermal power	140 MW
Total	3075 MW

Out of the 18 000 villages in remote areas, it is proposed to electrify 5000 villages through decentralized energy sources, 4000 of them by solar and the remaining villages by biomass and small hydro power plants. It is also proposed to install 1 000 000 biogas plants, 25 million domestic plus 6 million solar lantern SPV (solar photovoltaic) lighting systems, 5 MW of SPV power plants, 8000 SPV pumps, and 10 000 SPV generators.

In addition, solar water heating systems, solar cookers, solar air heating systems, etc. are also proposed to be encouraged.

The MNES provides interest subsidy for cogeneration projects. In addition to this, for bagasse cogenerated projects in cooperative and public sector sugar mills' capital subsidy is also provided by the MNES. The state governments also provide various fiscal and financial incentives. Tamil Nadu has taken the lead in installing high-pressure cogeneration units with steam conserving measures through innovative technologies. The Maharashtra Electricity Regulatory Commission has issued the tariff order for bagasse-based cogeneration projects in July 2002, which will be reviewed after 31 March 2007, or after a cumulative installed capacity of 300 MW, whichever being earlier.

The Ninth Plan focused on the promotion of biomass power generation through demonstration programmes and financial incentives such as interest subsidy. The target set for biomass power generation, including bagasse cogeneration, was 314 MW. The cumulative achievement during the Ninth Plan was around 290 MW. The cumulative installation of biomass/bagasse cogeneration plants is given in Table 1.104. It is planned to continue with the promotion of biomass power generation during the Tenth Plan with a target of installing 700 MW through biomass/cogeneration (Planning Commission 2002). With new initiatives being taken in states such as Maharashtra and Tamil Nadu, higher growth in the bagasse cogeneration sector is expected in 2003/04 (Box 1).

Biomass gasifiers

Biomass-based power plants are ideal for decentralized applications in rural areas, where either it is expensive to extend the grid or the power demand is low. Agro residues as well as biomass from agro-processing industries – such as cigarette factories, cashew-processing units, and ayurvedic medicine manufacturing units – could be used for power generation using the biomass gasifier. The viability of gasifier power plants is strongly linked to the supply mechanisms of biomass.

In many states of India, due to the poor quality of the grid and its reliability, industries are forced to switch over to their own captive power generation using diesel. Considering the relatively stable and low price of biomass, it makes good sense to couple these gensets with gasifiers. Dual-fuel (gasifier and diesel) operating electric power generators thus offer a great potential for fuel-saving and decentralized power generation.

Till December 2002 the total installed capacity of biomass gasifiers was 53.16 MW. An yearwise break-up of gasifiers installed in different states is given in Table 1.105. During the Ninth Five-year Plan gasifier systems of about 42 MW equivalent were installed, whereas the target set was to install systems of 40 MW. The Tenth Five-year Plan now has a target of 50 MW.

Solar photovoltaic

Solar PV (photovoltaic) is one of the most mature, field-proven, and fastest growing technology among all non-conventional energy technologies. A programme for demonstration and utilization of PV systems in India was started in the 1980s. Since then, numerous applications of the technology have been developed and demonstrated in the country. Several organizations at the central and state levels, as well as in the non-governmental sector, are involved in expanding the use of PV technology both in the urban and rural sectors. India has a strong industrial base, which not only caters to the local market, but also to export. Development of the Indian PV industry started with the setting up of a public sector electrotechnology company called the CEL (Central Electronics Ltd) and subsequently, the start of PV operations by the BHEL (Bharat Heavy Electricals Ltd). In the early 1990s, private companies entered into this field. The Indian PV industry today consists of nine companies that manufacture solar cells, 20 manufacture modules while about 60 are in the business of system integration with most of them manufacturing their balance-of-systems as well. There is also an annual manufacturing capacity of about 2 million silicon wafers. The industry produced 20 MW_p of solar cells and 20 MW_p of modules during 2001/02. Production during 2002/03 (till December 2002) is 12 MW_p of solar cells and 14 MW_p of modules. The cumulative worth of the Indian PV market is about 107 MW_p. Figure 1 shows the details of the annual production of solar cells and modules in India.

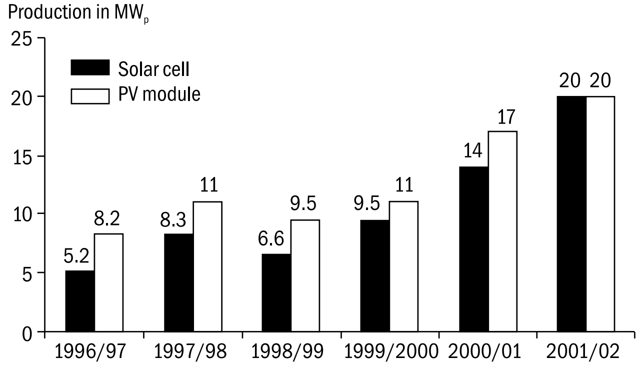


Figure 1 Annual production of solar cells and modules

Typical applications

About 61 MW_p worth of PV power is currently in use in India. In addition, the industry has exported PV products of 46 MW_p capacity. The market in India is traditionally divided as

Minimal rural energy needs It is a socially driven, subsidy-supported market segment aimed at providing benefits to the rural population. Markets for solar lighting systems, mainly portable lanterns and home systems, represent this steady segment, which continues to be benefited by government support and commitment.

Decentralized energy supply Products and systems that are meant for the decentralized energy supply for domestic and commercial applications in both rural and urban sectors formulate this semi-commercial segment. It is partially supported by government subsidy, and partially through soft loans that are made available by IREDA and banks.

Grid-connected power supply Grid-connected power supply market, although the fastest growing market segment in the developed countries, is at a technology demonstration and validation stage in India. The two applications in this market segment are rooftop systems on public buildings for peak load saving, and tail-end voltage support for rural grids. So far, grid interactive projects with an aggregate capacity of 2.49 MW_p have been established. List of grid interactive projects completed and under execution is given in Tables 1.106 and 1.107.

Others and exports The largest market for PV in India has been for applications such as the telecom power, railway network, oil and gas sector, defence services, exports, etc. This market is independent of government subsidies and thrives purely on the merits of the technology for providing reliable power to unmanned locations both within and outside the country.

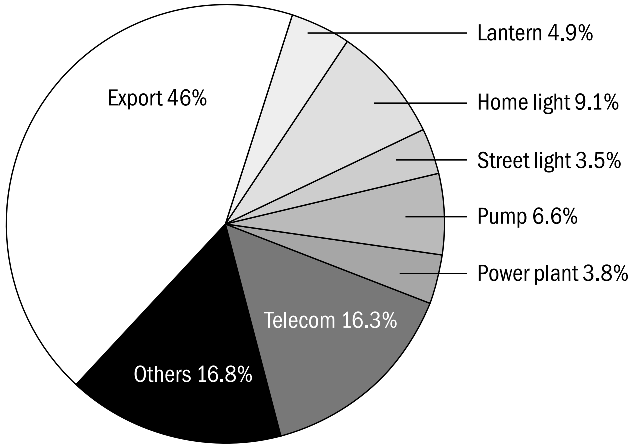


Figure 2 Use of PV modules

Figure 2 provides the sectorwise use of PV modules in India.

Markets for the future

Among several applications of PV, BIPV (building integrated PV) (PV as a building material) is one of the fastest growing market segments in Europe. In India, this concept is slowly gaining popularity, pioneered by TERI and followed by a few other projects such as those in IIT Delhi[1]. Traditionally, PV arrays have been mounted on special support structures, however, they can also be made an integral part of the building envelope. In order to encourage this application and prepare manufacturers and users, the MNES has recently launched a scheme to support BIPV in a demonstration mode in which up to 80% of the module costs will be subsidized.

In the decentralized energy supply segment, a new component of solar generators has been introduced under the 2002/03 programme, targeting the effective use of PV technology as an alternative to oil-based small power generators. The scheme aims at encouraging small shopkeepers, doctors, nursing homes, and other establishments to install solar generators. To begin with, four models of solar generators with PV panel sizes of 150–600 W_p will be promoted under the scheme. A subsidy of up to 40% will be provided on each generator.

The village electrification programme of the Government of India has opened a significant market segment for PV. There are about 80 000 villages in the country, which are yet to be electrified, of which about 18 000 villages are in remote and inaccessible areas. All these villages are proposed to be electrified using RETs and executed by the MNES. The Tenth Five-year Plan (2002–07) targets to electrify 5000 of these villages using mainly PV, biomass, and small hydro power technologies, of which 4000 will use PV technology.

The MNES provides a capital subsidy of up to 50% of the *ex-works* cost of certain systems covered under the demonstration and utilization programme. About 385 000 lanterns have been sold under the subsidy scheme so far. They will now be promoted through the interest subsidy scheme for solar PV market development (up to 85% of the cost @ 5% per annum). The scheme will be implemented through IREDA and other commercial banks. In terms of physical numbers, 296 457 lanterns were sold against a target of 300 000 in the Ninth Plan. As compared, only 154 427 (77%) home lighting systems were sold against a target of 200 000. Achievements in the area of power plants and other systems, such as street lights, were 1.341 MW_p (84%) against the target of 1.600 MW_p. In addition, 22 grid-interactive power plants with an aggregate capacity of 1.64 MW_p have been installed.

Measuring the success of the Ninth Plan and based on its experience, the pattern of PV demonstration and utilization programme has been modified for the Tenth Plan period. Accordingly, targets have been set as 250 000 for home lighting systems, 10 000 for solar generators, and 5 MW_p of power plants and other systems including BIPV applications. A total of 5000 villages are proposed to be electrified during the Tenth Plan out of which 4000 are likely to use PV technology. Additionally, a target for selling 600 000 solar lanterns through the aid of interest subsidy has also been set. For grid interactive power, the Plan proposes a total of 15 MW_p additional capacity out of which 5 MW_p is for captive use by the industry.

Wind energy systems

Wind power is one of the most viable renewable technology for power generation in India. The wind power programme had started in India as early as 1983/84 with initial demonstration projects. Right from the initial stage, market-driven policies were prepared which resulted in more private participation. With an installed capacity of over 1870 MW (as of March 2003), India now ranks fifth in the world after Germany, USA, Denmark, and Spain. The

[1] Though the PV roof project of IIT Delhi is strictly not a BIPV application, it is a novel concept of utilizing PV as a part of the building itself.

wind power programme of the MNES also focuses on resource assessment, capacity development, etc. Tables 1.108 and 1.109 give details of the statewise distribution of the wind monitoring station and wind speed and wind power density at the monitoring stations. The gross wind power potential in India is estimated to be 45 000 MW, the sites with high wind energy potential have been identified in the states of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, and Kerala (Map 1). Tables 1.110 and 1.111 provide estimations of wind potential at 30 m and 50 m heights in different states. The technical potential, which depends on the grid availability, is estimated to be 13 000 MW. The statewise gross potential as well as technical potential is given in Table 1.112. A special project is also taken up for resource assessment in the northern and north-eastern regions.

Growth in the wind energy sector continued in the year 2002 also with the installed capacity reaching 1870 MW. The year 2001/02 saw major growth in wind power installations with states such as Maharashra taking the lead; the annual installation in this year was around 288 MW. In 2002/03 progress was slow as compared to 2001/02 with about 245 MW installed till March 2003. Wind power installed capacity and generation data are given in Tables 1.113–1.116. The present installed capacity of wind represents a little over 1.5% of the total installed power generating capacity in the country. More than 5 billion units of electricity have been generated and fed to state grids from wind power plants. The Ninth Five-year Plan had set the target of installing 800-MW capacity in five years; the achievement during the Ninth Five-year Plan was 728 MW. This target has been increased to an additional capacity of 1500 MW in the Tenth Five-year Plan.

On the technology front, the individual wind turbine capacity has also increased from 55 kW in the mid-1980s to 1000 kW at present. Further, 1.25 MW scale wind turbines are envisaged to enter the Indian market in the near future.

The performances of wind projects are being closely monitored on a regular basis. The Centre for Wind Energy Technology set up in Chennai has already carried out the power curve testing of two wind turbine makes and has initiated other R&D projects to enhance the performance of wind turbines in India.

In order to foster the growth of wind power in India, several financial and fiscal incentives are available. The MNES has issued guidelines to the states for policies regarding the purchase of power. The major change in the fiscal incentive, which will have its impact, is the reduction of 100% accelerated depreciation in the first year for renewable energy projects to 80%.

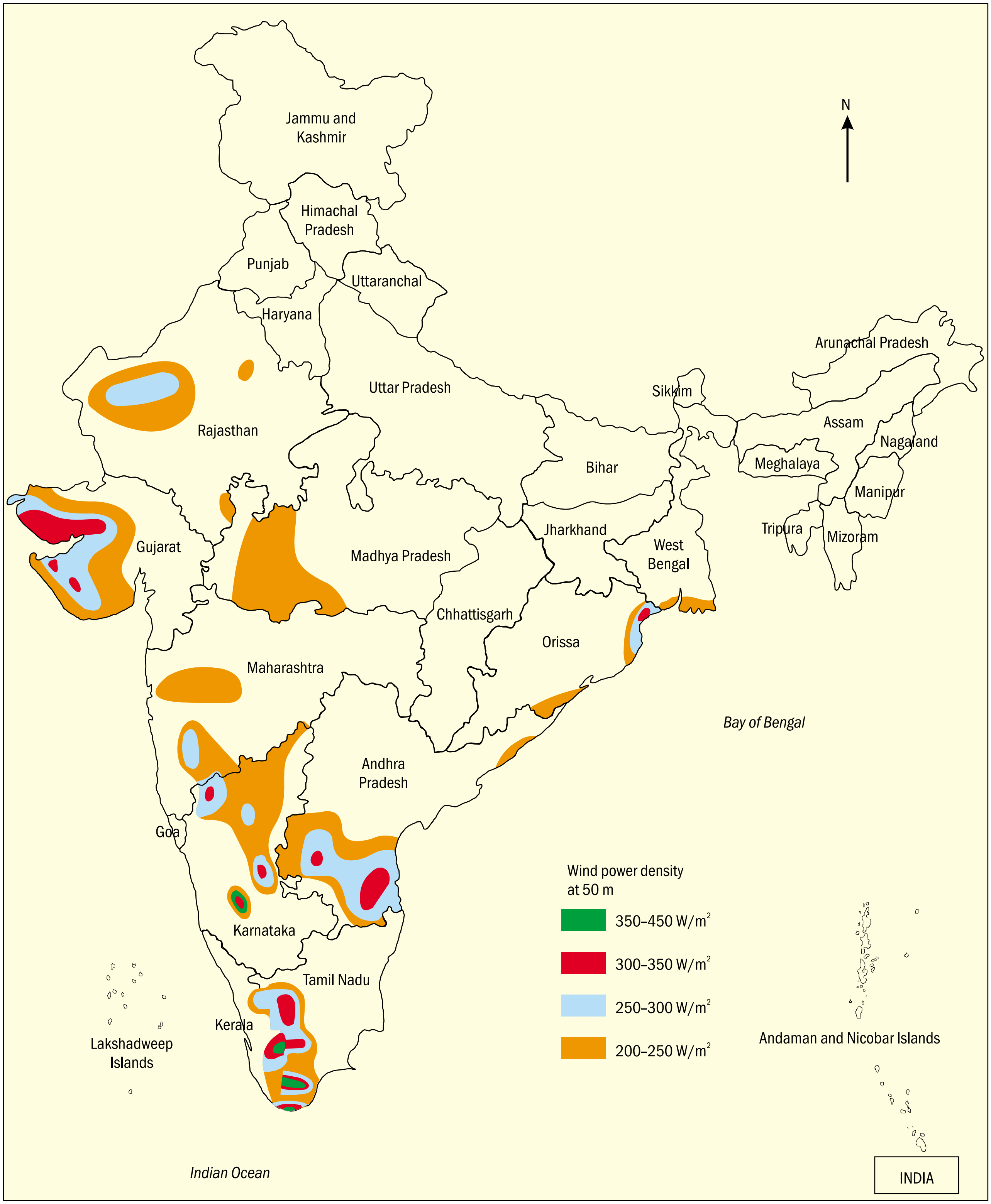
Conducive policy is required for the growth of the wind energy sector. The delay in announcing a policy in states, which have a higher potential for growth along with problems in tariff fixation in certain states undergoing restructuring of power sector, have contributed to the lower growth than expected.

IREDA has been playing a significant role in promoting renewable energy projects in general, and wind power projects in particular. It has attracted bilateral and multilateral financial assistance from the World Bank, GEF, Danish Agency for Development Assistance, KFW (The German Development Bank), and the ADB. Major national financial institutions such as the Industrial Development Bank of India, Industrial Credit and Investment Corporation of India, Industrial Finance Corporation of India, Rural Electrification Corporation, and Power Finance Corporation, have also been financing wind power projects. IREDA's financing norms have been periodically reviewed and reformed in line with the market trends so as to suit the wind farm investor. Another major development has been the entry of central and state power-generating entities such as the National Thermal Power Corporation, National Hydroelectric Power Corporation, and State Power Corporation into the wind sector in India. Other leading public sector units are also in the process of diversifying into the wind sector, and a few have already initiated the development of large wind farms.

Wind pumping

Wind energy has been used for water pumping application for a long time. Wind pumping systems can be used at any location with an average wind speed higher than 10 km/h. In the early 1950s, about 100 Australian 'Yellowtail' machines were imported by the Public Health Department of the Government of India and installed under a project to provide drinking water. During the 1970s and 1980s, several new wind-pump models, such as the NAL-MP series, CAZRI, ANILA, POGHIL, and SAMIR were developed and tested. In the early 1980s, the 'Apoly 12PU500' was designed and fabricated at the Institute of Engineering Technology, Allahabad, with Dutch assistance.

Since 1993, the MNES has also been supporting 3-m diametre geared-type deep-well wind pumps under its demonstration programme. This is a first generation wind pump that has a proven performance record for unmanned operation in Australia, Argentina, Canada, USA, etc.



Map 1 Wind resource in 10 states in India at 50 m above ground

Table I Statewise installation of water pumping windmills under the programme taken up by the MNES from 1993/94

State/Union Territory	*Number of windmills installed* 1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/2000	2000/01	2001/02	*Cumulative windmills installed*
Andhra Pradesh	0	0	0	0	0	1	1	0	0	2
Assam	0	0	0	3	0	0	0	0	0	3
Andaman and Nicobar Islands	0	0	0	0	0	0	2	0	0	2
Bihar	0	0	30	0	12	0	0	0	0	42
Gujarat	0	3	32	36	57	6	86	57	0	277
Karnataka	0	0	3	0	11	0	6	0	0	20
Kerala	0	10	14	20	11	0	12	12	0	79
Maharashtra	0	3	1	0	7	0	7	0	8	26
Rajasthan	0	32	8	32	100	50	0	0	0	222
Tamil Nadu	0	8	2	7	7	5	12	8	0	49
Total	0	56	90	98	205	62	126	77	8	722

Another wind pump supported by the MNES under their subsidy schemes is the 'AV-55' wind pump developed by the Centre for Scientific Research, Auroville (5.5-m diametre, 18-blade, direct-drive). A statewise list of wind pumps supported by the MNES since 1993 is given in Table I.

The MNES has been providing a subsidy of Rs 20 000 for direct-drive windmills; Rs 30 000 for geared-type windmills; and Rs 45 000 for an AV-55 type direct-drive windmill. A total of 854 wind pumping systems have been installed till December 2002, with 61 wind pumps installed in 2002/03.

The target for the Ninth Plan was to install 900 wind pumping systems while the achievement till 31 July 2001 was about 484.

Wind battery chargers

There are many unelectrified sites in India, which are at such a distance from the main grid lines that it would be uneconomical to extend the grid lines to these sites. If the wind speeds are good enough, wind energy can be used at such locations to provide electricity by installing small wind generators with battery storage (also called wind battery chargers or aerogenerators).

The wind battery chargers are being promoted with provisional subsidy for more than a decade now. A statewise list of aerogenerator systems installed since 1993 is given in Table II.

Table II Statewise installation of small aerogenerator systems: 31 March 2000

State/Union Territory	*Small aerogenerator systems installed* (kW) 1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/2000	2000/01	*Cumulative small aerogenerators systems installed*
Andhra Pradesh	0	0	0	4	12	0	0	–	16
Assam	0	0	0	6	0	0	0	–	6
Kerala	0	0	0	0	0	8	8	–	16
Karnataka	0	0	0	0	0	0	25	–	25
Rajasthan	0	0	0	0	4	0	0	–	4
Tamil Nadu	0	0	0	0	8	0	0	16.5	24.5
Total	0	0	0	10	24	8	33	16.5	91.5

Note Till December 2002, small aerogenerator systems of l83 kW capacity had been installed in India, out of which 58 kW had been installed in 2002.

Hybrid systems

Combined use of natural resources such as wind, solar or biomass offers a solution to the problem of variations in energy supply. At many locations these renewable energy sources are complementary, i.e. the solar radiation is low during periods of high wind speeds and vice versa. For example, in many parts of peninsular India, during the monsoon months, solar radiation is low and wind speeds are high, whereas during the rest of the year the radiation is high and the wind speeds are low. The MNES supports deployment of hybrid energy systems through demonstration projects, R&D, training/manpower development and financial incentives/subsidy to users.

The government target was to install an additional 125 kW capacity during the year 2002/03, out of which wind solar hybrid systems of 57.4 kW capacity have been installed by 31 October 2002. Seven wind–solar hybrid systems of 29.7 kW aggregate capacity have been installed by the Maharashtra Energy Development Agency. Two wind–solar hybrid systems of 14.7 kW capacity have been installed in Goa. Another seven small aerogenerators and wind–solar hybrid systems of an aggregate capacity of 50 kW are under installation. A number of proposals, including one 90 kW hybrid system at Elephanta Caves island near Mumbai, are being generated in Maharashtra.

In the Ninth Five-year Plan (1997–2002), the overall target was to install an additional 285 kW from aerogenerator and hybrid systems. In the Tenth Five-year Plan, the target is to deploy 1 MW aggregate capacity of aerogenerator-based systems including hybrid systems with solar, biomass, and diesel. Considerable growth in this sector is expected in Maharashtra. The use of hybrid systems is expected to grow in various locations of the Indian armed forces.

Small hydro power

The small hydro systems harness the energy of running water through turbine, and convert this energy into either DC or AC electricity.

An estimated potential of about 15 000 MW of SHP (small hydro power) projects exists in India. The MNES has created a database of potential sites of SHP projects based on information from various states and on studies conducted by the Central Electricity Authority. There are about 4096 potential sites with an aggregate capacity of 10 071 MW for projects up to 25-MW capacity. Statewise break-up of potential SHP sites is given in Table 1.117. Through efforts made by the MNES during the Eighth Five-year Plan, the SHP programme was upgraded and additional funds allocated for improvement and expansion. SHP development is one of the thrust areas of power generation from renewables by the MNES. It is encouraging development of SHP in the state sector as well as through private sector participation in various states. The 13 potential states that have announced their policies for private sector participation in the SHP sector are Andhra Pradesh, Haryana, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, and West Bengal.

The total installed capacity of SHPs (up to 3 MW) has increased nearly fourfold from 63 MW to 226 MW. As on March 2003 the installed capacity of SHPs, up to 25 MW capacity, is 1509 MW. There are over 187 projects in this range with an aggregate capacity of 521 MW under construction. Table 1.118 gives statewise details of SHP projects installed and under implementation. Other activities under the programme include renovation and modernization of SHP projects, setting up of portable microhydel sets, development/upgradation of water mills, and implementation of the UNDP/GEF Hilly Hydro Project. In India, the Hilly Hydro Project has shown considerable amount of interest in the sector in 13 Himalayan and sub-Himalayan states.

On commencement of the Ninth Plan, the installed capacity up to 3 MW of SHP projects was 144 MW. In the Ninth Plan, a capacity addition of 269 MW was achieved against a target of 130 MW during the Plan period. Keeping in mind the high potential and achievements in the Ninth Plan the overall target of capacity addition of 600 MW from SHP projects has been projected for the Tenth Plan.

Energy from urban and industrial waste

A large quantity of waste is generated due to different human activities which includes domestic, industrial, and agricultural source. The quantity of municipal solid waste from class-I cities alone is about 30 MT and that of liquid waste is about 4400 million m^3. Different categories of municipal waste and their estimated quality available in India is shown in Table 1.119. These wastes are disposed off in an unscientific manner leading to severe environmental degradation. However, the energy generation potential from these wastes is estimated to be 1700 MW which includes 1000 MW from urban municipal wastes and 700 MW from industrial wastes such as dairies, distilleries, pulp and paper, tanneries, food, and fruit processing waste. By the end of the Tenth Five-year Plan, this is expected to increase to 2500 MW (MNES 2002).

The regionwise estimation of energy potential based on the data collected on solid waste and liquid waste generation indicates more than 1000 MW from urban wastes of class-I cities alone and nearly 1000 MW from industrial wastes (Tables III and IV).

Various technologies available for the recovery of energy from waste are sanitary landfilling, pelletization, incineration, and anaerobic digestion. Each technology has its own importance due to its application to specific substrates. In India, anaerobic digestion technology is largely being used for various industrial and municipal wastes.

A national programme on energy recovery from urban, municipal, and industrial wastes was launched by the MNES in June 1995. The Ministry provides financial assistance and interest subsidy for setting-up projects, incentives to local bodies, nodal agencies, and state electricity boards so as to promote and disseminate utilization of wastes for recovery of energy and resources. The total projects of capacity 25 MW have been commissioned since the start of the programme (Table V).

Table III Estimates of power generation potentials of urban liquid and solid wastes (2001/02)

Region(MLD)	*Liquid waste*		*Solid waste*	
	Total liquid waste potential	*Energy* (tonnes/day)	*Total solid waste generated* (MW)	*Energy potential*
South	6000	49	22955	299
North	7904	65	27485	356
West	8920	71	30893	396
East	6914	56	23565	306
Total	29738	241	104898	1357

Table IV Estimates of power generation of some industrial wastes (2001/02)

Industrial sector	*Energy potential* (MW)
Distillery	350
Sugar	285
Paper and pulp	58
Dairy	22
Poultry	44
Starch	40
Slaughter house	150
Others(variable)	–
Total	>1000

Table V Installation of waste-to-energy projects

Year	*Energy projects* (MW)
1996/97	2.750
1997/98	2.000
1999/2000	8.400
2000/01	1.000
2001/02	10.000

A list of projects commissioned under installation and development during 2002/03 is given in Table 1.120.

A national master plan is being prepared by the MNES for the development of waste to energy in India under the UNDP/GEF project on development of high rate biomethanation processes. The main focus of the plan is the treatment of urban and industrial wastes with recovery of energy from 300 class-I cities and selected 36 class-II cities along with 10 industrial sectors with a maximum bioenergy potential which include dairy, distillery, poultry, leather and tanneries, slaughter houses, cattle farms, starch, pulp and paper, sugar, and pharmaceutical.

During the Ninth Plan period the target was to install a total of 42-MW capacity waste-to-energy projects, the achievement till December 2001 was about 17 MW. The Tenth Plan target for this sector is 80 MW.

Solar thermal power generation

The solar thermal power generation technologies offer a basket of technically viable options. In India, work on a 140-MW integrated solar combined cycle power plant is already in the advanced stage at Mathania, Rajasthan. The capacity of the solar-alone plant is 35 MW and the balance of 105 MW is based on re-gasified LNG (liquefied natural gas). The project has a total collector area of 220 000 m^2 and it will generate 800 GWh (out of which contribution from solar power would be about 60 GWh)[2]. The CO_2 emissions mitigated by solar fraction against generation by coal are estimated to be 1.8 tonnes over

[2] http://www.solarpaces.org/berlin%20conference/Presentation-Argawal+Rajan.pdf

25 years of plant life. The RSPCL (Rajasthan State Power Corporation Ltd), a concern wholly owned by the state government, will implement the project. The approximate total cost is 280 million dollars. The World Bank/GEF has agreed to provide a grant of 49 million dollars while the Government of Germany, through the KFW, is to provide a composite loan of 250 million deutsche mark. There were delays as initially naphtha had been chosen as the alternative fuel. However, owing to the change in the international scenario, later alternative fuels were re-examined in detail and re-gasified LNG was chosen as the alternative fuel. For the supply of gas, a MoU has already been signed between RSPCL and GAIL (Gas Authority of India Ltd). Request for proposal had already been issued in June 2002.

Salt gradient solar pond

Solar pond is the only direct solar thermal system with an integrated energy collector and storage at a large scale. Typically, a solar pond consists of three zones—a UCZ (upper convective zone) with a uniform low density, NCZ (non-convective zone) with a gradually increasing density, and LCZ (lower convective zone) also called the storage zone with uniform high density. The solar radiation penetrating the pond is absorbed into the different layers raising the temperature. In a solar pond, thermal convection is suppressed because of the unfavourable density gradient, and hence the hot layers remain hot. Thus, the large mass of saline water in the lower zone gets transformed into a large thermal storage, from which heat can be extracted for useful purposes. This heat could be used for driving the organic Rankine turbine. While the overall efficiency of such a system is only 5%, the advantage is that it operates on both, the direct and diffuse portions of solar radiation. Also, by virtue of having an in-built thermal storage, it can be operated at any time and in any season. But considering the present costs of power generation system for solar ponds, it is preferable to operate the same at a high capacity utilization and not at the peaking mode.

Presently, there is no official policy with regard to the development of STP (solar thermal power) projects in India. In terms of institutional aspects, STP technologies are similar to large hydroelectric projects than other solar technologies. Technologies, such as PVs, are well suited to low demand applications in remote and rural areas whereas most STP technologies are best suited to large-scale developments in megawatts. As a result, the scale of financing needed is much larger and more concentrated, as with large hydro projects. Therefore, at least initially, major funding for STP plants has to come from multilateral/bilateral financial institutions. This would help remove the barrier of the perceived high technical risks, thereby attracting private investments. A lesson learnt from the STP developments in California is the need for an incentive structure that would enable prospective investors to view the operation of the STP facility as an integral part of their business rather than as a mere tax shield or marginal investment. Once technical risks are reduced, commercialization programme can commence.

Thermal applications

Biogas plants

The National Project on Biogas Development was started in 1981/82 for the promotion of family-type biogas plants. The project aimed at providing a clean and inexpensive energy source, producing enriched manure, improving sanitation, in rural areas. Against a potential of 12 million biogas plants, 3.4 million family-type biogas plants were installed till December 2002. Table 1.121 gives the details of family-type biogas plants in each state. The Ninth Five-year Plan had set a target of installing 1 million biogas plants, by December 2001 about 0.8 million plants had been installed.

The community and institutional biogas programme has been undertaken since 1982/83, in order to promote community-sized biogas plants, which can be used for power generation in addition to meeting cooking needs. During the Ninth Five-year Plan, till December 2001, about 1100 community-type biogas plants had been set up as against a target of 800.

Improved cookstove

With an objective to improve the indoor air quality in rural kitchens along with fuel conservation, a National Programme on Improved *chulhas* was initiated in 1986/87. The improved *chulhas* have a thermal efficiency of 20%–35% as compared to the traditional *chulhas*, which have an efficiency of 10%. From 2000/01 the focus of the programme has shifted to the promotion of durable fixed-type improved *chulhas* with chimneys. Till August 2002, over 35 million improved *chulhas* had been installed. The statewise details of installation of improved *chulhas* are given in Table 1.122. The evaluation study carried out by the NCAER (National Council of

Applied Economic Research) in 2001 shows that 57% of the improved *chulhas* are in use. The installation of about 11 million improved *chulhas* by December 2001 has been below the target of 15 million set for the Ninth Five-year Plan.

Solar thermal technologies

The following section discusses the utilization of solar thermal energy for various end-uses.

Solar water heating systems

In India, solar thermal systems are used both in domestic as well as commercial and industrial applications. In the industrial sector, solar thermal energy is utilized for supplying process heat requirements. The resultant savings are mainly in terms of boiler fuel. In the commercial sector, solar water heating systems are used to meet hot water requirements in hotels, hospitals, and hostels. In the domestic sector, the replacement of electric geysers by solar water heating systems results in saving of electrical energy. According to a conservative estimate, the potential for the deployment of solar water heaters is around 140 million m^2 of collector area.

Considering the vast potential and resource availability, the Government of India, through the MNES, provided various interventions in terms of subsidy and other fiscal benefits to promote solar water heating systems. These subsidies were abolished in July 1993 when the technology attained a certain level of commercialization. Instead, provisions were made to avail soft loans through IREDA and some other designated banks.

As on March 2003, the total collector area installed was 700 000 m^2. The trend of installation of solar water heating systems over the years is shown in Figure 3. Solar water heaters can effectively be used in the demand-side management, as approximately 1000 solar domestic water heaters (2000 m^2 of collector area) can contribute to a peak load saving of 1 MW.

There are now 60 manufacturers of solar flat plate collectors who have been approved by the BIS (Bureau of Indian Standards) for their products. The current annual production by these manufacturers is estimated to be more than 70 000 m^2 of collector area. There are many more units spread throughout the country, that purchase these collectors and assemble the solar water heating systems. The after-sale service network is also well developed now in many parts of the country (MNES 2002).

The total collector area installed during the Ninth Plan, through the interest subsidy scheme, was about

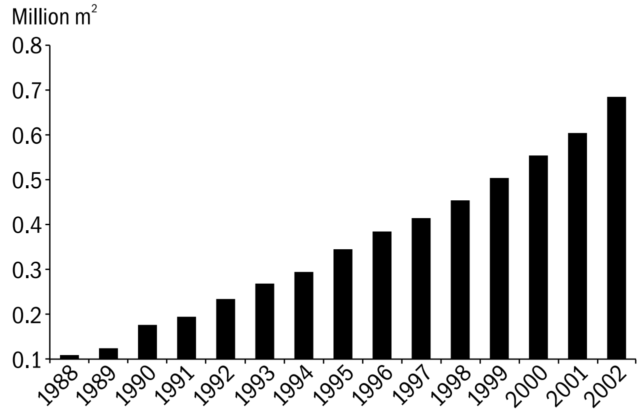


Figure 3 Cumulative installation of solar thermal systems in terms of installed collector area

117 000 m^2 till December 2001 as against the target of 150 000 m^2. The total collector area installed during this period, including the solar thermal systems which were not installed through the interest subsidy scheme, was about 205 000 m^2.

In addition to flat plate collectors, which are presently being used in the solar thermal systems, the evacuated tube collectors, which can deliver thermal energy at higher temperatures, up to 150 °C, have been introduced into the Indian market.

Solar energy for industrial applications

A major portion of thermal energy requirements in the Indian industrial sector lies in the temperature range of 100 °C–250 °C, which corresponds to the medium-temperature range of solar thermal systems. This is supplied either as high-temperature pressurized water or as low-pressure steam. These medium-temperature requirements are met primarily by combustion of fossil fuels such as coal, lignite, and furnace oil. There are 22 major industries where boilers supply process heat in the form of either steam or hot air up to a maximum temperature of 150 °C. These industries include dairy, food processing, textiles, hotels, edible oil, chemical, marine chemicals, bulk drug, breweries, and distilleries.

Solar thermal systems can be employed to meet this demand in a complementary manner. It is estimated that about 60% of thermal energy consumed in the industry is used to process end products. Even if only 10% of this requirement is met through solar thermal systems it will lead to a saving of about 292 400 kilolitres of furnace oil (Dr Rao Associates 1991) a year and a reduction in the resultant CO_2.

Solar cooking

A major component of household energy requirement in India is for cooking. Fuelwood, kerosene, and LPG (liquefied petroleum gas) are the major sources supplying cooking energy, however, there is a gradual shift from fuelwood to LPG for cooking. Solar cooking offers a viable option in the domestic sector. At the micro level, solar cookers facilitate financial savings for the consumer; at the macro level, they help conserve LPG and fuelwood. Of the many types of solar cookers – such as concentrating (dish) type solar cookers, indirect heating-type solar cookers with or without heat storage, and hybrid-type solar cookers – the box type solar cookers have reached the commercialization stage. The solar cooker programme started in India with various promotional efforts including subsidy. In April 1994, the subsidy provided by the MNES on solar cookers was replaced by financial support for promotional activities such as publicity, cooking demonstrations and competitions, and training, etc. Soft loans are presently available for the purchase of solar cookers through some designated nationalized banks. As of December 2002, about 530 000 cookers had been sold. During the Ninth Plan, the total number of solar cookers sold, till December 2001, was about 77 000 against the target of 150 000. The target considered for the box-type solar cookers for the Tenth Plan is to sell about 250 000 solar cookers.

Besides more popular box-type cookers, there are 'concentrating cookers', for example, parabolic dish-type cookers. A parabolic dish-type solar cooker has a concentrator that converges the solar radiation on to a focal point. The cooking pot is placed at the focal point. The advantage of this type of a concentrator system is that it can reach higher temperatures; besides, cooking this way is much faster compared to other box-type cookers. However, the need for frequent tracking, forces the user to work in sunshine under particularly strenuous conditions of heat and glare. In addition to preparing cooked meals, the concentrating-type solar cooker is suitable for sterilizing water, baking, and frying (Box 2).

For higher capacity community cooking requirements, the Scheffler cooker is being promoted in India. It comprises a parabolic dish that reflects solar light into the kitchen and then on to a secondary reflector located below a specially designed cooker. The cooker's temperature can be regulated as easily as in conventional cooker. The Scheffler cooker requires tracking once in the morning and the special automatic tracking feature rotates the parabolic dish to track the sun throughout the day. One of the world's biggest solar cookers is operating at Tirupati in India. The array of Scheffler cookers is used to generate steam, which is used to prepare over 30 000 meals daily. About 60 such community solar cookers have been installed till December 2002.

Rational use of energy in buildings

Increased urbanization is leading to increased demand for buildings. These buildings consume energy for heating, cooling, lighting, and power systems. Through efficient use of energy, the buildings can levy minimal environmental impact, while enhancing users' comfort and productivity. Lighting and air/space conditioning, accounted for major consumption in both the sectors. While energy consumption in the Indian residential sector continues to be dominated by the use of biofuels; a substantial amount of electrical energy is consumed especially in urban households for lighting, and other end uses, for example refrigeration, space conditioning, and water heating and for operating such appliances as television sets, irons, and mixers, etc. The energy demand in the commercial sector is governed by the use of electricity for meeting the requirements for lighting, cooking, space conditioning and refrigeration by shops, hotels, commercial establishments, etc. Suitable technological interventions can substantially reduce energy demand especially during peak demand conditions. It is possible to save up to 20% of energy consumption by application of suitable retrofit measures in existing buildings. The saving

Box 2 Solar steam cooking system at Tirumula, Andhra Pradesh

The world's largest solar steam cooking system has been installed at Tirumula in Andhra Pradesh in October 2002. The system consists of 106 automatic tracked parabolic concentrators arranged in a series and parallel combination, each of 9.2 m^2 reflector area. The system is made of indigenous components with acrylic mirror reflectors having over 75% reflectivity. The system has been designed to generate over 3.5 tonnes steam/day at 10 kg/cm^2 pressure. The steam generated for the solar concentrating cooker is used in the kitchen for cooking. The system has a capacity to prepare food for 15 000 people/day. The solar cooking system has been integrated with the existing diesel boiler for continuous operation round the year. The fuel (diesel) saving from the solar cooking systems is approximately 400 litres/day for approximately 270 days in a year.

potential is maximum in the air-conditioning systems, followed by lighting systems, other electrical systems, and thermal systems. Provisions for incorporation and promotion of energy-efficient measures and renewable energy options have been made within the framework of the National Housing and Habitat Policy, Energy Conservation Act 2001, and the Solar Buildings Programme of the MNES, Government of India. The Energy Conservation Act, 2001 aims at instituting certain statutory measures, which will promote conservation of energy and facilitate its efficient use in various sectors of our economy. In order to effect the same it has set up a statutory authority (Bureau of Energy Efficiency) which would have the function and power to recommend to the central government.

- The norms for process and energy consumption standards for equipment and appliances
- Take suitable steps to prescribe guidelines for energy conservation building codes
- Take necessary measures to create awareness and disseminate information for efficient use of energy and its conservation
- Promote innovative financing mechanisms for energy efficiency projects, specify energy audit criteria
- Prepare educational curriculum on the subject

The objective of the Solar Buildings Programme of the MNES is to promote energy-efficient building designs by optimal use of available solar energy (and other forms of ambient energy) in building energy management. In addition to this, to demonstrate the concept of solar buildings, the Ministry provides partial financial assistance for preparation of DPRs (detailed project reports) and 1.5% of the estimated cost of the building with a maximum of 50 000 rupees for each project. And up to 10% of the building cost with a maximum of 1 million rupees for each project in case of construction of solar buildings.

New technologies

Fuel cells

Fuel cells convert the chemical energy of hydrogen-rich fuels to generate electricity and heat. The conversion is an electrochemical process and does not involve a combustion reaction and thus is not limited by the Carnot efficiency cycle. The applications of fuel cells range from low/zero emission decentralized stationary power generation to highly efficient automotive traction. Four types of fuel cell technologies exist to date which is PEMFC (Polymer electrolyte membrane fuel cell), PAFC (phosphoric acid fuel cell), MCFC (molten carbonate fuel cell), and SOFC (solid oxide fuel cell). However, the current development initiatives are focused around PEMFC for automotive and low-capacity stationary applications, and SOFC for decentralized power generation and cogeneration. Internationally also, the fuel cells are being viewed as an alternate to internal combustion engine for automotive traction. All major automobile manufacturers have an ongoing plan for developing fuel cell vehicles and most of these plans have reached beyond the prototype testing stage. The barriers being foreseen are the high capital cost, lack of long-term performance data and strategy. The current price of the fuel cell systems falls in the range of $3000–5000/kW. The fuel cell technology is expected to be able to compete in high cost, decentralized generation market once it falls below $1500/kW. For the automotive applications, the cost ranges between $50/kW and 200/kW. Stationary power generation is an area where developing countries such as India could concentrate to benefit from the developments in fuel cell technology. The indigenous skills supplemented by knowledge transfer from developed countries and government subsidies for R&D and product development can be used in efficient ways to create the market mechanism and efficiency criteria. The MNES and CSIR (Council of Scientific and Industrial Research) have funded R&D programmes for fuel cell technology. The achievement so far include development of 50 kW PAFC stack by BHEL, up to 1 kW MCFC stack by TERI/CECRI, and 10 kW PEMFC stack by SPIC Science Foundation. The SPIC Science Foundation has also integrated a fuel cell stack into an electric vehicle. In addition, under the New Millennium India Technology Leadership Initiative of CSIR, a 5-kW decentralized fuel cell power pack based on LPG fuel is being developed.

Hydrogen energy

Hydrogen is being termed as the clean fuel which is also a viable option for energy storage. Hydrogen can be produced using conventional as well as renewable energy sources by electrolysis of water. Various research and development projects are under way in India ranging from production, storage, utilization to commercialization.

Alternative fuels for surface transport

The electric vehicle is an environment-friendly option for urban transportation. Batteries in the electric vehicles can be charged by conventional power from renewable energy. The barrier in propagation of electric vehicles is the limited distance which can be covered per charging of battery and inadequate infrastructure for replacement/charging of batteries, and high costs. In order to facilitate faster market penetration of electric vehicles, the MNES provides incentives including subsidy and support to R&D projects aiming efficient batteries, performance evaluation of electric vehicles in field conditions. During 2001/02 around 20 battery-operated vehicles were provided to the state nodal agencies/departments.

In 2002/03, the scope of ongoing demonstration programme on battery-operated vehicles was widened to cover battery-operated passenger three-wheelers and cars (about 250). Battery-operated three-wheelers are operating in Agra, Ahmedabad, Allahabad, Delhi, Kolkata, Lucknow, and Pune.

Geothermal energy

Geothermal energy extracted from geothermal fluids could be used for different applications such as power generation, space heating and so on. There are about 300 geothermal springs in the country, out of which locations in Chattisgarh, Jammu and Kashmir, and Madhya Pradesh can be used for power generation. A geothermal power generation project of 300-kW capacity is planned at Tattapani in Chattisgarh.

Ocean energy

The oceans offer renewable sources of energy in the form of waves, tide, thermal gradient and so on. With the presently available technologies, tidal energy can be harnessed. There are three potential sites of tidal energy in India—Gulf of Kutch and Cambay in the state of Gujarat and the Ganga delta in West Bengal. The fist tidal energy power plant of 3-MW capacity is being planned in the Ganga delta in West Bengal.

Climate change and renewables

With RETs offering options for reducing the greenhouse gas emissions, it is expected that investments as well as technologies will flow to India through mechanisms like CDM (clean development mechanism) or the GEF.

In the year 2002, India announced the ratification of the Kyoto Protocol thus clearing the way for CDM projects in India. The MNES is playing a facilitator's role in the process. It had undertaken different initiatives to promote renewable energy CDM projects in India. A climate change advisory group has been formed by the MNES to decide various enabling activities, which can be undertaken. The MNES has sponsored the following activities to facilitate CDM projects in the field of renewables in India.

- Development baselines
- Development of sustainability indicators
- Possibilities for reducing transaction costs
- Retrofitting of existing programmes of MNES in CDM framework

Different projects have been initiated, with support from the GEF. The 'Development of high rate biomethanation process as a means of reducing greenhouse gas emission' and 'Optimizing development of small hydel resources in hilly regions in India' are under implementation.

Under the GEF-supported project 'Selected options for stabilizing greenhouse gas emissions for sustainable development', following projects in the field of renewable energy were forwarded by the GEF focal point.

- Increased market penetration of solar thermal technologies for low- and medium-grade heating applications in India
- Rural electrification with grid quality power using mini grid in ecologically fragile areas of West Bengal and Orissa
- Use of biomethanation technology for greenhouse gas abatement and generation of energy and manure from industrial, household, and agricultural waste
- Cleaner and efficient technological interventions in small- and medium-scale industries in India, using biomass gasifier systems.

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Chronology of events

April 2002	▪ Wind diesel project for West Bengal ▪ Rajasthan establishes wind power projects
May 2002	▪ Supreme Court orders solar power plant for the Taj Mahal ▪ Andhra Pradesh villages to get solar-powered phones
July 2002	▪ The BHEL's (Bharat Heavy Electricals Ltd) 150-kW solar plant in Lakshadweep
October 2002	▪ Suzlon Energy starts wind turbine export to US ▪ IBRD and IDFC team up to fund clean energy projects
February 2003	▪ The BHEL supplies solar power sets to Gujarat
March 2003	▪ With the aim of helping 18 000 households to finance clean and reliable electricity from solar power, especially in Karnataka, Syndicate Bank and Canara Bank are now offering loans in which the United Nations Environment Programme is buying down the financing cost of photovoltaic solar home systems ▪ The Power Finance Corporation ventures into renewable energy ▪ The Tamil Nadu government has made it mandatory for solar heating systems to be fitted in new constructions of over 1500 square feet to conserve conventional power.