Renewable energy in India: Historical developments and prospects

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ABSTRACT

Promoting renewable energy in India has assumed great importance in recent years in view of high growth rate of energy consumption, high share of coal in domestic energy demand, heavy dependence on imports for meeting demands for petroleum fuels and volatility of world oil market. A number of renewable energy technologies (RETs) are now well established in the country. The technology that has achieved the most dramatic growth rate and success is wind energy; India ranks fourth in the world in terms of total installed capacity. India hosts the world’s largest small gasifier programme and second largest biogas programme. After many years of slow growth, demand for solar water heaters appears to be gaining momentum. Small hydro has been growing in India at a slow but steady pace. Installation of some of the technologies appears to have slowed down in recent years; these include improved cooking stoves (ICSs) and solar photovoltaic (PV) systems. In spite of many successes, the overall growth of renewable energy in India has remained rather slow. A number of factors are likely to boost the future prospects of renewable energy in the country; these include global pressure and voluntary targets for greenhouse gas emission reduction, a possible future oil crisis, intensification of rural electrification programme, and import of hydropower from neighbouring countries.

1. Introduction

India’s commercial energy consumption has been growing fast in recent years keeping pace with high economic growth rate. Table 1 shows the growth in commercial energy consumption of India and a few other selected countries and regions during the period 1995–2005. India had the second highest percentage growth in energy consumption among the listed countries after China during this period.

India depends heavily on coal and oil for meeting its energy demand. The shares of different sources in primary conventional energy consumption in 2005 were: coal – 55.0%; oil – 29.9%; natural gas – 8.5%; hydroelectricity – 5.6%; and Nuclear energy – 1.0% [1]. This pattern of energy consumption is highly problematic for the country. Coal is a polluting fuel and is the biggest source of national greenhouse gas emissions; its use needs to be curtailed for reducing emissions of both greenhouse gases and local air pollutants. India depends heavily on imports for meeting its domestic oil requirements; imports accounted for 72% of India’s total oil consumption in 2004–2005 [2]. As a result of growing import, India’s oil import bill has also been growing rapidly; the bill was INR 1717 billion (US$ 39 billion) in 2006. Growing oil import would imply even greater economic burden in the future and greater energy insecurity.

The above obviously shows the need to reduce India’s dependence on both coal and oil. Currently, India’s per capita energy consumption is very low; in 2003 the consumption was 439 kgoe per capita compared with 1090 kgoe per capita in case of China, 4052 kgoe per capita for Japan and 1688 kgoe per capita for the world [2] Energy consumption of India is therefore expected to continue growing significantly in the future. The only practical options for enhancing energy security and reducing coal consumption as well as oil import bill would be improving efficiency of energy use and promoting renewable energy.

This paper presents the highlights of historical development of renewable energy technologies (RETs) in India and related issues. It also compares the development of RETs in India with developments outside the country and explores their future prospects.

2. Potential of renewable energy sources in India

2.1. Power potential

For many years until recently, the Ministry of New and Renewable Energy (MNRE) estimated the total potential of
biopower in India to be 19,500 MW including 3500 MW of exportable surplus power from bagasse-based cogeneration in sugar mills [3].

Biomass power potential estimates of MNRE have been revised some time ago for the medium term (up to 2032) to be: 16,000 MW from agro-residues; 45,000 MW from plantation biomass from 20 million ha of wasteland yielding 10 metric tonnes/ha/year with 30% efficiency; 5000 MW from bagasse-based cogeneration; and 7000 MW from wastes [4]. More recently, the Indian parliament set up a committee to work as a watchdog for the MNRE. The committee estimated that the total biomass power potential in the country was above 100,000 MW, including 16,000 MW from surplus agro-residues.

The above assumed efficiency of 30% for electricity generation from biomass for the period up to 2032 appears to be too low considering that efficiency of biomass integrated gasification combined cycle (BIGCC) can be up to or above 40%; assuming this level of efficiency for power generation from plantation biomass and agro-residues, the potential from these two sources could be as high as 81,300 MW. MNRE [5] suggests that the area of wastelands and agro-residues, the potential from these two sources could be as high as 81,300 MW. MNRE [5] suggests that the area of wastelands in India to be around 40 million ha. Assuming that 30 million ha could be used for biomass plantation for energy, and efficiency of 40%, the potential of power from plantation biomass and agro-residues in India would be as high as 111,000 MW. Considering 5000 MW from bagasse-based cogeneration and 7000 MW from wastes, the authors estimate that the total potential of biopower in India to be above 123,000 MW.

A recent document of the Planning Commission of India [2] indicates the potential of wood from plantation in wasteland to be 620 Mtoe/year assuming plantation in 60 million ha of wasteland and biomass yield of 20 metric tonnes/ha/year; this may be compared with India’s total estimated primary commercial and non-commercial energy consumption of about 530 Mtoe in 2006–2007. If the wood from 60 million ha yielding 20 metric tonnes/ha/year is used for power generation at 40% efficiency, the power potential of plantation biomass in India would be 360,000 MW. The potential would be even higher if additional plantation options are considered, e.g. plantations by the side of roads, rail tracks, canals and rivers as well as agro-forestry and aquatic biomass. It may be noted that efficiencies of currently used biomass fueled systems such as cookstoves, biomass-fired boilers and furnaces are quite low. Replacing these systems by modern efficient systems can result in significant saving of biomass fuels; these fuels could then serve as additional source of energy for power or heat generation [6].

Thus, although the new estimates of MNES and the parliamentary committee are more realistic compared to the earlier estimate of 19,500 MW, it is likely that actual potential of biomass power in India will be more than 123,000 MW as estimated above.

So far as solar energy is concerned, the MNRE had been indicating the potential of photovoltaic (PV) as 20 MW/square kilometer until recently in official documents, e.g. its annual report of 2004–2005; More recently, the potential of solar power has been tentatively estimated to be 50,000 MW; the basis of this estimation is not quite clear.

Wind power potential in India was initially estimated to be 20,000 MW and later revised upwards to 45,000 MW by MNRE excluding off-shore potential; a potential of 65,000 MW has been quoted by the Planning Commission of India [2] inclusive of off-shore potential. According to Indian wind energy association (INWEA), the potential is 65,000 MW exclusive of off-shore wind. Recently the president of the Indian Wind Turbine Manufacturers Association has claimed that the total wind potential in the country was as high as 100,000 MW.

The potential of small hydro (up to 25 MW) in India is estimated to be 15,000 MW. No reliable estimates of ocean thermal energy conversion, tidal, wave and geothermal energy in India are yet available. The potential of tidal energy has been preliminarily estimated to be about 8000–9000 MW [7,8] in three sites. The power potential of hot springs has been estimated to be about 10,000 MW, although no estimate is available yet, the potential of hot dry rock appears to be very large.

2.2. Other potentials

The estimated potentials of other RETs in India include: family type biogas plants – 12 million; ICSs – 120 million; and solar collector – 140 million square meter [4]. Here again the bases of the above solar collector and biogas plant potential estimates of the MNRE are not clear. Assuming that 25 kg cow dung is needed per cubic meter of gas, and that 75% of cow dung produced in the country could be collected for gas production, TERI [9] estimated India’s biogas potential to be 40 million biogas plants of capacity 2 cubic meter per day. Considering the possibility of biogas production from other animal wastes and industrial wastewater, the biogas potential of the country would be substantially higher. Bhattacharya et al. [10] estimated the potential of biogas production from recoverable animal wastes in India to 1046 PJ/year, which is equivalent to about 60 million digesters of 2 cubic meter capacity.

2.3. Historical development of RETs in India

Promotion of renewable energy in India effectively started with the setting up of a Commission for Additional Sources of Energy in the Department of Science and Technology in 1981. An independent department – the Department of Non-conventional Energy Sources – was set up in 1982; the Department was converted into the Ministry of Non-conventional Energy Sources (MNES) in 1992. Indian Renewable Energy Development Agency (IREDA) was established in 1987 to finance renewable energy projects. The MNES was renamed to MNRE in October 2006. A new and renewable energy policy statement is currently under preparation.

MNRE established a wide range of research, development and demonstration activities, elaborate incentive schemes and state level nodal agencies for promoting RETs in the country. Renewable energy business in India has now grown into a sizable industry as a result of sustained efforts of MNRE and its state nodal agencies, impetus from occasional energy shocks and growing involvement of the private sector.

3. Improved cooking stoves (ICSs)

3.1. Historical development of ICSs in India

According to the Census of India 2001, 72.3% of the country’s 191,963,935 households depend on biomass, e.g. fire-wood (52.5%); crop residue (10%) and cow-dung cake (9.8%). The percentage of
households using biomass for cooking in rural areas, where 72% of the households are located, is 90%; in the urban areas, 26.8% of the households depend on biomass. It has been reported that an average woman spends about 40 min collecting biomass fuels per day in India [11].

The National Programme on Improved Stoves (NPIC) was launched in December 1983 in order to promote efficient use of biomass fuels, reduce pressure on forest resources, reduce indoor air pollution and alleviate the drudgery of collecting biomass fuels. It is reported that over 80 different improved stove models have been developed since then, some of these bearing the mark of the Indian Standards Institution (ISI); at one stage technical back-up units were functioning in 13 states of the country [12]. A wide range of subsidies were introduced, training for entrepreneurs and women users was organised, and publicity and public awareness campaigns were carried out. Table 2 shows indicative features of ICs installed in India.

Fig. 1 shows the historical growth in the number of improved stoves installed in India; a total number of 35.2 million improved stoves were installed by September 2006. The annual ICS installation rate was the highest at about 3 million stoves per year during the period September 1995 to March 2000 corresponding to slightly less than 3 thousand ICs per million people. Installation of improved stoves slowed down significantly after March 2000; in the first 9 months of the year 2001–2002, the number of stoves installed was 700,346 [14], corresponding to an annual rate of slightly below 1 million stoves.

As pointed out by Greenglass and Smith [16], “in 2002 the NPIC was deemed a failure and funding was discontinued; responsibility for continued ICS dissemination was passed to the states.”

3.2. Impact of ICS programme

Although on paper India has installed a large number of improved stoves and hosts the world’s second largest ICS programme after China, the actual impacts and achievements of the programme appear to be far from satisfactory. A survey carried out by National Council for Applied Economic Research (NCAER) in 1995–1996 estimated that only 71% of ICs were in working condition and 60% were in use [17]. According to a 2001–2002 evaluation of NCAER, “of the 11.2 million improved stoves installed between 1996 and 2001, 24.4% were working but not in use and over 18% had been dismantled”, suggesting that less than 60% of the stoves installed during this period were in use [15]. Discarding the possibility of stoves installed before 1996 to be still operating, the total number of stoves operating at the end of 2001 can be assumed to be 6.45 million. Smith [14] assumed that only 7.6 million households were using ICs in 1991–1992. According to ESMAP [18], of the 7 percent rural households that adopted ICs by the end of 2000, most reverted to traditional stoves as the ICs developed cracks or needed spare parts.

As pointed out above, the annual ICS installation rate was the highest at about 3 million stoves per year during the period September 1995 to March 2000. For an assumed life of two years, the number of stoves operating at any time can be estimated to be the number of stoves installed in the last two years. Thus the number of ICs operating in India probably was at peak of about 6 million stoves during this period, corresponding to about 3.14% of the total households. Since installation of improved stoves slowed down significantly after March 2000, it is likely that the number of households using improved stoves at present will be well below 6 million; this implies that of the 124 million households, i.e. about 650 million people of country that depend on biomass fuels for cooking, more than 118 million households (i.e. more than 625 million people) still depend on traditional stoves.

According to the Census of India 2001, the percentages of the total number of households using kerosene, LPG, electricity and biogas for cooking in India were 6.5%, 17.5%, 0.2% and 0.4% respectively; the values for rural areas were 1.6%, 5.7%, 0.1%, 0.6% respectively.

Lack of access of a large number of people to modern energy sources for cooking, and failure of the NPIC to reach the overwhelming majority of them, indoor air pollution is currently the third highest risk to human health in India after malnutrition and water related diseases and above unsafe sex, iron deficiency, tobacco and high blood pressure. It is estimated that pollution from use of solid fuels caused 424 thousand deaths in 2000 in the country [18].

3.3. Comparison with developments outside India

Although some attempts to disseminate ICs have been made in practically all developing countries, significant success has been achieved only in a small number of countries. In China, which hosts the world’s largest ICS programme, more than 185 million improved stoves were disseminated and 75% of rural households had access to such stoves in late 1990s; this is in stark contrast to about 3% or less of total households in India as estimated above. The present dissemination rate of the most successful stove (Anagi Stove) in Sri Lanka is around 300,000 stoves per year, corresponding to about 15 thousand ICS per year per million people compared with peak dissemination rate in India of less than 3 thousand ICS per year per million people in late 1990s.

The Indian ICS programme has also lacked bold and innovative approaches tried in China and Sri Lanka, e.g. household gasifier stoves, which are available commercially in both of these countries, or producer gas supply network, a few hundred of which appear to exist in China.

3.4. Way forward for improved stoves in India

A number of factors appear to have contributed to the failure of ICS programme in India. Shastri et al. [19] noted the lack of impact

Table 2

<table>
<thead>
<tr>
<th>Features</th>
<th>Value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stove life</td>
<td>Less than 2 years</td>
<td>[13]</td>
</tr>
<tr>
<td>Efficiency</td>
<td>20–25%</td>
<td>[14]</td>
</tr>
<tr>
<td>Smoke removal</td>
<td>None or low</td>
<td>[15]</td>
</tr>
<tr>
<td>Cost</td>
<td>INR 170–700</td>
<td>[14]</td>
</tr>
</tbody>
</table>

of the NPIC and attributed this to a number of reasons: absence of quality control; lack of post-construction servicing; absence of accountability for poor performance; and target-, budget-, and subsidy-driven nature of the programme. According to Sinha [17], a large government subsidy was in fact a barrier to its success; e.g. the stove builders were concerned about government specifications in order to avail subsidy for stove building rather than consumers’ preference; the heavy subsidy was a deterrent to private entrepreneurs developing and disseminating their own stoves; the subsidy was used by some households to make better use of the some stove materials like metallic sheets and pipes. Failure to target resource-poor regions for stove dissemination and highlight the health problems created by traditional stoves was among other factors that contributed to the failure of the programme.

With the discontinuation of NPIC, a new phase of ICS dissemination is likely to begin in India. Although no significant development has taken place in the field so far, new players appear to be taking up position. Involvement of NGOs and private sector entities, e.g. Appropriate Rural Technology Institute (ARTI) and Development Alternatives (DA), British Petroleum and Shell Foundation may eventually push the spread of ICSs in the country. ARTI has set a goal of 1.5 million stoves in Maharashtra; Shell Foundation has launched its “Breathe Easy” programme to promote ICSs through involvement of rural micro-enterprises; and British Petroleum (BP) has started marketing an efficient stove fuelled by biomass pellets.

4. Biomass gasifiers

4.1. Historical development of gasifiers in India

Initial work on biomass gasification started in India in early 1980s, although serious development work started only in mid-1980s [20,21]; India launched its national programme for demonstration of gasification technology in 1987. Initially the focus of the activities was on small wood gasifiers to run diesel engines for mainly water pumping and to some extent power generation. The second phase of the programme started in early 1990s with emphasis on power generation and development of larger gasifiers as well as market orientation though reduction in subsidies. The reduction in subsidy resulted in temporary reduction in sales volume and almost total elimination of gasifier use for irrigation [20]. MNES established gasifier action research programmes in five institutes in early 1990s. One of these institutes, Indian Institute of Technology, Bombay played an important role in gasifier development in India by establishing a gasifier test facility. Another institute, Indian Institute of Science, actually developed gasifiers for power generation; its gasifiers are now used significantly in India and have also been exported.

For power generation, gasifiers were normally coupled with diesel engines operating in dual fuel mode until recently. Engines operating on 100% producer gas are now available commercially. Three 250 kW producer gas engines were commissioned at Coimbatore, Tamil Nadu in December 2004 as the first large project installed by September 2006, hosts the largest small gasifier programme of the world. The programme is also much more well established compared with other developing countries, in many of which gasification suffered a setback in 1980s and 1990s, for example, the Philippines and Thailand.

India’s gasifier programme is so far geared towards developing country situations with little or no emphasis on automatic operation; this may be compared with fully automated small gasifiers being introduced by Community Power Corporation in the USA.

India has also been lagging behind in developing and employing advanced gasifier systems, e.g. integrated gasification combined cycle (IGCC), which is probably the most exciting biomass energy and elaborate gas cleaning. However, the problem of disposing polluting water from gas cleaning appears to still exist.

Being propelled by large-scale involvement of private entrepreneurs, the national programme has gained good momentum in recent years and has been playing a key role in electrification of rural areas. Apart from provision of electricity at reasonable rates, biomass gasification systems also develop significant employment in rural areas and contribute to sustainable development if the biomass comes from plantations.

Rice husk gasification serves to generate captive power in rice mills and facilitates productive use of the husk produced in rice mills, which otherwise often creates a disposal problem and pollution from inefficient combustion.

Thermal gasifiers are available commercially in the country, although their acceptance by potential users so far remains rather insignificant.

4.3. Comparison with developments outside India

India, with slightly more than 75 MW of gasifier power capacity installed by September 2006, hosts the largest small gasifier programme of the world. The programme is also much more well established compared with other developing countries, in many of which gasification suffered a setback in 1980s and 1990s, for example, the Philippines and Thailand.

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<tr>
<th>Features</th>
<th>Value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity range</td>
<td>5–1000 kW</td>
<td>[22]</td>
</tr>
<tr>
<td>Indicative capital cost for gas only systems</td>
<td>US$ 1000/kW</td>
<td>See note 1</td>
</tr>
<tr>
<td>Indicative power generation cost</td>
<td>Rs. 3–8 depending on biomass cost and operating hours per year.</td>
<td>See note 1</td>
</tr>
<tr>
<td>Wood consumption (efficiency)</td>
<td>1 kg/kWh; 70% diesel replacement, (20%)</td>
<td>[23]</td>
</tr>
<tr>
<td>Dual fuel</td>
<td>1.5 kg/kWh for 9 kW system</td>
<td>[24]</td>
</tr>
<tr>
<td>Gas only operation</td>
<td>1.2 kg/kWh for 250 kW system</td>
<td>[22]</td>
</tr>
</tbody>
</table>

Note 1: author’s assessment based on different sources.
technology that has been developed and demonstrated in recent years. A private company, Carbona Corporation of USA, was planning a 14 MWe BIGCC plant in Andhra Pradesh; however the project has been aborted due to financing problems.

5. Biomass combustion based power generation and cogeneration

India has been promoting generation of electrical power from biomass fuels using steam turbine-based power generation and cogeneration systems.

Interest in cogeneration in sugar mills started to grow in early 1990s and has attracted particular attention so far. Most sugar mills use traditional cogeneration systems to meet their own process and electricity requirements by using low-pressure (around 32 kg/cm²) boiler-steam turbine systems. By using high-pressure systems and improving efficiency of steam use in sugar mills, a great deal of surplus electricity can be potentially generated for export to the grid [25]. Table 4 shows the major technical features of a bagasse-based cogeneration plant in a sugar mill of capacity 5000 tonnes of cane per day at Rajshree Sugars and Chemicals Limited, Villupuram, Tamil Nadu.

Fig. 3 shows annual installation of biomass power/cogeneration capacity during the period from 1995–1996 to 2005–2006. Installed capacities of different types of biomass based power generation as of September 2006 were: a) grid-connected power generation: agro-residues and plantation biomass based power generation – 466.5 MW; bagasse cogeneration – 571.8 MW; b) off-grid generation: biopower/ non-bagasse cogeneration – 11.5 MW.

Interest in biomass combustion based power generation in grid-connected and off-grid systems has also been growing. These use plantation biomass or agro-residues as fuel. Table 5 shows the major features of an agro-residue fired power generation system located at Kalpaturu Energy Venture Private Limited, Bharatpur, Rajasthan, which is a registered CDM project.

6. Biogas

Initial research and development efforts on biogas technology started in 1920s [26]. The first demonstration unit of floating-drum biogas digester design, popularly known as the Khadi and Village Industry Commission (KVIC) design (or simply the Indian type biogas digester design) was established in 1950. All India Coordinated Biogas Programme (AICBP) was launched in 1975 for large-scale dissemination of biogas plants. A fixed dome biogas digester design, called the Janata biogas plant, was developed in 1978. Demonstration of community biogas plants started in late 1970s. National Programme for Biogas Development (NPBD) was launched in 1981–1982. Deenbandhu biogas plant design, which was an improvement over the Janata biogas plant, was introduced by an NGO in 1984. Biogas programme gained momentum during 1985–1992 partly due to substantial subsidies, which were introduced to promote the technology; annual installation of biogas plants was 160,000–200,000 during this period. Although subsidies for biogas plants were reduced during early 1990s, dissemination of the technology was not much affected. By mid-1990s, biogas technology was well established in India; by 1996, the number of biogas plant designs approved by the MNES was seven. Table 6 shows the characteristic features of small biogas digesters in India [27,28]. Fig. 4 shows the historical growth in the number of family biogas plants in India. The number of such plants installed in the country by September 2006 was 3.89 millions [4].

Some of the installed biogas plants are not operational any more, although it is difficult to reliably establish the percentage of operating plants. Surveys carried out by NCAER and MNES in early 1990s suggest that 66–87% of the plants installed were in use [26]. Although biogas can be used for a number of applications, e.g. cooking, fueling engines and lighting, the most common use in India so far is for cooking. Therefore family biogas digesters are mostly seen currently as providing a convenient energy source for cooking. Building awareness of the potential users about the health benefits of biogas achieved as a result of eliminating smoke from the kitchen would make the digesters more attractive to them. Also, use of slurry as a manure in agriculture or as a source of nutrients in aquaculture would enhance economic viability of the technology. Although the vast majority of biogas plants in India is family-scale digesters based on cow dung, other types of digesters also exist. The number of Community/Institutional/ Night-soil-based biogas plants by the end of September 2006 was 3902.

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**Table 4**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial investment for high-pressure system</td>
<td>INR 80 million</td>
</tr>
<tr>
<td>Operating days</td>
<td>280 days per year</td>
</tr>
<tr>
<td>Generation capacity</td>
<td>22 MW</td>
</tr>
<tr>
<td>Boiler specification</td>
<td>120 tonnes per hour; 87 kg/cm² and 515 °C</td>
</tr>
<tr>
<td>Biomass fuel</td>
<td>Mill-generated bagasse</td>
</tr>
<tr>
<td>Surplus capacity and electricity</td>
<td>15 MW; 40.1 million kWh in 2005–2006</td>
</tr>
<tr>
<td>Revenue from power export</td>
<td>INR 125.3 million in 2005–2006</td>
</tr>
<tr>
<td>CO₂ equivalent GHG emission reduction</td>
<td>80,831 tonnes per year</td>
</tr>
</tbody>
</table>

**Table 5**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation capacity</td>
<td>8 MW</td>
</tr>
<tr>
<td>Boiler capacity</td>
<td>40 tonnes per hour</td>
</tr>
<tr>
<td>Steam condition</td>
<td>45 bar, 425 °C</td>
</tr>
<tr>
<td>Biomass</td>
<td>Mustard crop residue from 25–50 km radius</td>
</tr>
<tr>
<td>Biomass use</td>
<td>90,500 tonnes per year</td>
</tr>
<tr>
<td>CO₂ equivalent emission reduction</td>
<td>44,480 tonnes per year</td>
</tr>
</tbody>
</table>
Slurry production 80–100 l per day
Gas production 2 cubic meter per day
Hydraulic retention 40 days
Initial cost INR 12,000
Number of cattle 4–6
Cow-dung use 40–50 kg per day

7. Solar thermal energy in India

The solar thermal applications in India so far are mostly limited to water heating and cooking. Limited interest in a few other technologies also exists, e.g. drying, solar pond, and desalination.

7.1. Historical development

A subsidy-based solar thermal programme was launched in India in 1984 and continued up to 1993. Government support for the technology in the form of subsidy, demonstration, and training led to development of a substantial manufacturing base in the country and its steady, albeit slow, growth. Capital subsidy was removed and provision for soft loan was introduced in 1994 [29]; however, this did not significantly affect the growth of the technology. Growth of solar water heating was slow in India until recently; the cumulative installation of solar water heaters by the end of December 2004 was about 1 million square meter of collector area. Growth of solar water heating has increased quite significantly in the last two years; the cumulative collector area increased by 66% after 2004 to 1.66 million square meter at the end of January 2007.

One solar thermal application in which India appears to be the world leader at present is cooking. About 600,000 family solar cookers have been installed in the country so far; most of these are of box type, the number of dish type being about 6000. Apart from outdoor family type cookers, concentrating community cookers have been introduced in recent years; 74 community solar cookers have been sold/installated in the country till the end of June 2006.

The size of the community cookers varies widely, ranging from single concentrator systems used for cooking meals for 30–50 persons and to multiple concentrator systems, which produce steam for cooking food indoors. The biggest multiple concentrator system so far is used to cook for 15,000 persons in a temple complex.

7.2. Techno-economic and environmental aspects

Solar water heaters used in India mostly use flat plate collectors, typically having selectively coated copper absorber plate of area 2 m² bonded with copper riser tubes; evacuated tube type of collectors has also become available in recent years but are not commonly used. Introduction of solar collector testing standards by the Bureau of Indian Standards (BIS) provides quality assurance of solar collectors manufactured in India. At present, there are more than 70 manufacturers approved by BIS.

Table 7 shows the main features of household solar water heaters used in India [30].

7.3. Impact and way forward

Deployment of solar water heaters in India remains quite low until today. As pointed out by Milton and Kaufman [31], electric water heating is the preferred option for most people living in areas connected to the grid. However, considering the rising cost and shortage of electricity, as well as thermodynamic irrationality of using electricity for low temperature applications, it is likely that solar water heating will find growing acceptance in the future.

Solar cookers are technically mature in India. Community solar cookers could be considered for meeting the cooking needs of 40–15000 people; considering the number of residential schools, institutional kitchens, temple complexes, hotels, hospitals, police and armed forces kitchens, etc. in the country, the potential of future growth is significant.

The other solar thermal technologies, e.g. drying, absorption cooling/refrigeration and desalination have found minimal application so far; growth in their deployment is also expected in the future.

7.4. Comparison with developments outside India

Although India started promoting solar water heating more than 25 years ago, the actual installation so far is only about 1% of the ultimate potential. The total installed solar water heating capacity in India at the end of 2005 was only 1.3% of the total installed capacity worldwide. Because of increase in heater installation rate in the last two years, the share of solar water heating capacity addition in India in the recent past was slightly higher; the share was 2.1% in 2005.

Most water heating applications in India are in the commercial and industrial sectors; the household sector accounts for only 20% of all installations. This is contrast with Europe, where use of solar water heaters is mainly in the household sector.

Table 7

<table>
<thead>
<tr>
<th>Parameters/construction features</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>2 m²</td>
</tr>
<tr>
<td>Type</td>
<td>Flat plate</td>
</tr>
<tr>
<td>Absorber material</td>
<td>Copper</td>
</tr>
<tr>
<td>Surface treatment</td>
<td>Selective coating</td>
</tr>
<tr>
<td>Insulation</td>
<td>Glass wool/PUF</td>
</tr>
<tr>
<td>Transparent cover</td>
<td>Hardened/tempered glass</td>
</tr>
<tr>
<td>Casing</td>
<td>Aluminum/mild steel</td>
</tr>
<tr>
<td>Storage tank</td>
<td>Stainless steel/polyethylene/copper</td>
</tr>
<tr>
<td>Efficiency</td>
<td>~60%</td>
</tr>
</tbody>
</table>

Source: [30]
The solar water heaters installed in India are mostly of flat plate collector type; use of evacuated tube type of collectors is insignificant so far. This is in stark contrast to the situation in China, where the majority of solar water heaters is of evacuated tube type; also, although there are no direct government subsidies for heater manufacturers or end-users, the solar water heating market is much better established in China.

The cost of solar water heaters in India is rather high compared with China. As noted by Milton and Kaufman [31], the cost of flat plate collectors in China is around US$ 1.45 per liter capacity compared with US$ 3.5 per liter capacity in India.

7.5. Solar PV

IREDA launched its Solar PV development programme in 1993–94 in order to promote commercialization of the technology based on experience gained since the initiation of India’s national solar PV programme in the mid 1970s. Production of PV modules and cells has been increasing steadily, although rather slowly, since then.

India’s production of solar module increased from 9.5 MW in 1998–1999 to about 40 MW in 2004–2005 corresponding to 4.2-fold rise in 6 years. Although the growth is impressive, it is low compared with the global growth in recent years. Thus world PV production increased from 287.7 MW in 2000 to 1759 MW in 2005 corresponding to a 6.1-fold rise in five years [32].

Global demand for PV modules has been driving up their export from India. Also, export has been growing faster compared with PV production; the percentage of cumulative production exported was 35% in 2001, 43% in 2002, 50% in 2003, 55% in 2004 and more than 60% in the year 2005. Cumulative PV module production in India by the end of December 2005 was 245 MW; about 160 MW of this was exported.

PV systems are used for a wide range of applications in India. In 2002–2003, sectorwise deployment of PV modules in MW was: export – 46; telecommunication – 16.3; home light – 9.1; lantern – 4.9; pump – 6.6; power plant – 3.8; street light – 3.5; others – 16.8 [33].

The pace of PV installation in India has slowed down considerably in recent years. In the year 2004–2005 only 16,530 solar home systems (SHSs) were installed compared with 58,239 in 2003–2004. The cumulative installation was 52,102 in the year 2003–2004; it increased by only 5% to 54,659 at the end of the year 2006. The cumulative capacity of all PV installations in the country in 2005 was nearly the same as that in 2004.

7.6. Comparison with developments outside India

One major application of PV in India is provision of electricity in off-grid rural areas; the share of all off-grid rural applications of PV including pumping, lantern, SHS, and street lights was 27.5% in the year 2002–2003. This may be compared with 10.6% share of off-grid rural application in the total World PV application in 2003 [34].

Grid-connected PV is the most important application of PV worldwide; the share of this application was 57.4% of the total world PV capacity installed at the end of 2005. The use of grid-connected PV in India is very low until now. The total installed capacity of grid-connected PV in India at the end of December 2006 was 2.74 MW, which was about 3% of total PV installation in the country.

While building integrated PV is an established technology in many developed countries, it is in initial stage of demonstration in India.

One distinctive feature of PV industry in India is its export focus. The fact that PV export accounts for about two-thirds of the cumulative production so far and that it has been growing faster than production implies slower in-country installation of solar systems.

Although India initiated its PV programme about 30 years ago, the actual progress in promoting PV application in the country compared with the rest of the world is far from satisfactory. The cumulative installation of PV systems in India at the end of 2005 was about 85 MW, amounting to only 1.57% of the world’s cumulative installation of 5400 MW [35].

7.7. Impact and way forward

Rural household and remote areas are a major focus of PV programme in India. This has resulted in promotion of a large number of small PV systems, e.g. SHSs, solar lanterns, etc. However, in spite of the significant numbers of SHSs, solar lanterns and solar power plants installed so far, the total number of people who have benefited by these installations and the total installed capacity of these installations remains low. The situation may improve in the near future as a result of the national goal of electricity for all by the year 2012 since PV will be one of the major options for electrification in some of the very remote and inaccessible villages.

PV manufacturing in India is set to grow significantly in the near future with a number of manufacturer ready to expand production capacity or establish new production lines. The leading Indian Manufacturer, Tata BP, currently has a cell manufacturing capacity of 52 MW after the establishment of a 36-MW solar PV production line in early 2007; according to a recent press release of the company, the production capacity will rise to 128 MW in 2007–2008 and to 300 MW by 2010.

Another manufacturer, Moser Baer has inked a technology partnership with US-based Applied Materials for establishing a thin film solar modules manufacturing facility. It plans to start with a capacity of 40 MW initially and increase the capacity to 200 MW by 2009.

Solar Semiconductor, with offices in USA and India has signed a contract for the purchase of a state of the art module manufacturing line. The capacity of the new plant will be initially approximately 50 MW but may increase to 100 MW within a year of the installation of the first line.

8. Small hydropower (SHP)

8.1. Historical development

India has one of the world’s largest irrigation canal networks of the world with thousands of dams. The Himalayan ranges in the north have numerous rivers and streams with perennial flows. Considering the fact that small hydropower projects can provide a solution for the energy problem in remote hilly areas where extension of grid system is comparatively uneconomical, promoting small and mini hydro projects is one of the objectives of hydropower development in India.

Indian history in SHP developments is more than a century old; the first project of 130 kW was commissioned in the hills of Darjeeling in 1897. This was followed by Sivasamudram project of 4.5 MW in Mysore district of Karnataka in 1902. A 3 MW plant was established at Galgoi in Mussoorie in 1907, and a 1.75 MW plant was established in 1914 at Chaba near Shimla. Some of these nearly 100-year old plants are reported to be still functioning properly. Later, between 1930 and 1950, some low head plants were installed on a number of canals on the river Ganges.

MNRE has set up an Alternate Hydro Energy Centre (AHEC) at University of Roorkee in the year 1982 to promote SHP. MNRE has been responsible for small and mini hydro projects up to 3 MW station capacity since 1989. From 1989 to 1993, the thrust of the
programme was on setting up of demonstration projects in various States to create interest of State Governments and electricity boards to set up SHP projects. For this purpose, capital subsidy of up to 50% of the cost of project subject to a maximum of INR 250 million per MW was provided. During 1993–94, keeping in view the overall policy of Government of India to encourage private sector participation in the field of power generation, the thrust of SHP programme was also shifted to encouraging private sector to set up commercial SHP projects.

IREDA started financing small hydro projects from the middle of Seventh Five Year Plan (1985–90). Hydropower plants of capacity up to 25 MW were brought under the purview of MNES in 1999–2000. Estimated technical potential of small hydropower (up to 25 MW) in India is about 15,000 MW out of which about 1826 MW has been installed as on December 2006 from 556 projects; in addition, 203 SHP projects with an aggregate capacity of 468 MW are under implementation.

In addition to modern hydro turbines, water wheels, commonly known as ‘gharats’, have traditionally been used in the Himalayan regions for rice hulling, milling of grain and other mechanical applications. New and improved designs of watermills of capacity 3–5 kW have been developed for mechanical as well as electricity generation. One Indian state, Uttarakanchal, has taken a lead in setting up electricity generating watermills and over 300 such watermills have been installed in remote and isolated areas of the state.

8.2. Techno-economic aspects

India has well-established manufacturing base for small hydro equipment; there are over 8 manufacturers in the country manufacturing/supplying various types of turbines, generators, and control equipment.

In general, the capacity utilization factor (CUF) of SHP plants depends on location, e.g. hilly or non-hilly areas. In some states of India, the factor can be as low as 30%. The factor normally varies from year to year because of varying climatic and hydrological conditions. The factor is low in case of off-grid micro-hydro installations, where the load may exist only for a few hours per day and water flow reduces significantly during the dry season. The SHPs based on the drops of irrigational canals may have a better CUF since the discharge in these irrigational canals does not change much. Normally SHP plants have to be shut down for about a month during the rainy season due to high silt and debris in water [36]. Capital cost of SHPs per kW varies widely depending on capacity, and quality and origin of equipment. Based on review of a number of plants in India, Nouni et al. [37] found that the cost for 50 kW projects was in the range INR 97,000–181,000 per kW; for 100 kW projects, the cost was in the range INR 80,000–177,000 per kW. The cost of power generated varies depending on capital cost and CUF; Nouni et al. [37] estimated the cost of power generated to be in the range INR 5.7–8.3 per kWh for 20–100 kW plants for a CUF value of 40%.

8.3. Comparison with developments outside India

India’s small hydropower potential and installed capacity so far are small compared with the rest of the world. India’s installed capacity at the end of 2005 was 1747.98 MW compared with 66,000 MW for the world as whole. Growth of India’s small hydropower capacity in recent years has also been slow compared with the growth globally; the growth of SHP in 2005 over 2004 was 3.25% in India compared with 8.2% globally. India’s share in global capacity addition in 2005 was only 1.1%.

8.4. Way forward

As the government intensifies efforts to electrify remote hilly areas, it is expected that SHP will get a boost in the country, particularly in areas where extension of grid would not be feasible. Income generating and productive activities based on the use of electricity from SHP plants would also improve CUF and reduce cost of electricity generation. Considering the importance of employment generation in remote areas and reducing per unit cost of electricity, this would be an important option to pursue.

9. Wind power generation

9.1. Historical development of wind power in India

Work on wind energy started in India at low key in 1960s; a 4.9 m diameter conventional multi-vane wind mill was developed at National Aeronautical Laboratory (NAL) in mid-1960s. Sail-type windmills were developed under a project initiated by NAL during 1976–1977. The initial application of windmills was mostly for supplying irrigation water. A landmark “Wind Energy Data Handbook” was published by the Department of Non-conventional Energy Sources (now the MNRE) in 1983. India initiated a national wind power programme in 1983–1984 with three components: wind resource assessment, demonstration projects and industry-utility partnership. An extensive Wind Resource Assessment was launched in 1985; so far, five volumes of the Handbook on Wind Energy Resource Survey have been published.

Though incentives and market-oriented policies existed during the late 1980s, private sector participation in wind power generation effectively started only after the announcement of the ‘private power policy’ of 1991. This ultimately led to successful commercial development of wind power technology and substantial additions to power generation capacity in the country. The Indian wind industry was placed fourth in terms of total installed capacity in the world by the year 1993. A short-term decline of wind power in India started in 1996 as a result of changes in government policies, including introduction of Minimum Alternate Tax (MAT) in the year 1995–1996, that made the incentive package less attractive. As a result, India’s wind power programme fell back to fifth position after the United States, Germany, Denmark, and Spain in the year 1999. To overcome the problem of falling profitability of private wind farm operations in the country (in the mid-1990s, 96–98), some states started supporting the wind power companies and investors with liberal policy initiatives. The wind energy situation started to improve in 1999 and the upswing is still continuing. Technological maturity and introduction of suitable machines for the Indian conditions resulted in overall higher capacity utilization. In the year 2005 India again got back to fourth position in the world beating Spain. The cumulative installed wind power capacity in India at the end of 2006 was 6270 MW.

Table 8 shows the growth of installed capacity and capacity addition of wind power in India as well as India’s share in global capacity addition. The capacity added in 2005 and 2006 was 1454 MW and 1836 MW respectively.

9.2. Techno-economic aspects

Indicative techno-economic parameters of wind turbines are shown in [39] Table 9. Initial capital cost depends on the technology. CUF depends on both technology and the nature of local wind resource; improvements of wind power technology and better site selection have been improving the average CUF in the
country in recent years. The generation cost strongly depends on the local wind resource, being lower for higher average wind speed.

9.3. Comparison with developments outside India

Wind energy is one area in which India has managed to keep pace with developments in the world as a whole by maintaining its position in the 4th or 5th place for more than a decade.

While India had to depend on imported turbines in the 1990s, the local manufacturing capacity has improved tremendously in the last 15 years; it has also started exporting turbines in recent years.

Although large turbines are also manufactured in the country, relatively small turbines have significant share in the total installed capacity. Table 10 shows the share of different turbine sizes in the cumulative capacity till March 2006.

9.4. Way forward for wind power in India

With a wind energy association and a wind turbine manufacturers’ association promoting the cause of wind energy, it is likely that wind energy will develop faster in India compared with other RETs for power generation.

Because of well-established manufacturing base, reliance on imported turbine and components is expected to diminish and export is expected to grow in the future.

Off-shore wind has so far remained an unexploited resource in India. India’s long coast-line is likely to offer a large potential; proper assessment and development of this potential would offer challenges and new opportunities to India’s wind energy industry.

10. Highlights of achievements and failures

India embarked on renewable energy development in early 1980s as pointed out above by establishing dedicated government entities to provide incentive and remove barriers. Provision of detailed incentives and subsidies created a conducive environment that supported market development of a number of RETs.

Table 8
India’s share of global wind power capacity addition.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cumulative installed capacity in India</th>
<th>Capacity addition in India</th>
<th>India’s share of global capacity addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>79</td>
<td>40</td>
<td>8.3%</td>
</tr>
<tr>
<td>1994</td>
<td>185</td>
<td>106</td>
<td>21.3%</td>
</tr>
<tr>
<td>1995</td>
<td>576</td>
<td>391</td>
<td>19.5%</td>
</tr>
<tr>
<td>1996</td>
<td>820</td>
<td>244</td>
<td>14.8%</td>
</tr>
<tr>
<td>1997</td>
<td>940</td>
<td>120</td>
<td>7.8%</td>
</tr>
<tr>
<td>1998</td>
<td>992</td>
<td>52</td>
<td>2.1%</td>
</tr>
<tr>
<td>1999</td>
<td>1095</td>
<td>103</td>
<td>3.0%</td>
</tr>
<tr>
<td>2000</td>
<td>1167</td>
<td>72</td>
<td>1.7%</td>
</tr>
<tr>
<td>2001</td>
<td>1407</td>
<td>240</td>
<td>3.7%</td>
</tr>
<tr>
<td>2002</td>
<td>1702</td>
<td>295</td>
<td>4.4%</td>
</tr>
<tr>
<td>2003</td>
<td>2483</td>
<td>781</td>
<td>8.51%</td>
</tr>
<tr>
<td>2004</td>
<td>2980</td>
<td>497</td>
<td>6.53%</td>
</tr>
<tr>
<td>2005</td>
<td>4434</td>
<td>1454</td>
<td>12.8%</td>
</tr>
<tr>
<td>2006</td>
<td>6270</td>
<td>1836</td>
<td>12.1%</td>
</tr>
</tbody>
</table>

Source [38] and MNRE Annual Reports.

However, in the long run the dedicated agencies appear to have indirectly hindered integration of renewable energy in mainstream energy planning; this is reflected by the fact that targets regarding contribution of renewable energy in national energy supply and power generation have been considered only in recent years. This was compounded by the systematic under-estimation of the potential of renewable energy as indicated above, which obviously implies an under-estimation of its importance. Such under-estimations (e.g. in the case of biopower) and lack of firm figures (e.g. in the case of solar energy and other renewable energy sources) obviously created the impression that renewable energy had only a low potential in the country and could be best considered for small-sale systems in remote and rural areas and indirectly excluded renewable energy from being considered a main component of national energy supply.

RETs that are now well established in India include solar PV, solar thermal, wind, biogas, biomass for power and heat generation as well as cogeneration and small hydro. Development of a few technologies in India was particularly successful, e.g. small gasifiers and wind power. The success in these cases was largely due to well-coordinated efforts by all major stakeholders, e.g. MNRE, IREDA and the private sector. On the other hand growth of some RETs, for example improved stoves and biomass densification appears to have slowed down in spite of tremendous potential. Considering the record growth worldwide, the pace of application of solar PV has been rather slow in India in recent years.

Lack of coordination among different concerned entities led to failure to trigger large-scale early development in case of some technologies, e.g. use of ethanol as a fuel for internal combustion engines, early research and development work on which was carried out rather in isolation in the Indian Institute of Technology, Delhi in 1980s or Stirling engines, more than one hundred of which were field-tested in India by a private company around 1990.

Development efforts on some important technologies have not yet been initiated in India; these include cellulosic ethanol and hot dry rock geothermal resources. The Indian renewable energy programme is also characterised by notable lack of promotion and interest in certain promising technologies, e.g. BIGCC and cofiring. BIGCC is probably the most exciting biomass energy technology that has emerged/matured in recent years. Cofiring of coal and biomass in utility boilers is well established in many developed countries, particularly Europe and is an easy option for promoting efficient use of biomass. Abandoning a proposed integrated solar combined cycle project in Rajasthan has been a setback to development of solar thermal power in the country.

Box 1 highlights some of RETs in which India has lagged behind other countries and regions. Interest in alternative liquid fuels, e.g. ethanol and biodiesel has grown in India only recently.

11. Prospects of renewable energy in India

Although the emphasis on renewable energy in India has been growing, aggressive policies, targets and work programs for
promoting RETs are still lacking. According to a document of the Planning Commission of India [2], the projected installed capacities of renewable energy based power generation in India in 2031–2032 in the most optimistic scenario are: hydro – 150,153 MW; onshore wind – 32,141 MW; wind offshore – 1200 MW; solar – 10,000 MW; biomass gasification – 1200 MW; biomass combustion – 50,000 MW. This would amount to a total of 243,494 MW from the renewables out of a total generation capacity of 700,703 MW in 2031–2032; the total contribution of new renewable energy sources would be 122 Mtoe, with hydro providing 35 Mtoe and the other sources contributing 87 Mtoe. In comparison, the contribution of crude oil will be 350 Mtoe and total commercial energy consumption will be 1351 Mtoe in this scenario.

The above scenario obviously does not consider the possibility of any large-scale deviation from the current pattern of global energy supplies. However, the following factors may particularly enhance the prospects of renewable energy in India.

### 11.1. Growing oil crunch

India depends heavily on imported oil for meeting its liquid fuel demand; India imported about 65% of its oil requirement in 2000; it is projected that the oil dependence will grow to 94% in the year 2030 [40]. The growing import and soaring oil import bill are likely to accelerate renewable energy development in the country. It is likely that the world oil supplies will see some turbulent times in the years ahead; a number of studies suggest that world oil production will peak in the not-so-distant future. A recent review of literature on this topic quoted 12 studies of which suggest that the oil peak would occur around 2010, implying that an unprecedented global energy crisis may break out in a few years [41]. The growing awareness regarding this possibility is likely to further intensify renewable energy development in India and other countries, which depend heavily on imports for meeting their liquid fuel requirements.

It is likely that prospects of ethanol and biodiesel, which are the most promising renewable options for substituting fossil liquid fuels, will get significant boost as a result of the growing uncertainty regarding world oil supplies.

### 11.2. Rural electrification

In April 2005, the government of India launched Rajiv Gandhi Grameen Vidyutikaran Yojana – a scheme to electrify 125,000 unelectrified villages and giving access to 78 million rural households in five years. By December 2006, a total of 19,758 villages were electrified; full rural electrification is likely by 2012. There are about remote 18,000 villages in the country that cannot be electrified in the conventional manner by extending the grid; these villages will be mostly electrified using RETs. This will provide a significant opportunity to PV, micro-hydro and biopower technologies in the coming years.

### 11.3. Hydropower and regional collaboration

Meeting the growing energy demand will require a great deal of government effort in the future. One renewable energy option that may come handy for India is its hydropower, the potential of which is 148,700 MW in terms of installed capacity. The capacity developed at the end of September 2003 was 31,800 MW. The government launched in 2003 a “50,000 MW” Hydro-electric Initiative with the aim of installing 50,000 MW of hydropower capacity by 2017. Further development of hydropower will however be slow after 2020 as most of the favourable sites will have been developed by then [42].

Imported hydropower from Bhutan, Nepal and Myanmar would also be particularly important for India. All these countries have substantial hydro potential, i.e. 16,000 MW, 42,000 MW and 37,000 MW in Bhutan, Nepal and Myanmar respectively. Current use of hydropower in these countries is quite low. With the commissioning a 1020 MW plant in July 2006, the total installed capacity of hydropower in Bhutan reached 1488 MW. With maximum domestic demand of 130 MW, most of the hydropower is exported to India; the power sector is expected to contribute over 60% of government revenue after 2007. Developing the surplus hydropower potential in Bhutan would be a win-win proposition for Bhutan and India.

In Nepal, only about 550 MW of its huge hydro potential has been installed so far; it is projected that the peak demand in the country will be 1820 MW in the year 2020; this is only 4.3% of the total viable hydro potential of the country. The current hydro capacity in Myanmar is around 390 MW. Thus, development of the remaining hydropower potential in Myanmar and Nepal can contribute substantially to India’s growing electricity demand after meeting national requirements of both these countries.

In spite of great potential, hydropower development has remained very low in Bhutan, Myanmar and Nepal because of a variety of factors including political instability. The process of hydropower development for export has already started in Bhutan, the most politically stable of these countries. It is expected that such development will start taking place in Myanmar and Nepal as the economic benefits of hydropower export become clear and established. However, as and when hydropower development starts gathering momentum, other countries, e.g. China in case of Nepal and Thailand in case of Myanmar, will also become actively interested for importing hydropower. India has to follow a proactive and positive approach to avail significant fractions of the growing hydropower market in the region.

### 11.4. Mitigating greenhouse gas emission

With EU recently deciding to reduce greenhouse gas emissions by 20% below 1990 level or even by 30% if others join, pressure will grow on the major developing countries, including India, to initiate actions for reducing their own future emissions compared with
their business as usual scenario. The emission reductions will obviously mostly come from substituting fossil fuels by renewable energy and improving efficiency of energy use. Thus, the growing global concern regarding climate change is expected to serve to promote renewable energy in India.

12. Concluding remarks

India’s energy consumption is poised to increase rather rapidly in the years to come for supporting and sustaining the economic growth that the country is now enjoying.

Meeting the growing energy demand based on the current pattern of energy supply, which is characterised by heavy dependence on coal and imported oil, will become increasingly difficult in view of the needs to keep GHG emissions and crude oil import bill low. Thus the importance of renewable energy in the case of India is likely to grow monotonically in the future.

In spite early initiation of renewable energy programmes, India lags behind certain other countries and regions in the case of some RETs. The role of renewable energy in future energy supplies was probably under-estimated because of lack of reliable potential estimates of most of the renewable sources; this was compounded by the fact that the potential of some of the sources, for example biomass was grossly under-estimated.

India has the world’s largest small gasifier programme and the second largest biogas and ICS programs. However, a large number of the installed biogas plants are not in use any more; of the 35 million ICSs installed so far, it is estimated that less than 6 million are in use at present.

Solar thermal and PV systems are technically well established in India. However, their installation has been rather low in comparison with certain other countries, regions and world as a whole.

Programmes on alternative liquid fuels (e.g., ethanol and biodiesel) have been launched in India only recently. Given the growing interest in these fuels worldwide and India’s heavy dependence on imported oil, it is likely that interest in these fuels will grow rapidly in the country.

India’s most successful renewable energy programme so far is wind power generation. Involvements of the private sector, enabling environment created by the government and low cost of wind power have contributed to the success of wind power in the country.

Some emerging and established promising RETs are largely missing in the portfolio of technologies being promoted in India. These include BiCICC, cofiring, cellulosic ethanol, Stirling Engine, off-shore wind energy generators, etc. Considering the long coastline of the country, there is also a need to reliably estimate the potential of OTEC, wave and tidal energies in the country. For renewable energy to play a role commensurate with its large potential, it would be important to initiate activities to transfer, further develop and promote all promising RETs in the country.

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