

**BIOMASS ENERGY IN INDIA:
TRANSITION FROM TRADITIONAL TO MODERN**

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Published in The Social Engineer, Vol. 6, No. 2

STATUS OF BIOMASS ENERGY

Biomass materials are used since millennia for meeting myriad human needs including energy. Main sources of biomass energy are trees, crops and animal waste. Until the middle of 19th century, biomass dominated the global energy supply with a seventy percent share (Grubler and Nakicenovic, 1988). Among the biomass energy sources, wood fuels are the most prominent. With rapid increase in fossil fuel use, the share of biomass in total energy declined steadily through substitution by coal in the nineteenth century and later by refined oil and gas during the twentieth century. Despite its declining share in energy, global consumption of wood energy has continued to grow. During 1974 to 1994, global wood consumption for energy grew annually by over 2 percent rate (Figure 1). Presently, the biomass sources contribute 14% of global energy and 38% of energy in developing countries (Woods and Hall, 1994). Globally, the energy content of biomass residues in agriculture based industries annually is estimated at 56 exajoules, nearly a quarter of global primary energy use of 230 exajoules (WEC, 1994).

ADVANCEMENTS IN BIOMASS ENERGY TECHNOLOGIES

Technological advancement in biomass energy is derived from two spheres - biomass energy production practices and energy conversion technologies. A rich experience of managing commercial energy plantations in varied climatic conditions has emerged during the past two decades (Hall et al, 1993). Improvements in soil preparation, planting, cultivation methods, species matching, bio-genetics and pest, disease and fire control have led to enhanced yields. Development of improved harvesting and post harvesting technologies have also contributed to reduction in production cost of biomass energy. Technological advancements in biomass energy conversion comes from three sources - enhanced efficiency of biomass energy conversion technologies, improved fuel processing technologies and enhanced efficiency of end-use technologies. Versatility of modern biomass technologies to use variety of biomass feedstock has enhanced the supply potential. Small economic size and co-firing with other fuels has also opened up additional application.

Biomass integrated gasifier/ combined cycle (BIG/CC) technology has potential to be competitive (Reddy et al, 1997; Johansson et al, 1996) since biomass as a feedstock is more promising than coal for gasification due to its low sulfur content and less reactive character. The biomass fuels are suitable for the highly efficient power generation cycles based on gasification and pyrolysis processes. Steady increase in the size of biomass technologies has contributed to declining fixed unit costs.

For electricity generation, two most competitive technologies are direct combustion and gasification. Typical plant sizes at present range from 0.1 to 50 MW. Co-generation applications are very efficient and economical. Fluidized bed combustion (FBC) are efficient and flexible in accepting varied types of fuels. Gasifiers first convert solid biomass into gaseous fuels which is then used through a steam cycle or directly through gas turbine/engine. Gas turbines are commercially available in sizes ranging from 20 to 50 MW. Technology development indicates that a 40 MW combined cycle gasification plant with efficiency of 42 percent is feasible at a capital cost of 1.7 million US dollars with electricity generation costs of 4 cents/ KWh (Frisch, 1993).

BIOMASS ENERGY IN ASIAN DEVELOPING COUNTRIES

Biomass remains the primary energy source in the developing countries in Asia. Share of biomass in energy varies - from a very high over three quarters in percent in Nepal Laos, Bhutan, Cambodia, Sri Lanka and Myanmar; nearly half in Vietnam, Pakistan and Philippines; nearly a third in India and Indonesia, to a low 10 percent in China and 7 percent in Malaysia (FAO, 1997). In the wake of rapid industrialization and marketization during past two decades, the higher penetration of commercial fossil fuels in most Asian developing nations has caused decline in the share of biomass energy. The absolute consumption of biomass energy has however risen unabatedly during past two decades, growing at an annual rate of over 2 percent (FAO, 1997). Various factors like rising population and shortages or unaffordability of commercial fuels in rural and traditional sectors have sustained the growing biomass use. The increasing pressure on existing forests has already lead to considerable deforestation. Despite policy interventions by many Asian governments, the deforestation in

tropics far exceeded afforestation (by a ratio of 8.5:1) during the 1980's (Houghton, 1996). The deforestation and land degradation has made tropical Asian forests the net emitters of atmospheric CO₂ (Dixon et al, 1994). The sustainable growth of biomass energy in Asia therefore would require augmenting existing biomass resources with modern plantations and energy crops and by introducing efficient biomass energy conversion technologies. Lately, many Asian countries have initiated such programs.

BIOMASS ENERGY IN INDIA: STATUS

Biomass contributes over a third of primary energy in India. Biomass fuels are predominantly used in rural households for cooking and water heating, as well as by traditional and artisan industries. Biomass delivers most energy for the domestic use (rural - 90% and urban - 40%) in India (NCAER, 1992). Wood fuels contribute 56 percent of total biomass energy (Sinha et. al, 1994). Consumption of wood has grown annually at 2 percent rate over past two decades (FAO, 1981; FAO, 1986; FAO, 1996).

Estimates of biomass consumption remain highly variable (Ravindranath and Hall, 1995; Joshi et. al., 1992) since most biomass is not transacted on the market. Supply-side estimates (Ravindranath and Hall, 1995) of biomass energy are reported as: fuelwood for domestic sector- 218.5 million tons (dry), crop residue- 96 million tons (estimate for 1985), and cattle dung cake- 37 million tons. A recent study (Rai and Chakrabarti, 1996) estimates demand in India for fuelwood at 201 million tons (Table 1). Supply of biomass is primarily from fuels that are home grown or collected by households for own needs. The Government sponsored social forestry programme has added to fuel-wood supply to the tune of 40 million tons annually (Ravindranath and Hall, 1995).

Table 1: Fuelwood Demand in India in 1996

Consumption of Fuelwood	Million Tons
1. Household	
(a) Forested Rural	78
(b) Non Forested Rural	74
(c) Urban Areas	10
Sub Total	162
2. Cottage Industry	25
3. Rituals	4
4. Hotels etc.	10
Total	201

Source: Rai and Chakrabarti, 1996

Problems of Traditional Biomass Energy Use

Most biomass energy in India is derived from owned sources like farm trees or cattle, or is collected by households from common property lands. The biomass energy consumption is primarily limited to meet cooking needs of households and traditional industries and services in rural areas. In absence of a developed energy market in rural areas, most biomass fuels are not traded nor do they compete with commercial energy resources. In developing countries, due to excess labour, biomass acquires no resource value so long as it is not scarce. In the absence of an energy market, the traditional biomass fails to acquire exchange value in substitution. Absence of market thus acts as a barrier to the penetration of efficient and clean energy resources and technologies.

An additional problem with the traditional biomass use is the social costs associated with excessive pollution. The incomplete combustion of biomass in traditional stoves releases pollutants like carbon monoxide, methane, nitrogen oxides, benzene, formaldehyde, benzo(a)pyrene, aromatics and respirable particulate matter. These pollutants cause considerable damage to health, especially of women and children who are exposed to indoor

pollution for long duration (Smith, 1987; Smith, 1993, Patel and Raiyani, 1997). The twin problems of traditional biomass use are the energy inefficiency and excessive pollution.

Exploitation of abundant biomass resources from common lands sustained the traditional biomass consumption since millennia. Increasing pressure from growing population, growing energy needs from rural industry and commerce and penetration of logistics infrastructure into remote biomass rich areas have now led to an unsustainable exploitation of biomass. Three main problems associated with the traditional biomass are - inefficient combustion technologies, environmental hazards from indoor pollution and unsustainable harvesting practices. The aim of modern biomass programmes are to overcome these problems.

Biomass Energy Policies and Programmes

India has a long history of energy planning and programme interventions. Programmes for promoting biogas and improved cook-stoves began as early as in 1940's. Afforestation and rural electrification programmes are pursued since 1950's. A decade before the oil crisis of 1973, India appointed the Energy Survey Committee. The national biomass policy originated later, in the decade of 1970's, as a component of rural and renewable energy policies as a response to rural energy crisis and oil imports. Rural energy crisis in the mid-1970s arose from four factors - i) increased oil price, ii) rising rural household energy demand (following the population growth), iii) trading of wood in rural areas and urban peripheries to meet demand of growing industries like brick making and services like highway restaurants in the wake of sustained shortages of commercial energy, and iv) over exploitation of common property biomass resources. The crisis called for a national policy response to find economically viable and sustainable energy resources to meet growing rural energy needs.

A short term response resorted to was of importing kerosene and LPG to meet cooking needs and diesel for irrigation pumping. India's oil imports rose rapidly during 1970's with kerosene and diesel contributing most to the rising oil imports bill. Share of oil in imports, which was 8 percent in 1970, increased to 24 percent in 1975 and 46 percent in 1980 (Shukla, 1997). In following decade, oil imports became the major cause of growing trade deficit and balance of

payment crisis. The oil import was neither a viable solution at micro economy level. A vast section of poor households had little disposable income to buy commercial fuels. To ameliorate increasing oil import burden and to diffuse the deepening rural energy crisis, programmes for promoting renewable energy technologies (RETs) were initiated in late 1970s. Biomass, being a local, widely accessible and renewable resource, was potentially the most suitable to alleviate macro and micro concerns raised by the rural energy crisis.

Biomass policies followed a multi-pronged strategy: i) improving efficiency of the traditional biomass use (e.g. improved cook-stove programme), ii) improving the supply of biomass (e.g. social forestry, wasteland development), iii) technologies for improving the quality of biomass use (e.g. biogas, improved cook-stoves), iv) introduction of biomass based technologies (wood gasifiers for irrigation, biomass electricity generation) to deliver services provided by conventional energy sources, and v) establishing institutional support for programme formulation and implementation. The institutional response resulted in establishment of DNES (Department of Non-Conventional Energy Sources) in 1982 and state level nodal energy agencies during the early 1980s decade.

Early Policy Perspective - The Technology Push Strategy

The RETs programmes received enhanced support with the establishment of DNES which emphasized decentralized and direct use renewable technologies. The renewable energy sources were viewed primarily as the solution to rural and remote area energy needs, in locations and applications where the conventional technology was unavailable or as stop gap supply options where commercial energy could not be supplied. In other words, RETs were never viewed as viable competitive options. Direct subsidy to the user and supply orientation were the major element of the Renewable Energy Programme. The energy projects were thus pushed by the government.

Some of the programme achievements include introduction of efficient and clean technologies for household energy use like improved cook-stoves (22.5 million), family sized biogas plants of 2 to 4 cubic meter per day capacity (2.4 million) and community biogas plants (1623) have

been added (till March 1996) to the technology stock (CMIE, 1996). Although, the biogas and improved cook-stove programmes have been moderately successful, their overall impact on rural energy remains marginal (Ramana et al, 1997). Two deficiencies in policy perspectives contributed to the slow progress in the penetration of biomass technology. Firstly, the biomass was viewed solely as a traditional fuel for meeting rural energy needs. Secondly, the policies primarily focused on the supply-side push. Market instruments had little role in biomass policies. Under the circumstance, neither the modern plantation practices for augmenting the biomass supply nor the growing pool of advanced biomass energy conversion technologies could penetrate the Indian energy market.

Perspective Shift Towards Market Pull Policies

It was increasingly realized that a limiting factor to the success of programmes was the restrictive perception of biomass as a traditional fuel for meeting rural energy needs and focus on the supply-side push. Since energy markets were non-existent or weak in rural areas, the traditional approach did not consider any role for market in promoting biomass supply or efficient use. Since early 1990s, the policy shift towards market oriented economic reforms by the Government of India has shifted the perspective towards allowing a greater role by market forces. The policy shift is characterized by: i) higher emphasis on market based instruments compared to regulatory controls, ii) reorientation from technology push to market pull, and iii) enhanced role of private sector. Besides, the alleviation of DNES in 1992 to a full fledged ministry, MNES (Ministry of Non-Conventional Energy Sources), led to the enhanced status of RET programmes.

Under the old perspective, biomass was viewed as a non-commercial rural resource (a poor man's fuel), the use of which had to be improved through a push by government programmes. The new perspective views biomass as a competitive energy resource which can be pulled through energy markets. Under this view, government's role is not to push programmes but to enact policies which internalize social benefits and costs of competing fuels. The timing of the change in the perspective coincided with the development of several advanced biomass technologies. As a result, the MNES's policy shift towards market based incentives and

institutional support has led to introduction of modern biomass technologies such as bagasse based co-generation and large scale gasification and combustion technologies for electricity generation using a variety of biomass.

MODERN BIOMASS TECHNOLOGY IN INDIA: EXPERIENCES

A decade of experience with modern biomass technologies for thermal, motive power and electricity generation applications exists in India. Gasifier technology has penetrated the applications such as village electrification, captive power generation and process heat generation in industries producing biomass waste. Over 1600 gasifier systems, having 16 MW total capacity, have generated 42 million Kilo Watt hour (KWh) of electricity, replacing 8.8 million litres of oil annually (CMIE, 1996). An important aspect of small gasifier technology in India is the development of local manufacturing base. The large sized gasifier based power technologies are at R&D and pilot demonstration stage. The thrust of the biomass power programme is now on the grid connected megawatt scale power generation with multiple biomass materials such as rice straw, rice husk, bagasse, wood waste, wood, wild bushes and paper mill waste. Nearly 55 MW of grid connected biomass power capacity is commissioned and another 90 MW capacity is under construction. Enhanced scale has improved economics as well as the technology of biomass power generation. Technology improvement is also derived from joint ventures of Indian firms with leading international manufacturers of turbines and electronic governors.

R&D and Pilot Project Experiences

Four gasifier Action Research Centers (ARCs) located within different national institutions and supported by the MNES have developed twelve gasifier models, ranging from 3.5 to 100 KW. Two co-generation projects (3 MW surplus power capacity) in sugar mills and one rice paddy straw based power project (10 MW) were commissioned. While the co-generation projects are successfully operated, the 10 MW rice straw based power project completed in 1992 ran into technological problems and is closed since last two years due to want of suitable raw material. A rice husk based co-generation plant of 10.5 MW capacity installed by

a private rice processing firm in Punjab and commissioned in 1991 faced problems such as unavailability of critical spares of an imported turbine and uneconomical tariffs from the state utility despite power shortage in the state (Ravindranath and Hall, 1995). The rapid escalation in the price of rice husk and low capacity utilization added to the cost making the operation uneconomical. The experiences with R&D and pilot project suggests the need for considerable technological and institutional improvements to make biomass energy competitive.

Large Scale Electricity Generation Programmes

The future of modern biomass power programme rests on its competitive ability vis-à-vis other centralized electricity generation technologies. Policies for realizing biomass electric power potential through modern technologies under competitive dynamics has a recent origin in India. The biomass electricity programme took shape after MNES appointed the task force in 1993 and recommended the thrust on bagasse based co-generation. The focus of modern biomass programme is on the cogeneration, especially in sugar industry. A cogeneration potential of 17,000 MW power is identified, with 6000 MW in sugar industry alone (Rajan, 1995).

Programme for biomass combustion based power has even more recent origin. It began in late 1994 as a Pilot Programme launched with approval of two 5 MW projects. Interest subsidy programmes on the lines of that for the bagasse based co-generation was extended in 1995. The programme also initiated a grid connected biomass gasification R&D-cum-Demonstration project of 500 Kilo Watt (KW) capacity. A decentralized electricity generation programme initiated in 1995 provided support for total of 10 to 15 MW of small decentralized projects aimed at energy self sufficiency in electricity deficient rural locales. The programme aims to utilize some of the 350 million tons of agricultural and agro-industrial residues produced annually in India. The cost of electricity generation from these plants are anticipated to be quite competitive at Rs. 1.8 per KWh.

Technology for Production of Biomass

Modern biomass supply has to be driven by the dynamics of energy market. Supply of biomass at a competitive cost can be ensured only with a highly efficient biomass production system. Productivity of crops and trees depend critically on agroclimatic factors. To enhance biomass productivity, the MNES is supporting nine Biomass Research Centers (BRCs) in nine (of the fourteen) different agroclimatic zones in India with an aim to develop packages of practices of fast growing, high yielding and short rotation (5-6 years) fuelwood tree species for the degraded waste lands in these zones. Some centers have existed for over a decade. Packages of practices for 36 promising species are prepared. Biomass yield of up to 36.8 tons per hectare per year is reported (Chaturvedi, 1993) from some promising fuel-wood species.

Since the knowledge of these package of practices has remained limited within the research circles, their benefits remains to be realized. The mean productivity of farm forestry nationally is very low at 4.2 tons per hectare per year (Ravindranath and Hall, 1995). Exploitation of bioenergy potential is vitally linked to the adequate land supply. While the use of cultivable crop land for fuel remains controversial under the "food versus fuel" debate, there exists a vast supply of degraded land which is available cheaply for fuel-wood plantations. The estimates of degraded land vary from 66 million hectares (Ministry of Agriculture, 1992) to 130 million hectares (SPDW, 1984). With improved biomass productivity and efficient energy conversion, it is feasible to sustain a significant share of biomass in total energy use in India by utilizing a fraction of this degraded land for biomass plantation.

MODERNIZATION OF BIOMASS ENERGY IN ASIA

Modernization in biomass energy use in Asia has happened in the last two decades along three routes - i) improvement of technologies in traditional biomass applications such as for cooking and rural industries, ii) process development for conversion of raw biomass to superior fuels (such as liquid fuels, gas and briquettes), and iii) penetration of biomass based electricity generation technologies. These developments have opened new avenues for biomass energy in several Asian nations, besides India.

China, in early 1980's, initiated a nationwide programmes to disseminate improved cookstove and biogas technologies. The programme led to raising energy efficiency of cookstoves to 20 percent, saving nearly a ton of wood fuel per household (Shuhua et al, 1997). In 1995, nearly 6 million biogas digesters produced 1.5 billion m³ gas annually (Baofen and Xiangjun, 1997). Another 24,000 biogas purification digesters, with a capacity of 1 million m³ were in use for treating waste water for 2 million urban population (Keyun, 1995). Two hundred small biogas based power plants, adding to a capacity of 3.5 MW, produced 3 GWh of electricity annually (Ravindranath and Hall, 1995).{PRIVATE } Research and development (R&D) in China has focused on a process for converting a high quality Chinese sorghum breed into liquid fuel, pyrolysis technology and gasification of agriculture residue and wood. Biomass based electricity generation technologies have penetrated the Chinese market lately, with a penetration of 483 MW and 323 MW respectively in sugar industry in two major sugar cane producing provinces Guandong and Guangxi (Baofen and Xiangjun, 1997). The policy support points to a promising future for modern biomass in China.

Philippines is a major biomass using nation, where 44% of energy is contributed by biomass. Philippines was among the first nations to initiate the modern biomass programme. In 1970's, a three quarters of electricity in Philippines was generated from oil and diesel fired power plants. and a third of the imported oil in 1979 was used for electricity generation (Bawagan and Semana, 1980). A biomass combustion based (dendrothermal) power programme was launched in 1979 with aims to reduce the share of imported oil fired electricity plants to 30% (Durst, 1986). Programme met with failure inn 1980's due to myriad circumstances - like political instability, declining oil prices, inappropriate technology, over reliance on a single tree species, inadequate institutional support and lack of functioning biomass energy market.

Thailand is a large user of biomass energy, which contributes a quarter of total energy. A third of biomass energy is consumed in industry. Bagasse is used in sugar mills as a boiler feedstock (Panyatanya, 1997). The policy of purchase of power from Small Power Producers - SSP announced in 1992 by Electricity Generating Authority of Thailand (EGAT) can be favourable to biomass electricity producers (Verapong, 1997). The response on the SSP policy

is still slow. A cogeneration potential of 3100 MW biomass based power is identified in chemical, agroprocessing and textile industries (Verapong, 1997).

Indonesia has immense biomass resource endowment, with 109 million hectares forest area covering sixty percent of land mass. Besides, 9 million hectares of land is under wood plantation. Biomass contributes over a third of energy. The wood waste from over a hundred plywood plants has potential to fuel 200 MW power. The saw mill waste is adequate to support another 800 MW. The recent policy of facilitating the small scale private producers (30 MW) is expected to be beneficial for biomass electricity applications. Although a large potential exists, cost of biomass energy is not yet competitive (Martosudirjo, 1997) and penetration has remained marginal.

Malaysia also has considerable biomass resource base. Nearly sixty percent land is under forests and fifteen percent under cultivation. The forest and agriculture industry generate substantial quantities of wastes and residues which are available cheaply. Wood briquettes from saw dust has grown around domestic and export demand. Palm oil industry is a major source of residues. Another vast biomass source is rice husk. In 1995, there were 328 rice mills producing 430 thousand tons of rice husk (Ang, 1997). Several fishmeal manufacturers use rice husk for drying. Cogeneration systems (350 KW size) using rice husk are established in three rice mills. Seven demonstration plants for cogeneration and efficient biomass combustion are also being promoted (Ang, 1997).

COMPETITIVENESS OF MODERN BIOMASS ELECTRICITY

Biomass based electric power generation technologies succeeded in niche applications such as supplying electricity in decentralized location and industries generating biomass waste. The large scale penetration of biomass power technologies depends on their delivered cost and reliability in direct competition with conventional electricity sources in centralized electricity supply. In India, the principal competing source for electricity supply is the coal based power. Biomass energy cost is highly variable, depending upon the source, location etc. Delivered cost of coal also varies depending upon the extraction costs and logistic costs which vary with

the distance from the mine. Coal power plants are built with large scale technology, with a standard size of 500 MW. Scale of grid based biomass plants vary from a 1 MW to 50 MW. Assuming the base price of coal in India as Rs. 48 per giga joule (GJ) and biomass as Rs. 72 per GJ, the composition of delivered cost of electricity from different plants is as shown in Figure 1. Evidently, the delivered cost of electricity from a 50 MW biomass based power plants is higher compared to coal power plant by 15 percent. In future this gap can be expected to reduce due to three reasons - the scale difference between coal and biomass plants shall narrow, cost of biomass shall reduce due to improved plantation practices and coal price shall increase since it is an exhaustible resource.

Biomass Power Under Fair Competition: Internalizing the Externalities

Associated with conventional electric power plants are some negative social and environmental externalities. Throughout the coal and nuclear fuel cycles, there are significant environmental and social damages. Contrarily, biomass energy offers positive environmental and social benefits. Biomass plantation is often a best way to reclaim degraded lands and to generate sizable employment (Miller et al., 1986). Fossil fuel plant operations pose local, regional as well as global hazards. Biomass combustion also emits pollutants, however aggregate damage during the fuel cycle is much less compared to fossil or nuclear fuel cycle (Sorensen, 1997). Governments in countries like Sweden and Denmark have now implemented measures to internalize the externalities (Hilring, 1997) from conventional fuel use. Biomass offers most promising future carbon mitigation options.

A fair competition requires internalization of the social and environmental externalities of competing sources. Coal combustion for electricity generation is associated with two negative externalities - namely CO₂ and SO₂ emissions. Typical coal used in Indian power plants emits 3.2 tons of carbon per tera joule (tC/TJ) and 0.1 ton of sulfur dioxide per TJ. Estimates of carbon tax for stabilizing emissions in 2010 at 1990 level are highly variable. Comparative assessment of different models in the U.S.A. by Energy Modelling Forum indicates a range of \$20 to 150 (EMF, 1993). In developing countries, lower marginal costs for carbon mitigation are reported (UNEP, 1993; Shukla, 1995; IPCC, 1996). SO₂ tax in the range of \$100 to \$400

per tons are reported (Hilring, 1997). Figure 2 shows the cost structure of delivered electricity with internalized costs of CO₂ and SO₂ emissions under two plausible tax scenarios - i) *High Tax Scenario*: \$50 per ton of carbon tax and \$400 per ton of sulfur dioxide tax, and ii) *Low Tax scenario*: \$25 per ton of carbon tax and \$200 per ton of sulfur dioxide tax. Even with low environmental taxes, electricity from coal power plant is more expensive than biomass power plant. With high taxes, biomass electricity is far cheaper. Under a fair competition therefore, when environmental externalities from fossil fuels are internalized, the biomass produced electricity can be competitive vis-à-vis conventional coal power plants. This points to a very promising future for biomass power technologies.

FUTURE OF BIOMASS ENERGY IN INDIA

Biomass use is growing globally. Despite advancements in biomass energy technologies, most bioenergy consumption in India still remains confined to traditional uses. The modern technologies offer possibilities to convert biomass into synthetic gaseous or liquid fuels (like ethanol and methanol) and electricity (Johansson et al, 1993). Lack of biomass energy market has been the primary barrier to the penetration of modern biomass technologies. Growing experience with modern biomass technologies in India suggests that technology push policies need to be substituted or augmented by market pull policies.

A primary policy lacuna hampering the growth of modern biomass energy is the implicit environmental subsidy allowed to fossil fuels. Increasing realization among policy makers about positive externalities of biomass has now created conditions for biomass to make inroads into the energy market. Modern biomass has potential to penetrate in four segments - i) process heat applications in industries generating biomass waste, ii) cooking energy in domestic and commercial sectors (through charcoal and briquettes), iii) electricity generation and iv) transportation sector with liquid fuels. Economic reforms have opened the doors for competition in energy and electricity sectors in India. Future of biomass energy lies in its use with modern technologies. An analysis under competitive dynamics in energy and electric power markets using the Indian-MARKAL model (Shukla, 1996; Loulou et al., 1997)

suggests that biomass energy has significant potential to penetrate the Indian energy market under strong global greenhouse gas mitigation scenarios in future.

Future of biomass energy depends on providing reliable energy services at competitive cost. In India, this will happen only if biomass energy services can compete on a fair market. Policy priorities should be to orient biomass energy services towards market and to reform the market towards fair competition by internalizing the externalities of competing energy resources. Most economical option is utilization of waste materials. Potential availability of agro residues and wood processing waste in India can sustain 10,000 MW power. Biomass waste however shall be inadequate to support the growing demands for biomass resources. Sustained supply of biomass shall require production of energy crops (e.g. wood fuel plantations, sugar cane as feedstock for ethanol) and wood plantations for meeting growing non-energy needs. Land supply, enhanced biomass productivity, economic operations of plantations and logistics infrastructure are critical areas which shall determine future of biomass in India. Policy support for a transition towards a biomass based civilization in India should consider the following:

Short-term Policies (1 to 5 years): i) enhanced utilization of crop residues and wood waste, ii) information dissemination, iii) niche applications (e.g. remote and biomass rich locations), iv) technology transfer (e.g. high pressure boiler), v) co-ordination among institutions, vi) demonstration projects, vii) participation of private sector, community and NGOs, viii) waste land development, and ix) subsidy to biomass technologies to balance the implicit subsidies to fossil fuels.

Medium Term (5 to 20 years): i) R&D of conversion technologies, ii) species research to Match agroclimatic conditions, iii) biomass Plantation, iv) scale economy based technologies, v) Local Institutional Developments, and vi) removal of distortions in fossil energy tariffs.

Long term (over 20 years): i) Infrastructure (logistics, T&D), ii) multiple biomass energy products (e.g. gas, liquid, electricity), iii) institutions and policies for competitive biomass energy service market, and iv) land supply for biomass generation

Experience of operating the modern biomass plantations and energy conversion technologies is growing. The learning effects and the shared knowledge from innovations in conventional technologies are rapidly enhancing the efficiency and reliability of biomass production systems and conversion technologies. Although present penetrations of modern biomass energy services is little, technological developments and policy reforms which propose to eliminate energy subsidies and internalize externalities from fuel cycle is set to be advantageous to biomass technologies. Realization of biomass potential shall help many developing countries to make a smooth transition from the present inefficient biomass energy use in traditional sectors to a competitive, commercial and efficient biomass energy use in the future. This will reduce their energy import and conserve scarce finances for national development.

The government policies in India during the next decade shall play decisive role in penetration of biomass energy. Global climate change policies shall also have significant influence on future of biomass. Myriad economic, social, technological and institutional barriers remain to be overcome. Future of biomass technologies depends on will and ability to overcome these barriers. A key issue before Indian policy makers is to develop a fair market for biomass energy services.

Significant social and environmental benefits make biomass a deserving alternative for support from governments committed to sustainable development. Governments have in the past promoted new energy technologies like nuclear power in France (Johansson et al., 1996), wind power in Denmark (Johansson et al., 1996) and India (Naidu, 1997), and ethanol from sugarcane in Brazil (Goldemberg et al., 1993). The challenge is with the Indian policy makers to support the energy transformation away from exhaustible and polluting energy resources towards renewable and clean energy resources on the road to sustainable development. Modern biomass technologies provide viable options for such an energy transformation, on the way to a sustainable energy system of the future.

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