Discussion paper issued without formal editing

FOR PARTICIPANTS ONLY
19 October 2016
ENGLISH ONLY

UNITED NATIONS
CENTRE FOR REGIONAL DEVELOPMENT

In collaboration with

Australian Government,
Office of Green Industries SA on behalf of the Government of South Australia,
Commonwealth Scientific and Industrial Research Organisation, and
Ministry of the Environment, Government of Japan

SEVENTH REGIONAL 3R FORUM IN ASIA AND THE PACIFIC,
2-4 NOVEMBER, 2016, ADELAIDE, SA, AUSTRALIA

Potential of economic utilization of biomass waste in India - Implications towards SDGs

(Short Background Paper for Plenary Session 3 of the Programme)

Final Draft

This background paper has been prepared by Prof. Sadhan Kumar Ghosh, for the Seventh Regional 3R Forum in Asia and the Pacific. The views expressed herein are those of the author only and do not necessarily reflect the views of the United Nations.

Seventh Regional 3R Forum in Asia and the Pacific
2-4 November 2016, Adelaide, SA, Australia

Short Background paper
On

Potential of economic utilization of biomass waste in India - Implications towards SDGs

Prof. Sadhan Kumar Ghosh

Professor, Mechanical Engineering Department,
Jadavpur University, Kolkata, India
Email : sadhankghosh9@gmail.com;

Summary/Abstract

Biomass has always been an important energy source for India considering the benefits it offers for power generation, cooking gas production and other valuable recycled products which need to be carried out in effectively carried out for efficient resource utilisation. The process of is renewable. Biomass and biomass wastes are carbon-neutral widely available, can produce renewable power / gas, and has the potential to provide significant employment in the rural areas in India and many Asian and African countries. The global community has developed an agenda that promises to address the concerns of human development for all while ensuring the health of the planet and its ecosystems. The Post 2015 UN Development Agenda is a unique participatory exercise that has led to the design of a sustainable development framework consisting of 17 Sustainable Development Goals (SDGs) that address the key concerns of humanity and 169 interlinked targets within these goals that reflect the complex and interrelated nature of social, economic and ecological well-being parameters. With the scarcity of fossil fuels and to achieve SDGs, focus has been shifted to the use of alternative fuel. Biomass is one of the best choices for many countries worldwide including India. In India, bioenergy demand rises by around 11% over the projection period to 2040, a moderate increase that results in the share of bioenergy steadily shrinking in the Indian energy mix. Data from the United Nations Food and Agriculture Organization (UNFAO, 2015) indicate that the total area covered by forests in India has actually increased in recent years, suggesting that – despite evidence of localised shortages in parts of the country, including the northeast – there is no overall scarcity of fuelwood for use by rural households as a traditional cooking fuel. In developing regions reliant on biomass, women and children are responsible for fuel collection, a time-consuming and exhausting task. This can limit the economic incentive for rural households to switch to alternative fuels, such as LPG where it is available, or to invest in more efficient biomass cook stoves.

For other predominantly rural but modern energy applications, such as power plants fired with bioenergy (e.g. bagasse-based cogeneration at sugar mills) or biomass gasifiers to produce biogas, there is, in principle, ample surplus biomass available (mainly from agricultural and forestry residues), although supply in practice depends on reliable systems for collection, transportation and storage. The power generation based on biomass will rise by more than five-times to reach around 120 TWh in 2040, providing a valuable contribution to the reliability of rural electricity supply. But despite policy support for modern biomass technologies in India, the uptake of bioenergy-based supply is constrained by relatively high costs and by poor access to financing. One under-utilised option for urban energy supply is municipal waste – a natural product of the rise in India's cities but one that is becoming a major health and environmental hazard: it is estimated that only 20% of the total urban waste is treated, leaving the rest to be dumped untreated at open sites (Planning Commission, 2014). This is a largely unexploited resource, the use of which would not only generate electricity and biogas, but which also has the potential to bring co-benefits by reducing the area required for landfill, a major consideration in India's sprawling cities, and improving public health (although care would be needed to avoid toxic emissions from waste incineration). The Ministry of New and Renewable Energy has classified waste-to-energy as a renewable energy source and put in place subsidies and incentives to encourage projects. Question is how to use the biomass and biomass wastes in economical way and what is the implication on the SD Goals. This document reviews the potential utilisation of biomass and its wastes in India and the implication towards the Sustainable Development Goals.

Table of Contents

1 Introduction

Concern about assuring affordable, equitable and environmentally sustainable access to natural resources is well established. Global use of natural resources has accelerated during the past decades and emissions and wastes have grown in line with growing extraction and use of resources. India is one of the most dynamic countries with respect to the growth in resources use through urban– industrial transformation. With the scarcity of fossil fuels and achieving Sustainable Development Goals (SDGs), focus has been shifted to the use of alternative fuel. As per UNCTAD, the annual investment needed globally to achieve SDGs USD 5-7 trillion. Annual spending needed in India to achieve SDGs is USD 0.96 trillion with a gap of nearly USD 0.56 trillion (Bhamraet al, 2015). Biomass is one of the best choices for many countries worldwide including India. Biomass is basically a stored source of solar energy initially collected by plants during the process of photosynthesis whereby carbon dioxide is captured and converted to plant materials mainly in the form of cellulose, hemi-cellulose and lignin. The term "Biomass" therefore covers a range of organic materials recently produced from plants, and animals that feed on the plants. The biomass can be collected and converted into useful bioenergy, includes crop residues, forest and wood process residues, animal wastes including human sewage, municipal solid waste (MSW) (excluding plastics and non-organic components), food processing wastes, purpose grown energy crops and short rotation forests. A significant amount of biomass is generated in the East Asian countries, namely, Bangladesh, China, India, Indonesia, Philippines, Thailand and Vietnam, where the principal resources of biomass wastes are residues from agriculture and forest industries, animal manure from medium and large-scale livestock farms and municipal solid waste (MSW). Potential of lignocellusosic biomass for bio-energy production in India have been evaluated for the past decades with inclusion of updated technologies (Bhavik, 2016). Biomass availability in India is estimated to be around 915 million metric ton which includes both agricultural and forestry and wasteland residues, the power potential of which is estimated at 33,292 MWe (Mega Watts) (Ghosh, 2016).

Biomass has always been an important energy source for India considering the benefits it offers for power generation, cooking gas production and other valuable recycled products. It is renewable, widely available, carbon-neutral and has the potential to provide significant employment in the rural areas. Biomass is also capable of providing firm energy. About 32% of the total primary energy use in the country is still derived from biomass and more than 70% of the country's population depends upon it for its energy needs. Ministry of New and Renewable Energy has initiated a number of programmes for promotion of efficient technologies for its use in various sectors of the economy to ensure derivation of maximum benefits (Source: Scheme wise Physical Progress in 2016-17). Biomass power generation in India is an industry that attracts investments of over Rs. 1 billion USD (nearly 600 crores INR) every year, generating more than 5000 million units of electricity and yearly employment of more than 10 million man-days in the rural areas. For efficient utilization of biomass, bagasse based cogeneration in sugar mills and biomass power generation have been taken up under biomass power and cogeneration programme **(http://mnre.gov.in/schemes/grid-connected/biomass-powercogen/)**.

Ethanol from lignocellulosic biomass is a complex technology; it has been noted that extensive research efforts are underway by industry and academia in making this technology technically and economically viable in near future. Efforts are needed in developing resource databases, evaluation, development of pre-treatment technologies, logistics, reactor design, organism development, protein engineering to label a few, and apparently needs a focused centre to lead and coordinate the R&D activities towards achieving success in all the unit operations involved.

Renewable resources for power generation is now gearing up in India due to enhanced awareness, acceptability of renewable energy sources by power consumer and government initiatives. The ambitious targets would see India quickly becoming one of the leading green energy producers in the world and surpassing numerous developed countries. The government intends to achieve 40% cumulative electric power capacity from non-fossil fuel sources by 2030. The Renewable Power target to be achieved by the year 2022 So that cumulative achievement is 1,75,000 MW in the country, where as the Biomass Power target is 10,000 MW including the 100,000 Family Biogas Plants, waste to energy plants and rural & industrial Biomass Gasifiers given in table 1.

Table 1. Programme/ Scheme wise Physical Progress in 2016-17 (& during the month of August, 2016) (Source : Scheme wise Physical Progress in 2016-17)

Source	**Installed Capacity, Total inMW**	**FY- 2016-17**		**Cumulative Achievements (as on 31.08.2016)**	**2022 target (MW)**
		Target	**Achievement (April - August,2016)**		
I. Grid-interactive power (capacities in MW)					
Wind Power	27,441.15	4000	897.10	27674.55	60,000
Solar Power	8,062.00	12000	1320.32	8083.17	100,000
Small Hydro Power		250	36.40	4310.35	
Biomass Power (Biomass &Gasification, Bagasse Cogeneration) *	4,860.83	400	51.00	4882.33	*10,000
Waste-to-Power	115.08	10	7.50	115.08	
Total		**16660**	**2312.32**	**45065.48**	
II. off-grid/ captive power (capacities in W_{EQ})					
Waste to Energy	160.16	15	1.23	161.39	
Biomass(non-bagasse)Cogeneration	651.91	60	0.00	651.91	
Biomass Gasifiers* -Rural -Industrial	18.15 163.24	2 8	0.00 1.80	18.15 166.04	
Aero-Genrators/Hybrid systems	2.59	1	0.20	2.79	
SPV Systems	313.88	100	28.30	342.18	
Water mills/micro hydel (WM =Water Mills)		1 MW+ 500WM	0.10 MW + 100 WM	18.81	
Total		**187**	**31.63**	**1361.27**	
III. other renewable energy systems					
Family Biogas Plants*		100,000	900,00	4,864,000	

India has adopted agenda and actions based on the UN post-2015 development agenda – Transforming our world: the 2030 Agenda for Sustainable Development, with 17 Sustainable Development Goals (SDGs) for the people, planet and prosperity reflecting the commitment of shifting on to a sustainable and resilient path. The economic utilisation of biomass has been helping in achieving the SDGs. The objective of this working paper is to address a number of questions in view of biomass, demand potential and economic utilisation in India as well as the uncertainties concerning supply chain in a sustainable, affordable way and how this might be ensured and the implications towards SDGs. The study tries to address the following questions.

- How much biomass is available and recoverable?
- What is the potential economic utilization of biomass wastes?
- What are the key uncertainties for biomass prospects in India?
- What will be the supply cost and future price of biomass?
- What role government is playing to strengthen biomass deployment?
- What are the implications towards SDGs?

2 How much biomass is available and recoverable in India

The bioenergy assessment framework in Figure 1illustrates that biomass energy comes from two different sources. One is primary bioenergy, which uses farmland or forests to produce biomass, the other is biomass residue, which is generated as a by-product of food or wood products throughout their supply-consumption chain. The potentials of four main types of biomass are, (i) Energy crops, including food crops; (ii) Forest products (fuelwood, residues and processing, and post-consumer waste); (iii) Agricultural residues (harvesting residue, processing residue and food waste); and (iv) Animal manure. (Global Bioenergy Supply and Demand Projection, 2014).

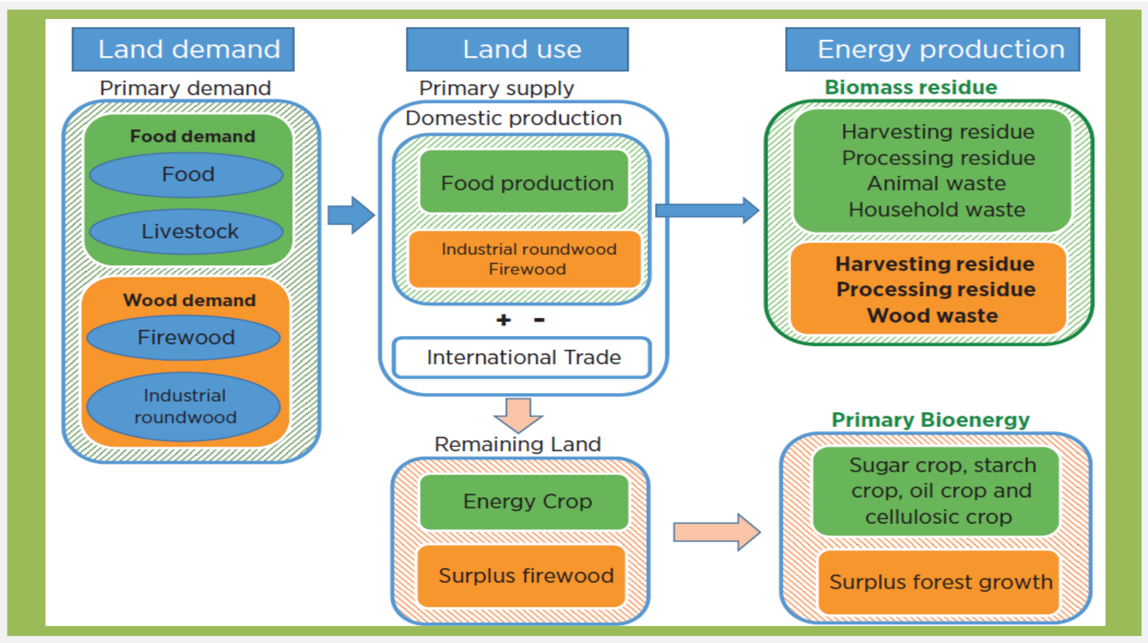


Figure 1: Supply and demand framework of bioenergy
(Source : Global Bioenergy Supply and Demand Projections for the Year 2030)

India and China produce and consume more than half of the world's total rice supply. Rice is the staple food crop in Asia, where 91% of it is grown and consumed. For every 4 tonnes of rice grain, 6 tonnes of straw is produced. In India, 97.19 Mt of rice straw is produced every year, and around 23% of it is left unutilized. Mostly these are burnt in fields which emit greenhouse gases hazardous to human and ecosystem health (Ghosh, 2016). Rice straw can be alternatively used as feedstock for clean energy and the conversion can be achieved mainly by thermo-chemical or biochemical/biological processes. The technology and bottlenecks for commercialisation of lignocellusosic biomass for various energy precursors have been well studied (Banerjee et al., 2010). Thermochemical conversion includes combustion, pyrolysis, gasification and liquefaction while biochemical conversion encompasses digestion and fermentation.

A study by TIFAC shows that Rice, Wheat, Maize, Jowar, Ragi and Bajra residue are mainly used as cattle fodder. Cotton, chilli, pulses and oilseeds residues are mainly used as fuel for household needs. Rice husk is mainly used in boilers as fuel and bagasse mainly for power or paper production. Sugarcane tops is the most surplus residue as it is mostly burnt in the fields itself. Other fuel crops like Cotton, Chilli, Pulses and Oilseeds generate surplus because they do not have much other use apart from fuel. These residues are typically burnt in the fields or used to meet household energy needs by farmers and villagers. As India makes further economic progress, farmers are likely to shift to modern fuels like kerosene and LPG. This will further increase availability of such crop residues. A potential 61.1 Mt of fuel crop residue and 241.7 Mt of fodder crop residues are being consumed by farmers themselves. This can be freed up if alternatives are provided to them. The survey shows that farmers are willing to sell crop residues provided they get decent remuneration and alternatives. Gross biomass residue available from crop production in India is shown in figure 2.

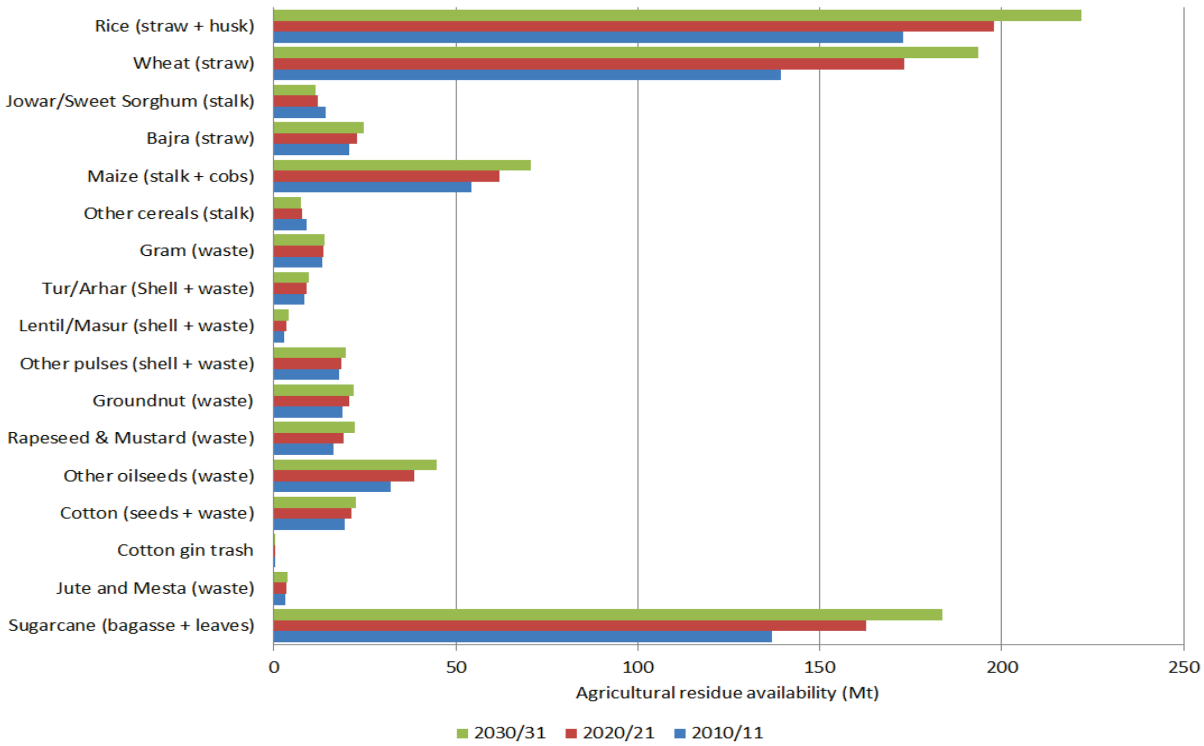


Figure 2. Gross residue availability from crop production in India (Purohit, 2015)

Biomass power & cogeneration programme in India is implemented with the main objective of promoting technologies for optimum use of country's biomass resources for grid power generation. Biomass materials used for power generation include bagasse, rice husk, straw, cotton stalk, coconut shells, soya husk, de-oiled cakes, coffee waste, jute wastes, and ground nut shells, saw dust etc. The gross residue availability in India from the cultivation of different grains, oilseeds, fibres and sugarcane is estimated at 680 Mt for 2010-11 and 877 Mt for 2030–31 respectively (Purohit, 2014). As per the Ministry of New and Renewable energy, the current availability of biomass in India is estimated at about 500 Mt per year. Studies sponsored by the Ministry has estimated surplus biomass availability at about 120 – 150 million tons per annum covering agricultural and forestry residues corresponding to a potential of about 18,000 MW. This apart, about 7000 MW additional power could be generated through bagasse based cogeneration in the country's 550 Sugar mills, if these sugar mills were to adopt technically and economically optimal levels of cogeneration for extracting power from the bagasse produced by them. (http://mnre.gov.in/schemes/grid-connected/biomass-powercogen/). The biomass used and available in different states in India are, Rice, Wheat, Sugar cane, Maize, Cotton, Chilli, jowar, ragi, bajra, Pulses, Oilseeds, Bamboo, Pine Needles, Water Hyacinth (http://www.erewise.com/current-affairs/biomass-resources-in-india_art52cbbb9bcd5df.html#.V_htcDR97IU).

3 Potential economic utilization of biomass waste in India

Potential of lignocellusosic biomass for bioenergy production in India have been evaluated for the past decades with inclusion of updated technologies (Bhaviket al, 2016). Concerns about increasing energy demand and global warming has urged the world scientific community to search for renewable and sustainable alternatives. One of the best alternative include production of biofuels and biomaterials building blocks from biomass waste, which include solid waste of agricultural residues, agro-industrial wastes, liquid waste and food etc. This energy conversion from waste (Efw) technology requires pre-treatment of biomass which is subsequently converted to biofuels of different forms (methane, hydrogen, ethanol, biodiesel, etc.) (Chun-Min Liu et al 2016).Government of India has taken some initiatives for economic and effective utilisation of biomass and biomass wastes. The possible co-products that could be produced in the bio refinery and their importance to reduce the processing cost of biofuel are encouraged. Recent estimates of biofuel production costs show that second generation biofuels are two to three times more expensive than petroleum fuels on an energy equivalent basis (Carriquiry, et al, 2011). To bring down the production cost, several challenges in converting lignocellulosic biomass to biofuels and chemicals using biochemical platforms (Hoekman, 2009; Menon et al, 2012; Luo et al, 2010) need to be addressed. These challenges are in the areas of, (i) feedstock production, (ii) feedstock logistics, (iii) development of energy efficient technologies (pre-treatment, enzyme hydrolysis, and microbial fermentation), (iv) co product development, (v) establishment of biofuel and biochemical standards, (vi) biofuel distribution, (vii) societal acceptance, and (viii) environmental impact minimization. All of these challenging areas require expertise in agronomy, biomass logistics, biomass conversion, process engineering, chemistry, conversion technology, genetic engineering, microbial fermentation, economics, and environmental science. In India, there is huge scope of utilisation of waste biomass in economic and environment friendly process. (Kumar et al, 2015).

Biofuels and biochemicals produced using non-edible feedstock such as lignocellulosic biomass provide several benefits to the society, like (i) being renewable and sustainable, (ii) indirectly helping carbon dioxide [a greenhouse gas (GHG) that is responsible for global warming] fixation in the atmosphere, (iii) facilitating local economy development and stimulation, (iv) reducing air pollution from burning of biomass in fields and biomass rotting in fields, (v) bringing energy security for countries dependent on imported oil, and (vi) creating high technology jobs for engineers, fermentation specialists, process engineers, and scientists (Greenwell et al, 2012). The potential use of biomass residues are animal fodder, mulching, thatching, consumption in process plants such as oil mills, internal consumption of rice husk by mills, cement plant, Brick Kiln, paper, biomass based power plants, net import/export of biomass from catchment area. The result of the study has been given in table 2 as percentage distribution of biomass usage in some states in India. Some of the plants may be closed and some new plants may be emerged by this time. The commitment and control of the stakeholder directly / indirectly associated with biomass project are shown in table 3.

Table 2. Percentage distribution of sample survey of biomass usage in some states in India (Source: Final Report on Review of Performance of the Grid- connected Biomass-based Power Plants Installed in India, August 2009)

Name of the state	Biomass usage
Chhattisgarh	• Nearly 64% of the total biomass is consumed as animal fodder. • Nearly 7.7% is consumed for mulching and thatching. • Biomass power plants in the region consume about 18.4%. • Nearly 5% is imported from Ambikapur& surrounding area at the rate of Rs 1600–2300 per MT.
Maharashtra	• About 44% of the total biomass generated is used as animal fodder. • About 9% is consumed as domestic fuel. • Biomass power plants (Rake Power Ltd, Nagpur and Shalivahana Projects Ltd. &Yavatmal) consume only 8.6%. • Oil mills and brick kilns consume about 20% and 1.79%, respectively. • About 10% is exported outside the catchment area.
Rajasthan	• About 60% is used as animal fodder. • About 11% is consumed as domestic fuel. • Nearly 4.6% is consumed in Biomass power plants (Suryachambal Power Plant Ltd, Kota and AmritEnv. Technologies Pvt Ltd [AETPL], Kotputli) • Oil mills and brick kilns consume 6.9% and 3.4%, respectively. • About 2% is exported outside the catchment area • 4.6% is left in the fields to decompose or burnt in the fields.
Punjab	• About 57% of total biomass generated is consumed as animal fodder. • About 5.6% is consumed in Biomass power plants in the region. • About 17% is exported outside the catchment area. • About 12.5% of total biomass is left on the fields because of low density of fuel and lack of proper mechanical equipment to collect and transport the biomass resulting in low collection efficiency.

Table. 3. Stakeholder directly / indirectly associated with biomass project and control group

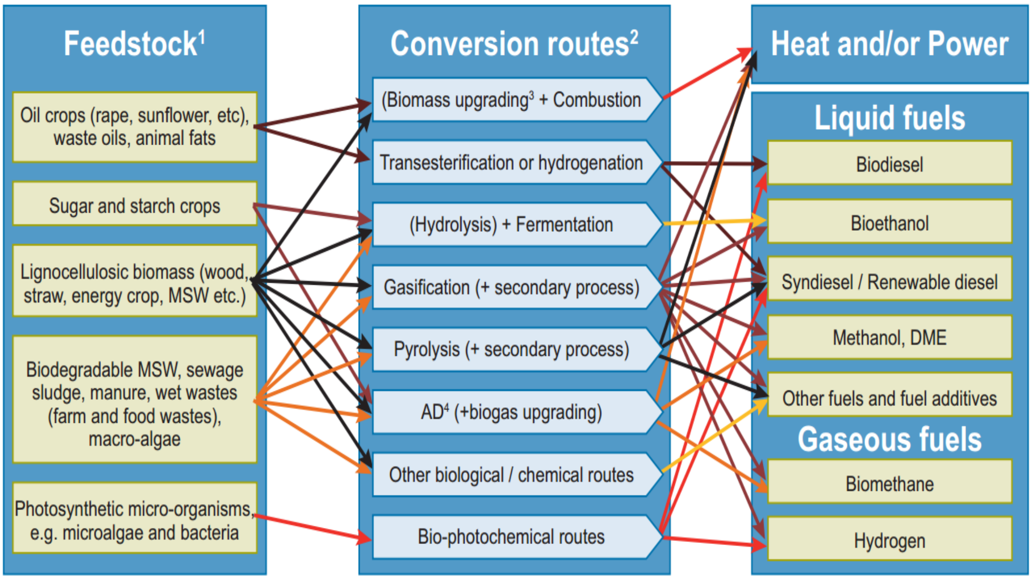
Stakeholder directly associated with biomass project	Stakeholder directly associated with biomass project	Stakeholder (not associated with biomass project and control group)
Employees of biomass	Farmers and labourers	Villagers (not associated with

power projects	associated with Biomass fuel supply chain	farming activities)
Temporary and Contract employees	Transporters	labour, daily wagers (not associated with supply chain)
Vendors (Fuel etc.) and contractors	Farm labour, daily wagers and landless farmers	Shopkeepers & businessman; Employed and unemployed youth / villagers temporarily or permanently migrated)

3.1 Biomass based power production methods

There are multiple ways to produce power from biomass. Most biomass power plants in India (as well as in many other parts of the world) are following the rankine cycle route for biomass based power production. But other well-known technologies – especially gasification – are also being increasingly used. Emerging processes such as pyrolysis could also start contributing in future. The three primary routes for biomass to power are: Combustion, Gasification and Anaerobic Digestion. Combustion is easy to understand – instead of coal or other fossil fuels, biomass is used to produce steam that runs a turbine. Combustion of biomass for power could either be in the form of co-firing (when it is burned along with coal) or pure play biomass based combustion. In the case of gasification, the biomass is first gasified and this gas in turn produces power in a gas engine. Anaerobic digestion is usually applied to biomass that typically has a high amount of water in them (anaerobic digestion is commonly used for treating organic waste such as kitchen waste and sewage waste into energy). Under this route, microorganisms act upon the organic matter present in the biomass under anaerobic (absence of air) conditions and convert it into biogas. An emerging route for biomass based power is pyrolysis. In this, the biomass is rapidly heated to 450 - 600°C in the absence of air, and results in a bio-oil called the pyrolysis oil, which in turn could be used for firing the boilers. Typically, 50 - 75 % (by weight) of the feedstock is converted into pyrolysis oil. Several routes and supply chain are followed for the conversion of fresh and wastes biomass into various products, mainly fuels. E.g., Biodiesel, Bioethanol, Renewable Diesel, Methanol, Pyro-oil, Methane, Hydrogen, synthetic gas, different pesticides, fertiliser etc. (Figure 3 and Figure 4).

The Ministry of New and Renewable Energy, Government of India, has been implementing biomass power/co-generation programme since mid-nineties. India has a total of approximately 500 biomass power and cogeneration projects aggregating to over 5,940 MW biomass based power plants comprising 4,946 MW grid connected and 994 MW off-grid power plants. Out of the total grid connected capacity, major share comes from bagasse cogeneration and around 115 MW is from waste to energy power plants. Whereas off-grid capacity comprises 652 MW non bagasse cogeneration, mainly as captive power plants, about 18 MW biomass gasifier systems being used for meeting electricity needs in rural areas, and 164 MW equivalent biomass gasifier systems deployed for thermal applications in industries. Around 70 Cogeneration projects are under implementation with surplus capacity aggregating to 800 MW. States which have taken leadership position in implementation of bagasse cogeneration projects are Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra and Uttar Pradesh. The leading States for biomass power projects are Andhra Pradesh, Chattisgarh, Maharashtra, Madhya Pradesh, Gujarat and Tamil Nadu. India state-wise/year-wise list of commissioned biomass power/cogeneration projects are shown in table 4.



[1] Parts of each feedstock, e.g. crop residues, could also be used in other routes

[2] Each route also gives co-products

[3] Biomass upgrading includes any one of the densification processes (pelletisation, pyrolysis, torrefaction, etc.)

[4] AD = Anaerobic Digestion

Figure 3. Conversion routes of Biomass to Biofuel Products (Source: EBRI, UK)

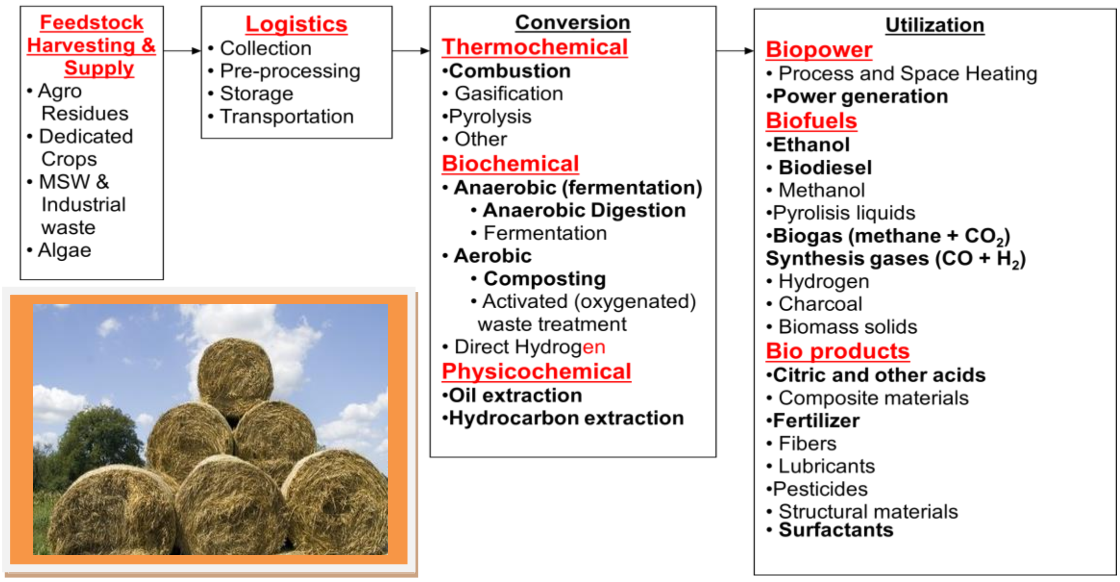


Figure 4. Supply Chain in the Conversion of Biomass to Biofuel Products

Bihar is one of the most poorly-served states in India when it comes to electricity. Husk Power is connecting remote villages in Bihar to a clean, reliable electricity supply, which provides better light, harnesses a widespread waste product and costs less than alternatives. Husk Power's 65 plants gasify rice husks and other biomass waste to supply electricity to around 180,000 people and, by replacing kerosene, they cut greenhouse emissions by over 8,000 tonnes of CO2 a year. The Filling gasifier plant with rice husk, Tamkuha, In figure 4 where Dhaincha is the main fuel for SRE's gasifier plant, Bihar, India, figure 5. Power plants in different states are shown in figure 6.

Figure 5. Filling gasifier plant with rice husk, Tamkuha and Dhaincha is the main fuel for SRE's gasifier plant, in Bihar, India (Source: http://www.ashden.org/winners/husk11 02.10.2016)

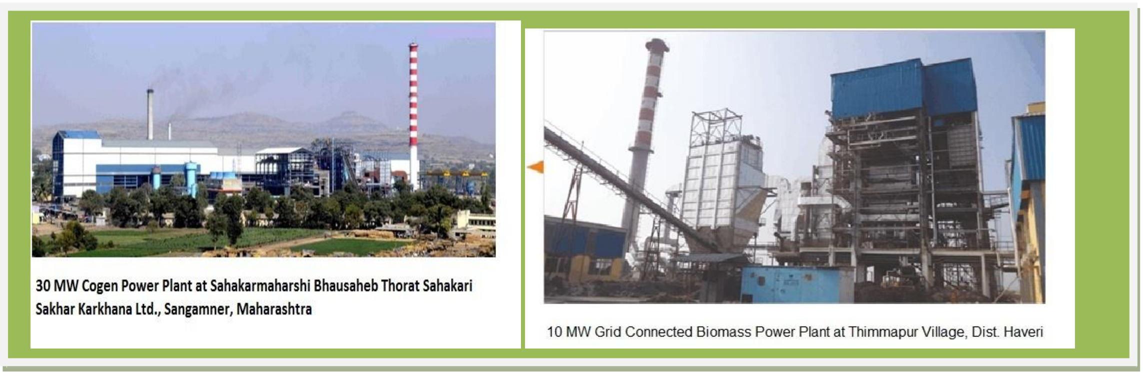


Figure. 6. 30 MG cogen power plant and 10 MW Biomass Power Plant connected to grid in India

Studies project that under the current policy scenarios, India's primary energy demand will double, from 750 Mtoe in 2011 to 1469 Mtoe in 2030 (IEA, 2014). After coal, oil is the country's largest energy source, accounting for about 30.5 percent of primary energy consumption (BP, 2013). The transport sector's share of the country's total primary energy consumption will increase from 8.1 percent in 2010 to 11.3 percent in 2030. As stated in India's National Action Plan for Climate Change (NAPCC), transport emissions can be reduced by adopting a sustainability approach, which includes measures such as increased public transport use, higher penetration of biofuels, and enhanced vehicle efficiency.

Table 4. India state-wise/year-wise list of commissioned biomass power/cogeneration projects (as on 01.04.2016) [Source: MNRE Annual Report 2015-16]

S. No.	State	Upto 31.03.2012	2012-13	2013-14	2014-15	2015-16	Total (in MW)
1	Andhra Pradesh	363.25	17.5				380.75
2	Bihar	15.5	27.92				43.42
3	Chattisgarh	249.9		15	15		279.9
4	Gujarat	20.5	10	13.4	12.4		56.3
5	Haryana	35.8	9.5				45.3
6	Karnataka	441.18	50	112	111	158	872.18
7	Madhya Pradesh	8.5	7.5	10	9		35
8	Maharashtra	603.7	151.2	185.5	184	96.38	1220.78

9	Odisha	20					20
10	Punjab	90.5	34	16	15		155.5
11	Rajasthan	83.3	10	8	7		108.3
12	Tamil Nadu	532.7	6	32.6	31.6	39	626.9
13	Uttarakhand	10		20	20	13	50
14	Uttar Pradesh	644.5	132			93.5	842
15	West Bengal	16	10				26
	Total	**3135.33**	**465.6**	**412.5**	**405**	**400**	**4831.33**

3.2 National Biogas and Manure Management Programme (NBMMP)

Biomass energy consumption is in practice in India since ancient time used in the form of cow dung cake, firewood, husk and many available natural feed stocks. Government of India has taken up a target of installing 1000,000 biogas plants in the year 2016-17 with the existing number of bio gas plants 4,864,000. Biogas Power (off-grid) Programme for decentralized power generation in the range 3 - 250kW and thermal applications during 2015-16 and the remaining period of 12th Five Year Plan was geared up by the government of India to use biomass waste and MSW. Biogas plant are being encouraged by Indian Govt. as they produce no smoke i.e. pollution free. Many subsidies are provided for establishment of the biogas plant. New biomass gasification Technology was also evolved which converts biomass in to syngas, which are more efficient. In India a number of small sizes up to 5tpd are available in urban areas. National Biogas and Manure Management Programme is a Central Sector Scheme, which provides for setting up of Family Type Biogas Plants mainly for rural and semi-urban/households. A family type biogas plant generates biogas from organic substances such as cattle–dung, and other bio-degradable materials such as biomass from farms, gardens, kitchens, msw and night soil wastes etc. The process of biogas generation is called anaerobic digestion (AD) and salient benefits of biogas technology are, (i) It provides clean gaseous fuel for cooking and lighting; (ii) Digested slurry from biogas plants is used as enriched bio-manure to supplement the use of chemical fertilizers; (iii) It improves sanitation in villages and semi -urban areas by linking sanitary toilets with biogas plants; and (iv) Biogas Plants help in reducing the causes of climate change.The Biogas plant is the best option for households having feed material, to become self- dependent for cooking gas and highly organic enriched bio-manure. It provides the solution to protect the households from the problems of indoor air pollution and while saving on cost of refilling of LPG cylinders. The Ministry provides subsidy for family type biogas plants.

3.3 Ethanol and biodiesel Production from Biomass and waste biomass in India

India is the world’s second largest sugarcane producer and a major manufacturer of molasses-derived ethanol. The states of Uttar Pradesh, Maharashtra, Karnataka and Tamil Nadu contributed more than 80 percent of the country’s total sugarcane production in 2010-11 (MoA, 2012). Ethanol in India is primarily produced by the fermentation of molasses. It is estimated that 85-100 kg of sugar (8.5–10%) and 35-45 kg (3.5-4.5%) of molasses can be obtained from 1 tonne of sugarcane whereas the recovery of ethanol from molasses is 22-25%, as per Indian standards (Ravindranath et al., 2005). Theoretically, if the entire sugarcane crop (342.4 Mt in 2010–11) is used for sugar production, estimated molasses production is 15.4 Mt, and the associated estimated ethanol yield is 3.6 billion litres (Purohit and Fischer, 2014). In reality, 70 to 80 percent of sugarcane produced in India is used for sugar production, and the remaining 20 to 30 percent is used for alternative sweeteners (jiggery and khandsari) and seeds (Raju et al., 2009). Moreover, 32.5 percent of the available molasses is used in alcoholic beverages, 25 percent by industry, and 3.5 percent for other applications. The surplus available alcohol is diverted for blending with transportation fuel. (PallavPurohitet al, 2015). Figure 5 shows the Ethanol demand with blending targets (%) in India.

Public sector oil marketing firms will procure 120 crore litres of ethanol to reach the target of 5 per cent blending for petrol by September 2016, which is the end of the crop year 2015-16. “Last year, we procured about 67 crore litres. But this year we will get 120 crore litres and maybe even higher. This would help in about 5 per cent blending for petrol…,” said the Minister of State (Independent Charge) for Petroleum and Natural Gas, after inaugurating a national seminar on ethanol in February 2016. In the States of Uttar Pradesh, the blending levels can go up to 10 per cent which would benefit the farmers. “PSU (Public Service Undertaking)s are in the process of increasing the storage capacity for ethanol. This year PSUs have also started procuring bio-diesel. Out of 85 crore litres that was tendered for procurement, 4 crore litres have come in already. In the next step, we want farmers to produce ethanol from different feedstock like wheat straw, rice straw, corn straw and others,” the minister said. Currently, the production cost of ethanol is ₹42 a litre. It has been found that blending can be raised till 15-20 per cent for both ethanol in petrol and bio-diesel in regular diesel without a major change in existing car engines. “For agricultural water pumps, the blending can even be 100 per cent of bio-diesel,” he added. The Minister said that International Energy Agency estimates India’s crude oil imports to rise to 550 million tonnes by 2040 and increasing use of bio-fuels will help reduce dependence on imports as well as benefit the farmers.

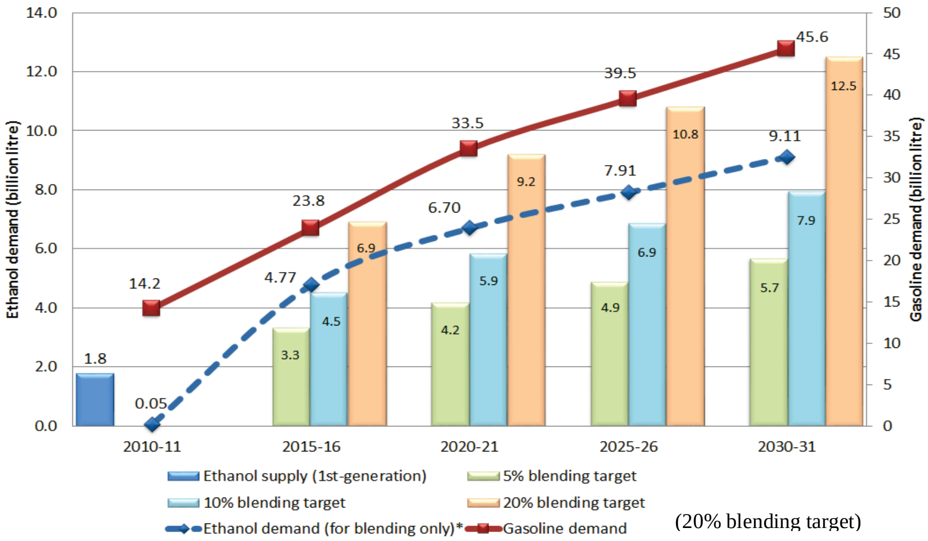


Figure 7: Ethanol demand with blending targets (%) in India

Government of India is planning to take the blending limit of ethanol in petrol to 22.5 % and diesel to 15 % as was said by the central transport minister in July 2016, as also second generation ethanol production from bamboo, rice straw, wheat straw, cotton straw etc to power vehicles. Biofuels are emerging as the most promising alternative options to conventional fuels, as they can be produced locally, and can substitute diesel or gasoline to meet the transportation sector’s energy requirements. Biofuels have positive implications for national energy security, local air quality and GHG mitigation, employment generation, rural development and achieving Sustainable Development Goals. Figure 8 shows the Biodiesel demand with blending targets (%) in India.

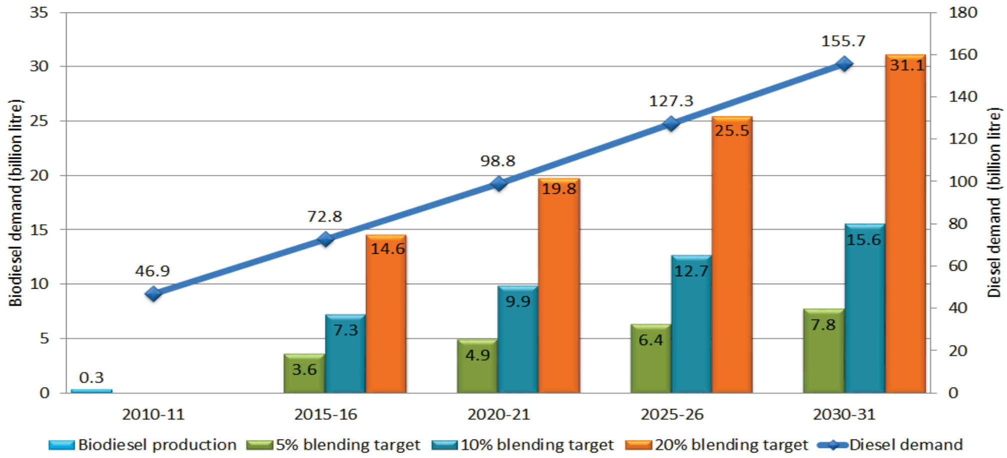


Figure 8: Biodiesel demand with blending targets (%) in India

The central and several state governments provided fiscal incentives to farmers for planting Jatropha and other non-edible oilseeds. Consequently, there were no biodiesel sales. Approximately, 20 Indian biodiesel plants annually produce 140 to 300 million litres of biodiesel (USDA, 2010; Raju et al., 2012), which is mostly utilised by the informal sector locally for irrigation, electricity etc., and by automotive companies for experimental projects. Under a BAU scenario, demand for diesel for transport is expected to grow from 46.9 billion litres in 2010 to 155.7 billion litres in 2030 (Dhar et al., 2015). Figure 6 shows biodiesel demand for the three different blending targets in the near future. Biodiesel demand for 20 percent blending targets is expected to grow 19.8 and 31.1 billion litres in 2020-21 and 2030-31, respectively.

3.4 Energy from fruit waste

India is the second largest producer of fruits and vegetables in the world. Of the 370 Mt of fruits harvested globally, India accounts for 30 Mt. It is the world's largest producer of mangoes and banana. According to reports, 72% of India's vegetable and fruit goes to waste due to improper supply chain, storage and handling. The value of this wastage accounts to INR 333 - 1000 billion annually. Also the decomposed fruit waste becomes a breeding ground for disease and pests. The energy content stored in the fruit waste can be properly channelized to produce clean fuel for biofuel application, heat homes or for cooking. All fruits contain 10% sugar or 5% ethanol, which makes it a suitable feedstock for fermentation.

3.5 Utilisation of algal and yeast biomass

The algal biomass from various sources have been reported from India to have potential for design of a bio refinery to harvest bioenergy and other value added products [(Fathima et al, 2016), (Prajapati, et al 2016), (De Bhowmick, et al, 2015)]. Recently, yeast which was popularly used for whole cell catalysed reactions have also been utilised for harvesting energy. Apart from other value added products (Werpy, et al, 2004), yeast biomass have been recently reported from India to be successfully utilised for biodiesel production (Chopra, et al, 2016).

3.6 Process technology for harvesting energy from biomass

Pyrolysis is well established to be a successful procedure to utilize the energy in the biomass but it has its limitations of being a highly energy utilising process itself (Raveendran, et al,1996). People have also established greener alternatives (Saxena, et al, 2009) like anaerobic digestion and other novel technologies for different types of biomass (Dineshkumar, et al, 2015; Weng, et al. 2008; Simonetti, et al, 2008). But chemical process technology route have not completely been neglected. Hydrothermal liquefaction still remains a successful process for biomass conversion till date (Lee et al. 2016; Déniel, et al. 2016; Lavanya, al, 2016). All the process technologies have been constantly evaluated with respect to commercial implications (Edrisi, et al, 2016; Bhatt, et al. 2016; Motghare, et al. 2016). But still fossil fuels remain a cheaper alternative to energy from biomass. This still prevents us from switching to these greener alternatives. However as the technologies become more precise and optimised, the cost of recovering energy from biomass will definitely reduce to offer us a greener alternative to fossil fuels. In India, pyrolysis process using biomass as feed stock has not been

4 Biomass supply cost

The price for primary biomass is determined by three factors:

1) the supply side factor (technically achievable biomass supply volume with associated cost),
2) the demand side factor (energy demand, land demand associated with food and feed production/energy crop production/and other usages, the price of competing usage (i.e., fossil fuel price, food price)), and
3) the policy factor (i.e., tax incentives, blending mandate).

All three factors are dynamically interlinked and require economic models for detailed assessment. In India, no reliable statistics is available for the price of the residue and waste biomass. The supply cost of each biomass type can be estimated for each region and a bottom-up approach can be applied to estimate the total cost.

5 Key uncertainties for biomass prospects in India

Biomass is relatively a much reliable source of renewable energy free of fluctuation than solar and wind, and does not need storage as is the case with solar. Biomass is not the preferred renewable energy source till now, mainly due to the challenges involved in ensuring reliable biomass supply chain. This is because of the wide range in its physical properties and fluctuation in availability round the year depending on cropping patterns. The supply chain of biomass in India is not robust. Biomass from agriculture is available only for a short period after its harvesting, which can stretch only for 2-3 months in a year. So there is a need to have robust institutional and market mechanism for efficient procurement of the required quantity of biomass, within this stipulated short time, and safe storage till it is finally used.

Existing biomass power plants face the challenge of collecting vast amounts of crop residue for sustained power production. Some of the major barriers faced in faster realization of available biomass power potential for a variety of end user applications are, (i) inadequate information on biomass availability, (ii) absence of organized formal biomass markets, (iii) problems associated with management of biomass collection, transportation, processing and storage; problems associated with setting up large size biomass plants, (iv) non-availability of cost effective sub megawatt systems for conversion of biomass to energy in a decentralized manner, and (v) lack of capability to generate bankable projects on account of financial and liquidity problems, (vi) Policy and regulatory framework, Local, social, and environmental impacts, (vii) Technical assistance and O&M challenges, (viii) Sustainable biomass fuel linkage, (ix) Policy and regulatory support including incentives in different states, and (x) scaling up of different experimental research as implementable project, etc.

The major challenge in ensuring sustained biomass supply at reasonable prices are: Increasing competing usage of biomass resources, leading to higher opportunity costs; unorganized nature of biomass market, which is characterized by lack of mechanization in agriculture sector, defragmented land holdings, and vast number of small or marginal farmers. Another major challenge is the cost of biomass storage and transportation to power plants, which is consistently rising rapidly with time. There is the need to evolve a robust organized biomass market through innovative business models, motivating rural entrepreneurs to take up the responsibility of supplying biomass to processing facilities. There is also the need to develop and exploit energy plantations to take up energy crops on marginal and degraded land, as a substitute for crop wastes. Some of the Indian states leading the pack in establishing biomass based power supply are Uttar Pradesh, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, and Chhattisgarh. Ironically, many states with agriculture based economy, despite good biomass power potential, have not properly been able to utilize the opportunity and figure low in biomass power achievements. Only Uttar Pradesh in north India has utilized large part of the biomass potential, which can be attributed to its sugarcane industry, with cogeneration power plants. There is also wide variation in tariff being offered for biomass power plants in different states. Government policy can play a big role in enhancing the viability of biomass power plants and in supporting investment growth in the biomass power sector in states with high biomass power potential.

5.1 Framework for Biomass utilisation for BoP group for local Economy & inclusive Development

Based on different projects, a potential a framework has been developed (Figure 9) for the Biomass utilisation by the Base of the Pyramid (BoP) marginal group for local Economy Development. The Base of the Pyramid group of people has the closest proximity of the location where biomass is generated with a potential to the local economy development (Ghosh, 2016). The intervention of Multi-National Companies is vital to help the BoP groups in this regard. This will help in many ways, 1) The BoP group will be trained on technologies which will be utilised by the group for effective utilisation of Biomass, 2) keeping their health and environmental impact lower, 3) Knowing the pre-treatment for improved yields, 4) Improving local economy, 5) involving the BoP group in developing their own business, 6) getting better products and services by the BoP group.

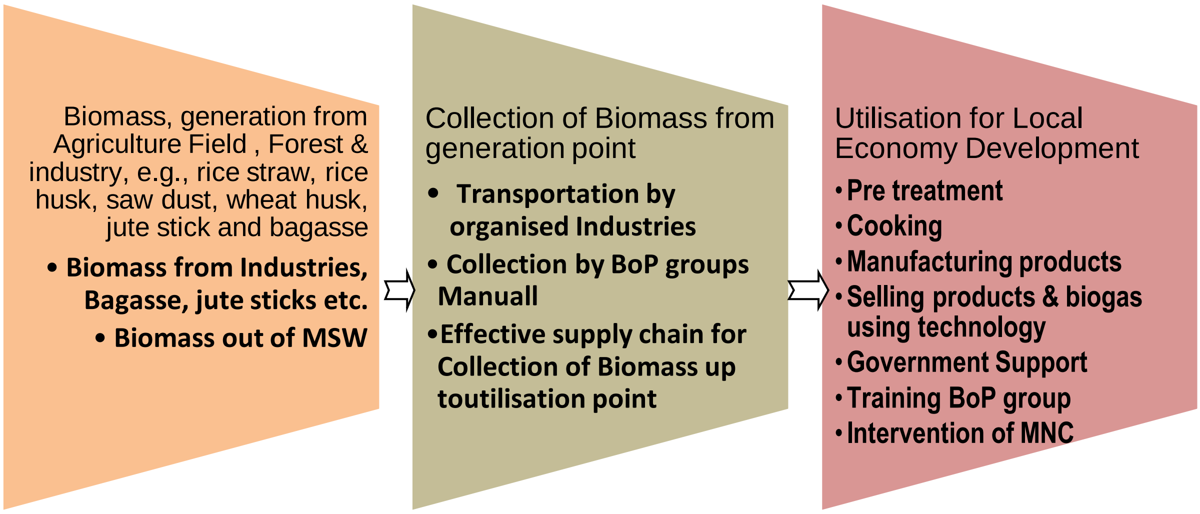


Figure 9. Framework for Biomass utilisation for BoP group for local Economy Development

6 Government of India initiatives

The Ministry of New and Renewable Energy (MNRE) in India has taken up programmes on Biofuels through research, development and demonstration projects at various research, scientific and educational institutes, universities, national laboratories, industry, etc. India has adopted agenda and actions based on the UN post-2015 development agenda – Transforming our world: the 2030 Agenda for Sustainable Development, with 17 Sustainable Development Goals (SDGs) for the people, planet and prosperity reflecting the commitment of shifting on to a sustainable and resilient path. The overall aim of the Integrated Bio Energy Mission would be to contribute to achieve the GHG emissions reduction targets as agreed in the Nationally Determined Contributions at COP 21 through the progressive blending/ substitution of fossil fuels such as coal, petrol, diesel, natural gas and LPG with biomass pellets, bioethanol, biodiesel, biomethane, and similar green fuels, both for electrical and non-electrical uses. The indicative outlay for the Mission would be Rs 10,000 Crore from 2017-18 to 2021-22.The major goals of the National Policy on Biofuels are the development and utilization of indigenous non-food feed stocks raised on degraded or waste lands, thrust on research and development on cultivation, processing and production of biofuels and a blending mandate of 20% Ethanol and Bio-diesel by 2017. The objective of biofuel programme is to support R&D, Pilot plant/Demonstration projects leading to commercial development of 2nd Generation biofuels. (Source: http://mnre.gov.in/file-manager/UserFiles/biofuel_policy.pdf). The ministry supports R & D projects for development of technologies for production of biofuels through Biogas, Pyrolysis and Gasification, besides promoting deployment of technologies for pilot and full-scale projects on biofuels in general.

Besides the Central Financial Assistance, fiscal incentives, concessional import duty, excise duty, tax holiday for 10 years, bank loans of up to Rs 1.5 billion INR for biomass-based power generators will be considered part of PSL etc., are available for Biomass power projects. The benefit of concessional custom duty and excise duty exemption are available on equipment required for initial setting up of biomass projects based on certification by Ministry. In addition, State Electricity Regulatory Commissions have determined preferential tariffs and Renewable Purchase Standards (RPS). Indian Renewable Energy Development

Agency (IREDA) provides loan for setting up biomass power and bagasse cogeneration projects. Formulate of a complete scheme for supporting a feed-stock/ crop-residue supply chain management system incorporating assistance component for harvesting equipment such as balers on the lines of the Punjab Government, setting up of biomass depots, and mechanisms for collection, densification, transportation, and storage is under consideration. A plan has been taken to create a rational and uniform taxation structure to support the growth of this sector. It was also decided to initiate extending all benefits available to other renewable sectors such as customs and excise exemptions, tax holiday etc., to the biofuels sector.

7. Implication towards Sustainable Development Goals

To end the poverty in all its forms everywhere the all India Poverty Head Count Ratio (PHCR) has been brought down from 47% in 1990 to 21% in 2011-2012, nearly halved which is still in its continually enhanced performance in 2016 (http://niti.gov.in/content/goal-1-end-poverty-all-its-forms-everywhere).India will ensure availability and sustainable management of water and sanitation for all and build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation through it Swachh Bharat Mission and other new initiatives. India's CO_2 emissions per capita are 1.8 (metric tons in 2014), one of the lowest in the world, the global average being around 4-5(metric tons). Per capita consumption of electricity has reached 1075 kWh in 2015-16 in India compared to the global average of 2977 kwH, just 1/3rd.The inclusion of energy from biomass wastes will continue the reduction in CO_2 emissions per capita in India. To make cities and human settlements inclusive, safe, resilient and sustainable, India has very recently taken the Smart City Programme. 68% of India's total population lives in rural areas (2013-14).By 2030, India is expected to be home to 6 mega-cities with populations above 10 million. Currently 17% of India's urban population lives in slums. Ensure sustainable consumption and production patterns. India is the fourth largest GHG emitter, responsible for 5.3% of global emissions. India has committed to reduce the emissions intensity of its GDP by 20 to 25% by 2020 (http://niti.gov.in/content/goal-1-end-poverty-all-its-forms-everywhere)..India is taking certain urgent action to combat climate change and its impacts, one of these strands is through the energy recovery from biomass.

8. Conclusion

A sustainable source of biomass is a necessity for any biofuel manufacturing facility as the sources of biomass are highly dispersed in rural areas. The supply chain sustainability of biomass is should be made sustainable by organising 'anchor suppliers' of biomass for any biofuel manufacturing facility. These anchor suppliers could be existing concentrated sources of biomass like sugar mills and rice mills. For other types of crop residues, co-operatives or other local bodies could be encouraged to collect and supply fixed amount of crop residues over a sustained period, the way milk is collected by large cooperatives in many states of India. Standard business cases and effective detailed Project Reports (DPR) for small scale biomass utilisation projects are the need in India for developing local economy. More focus should be given on non-fodder crops for biofuel purposes. Proper awareness and education should be imparted to the farmers by various government schemes & programs. It can thus save a lot of precious foreign currency and protect environment from biomass open burning, which can in turn act as a game changer for the rural economy. It will also generate enough employment in the rural areas. Appropriate Environmentally Sound Technology (EST) for effective utilisation of waste biomass of available character in India in also a need. Capacity Building, Government support, Research and collaboration, Resource Efficiency, Resource

Productivity and standardisation of the energy recovery and possible products from waste biomass need to strengthen in India.

9. The Way Forward

The economic utilisation of biomass and the biomass waste should be considered in mission mode. There are initiatives taken by the government but what is the gap between the implementation of different schemes and the reality of economic utilisation of biomass? Some of the questions must be addressed to resolve various related issues. What is the sustainable business model for economic utilization of biomass waste through small business near the biomass generation points? What strategies should be adopted to reduce CO_2 emissions per capita and inclusive development by involving the base of the pyramid (BoP) people supported by Multi-National Companies and the local governments?

10. References:

Banerjee, Saumita, et al. "Commercializing lignocellulosic bioethanol: technology bottlenecks and possible remedies."Biofuels, Bioproducts and Biorefining, 4.1 (2010): 77-93.

Bhamra Anshul, Shanker Harshini, Niazi Zeenat, 2015, Achieving the Sustainable Development Goals in India- A Study of Financial Requirements and Gaps, Technology and Action for Rural Advancement, New Delhi

Bhatt, B. P., et al. "Fuelwood energy pattern and biomass resources in Eastern Himalaya." Renewable Energy 94 (2016): 410-417.

Bhavik Prasad Mandade, R. Bakshi R, Yadav G. D. “Ethanol from Indian agro-industrial lignocellulosic biomass: an emergy evaluation” Clean Technologies and Environmental Policy (2016) 1-10.

Carriquiry M. A., X. Du X., and Timilsina G. R., “Second generation biofuels: economics and policies,” Energy Policy, vol. 39, no. 7, pp. 4222–4234, 2011. View at Publisher · View at Google Scholar · View at Scopus

Chopra, Jayita, et al. "Integrated in situ transesterification for improved biodiesel production from oleaginous yeast: a value proposition for possible industrial implication." RSC Advances 6.74 (2016): 70364-70373.

Chun-Min Liu Shu-Yii Wu. “From biomass waste to biofuels and biomaterial building blocks”, Renewable Energy 96 (2016) 1056e1062

De Bhowmick, Goldy, LokanandKoduru, and Ramkrishna Sen. "Metabolic pathway engineering towards enhancing microalgal lipid biosynthesis for biofuel application—A review." Renewable and Sustainable Energy Reviews 50 (2015): 1239-1253.

Déniel, Maxime, et al. "Energy valorisation of food processing residues and model compounds by hydrothermal liquefaction." Renewable and Sustainable Energy Reviews 54 (2016): 1632-1652.

Dinesh Kumar, R., Sukanta Kumar Dash, and Ramkrishna Sen. "Process integration for micro-algal lutein and biodiesel production with concomitant flue gas CO 2 sequestration: a bio refinery model for healthcare, energy and environment." RSC Advances 5.90 (2015): 73381-73394.

Edrisi, Sheikh Adil, and P. C. Abhilash. "Exploring marginal and degraded lands for biomass and bioenergy production: an Indian scenario." Renewable and Sustainable Energy Reviews 54 (2016): 1537-1551.

Final Report on Review of Performance of the Grid- connected Biomass-based Power Plants Installed in India, DSCL Energy Services Company Ltd, New Delhi, August 2009.

Ghosh, Sadhan Kumar. "*Biomass & Bio-waste Supply Chain Sustainability for Bio-energy and Bio-fuel Production*" Procedia Environmental Sciences 31 (2016) 31 – 39

Global Bioenergy Supply and Demand Projections for the Year 2030, Irena_REmap_2030_Biomass_Paper_2014

Greenwell, H. C., Loyd-Evans M., and Wenner C. "*Biofuels, science and society*" Interface Focus, vol. 3, pp. 1–4, 2012.

Hoekman S. K., "Biofuels in the U.S.—challenges and opportunities," Renewable Energy, vol. 34, no. 1, pp. 14–22, 2009. View at Publisher · View at Google Scholar · View at Scopus http://niti.gov.in/content/goal-1-end-poverty-all-its-forms-everywhere)

Kumar Anil, Kumar Nitin, Prashant Baredar Prashant, Ashish Shukla Ashish, A review on biomass energy resources, potential, conversion and policy in India, Renewable and Sustainable Energy Reviews 45 (2015) 530–539.

L. Luo, E. van der Voet, and G. Huppes, "Bio refining of lignocellulosic feedstock—technical, economic and environmental considerations," Bio resource Technology, vol. 101, no. 13, pp. 5023–5032, 2010. View at Publisher · View at Google Scholar · View at Scopus.

Lavanya, Melcureraj, et al. "Hydrothermal liquefaction of freshwater and marine algal biomass: A novel approach to produce distillate fuel fractions through blending and co-processing of bio crude with petro crude." Bio resource technology 203 (2016): 228-235.

Lee, Andrew, et al. "Technical issues in the large-scale hydrothermal liquefaction of micro-algal biomass to bio crude." Current opinion in biotechnology 38 (2016): 85-89.

Motghare, Kalyani A., et al. "Comparative study of different waste biomass for energy application." Waste Management 47 (2016): 40-45.

Menon V and M. Rao M., "Trends in bioconversion of lignocellulose: biofuels, platform chemicals & bio refinery concept," Progress in Energy and Combustion Science, vol. 38, no. 4, pp. 522–550, 2012. View at Publisher · View at Google Scholar · View at Scopus

Purohit Pallav, Dhar Subash, Promoting low carbon transport in India, Biofuel Roadmap for India , UNEP DTU Partnership, DTU Management Engineering, Technical University of Denmark, Denmark, Nov 2015

Planning Commission, Report of the Task Force on Waste to Energy (Volume I), May 12, 2014.

Prajapati, Sanjeev Kumar, et al. "A method for simultaneous bio flocculation and pre-treatment of algal biomass targeting improved methane production." Green Chemistry 18.19 (2016): 5230-5238.

Purohit, P., Fischer, G. 2014. "Second Generation Biofuel Potential in India: Sustainability and Cost Considerations," UNEP Risø Centre on Energy, Climate and Sustainable Development, Technical University of Denmark, Copenhagen.

Raveendran, Karuppiah, Anuradda Ganesh, and Kartic C. Khilar. "Pyrolysis characteristics of biomass and biomass components." Fuel 75.8 (1996): 987-998.

Roye Jonardhan, Generating valuable energy from fruit waste, 2009, deccanherald.com

Saxena, R. C., D. K. Adhikari, and H. B. Goyal. "Biomass-based energy fuel through biochemical routes: a review." Renewable and Sustainable Energy Reviews 13.1 (2009): 167-178.

Scheme wise Physical Progress in 2016-17. Report. Ministry of New & Renewable Energy. 31 July 2016. Retrieved 31 August 2016.

Simonetti, Dante A., and James A. Dumesic. "Catalytic Strategies for Changing the Energy Content and Achieving C Coupling in Biomass ‐ Derived Oxygenated Hydrocarbons." ChemSusChem 1.8 ‐ 9 (2008): 725-733.

Sho Yamaguchi, and Baba Toshihide. "A Novel Strategy for Biomass Upgrade: Cascade Approach to the Synthesis of Useful Compounds via CC Bond Formation Using Biomass-Derived Sugars as Carbon Nucleophiles." Molecules 21.7 (2016): 937.
TIFAC Report; http://www.tifac.org.in/index.php?option=com_content&view=article&id=747&Itemid=208

Venkatesh Balan. "*Current Challenges in Commercially Producing Biofuels from Lignocellulosic Biomass*", ISRN Biotechnology, volume 2014 (2014), Article ID 463074.

Weng, Jing-Ke, et al. "Emerging strategies of lignin engineering and degradation for cellulosic biofuel production." Current opinion in biotechnology 19.2 (2008): 166-172.

Werpy, Todd, et al. Top value added chemicals from biomass. Volume 1-Results of screening for potential candidates from sugars and synthesis gas. No. DOE/GO-102004-1992. Department of Energy Washington DC, 2004.