

Biomass, Its Potential and Applications

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Abstract India is an agrarian country with the abundant availability of biomass. Therefore, it is essential to make the best use of the biomass potential. It is indispensable to effectively use this resource so that the problem of energy could be eased. In order to accomplish this objective, an effective and efficient utilization of the biomass is the key. Biomass is the only source of energy that stores carbon into its structure and releases back into the environment upon the use. Uses of biomass for different application results into various operational, environmental, financial and even logistic issues. The aim of this chapter is to make the reader aware of the liberal spectrum of biomass available in general and India in particular. This chapter also presents the utilization of biomass under different technology pathways for various applications and operational issues are discussed. The data is helpful to arrive at the correct technology alternate for the use of a given biomass type.

Keywords Biomass · Renewable Energy · Gasification · Pyrolysis
Fuel

1 Introduction

Humans have been using biomass as a prime source of energy for a very long period of time, in fact, biomass was the first ever source of energy human had used. The innovation of the steam engine in 1698 by a British engineer ‘Thomas Savery’, made coal as an important fuel option. The constant pursuit of technology to get quicker transportation alternate lead to the search of cheap fossil fuel sources, which was

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successful by exploring cheap and abundant oil discovery in the twentieth century. This made petroleum, coal, natural gas based refinery a prime activity for economic consumption of fossil fuel. A significant portion of the global energy requirements depends on these choices. Merchandise such as fuel, fine chemicals, pharmaceuticals, synthetic fiber, plastics, fertilizers and so on, to meet the growing demand, are formulated and employed for solving human need. Wild and inappropriate use of fossil fuel gave birth to large-scale production of carbon dioxide and other harmful gases, at the scale that is several times larger than the capacity of the earth to absorb as a natural sink. Slowly the world started facing the bitter reality of global warming. Today we are in the transition towards the warm earth, due to the greenhouse effect caused because of the excessive use of fossil fuel. The earth is on the cross road to two distinct possible future scenarios. The most optimistic scenario is an environmental abatement of greenhouse gases, whereas irreversible degradation of the global environment is the harsh reality we are drifting towards.

2 Biomass as Renewable Energy Alternative

Large emissions of greenhouse gases accumulated in the atmosphere contributes to the problem of global warming. This situation made renewable energy attractive, particularly biomass. Thus, in that respect there is a renewed interest in the production and use of fuels from plants and organic waste (Naik et al. 2010). Biofuel when produce from the plant or organic waste will help cut dependence on already depleting fossil fuel reserves and avoid the production of greenhouse gases, and help mitigate global warming. Comparing the carbon cycle of fossil fuel and biomass, it can be noted that the production of biofuel is sustainable and therefore follows a closed cycle, while production and use of fossil fuel leads to the accumulation of carbon dioxide in the environment, which is a principal cause of global warming (Kavalov and Peteves 2005). This non-sustainable mode of energy production is one of the causes of environmental degradation.

Biomass is the oldest, and as on date, a major supply of renewable energy. It is the only renewable energy alternative that holds the capacity to absorb the carbon from the environment. Biomass has been a major resource of bioenergy that can offset the economic consumption of fossil fuel and mitigate the environment from the global warming crisis. Currently, biomass is the fourth largest source of energy after coal, oil, and natural gas (Ladanai and Vinterbäck 2009). Various conversion techniques such as physical, thermal, chemical and biological schemes have been utilized in order to produce utilization of biomass as energy resources. Amongst all other fossil fuel options, biomass is observed to have the shortest span of growth and formation of fuel, as it can be viewed from the Fig. 1. Petroleum, natural gas and coal take a longer period to get converted into fuel, this makes them non-renewable in character. Peat is a collection of partially decayed vegetation, available from natural areas called peat lands which is essentially forest areas, the products of which is set aside to be employed as a fuel due to environmental concern.

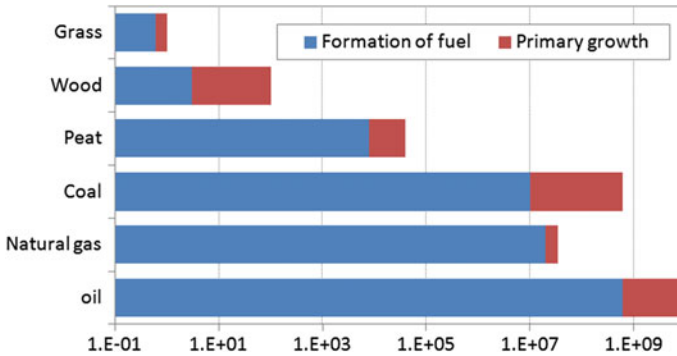


Fig. 1 Stations of Carbon during a growth and formation of fuel (Judex 2010)

Wood and grass are the most frequently used biomass materials for energy. This category of biomass has the capability to replenish in a short span, and thus affected as a renewable energy reserve (Judex 2010).

2.1 Biomass Potential

Biomass is certainly an only renewable energy option, which is having potential to store carbon into its structure with the help of photosynthesis activity. The selection of biomass is even more hopeful given the fact that the biosphere is witnessing large potential of photosynthesis and can play as a large carbon sink. It is possible to achieve a sustainable bioenergy supply of at least 270 EJ and that can satisfy almost 50% of the global primary energy need (Ladanai and Vinterbäck 2009).

As per an estimate, the production of biomass on the earth is around 100 billion tons on land (Naik et al. 2010). Sun is the principle source of exergy on the earth, which makes the biosphere act as a vast biomass generation facility. The energy of the sun is utilized on the earth for a different activity, towards natural decay and growth of vegetation, utilization towards human activity, etc. It is important to mention here that the energy from the sun will not be reduced, but its capacity to do the work or exergy will be destructed. Figure 2 shows the flow of such exergy as it is released from the sun in the process of decay or it may be used by the humans for the purpose of releasing energy. The values quoted in the bracket show the progressive reduction in the exergy values. Out of 86 PW delivered by the sun to the earth is in the form of radiant energy. Out of all this, radiation, 90 TW is utilized by photosynthesis to the plants, this is the net primary production (NPP) and includes land biomass (65 TW) as well as marine biomass (25 TW). This NPP is utilized to add to the reserves of plants on the earth in the form of terrestrial biomass reservoir. The reservoir is assumed to be as large as 30 ZJ. A similar reserve of marine plants may be contributed (0.15 TW) which eventually goes to decay and will be buried in the deep earth to be converted into fossil fuel. Out of the land, biomass reserves

human use are responsible for the exergy destruction equivalent to 15 TW of biomass. Note that any additional use of a portion of the terrestrial biomass reservoir of 30 ZJ may lead to a reduction in the land plant reserves. This is what has been observed in the recent past, the land use change is responsible for a reduction in the natural forest and reserves on the land, and such irreversible degradation of environmental sink is responsible for the decrease in the carbon absorption capacity and increase in global warming phenomenon. Out of this around 5 TW of human use are associated with harvest of wood. This activity resulted into 1.5 TW of exergy destroyed through the utilization of biomass for burning. Another 5 TW of exergy destruction is in the form of vast reserves of plant that is grown due to agricultural activity in the form of agro products. Out of this only 0.8 TW is the useful product and the production of transportation fuel, 0.02 TW (e.g. 30 billion liters of ethanol are utilized for producing ethanol) as well as the remaining exergy is locked in the form of agro residues. This indicates the huge potential of biomass is still available for generation of energy through the use of agro residue.

Previous discussion leads to some interesting conclusions. It is interesting to note that out of the total global biomass production, forest contributes largest option of biomass reservoir and has the greatest potential in terms of the return of energy (Table 1). The potential of growth and productivity of forest reservoir is also high amongst different alternatives. This helps one to infer that growing biomass under forest reservoir has the highest capacity not only to store carbon but also to recycle the same from the energy point of view. The example of use of agro residue is an attractive alternate and superior compared to the use of forest biomass reserves. Since using agro residue, the dual objectives can be achieved, i.e. obtaining food as well as energy from residue.

Biomass contributes about 12% of today’s world primary energy supply, while in many developing countries, its contribution ranges to even 40–50%. Use of biomass has certain distinct benefits such as, renewable in nature, and in most of the cases a source of indigenous fuel that help improve energy security of a nation.

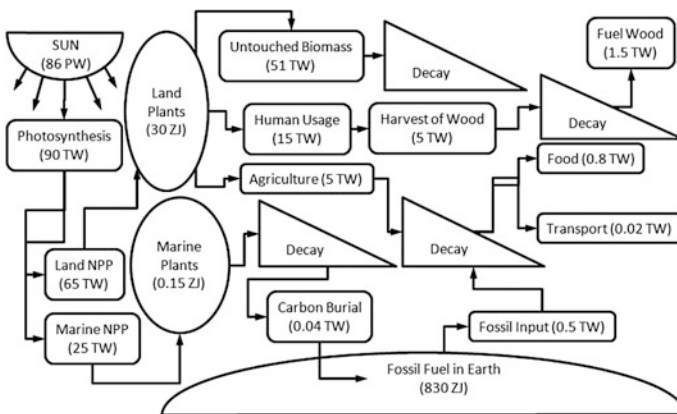
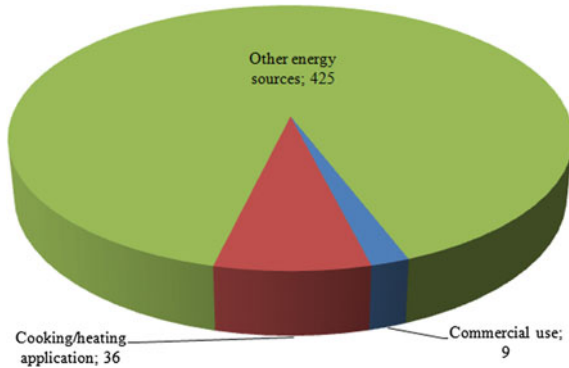


Fig. 2 Exergy flow through the terrestrial biomass system [adapted from (Hermann et al. 2005)]

Table 1 Biomass production and productivity (Adapted from Hermann et al. 2005)

Biomass	Forests	Savanna and grasslands	Swamp and marsh	Other terrestrial
Biomass reservoir (ZJ)	29	1	0.5	1
Biomass per area (MJ/m ²)	600	40	250	10
Net productivity (TW)	42	10	3	9
Surface area (10 ⁶ Km ²)	48.5	24	2	74.5

Fig. 3 Contribution of biomass in global primary energy demand of 470 EJ (2007) [Adapted from (Ladanai and Vinterbäck 2009)]



Utilization of biomass as a fuel also offers an opportunity of rural employment, if not utilized as a fuel, its natural decomposition will produce harmful gases such as methane (CH₄), which is causing a global warming potential (GWP) 20 times greater compared to CO₂, this is also one of the causes why it is indispensable to use biomass. Biomass does not contain sulfur so no SO₂ is produced and offers low NO_x when burned. Its use result in reduced economic pressure on the economy, due to lower cost of biomass. However, use of biomass as an energy source has certain limitations also. They are as follows - it differs to the other options in terms of variability of resources, the use of biomass is suitable to low or medium application due to poor perennial availability, poor supply chain management, low energy density, high moisture content, etc.

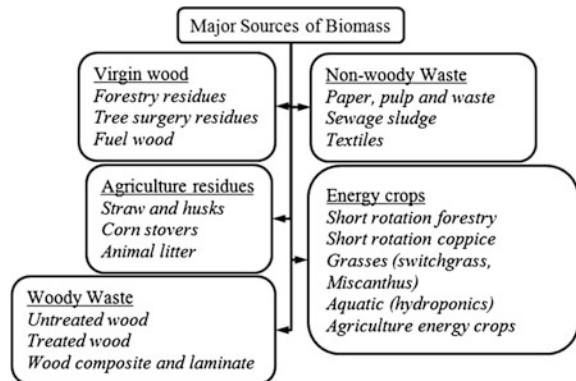
The above-mentioned advantages and limitations when evaluated, it is found that there is a long way to go for biomass to be used as fuel compared to conventional energy options. The effect is reflected while summarizing global primary energy usage (Fig. 3). It is mentioned that commercial use of biomass is limited to just 2% of the amount. The continuing use of biomass is found limited to the cooking and other thermal applications. The use is essentially limited in rural regions and associated with inefficient use of biomass. Use of biomass is largely limited to underdeveloped and developing economy and less prevalent in developed

countries. However, the issue of global warming has renewed interest in the use of biomass. Use of forest and wood scrape consists of nearly half of current biomass usage, while the bulk of the balance of biomass use is intended for the production of biofuels (Kushwaha 2011).

A large diversity in the supply of biomass is associated due to the different source of origin, drying of wood, different size, and so on. These factors result in large variability in the biomass resource supply, the variation can be divided into the four categories (Fig. 4); biomass generated due to wood waste, agricultural residue, and residue collected from forests (trees, wood and logging residues, bark, plant and leaves). Another category is human induce wood waste, this includes waste generated from industrial activity like, paper and pulp industry waste, waste generated from the textile industry, and waste due to sewage sludge (Lewandowski et al. 2012). Another source from this category is dedicated biomass grown for energy, short rotation crops, herbaceous plant, bagasse, from management of forest and from aquatic source such as algae and water weeds (Ciubota-Rosie et al. 2008). Miscanthus (average yield 15 t/ha/year) and switchgrass (average yield 10 t/ha/year) are the two grass types grown on wasteland especially for the energy purposes (Kavalov and Peteves 2005).

Traditionally, the use of wood logs obtained from trees is the oldest type of fuel source. Due to its low surface area and high moisture content it can be used only for low heating rate applications. Wood logs have other non-energy uses, e.g. for paper and pulp production, furniture industry, etc. This type of use of biomass is not sustainable due to large mismatch in the growth and consumption pattern. To counter this limitation, option of short rotation biomass forestry is adopted, since the cultivation and harvesting consumes much lesser cost (around 4%), the dedicated plants grown for energy purpose are managed for regular dressing and removal. Growing willow and poplar are two most popular selections, under this it is possible to increase the output of biomass to 10–15 t/ha/year, which is normally in the range of 5–10 t/ha/year. Option of planting such dedicated tree at a certain distant location in the existing farm along with wheat and rice crop is another alternate. Wood collected from short rotation forestry many times loses its source, hence this type of

Fig. 4 Sources of biomass for energy production (Ladanai and Vinterbäck 2009)



wood is essentially heterogeneous in nature. The material obtained under this category is high in moisture and requires pre-drying, moisture content in the forest residue account for 20–45% of the harvested wood (Judex 2010).

Drying of wood is essential for effective heat release. Drying can be carried out in three possible ways; by natural drying in which moisture can reduce from 50–55% to 35–45%, by forced drying either by passing waste heat or by making pellets of biomass, both can reduce the moisture to less than 7% and can benefit in terms of calorific value, transportation, storing, etc. However, energy cost may rise by 7–10% of the net available. It is worth noting that more than 15% of moisture content will encourage bio-degradation of material and development of fungi and bacteria (Judex 2010).

The large agricultural residues are another source of biomass. Table 2 gives an idea of vast possibility of the biomass as a source. It is possible that the ample amount of biomass can also be made available from the agricultural activity, this is in terms of residue, husk, straw, and other residues of the crop. Crops such as rice, wheat, sugarcane are prime choice, the residue of these crops can be targeted for use as a waste. Significant potential of these lignocellulosic biomass is available for possible use, given the fact that, biomass under this category accounts for about 50% of the total inventory of biomass in the world, which measures up to around 10–50 billion tons (Claassen et al. 1999). A survey of the global agricultural production suggests that Asia is the hub of large agriculture activity involving these crops, followed by North and Central America. Residue straw from different crops is an example of herbaceous material; which could be made available at relatively low or negative price in most of the instances. Straw has a lower bulk density, lower calorific value and high ash content (Kavalov and Peteves 2005). Given the fact that 23% of rice straw residue produced in India, 48% in Thailand, and around 95% in the Philippines burns in open field (Gadde et al. 2009), possibility of use of residue straw is large. The use of corn residue is well developed in the USA and Brazil. The residue is utilized by way of producing biodiesel to be used as transportation fuel.

Table 2 Estimated global production of major agricultural crop (MMT) § (Reprinted with permission © Springer)

	Asia	Africa	Australia	Europe	N&C America	South America	Oceania	Total
Rice	513	16	~	3	10	18	24	562
Wheat	230	23	~	127	96	21	~	585
Cane	505	80	40	~	156	404	45	1192
Corn	155	44	~	60	264	48	1	576
Soyaben	21	~	~	1	67	39	~	130
Beet	36	4	~	188	25	3	~	255
Potatoes	89	8	1	156	28	12	1	295
Sweet potatoes	124	7	~	~	1	1	~	234
Cassava	46	85	~	~	1	31	~	163

§FAO production year book, 1996 referred in Claassen et al. (1999), ~ negligible quantity

If the biomass potential is assessed from an Indian perspective, one can notice that cotton stalk, sugarcane and rice could also be a principal crop residue that can be targeted for biomass energy (Table 3). Cotton stalk is an attractive fodder for the cattle and hence it has a strong alternate value chain. Sugarcane is largely used as a fuel for cogeneration plant for the sugar industries. However, the use of rice residue is an attractive alternate since rice straw generated in the field is not a preferred fodder alternate. Use of maize cobs can be explored further under fermentation route to extract energy. Crop and wasteland are two alternates that can be explored, but wasteland is highly stressed due to the change of land use and the quantity of this type of biomass obtained tends to reduce with the passage of time. Municipal solid waste is also a good potential to explore, but it requires a well-developed supply chain management. Use of '*Jatropha curcas*' can be another good potential, however, its use is under scanner due to 'fuel-for-food' debate. Cattle dung also needs strong supply chain management and segment is highly unorganized.

One of the biggest limitations in the usage of biomass residues are poor supply chain management. Poor volume density and low calorific value are the main reasons which make them unattractive from the transportation point of view. The limitation to carry over a long distance limits an alternate supply chain. This fact is demonstrated with the help of density statistic for straw under various compacting options as presented in Table 4, as it proceeds from the field under various options of its utilization, the corresponding density change is shown in the table. To begin with, the fresh straw has density of the order of 50 kg/m³; the filling will increase its density to some extent, chopping and drying can further help to increase its density.

Table 3 Bioenergy potential for India (Ravindranath and Balachandra 2009) (Reprinted with permission © Elsevier)

Feedstock	Area (Mha)	Biomass potential	Pathway	Qty. (MT/year)	Energy potential
Rice	46.1	Straw + husk	Gasification	41	4700 MW
Maize	6.6	Stalk + cobs		6.2	700 MW
Cotton + coconut	16.8	Stalk, coconut shells		240	28,000 MW
Sugarcane	5.5	Bagasse + leaves	Cogeneration	163.5	8900 MW
crop land	14	Woody	Gasification	84	9700 MW
Waste land	28.5	Mixture and woody		171	20,000 MW
MSW		organic matter	Biomethanation	56	6500 MW
<i>Jatropha curcas</i>	65	1.50 MT of oil seeds	Biodiesel for transp.	3.23	34.11 PJ
<i>Jatropha curcas</i>	13.4	<i>Jatropha curcas</i> oil	Biodiesel for transp.	16.08	530.6 PJ
Sugarcane	5.5	Ethanol	Transportation fuel	20.9	562.2 PJ
Cattle		Dung	Biogas for cooking	344	336 PJ

Making pellets are a better option to compact the straw, this will enhance its density due to compaction as well as removal of moisture from the biomass due to heat during the process of pelletization. It is possible to achieve a density of around 1000 kg/m^3 by pelletizing.

Table 5 shows the Indian scenario of the potential of residue for the crops produced in India. It is important to mention that not all biomass available in the form of residue can be practiced for the energy purpose. For example, coconut fronds has strong alternate supply chain system and hence cannot be made available for the energy use, the same is true for banana residue (Singh and Gu 2010). Out of them all, rice and wheat are promising residues that could be utilized for energy use.

Rice-wheat growing pattern is very popular in South Asian countries, which includes India, Pakistan, Bangladesh, Bhutan, and some parts of China. The rice and wheat straw are an important second-generation biomass material. This establishes the potential of agro residue derived from rice and wheat cultivation is a significant one in South Asian countries. More than 85% of the RW (Rice-wheat) system practiced in South Asia are located in the Indo-Gangetic Plains (IGP). Nearly one-third of the total grains of India are produced in this area. In India, the IGP covers about 20% of the total geographical area (329 Mha) and produce about 50% of the total food consumed in the country (Chauhan et al. 2012). It is estimated that approximately 45 and 35% of the harvested over-ground biomass are accounted towards wheat crop, grain and straw respectively (Claassen et al. 1999). Rice-wheat (RW) cropping system are critical for food security of India. As much as 10 million hectares of land are engaging in rice and wheat production in sequence (Table 6), which expands to about 85% of the total cereal production. This crop system engages around 150 million people in South Asia (Chauhan et al. 2012). In the state of Punjab (India) alone rice and wheat cropping is observed in about 60 and 80% of the total land respectively. It is surprising to note that around 90% of rice straw alone is burnt each year in Punjab, India. The statistic suggests possible utilization of rice straw for power generation as a strong biomass alternate.

Table 4 Density of straw and grass in different form (Lewandowski et al. 2012)

State	Density (kg/m^3)
Fresh (green)	50
Standard fill	85–100
Dried and chopped grass pellets	170–380
Bale (grass)	120–150
Compact roll	350
Bale (straw)	800–1200
Dust (crops)	150
Pellets (bulk straw)	540–660
Pellets (single, straw)	1100
Pellets (agricultural)	950–1250
Pellets (grass)	1300
Oil (rape)	920
Pyrolysis oil	1200–1300

Table 5 Production of crops and availability of residue in India (Singh and Gu 2010) (Reprinted with permission © Elsevier)

#	Name of crop	Per year, KMT	Type of residue	Residue as % of crop
1	Arhar	1950	Husks-Stalks	30-250
2	Bajra	7690	Cobs-Husks-Stalks	33-30-200
3	Banana	80,000	Residue	300
4	Barley	1200	Stalks	130
5	Coconut	13,125	Fronks-Husks-Shell	400-53-22
6	Rice	1,45,050	Husks-Stalks-Straw	20-150-150
7	Sugarcane	2,76,250	Bagasse-Top and leaves	33-5
8	Wheat	78,000	Pod-Stalks	30-150
9	Maize	18,500	Cobs-Stalks	30-200
10	Rubber	825	Primary wood-Secondary wood	300-200

Table 6 Area under Rice–Wheat cropping system in various Asian countries (Adapted from Chauhan et al. 2012)

Country	Area (Mha)	Rice (%)	Wheat (%)	Total (%)
China	13	31	35	72
India	10.3	23	40	85
Pakistan	2.3	72	19	92
Bangladesh	0.5	5	85	100

2.2 Biomass as a Feedstock

Biomass feedstock can also be classified based on the way it influences the environment. A tentative classification is presented in Fig. 5. The first generation of biofuels is selected based on the premise that biomass releases the same amount of CO₂ when burned which it absorbs and captures during its growth. Various aspects of economic consideration and increased energy security prompted the use. This trend is significantly reinforced with the growth in the price of fossil fuel. Another consideration made in the first-generation biofuel is the substitution of fossil fuel in existing infrastructure. Biofuels like biodiesel, bio-ethanol and biogas are examples under this category. Its ability to blend with the existing fossil fuel type and possible use of the existing engine facility make biofuel of the category a relatively easy task. Today world is witnessing the commercial success of the first generation of biofuel with approximately 50 billion liters of biofuels produced annually.

The popularity of biofuel is questioned from the environmental considerations. The release of greenhouse gases from the use of such biofuels are a concern for the environment and in turn for human beings. This issue puts environmental impacts and carbon balance of products and technology pathways under scanner. The case is sufficient to highlight the disadvantage of first-generation fuel and is proving that

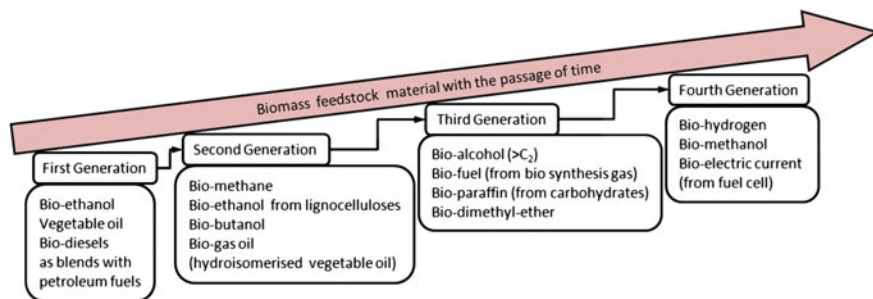


Fig. 5 Classification of biomass based on its chronological use of energy and chemicals [Adapted from (Lako et al. 2008)]

these types of fuel are not sustainable, and it puts stress on existing use of land. There is a debate over whether the race of scarifying food-for-fuel is justified, especially when a large sections of humankind is malnourish and has a scarcity of food. This involves people from Africa that includes large numbers of malnourished children (Naik et al. 2010).

Second-generation biomass are a biomass option that arises out as an alternate to the limitation of first-generation biomass (Naik et al. 2010). The want of a sustainable biomass fuel source gave birth to the second-generation biofuels. Second-generation biofuels is produced from Lignocellulosic biomass, primarily derived from agro residues or ‘plant biomass’. The line of reasoning in favor of this feedstock is; cheap and abundant availability and its lower price sensitivity to the existing food cycle and not competing right away with food. Few of the feedstocks worth mentioning are agriculture and forestry residue, weed, aquatic biomass, and water hyacinth, etc. These biomass materials are burned conventionally in an inefficient manner and in some cases leads to release of harmful aerosols posing threats not only to the environment but also to human lives. Likewise, if not utilized and left unattainable in the fields, these feedstocks may lead to the decay and be responsible for the release of methane (which is having even greater environmental threat). Therefore, the use of second-generation biomass may result in lower cost and greater capability to tackle the environmental problem and hence it is the most effective route to renewable, low carbon energy for road transport. The products in this category are, hydro-treated oil, bio-oil, Fischer-Tropsch (FT) oil, lignocellulosic ethanol, butanol, mixed alcohols. The technology for the second-generation biomass are in progress, a number of technology barrier that need to be overcome and therefore large-scale production of second-generation biofuels are a distant reality. Conversion process of second-generation biomass involves thermochemical as well as biochemical routes. Under thermochemical processing biomass are subjected to thermal decay and chemical reformation by heating biomass in an environment of different concentrations of oxygen (Naik et al. 2010).

Third and fourth generation biomass feedstock take care of not only the economic and environmental concerns, but its use results in societal benefit as well and

thus addressing all aspects of sustainability (economic-environmental-societal). One of the examples of third and fourth generation biomass feedstock is ethanol-gel, which is a clean burning fuel made-up of gelatinized ethanol bound, thickened by cellulose and water. The feedstock can be readily used with an existing cook stove with slight modification in design. The fuel gives clean smokeless combustion, which presents a drastic decrease in CO_2 emission and hence leads to a decrease in indoor air pollution. The improved combustion results in higher combustion efficiency of around 40%. In a separate study an LPG-assisted conventional cook stove is compared with gasifier based cook stove using rice husk as fuel. The testing results along with an economic analysis for the gasifier based model after a successful field operation of 2 years are reported (Suvarnakuta and Suwannakuta 2006).

3 Assessment of Biomass

It is indispensable to evaluate suitability of a fuel option for the purpose of employment to obtain energy. Prof. Van Krevelen suggested a simplified diagrammatic method to identify the suitability of fuel option based on its molar ratio. He defined the zone for different fuel options (Fig. 6). From the figure, it is observed that a fuel with the lower value of (H/C) and (O/C) gives a high quality of fuel. Under this mode of classification it is possible to allocate definite zone for a particular type of fuel or its constituents, anthracite and coal will occupy lower value of H/C and O/C, followed by lignite and peat. Biomass is the next fuel option and occupies a wider range of the variation. Due to the higher oxygen content, biomass has a high score on O/C ratio.

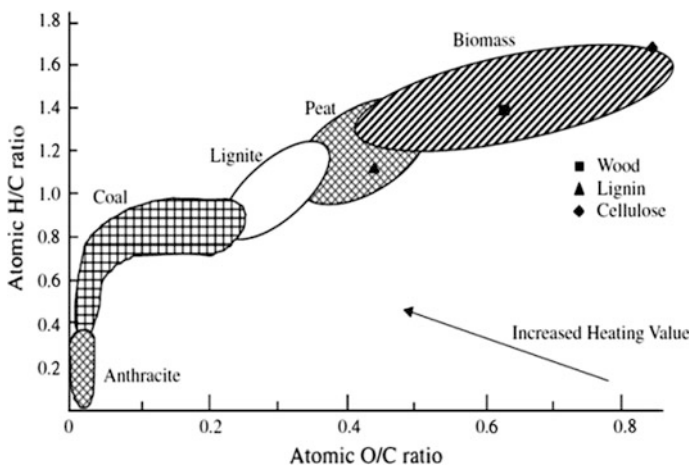
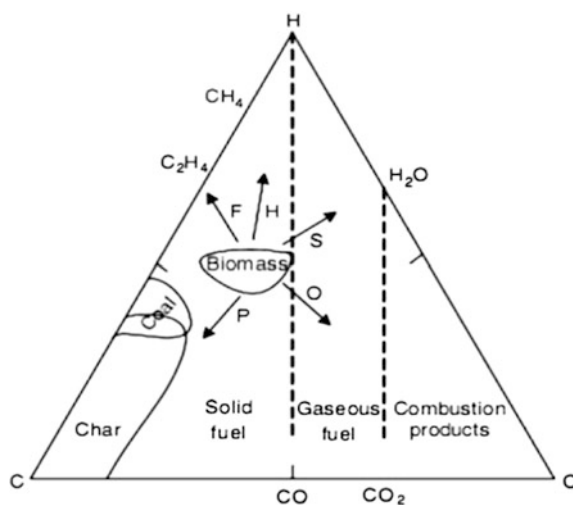


Fig. 6 Van Krevelen diagram. Plot of fuel for H/C and O/C ratio (Judex 2010; Prins et al. 2007)

Some other popular method of mapping the fuel structure is by the use of C–H–O diagram. The advantage of using this three-axis diagram is that on this diagram not only the biomass feedstock can be precisely figured, but this can also depict the effect of biomass change, when followed by a particular conversion process. It is also possible to identify clearly core zones, solid zone as well as gaseous fuel zone. One such example is as shown in Fig. 7. The state of biomass is shown on the diagram and the occurrence of different processes on the path are shown on this. For instance, H shows the process of biomass treatment by addition of hydrogen, S shows the use of steam for processing of biomass, O shows the addition of oxygen, P shows slow pyrolysis and F shows fast pyrolysis treatment of the biomass material.

Suitability of biomass feedstock is ensured predicting different constituents of biomass. This is obtained by carrying out different types of analysis, which is useful to predict the various constituents of biomass. Lignocellulosic biomass is made of three basic structural units - cellulose, hemicelluloses and lignin. Cellulose is a simple and crystalline glucose polymer, while hemicelluloses is an amorphous polymers of xylose, arabinose. Lignin a large poly-aromatic compound consists of 3D structure and gives the biomass much needed rigidity and support (Naik et al. 2010). Heating value of dry biomass is around 17 MJ/kg. Out of the basic component of the biomass, cellulose (17 MJ/kg) and lignin (25 MJ/kg) contribute to the list and maximum respectively to the calorific value of biomass. Out of two fundamental building blocks (C and H), C has a mass fraction of 0.48 kg/kg and a molar fraction of 40.36 Mol/kg, while energy from the combustion as -15.88 MJ/kg. H has a mass fraction of 0.0298 kg/kg and a molar fraction of 27.56 Mol/kg, while energy from the combustion as -6.67 MJ/kg (Judex 2010). One such comparative analysis of herbaceous, woody and waste biomass is as shown in Table 7. It is important to note that the woody biomass contains a high percentage

Fig. 7 Location of Biofuels in ternary C–H–O diagram (Basu 2010)



of lignin, which is having high carbon content and effective use of this carbon would give high calorific value. Herbaceous type of fuel has high quantity of cellulosic and hemicellulosic parts. Since the cellulose and hemicellulose contain relatively simple construction and therefore possess lower quantity of carbon content compared to lignin, which is essentially a 3 dimensional structure. Lower carbon content in turn gives lower calorific value as a fuel.

The detailed characterization of biomass as a fuel material is as shown in Table 8. Compared to coal it is observed that although the ash content of coal is high, however, very low moisture content and high amount of carbon content makes it dense and energy efficient and results in high net calorific value. High H content and low O content make coal an ideal choice for higher calorific value fuel. However, large S content goes against a selection of coal as a good fuel option. Comparing different biomass material it is noticed that poor density can have certain operational issues. This can be overcome by making pellets to improve the operation. Another important issue in the case of the use of biomass is low melting temperature of ash due to high minerals in biomass. Such melting can form clinker and agglomeration and in extreme case can choke the combustion chamber. This type of phenomenon can occur frequently in the case of rice straw (due to the high silica content) and use of poultry litter (high mineral content) as fuel under gasification route.

Elemental analysis along with specific exergy is another way of determining suitability of biomass as a fuel option. Table 9 indicates these data for the different biomass materials. It is easy to observe that large carbon content gives higher specific exergy for the biomass material. However, while in operation different proportion of moisture content may affect the results to a large extent. It is essential to estimate the calorific value for the biomass in order to access the suitability of the fuel. An empirical rule for finding the energy capacity of biomass (MJ/kg) are given by Eq. (1) (Judex 2010) and Eq. (2) (Channiwala and Parikh 2002) given as under:

$$\text{LHV} = 34.8C + 93.9H - 10.8O \quad (1)$$

$$\text{HHV} = 34.91C + 117.83H - 10.34O - 1.51N + 10.05S - 2.11\text{Ash} \quad (2)$$

Table 7 Biomass composition and properties [Adapted from (Hermann et al. 2005)]

Biomass component	Bermuda grass (herbaceous)	Poplar (woody)	Pine (woody)	Refuse fuel (waste)	Carbon content	HHV (MJ/kg)
Cellulose	32	41	40	66	40–44	17
Hemicellulose	40	33	25	25	40–44	17
Lignin	4	26	35	3	63	25
Protein	12	2	1	4	53	24
Ash	5	1	1	17	0	0

Table 8 Properties of biomass considered as feedstock (Adapted from Kavalov and Petevs 2005)

	Coal	Wood	Forest residue	Wood chips	Wood Pellets	Cereal straw	Energy crops
Ash (d%)	8.5–10.9	0.4–0.5	1.0–3.0	0.8–1.4	0.4–1.5	3.0–10	6.2–7.5
Moisture (w%)	5.0–10	5.0–60	50–60	20–25	7–12.0	14–25	15–20
NCV (MJ/kg)	26–28.3	18.5–20	18.5–20	19.2–19.4	16.2–19	16.5–17.4	17.1–17.5
Density (kg/m ³)	1100–1500	390–640	–	250–350	500–780	100–170	200
Volatile (w%)	25–40	>70	>70	76–86	>70	70–81	>70
Ash melting (°C)	1100–1400	1400–1700	–	1000–1400	>1200	700–1000	700–1200
C (d%)	76–87	48–52	48–52	47–52	48–52	45–48	45.5–46.1
H (w%)	35–5	6.2–6.4	6.0–6.2	6.1–6.3	6.0–6.4	5.0–6.0	5.7–5.8
N (d%)	0.8–1.5	0.1–0.5	0.3–0.5	<0.3	0.27–0.9	0.4–0.6	0.50–1.0
O (d%)	2.8–11.3	38–42	40–44	38–45	40	36–48	41–44
S (d%)	0.5–3.1	<0.05	<0.05	<0.05	0.04–0.08	0.05–0.2	0.08–0.13
Cl (d%)	<0.1	0.01–0.03	0.01–0.04	0.02	0.02–0.04	0.14–0.97	0.09
K (d%)	0.003	0.02–0.05	0.1–0.4	0.02	–	0.69–1.3	0.3–0.5
Ca (d%)	4–12	0.1–1.5	0.2–0.9	0.04	–	0.1–0.6	9

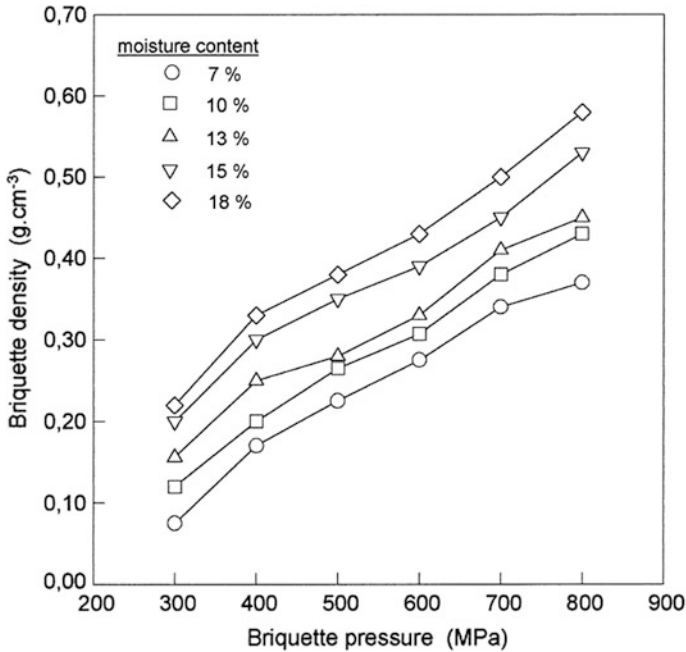


Fig. 8 Effect of pressure on the wheat straw briquette density (Demirbaş and Şahin, 1998)

Table 9 Specific Exergy on dry basis of certain biomass materials (Adapted from Hermann et al. 2005)

Biomass	Elemental mass fraction (%)		Sp. exergy (MJ/kg)				
	C	H	O	N	S	Ash	
Poplar	49	6	43	0	0	1	19.2
Corn stover	44	6	43	1	0	6	18.2
Bagasse	45	5	40	0	0	10	17.8

4 Use of Biomass as Fuel

Conventional use of biomass for energy generation, that includes heat as well as electricity, depends on several factors. Few of them are—type of biomass, available quantity, the application for which energy is intended, capital investment and operational issues, availability of resources for operations, existing supply chain for biomass. Biomass utilization in the existing thermal and power generation application is prompted by economic considerations. Few successful applications are listed as below:

- Substituting part of fossil fuel by means of co-firing of biomass in existing coal-fired boiler application.

- Use of biomass for cooking and drying application (fish drying, onion drying), small gasifiers for cooking using rice husk, pellets of rice straw, wheat straw or bagasse, etc.
- Use of biomass for cooking, that save the use of LPG by
 - use of gasifier or
 - use of anaerobic digestion.
- Replacing fossil fuel completely with biomass in steam generator or hot water boilers using logs of wood.
- Use of biodiesel or bio-ethanol fully or in part with fossil fuel in the engine.
- Use of bio-oil obtained via pyrolysis to produce chemical compounds.
- Use of gasification technology to produce producer gas from biomass, and to produce H₂ or use of reforming reaction to produce NH₃.
- Producing high quality carbon dioxide from combustion of producer gas via gasification route.
- Producing charcoal through slow pyrolysis.

Biomass suffer several limitations. Tables 10 and 11 give a direct comparison of the biomass with the other fuel options. Clearly, it is found that the biomass has only 1/3rd available energy at 50% moisture. The dry wood has a calorific value between 19 and 20 MJ/kg. It consists of roughly 70% volatile matter 28% fixed carbon and 2% ash (de Miranda et al. 2013). On thermal efficiency count the biomass has lower thermal efficiency. This is due to slow rate of combustion, high moisture content, large surface area and higher excess air for combustion.

Table 12 shows the comparison of thermal efficiency of different fuel options. It is noted that the use of wood releases more carbon dioxide than fossil fuel, besides this it has a poor combustion efficiency compared to fossil fuel. Wood ends-up consuming more energy per kJ of energy released and also releases higher greenhouse gases. Due to this fuel switching option from fossil fuel to biomass would not be advisable in the short run (Ingerson 2009). Besides this, the use of some of biomass materials is technically difficult to process thermally, e.g. excessive tar production when using rice husk in the small cooking gasifier stove is a problem for rice husk gas technology (Belonio 2005). On the emissions front, compared to conventional fuel options, biomass use is found to emit large amounts of particulate matter, this leads to the release of fly ash in the form of black carbon and harmful aerosols. Use of pellets is a safe alternate for this problem. Due to the large volume-to-surface area and slow release rate, biomass use (woody as well as pellets of biomass) will contribute to the discharge of unburned carbon dioxide gases. The consequences of carbon monoxide are more serious in the urban area due to

Table 10 Comparison of biomass and fossil fuel energy (Adapted from McKendry 2002)

Material	Energy Density
Mineral Oil	42 GJ/t
Coal	28 GJ/t
Biomass (wood, 50% moisture)	8 GJ/t

Table 11 Combustion characteristics of coal and biomass (Adapted from Tumuluru et al. 2011)

	Coal	Wheat straw
HHV	20.42	17.99
LHV	19.65	16.73
Yield (t/ha)	–	2.2
Moisture (d%)	5.5	10
H ₂ (w%)	3.49	5.7
Ash (w%)	34.2	7.9

Table 12 Average efficiency of various fuel options (Adapted from Ingerson 2009)

Fuel	Power plant (%)	Other use (%)
Coal	35	45–60
Gas	45	80–90
Oil	38	80
Wood	22–25	65–80

Table 13 Emission from wood and fossil fuels in kg/kJ (Adapted from Ingerson 2009)

Pollutant	PM10	CO	NO _x	SO ₂
Oil boiler	0.0060	0.0151	0.0615	0.2150
Natural gas boiler	0.0030	0.0344	0.0387	0.0002
Coal boiler	0.0176	0.1208	0.3909	0.4408
Woodchip boiler	0.0430	0.3139	0.0710	0.0035
Wood pellet boiler	Low	0.2193	0.1170	Low

stagnant air conditions. Table 13 gives emission comparison of different fuel options. It is likewise observed that biomass when used as a fuel releases a similar amount of NO_x compared to petroleum, and higher amount of particulate matter. Small particulates are more harmful, for two reasons, they remain in the air for longer duration of time and another is it contained toxic substance which can reach to the lungs because of inhalation (Ingerson 2009). Home wood stove releases a considerably large amount of pollutants compared to a commercial arrangement. Outdoor boilers limit combustion air and create fire smoldering, produce more particulate release and with its low elevation of the chimney the effect is even more serious (Ingerson 2009).

4.1 Use of Biomass as a Boiler Fuel

The most feasible low-cost option for the use of biomass is co-firing with coal in existing boilers. Co-firing technology is demonstrated in almost all types of boilers, include pulverized coal boilers (wall-fired and tangentially fired designs), coal-fired

cyclone boilers, fluidized bed boilers, and spreader stokers. It is seen that about 15% of the total energy input can be substituted with biomass under co-fired option requiring little or no modification. Under such switchover there is little or no loss in overall efficiency. Conversion efficiency from Biomass to electricity is observed at 33–37%. Since biomass have very less sulfur than coal, significant decrease in SO₂ is observed. A further NO_x reduction of 30% is observed (Bain et al. 2002). Developing local biomass supply option is a great challenge to the use of biomass as fuel.

4.2 Use of Biomass to Generate Power

Power generation from coal can be a disadvantage from the environmental point of view. Using only biomass for power generation can get important advantages; even so, there are a number of limitations to overcome. Few limitations of use of 100% biomass applications are; large storage space, need of supply side management, intensive biomass feeding system, biomass availability due to seasonal variation and adaptability to different types of fuel, capital investment required for modification in existing system, lower heating value, poor bulk density, high moisture and ash content, stability during storage and grind-ability, flame stability, formation of smoke and flue gases, fouling of boiler tube due to higher particulate release, etc. (Tumuluru et al. 2011). The issue of ash after the combustion of biomass also has serious consequences, for instance a 50 MW plant has to handle about 16–20 tons of ash per day (Ingerson 2009). For such plant approximately 70–80 truckloads are required per day. The issue of a sustainable provision of wood is also in doubt. The particles generated from the usage of biomass can contribute to fouling and corrosion of hot gas parts as well as erosion of the nozzle and valves (Ingerson 2009). It is likewise observed that the wood fuel feed rate needed for an equivalent heat input is nearly double that of coal on a weight basis, and more than four times that of coal on a volume basis (Ingerson 2009). Wood combustion required more excess air compared to coal, this requires large induced draft fan compared to coal. CO in wood fired flue gases is more compared to coal burning, this make option of preheat combustion air is essential.

4.3 Option of Biomass Co-firing

Residues, energy crops, herbaceous crops and woody biomass can be utilized as fuel for co-firing, by using the cyclone type combustion chamber. Co-firing results in little derating of boiler thermal efficiency and boiler capacity. Due to such derating it is not preferred to go for co-firing greater than 20%. The capacity derating can be overcome by increasing the thermal loading or by increasing fuel combustion rate. Reduction in terms of NO_x, SO₂ and mercury emission can take

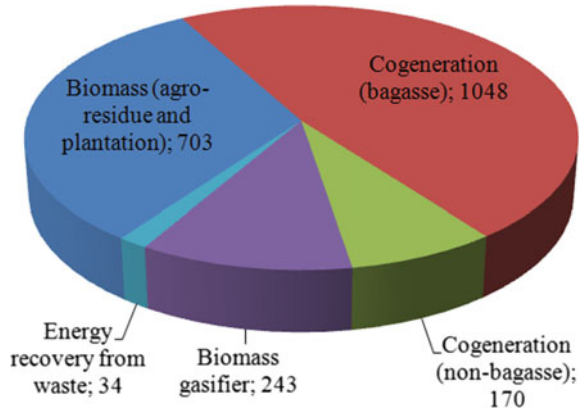
place. Co-firing option is also feasible in a fluidized bed boiler, where saw dust is supplied along with the coal powder. At higher proportion of coal replacement by the biomass, problem of slagging and fouling become serious because of interaction between alkaline in wood and sulfur in coal (Wiltsee 2000).

Compared to coal, biomass has a higher composition of hydrogen and oxygen and lower amount of carbon, this gives biomass a very low calorific value compared to coal. Moreover biomass has a higher fraction of volatile matter, this will result into the combustion with flame, while in the case of coal the combustion will be followed by glow almost without flame. These issues need to be considered when fuel switch over is considered with respect to heat load and sizing. The issue of high moisture content is also critical for the biomass combustion. At the time of cutting, the moisture in the biomass is in the range of 40–45%, this high moisture is not acceptable from the combustion point of view. Especially when mixed with coal having moisture levels as low as around 5%. Sun drying is the most sought option to drive out high moisture content, however this option is limited to the space available to store the biomass and the capacity of the plant. High moisture content reduces the combustion temperature and increase the time to release the same amount of energy by burning in the combustion chamber. As far as the ash is content, biomass has low ash and this reduces the heat carried away from the combustion chamber along with ash. Some biomass has high sand, salt or clay (rice straw ~ 15% silica). High alkaline matter in the ash can cause fouling of heat transfer surface. Chlorine and sulfur content in the coal can cause corrosion problem, use of biomass as fuel help resolve this issue (Tumuluru et al. 2011).

The quantity of moisture content can reflect in terms of low calorific value, durability, storage and self-ignition chances. Poor bulk density may result into problems in storage, transport and handling of fuel. High ash content can result in the formation of dust on heat transfer surfaces, emission of particles in the environment as well as additional cost of ash handling. Potassium and sodium may result in corrosion, lower ash melting temperature and aerosol formation. Another limitation of biomass use is a mixture of the biomass with different origin, these cannot be burned together in most of the furnaces. However, fluidized bed combustion is more flexible from that angle.

Besides this, there is technical complexity when biomass is used along with the coal; for instance, pyrolysis temperature for the biomass is much lower compared to coal. Since biomass have high volatile matter the heat supplied from it is about 70% in the case of biomass while the same in the case of coal is only 30–40%. Although specific heat released due to volatile matter is lower for biomass compared to coal. Due to the high oxygen content in the biomass the char made from biomass contains more oxygen and is highly porous compared to char produced from coal. Highly porous char is a good candidate for use in the applications as biochar in the field. Biomass ash is more alkaline in nature, and leads to high fouling of heat transfer surfaces.

Fig. 9 Actual power generation (MW) from biomass in India 08–09 (MNES report) (Singh and Gu 2010)



4.4 Use of Biomass by Making Briquettes/Pellets

Densification of biomass by pellets and briquette making is an essential biomass-preprocessing requisite. This is due to the fact that certain agro residue and waste biomass materials are often difficult to directly utilize as biofuel material. This is due to its poor bulk density thin size and at times high and uneven moisture content. Studies suggest that densification improves homogeneity, reduction in particulate matter and lower moisture content, and also ease in storing and transportation (Naik et al. 2010). Figure 8 shows the effect of briquette density with briquette pressure for different levels of moisture content.

4.5 Use of Biomass by Grinding and Torrefaction

Option of grinding of biomass (to a size <5 mm) can be chosen to overcome the slow combustion and reduction in moisture content of biomass. Another viable option is to pelletize the biomass (6–8 mm diameter), this brings homogeneity in the fuel structure, reduction in moisture content as well as, reduction in ash generation. Use of pellets or briquettes can help increase the rate of combustion to the coal, and also improve the combustion characteristic.

The option of torrefaction can also be considered. This is achieved by thermo-chemical heating of biomass in the absence of oxygen for 30–60 min. This process will drive out moisture and volatile matter from the biomass. This will give increased heating value, improves grinding and binding properties, because now more lignin is available in biomass. It makes biomass hydrophobic in nature and can be stored for longer duration, as now biomass will not absorb moisture from the surroundings. Table 14 presents a comparison between three solid wood fuel options - wood chips, pellets and torrefied wood pellets. It is observed that making wood chips, pellets and torrefied wood pellets will reduce moisture content,

Table 14 Physical properties of wood chips, wood pellets and pellets made out of torrefied wood pellets (Adapted from Tumuluru et al. 2011)

Physical property	Wood chips	Wood pellets	Torrefied wood pellets
Moisture (%)	35	6–10	1–5
Density (kg/m ³)	300–500	600–650	750–800
Calorific Value (MJ/kg)	10.5	16	21
Energy bulk density	5.8	9	16.7

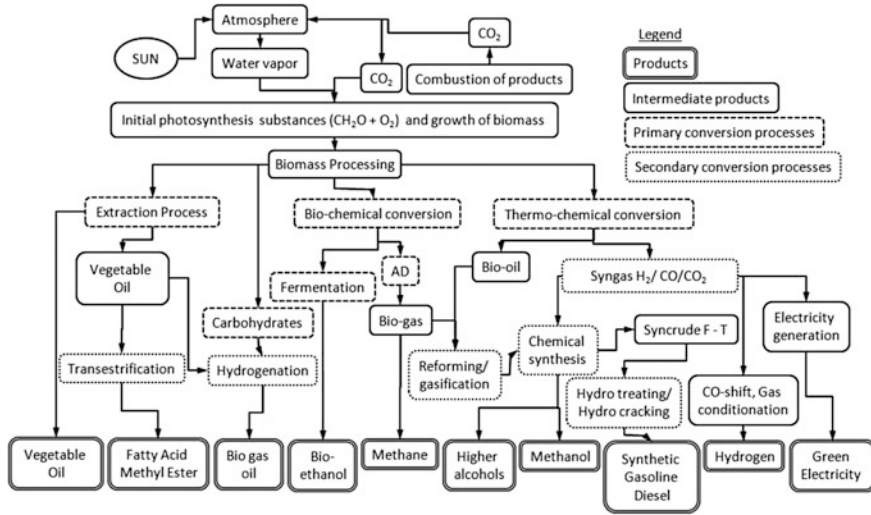


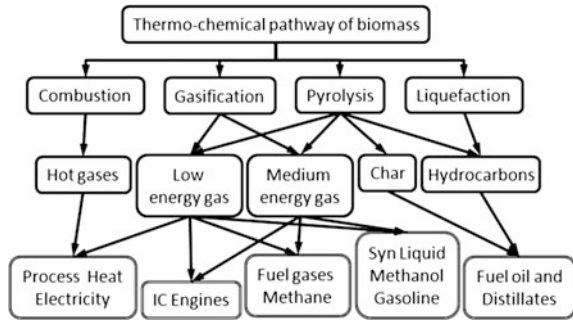
Fig. 10 Technology options for biomass adapted from (Lako et al. 2008; Adams 2011; Ciubota-Rosie et al. 2008)

increase density and improve the calorific value of fuel, in the given order. The option of torrefied wood pellets gives the extra-long storage capability. This is because the pellets are hydrophobic in nature and do not absorb moisture from the environment and increase the shelf life of pellets, without collapsing shape or disintegrating.

5 Technology Options

Utilization of biomass is traditionally dominated in rural India, this includes primary utilization of biomass for cooking and heating applications. Besides this, biomass is also utilized largely for power generation. Figure 9 gives the statistics of actual power generation pattern (in MW) from different routes of biomass used in

Fig. 11 Biomass utilization pathways under thermo-chemical conversion [Adapted from (McKendry 2002)]



India. Cogeneration using bagasse is the largest biomass power generation option, practiced at a large sugar belt in India (1048 MW). This is followed by power generation by use of biomass by direct combustion, this includes agro residue and yield from energy plantation (703 MW). Biomass gasification route is demonstrated at several installations (243 MW), this includes gasification of woody biomass as well as gasification of rice straw and a small number of briquettes/palletized fuel using agro residues.

Figure 10 shows the broader picture of biomass production to its usage. The production of biomass takes place by consuming CO₂ and water vapor in the presence of energy from the sun. This initial photosynthesis substance grows over a period to produce different biomass products. These biomass products when subjected to different processes based on the physical and chemical composition of biomass result in different pathways for the generation of energy. Direct combustion is the oldest method known to humankind for heating and power generation. It is a chemical reaction between heated biomass and oxygen that result in the release of heat and gaseous products. Theoretically complete combustion releases gases and vapor (CO₂ and H₂O) (Naik et al. 2010). A common application of combustion is found in domestic stoves and water heaters and small boilers. Direct combustion does not require any pretreatment of biomass and therefore is excluded from the present discussion.

5.1 Direct Extraction Process

First and oldest type of use of biomass is direct extraction. Under extraction process, biomass is used to obtain crude vegetable oil from oil seeds using a screw press. The residues are many times used for producing other biofuels. The residue oil cakes can also be used as a binder for making pellets and briquettes. Production of vegetable oil was once encouraged by the Planning Commission of India by launching massive plantation of *Jatropha* (*Jatropha curcas*) and *Karanj* (*Pongamia pinnata*) under biodiesel project, which include 200 districts and 18 states. Although, there are several problems to be resolved if vegetable oil is to be used in

place of diesel in existing engines. Major limitation is the high viscosity of oil, which limits proper atomization, poor mixing of oil with the combustion air leads to incomplete combustion and high smoke and carbon deposition, sticking of piston ring and scuffing of the engine liner, and failure of injection nozzle (Singh and Gu 2010). Also, high cloud level and pour point, compared to diesel, limits its use in cold climate. Research suggests that the large molecule of triglycerides of heavy molecular weight are responsible for this. Chemical treatment of this molecule via transesterification to produce biodiesel can be an option to resolve this issue. Biodiesel is mono alkyl esters of long chain fatty acids, which can be readily used in engine for power generation. Production of biodiesel is not attractive from an Indian perspective due to factors such as—low productivity of oil seed cultivation (1 t/ha), and large gaps in production and import of vegetable oil, which may find it difficult to see the feasibility of biodiesel in India. Due to this non-editable oil produced from *Jatropha* oilseed as biodiesel feedstock which has high yield (3.75 t/ha) is preferred (Singh and Gu 2010).

5.2 *Biochemical Conversion*

Biochemical conversion includes two primary processes anaerobic digestion (AD) and fermentation. It is the process that includes the conversion of organic material directly into a gas, popularly known as biogas. The AD route results in the formation of methane and carbon dioxide gas. While, fermentation process can generate bio-ethanol. The conventional AD process may yield methane of the order of 60%, however, with the use of advance bi-phasic system yield can be increased to as high as 80%. Organic, wet and non-lignocellulosic material is ideal for this type of reaction process. The feedstock is converted into gas in the absence of oxygen. This natural breakdown of the biomass in the absence of air can be a useful process to use for even energy grass and animal manure. The residue of the process is a slurry which is a stable, commercially useful compound. The slurry can be considered as a soil conditioner.

Fermentation process can produce large-scale bio-ethanol from sugar crops like sugar cane and sugar beet and starch crops like maize, wheat. The solid residue produced from the fermentation process can be used to feed the cattle. Production of large-scale ethanol from sugar cane can be a total substitute for the fossil fuel and is found popular in Brazil. Likewise, the use of maize for the ethanol production is also widely practiced in the US. Although, uses of wheat and sugar beets have been restricted since both these feedstock violate the condition of fuel-for-feed, still production of ethanol from wheat and sugar beets is picking up in the UK.

5.3 Thermochemical Conversion

Under thermochemical conversion process the conversion of biomass using thermal energy is considered. Under this, four main processes are available combustion, gasification, pyrolysis and liquefaction (Fig. 11). Combustion is burning of biomass in the air. The combustion of biomass can take place in different places and for different applications. This includes combustion of biomass over the grate to generate steam in the boiler, combustion at fireplaces for thermal heating, combustion at stoves for cooking application, in the combustor for the gas turbine power generation application. Combustion results in the generation of hot flue gases at around 800–1000 °C. There is a large variation observed in the temperature of the flue gases. It mainly depends on the factors like type and size of biomass and moisture content. Due to poor energy density of the biomass and variability in the quality and other logistic issues the plant size of biomass is generally low and ranges from 5 to 15 kW.

Generation of bio-oil using pyrolysis technology is a recent development. Pyrolysis technology can use agro residue and it produces viscous dark liquid called bio-oil (Bridgwater 2012a) which can be used to partially replace diesel to generate off-grid electricity (Sagi et al. 2014). Pyrolysis is a thermochemical conversion process in which feedstock is heated at less than 400 °C in a reactor in the absence of oxygen to obtain vapor and char (Evans and Milne 1987). Pyrolytic thermal biomass decomposition is a complex process which consists of simultaneous reactions of dehydration, isomerization, aromatization, carbonization, oxidation. While secondary reactions like thermal water decomposition into synthesis gas, cracking, condensation also take place (Lewandowski et al. 2012).

Vapor fractions from pyrolysis process are condensed in a condenser to obtain bio-oil (Bridgwater et al. 1999), while char can be utilized as a fuel in the boiler and for other thermal applications or as a slow-release fertilizer in the field (Woolf et al. 2010; Major 2009; Lehmann and Joseph 2009; Novak et al. 2009). The advantage of pyrolysis is that it requires lower temperature compared to gasification. Product yield can be controlled by varying different residence time for the vapor in the reactor. High temperature and longer residence time can increase the conversion of biomass to gas, whereas the moderate temperature and short residence time is ideal for producing large quantities of liquid in the form of bio-oil.

Pyrolysis can be of three types. Fast pyrolysis, in which biomass are subjected to high heat transfer rates and low residence time to maximize bio-oil generation (Bridgwater 2012b). Slow pyrolysis, in which biomass are subjected to slow heating rates and longer residence time to maximize char production (Bridgwater 2012b). It is a typical process by which charcoal is produced. The third variant of this process is Intermediate pyrolysis. It is characterized by low heat transfer rates, short residence time for vapors and longer residence time for solids. The intermediate pyrolysis technology, developed by EBRI at Aston University, Birmingham, U.K. (Hornung 2011) is a process which reduces the formation of high molecular tars and produces dry and brittle char. Intermediate pyrolysis works

with a reactor system called “Pyroformer” which is a specially designed reactor to process straw pellets and to separate ash rich residues from fuel on a continuing basis.

Liquefaction is the conversion of biomass into a stable liquid hydrocarbon using low temperature and high hydrogen pressures. Interest in the liquefaction process is low due to the requirement of high pressure parts, especially reactor and fuel feed system, and complexity of the process. High cost and complexity deter the growth of the liquefaction process.

Franz Fisher and Hans Tropsch proposed syngas production from biomass. Under this process, biomass is first converted into gases by way of gasification process, and using these gases CO and H₂ gases are converted into liquid fuels, with the help of a metal catalyst. The technology suffers from disadvantage of production of large products due to polymerization of fuel. This wax-like material is required to undergo complex hydro-cracking reaction (McKendry 2002). Under hydro treating or hydro thermal upgrading, liquefaction is the process that converts biomass into partly oxygenated hydrocarbons under wet environment and at high pressure (McKendry 2002).

6 Summary

It is very important for an agrarian economy like India to appreciate its waste biomass resources. It is essential that an extensive use of these resources be made so that the huge availability of biomass can be utilized to address the issues of energy scarcity in the country. Biomass is the only renewable energy source capable of storing carbon in its structure. With the advent of efficient technology and the use of second-generation biomass fuels, it is possible to control the emission arising from the use of agro residue. India has traditionally been an agrarian economy and has the potential of large biomass waste. However, currently these biomasses are not efficiently utilized, remain unattended and are allowed to decay. This may result in the generation of greenhouse gases like CH₄, which are 21 times more severe compared to carbon dioxide to cause global warming phenomena. Any efficient use of biomass would not only provide much wanted electricity, but will also provide an efficient alternate to the use of agro residue. The biggest limitation of the use of biomass under thermal application is its moisture content and release of soot particles. Biomass can also be treated under biochemical and thermochemical conversion processes. It is observed that anaerobic digestion and pyrolysis are promising technology alternates available for treatment of biomass under these options. It is concluded that biomass when used in the industrial unit as a fuel, several factors need to be addressed before such switch-over could take place. Treatment of biomass using biochemical and thermochemical conversion option is fast developing and may lead to an economic and efficient alternative.

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