Chapter 13
Biomass Briquetting for Gasification: Waste to Wealth

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Abstract World is progressing toward renewable and clean energy. The main driving forces are dependency on fossil fuel, limited sources, increasing demand, and environmental concerns. There is a requirement of shifting from petroleum-based fuel to renewable energy sources, and biomass is a potential source of renewable energy. Gasification provides a solution for renewable and clean energy as well as utilizes waste and/or abundant biomass in a better way, where partial combustion in limited supply of oxygen takes place to produce combustible gases called producer gas. The producer gas can directly be burnt to produce heat or can be purified to syn gas for production of electricity or liquid fuel. Biomass are mostly industrial waste, forest residue, farm produce, etc., having low bulk density and are largely varying in physical and chemical properties. Bulk density of biomass ranges from 40 kg/m^3 for loose straw to 250 kg/m^3 for wood residue which is unmanageable for handling, storage, or transportation. Densification increases bulk density by 2–10 folds and can be done with high, low, or medium compaction. Low compaction of biomass always requires binder. Screw press, piston press, hydraulic piston press technologies are in practice for compaction of biomass. Selection of any one of these technologies depends upon the feedstock availability, physical and chemical properties as well as characteristics of the product. Densification necessitates prior evaluation of the physicochemical properties of biomass like moisture, ash, lignin, calorific value, volatile matter, etc. Briquettes properties like low moisture content, good water resistance, high calorific value, good compressive strength, low ash content, etc., are the desirable properties for their acceptance by the users.

Keywords Lignocellulosic biomass · Energy density · Densification · Briquetting technologies · Gasification

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13.1 Introduction

13.1.1 Renewable Energy

Crude oil is the world's main source of energy generating gasoline, diesel, jet fuel, asphalt, and lubricant oil, used mainly for power production, transportation, and heat generation. The oil reserves were 1732 billion barrels at the end of year 2020, two billion down to the figure of 2019. Demand of world's crude oil in first quarter of 2021 was 93.30 million barrel per day and is expected to increase as per IEA World Oil Supply and Demand Forecast. Road transportation took a major share of the oil in OECD (Organization for Economic Co-Operation and Development) member states. Motor vehicle usage was 35.23 percent of total oil consumption in 2019. Global purchase of imported crude oil in 2020 was US$ 683.1 billion reflecting demand from 115 countries, territories, and islands. Top four countries namely China, United States, India, and South Korea accounted 53.7% of the overall value of imported crude oil in 2020 [1]. India imported crude oil costing US$ 64.6 billion during 2020. Iraq, Saudi Arabia, and UAE were the top 3 suppliers of crude oil generating one-half (54.4%) of total Indian import of crude petroleum [1].

Petroleum products from crude oil are neither sustainable nor renewable and posing environmental threat because of their obnoxious exhaust products [2–8]. Earth climate is rapidly changing and one of the contributors is excessive greenhouse gases in the earth atmosphere. Atmosphere's share of carbon dioxide, one of the greenhouse gases, has increased by 46% since pre-industrial times. Most of the greenhouse gases caused by human activities come from burning of fossil fuel for electricity, transportation, and heating. World total carbon dioxide emissions in 2018 were 35.92 billion metric tons. India ranked third in carbon dioxide emissions with a figure of 2.65 billion metric tons (7%) after China (28%) and United States (15%) [9]. As per the World Resources Institute Climate Analysis Indicators Tool (WRI CAIT), India's 2014 GHG profile was dominated by emissions from the energy sector and accounted for 68.7% of total emissions. Further, extraction and transportation of oil poses environmental and safety risk. Deepwater Horizon disaster of 2010 released three million barrels of oil into the Gulf of Mexico leaving impact on ecosystem for decades.

Besides the concern of environmental impact, fossil fuels are having geopolitical impact too. These are typically found in specific parts of the world, hence making them plentiful for some nations only. World top ten oil producers share 72% of total oil production in the year 2020 as per International Energy Statistics 2021. This imparts monopoly of fossil fuel-rich countries which controls the oil prices as well as having concern of national security which import the oil from fossil fuel-rich countries. Fluctuating prices of crude oil, rapidly changing world political scenario, and adverse environmental impact are always being a big concern for India. Increasing energy demand, depleting resources, and notorious exhaust products of fossil fuel justify renewable, economic, and ecofriendly energy source [10–12].

Renewable energies are those which come from natural sources or processes that are constantly replenished. These are also termed as clean energy. Renewable energy sources are Solar energy, Wind energy, Hydro energy, Geothermal energy, and Biomass energy. Global renewable energy capacity in 2020 was 2.8 million MW [13]. India had 96.96 GW of renewable energy capacity as on July 2021, which is 25.2% of overall installed power capacity. India ranked fourth in wind power, fifth in solar, and fourth in renewable power installed capacity in 2020. Government of India is encouraging Industries/Academia/Organizations to work in the field of renewable energy via policies, subsidies, and other incentives. According to the analytics firm British Business Energy, India ranked 3rd globally in terms of its renewable energy investments and plans in 2020. The Ministry of New and Renewable Energy (MNRE) has set an ambitious target to set up renewable energy capacities to the tune of 227 GW by 2022, of which about 114 GW is planned for solar, 67 GW for wind, and other for hydro and bio among others.

Among all the renewable energy sources, the largest contribution, especially in the short to medium terms is expected from lignocellulosic biomass. According to IREDA "Biomass is capable of supplementing the coal to the tune of about 260 million tons," "saving of about Rs. 250 billion, every year." Biomass energy potential in India is 16,000 MW from biomass energy and 3,500 MW from bagasse cogeneration. In India approx. 19% of the electricity was produced through renewable energy sources and out of which the contribution of biomass energy was 0.62% for the year 2018–19 [14]. Biogas production in 2014–15 was 5% of the total LPG consumption in the country. As per the latest report, the biogas energy capacity in India was approximately 14 MW in 2021 [15]. The current ethanol production capacity in India is 4260 million liters from sugarcane-based distilleries and 2580 million liters from grain-based distilleries [16].

India implemented biomass power and cogeneration program 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, groundnut shells, saw dust, etc. The Study indicated estimated surplus biomass availability at about 230 million metric tons per annum covering agricultural residues corresponding to a potential of about 28 GW. Over 800 biomass power and bagasse/non-bagasse cogeneration projects aggregating to 10,170 MW capacity have been installed in the country for feeding power to the grid.

13.1.2 Lignocellulosic Biomass and Conversion Technologies

The term biomass (Greek bio meaning life + maza meaning mass) refers to any material of biological origin excluding those that have been embedded in geological formations undergoing a process of mineralization. The term lignocellulosic biomass is used for biomass, particular of plant origin like agricultural waste (straw and husk from paddy and other, vegetable residue, fruit waste, etc.), forest residue (palm leaves, pine needles, oak leaves, etc.), industrial waste (corn cobs, oilseed cake, coconut shell, groundnut shell, etc.) [17, 18]. It is mainly composed of cellulose, hemicellulose, and lignin, including a few organic components like lipid and extractives [18–21]. Cellulose consists of long chains of β-glucose monomers which are arranged in highly ordered manner, whereas hemicelluloses consist of pentoses and hexoses sugar monomer units and are amorphous in nature. The third major constituent of lignocellulose biomass, i.e., lignins are phenolic compounds which are formed by polymerization of three types of monomers, i.e., p-coumaryl, coniferyl and synapyl alcohols [18]. The lignocellulosic nature makes biomass rich in energy content [22–24].

The ISO 17225-1: classified biomass feedstock resources into four groups, namely woody, herbaceous, fruit, and aquatic biomass [25]. In developing countries large amount of biomass residues are generated annually as by product of the commercial forestry, agriculture, and industrial sector [26, 27]. The supply of biomass from various sources around the globe is approximately 220 billion ton/year [28]. In USA, more than a billion tons of biomass are available which can replace about 30% of its petroleum consumption [29]. Annual potential of biomass in world is expected in between 200 and 500 EJ/year excluding aquatic biomass by 2050 [30]. In India, 750 million metric tons of biomass is produced every year as per the recent study report sponsored by MNRE. Agricultural residues annually amount to a total of 98 million tons of which 41 million tons can be used as energy source [31].

Biomass can be converted to fuel via biological or thermo-chemical processes [32–36]. Biological conversion includes fermentation to ethanol, biomethanation to methane, etc., whereas thermo-chemical conversion includes combustion to generate heat, pyrolysis to solid and liquid fuel, gasification to combustible gas or liquid fuel via Fischer–Tropsch reaction, etc.

Combustion of biomass for energy is being practiced since discovery of fire, however, this poses environmental threat like global warming because of their exhaust products like CO_2, CO, NOx, etc. [37–39]. Further, these biomass neither burn completely nor harness the total energy of the biomass. Gasification is the emerging and promising technology for harnessing biomass energy in the form of gaseous fuel [40].

13.1.3 Gasification

Gasification is a thermo-chemical process where carbonaceous materials are converted to combustible gases in presence of reagent, typically air, steam, hydrogen, oxygen, or a combination of these at high temperature (>700 °C). Unlike combustion, which takes place in presence of oxygen to give CO_2 and H_2O, gasification takes place in limited supply of oxygen to give combustible gases along with char and tar [10, 12, 41]. The crude combustible gaseous product is called Producer gas which consists of CO_2, CO, H_2O, CH_4, NOx, N_2, etc., and can be burned as a fuel such as in a boiler for heat or in an internal combustion gas engine for electricity generation or combined heat and power (CHP). This gas can further be purified to Syn gas which is mainly consists of CO and H_2. The Syn gas can be used as a fuel for electricity generation or heating and warming appliances or can be converted to liquid fuel via Fischer–Tropsch process, biomethanol, or biohydrogen.

Gasifiers are being used for biomass gasification to combustible gases. These are broadly classified into two types, i.e., fixed bed and fluidized bed gasifiers. Fixed types of gasifiers are updraft and downdraft types. In both type of gasifier material is loaded from the top of the gasifier and reactive agent is passed from the bottom of the gasifier. However, in the first type of gasifier, the combustible gases exit from the top and in the second type it exits from the bottom side. Each gasifier is having its own advantages and disadvantages, however, for small-scale gasification downdraft gasifiers (Fig. 13.1.) are mostly being used because of less complexity, less tar formation, and better performance [42].

Like any technology, gasification is having its own challenges. One of such challenge is feedstock material which is mainly low bulk density lignocellulosic biomass with varying shapes, sizes, and characteristics. Low bulk density of biomass poses difficulty in transportation, storage, and handling as well as affects feeding of biomass to gasifier especially in fixed bed gasifier. Because of low density, less material is

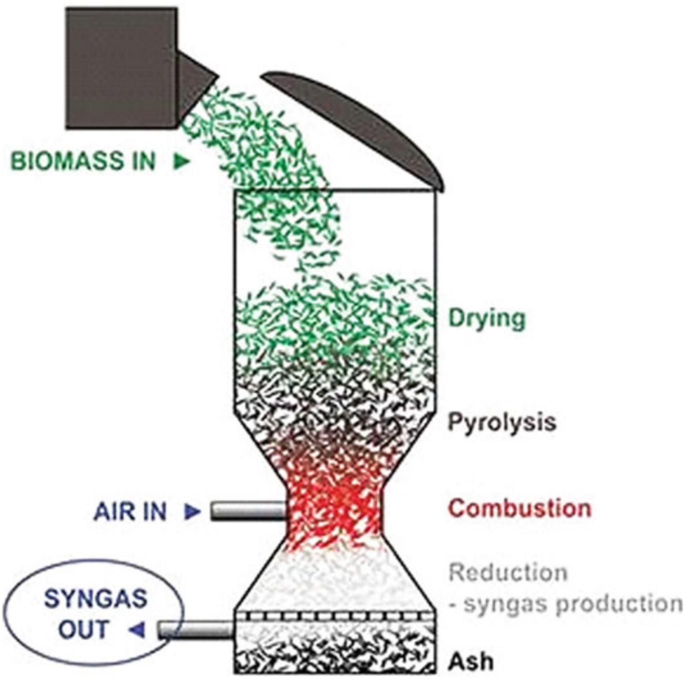

Fig. 13.1 Downdraft gasifier

loaded in the limited space of gasifier. For improving feeding characteristics, densification of biomass is the prime requirement which improves the energy density of biomass, subsequently enhancing the performance of gasifier.

13.2 Briquetting

Briquetting is densification of low-density biomass to get intact solid fuel with improved energy density. Biomass bulk density ranges from 40 kg/m^3 for loose straw to 250 kg/m^3 for wood residue [43]. Voluminous biomass possesses many problems in handling, transportation, and storage [44–53] and decreases transportation and storage efficiency. Densification in form of briquettes minimizes the handling, transportation, and storage problems [51, 52]. Besides this, briquetting also improves physical and mechanical properties of loose biomass [50, 51]. Based on physical and mechanical characteristics, briquettes have been presented to significantly reduce costs of storage and transportation [54–56]. Further, to improve feeding characteristics of these biomass to combustor/gasifier, densification is the prime requirement. Densification improves bulk density 2–10 times [57, 58] with enhanced energy density of the biomass, ultimately enhancing the performance of gasifier [59–63]. In addition, densification improves storage life of biomass as well as more convertibility into liquid fuels as compared to raw biomass [64–67].

Briquette can be classified based on biomass used, shape of briquette as well as size of briquette (Fig. 13.2). Based on the biomass used for briquetting there are rice husk briquette, coal briquette, coconut shell briquette, etc. These briquettes can be prepared in oval, round, cylindrical, hollow, or brick shape with variable sizes as per the requirement.

Fig. 13.2 Briquettes of different shapes and sizes

13.2.1 Potential Biomass and Their Characteristics

Availability. The biomass must be abundant and easy to collect for further processing like rice husk, ground nut shell, corn cobs, coconut shell, oilseed cake, etc. Sufficient suitable biomass must be available in the proximity of the biomass processing unit as well as to the biomass to bio-energy conversion facility to make the whole process sustainable and economic.

Moisture content. Moisture content for densification should not be >10% as high moisture content results in poor quality briquettes [68, 69]. However, the presence of moisture in optimal quantity helps in lowering the Tg of binder (lignin) and promotes solid bridge formation and increases the inter-particle contact via Van der Walls forces [60, 69].

Volatile Matter. It is a mixture of combustible and non-combustible gases consisting of short and long chain hydrocarbons which strongly affect the combustion behavior of briquettes [70]. High amount of volatile matter has positive influence on the sustainability of combustion, and it makes biomass a highly reactive fuel [70].

Ash content. Low Ash content is desirable in view of fuel properties of biomass as it is an indicator of slagging behavior of biomass [69]. In general, biomasses are having low ash content (<5%) but there are some exceptions like tobacco dust (19%) rice husk (22%), etc.

Particle size. Particle size and shape of biomass effects densification. Small particle results in smooth finishing without clogging and jamming of the machine. Very fine particles (<1 mm) are not suitable for screw extruder because of their cohesiveness and non-free flowing properties. The presence of different size particles improves the packing dynamics and contributes to high static strength [43–54].

Lignin content. Lignin shows glassy and brittle behavior below its glass transition temperature (Tg) (65–70 °C), becomes viscous, and spreads above this temperature and upon cooling it re-solidified. Lignin imparts binding properties and helps in densification [29, 51, 60].

Calorific value. High calorific value of biomass is desirable in briquetting for end application. Calorific value of biomass ranges from 3000 to 4700 cal/g for agricultural and forest residue from 5000 to 6000 cal/g for oilseed cake.

13.2.2 Biomass Processing to Briquette and Challenges

Suitability of biomass for briquetting depends on their physical and chemical properties [71–73]. These lignocellulosic biomasses are heterogeneous in nature with varying shapes and sizes. Moisture content and density also varies widely. Hence, prior to densification these biomass must undergo several stages like collection, storage, cleaning, drying, and size reduction. Biomass may be small, medium, or large. Medium and large size particles like pine needle, wheat straw, grasses, etc., are shredded to smaller size of 20–30 mm prior to pulverization. However, smaller particles like rice husk, camelina husk, leaves, etc., are directly pulverized to powder. Pulverizer selection depends upon the shape, size, and density of biomass. As moisture affect the densification process, hence, it must be reduced to acceptable value prior to compaction. Air drying does not add any cost but takes more time and is environment dependent. Low-temperature oven drier or solar drier can be used for reduction of biomass moisture in reduced time frame.

13.2.3 Fundamental Aspect of Briquetting

There are three fundamental aspects of briquetting [69].

Pressure compaction: There are high pressure compaction (100 MPa), medium pressure compaction (5–100 MPa), and low pressure compaction with binder. Under high pressure compaction, some of the components like lignin get activated as binder.

Binding mechanism: Binding mechanism under high pressure are (a) Adhesion and cohesion forces, (b) Attractive forces between solid particles, and (c) Interlocking bonds (Fig. 13.3).

Adhesion forces at the solid–liquid interface and cohesion forces within the solid are used for binding. Viscous binder such as tar form bonds very similar to solid bridges. Finally divided particles attract free atoms or molecules from the surrounding

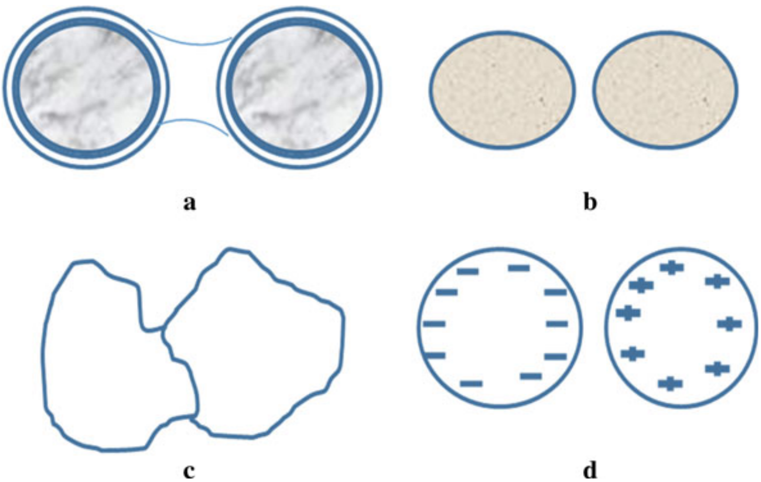

Fig. 13.3 Various binding mechanism: **a** Hardening binder, **b** Van der walls forces, **c** interlocking, **d** electrostatic forces

atmosphere. The thin layer formed is not freely movable and to some extent penetrates each other.

Upon applying external pressure, it further increases the contact area. This increases the molecular forces to transmit high enough and increases the bond strength between the adhering partners. Another important binding mechanism is Van der Walls forces which are very prominent between the adhesion partners separated by short distances. This type of adhesion possibility is much higher for powders. Interlocking or closed bonds are prominent in case of Fibrous and bulky particles.

Mechanism of Compaction. In case of screw extruder compaction occurs by the following mechanism:

(a) reaching the compression zone the biomass gets partially compressed. This leads to closer packing and increased density.
(b) At the compression zone, the biomass becomes relatively soft because of high temperature (200–250 °C). Loss of elasticity resulting in the biomass pressed into voids and the area of inter-particle contact increases. When the particles come together, they form local bridges which selectively support and dissipate the applied pressure. Interlocking of the particles may also take place depending upon the particle shape and size.
(c) The biomass gets further compressed in the tapering die (~280 °C) to form the briquette. The removal of steam and compaction takes place simultaneously during this step. Here, the pressure exerted transmits throughout the material giving uniform pressure and thus uniform density.

Different Briquetting technologies. Various types of briquetting technologies are in use [69, 74, 75]. Three widely used briquetting technology are discussed below:

Screw Press. Biomass in powder form or in recommended size is fed continuously into a screw which forces the material into a cylindrical die. Pressure is applied with augur continuously by passing the material through a screw with diminishing volume with or without heating system. Internal temperature often reaches 250–300 °C. At this temperature lignin of biomass liquifies and acts as binder excluding the external binder requirement. Briquettes form are of high density and good quality but the power requirement per ton is also high when compared with other technologies.

Piston Press. In this technology, material in powder form is fed into a cylinder which is then compressed by a piston mechanically into a slightly tapering die. It uses rotary power to generate a pressing force to shape the material in the form of briquette. Unlike Screw Press, pressure is applied discontinuously. Briquettes form are of good quality but with less density as compared to those produced from Screw Press. Binder may or may not require depending on the type of biomass.

Hydraulic Piston Press. This is similar to Piston Press with only difference that energy to the piston is transmitted from an electric motor via a high-pressure hydraulic oil system. Pressure is applied discontinuously by the action of a piston on material packed into a cylinder.

The briquette processing technology is being selected depending upon the feedstock availability, physical and chemical properties as well as characteristics of the product.

13.2.4 Physical and Chemical Parameters of Briquettes

Moisture content (%). Presence of moisture in briquette has adverse effect on shelf life and will lead to chemical and physical degradation. It has been reported that the moisture should be between 6 and 10% by weight [31]. One of the researchers reported that maximum durability rating of biomass pellets was obtained with moisture content 8.6% [58].

Apparent and bulk Density (kg/m³). The apparent density of a briquette from almost all types of biomass ranges from 1200 to 1400 kg/m^3. The apparent density of briquette is always higher than that of the bulk density of the briquette and usual reduction is approximately 600 to 700 kg/m^3 or sometimes less. Unit and bulk densities of briquettes depend upon material moisture, particle size, process temperature, and pressure [76, 77]. One researcher reported that bulk density of ground switchgrass was 165.5 kg/m^3 whereas, density of its pellets at 6.3% to 17% (wet basis) moisture content varies between 536 and 708 kg/m^3 [58]. Further, the density of blended biomass pellet also increases significantly than the individual agricultural biomass pellets [53]. Higher density leads to higher energy per unit volume and longer burning time.

Compressive strength (MPa). It shows the strength of briquette against compression. It should be more than 0.38 MPa for Industrial application [78].

Durability Index (%). Its significance is response of briquette during transportation. It is determined by tumbling test [80]. High durability index is desirable for commercial application of briquette.

Impact Strength Index (%). This signifies the strength and hardness of briquette. This is determined by dropping the sample three times from a height of 2 m into a metal floor. Impact Strength Index was calculated in percentage and it should be at least 90% [79].

Ash content (%). Ash content normally causes an increase in the combustion remnant, thereby lowering the heating effect [80–87]. Briquettes produced from high ash content biomass have high ash content as reported in case of corn cob and groundnut shell briquettes. In contrary mixture of wood residue of lower ash content to the agro wastes considerably reduced their ash content. Lower ash content is an indication of good-quality briquettes.

Volatile matter (%). Lower volatile matter is an indication that the briquettes might not be easily ignited, but once ignited they will burn smoothly, whereas high volatile matter results in high combustibility with low ash content [85]. As per one of the researchers, briquettes with higher volatile matter had higher specific heat of combustion [86].

Water resistance (Min). It shows the resistance of briquette to water and becomes significant during storage or transportation of briquettes. High water resistance is a desirable property to keep the material intact. It is determined by standard methods ASTM (1993), D870-09 [88].

Mass burning rate (g/sec). It is the time required to completely burn the unit mass of material. It signifies that how long a briquette will burn. It gets influenced by density due to reduced porosity which tends to hamper the rate of infiltration of oxidant and outflow of thermo-combustion products [53].

Calorific value (MJ/kg). It is the amount of energy released when unit mass of a substance burns completely in the presence of sufficient amount of oxygen. For commercial application, it should be more than 17.5 MJ/kg [63].

13.3 Conclusion

Gasification of biomass is an emerging and promising technology for renewable and sustainable energy source. Low bulk density of feedstock materials with varying shapes and sizes is a challenge for biomass gasification. It poses difficulty in transportation, storage, and handling as well as affects the feeding of biomass to gasifier. For improving feeding characteristics, densification of biomass is the prime requirement. Loose biomass bulk density ranges from 40 kg/m^3 for loose straw to 250 kg/m^3 for wood residue. Two to ten times gain in bulk density can be achieved through briquetting. Briquetting not only eases handling, transportation, and storage but also improves energy density. Briquettes can be prepared with high, low, or medium compaction in various shapes and sizes. Low pressure compaction of biomass always requires binder for densification in the form of briquette and is suitable for production of briquettes at smaller scale with lower investment. On the other hand, medium and high-pressure compaction can be achieved with or without binder, however, energy and infrastructure requirement make these processes more cost intensive. Such processes are suitable for large-scale industrial production. Different types of briquetting technologies like Screw press, piston press, hydraulic piston press, etc., are available in the market. Selection of the briquette processing technology depends upon the feedstock availability, physical and chemical properties as well as characteristics of the product. Prior to densification it is necessary to evaluate the physicochemical properties of biomass like moisture content, ash content, calorific value, volatile matter, density, lignin content, and other as these not only affect the densification process but also affect the properties of finished product. Further to this densification of biomass requires shredding to smaller particles or pulverizing to powder depending upon the type of briquetting technologies. Physical and chemical properties of briquettes like less moisture content, good water resistance, high calorific value, good compressive strength, low ash content, etc., are the desirable properties for their acceptance in the market. Regular supply chain of biomass for running large industrial briquetting plant is a critical factor, however, this can be addressed by using wide spectrum of available biomass as well as plantation of short duration woody crops. Cost of briquette production is another critical factor for sustained growth of the technology and need attention. Despite these challenges, biomass briquetting is the only solution to handle the voluminous material in a better way in terms of storage, transportation, and application.

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