

Towards Green Energy: Assessing Biomass Densification Technologies for Power Generation

Pragya Yadav¹, A.K. Sarma^{2*}

Abstract

Technologies for biomass densification have become essential for improving the profitability and efficiency of biomass-based energy production. This thorough review article examines several biomass densification-related topics, such as the technologies involved, process variables, benefits, difficulties, and possible uses. We explore the basic ideas behind biomass densification, including torrefaction, briquetting, and palletization, and we talk about the factors that affect their efficacy as well as their mechanisms. Furthermore, we examine the economic and environmental effects of biomass densification, emphasizing its contribution to the reduction of greenhouse gas emissions and the promotion of sustainable energy practices. This review aims to provide important insights into the development and application of biomass densification technologies for energy production by synthesizing recent research findings and technological advancements.

Keywords: Biomass densification, Energy, Production, Pelletization, Sustainable

Introduction

Technologies such as biomass densification are used to turn plant leftovers into fuel. These technologies, which enhance the handling qualities of the materials for transportation, storage, etc., are also referred to as agglomeration, briquetting, or pelleting [1]. A dense, uniform, bulk-flowable commodity material that has the following qualities is essential for its production: (a) controlled particle-size distribution for improved feedstock uniformity and density; (b) fractionated structural components for improved compositional quality; (c) conformance to predetermined specifications based on particular supply-system constraints and conversion technologies; and (e) lower storage, handling, and transportation logistics costs [2, 3]. In recent years, many workers have contributed in evolution of these technologies. For example, Tabil and Sokhansanj (1996) [5] studied the compression characteristics of alfalfa pellets while Adapa et al. (2002b and 2003) [6] worked on fractionated products of alfalfa pelleting. The impact of die pressure on relaxation characteristics of biomass briquettes. Li and Lu [7] high-pressure densification of wood residues for production of upgraded fuel. Further, Mani et al. (2009) [8] focussed on the compaction characteristics of lignocellulosic biomass with the help of Instron, and Tumuluru et al. (2010) [4] researched the outcome of pelleting process variables on the quality parameters of a wheat distiller's dried grains with solubles (Table 1).

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Among the different densification models available on compaction, the Kawakita-Ludde model best describes the compression characteristics of agricultural biomass samples. Experimental data analysis using both statistical methods (such as ANOVA) and response surface methods and evolutionary algorithms (such as genetics, simulated annealing, or particle swarm algorithms) can help to better explain the complex densification process.

Table 1. Mechanism of biomass densification.

Sastry & Fuerstenau (1973) [9]	Formation of solid bridges as the possible mechanism of binding during agglomeration
Tabil L (1997) [10]	Lowering of melting point of the particles subjected to high pressure during densification reduces the melting point of the particles and causes them to move toward one another, thereby increasing the contact area and creating a new equilibrium melting point.
Thomas et al. (1998) [11]	During densification of starch rich biomass using pelleting the presence of heat and moisture gelatinizes the starch and results in better binding
Tabil and Sokhansanj (1996) [5]	The compaction of the biomass grinds during pelletization can be due to the elastic and plastic deformation of the particles at higher pressures.
Briggs et al. (1999) [12]	Presence of liquid-like water during pelletization results in interfacial forces and capillary pressures that increase the bonding of the particles.
Mani et al. (2007) [13]	Through their study of the compaction behavior of some biomass grinds, postulated that there are three stages of biomass densification. In the first stage, particles rearrange themselves to form a closely packed mass where most of the particles retain their properties and the energy is dissipated due to inter-particle and particle-to-wall friction. In the second stage, the particles are forced against each other and undergo plastic and elastic deformation that significantly increase the inter-particle contact promoting bonding through electrical and van der Waals forces. Greater pressures cause the volume to decrease dramatically in the third phase until the pellet's density resembles the actual densities of the constituent ingredients. By the end of the third stage, there are fewer cavities and 70% inter-particle conformance, meaning that the broken and deformed particles are unable to reposition themselves.
van Dam et al. (2004) [14]	Lignin present in the biomass acts as a glue and improve the binding characteristics of the biomass.

Table 2. Comparison of different densification equipments.

	Screw pens	Poison Press	Roller press	Pellet mill	Agglomerator
Optimum moisture content of the raw material	8-9%	10-15%	10-15%	10 I.	No information
Particle size	Smaller	Larger	Larger	Smaller	Smaller
Wear of contact parts	High	Low	High	High	Low
Output from machine	Continuous	In strokes	Continuous	Continuous	Continuous
Specific energy consumption (kWh/ton)	36.8-150	37.4-77	29.91-83.1	16.4-74.5	No information
Throughput (ton/hr.)	0.5	2.5	5-10	5	No information
Density of briquette	1-1.4 g/cm ³	1-1.2 g/cm ³	0.6-0.7 g/cm ³	0.7-0.8 g/cm ³	0.4-0.5 g/cm ³
Maintenance	Low	High	Low	Low	Low
Combustion performance of briquette	Very good	Moderate	Moderate	Very good	No information
Carbonization of charcoal	Makes good charcoal	Not possible	Not possible	Not possible	Not possible
Suitability in gasifiers	Suitable	Suitable	Suitable	Suitable	Suitable
Suitability for corning	Suitable	Suitable	Suitable	Suitable	Suitable
Suitability for biochemical conversion	Not suitable	Suitable	Suitable	Suitable	No information
Homogeneity of densified biomass	Homogeneous	Not homogeneous	Not homogeneous	Homogeneous	Homogeneous

Forms of Densification

Conventional processes for biomass densification can be classified into baling, pelletization, extrusion, and briquetting, which are carried out using a baler, pelletizer, screw press, piston or a roller press (Figures 1 and 2). Pelletization and briquetting are the most common processes used for biomass densification for solid fuel applications (Table 2).

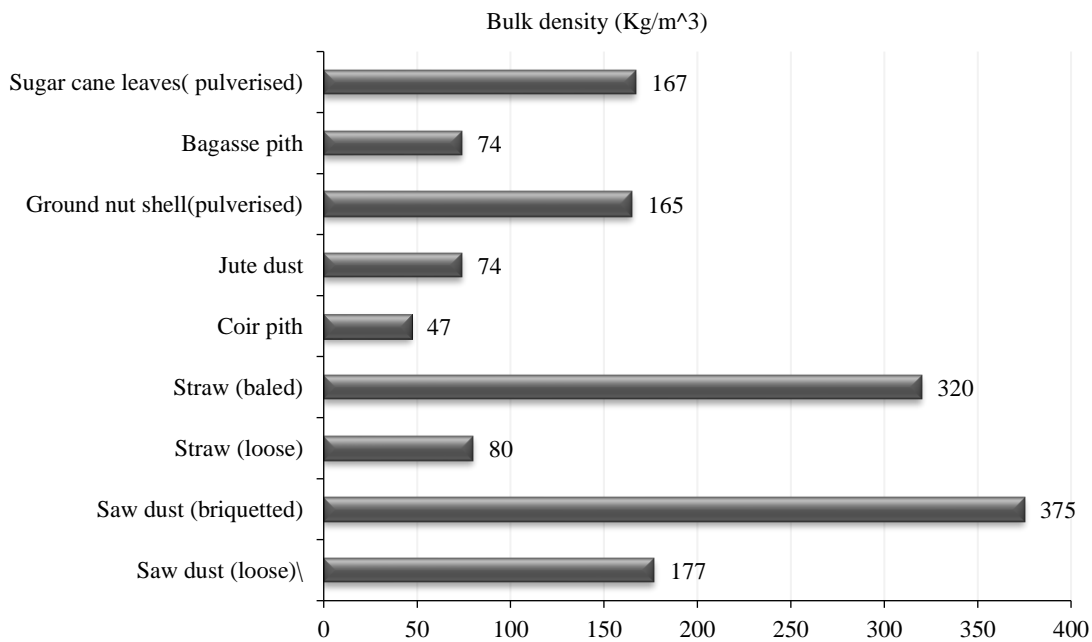


Figure 1. Bulk density of major agro-residues of India [4].

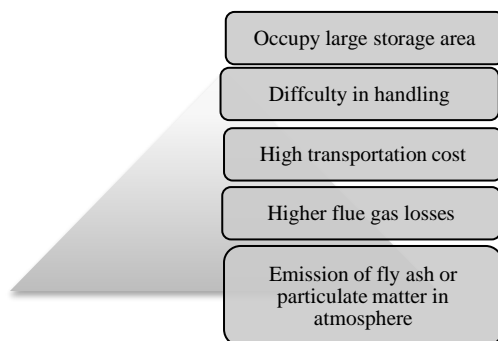


Figure 2. Consequences of low bulk density: significant depreciation in market value of biomass [4].

Table 3. Permissible moisture content of biofuel.

Domestic use	Below 30 wt% (w.b.)
Small scale furnace	10-30 wt% (w.b.)
Pellets and briquettes	10 wt% (w.b.)

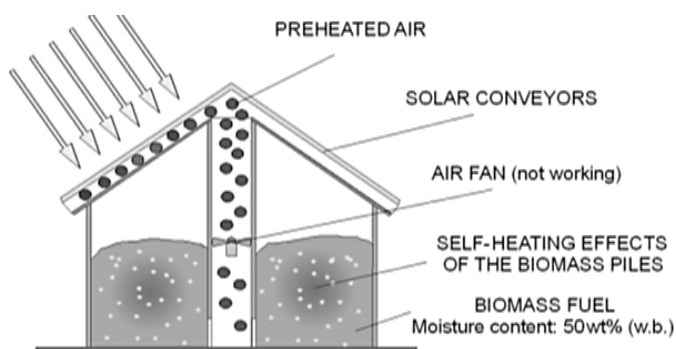
Biomass Drying

Only dry matter is useful for energy production especially via thermochemical process. The moisture content decreases the heating value of fuel and requires additional fuel for transportation and an additional area for storage (Figure 3). Biomass Drying Methods can be classified as:

- a. *Natural Drying*: It refers to the drying of biomass under sun. It is generally practised for drying of wood logs and agro-residues outdoors.
- b. *Mechanical drying*: Mechanical drying is with the help of various machines available for drying of biomass directly with the help of heated flue gas from a combustion process or indirectly with hot water, steam or thermal oil (Table 3).

1. STEP

- WARMING UP OUTSIDE AIR BY SOLAR CONVEYORS
- SELF-HEATING EFFECTS OF THE BIOMASS PILES



2. STEP

- PREHEATED AIR IS BLOWN BY THE AIR FAN THROUGH THE BIOMASS PILES
- THE WATER FROM THE BIOMASS IS CARRIED OUT BY THE AIR

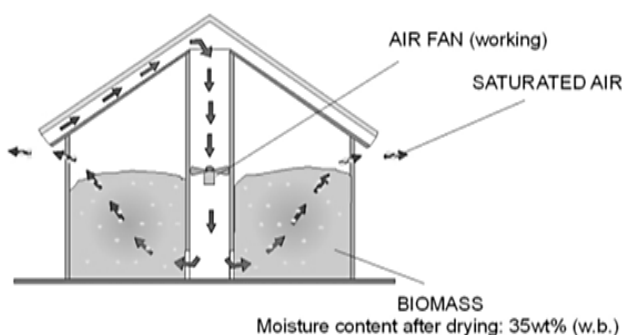


Figure 3. Natural drying process by solar energy.

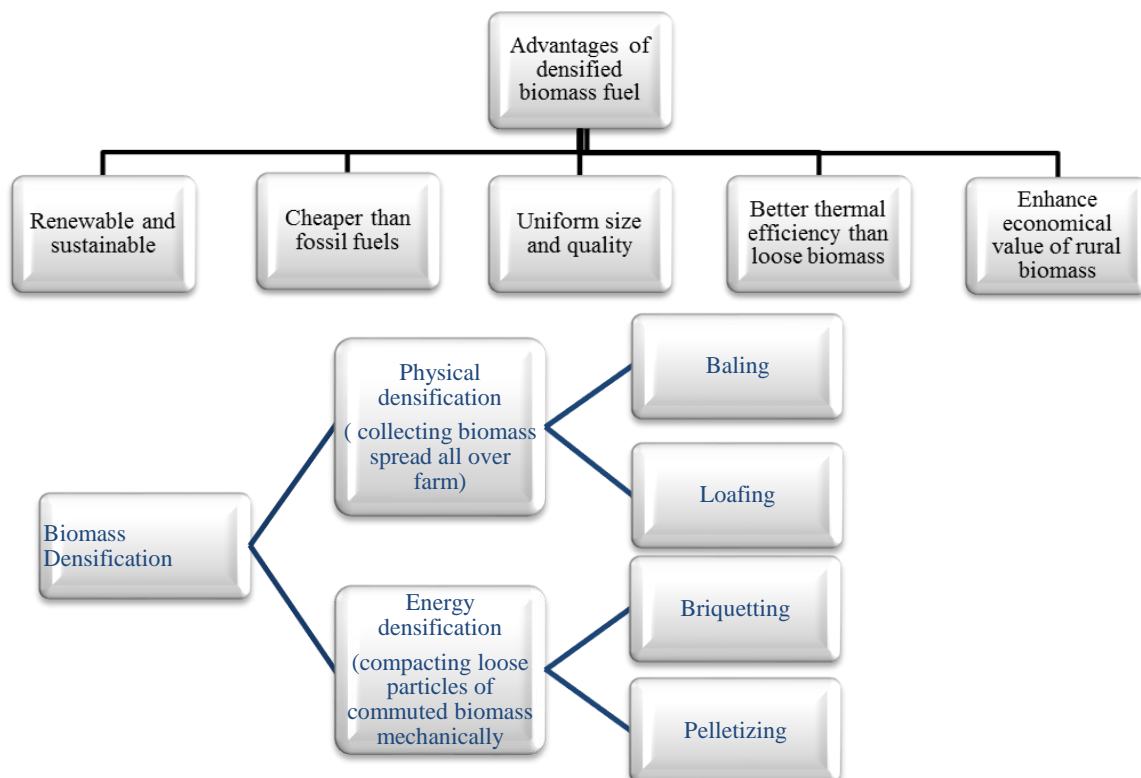


Figure 4. Biomass densification.

BIOMASS DENSIFICATION

Biomass has low energy density or bulk density, it means on burning a unit mass of it, we will get very less amount of energy in comparison to same mass of fossil fuel (Figure 4).

Biomass energy densification is done by two basic technologies which compress loose biomass into densified form.

1. Briquetting
2. Pelleting

Briquetting

Although densification is possible for almost all types of biomass, it is not economically feasible in each case. Therefore, many factors are taken into consideration, before commercially utilizing any biomass for briquetting.

Briquetting Machine

Principle and Working: In a briquetting machine, individual particles are compressed together in a confined volume and they bind together under pressure owing to adhesive and cohesive forces between biomass particles. Van der Waal's forces of attraction between solid particles and mechanical interlocking bonds under pressure provide strength to the structure of briquette so formed. Binders are used in low pressure briquettes to enhance adhesive force between biomass particles by creating solid liquid bridges. Examples of binders include highly viscous bonding media such as tar and other molecular organic liquid or cow dung. Lignin present in biomass gets softened at higher temperature and gets adsorbed on solid particle layer leading to binding of particles (Figure 5).

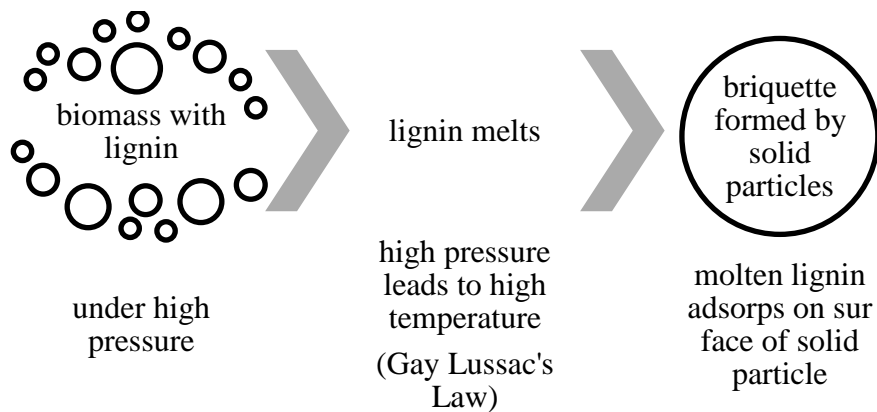


Figure 5. Pictorial representation of basic concept of briquetting.

Briquetting Technologies

Briquetting technologies are divided into three major categories (Tables 4-6).

- High pressure or high compaction technology: It comprises of two main types Piston press and Screw Press
- Medium pressure technology
- Low pressure technology (Figures 6 and 7)

Table 4. Comparison of various briquetting technologies.

Briquetting	High pressure	Medium pressure	Low pressure
Pressure	100 MPa	5MPa -100MPa	Less than 5 Mpa
Temperature generated due to pressure	200-250C	Lower heat generation	Room temperature is maintained as negligible heat is generated.
Material	For high lignin content	High to moderate lignin content.	Carbonized or low lignin material
Characteristics	High temperatures fuse lignin so no need of additional binding material	Additional heat is required to fuse lignin but no binding material needed.	Requires addition of binding material.

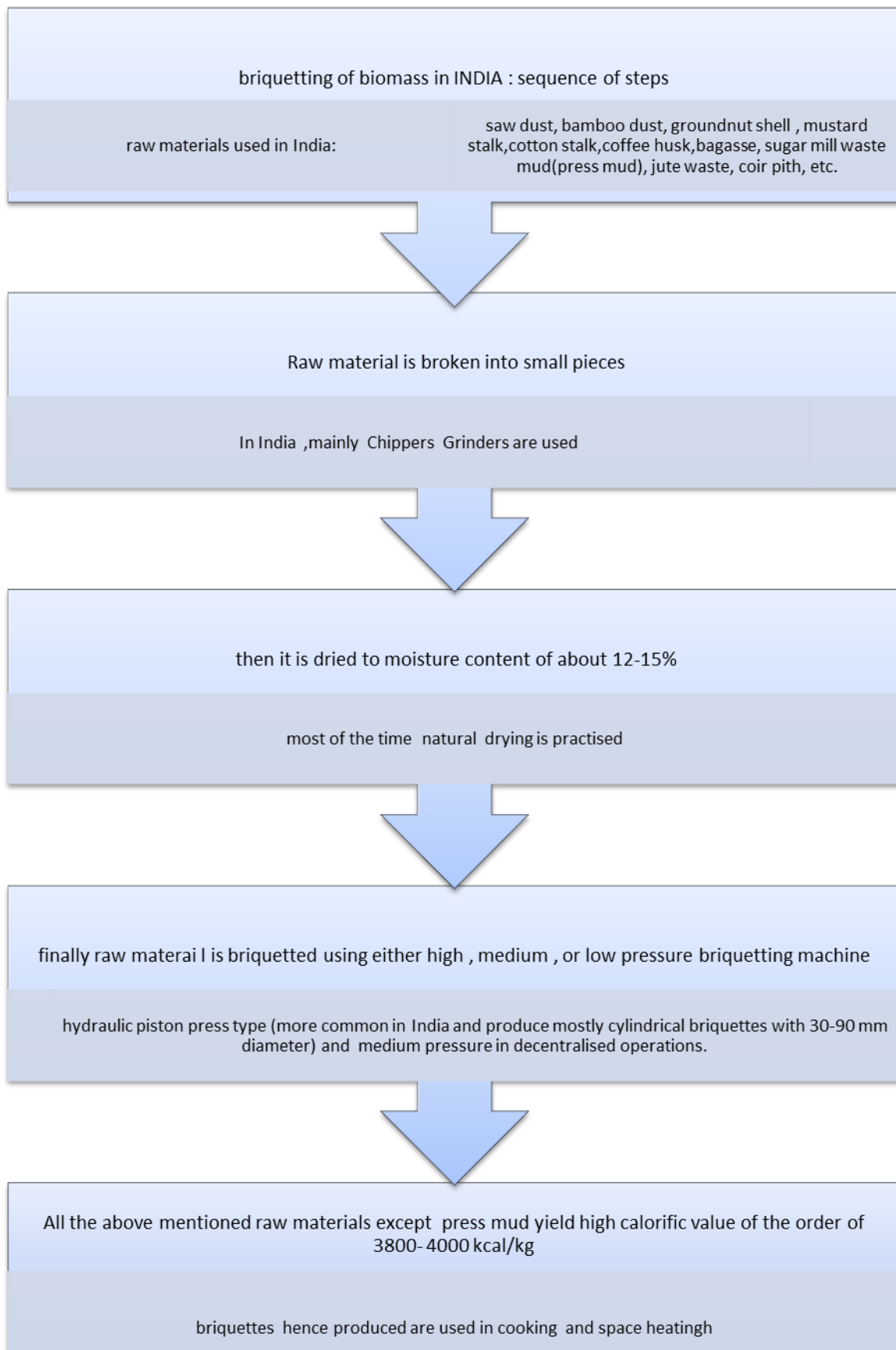


Figure 6. An Overview of biomass briquetting in India.

Table 5. Operating parameters of a briquetting machine.

Parameter	Desired Value	Significance
Particle size	Granular biomass of 6-8 mm in size with about 10-20% material in powdered form.	High pressure machines can briquette even larger sized particles but it could lead to choke of ram or die portion of briquetting machine Condensation of vapour released from large particles could lead to lumping of small particles obstructing the free flow. Presence of only finer particles is also not good due to its low density and flow characters. The packing dynamics are therefore improved by the presence of different-sized particles, leading to higher strength.
Moisture	7-10%	Optimum moisture content is necessary for development of self- bonding properties in lingo cellulosic matter at high temperature and pressure. A higher moisture content can result in poor and weak briquettes having cracks due to escape of moisture. In order to prevent them from regaining moisture from the air and swelling in humid conditions, briquettes should be produced with a moisture content higher than the equilibrium value.
Biomass feed temperature	High temperature up to 300 degree centigrade.	Increased temperature causes moisture to turn into steam, which hydrolyzes biomass into smaller molecules such as sugar polymers, lignin products, carbohydrates, and other derivatives that function as in-situ binding agents. Increased temperature and pressure from the biomass feed cause the fibers to become softer and more resistant to briquetting, which reduces power consumption and the wear and tear on the contact parts. However, temperature should not be raised above 300 degree Celsius to avoid pyrolysis.

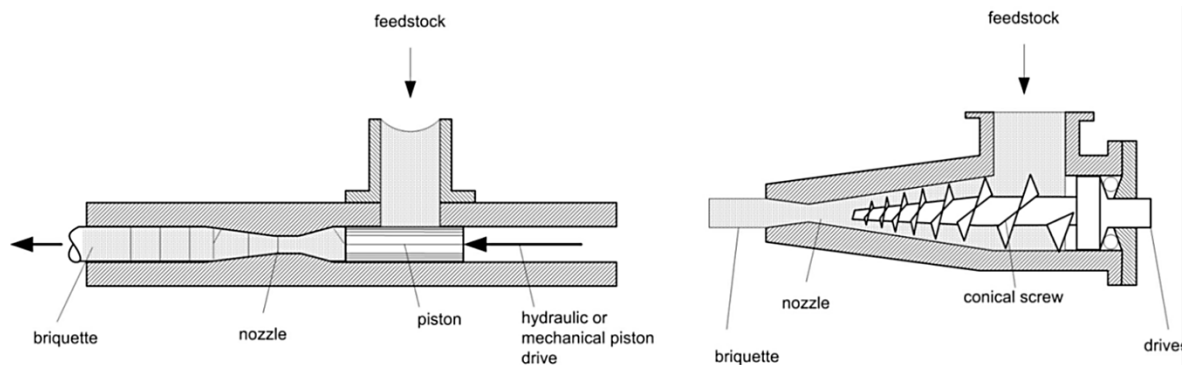


Figure 7. Piston press vs screw press briquetting machine.

Table 6. Comparison of piston press and screw press briquetting machines.

Parameter	Piston Press	Screw Press
Optimum moisture content of raw material	10-15%	8- 9%
Wear of contact parts	Lower	Higher
Output of machine	In strokes	Continuous
Power consumption	50 kWh/tonne	60 kWh/tonne
Density of briquettes	1-1.2g/cm ³	1-1.4g/cm ³
Maintenance	Higher	Lower
Combustion performance of briquettes	Good	Better
Homogeneity of briquettes	Less homogeneous	More homogeneous
Ignition	Smoky	Clean and easy (due to carbonation of outer surface)
Storage life	Short	Longer (as outer layer impervious to moisture)

Biomass Char Briquetting (Beehive Briquettes)

Agro-residues can be upgraded to convenient, smokeless fuel in the current fuel wood crisis. IIT Delhi has developed simple hand operated beehive briquetting machine.

Characteristics

- It uses locally available leafy biomass, Lantana or pine needles which are carbonised using simple drum charring system.
- Large cylindrical briquettes of 90 mm height X 125 mm diameter with 19 parallel holes are produced having calorific value of 9 MJ per briquette and weigh 0.5 kg each
- Clean gaseous combustion, similar to that of LPG, is produced by a single briquette used in a stove.
- Briquettes can be used for space heating as well as cooking because their holes function as a gasifier, producing gases for uniform combustion.

Note: Compared to coal or lignite, biomass briquettes are not competitive. Therefore, the briquette industry is not a financially viable option in states close to the coal belt, such as Orissa, Bihar, West Bengal, etc., whereas states farther from the coal belt, such as Punjab, Haryana, Rajasthan, Gujrat, Karnataka, TN, Kerala, etc., can benefit from the use of biomass briquettes since they reduce transportation costs (Figure 8).

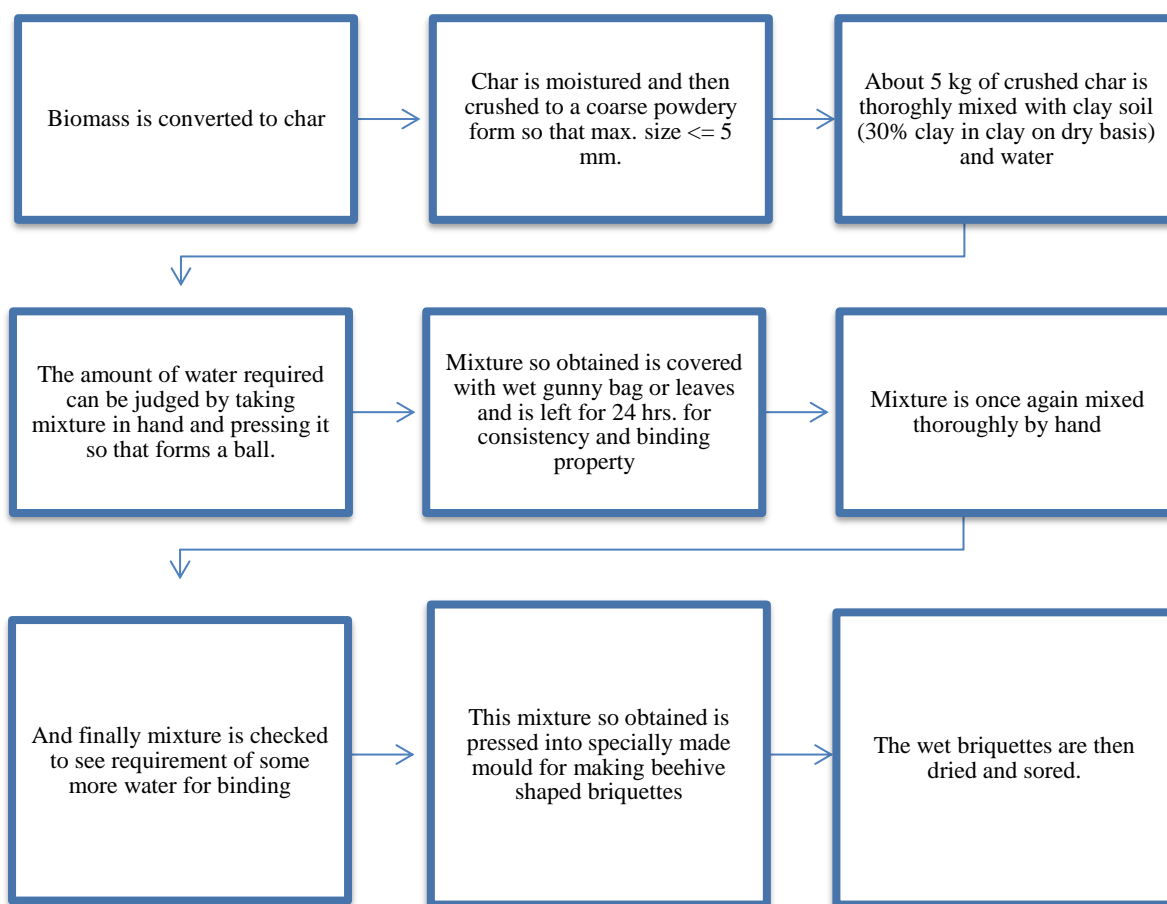


Figure 8. Beehive briquetting: sequence of steps.

Pelleting

Pelleting is a comparatively simpler method of biomass densification that produces pellets which are smaller and lighter biomass fuels in comparison to pellets (Figures 9, 12).

- Pellet mills are simpler in comparison to the briquetting machine
- Pellet mills operate at lower pressure thereby reducing the power consumption and also production cost.
- The processing of raw material is relatively easy than in case of briquetting.
- Such mills are based on fodder making technology.

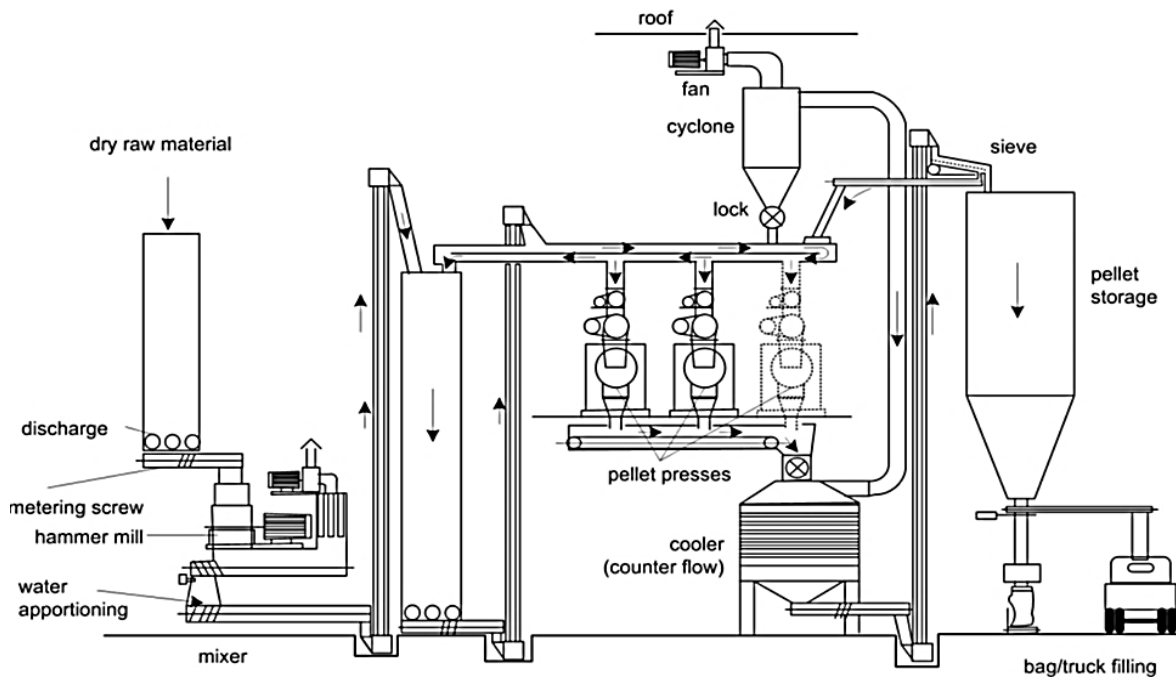


Figure 9. Layout of a typical pelleting machine.

The process of pellet production consists of five steps:

1. *Drying:* Before the raw material is fed into the pellet press, its moisture content needs to be between 8 and 12 weight percent (w.b.). Friction between the gooseneck and raw material must be maintained at a constant moisture content. If the wood is too wet, the moisture in the pressings cannot escape, increasing the volume of the product and weakening it mechanically. Conversely, if the wood is too dry, the particle's surface may carbonize and the binders will burn before the process is completed.
2. *Milling:* According to the required diameter of the pellet the particle size of the raw material must be reduced and homogenized using hammer mills.
3. *Conditioning* To improve adhesive property by the particles are covered with a thin layer of steam.
4. *Pelletizing:* For pelletizing wood, flat die or ring die pelletizers are used with the production range of 100kg to about 10 tonnes per hour.
5. *Cooling:* Cooling is required as the last step to guarantee excellent durability because the temperature of the pellets rises during the densification process (Figures 10 and 11).

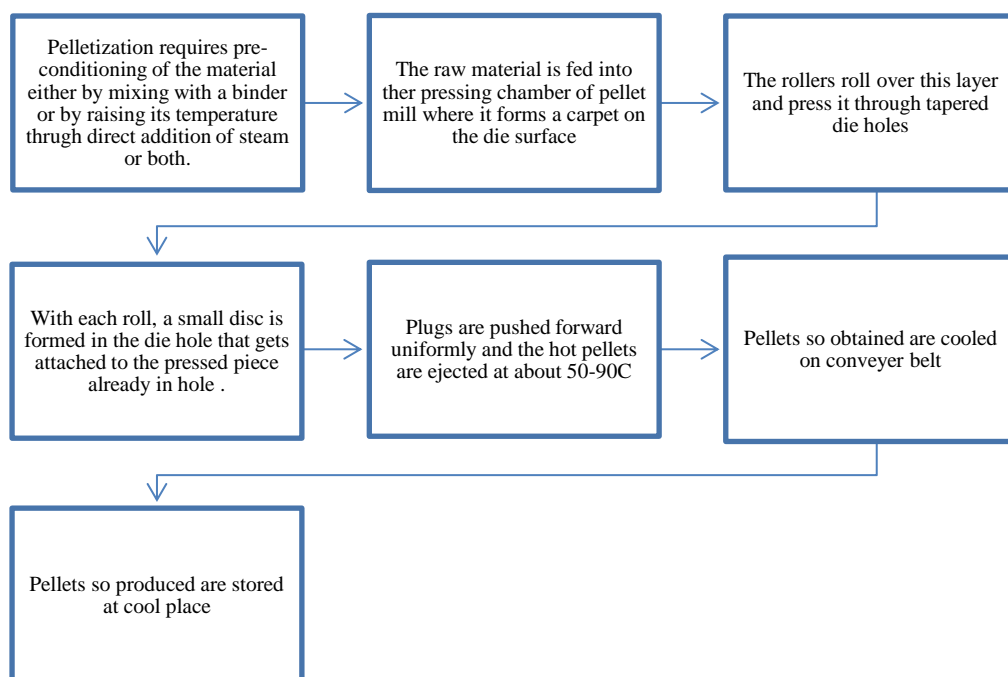


Figure 10. Flowchart for Pelleting of biomass.



Figure 11. Pellets.



Figure 12. Briquettes.

Table 7. Comparison of pellet and briquette.

Property	Pellet	Briquette
Dimensions	6-10 mm	30-100 mm
Use	Automatic stoves and boilers	Mostly in domestic stoves
Grain size	Uniform	Comparatively less uniform
Chemical composition	Uniform	Comparatively less uniform
Water content	Uniform	Comparatively less uniform

CONCLUSION

In conclusion up, the utilization of biomass densification technologies holds great potential in terms of improving the effectiveness, durability, and financial feasibility of energy generation derived from sustainable biomass resources. We have covered a wide range of biomass densification topics in this thorough review, including pelletization, briquetting, and torrefaction, explaining their benefits, drawbacks, and uses. In order to fully realize the promise of biomass densification technologies and

move towards a cleaner, more sustainable energy future, stakeholders from a variety of industries must work together.

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