

Solid Biofuel Densification for Energy Generation

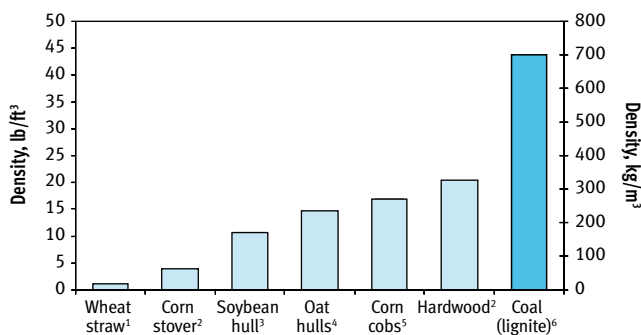
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INTRODUCTION

Solid biofuels are a potential source of renewable energy. One of the major barriers to their widespread use is they have a lower energy content than traditional fossil fuels, which means more fuel is required to get the same amount of energy. When combined — low energy content with low density — the volume of solid biofuels handled increases enormously. Compaction or densification is one way to increase the energy density and overcome handling and storage difficulties, especially for sources of agricultural-based solid biofuels. This Factsheet examines the density properties of solid biofuels and potential densification technologies.

BULK DENSITY

Bulk density is defined as the weight per unit volume of a material, expressed in kilograms per cubic metre (kg/m^3) or pounds per cubic foot (lb/ft^3). Most agricultural residues have low bulk densities, as shown in Figure 1.



Source: ¹ Reisinger et al. (2006); ² Preto (2007); ³ Blasi et al. (1998); ⁴ Shaw and Tabi (2006); ⁵ Murphy (1993); ⁶ Scurlock (2008)

Figure 1. Typical bulk densities of unprocessed solid biofuels and fossil fuels.

For example, the bulk density of loose wheat straw is approximately $18 \text{ kg}/\text{m}^3$ ($1.1 \text{ lb}/\text{ft}^3$), in comparison to coal at $700 \text{ kg}/\text{m}^3$ ($44 \text{ lb}/\text{ft}^3$). For this reason, it is only economically feasible to transport unprocessed solid biofuels less than approximately 200 km.^[7]

ENERGY DENSITY

Energy density is a term used to describe the amount of energy stored per unit volume, often expressed in MJ/m^3 or BTU/ft^3 .

Figure 2 is a graphical representation of common volume ratios for unprocessed material, with the cubes representing the volume of material required for equal energy, 16:4:1 for straw to wood to coal.

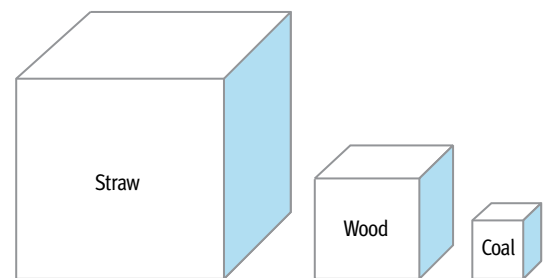


Figure 2. Typical bulk densities of unprocessed solid biofuels and fossil fuels.

WHY DENSIFY?

The low density of solid biofuels poses a challenge for the handling, transportation, storage and combustion processes. These problems may be addressed through

densification, a process that produces either liquid or solid biofuel with denser and more uniform properties than the raw biomass.

The main advantages of solid biofuel densification for combustion are:

- simplified mechanical handling and feeding
- uniform combustion in boilers
- reduced dust production
- reduced possibility of spontaneous combustion in storage
- simplified storage and handling infrastructure, lowering capital requirements at the combustion plant
- reduced cost of transportation due to increased energy density

The major disadvantage to solid biofuel densification technologies is the high cost associated with some of the densification processes.

PRE-TREATMENT OF SOLID BIOFUEL

Prior to solid biofuel densification, pre-treatments may be required to optimize the energy content and bulk density of the product.

Pre-treatment can include:

- chop length/grinding
- drying to required moisture content
- application of a binding agent
- steaming
- torrefaction

Chop Length/Grinding

Each densification process requires specific chop length and/or grinding to achieve:

- lower energy use in the densification process
- denser products
- a decrease in breakage of the outcome product^[2]

Drying

Low moisture results in improved density and durability of the biofuel.^[8] For most solid biofuel densification processes, the optimum moisture content is in the range of 8%–20% (wet basis).^[3] Most compaction techniques require a small amount of moisture (such as steam) to

“soften” the biomass for compaction. Above the optimum moisture level, the strength and durability of the densified solid biofuel are decreased.

Addition of a Binding Agent

The density and durability of densified solid biofuel are influenced by the natural binding agents of the material. The binding capacity increases with a higher protein and starch content.^[10] Corn stalks have high binding properties, while warm-season grasses, which are low in protein and starch content, have lower binding properties.^[4] Binding agents may be added to the material to increase binding properties. Commonly used binders include vegetable oil, clay, starch, cooking oil or wax.

Steaming

The addition of steam prior to densification can aid in the release and activation of natural binders present in the solid biofuel, such as lignin.

Torrefaction

Torrefaction is a version of pyrolysis processes that involve the heating of solid biofuel in the absence of oxygen and air. Torrefaction is a pre-treatment process used to improve the properties of pellets. It can also be used as a stand-alone technique to improve the properties of solid biofuel. Torrefaction is a mild version of slow pyrolysis where the goal is to dry, embrittle and waterproof the solid biofuel. This is accomplished by heating the solid biofuel in an inert environment at temperatures of 280°C–320°C.

TECHNIQUES FOR SOLID BIOFUEL DENSIFICATION

Solid biofuel is densified via two main processes: mechanical densification and pyrolysis. Mechanical densification involves applying pressure to mechanically densify the material. Pyrolysis involves heating the solid biofuel in the absence of oxygen. In general, lower temperatures at longer processing times (i.e., slow pyrolysis) favour solid (charcoal) production. Medium temperatures (400°C–500°C) at very short times (1–2 seconds), known as fast pyrolysis, favour liquid biofuel or bio-oil production.

The method of densification depends on the type of residues and the local situation. [Table 1](#) outlines the various technologies used to increase the solid biofuel energy density and/or mould the fuel into a homogeneous size and shape.

CONVERSION

From	To	Multiply By
mm	inch	0.0394
inch	ft	0.0833
kg/m ³	lb/ft ³	0.0624
MJ/kg	BTU/lb	430

Table 1. Densification Technologies

Mechanical Densification



BALES are a traditional method of densification commonly used to harvest crops. A bale is formed using farm machinery (called a baler) that compresses the chop. Bales can be square, rectangular or round, depending on the type of baler used. The dimensions of round bales range from 1.2 m x 1.5 m (4 ft x 5 ft) to 1.5 m x 1.5 m (5 ft x 5 ft). Large rectangular bales typically measure 0.9 m x 0.9 m x 1.8 m (3 ft x 3 ft x 6 ft) in length. Round bales are less expensive to produce, however, large square bales are usually denser and easier to handle and transport.



PELLETS are very high in density. They are easier to handle than other densified solid biofuel products, since infrastructure for grain handling is used for pellets. Pellets are formed by an extrusion process, using a piston press, where finely ground solid biofuel material is forced through round or square cross-sectional dies and cut to a desired length. The standard shape of a solid biofuel pellet is a cylinder, having a length smaller than 38 mm (1.5 in.) and a diameter around 7 mm (0.3 in.). Although uniform in shape, pellets are easily broken during handling. Different grades of pellets vary in energy and ash content.

Source (Photo): CanmetENERGY.



CUBES are larger pellets, usually square in shape. Cubes are less dense than pellets. Cube sizes range from 13–38 mm (0.5–1.5 in.) in cross section, with a length ranging 25–102 mm (1–4 in.). The process involves compressing chopped solid biofuel with a heavy press wheel, followed by forcing the solid biofuel through dies to produce cubes.

Source (Photo): CanmetENERGY.



BRIQUETTES are similar to pellets but differ in size. Briquettes have a diameter of 25 mm (1 in.) or greater and are formed when solid biofuel is punched, using a piston press, into a die under high pressure. Alternatively, a process referred to as screw extrusion can be used. In screw extrusion, the solid biofuel is extruded by a screw through a heated die. Solid biofuel densified through screw extrusion has higher storability and energy density properties compared to solid biofuel produced by piston press.

Source (Photo): Wayne Winkler.



PUCKS are similar in appearance to a hockey puck, with a 75 mm (3 in.) diameter. They are produced using a briquetter and are resilient to moisture. Pucks have a similar density as pellets, with the advantage that they require lower production costs compared to pelletization.



WOOD CHIPS are used in many operations, from household appliances to large-scale power plants. Woodchips for boilers range in size, 5–50 mm (0.2–2 in.) in length. Woodchips are made with a woodchipper. In terms of fuel, woodchips are comparable in cost to coal.

Source (Photo): CanmetENERGY.

Pyrolysis



TORREFACTION is carried out by heating solid biofuel in an inert atmosphere at temperatures of 280°C–320°C for a few minutes. The torrefied fuel shows improved grindability properties. Torrefied solid biofuel has hydrophobic properties (repels water), making it resistant to biological attack and moisture, thereby facilitating its storage. The process requires little energy input since some of the volatile gases liberated during heating are combusted, generating 80% of the heat required for torrefaction. Torrefied solid biofuel is densified into pellets or briquettes, further increasing the density of the material and improving its hydrophobic properties.

Source (Photo): CanmetENERGY.



SLOW PYROLYSIS involves heating biomass to 350°C–500°C in the absence of oxygen and air for extended periods of time (typically 0.5–2 hours). The principal product is a solid (charcoal) that retains 30%–40% of the original energy from the raw solid biofuel. The energy density can be increased, and thus charcoal is a suitable fuel for commercial uses similar to torrefied solid biofuel, residential use, i.e., barbecues, and as a potential soil improvement additive known as bio-char.

Source (Photo): CanmetENERGY.



FAST PYROLYSIS involves processing solid biofuel at temperatures of up to 450°C–500°C for 1–2 seconds. The process yields up to 75% bio-oil and 10%–15% charcoal. Bio-oil is a higher-energy density fuel, and its handling properties are simplified, as the fuel is a liquid that is pumped and stored in tanks. Precautions are necessary, as bio-oils are very acidic, have a pungent odour and are prone to separation/settling. Substitute bio-oil for fossil fuel, heavy and middle oils. Research is under way to explore conversion to lighter oils such as diesel and gasoline. Source (Photo): CanmetENERGY.

Table 2. Density of Solid Biofuel for Selected Densification Technologies

Form of Solid Biofuel	Shape and Size Characteristics	Density (lb/ft ³)	Density (kg/m ³)	Energy Density (GJ/m ³)
Traditional Method				
Baled agricultural residues	Large round, Soft core 1.2 x 1.2, 1.2 x 1.5, 1.5 x 1.2, 1.8 x 1.5 m (4 x 4, 4 x 5, 5 x 4, 6 x 5 ft) diameter x width	10–12	160–190	2.8–3.4
Baled agricultural residues	Large round, Hard core 1.2 x 1.2, 1.2 x 1.5, 1.5 x 1.2, 1.8 x 1.5 m (4 x 4, 4 x 5, 5 x 4, 6 x 5 ft) diameter x width	12–15	190–240	3.4–4.5
Baled agricultural residues	Large/Mid-size square 0.6 x 0.9 x 2.4 m (2 x 3 x 8 ft) 0.9 x 1.2 x 2.4 m (3 x 4 x 8 ft)	13–16	210–255	3.7–4.7
Non-Traditional Method				
Ground forestry residues ^[9] (i.e., hammermill)	1.5 mm (0.06 in.) pack fill with tapping	13	200	3.6
Briquettes ^[9]	32 mm (1.3 in.) diameter x 25 mm (1 in.) thick	22	350	6.4
Cubes ^[9]	33 mm (1.3 in.) x 33 mm (1.3 in.) cross section	25	400	7.3
Pucks ^[11]	75 mm (3 in.) diameter x 12 mm (0.5 in.) thick	30–40	480–640	8.6–12.0
Pellets ^[9]	6.24 mm (0.2 in.) diameter	35–45	550–700	9.8–14.0
Torrefied pellets ^[5]	6.24 mm (0.2 in.) diameter	50	800	15.0
Bio-oil ^[5]	liquid	75	1,200	20

Note: Loose solid biofuel has a density of 3.5–5 lb/ft³ or 60–80 kg/m³.

Through various densification technologies, raw solid biofuel is compressed to densities in the order of 7–10 times its original bulk density.^[1] The bulk densities for selected pre-processing technologies are displayed in Table 2, as well as in Figure 3.

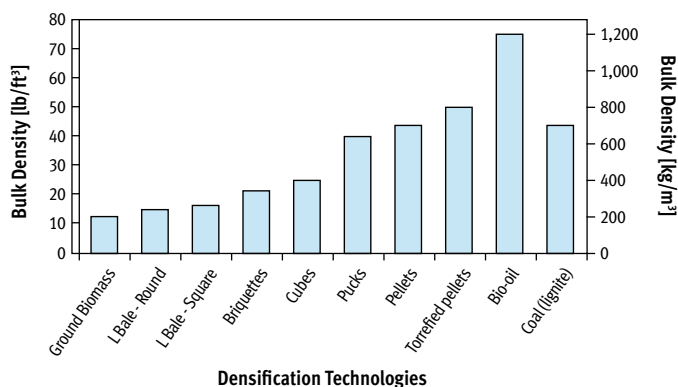


Figure 3. Resulting bulk densities of solid biofuel for selected densification technologies.

SOLID BIOFUEL DENSIFICATION COST

Pyrolyzed materials are the most expensive to densify, with cubes, pucks, briquettes and woodchips being less expensive.

Factors affecting the cost of densification technologies include:^[6]

- size of densification plant (tonnes/year)
- operating time (hours/day)
- equipment cost
- personnel cost
- raw material costs

Densification technologies result in higher energy inputs and increased costs. A portion of the cost is recuperated by the lower handling, storage and transportation costs, and better operability of the boiler and combustion process. Some densification technologies mentioned are commercially available, while others are emerging.

CONCLUSION

The low-energy density of solid biofuel by volume, in comparison with fossil fuels, results in higher handling, storage and transportation costs. Consequently, solid biofuel is most economically feasible when used close to the source. The cost of transportation is reduced through

densification technologies. Densification technologies produce a homogeneous product with a higher energy density than that of the original raw material, at the expense of new capital and operating costs.

RESOURCES

[Renewable Energy on Farms](#)

[Canadian biofuel](#)

[CanmetENERGY](#)

[R.E.A.P. \(Resource Efficient Agricultural Production\)](#)

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