Biomass Densification for Energy Production

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Factsheet

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INTRODUCTION

Biomass fuels are a potential source of renewable energy. One of the major barriers to their widespread use is that biomass has a lower energy content than traditional fossils fuels, which means that more fuel is required to get the same amount of energy. When combined — low energy content with low density — the volume of biomass handled increases enormously. Compaction or densification is one way to increase the energy density and overcome handling difficulties. This Factsheet examines the density properties of solid biomass 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.

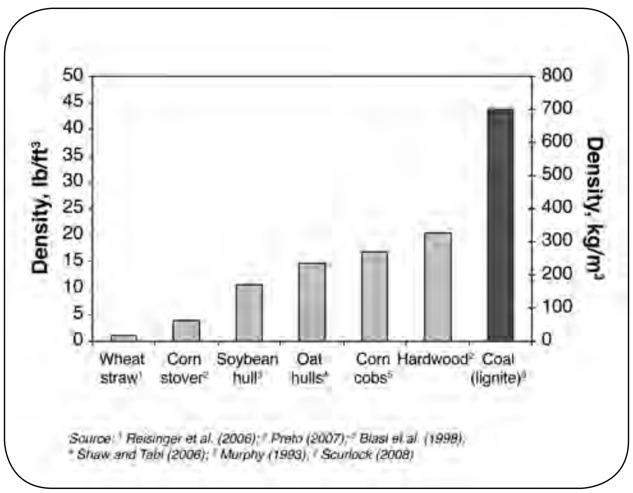

Figure 1. Typical bulk densities of unprocessed biomass materials.

For example, the bulk density of loose wheat straw is approximately 18 kg/m^3 (1.1 lb/ft^3), in comparison to coal at 700 kg/m^3 (44 lb/ft^3). For this reason, it generally is only economically feasible to transport unprocessed biomass less than approximately 200 km (Preto 2007).

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.

WHY DENSIFY?

The low density of biomass materials 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 fuel with denser and more uniform properties than the raw biomass.

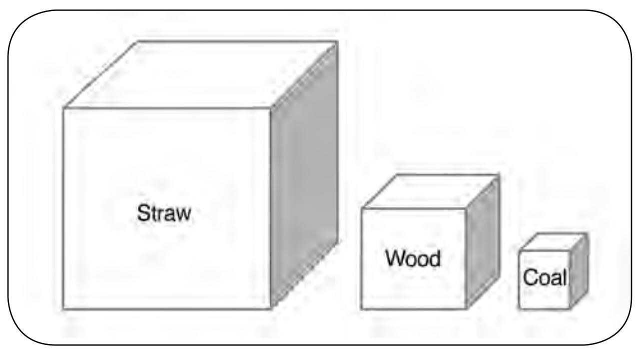

Figure 2. Equivalent energy content by volume of unprocessed materials. *Source: Preto (2007).*

The main advantages of biomass 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 biomass densification technologies is the high cost associated with some of the densification processes.

PRE-TREAMENT OF BIOMASS

Prior to biomass 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 (Dobie 1959)

Drying

Low moisture results in improved density and durability of the fuel (Shaw and Tabil 2007). For most biomass densification processes, the optimum moisture content is in the range of 8%–20% (wet basis) (Kaliyan and Morey 2009). Most compaction techniques require a small amount of moisture to "soften" the biomass for compaction. Above the optimum moisture level, the strength and durability of the densified biomass are decreased.

Addition of a Binding Agent

The density and durability of densified biomass are influenced by the natural binding agents of the material. The binding capacity increases with a higher protein and starch content (Tabil et al. 1997). Corn stalks have high binding properties, while warm-season grasses, which are low in protein and starch content, have lower binding properties (Kaliyan and Morey 2006). 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 biomass.

Torrefaction

Torrefaction is a version of pyrolysis processes that comprise the heating of biomass 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 biomass. Torrefaction is a mild version of slow pyrolysis in which the goal is to dry, embrittle and waterproof the biomass. This is accomplished by heating the biomass in an inert environment at temperatures of 280°C–320°C.

TECHNIQUES FOR BIOMASS DENSIFICATION

Biomass is densified via two main processes: mechanical densification and pyrolysis. Mechanical densification involves applying pressure to mechanically densify the material. Pyrolysis involves heating the biomass 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 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 biomass 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 biomass products, since infrastructure for grain handling is used for pellets. Pellets are formed by an extrusion process, using a piston press, where finely ground biomass material is forced through round or square cross-sectional dies and cut to a desired length. The standard shape of a biomass 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. *Photo courtesy of 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 biomass with a heavy press wheel, followed by forcing the biomass through dies to produce cubes. *Photo courtesy of 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 biomass 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 biomass is extruded by a screw through a heated die. Biomass densified through screw extrusion has higher storability and energy density properties compared to biomass produced by piston press. *Photo courtesy of 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. *Photo courtesy of CanmetENERGY.*
Pyrolysis	
	**TORREFACTION** is carried out by heating biomass in an inert atmosphere at temperatures of 280°C–320°C for a few minutes. The torrefied fuel shows improved grindability properties. Torrefied biomass 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 biomass is densified into pellets or briquettes, further increasing the density of the material and improving its hydrophobic properties. *Photo courtesy of 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 60%–70% of the original energy from the raw biomass. The energy density can be increased, and thus charcoal is a suitable fuel for commercial uses similar to torrified biomass, residential use, i.e., barbecues, and as a potential soil improvement additive known as bio-char. *Photo courtesy of CanmetENERGY.*
	**FAST PYROLYSIS** involves processing biomass 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. *Photo courtesy of CanmetENERGY.*

Table 2. Density of biomass for selected densification technologies

Form of biomass	Shape and size characteristics	Density (lb/ft^3)	Density (kg/m^3)	Energy density (GJ/m^3)
Traditional method				
Baled biomass[3]	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
	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
	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 biomass[1] (i.e., hammermill)	1.5 mm (0.06 in.) pack fill with tapping	13	200	3.6
Briquettes[1]	32 mm (1.3 in.) diameter x 25 mm (1 in.) thick	22	350	6.4
Cubes[1]	33 mm (1.3 in.) x 33 mm (1.3 in.) cross section	25	400	7.3
Pucks[4]	75 mm (3 in.) diameter x 12 mm (0.5 in.) thick	30–40	480–640	8.6–12.0
Pellets[1]	6.24 mm (0.2 in.) diameter	35–45	550–700	9.8–14.0
Torrefied pellets[2]	6.24 mm (0.2 in.) diameter	50	800	15.0
Bio-oil[2]	liquid	75	1,200	20
Note: Loose biomass has a density of 3.5–5 lb/ft^3 or 60–80 kg/m^3				
Source: [1]Sokhansanj et al. (2006); [2]Kiel (2007), [3]Clarke (1995), [4]Winkler				

Through various densification technologies, raw biomass is compressed to densities in the order of 7–10 times its original bulk density (Demirbas et al. 2009). The bulk densities for selected pre-processing technologies are displayed in Table 2, as well as in Figure 3.

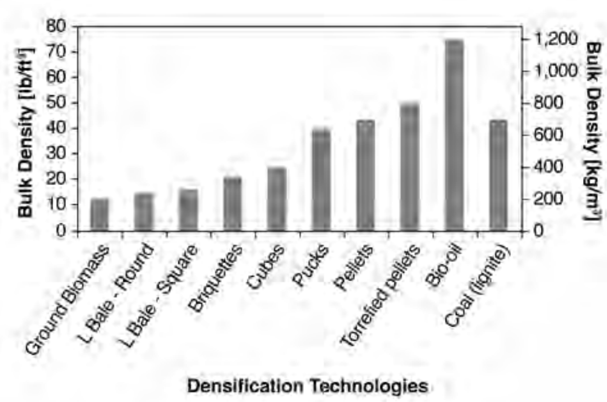

Figure 3. Resulting bulk densities of biomass for selected densification technologies.

BIOMASS 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 (Mani 2006):

- 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 biomass by volume, in comparison with fossil fuels, results in higher handling, storage and transportation costs. Consequently, biomass is most economically feasible when used close to the source. The cost of biomass 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.

ADDITIONAL RESOURCES

BIOCAP Canada. www.biocap.ca.

Canadian biofuels. www.canadianbiofuel.ca/biomassfuel.html.

CanmetENERGY, Natural Resources Canada. www.canmetenergy-canmetenergie.nrcan-rncan.gc.ca.

Ontario Ministry of Agriculture, Food and Rural Affairs. www.ontario.ca/greenfarming.

R.E.A.P. (Resource Efficient Agricultural Production). www.reap-canada.com.

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