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 fossil 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. 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 1. Typical bulk densities of unprocessed biomass materials.

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-TREATMENT 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:**

<table>
<thead>
<tr>
<th>From</th>
<th>to</th>
<th>Multiply by</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>inch</td>
<td>0.0394</td>
</tr>
<tr>
<td>inch</td>
<td>ft</td>
<td>0.0833</td>
</tr>
<tr>
<td>kg/m³</td>
<td>lb/ft³</td>
<td>0.0624</td>
</tr>
<tr>
<td>MJ/kg</td>
<td>BTU/lb</td>
<td>430</td>
</tr>
</tbody>
</table>
机械压密化

**BALES**是传统的压密化方法，用于收获农作物。一捆由农用机械（称为打包机）压缩草料形成。巴勒可以是方形、矩形或圆形，这取决于所使用的打包机类型。圆形巴勒的尺寸范围从1.2 m x 1.5 m（4 ft x 5 ft）到1.5 m x 1.5 m（5 ft x 5 ft）。大矩形巴勒通常测量0.9 m x 0.9 m x 1.8 m（3 ft x 3 ft x 6 ft）长度。圆巴勒生产成本较低，然而，大矩形巴勒通常更密实且更容易处理和运输。

**PELLETS**密度非常高。它们更容易处理，而与其他压密化生物质产品相比，由于用于谷物处理的基础设施而被用于压密化。颗粒是由挤压过程形成的，使用一个活塞压机，将粉碎的生物质材料通过圆形或方形截面的模具并切割成所需的长度。标准形状的生物质颗粒是一个圆柱体，长度小于38 mm（1.5 in.），直径约为7 mm（0.3 in.）。虽然形状统一，但颗粒在处理过程中很容易破碎。不同等级的颗粒在能量和灰分含量上有所差异。照片来源：CanmetENERGY。

**CUBES**是较大的颗粒，通常方形。立方体密度低于颗粒。立方体尺寸范围为13–38 mm（0.5–1.5 in.）的横截面，长度范围为25–102 mm（1–4 in.）。该过程涉及将切碎的生物质用重型压轮压缩，然后将生物质通过模具产生立方体。

**BRIQUETTES**与颗粒类似，但尺寸不同。 briquettes具有直径为25 mm（1 in.）或更大的尺寸，并且是当生物质被冲压时形成的，使用活塞压机，放入一个高压下。此外，一种称为螺杆挤出的工艺也可以使用。在螺杆挤出中，生物质通过一个加热的模具被挤出。生物质通过螺杆挤出的密度高于通过活塞压机产生的密度。照片来源：Wayne Winkler。

**PUCKS**类似于冰球，直径为75 mm（3 in.）。它们通过压密机产生，并且在湿润条件下具有良好的弹性和韧性。Pucks与颗粒具有相似的密度，但它们的优点是生产成本较低。

**WOOD CHIPS**在许多应用中使用，从家用电器到大型发电厂。木片尺寸范围为5–50 mm（0.2–2 in.）长度。木片是通过木片机制成的。在燃料方面，木片与煤炭具有相似的成本。

**PYROLYSIS**是通过在惰性大气中加热生物质，在280°C–320°C的温度下几分钟进行的。热解燃料显示改善的研磨性。热解生物质具有疏水性特性（排斥水），使其对生物性攻击和湿度具有抵抗力，从而改善其存储。该过程需要少量能源输入，因为一部分在加热过程中释放的挥发性气体被燃烧，提供80%的热能用于热解。热解生物质被热解为颗粒或 briquettes，进一步增加了材料密度和提高其疏水性。照片来源：CanmetENERGY。

**SLOW PYROLYSIS**涉及在350°C–500°C的温度下快速热解生物质，以氧气和空气为载体进行较长时间的氧化处理（通常为0.5–2小时）。主要产品是固体（木炭）保留了60%–70%的原始能量来自原始生物质。能量密度可以增加，而木炭是一种适合用于商业用途的燃料，类似于热解生物质，住宅用途，如烧烤，以及作为土壤改良添加剂，如生物炭。照片来源：CanmetENERGY。

**FAST PYROLYSIS**在450°C–500°C的温度下快速热解生物质，以氧气和空气为载体进行较长时间的氧化处理（通常为0.5–2小时）。主要产品是固体（木炭）保留了60%–70%的原始能量来自原始生物质。能量密度可以增加，而木炭是一种适合用于商业用途的燃料，类似于热解生物质，住宅用途，如烧烤，以及作为土壤改良添加剂，如生物炭。照片来源：CanmetENERGY。
Table 2. Density of biomass for selected densification technologies

<table>
<thead>
<tr>
<th>Form of biomass</th>
<th>Shape and size characteristics</th>
<th>Density (lb/ft³)</th>
<th>Density (kg/m³)</th>
<th>Energy density (GJ/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional method</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Baled biomass¹ | 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  
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  
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 biomass¹ (i.e., hammermill)  
1.5 mm (0.06 in.) pack fill with tapping | 13 | 200 | 3.6 |
| | Briquettes⁴  
32 mm (1.3 in.) diameter x 25 mm (1 in.) thick | 22 | 350 | 6.4 |
| | Cubes³  
33 mm (1.3 in.) x 33 mm (1.3 in.) cross section | 25 | 400 | 7.3 |
| | Pucks⁴  
75 mm (3 in.) diameter x 12 mm (0.5 in.) thick | 30–40 | 480–640 | 8.6–12.0 |
| | Pellets³  
6.24 mm (0.2 in.) diameter | 35–45 | 550–700 | 9.8–14.0 |
| | Torrefied pellets²  
6.24 mm (0.2 in.) diameter | 50 | 800 | 15.0 |
| | Bio-oil²  
liquid | 75 | 1,200 | 20 |

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

Source: ¹Sokhansanj et al. (2006); ²Kiel (2007), ³Clarke (1995), ⁴Winkler

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.

**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.


REFERENCES


ACKNOWLEDGEMENTS
A special thanks is extended to Chantal Quesnel for all of her hard work in helping create this Factsheet, Benjamin Bronson for his contributions and conscientious review and Shalin Khosla, Greenhouse Specialist, OMAFRA, for his considerable assistance in evaluating alternate technologies.

This Factsheet was written by Steve Clarke, P.Eng., Engineer, Energy and Crop Engineering Specialist, OMAFRA, Kemptville, and Fernando Preto, Bioenergy Systems, CanmetENERGY.