


Woody Biomass Factsheet – WB2

Densified Wood Fuels

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Wood has likely been valued by people as a fuel that can supply heat since the first lighting strike to a tree was observed! Wood is often the fuel of choice because it is readily available, burns easily, and is renewable. The rapid expansion of the energy needed to fuel the industrial revolution, however, emphasized the value of other fuels such as coal and crude oil that are more energy dense (higher energy value per unit volume). Densification is a process of compressing a given amount of material into a smaller volume in such a way that the material maintains its smaller volume. Densification improves the positive attributes of wood fuels while retaining the environmental benefits of a renewable fuel and improving its comparison to fossil fuels [1, 2]. These include:

- Uniform size and shape promotes efficient transportation, storage, and automatic feeding systems
- Consistent low moisture content
- Greater energy density than non-densified wood, reducing transportation costs
- Provide a uniform, reliable source of a renewable natural resource as a fuel supply

Densified wood fuels are manufactured to a particular size and shape for a given market. Typically, wood particles are compressed into pellet, log, or brick shapes. Figure 1 shows the relative amount of various fuel types needed to produce about 15,000 Btu of heat.

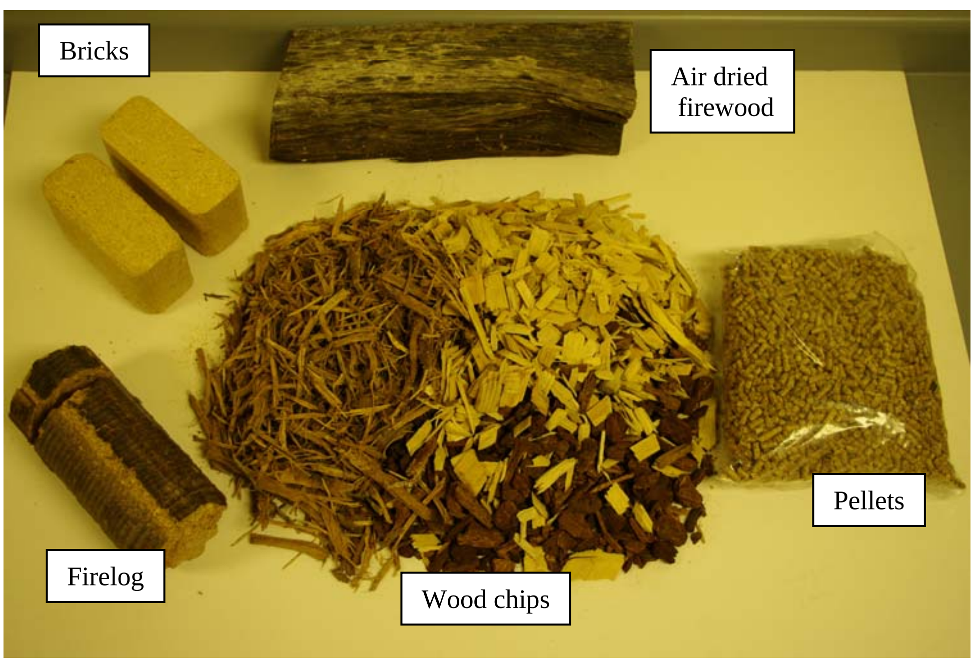

Figure 1. Comparison of the volume of different fuel types needed to produce an equivalent amount of heat.

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Markets

Densified fuels, being a manufactured product, can be designed for specific market goals and uses. The processing methods and quality standards differ depending on the specific use and set of goals. The following discussion covers these differences and presents a detailed description of the fuel pellet manufacturing process – the product with the greatest market growth potential. Table 1 describes the main differences between the various types.

The biggest global use of wood fuel pellets is in commercial heating systems and as a supplemental fuel (co-fire) for coal fired powerplants. Co-firing coal with wood pellets at substitutions from 1-20% is common in Europe. This trend has been driven by legislation to increase the amount of electricity generation from renewable sources including wood pellets [3, 4]. However, in the US the primary use for fuel pellets is in dedicated stoves used for domestic heating. If co-firing becomes more developed in the US, then the market for fuel pellets is expected to dramatically expand. Densified wood pellets also have other uses, including animal bedding and grilling (barbeque) pellets for heat and flavor. The main markets for firelogs and bricks are homes with existing wood-burning fireplaces. Short sections of firelogs, shaped like and called "pucks", are also marketed for use in commercial heating systems designed to handle solid fuels (e.g. chunks).

Table 1: Densified wood fuel types

Densified Wood Fuel*	Primary market	Characteristics
Pellets	Residential stoves Commercial boilers Co-firing with coal Animal bedding	**Size:** 0.229 to 0.284 inch diameter (5.84 to 7.25 mm), 99% must be shorter than 1.5 inches (38 mm) long **Grade:** Premium, Standard, and Utility [5] **Packaging**: 40 lbs (18 kg) bags or bulk delivery
Firelogs	Fireplaces	**Size:** Log shaped in various profiles and diameters, no larger than typical split firewood. **Weight:** 2.2 to 3lbs (1 to 1.4kg) **Packaging**: boxes of 4 - 6, bundles, or bulk
Bricks	Fireplaces	**Size:** Brick shaped, various sizes from 6 x 2.5 x 3.75 to 10.5 x 5 x 4 inch (150 x 60 x 90 to 260 x 130 x 105 mm) **Weight:** 1.8 to 7lbs (0.8 to 3.3 kg) [6] **Packaging**: boxes of 12 or bulk
Wood-wax Firelogs	Fireplaces	**Size:** Log shaped, manufactured with 50% wax and accelerant additives to improve ignition and combustion characteristics. Generally sold on length of burn time. **Weight:** 3 to 6lbs (1.3 to 2.7 kg) [7] **Packaging**: individually or boxes of 4 - 6.

* Subscript numbers refer to the citation in the List of References

Standards

Standards for manufactured products ensure that the product meets specific minimum requirements for a desired outcome, often specify different levels of quality, and provide the expectation of consistent performance and customer satisfaction. Standards can be set by government agencies or manufacturer groups (e.g. trade organizations). Standards exist for fuel pellets and briquettes which are considered commodity products. Other densified fuel products are manufactured to a particular company's specifications but generally do not fall under the jurisdiction of a standards setting agency or organization.

The primary standards for fuel pellets manufactured in the US are set by the Pellet Fuels Institute [5]. Densified wood fuels (e.g. pellets, bricks, briquettes) destined for global markets may also need to comply with other country's standards such as the European pellet standard EN 14961-2 or the German standard DIN5173 [6, 8].

Feedstock Requirements

The characteristics of the feedstock used in manufacturing densified fuel products plays an important role in determining the procedures needed to produce products of acceptable quality. The properties affect the densification process and the end product quality in terms of durability and the heat and ash produced [9, 10]. The most important feedstock properties are wood density, particle size, moisture content, and chip cleanliness as defined by bark and dirt content. These properties are influenced by the inherent characteristics of each species of wood used as well as how the raw material was handled.

Both softwoods (conifers) and hardwoods (broadleaf) are suitable for manufacturing pellets, fire logs and bricks but differences in chemical and physical composition between species may affect the manufacturing methods or the quality of the product [11, 12]. For example, the higher density and lower lignin content found in hardwoods than softwoods means that higher temperatures and pressures are typically needed to produce acceptable densified hardwood products [12]. Adding bark to a hardwood feedstock will in effect increase the lignin content and improve the densification process but it downgrades the pellet quality because ash content increases with bark content.

The highest grade residential fuel pellets require clean, bark free wood particles. Fuel pellets have the strictest feedstock requirements (Table 2), requiring the wood particles to be dried to 5-10% moisture content and no larger than 3/16-inch (4mm) in the largest dimension. Because fire logs and bricks are designed for use in regular fireplaces or stoves where quality and ash content are less important, it is possible to produce marketable products using feedstock with less restrictive requirements. Larger particles, up to 1 $^{9}/_{16}$" (40mm) in the longest dimension, of a higher moisture content (up to 15%), can be used for bricks [6, 13]. It is also possible to make fire logs and bricks from wood sources that contain bark and some dirt (e.g. forest residues).

*Table 2: Characteristics of selected densified wood fuels and firewood**

Wood Fuel	Feedstock requirements	Density		Fuel MC (%)	Energy content		Ash content (%)
		lb/ft^3	kg/m^3		BTU/lb	MJ/kg	
Pellets (Domestic/ 'premium')[5]	Clean, no bark, dry chip, shavings or sawdust	40 to 46	640 to 740	≤8.0	8500 to 8700	19.8 - 20.2 (~ 4800 kcal/kg)	≤1.0
Pellets (Industrial/ 'standard')[5]	Wood (bark OK), or agricultural residues	38 to 46	600 to 740	≤10.0	8500 to 8700	19.8 - 20.2 (~ 4800 kcal/kg)	≤2.0
Pellets (Utility)[5]	Wood (Bark OK), or agricultural residues	38 to 46	600 to 740	≤10.0	8500 to 8700	19.8 - 20.2 (~ 4800 kcal/kg)	≤6.0
Firelogs	Wood (Bark OK), or agricultural residues	60	960	≤8.0	7800 to 8460	18.1 - 19.7 (~ 4700 kcal/kg)	≤1.0
Wood-Wax firelog [14]	Wood, biomass particles, wax (natural or petroleum-based)	68 to 80	1100 to 1300	≤8.0	12,000 to 15,000	29 - 35 (~ 8300 kcal/kg)	<0.5
Bricks	Wood (Bark OK), or agricultural residues	55	880	10-12	7500	17.4 (~ 4200 kcal/kg)	≤1.0
Air dried seasoned Firewood	Hardwood or softwood logs	40	640	15-20	5500 to 8000	12.8 -18.6 (~ 4000 kcal/kg)	≤2.0

* Subscript numbers refer to the citation in the List of References

Whole trees and forest residues can be used to produce low quality densified fuels but the high mineral content and contaminants such as dirt found in bark increase tool wear and leads to increased ash when the product is combusted [1, 9, 10, 15, 16]. The typical densified fuel feedstock in the US industry is sawmill residues such as wood chips, shavings and sawdust. Some densified fuel manufacturing facilities with debarking and chipping equipment can also procure small diameter and low value logs to produce their own feedstock. Producing one's own feedstock can be a wise decision if the capitalized cost of producing the feedstock is substantially below the delivered cost of market feedstocks. For comparison purposes, the maximum price in the western US for the clean market feedstock used by pellet manufacturers is approximately $50 per delivered bone dry ton (BDT).

The length of time a feedstock is in storage also affects the manufacturing process. Mixing fresh and stored feedstock together was found to improve pellet durability and reduce energy consumption during manufacture when compared to using all fresh feedstock [16, 17].

Process and Equipment

The process of densifying wood is typically continuous where heat and high pressure are used to compress wood particles through a die or mold, to extrude or shape the particles into a denser log, pellet, or brick that when cooled maintains its new compressed shape [2]. Manufacturing of densified logs and pellets requires small, dry wood particles that are fed in bulk through a size reduction orifice under high temperature and pressure. Fire logs are extruded through a single die and pellets through holes in a circular die [1, 2]. Figure 2 shows the five main steps in manufacturing densified wood fuels assuming the starting feedstock is a clean, bark free wood chip.

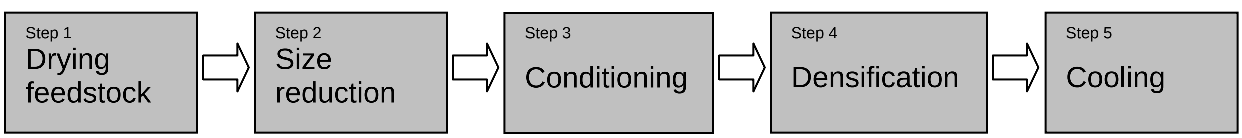

Figure 2: Steps in the manufacture of densified wood fuels

Step 1 – Drying feedstock

Moisture content is an important factor in the manufacture of densified wood fuels and plays a major role in the extrusion and bonding mechanisms discussed below in Step 4 [11, 17-19]. Since wood feedstock is found at a range of moisture contents, from about 6% to more than 50%, it is first necessary to dry the wood to a uniform moisture content.

Commercial operations in the US typically dry wood chip to between 5% and 10% moisture content prior to densification. Direct fired rotary drum dryers are the most common drying system used in the US, which use wood or fossil fuels (natural gas or oil) as a heat source and operate at high temperatures. A minimum of 480 ^{o}F (250^{o}C) inlet temperature is recommended. Typically these rotary drum particle dryers operate at about 600 ^{o}F (315 ^{o}C) with a residence time of up to 5 minutes [20]. The high temperature allows rapid drying although there is also an increased release of volatile organic compounds (VOCs) from the wood [21] and a risk of accidental fire in the system [20]. The dust and particulate emissions of these dryers are managed by using cyclone and filter systems to capture the emissions. Belt or bed dryers are also available (especially in Europe) and operate at lower temperatures (158-392^{o}F (70-200^{o}C)) using an indirect heat source thus reducing emissions and fire risk. However, due to the lower temperatures used these types of dryers require a higher air flow and a much longer residence time in order to maximize drying.

Step 2 – Size reduction

After drying the woodchips are passed through a hammermill to reduce their dimensions to a size less than 3/16 inch (4mm), which is suitable for densification. The wood particles are then screened to remove the oversized particles and fines. If using wood as a fuel source for the dryer some of the material will be fed into the burner after this stage.

Step 3 - Conditioning

The conditioning step uses steam or hot water to increase the temperature and/or moisture content of the feedstock immediately prior to densification. This step softens the natural binders (lignin) in the wood reducing energy consumption and improving tool wear [22-24]. The additional moisture also increases the efficiency of heat transfer to the wood particles and aids the pelletizing or extrusion process by providing feedstock lubrication [18]. Conditioners use paddles to mix the feedstock to ensure homogeneity. Some pellet manufacturers put in additives such as lignin and starch to assist with lubrication and bonding at the conditioning stage [9, 25].

Step 4 - Densification

Heat and pressure in the presence of the moisture in the feedstock causes plasticization and flow of the lignin, hemicelluloses, and the other amorphous components of wood [18, 26-29]. Once plasticized, then bonding of the compressed particles can occur through a combination of solid bridge, adhesion and cohesion, fiber intertwining and molecular attraction forces between particles (e.g. van der Waals forces and hydrogen bonding) [18, 27]. The manufacturing process and bonding mechanisms for fuel bricks relies less on plasticization and flow and more on fiber intertwining as the wood particles are compacted in a mold using a forming press at a lower temperature than pellets or other extruded products [2].

Fuel pellets are made by a continuous feed of wood particles forced through holes in a rotary die by mechanical pressure from two or three rollers. Dies may be flat or cylindrical, depending upon the equipment manufacturer, and have thousands of forming holes [2]. Parameters such as forming pressure, die dimensions (including input, output profiles, radius and channel length of the forming holes), die speed, gap between roller and die, specific energy input into the pellet mill and roller design pattern affect pellet properties [11, 30]. Preheating during the conditioning stage of wood particles before entry to the die is common; this reduces energy requirements and increases throughput [22]. Back pressure is built up at the die as the free flow of the feedstock is restricted and becomes compressed. The wood particles are therefore extruded through the die at high temperature and pressure, forming compressed pellets, which break to a standard length when they hit an adjustable bar as they exit the die. Pellet dimensions affect combustion, thinner pellets combust more evenly than thicker ones whilst shorter pellets flow more easily than longer ones [16]. To meet the US standards densified pellets are typically 0.230-0.285” (5.84-7.25mm) diameter and less than 1.5” (38 mm) long [5].

Fire logs are made by an extrusion process in which a mechanical ram, or screw press, forces the feedstock through a size reduction orifice, ranging from 4”-8” (100-200mm) in diameter. The material exits in a continuous fire log and is cut to length after cooling.

Bricks are manufactured using direct compaction in a mold rather than an extrusion process [6, 31]. Temperatures are lower than for pelleting or extrusion. It has been shown that furnish moisture content, dwell time and compression load are interrelated variables that determine the final product properties. It appears that bonding is primarily through fiber interlocking as well as other bonding mechanisms [13]. The equipment used to manufacture bricks is more durable and less prone to tool wear than extrusion equipment.

Step 5 - Cooling

Cooling of the product to ambient temperature in a controlled manner is of great importance for final product properties. During cooling, the plasticized material (lignin, hemicelluloses) solidifies and hardens, bonding the wood particles together in the compressed size and shape [18]. If cooling is not controlled the temperature differential between the cool air outside and hot core of the product can lead to crack propagation and reduced durability of the product [2]. Counter-flow coolers are typically used to cool pellets while fire logs have a long, continuous cooling line extending from the out feed of the densifying machine. As heat plays less of a role in manufacturing bricks a dedicated cooling line prior to packaging is not necessary.

Current Status of Wood Fuel Pellet Industry

In 2010, the global installed capacity of pellet mills was approximately 20 million tons per year. The capacity in the US has grown dramatically in the past decade in response to the increasing demand from Europe for industrial grade fuel pellets needed to co-fire coal powerplants. In 2006 the US capacity was about 1 million tons of pellets per year and by 2009 this had increased to approximately 4 million tons from about 70 mills [32]. In 2010 the market was considered saturated and some manufacturing facilities were closed but renewed growth of this sector is expected as more international demand for co-fire of coal powerplants develops. The US co-firing opportunities are unclear. If densified wood fuels receive from the US EPA a biomass classification that is exempt from solid waste combustion rules then domestic demand is likely to dramatically increase.

Typical Scale

Typical commercial densified wood fuel operations in the USA range from 10,000 tons per year of output to 600,000 tons per year, the majority of mills have a production capacity of between 10,000 and 70,000 tons per year [25]. New installations are typically 20,000 tons per year and above. The economics of the drying system determines the minimum scale. A 40,000 ton per year facility would cost in the region of $5.5-$7m, require a 3-5 acre site and could employ up to 30 people. A new pellet plant with 750,000 tons annual capacity opened in Georgia in 2011 to primarily serve European markets [33].

Small scale flat die pellet mills are also available from many vendors. These are generally designed for use in the home or farm to manufacture fuel for onsite use of non-commercial grade and contribute very little to the national market.

Opportunities to Use Woody Biomass in California to Manufacture Densified Fuels

California's only large scale manufacturers of densified wood fuels are wood-wax firelog operations. Other densified fuels (as well as animal bedding pellets) are produced in California but by manufacturers making products for specialty markets [34]. Most are small operations (<2,000 tons per year) serving local markets. California had three major wood-wax log manufacturers in 2011. The Duraflame company is based in Stockton and manufactures a range of fiber and natural wax fire logs and other products [7]. The Pine Mountain company manufactures wood-wax logs in Sacramento [35]. The CleanFlame company has a facility in Oroville and manufactures fire logs using food grade recycled wax corrugated card (WCC). The paraffin wax in the WCC acts as an accelerant in the final product [36].

Wood manufacturing residues, the typical feedstock for densified fuels, are in high demand in California for many value added products including paper and composite panels. Removing wood manufacturing residues from the woody biomass supply causes uncertainty in the availability of woody biomass feedstock for a densified fuel manufacturing facility. There may be, however, an untapped potential to utilize woody biomass from California's forest as a feedstock for densified fuels. For example, the low ash fuel pellet required by the primary US market of pellets for domestic stoves could be manufactured from small diameter debarked logs. Also, should a domestic industrial market develop then opportunities for higher ash fuel pellets will follow and these could readily be produced from forest-based residues. Challenges to developing these new markets include managing the high processing cost of forest-based raw materials and feedstock preparation (especially drying) and developing a strategy in order to brand and sell the pellets to California consumers [32].

Smaller scale facilities always have difficulty competing in commodity markets. Only large scale facilities can effectively address the high processing costs of using forest-based residues. For example, the economies of scale indicate that more 20,000 tons per year will need to be processed to offset the drying cost. However, specialty products designed for local markets, such as fuel bricks and firelogs branded to take advantage of locally produced or sustainably produced could sell at a premium in certain locales and this higher value could offset the higher costs of small scale drying or using forest-based residues. The processing and end-use equipment (fireplaces) are more tolerant of foliage and bark content. Drying would still be required but the other manufacturing costs and the value of the final product are such that the drying cost could be covered. Co-locating densified wood fuel manufacturing facilities with existing sawmills or powerplants is another strategy to lower costs by benefiting from sharing personnel and equipment. As markets develop and fossil fuel costs rise it is expected that the densified wood fuel opportunities will also rise.

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