Torrefaction? What's that?

Dana Mitchell, Research Engineer
USDA Forest Service, Southern Research Station, 521 Devall Drive, Auburn, AL, 36849-5418, danamitchell@fs.fed.us, 334 826-8700

Tom Elder, Research Forest Products Technologist
USDA Forest Service, Southern Research Station, 2500 Shreveport Highway, Pineville, LA, 71360, telder@fs.fed.us, 318-473-7008

Fueling the Future: 2010 Council on Forest Engineering Annual Meeting
June 6-9, 2010; Auburn, Alabama

Abstract
Torrefaction is a thermo-chemical process that reduces the moisture content of wood and transforms it into a brittle, char-type material. The thermo-chemical process can reduce the mass of wood by 20-30% resulting in a denser, higher-valued product that can be transported more economically than traditional wood chips. Through torrefaction, wood may retain 90% of the energy value. This energy dense end-product can be used as a coal replacement or co-fired/co-milled with coal in electricity generating power plants. Torrefied wood can be used as a soil amendment, for backyard grilling, residential heating, or as a feedstock in gasification processes. This paper is a literature synthesis that will present (1) the torrefaction process, (2) current developments in commercial torrefaction equipment, (3) characteristics of and markets for torrefied wood, and (4) feedstock specifications for torrefaction.

Introduction
Woody biomass torrefaction is a process of heating biomass in a low-oxygen environment. There is some variation in the reported temperatures used in torrefaction. In existing literature, torrefaction ranges were found from 220 - 300ºC (428 - 572ºF). These temperatures are much lower than those often related to fast pyrolysis (400-600ºC) or gasification (900ºC or higher) (Table 1).

Wood properties undergo changes when processed at temperatures associated with torrefaction. Woody biomass consists of hemicelluloses, cellulose, lignins, and extractives. Torrefaction releases water and volatile organic compounds. Some of the lignin is devalitized and the remaining lignin is loosened. Hemicellulose is released and the remaining bio-char is a product of the torrefaction process. It is an intermediate product between wood and charcoal and has most of the advantages of both products.

Compared to the coal it replaces, biomass reduces sulfur dioxide (SO_2), nitrogen oxides (NOx), and net greenhouse gas emissions of CO_2 (Lipinski et al, 2002). Co-firing torrefied wood is more attractive than using raw biomass such as wood chips because the torrefied wood is friable and can be blended, pulverized and co-fired with coal. The capital and operating costs for separate biomass fuel feed and firing systems are avoided.

Table 1. Types of thermal decomposition processes in the absence of oxygen				
Process	**Conditions**	**Bio-oil**	**Char**	**Gas**
Fast pyrolysis	Moderate temperatures. Very short time	60-75%	10-15%	10-15%
Carbonization	Low temperatures. Very long time	30%	40%	30%
Gasification	High temperatures. Long time	5%	10%	85%
Interpreted from: Oregon Wood Innovation Center, 2009				

The energy density of woody biomass can be increased through torrefaction. Various manufacturers and developers of equipment report that the mass of woody biomass can be reduced while retaining a large percentage of the energy value of the raw material. Several questions remain about how and where torrefaction fits into the traditional and non-traditional forest products industries. This paper is a literature synthesis that presents information on (1) the torrefaction process, (2) current developments in commercial torrefaction equipment, (3) characteristics of and markets for torrefied wood, and (4) feedstock specifications for torrefaction.

Developments in commercial torrefaction equipment

A variety of manufacturers and researchers are developing torrefaction units for commercial use. A few are described in this section to provide an overview of the potential conversion manufacturers that are trying to enter the market.

Integro Earth Fuels, LLC (2010) reports that their torrefaction process reduces 20-30% of the mass while retaining 90% of its energy. Their torrefaction process operates in the temperature range of 240 - 270ºC. The company anticipates producing 4,000 tons of torrefied biomass each month in the pilot plant. Information gained from the pilot plant will be used to develop a full-sized torrefaction facility. Heating values of the final product range from 9,500 – 11,000 Btu/lb.

Southern pine species have an energy value of approximately 8,500 Btu/Lb (dry weight). Under this torrefaction process, the energy value from a dry ton of wood would be reduced from 8,500 Btu/lb to 7,650 Btu/lb (a 10% loss), however there are mass losses associated with the process. If the mass reduction from the process is 20%, the final product has an increased energy value of 9,563 Btu/lb, or a 12.5% increase in energy value.

Thermya, a French engineering company, has developed a continuous torrefaction process called TORSPYD. In April 2010, World Bioenergy News reported that Thermya was the only European company to offer an industrially proven, fully operational, continuous biomass torrefaction process. The system is reported to operate in the lower range of temperatures reported for torrefaction. TORSPYD processing operates in temperatures ≤240ºC (464ºF), a soft thermal treatment. Unit capacities can range from 100 kg/h to 5,000 kg/h. The final product is called BioCoal and is marketed as a coal substitute to be co-fired with coal or used in industrial boilers for producing electricity. The BioCoal can also be used in pellet manufacture, and eliminates the need for sawdust (Thermya, 2010).

Agri-Tech Producers, LLC, a company based in South Carolina, is reported to be nearing the completion of a commercial-grade torrefaction machine (James, 2010). Using technology developed at North Carolina State University, their process operates in a low-oxygen environment at temperatures ranging from 300 to 400ºC. The first commercial-grade machine is planned for completion during the summer of 2010. It will be called the Torre-Tech 5.0. The production rate of this machine will be five tons of torrefied wood per hour.

Researchers in The Netherlands are continuing research on a torrefaction process that began in the 1980s by a French aluminum company. Originally, the process was used to produce metal from metal oxides. Today, the current process is called TOP for torrefaction and pelletization. Early results in 2005 (Bergman and Kiel) indicate that a commercial scale plant could produce 60-100 green kton/year (approximately 66,000 – 110,000 green tons/yr) of high-energy torrefied pellets. Researchers indicate that TOP pellets could be delivered to power plants at a lower cost/Btu as compared to standard wood pellets. They attribute some of the cost savings to the pelletization process, but the majority of the savings is attributed to transportation logistics from transporting an energy dense product.

In 2009, Natural Fuels Industries, Inc. of Calgary, Alberta, Canada, announced plans to build biomass processing plants in Georgia (USA) and Brazil. The company plans to produce bio-coal briquettes using torrefaction technology. The briquettes will be shipped to European markets. In their initial announcement (Vega, 2009), they stated that there is a tremendous demand from European and American pulverized coal plants for bio-coal to meet cap and trade regulations and renewable portfolio standards for power generation.

There are many variables that can be attributed to the torrefaction process. The previous commercial developments discussion introduced the idea that a range of temperatures can be used in torrefaction. Another aspect of the process is the residence time, which can also vary. However, Fonseca et al (1999) determined that temperature has greater influence on the torrefied material than residence time. They recommend a temperature range of 250 to 300ºC with a residence time of less than 60 minutes.

In summary, a variety of conversion units using a torrifaction process are poised to enter the market. One barrier to commercialization is whether the markets are willing to bear the cost of the additional processing.

Characteristics of and markets for torrefied wood

There are other benefits of processing woody biomass through a torrefaction process. In addition to the changes in energy density, torrefaction changes other characteristics in the woody biomass. One of these changes is an increase in hydrophobicity. Because of the chemical changes in the structure of the torrefied wood, the end product does not absorb water. This property provides some advantages over green wood chips. Of particular interest is the ability to store the torrefied wood outside. Since the material will not absorb water, weather will not impact the quality of the product. For example, if wood is left in outside storage, it may increase in moisture. Southern Company found that wood chips delivered at 50% moisture content actually increased in moisture due to outside storage before it was conveyed into a power plant (Boylan et al, 2008). As these wet chips entered the boiler, the boiler was de-rated as a direct result of the moisture addition. Moisture content variations result in inefficiencies in energy conversion that cannot be accounted for in some existing power plant processes without the addition of a wood chip dryer or covered storage. This is just one example of how the hydrophobic characteristic of torrefied wood chips can be used to improve wood conversion processes and potentially create new markets for the forest products industry.

Another characteristic of torrefied wood is increased friability, or crushability. As wood chips are ‘roasted’, they not only lose moisture, but they become brittle. This characteristic could increase interest in the use of woody biomass in processes where raw materials must pass through a pulverizer or some type of crushing equipment, such as is commonly found in power plants to crush coal prior to entering the boiler. The moisture content and properties of green wood chips in these types of processes is not as conducive as either dried wood or torrefied wood because green wood does not possess this brittle, easily crushed characteristic. The power requirements to reduce the size of torrefied biomass are similar to coal, and in comparison, can be 70-90% less than the power requirements to reduce wood cuttings (Bergman and Kiel, 2005).

In the domestic household market, torrefied wood was tested in Europe as a replacement for charcoal used in grilling (barbecuing). Researchers (Girard and Shah, no date) surveyed users that compared using torrefied wood to traditional charcoal briquettes. Respondents indicated that the torrefied product was satisfactory in appearance and cleanliness; glowing embers formed more rapidly; the product appeared to be more appropriate to brisk cooking; and the absence of smoke during cooking was noted almost unanimously. However, objective measurements indicate that the ember phase is much shorter for torrefied wood than for charcoal.

Many of the handling issues associated with ‘bridging’ of wood chips in hoppers and the sheer volume of green wood chips required to produce an 8% mix by energy is often a barrier to using wood chips in power plants. Torrefied wood has been used to co-fire with coal or as a coal replacement in power plants. Compared to the coal it replaces, biomass reduces sulfur dioxide (SO_2), nitrogen oxides (NO_x), and net greenhouse gas emissions of CO_2 (Lipinski et al, 2002). Co-firing torrefied wood is more attractive than using raw biomass such as wood chips because the enhanced product is friable and can be blended, pulverized and co-fired with coal. The capital and operating costs for separate biomass fuel feed and firing systems are avoided.

A key advantage of the reduced mass and increased energy value of torrefied wood is the impact on transportation. A typical payload for a load of green chips is approximately 25 tons, or 50,000 lbs. Using an energy value of 4,500 Btu/lb (green weight), a load of green wood chips would contain 225 MMBtu. By comparison, when transporting a torrified wood product, the energy value of a 25 ton load could be 478 MMBtu, depending on the feedstock and torrefaction process used. By transporting a higher-valued product, the costs to transport energy (measured in BTUs) are decreased. Another consideration for the reduced mass is that storage space would be less for torrefied wood versus green chips.

In addition to use as a coal replacement or for backyard grilling, torrefied wood has other alternative markets. Other markets for torrefied wood include use as in the manufacture of metal, as feedstock in gasification processes, and for residential heating in boilers and wood stoves.

Feedstock specifications

Torrefied biomass can be produced from various sources of herbaceous and woody biomass while yielding similar product properties. Because the assorted biomass sources differ in physical properties that are sensitive to the torrefaction process, each will need specific operating conditions to yield similar product quality. Mass and energy yields will differ as the temperature and residence times are adjusted for different feedstocks (Bergman and Kiel, 2005).

Raw material is typically dried to 10% moisture content (or less) prior to torrefaction. This drying can be accomplished in a separate step, or even in separate kilns. After torrefaction, the moisture content can be reduced to <3%.

In addition to the biomass source, particle thickness can play an important role in torrefaction (Lipinksy et al, 2002). Due to increased heat transfer rates, reaction times are different for thinner chips versus wood chunks. In torrefaction systems that use a screw-type auger for continuous processing, heat transfer occurs as the wood particles come into contact with heated surfaces (Li and Gifford, 2001). This equipment requires a particle size of 10 mm or less. For systems that use a batch process, heat transfer occurs through conduction. Batch systems are not as sensitive to particle size.

Because torrefaction units are not currently commercially available, the conversion costs are not known. In lieu of that information, the spot coal price for the coal commodity region of Central Appalachia (12,500 Btu/lb) for the week ending on May 21, 1010 was $64.60/ton (EIA, 2010). If torrefied wood is used as a coal replacement, the cost of using torrefied wood should not exceed the cost of coal, measured in Btu/lb. If the torrefied wood has an energy value of 9,563 Btu/lb, then a comparable cost would be $49.42/ton. Torrefied wood costs should include stumpage; harvesting and transport of biomass; torrefaction processes; and any additional transportation costs. These costs should not exceed the cost of coal. If regulations require the use of renewable resources, perhaps buyers would be willing to pay more for torrefied wood.

Summary

The use of torrefied wood in commercial industry is still in development, even though torrefaction is not a new process. Several companies are developing commercial torrefaction equipment. The technologies under current development use a variety of combinations of temperature and residence time for processing woody biomass into torrefied wood.

There are a variety of proposed uses for torrefied wood. The hydrophobic and brittle properties of torrefied wood make it compatible with coal or as a coal replacement. In order for torrefied wood to compete in the coal market, the cost of producing torrefied wood, from the stump to the delivery point, must not exceed the price of coal deliveries. Other potential uses of torrefied wood include industrial boilers, residential heating, and for backyard grilling.

From the perspective of the logging and timber industry, literature indicates that raw material can vary in size and can include thin and thick chips, and even larger wood chunks. Depending on the equipment design, and considering characteristics such as pre-drying, processing temperature and reaction time; it appears that feedstocks for the torrefaction process could be produced by many of the types of in-woods processing equipment readily available on the market.

References

Bergman, P. and Kiel,J. 2005. Torrefaction for biomass upgrading. Energy Research Centre of the Netherlands. Publication No. ECN-RX—05-180. 6p.

Boylan, D.; Roberts, K.; Zemo, B.; and Johnson, T. 2008. Co-milling green wood chips at Alabama Power Company's Plant Gadsden unit 2. 59p. Accessed 5/24/2010 at www.cawaco.org.

EIA. 2010. Coal News and Market Report, report released 5/24/2010. Accessed on 5/25/2010 at www.eia.doe.gov.

Fonseca, F.F.; Luengo, C.A.; Beaton, P.; and Suarez, J. A. 1999. Efficiency test for bench unit torrefaction and characterization of torrefied biomass. BIOMASS: a growth opportunity in green energy and value-added products, Proceedings of the 4th Biomass Conference of the Americas, Oakland, California, USA. Ed. by R.P. Overend and E. Chonet. 3p.

Girard, P. and Shah, N. No date. Developments on torrefied wood an alternative to charcoal for reducing deforestation. Centre Technique Forestier Tropical. 7p. Accessed on 4/20/2010 at http://techtp.com/tw%20papers/fao_paper.htm.

Integro Earth Fuels, LLC. 2010. Integro Earth Fuels announces pilot torrefaction plant. Accessed 4/20/2010 at www.integrofuels.com

James, J. 2010. Using torrefied wood as a coal replacement, for superior pellets and cellulosic ethanol production. Agri-Tech Producers, LLC; Columbia, SC. (presentation)

Li J. and Gifford,J. 2001. Evaluation of woody biomass torrefaction. Accessed on 4/22/10 at http://techtp.com/recent%20/ TW%20New %20Zealand.htm. 4p.

Lipinsky, E; Arcate, J.; and Reed T. 2002. Enhanced wood fuels via torrefaction. Fuel Chemistry Preprints 47(1). 3p.

Oregon Wood Innovation Center. 2009. Energy from wood. Presented at the Forest Biomass Fast Pyrolysis Demonstration, Douglas County, August, 2009. (presentation)

Thermya. 2010. A continuous torrefaction process from France. Accessed 4/27/2010 at www.thermya.com.

Vega Promotional Systems, Inc. 2009. Promotional newsletter dated 12/22/2009 accessed on 4/27/2010 at www.vegabiofuels.com.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]