

## ENHANCED WOOD FUELS VIA TORREFACTION

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### Introduction

There is a pressing need for better biomass fuels. Raw biomass has a relatively low energy density, contains too much moisture, is too hygroscopic, can rot during storage, and is difficult to comminute into small particles. This paper presents a technology that has the potential to ameliorate many or all of these deficiencies. It is a form of thermal processing known as "torrefaction".

Torrefaction occurs during the heating of biomass between 200 C and 280 C in thermogravimetric analysis (1). Serious consideration of development of this process as a source of fuels, chemicals, and materials began with the work of Bourgeois in the 1980's (2). Pechiney used torrefied wood as a replacement for charcoal in production of metals from metal oxides (3). Work on related processes that are not directed to fuel and chemical products continues, especially in France and Finland (4,5).

Torrefaction achieves an equilibrium moisture content of 3%, reduction of mass by 20 to 30% (primarily by release of water, carbon oxides, and volatiles) while retaining 80% to 90% of the wood's original energy content as shown in Table 1 and 2. (2)

**Table 1. Characteristics of Torrefied Maritime Pine**

Species	Maritime Pine
Temperature reached (° C)	280
Yield (on bone dry wood)*	77%
Characteristics of torrefied woods	
High calorific value (bone dry)	
Kcal/kg	5,710
KJ/kg	23,900
Ashes %	
	0.55
Volatiles %	
	71.9
Fixed Carbon %	
	27.7
Elementary Analysis	
C %	59.7
H %	5.6
N %	0.25
O %	32.9

**Table 2. Mass & Energy Yields**

Species	Maritime Pine
Low calorific value of bone dry wood (kJ/kg)	19,150
Low calorific value of torrefied wood (kJ/kg)	22,600
Yield by weight %	77
Energetic Yield %	90.8

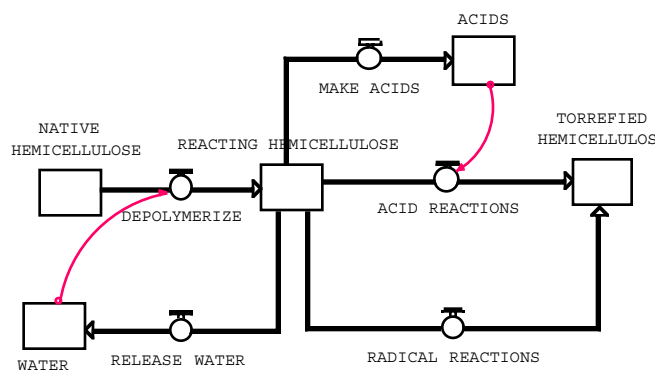
The lignocellulosic biomass feedstock is typically predried to 10% or less moisture content prior to torrefaction. Particle thickness plays an important role in torrefaction in that this parameter determines the duration of the process, given a specific heating rate. We believe that the reaction mechanisms and kinetics are different for thin (wood chips) and thick particles

(wood chunks). The chemical reactions that occur when reactive intermediates are trapped in a thick matrix differ from the situations in which products can escape and be swept away in a gas stream. The duration of torrefaction processing is adjusted produce friable, hydrophobic and energy-rich Enhanced Wood Fuels (EWF). The products of both types of reactions are hydrophobic, friable, and energy-rich fuels.

### Results and Discussion

**Chemistry.** The chemistry of torrefaction is influenced by many parameters, including: biomass composition; particle size; processing temperature and time; heating rate; and gas composition, pressure, and flow rate. In the temperature range of 220 C to 280 C, the major decomposition reactions concern hemicellulose. Cellulose also can undergo similar polymer restructuring. Cellulose and lignin also undergo depolymerization reactions, but to a lesser degree.

Commercially available dynamic simulation software (STELLA®, from High Performance Systems, Inc.) was employed to model the reactions of biomass. The model contains modules for hemicellulose, cellulose, lignin, and biomass. Here, we discuss the hemicellulose module of the model (Figure 1).



**Figure 1.** Dynamic simulation model of hemicellulose torrefaction.

The flow sheet shows stocks of hemicellulose, torrefied hemicellulose, water, and acids. The pipes show the flow of materials from starting material to products. The "wires" show transfer of information.

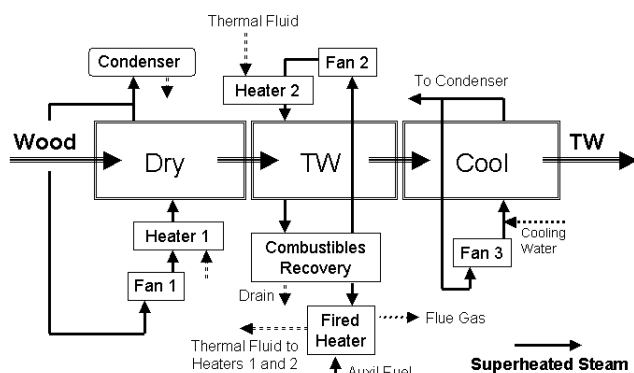
During thermolysis, native hemicellulose is partly depolymerized by hydrolysis and/or thermal chain scission to provide "reacting hemicellulose". This intermediate is decomposed by acid and radical reactions to yield many substances (e.g., furfural) that recombine to form torrefied hemicellulose. Water and acids are formed during the above reactions and are released into the reaction environment (6). Some of this water may be reused to depolymerize hemicellulose or to release acids from the hemicellulose by hydrolysis of acetate groups. Acids can also be formed by radical reactions.

The water and acids released by hemicellulose become available to depolymerize cellulose and lignin. Wooten (7) and Pastorova (8) have demonstrated that microcrystalline cellulose can form "disordered pyrolytic cellulose" that is a 3-dimensional polymer at about 270 C. If the cellulose is exposed to acids and radicals that originate with hemicellulose, even more degradation of cellulose would be expected. This disordered cellulose is thermostable and contains furan, aliphatic, and keto groups. Evans, et.al. have shown that lignin releases some small phenolic

fragments within the temperature range of torrefaction (9). There also are opportunities for grafting of torrefied hemicellulose onto cellulose and/or lignin. Thus, all of the lignocellulose polymers can participate in torrefaction.

**Process description.** Because water can play a significant role in torrefaction, the potential effects of added water (in the form of superheated steam or saturated steam) merit investigation. Figure 2 shows a generalized process schematic of such a process.

Raw lignocellulosic biomass is predried to less than 10% moisture using superheated steam (SHS). SHS has a much higher heat capacity than does hot air or nitrogen. Steam also provides an airless drying environment that reduces yield losses from oxidation.



**Figure 2.** Enhanced Wood Fuels Production Process

Both batch and continuous reactors have been used to produce torrefied wood. We prefer a continuous reactor using superheated steam at atmospheric pressure to dry and torrefy the wood feed. Torrefaction is, on balance, endothermic and releases water, acetic acid, carbon dioxide, carbon monoxide, and other volatiles. This local cooling effect needs to be counteracted. The reaction temperature is closely monitored and controlled. To avoid possible runaway exothermic conditions the torrefaction temperature reaction will not be allowed to exceed 280 C.

Steam containing wood acids and other volatiles is vented from the reactor continuously. This stream is condensed for recovery of acids and combustible volatiles or for waste treatment and disposal purposes.

The EWF is cooled to a safe unloading temperature. The specific properties of the final EWF product may vary depending on the cooling procedure because the hot EWF contains free radicals (10).

EWF can be used in cofiring with coal in electric power plants. Alternatively, EWF can be used in manufacturing fuel pellets and briquettes. Densifying EWF will produce energy-rich, transportable fuels with good properties for outdoor storage.

**Cofiring with Coal at Power Plants.** Cofiring involves substituting biomass fuels for a portion of coal in an existing power plant furnace. This allows the energy in biomass to be converted to electricity with the high efficiency (in the 33% to 40% range) of a modern coal-fired power plant. Table 3 presents examples of various levels of EWF cofiring.

**Table 3.** Cofiring TW with Coal in PC Power Plants

EWF tonnes per year	GWh/year	Mwe @ 7000h
30,000	75	12
60,000	150	25
90,000	225	37
120,000	300	49

Compared to the coal it replaces, biomass reduces sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), and net greenhouse gas emissions of CO<sub>2</sub>.

Cofiring EWF is more attractive than using raw biomass such as wood chips because EWF 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.

**Densification.** The mass density of EWF pellets is about 23kJ/Kg, compared with 19.3 kJ/Kg for conventional pine wood pellets. Densification of EWF to a volume energy density of about 18 GJ/m<sup>3</sup> can be attained by pelletization. Although this is less than coal (29 GJ/m<sup>3</sup>), it is 20% higher than commercial wood pellets. In addition, less than half as much electricity is consumed making EWF pellets. A study for the Pellet Fuel Institute (11) indicated that electricity costs are about \$10/ton of wood pellet product. These data are based on old experiments. There are methods for increasing the energy value and reducing further the energy costs of EWF pellets (12).

Densified EWF products have good prospects for use in pellet stoves in residential and commercial heating markets. The size of this market is more than 700,000 tons/year in the United States (13). EWF also could be briquetted or used to make HeatLogs® analogs. This segment of the domestic fuel market is larger than the pellet market. The fireplace log market has special requirements for sustained burning and flame quality because it is frequently a recreational fuel, rather than a utilitarian fuel.

## Conclusions

Torrefaction provides fuels that are rich in energy, low in moisture content, resistant to weathering, and easily pulverized or densified. Although these are good features, we must also consider the challenges that confront EWF developers.

The European pioneers in torrefaction have abandoned fuel markets and modified the process so that they can focus on furniture and construction markets. The first major **challenge** in development of EWF is to find and develop viable fuel markets. An example of a potentially viable opportunity is conversion of the wood pellet industry into a torrefied wood pellet industry. This is a matter of inserting torrefaction into an existing enterprise that already has a raw material supply, predrying equipment, and marketing channels. This is much cheaper than a “green field” venture. Another example is the cofiring of EWF with coal to improve environmental performance.

The thermal technology for torrefying biomass uses moderate temperatures in the range of 220 C to 280 C. Traditional torrefaction technology required many minutes for completion of the reactions. However, slowness is not an inherent feature of torrefaction. The major processing **challenge** is to create processes that reduce the processing time to a desirable degree. The superheated steam torrefaction process discussed here may be a successful example.

The chemical reaction mechanisms and kinetics that are at the foundation of torrefaction are complex and not well understood. The problems arise from the interaction of both acids and free radicals with the polymers that comprise lignocellulose. The major **challenges** here are to devise experiments that distinguish acid-catalyzed reactions from radical reactions and to

apply to torrefaction reactions some of the methods used in elucidating radical reaction pathways in hydrocarbon cracking. Modeling can help in thinking about the system, but usable experimental data are essential for progress in this activity.

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