



Overview of Renewable Densified Fuels, LLC Proprietary

Manufacturing Process

Fountainhead Engineering Ltd. has been working with Renewable Densified Fuels, LLC (RDF) to develop a patented technology that produces a high Btu (10,000 Btu/LB), low ash sustainable biomass fuel. This fuel can be customized using a variety of biomass, agricultural and process byproducts to create a biomass fuel with specific characteristics for boiler systems currently burning coal or (high moisture) biomass. This renewable biomass fuel was developed in consultation with boiler and grate manufacturers and has primarily been targeted for use in industrial, large commercial, institutional or utility boiler systems that combust fuel at very high temperatures and in most cases ***without changes to existing infeed, storage or solid fuel handling systems.***

The typical biomass fuel produced using this approach has a target Btu value 20%-35% higher than small residential or "retail" pellets. Depending on the application and feedstocks used the fuel has consistently achieved values between 9,800-10,500 Btu/lb and fuel tested by the University of Maine exceeded 12,000 Btu/lb. These results are higher than existing torrifaction processes based on independent laboratory results from testing over 50 different "Mix Designs". The mix designs developed for a specific application using renewable feedstocks can include bark, urban wood waste, sawmill residuals, pulp mill and paper mill residues (i.e. newsprint, tissue and cardboard waste fiber residuals) forest slash, agricultural residues such as corn stover, energy crops such as Miscanthus and switch grass, as well as other biomass residuals (i.e. dust collection fines, sawdust, etc.). The average (incoming) target moisture content of feedstocks should be approximately 10% and uniformly sized to $\frac{3}{4}$ " minus. After processing using the RDF system a biomass fuel is produced with usually less than 2% moisture and 2% ash depending on the biomass or residual feedstocks used to produce the densified fuel. In limited applications a small amount of the "biomass" feedstocks can be replaced with waxed cardboard and other "waste paper residuals" that could not be recycled or are "residuals" from paper sorting-recycling lines. Use of these items as feedstocks however increases ash content of the densified fuel which has been problematic in some boiler applications.

Added to the biomass feedstocks is a small amount of a Reconstituted Carbon Binder or RCB that is sourced as either recycled HDPE (No.2) or LDPE (No.4). These recycled products (i.e. retail bags, milk containers, liquid laundry containers, etc) are used for their very high carbon and hydrogen makeup and relatively low melting points when producing this fuel. The result, when used in this proprietary system, is a very durable fuel which provides a water resistant surface and binding of the biomass feedstocks which is superior to other biomass fuels not using this technology with RCB. This allows for the densified fuel to be shipped via a variety of transport systems as well as being able to be delivered into boiler systems without any special handling requirements and with very minimal fugitive dust during delivery and transport. This feature also allows for outside storage of this fuel for limited periods of time without any significant (Btu value) or physical degradation.

The flexibility of this proprietary system using the RCB allows for densified fuel to be formed into various configurations easily with a die change typically requiring 20 minutes or less to accommodate production of fuel to specific diameters and lengths and in some instances the ability to grind this fuel to 1" or ¾" in size (similar to coal). Unlike other biomass fuel systems this process produces a high Btu value, low ash renewable densified fuel **customized** to end users specifications (i.e. size, shape and density) in order to meet **specific** industrial or utility boiler applications. The ultimate fuel Mix Design for an assignment is in part based on utilization of available biomass or residual biomass feedstocks within a geographic region as well as shipping, storage and handling requirements which vary from geographic regions and from assignment to assignment.

The typical diameter of the densified biomass fuel manufactured using this proprietary process is 1" – 1.25" (2.5 cm - 3.2 cm) and is sized to various lengths. The fuel shown in Image 1 ranges from 1" – 3" (2.5 cm – 7.6 cm) in length and is 1" – 1.25" (2.5 cm – 3.2 cm) in diameter. The mix designs in Image 1 include particle board mixes, agricultural residues, infested trees (i.e. beetle kill biomass) and urban wood wastes. Image 2 represents various 1" diameter (2.5 cm) mix designs using pulp and paper residuals, forest slash, "hard and soft wood" as well as a ¾" (1.9 cm) diameter fuel for a smaller boiler feed system. The use of the RCB sourced (using recycled or post consumer HDPE or LDPE) was selected due to its ability to quickly dissolve into its components of carbon and hydrogen (within the Thermal Mixer) which allows for the RCB to infuse into the biomass quickly during the initial few seconds of the production cycle. During the final stages of the production cycle the temperature within the Thermal Mixer system reaches 300⁰ F and the RCB displaces "residual moisture" contained within the biomass, agricultural residues, etc. (that evaporates during the cycle) prior to being discharged to the variable hydraulic press system to create a specific size or shape of densified fuel. The melt point and properties associated with the RCB was a key breakthrough when developing this densified biomass fuel technology which combust

much cleaner than coal. Use of the RCB eliminates crumbling, dusting and creates a product with superior handling, storage and combustion characteristics (very low emissions) when used in conjunction with coal fired systems or boilers using high moisture biomass (over 30% moisture content). In these applications the densified fuel is designed to deliver more effective, cleaner renewable energy with less ash.



IMAGE 1: Four Mix Designs of One Inch Renewable Densified Fuel Sized to Various Lengths

In August 2007 a large scale boiler test was performed (following USEPA protocols) at Flambeau River Papers, LLC No. 6 Boiler in Park Falls, Wisconsin. This boiler system produces up to 165,000 lbs/hour of high temperature high pressure steam and generates 5 MW of electricity for use by the paper mill. The strategy at the paper mill was to replace “supplemental” coal being co-fired with high moisture hog fuel (biomass). In December 2008 the Wisconsin Department of Natural Resources (WDNR) approved renewable densified fuel for use in FRP’s No. 6 Boiler. The second bi-annual emissions testing for No. 6 Boiler was completed in October 2009. Renewable Densified Fuel continues to be tested at utility power plants, universities and industrial boilers in 2010.



IMAGE 2: Examples of One Inch (2.5 cm) and $\frac{3}{4}$ Inch (1.9 cm) Diameter Renewable Densified Fuel Sized to a Nominal Length of 2" (5.1 cm)

A simple description of the process that produces this unique biomass fuel requires biomass feedstocks or other biomass residuals to be sized 1" to $\frac{3}{4}$ " minus and dried to the target moisture of near 10%. The biomass feedstocks are first combined with the RCB in a Combined Feedstocks Mixer. Several of these mixing systems are commercially available and are very effective for mixing these feedstocks (Ribbon mixers, agricultural feed mixers, etc). Several different biomass or residual biomass feedstocks can be mixed together at the same time (i.e. hard woods, softwoods, urban wood, pulp and paper residuals, agricultural residuals, etc) assuming a Mix Design exists using these biomass feedstocks. When making a fuel for a specific application multiple biomass and process residual feedstocks exhibit varying densities which will impact (slightly) pressure settings of the technology. Agricultural residues have much less density than woody biomass, however this proprietary densified fuel system can adjust for a wide range of biomass or process feedstock densities. This is important when producing a densified fuel for a specific user to maintain uniform handling, combustion characteristics and of course Btu value. The use of the RCB is impacted by all of these issues in order to maintain and create a high value fuel. Therefore, appropriate design and planning for your proposed project can accommodate these factors easily and provides more flexibility as biomass supply markets change over time. Flexibility in feedstock supply and flexibility in mix designs is another feature of this process. The biomass feedstocks can be combined in numerous combinations (woody or herbaceous) prior to conveying into the Thermal Mixer.

After the feedstocks are mixed together the feedstocks are conveyed (via belt, auger or with lighter feedstocks pneumatic conveyance systems) into a surge bin. The surge bin capacity is based on your facility design and should be capable of holding an adequate supply of combined feedstocks (i.e. the project “Mix Design”) for constant infeed into the patented Thermal Mixer.

The target temperature at the beginning stage within the Thermal Mixer is 275⁰ F. Using PLC the combined feedstocks are transferred from the surge bin into the Thermal Mixer typically using a commercial auger system. Upon entering the Thermal Mixer the RCB is liquefied (in seconds) into its elemental components of carbon and hydrogen. The biomass and the RCB mix together for several additional seconds while the biomass continues to heat to between 275⁰–300⁰ F and during this stage of the process any residual moisture contained in the biomass continues to evaporate and is replaced by the remaining RCB. At the end of the cycle the RCB has infused the now liquefied carbon and hydrogen into the biomass. The heated mixture exits the Thermal Mixer directly into the adjacent press tube. The variable hydraulic compaction system presses the heated mixture through the systems proprietary die. This die provides a specific compaction profile for the material mixed within the Thermal Mixer and can be changed easily (typically in 20 minutes) and can provide multiple size densified fuel to (potentially) multiple end users. Therefore, the fuel can be designed for stoker grate applications or suspension boilers (which requires the fuel to be pulverized prior to its introduction into the boiler) or for different size infeed systems for boilers at different locations. The feed rate into the Thermal Mixer is based on the density of incoming (biomass) feedstocks. The nominal throughput of this proprietary production system marketed in the United States is 3.5 to 4.0 tons per hour (TPH).

The densified fuel exits the die at variable lengths and can be cut to a specific length prior to cooling. Typical diameters of densified fuel produced using this system range between ¾” to 2” and lengths range from 1.5” to 4.0” (3.8 cm – 10 cm). Standard commercial conveying systems transport the still “hot” densified fuel (exit temperatures range between 250⁰ - 265⁰) to a “cooling station” using either a cooling conveyor or other similar commercial cooling systems. Image 3 illustrates the handling and storage system used for the densified fuel produced for FRP No. 6 Boiler. A front end (bucket) loader removes the fuel as needed from this bunker and delivers the densified fuel into the mills boiler along with other biomass.



IMAGE 3: Outside Fuel Storage Bunker for Renewable Densified Fuel for No. 6 Boiler at Flambeau River Papers, LLC Park Falls, Wisconsin

After WDNR approval this new plant began producing densified fuel for the mills boiler system (in 2008) using a proprietary mix design developed for Flambeau River Papers, LLC based on their feedstock profile. Image 4 is a view of the renewable fuel bunker and the front end loader removing fuel for delivery into the infeed system at No. 6 Boiler. Image 5 is the south end of the densified fuel plant and renewable storage bunker taken in January 2009. Image 6 and Image 7 illustrates how the densified fuel is introduced into existing No.6 Boiler biomass feed system – no changes in the boilers handling or infeed systems. Densified fuel is removed from the outside fuel bunker via a front end loader (See Image 4) and then fed directly into the existing infeed system that contains bark, biomass and Renewable Densified Fuel.

The densified biomass fuel used in this boiler was targeted to replace coal that was co-fired with the existing ground biomass with average moisture content (seasonally adjusted average) of approximately 42%. The densified biomass fuel was designed to combust like coal without changing fuel storage or boiler infeed systems and significantly reduced the boilers carbon footprint as well as total sulfur emissions without adversely impacting routine system operations.



IMAGE 4: Front End Loader Retrieving Renewable Densified Fuel from Bunker at Flambeau Rivers Papers. LLC Park Falls, Wisconsin May 2009

As mentioned previously, emissions tests were performed under normal operating conditions at Flambeau River Papers No. 6 Boiler during the mills required bi-annual compliance testing (conducted in 2007 and 2009). This boiler historically used up to 45 tons per day (TPD) of coal (winter months) co-fired with 400-500 tons per day of biomass, with the biomass having a moisture content ranging between 35%-45%. The objective in this application at the paper mill was to illustrate the use of this densified biomass fuel to replace the coal co-fired with biomass in the No.6 Boiler. Testing indicated that sulfur emissions were drastically reduced and other regulated emissions also improved. The use of the densified biomass fuel also displaces an estimated 15,000– 20,000 tons per year (TPY) of carbon previously attributed to coal (fossil fuel) use. The carbon footprint of the mill has been reduced significantly while beneficially reusing onsite biomass fines and process residuals generated from the pulp mill. The change over from coal to Renewable Densified Fuel also improves the ash quality making the ash produced by No. 6 Boiler available for evaluations in other beneficial use applications.



IMAGE 5: View of Densified Fuel Plant and Renewable Fuel Bunker (right of building) for No. 6 Boiler Fuel January 2009



IMAGE 6: Renewable Densified Fuel Comingled with Bark and Biomass at No. 6 Boiler Park Falls, Wisconsin



IMAGE 7: Close up View of Distribution of Renewable Densified Fuel Comingled with Bark and Biomass at Flambeau River Papers, LLC Park Falls, Wisconsin

The No.6 Boiler shown in Image 8 is permitted by the WDNR at 249,000,000 Btu/hour and produces over 160,000 pounds per hour of high temperature, high pressure "process" steam for use in the paper mill and generates 5 MW of electricity as described previously, also used by the paper mill. A portion of the densified fuel used for the 2007 boiler tests used pulp mill rejects or "knots" to illustrate beneficial reuse of pulp mill residuals (at 30% of the total mix design for the mills' densified fuel) with up to 12% RCB and the plant has several specific mix designs depending on available feedstocks.

The mix design for the FRP No. 6 Boiler will continue to use reclaimed fines from the mills biomass grinding/hogging operations and knots generated by the pulp mill. A fines recovery system was installed as part of this project to provide biomass residuals to the onsite densified fuel plant and also assists with reduction of potential fugitive emissions from the boilers biomass handling systems.



IMAGE 8: A view of Flambeau Rivers Papers, LLC No. 6 Boiler from the Densified Fuel Production (North end of wood yard) Plant Park Falls, Wisconsin

This patented technology is unique by the way multiple biomass feedstocks are combined to produce a consistent high Btu value, low ash renewable biomass fuel. Over time feedstock supplies as well as pricing may fluctuate and this technology is adaptable due to the fact that it does not rely solely on one single feedstock to produce a sustainable renewable fuel. In addition, Renewable Densified Fuel can use existing infeed or fuel handing systems at most coal fired boilers and power plants. The fuel is very durable, resistant to moisture and precipitation, and can be shipped via dump trucks, live bottom trailers, in Gaylord containers, super sacks, by rail or barge with minimal physical or BTU degradation. It is a simple renewable alternative to use either as a supplemental fuel in existing high moisture biomass boilers or as a replacement for carbon based fuels in existing coal fired systems. This is an example of “green” made easy.