Process Name: Short Rotation Woody Crop Biomass Torrefaction

Reference Flow: 1 kg of Torrefied Biomass

Brief Description: This unit process considers the mass/energy inputs, mass outputs, and air emissions for the biomass torrefaction process. The biomass torrefaction process includes drying for torrefaction and the torrefaction process.

Section I: Meta Data

Geographical Coverage: United States **Region:** N/A

Year Data Best Represents: 2011

Process Type: Energy Conversion (EC)

Process Scope: Gate-to-Gate Process (GG)

Allocation Applied: No

Completeness: Individual Relevant Flows Captured

Flows Aggregated in Data Set:

☒ Process ☒ Energy Use ☐ Energy P&D ☐ Material P&D

Relevant Output Flows Included in Data Set:

Releases to Air:	☒ Greenhouse Gases	☒ Criteria Air Pollutants	☒ Other
Releases to Water:	☐ Inorganic Emissions	☐ Organic Emissions	☐ Other
Water Usage:	☐ Water Consumption	☐ Water Demand (throughput)	
Releases to Soil:	☐ Inorganic Releases	☐ Organic Releases	☐ Other

Adjustable Process Parameters:

None.

Tracked Input Flows:

Biomass [Intermediate product] — *Biomass generated and transported within the boundary of the study*

Power [Electric power] — *Electricity required for the torrefaction process*

Tracked Output Flows:

Torrefied Biomass [Intermediate Product] — *Reference flow*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage2_O_SRWC_Biomass_Torrefaction_2012.01.xls*, which provides additional details regarding relevant calculations, data quality, and references.

Goal and Scope

The scope of this unit process covers torrefaction of biomass from short rotation woody crops (SRWC) that has been green chipped (standard chip size) and transported to a torrefaction facility. Biomass torrefaction is the process of heating the incoming biomass, in the absence of oxygen, so as to produce a charred product that has properties that are amenable to cofiring or other uses in coal fired boilers or alternative fuel production equipment that is set up for coal feed. The heat required for the torrefaction reaction is derived from the incoming biomass, such that a portion of the total incoming biomass is lost to energy production and airborne emissions during the torrefaction process. This unit process also considers electricity consumption of the process, and quantifies applicable airborne emissions, which result from offgassing during the torrefaction process. Torrefied biomass produced within this unit process is routed into additional processing and/or energy conversion facilities downstream. The calculations presented for this unit process are based on the reference flow of 1 kg of torrefied biomass, as described below and shown in **Figure 2**. This unit process is used under Life Cycle (LC) Stage #2 to assist in the conversion of biomass to electricity or fuel products.

Boundary and Description

This study assumes that torrefaction of Southern pine takes place in a directly heated moving bed reactor at temperatures between 200 and 300 degrees C, in the absence of oxygen. The ensuing thermal degradation of Southern pine wood removes most of the moisture content and eliminates its fibrous structure. The hemicellulose component of the wood is thermally essentially destroyed by the torrefaction process. This improves both the grindability and calorific value of the torrefied biomass product while also making it resistant to water absorption. The product material is therefore easier to grind, pelletize, package, and transport. These properties make the torrefied biomass product suitable for use as a standalone or blend material with coal in combustion and gasification applications.

The time and temperature requirements for torrefaction can be varied depending on the desired characteristics of the torrefied biomass. The relationship between torrefaction time and temperature may be qualitatively described as follows:

1. As the torrefaction time and temperature increases, the yield of torrefied biomass decreases while the yield of gaseous products such as volatiles and water vapor increases.

2. As the torrefaction time and temperature increases, the calorific value of the torrefied biomass increases.
3. As torrefaction time and temperature increases, the production of CO, CH4, and C2 hydrocarbons in the gaseous products increase while the production of CO2 decreases.
4. At any torrefaction time and temperature, water vapor is always a significant gaseous product – on the order of 50 to 60 percent by mass of the gas stream - even when the biomass is dried to zero or near-zero moisture content. Typically, about 5 to 10 percent of the energy contained in the raw biomass is driven off as part of the gaseous products.

Comprehensive operating data from a commercial existing torrefaction process are not available but Integro Earth Fuels, Inc. has provided ultimate and proximate analyses and calorific values for raw and torrefied Southern pine solids from their test facility in Ashville, North Carolina (Childs, 2012). These data were used as the basis for the mass and energy balances used in developing the torrefaction simulation model.

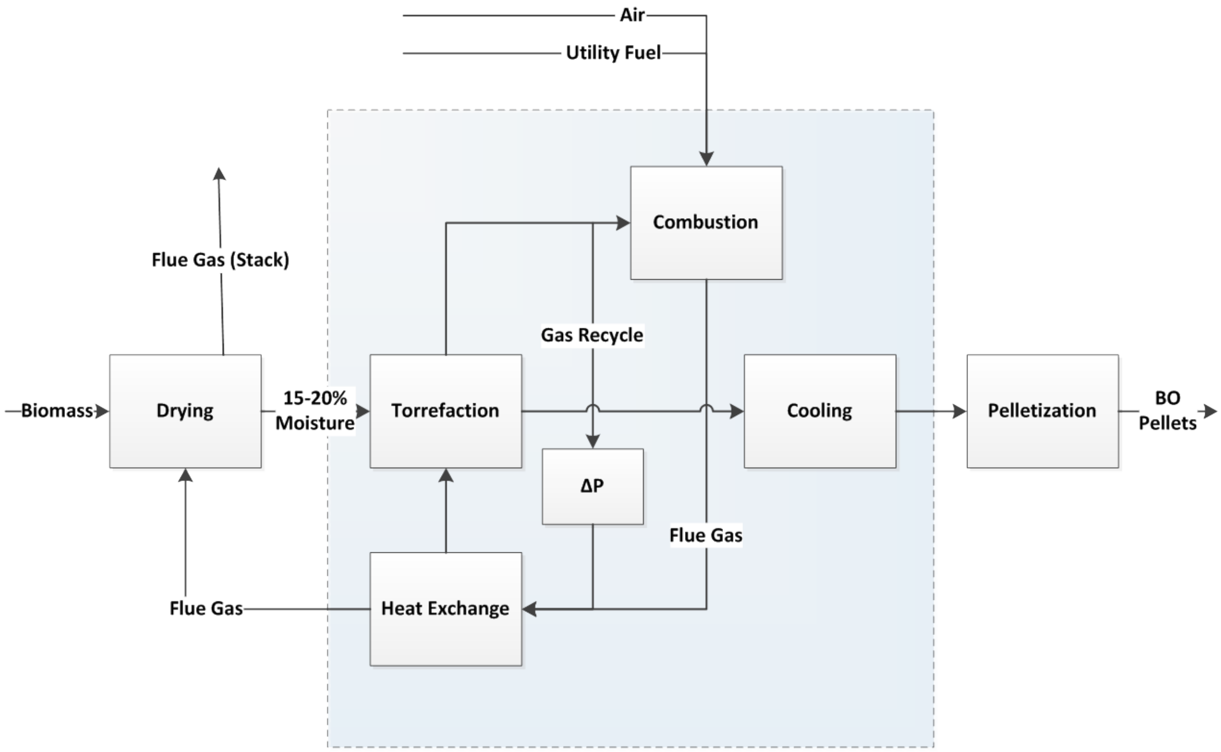
Figure 1 shows the schematic of the directly heated torrefaction system assumed for this study. This system is under development by ECN of the Netherlands (Bergman et al 2005). In this system some or most of the necessary heat for drying and torrefaction comes from the combustion of the volatile gases emitted during torrefaction. Additional heat when required to balance the heat load can be supplied by using natural gas, other biomass, or other available utility fuels. Air, fuel, and torrefaction gases are combusted in the combustion section of the plant and the flue gas from combustion is passed through a heat exchanger that heats the torrefaction gas recycle stream. The flue gas exiting the heat exchanger is used to dry the biomass before it enters the torrefaction reactor. The cooled flue gas is then discharged through the stack. The heated recycle gas that includes torrefaction gas and combustion flue gas directly contacts the biomass in the torrefaction reactor to supply the heat required for further dehydration and torrefaction. This also acts as the essentially oxygen-free blanket gas. The gases leave the torrefaction reactor and some of the gas is recycled to the torrefaction reactor via the heat exchanger and the rest is sent to the combustor. The solid torrefied biomass product leaves the reactor and is cooled.

In the ECN process the torrefied product is pelletized to produce their BO2 pellets. In this study, the unpelletized torrefied material is transported from the torrefaction facility to the CBTL Facility where it is ground, mixed with coal and gasified to produce synthesis gas.

Within this study, conceptually the Southern pine is dried to about 10 percent moisture prior to being fed to the torrefaction step. Torrefaction is accomplished in the directly heated moving bed torrefaction chamber at a temperature of 536 degrees F (280 degrees C). Heat for torrefaction is provided from a portion of the torrefaction product gas that is recycled and re-pressurized via a forced draft fan or blower, and heat exchanged with flue gas. A combustion chamber with air and natural gas as supplemental fuel burns the combustible portion of the torrefaction gas stream.

Although the torrefaction product gas consists of a wide variety of combustible components, the main constituents are the non-combustibles water and carbon dioxide. The heat content of torrefied solids and gases are dependent on a combination of the type of raw materials and torrefaction operating conditions (temperature and residence time). The heating value of the torrefaction volatiles can be too low to provide the necessary heat for drying and torrefaction in which case supplemental fuel is necessary. Some torrefaction producers like Integro Earth Fuels claim that the process can run autothermally and therefore does not need any supplemental fuel.

Figure 2: ECN Torrefaction Scenario



Source: Kiel 2011

Integro Earth Fuels, Inc. has an existing system for torrefaction of Southern pine that combines the drying and torrefaction steps into a single unit and requires supplemental fuel only during system start-up. At steady-state, their torrefaction process operates auto-thermally (Childs 2012). In a torrefaction systems study, Bergman and Boersma of ECN estimate the heat content of the torrefaction product gas to be 5.2 and 14.7 percent the value of the dry feed to the torrefaction reactor for woodcuttings and demolition wood, respectively (Bergman et al 2005). In that study, a portion of the raw wood is burned to provide process heat for the drying and torrefaction steps. For the purposes of this current analysis it is assumed that the default value for the heating content of the volatiles is set at 5.2 percent of the heating value of the feed to estimate the amount of supplemental fuel required.

There is an absence of relevant literature data for the composition of the volatiles from Southern pine biomass. However, very detailed torrefaction gas composition data are available for woods other than Southern pine. Kiel reports a torrefaction product gas composition from willow at 260oC for 32 minutes. These include mass yields for a torrefaction gas that contains CO, CO2, H2O, acetic acid, furfural, methanol, formic acid and the remainder CH4, CxHy, toluene and benzene. Bergman and Kiel and Bergman, et al provide mass yields for torrefaction reaction products for willow at 280oC for 17.5 minutes (Bergman et al 2005; Bergman and Kiel 2005). These data are in the form of mass distributions for solids, lipids (terpenes, phenols, fatty acids, waxes, and tannins), organics (sugars, polysugars, acids, alcohols, furans, and ketones), gases (H2, CO, CO2, CH4, CxHy, and benzenes), and water. Emissions of CO2 and SO2 are based on the oxidation of combustible constituents in the torrefaction product gas and the natural gas burned as supplemental fuel.

Torrefaction gases are assumed to be captured and combusted in order to provide heat for the torrefaction process. However, combustion of these gases generates various air quality pollutants, which are emitted to the atmosphere. **Table 1** provides a summary of the various emissions that are emitted during the torrefaction process.

Table 1: Airborne Emissions from Torrefaction Operations (kg/kg Torrefied Biomass Produced)

Airborne Emission	Value
Carbon Dioxide (CO_2)	6.98E-02
Methane (CH_4)	5.62E-07
Nitrous Oxide (N_2O)	5.38E-07
Particulate Matter (PM_{10})	1.86E-06
Carbon Monoxide (CO)	9.59E-05
Ammonia (NH_3)	7.82E-07
Nitrogen Oxides (NOx)	6.84E-05
Sulfur Oxides (SO_x)	1.47E-07
Non-Methane Volatile Organic Carbons	1.34E-06
Lead (Pb)	2.44E-08
Mercury (Hg)	1.27E-08

Figure 2 provides an overview of the boundary of this unit process. As shown, biomass that is produced and transported within upstream unit processes is input to biomass torrefaction operations. Emissions are then quantified for the drying process, and electricity requirements are also considered. Other energy use is presumed to be

negligible. This unit process then feeds into a separate assembly process within the GaBi model, within LC Stage #2 (Raw Materials Transport).

Figure 1: Unit Process Scope and Boundary

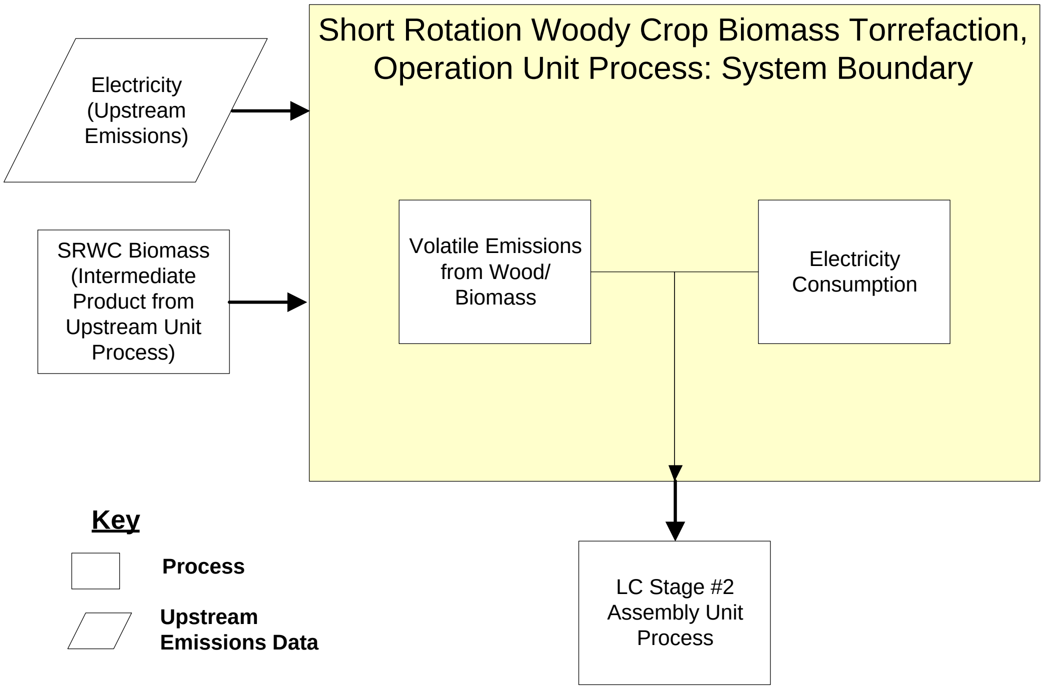


Table 2: Unit Process Input and Output Flows

Flow Name	Value	Units (Per Reference Flow)
Inputs		
Biomass [Intermediate Product]	1.328E+00	kg
Power [Electric power]	1.800E-02	MJ
Outputs		
Torrefied Biomass [Intermediate Product]	1.000E+00	kg
Carbon dioxide [Inorganic emissions to air]	6.977E-02	kg
Dust (PM10) [Particles to air]	1.857E-06	kg
Carbon monoxide [Inorganic emissions to air]	9.587E-05	kg
Methane [Organic emissions to air]	5.621E-07	kg
Nitrous oxide (laughing gas) [Inorganic emissions to air]	5.377E-07	kg
Ammonia [Inorganic emissions to air]	7.821E-07	kg
Nitrogen oxides [Inorganic emissions to air]	6.843E-05	kg
Sulfur oxides [Inorganic emissions to air]	1.466E-07	kg
Non-methane volatile organic carbons [Organic emissions to air]	1.344E-06	kg
Lead [Inorganic emissions to air]	2.444E-08	kg
Mercury [Inorganic emissions to air]	1.271E-08	kg

* **Bold face** clarifies that the value shown *does not* include upstream environmental flows. Upstream environmental flows were added during the modeling process using GaBi modeling software, as shown in Figure 1.

Embedded Unit Processes

None.

References

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Section III: Document Control Information

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