Process Name:	CBTL, 10% Biomass, Microchipped, Separate Gasifiers, Fischer-Tropsch Jet Fuel Production Facility
Reference Flow:	1 kg of F-T Jet Fuel
Brief Description:	This unit process quantifies the input flows and emissions associated with the operation of a Fischer-Tropsch (F-T) jet fuel production facility, based on a coal biomass to liquids (CBTL), 10% microchipped biomass, separate gasifiers configuration.

Section I: Meta Data

Geographical Coverage: US **Region:** Southeast

Year Data Best Represents: 2012

Process Type: Energy Conversion (EC)

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

Allocation Applied: No

Completeness: All Relevant Flows Recorded

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	*Microchipped Southern Pine woody biomass used for F-T jet fuel production*
Torrefied Biomass	*Torrefied Southern Pine woody biomass used for F-T jet fuel production*
Coal	*PRB Montana Rosebud Sub-bituminous coal used for F-T jet fuel production*

Tracked Output Flows:

F-T Jet Fuel	*This reference flow represents mass of F-T jet fuel produced.*
F-T Naptha	*Naptha co-product of F-T fuel*
F-T Diesel	*Diesel co-product of F-T fuel*
Carbon Dioxide [Intermediate Product]	*Carbon dioxide captured from F-T conversion process for sequestration or enhanced oil recovery*
LP Gas	*LP gas co-product of F-T fuel*
Sulphur [Inorganic Intermediate Product]	*Sulphur co-product recovered from F-T conversion process*
Electricity	*Electricity co-product exported from F-T conversion process*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage3_O_FTjet_CBTL_10pct_Microchipped_BiomassP_SepGasifiers _2012.01.xls*, which provides additional details regarding calculations, data quality, and references as relevant.

Goal and Scope

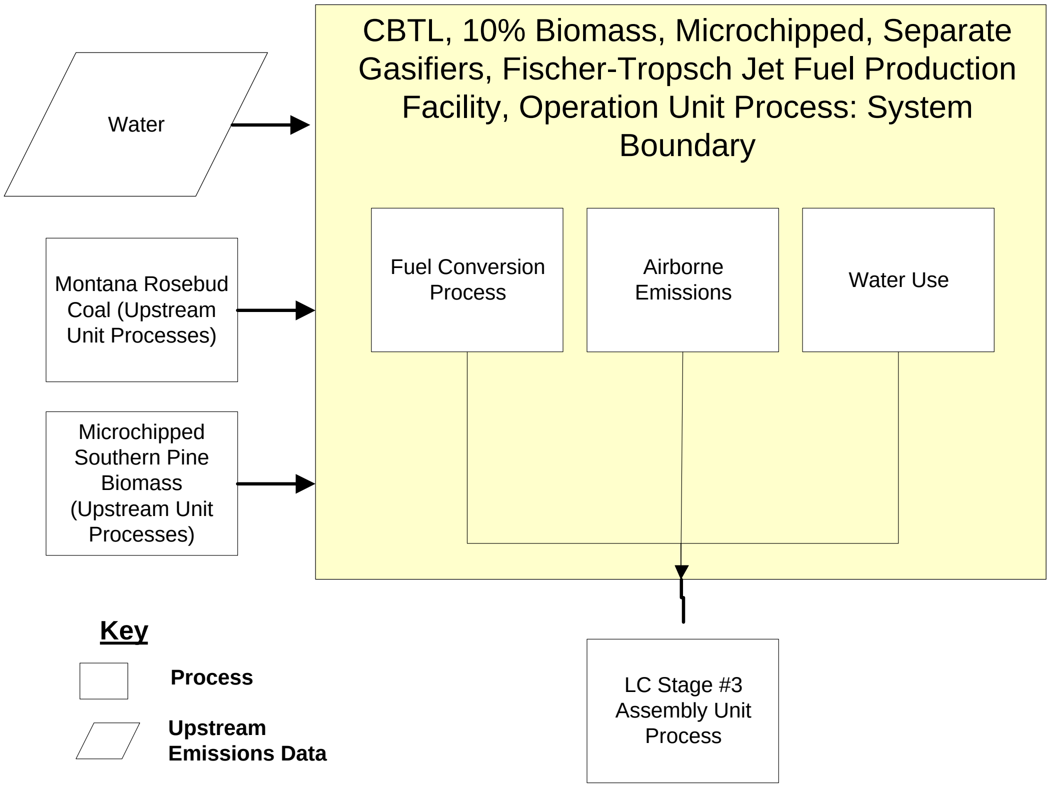
The scope of this unit process covers the production operations for F-T jet fuel from Montana Rosebud coal and green woody biomass in Life Cycle (LC) Stage #3. This unit process is based on the reference flow of 1 kg of F-T jet fuel production, as described below, and in **Figure 1.** The inputs to the unit process include Montana Rosebud coal (technosphere) biomass (technosphere), groundwater (resource), and surface water (resource). Rosebud coal and green woody biomass are used as the feedstocks for the F-T process; the energy and material flows for the upstream production and delivery of coal and biomass as well as LC emissions of coal and biomass production are not included in the boundary of this process. The air emissions from the CBTL facility process, and water usage, are included in the boundary.

Boundary and Description

The LC boundary of this unit process starts with the delivery of Montana Rosebud coal and woody biomass to the CBTL facility and ends with F-T jet fuel ready for delivery to end-use. The production operations for F-T jet fuel are based on the estimated coal, woody biomass, and water consumption of the conversion process and the yield rate of F-T jet fuel. **Figure 1** provides an overview of the boundary of this unit process. As shown, upstream emissions associated with the production and delivery of coal and biomass are accounted for outside of the boundary of this unit process. The methods for calculating these operating activities are described below. **Figure 2** provides a process diagram for the CTL facility.

At the CBTL facility, the coal is brought from the storage area and sent to milling and drying. Here, the coal is dried from the as-received value of 26% moisture down to 18% for feeding to the TRIG gasifier. The Southern pine woody biomass is delivered to the CBTL facility as whole wood chips with a size range of about 2-3 inches in length. These wood chips are assumed to be produced during biomass harvesting and enter the CBTL facility with about 50 % moisture content. Before co-feeding to the TRIG gasification system, the green woody biomass must be reduced in size to an average particle size of between about 0.4 and 0.8 mm (400-800 microns) and further dried to about 18% from an average after storage moisture content of 43.3%. This size reduction is accomplished in separate hammer mills from the coal milling machines. Such fine grinding of green woody biomass is energy intensive and, depending on the final particle size, the power consumed during this processing can be considerable, however, in this unit process, electricity usage is not considered.

Figure 1: Unit Process Scope and Boundary



The milled coal is injected into the TRIG gasifier just above the mixing zone. Steam and oxygen are added to the gasifier, and the coal is transformed into raw synthesis gas (syngas). Sensible heat from the hot syngas is recovered in a waste heat boiler/superheater and the gas is cooled for feeding to the raw shift and COS hydrolysis units. A portion of the cooled syngas is recycled to the TRIG gasifier.

The green woody biomass is gasified separately from the coal. In this configuration, the ClearFuels High Efficiency HydroThermal Reformation (HEHTR) gasification process is used to essentially steam reform and gasify the wood into synthesis gas and other products like higher molecular weight organic compounds, methane, higher hydrocarbons, various oxygen-containing species, and tar-like material. ClearFuels is an indirectly heated gasification system where fuel gas or F-T recycle gas is used to fire the gasification reactor and heat the tubes through which the wood and transport and reaction steam is passed. In principle this is similar to an indirectly fired steam methane reformer, however in the case of the ClearFuels system the tubes do not contain any catalyst. The hot flue gas after transferring heat to the reactor tubes passes through heat exchangers to generate steam before being vented to atmosphere.

The products emerging from the heated tubes are synthesis gas, hydrocarbons, higher molecular weight organics and gas phase liquid particulates, tars, and some unconverted woody biomass and ash. After passing through a cyclone to remove ash and unconverted wood, the gas and tars are sent to a Dual Fluid Bed Reformer (the Ni-DFB tar reformer process). This process has two fluid bed reactors and in many ways is similar to a catalytic cracker in design. In the reformer fluid bed, hot nickel catalyst reacts with and reforms the tars and hydrocarbons into additional synthesis gas. The reformed gas exits the bed, passes through a cyclone to disengage particulates, and is cooled and scrubbed with water to remove fine particles. The spent nickel catalyst is transferred to the second fluid bed (the regenerator), where fuel gas is combusted with air to burn off the accumulated carbon on the catalyst and prepare it to be transferred back into the reformer. The hot flue gas passes through heat exchangers to generate steam before being vented to atmosphere.

Both processes are under development by Rentech. The HEHTR process operates at about 40 psia pressure and can accept green wood microchips (~5-10 mm) as feed. The purpose of the Ni-DFB process, also operating in the same pressure regime, is essentially a reformer for the tars and hydrocarbon gases that are produced in the HEHTR reactor. This combination can then produce a clean synthesis gas that is at low pressure and this must be compressed so that this syngas can be combined with the high-pressure syngas coming from the TRIG coal gasification process.

The combined shifted syngas is further cooled and sent to mercury removal. Upon exiting mercury removal, the syngas enters the two-stage Selexol unit. Here, hydrogen sulfide and carbon dioxide are removed in separate absorbers. The hydrogen sulfide stream is sent to the Claus unit for sulfur recovery. The Claus offgas enters Claus Offgas Treating (COT) to reduce breakthrough sulfur dioxide. The hydrogen sulfide from COT is recycled to the Selexol unit. The carbon dioxide stream is sent to dehydration and compression to produce a high-pressure CO_2 stream suitable for pipeline transport and carbon management.

The cleaned syngas exiting Selexol is further reduced in sulfur by a zinc oxide sulfur polisher. The syngas would then contain less than 30 parts per billion of sulfur. The cleaned syngas then enters the slurry-phase, iron-based catalytic Fischer-Tropsch (F-T) reactors. The raw F-T products and unconverted synthesis gas are separated in the raw product separation unit into overhead gases that includes CO_2, CO, H_2, light hydrocarbons, an aqueous stream containing oxygenates, naphtha, distillate, and wax.

The overhead gas is sent to a methyldiethanolamine (MDEA) unit for CO_2 removal then to a cryogenic separation unit to separate a methane-rich gas, a hydrogen-rich gas, and liquefied petroleum gas (LPG). The methane rich gas that includes CO is sent to an oxygen-blown autothermal reformer (ATR). The ATR exit gas contains some methane, CO, H_2, and CO_2. This gas stream is divided so that some of the gas is used for plant fuel gas needs, some is recycled to the FT reactors, and the remainder is sent to the gas turbine combustors to generate electric power. The hydrogen-rich gas is sent to the pressure swing adsorption (PSA) unit to produce a pure hydrogen stream for the refinery and a low-pressure fuel gas. The LPG stream is separated as a co-product of the plant.

The aqueous stream contains the oxygenate compounds like alcohols, acids, and ketones. This stream is sent to wastewater treatment. The naphtha is distilled from the distillate stream and receives no further treatment. The distillate is hydro-treated to remove olefins and becomes the diesel fuel product. The wax is hydro-cracked to a jet fuel product. Jet fuel has a very narrow boiling point range and hence a small range of carbon numbers, typically from C_{10} to C_{16}. When the FT wax, which has a wide range of carbon numbers (~C_{23} to C_{400}), is hydro-cracked to be within the narrow jet fuel range a large amount of over cracking occurs. This produces, in addition to the jet fuel, a significant amount of light hydrocarbon gases including LPG, and additional naphtha. The final products from the refinery are jet fuel, diesel, naphtha, and LPG.

Refinery fired heaters for distillation and feed heating for hydro-treating and hydro-cracking are heated in heaters using fuel gases. The flue gases from these heaters are vented to the atmosphere. The separate fuel gases sent to the gas turbines generate electric power for the plant. Heat is recovered from the turbine exhaust in HRSGs and the steam raised is used in the steam turbine for additional power generation. The exhaust flue gas from the HRSG is vented to the stack. Power produced in excess of plant parasitic requirements is sold. Steam turbine exhaust is condensed using conventional mechanical draft cooling towers.

The F-T conversion process results in the direct emission of greenhouse gases (GHGs) and criteria air pollutants (CAPs). The emissions factors for GHGs are based on suggested values for F-T jet fuel production from coal and woody biomass (Noblis 2012a/Noblis 2012b).

Figure 1: CBTL, 10 % Biomass, Microchipped, Separate Gasifiers, Facility Configuration

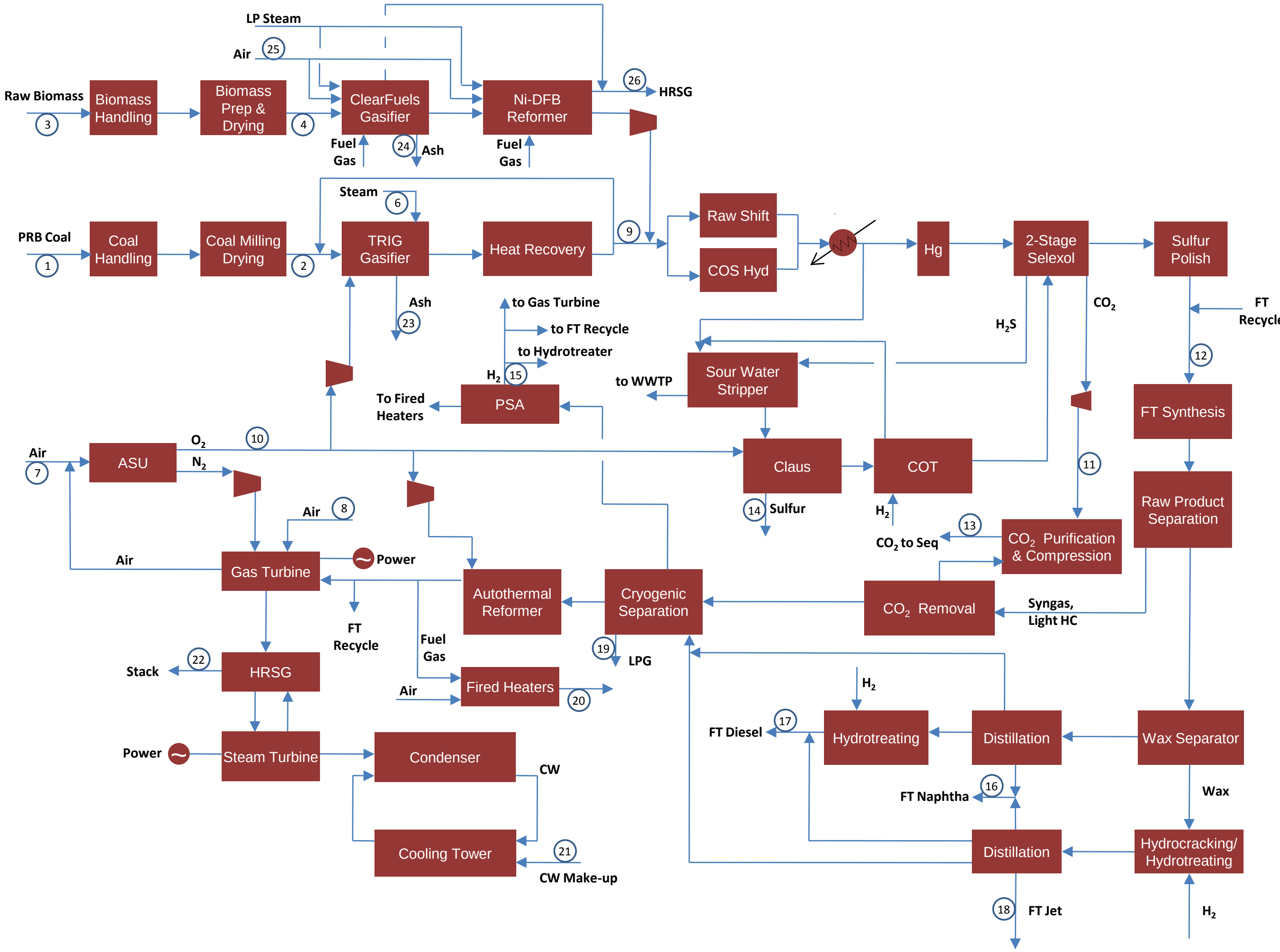


Table 1 provides a summary of the site conditions for the modeled CBTL facility. **Table 2** provides a summary of modeled input and output flows. Additional details regarding input and output flows, including calculation methods, are contained in the associated DS sheet.

Table 1: CBTL Facility Site Conditions

Site Characteristic	Site Condition
Elevation (Feet)	0
Barometric Pressure (PSIA)	14.7
Design Ambient Temperature, Dry Bulb (F)	60
Wet Bulb Temperature (F)	52
Ambient Relative Humidity (%)	60
Location	Greenfield, South Eastern USA
Topography	Level
Size, Acres	1,300
Transportation	Rail and Road
Ash Disposal	Off Site
Water	Municipal (assumed to be surface water) 50%: Groundwater 50%
Access	Landlocked; Access by rail and highway
CO_2 Disposition	Compressed to 2215 psia on site then transported by pipeline to an EOR facility

Table 2: Unit Process Input and Output Flows

Flow Name*	**Value**	**Units (Per Reference Flow)**
Inputs		
PRB Coal	**8.727**	**kg**
Biomass	**1.316**	**kg**
Torrefied Biomass	**0.000**	**kg**
Water (ground water) [Water]	**8.264**	**kg**
Water (surface water) [Water]	**8.264**	**kg**
Outputs		
F-T Jet Fuel [Valuable Products]	1.00	**kg**
FT Naphtha	6.40E-01	kg
FT Diesel	1.96E-01	kg
Carbon dioxide [intermediate product]	8.92E+00	kg
LPG	1.14E-01	kg
sulphur [inorganic intermediate product]	3.20E-02	kg
Electricity	1.67E-03	kg
Carbon dioxide [Inorganic emissions to air]	2.23E+00	kg
Carbon monoxide [Inorganic emissions to air]	0.00E+00	kg
Carbonyl sulfide [other emissions to air]	7.83E-13	kg
Hydrogen chloride [Inorganic emissions to air]	0.00E+00	kg
Ammonia [Inorganic emissions to air]	7.27E-05	kg
Sulphur dioxide [Inorganic emissions to air]	2.00E-11	kg
Ash [Waste for recovery]	8.34E-01	kg
Methane [Organic emissions to air (group VOC)]	0.00E+00	kg
Nitrogen dioxide [Inorganic emissions to air]	7.67E-06	kg
Particulate Matter, unspecified [Other emissions to air]	9.46E-04	kg
Mercury (+II) [Heavy metals to air]	8.41E-08	kg
NMVOC [Organic emissions to air (group VOC)]	0.00E+00	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

NETL 2010 — NETL (2010). NETL Life Cycle Inventory Data – Unit Process: CBTL Plant Operation with Coal and SRWC Feed. U.S. Department of Energy, National Energy Technology Laboratory. Last Updated: February 2010

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White et al. 2012a	White et al., Model for the Production of Jet Fuel from Coal and Woody Biomass: A Comparative Analysis of Coal/Wood Co-Gasification and Separate Coal and Wood Gasification Configurations. Noblis. 2012.
White et al. 2012b	White et al., Production of Jet Fuel from Coal and Woody Biomass: A Comparative Analysis of Coal/Wood Co-Gasification and Separate Coal and Wood Gasification Configurations. Noblis. 2012.

Section III: Document Control Information

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