NETL Life Cycle Inventory Data
Process Documentation File

Process Name:	BTL Plant Operation with SRWC Feed
Reference Flow:	1 kg of Fischer-Tropsch diesel (FTD)
Brief Description:	Inputs and outputs for Fischer-Tropsch diesel production by a 5,000-barrel-per-day BTL plant using short rotation woody crop (SRWC) feed. Includes scenarios for carbon capture and storage (CCS) and autothermal reforming (ATR). Naphtha is a co-product.

Section I: Meta Data

Geographical Coverage: US **Region:** Midwest

Year Data Best Represents: 2009

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:

BIOFEED	*Feedrate of biomass to biomass-to-liquids (BTL) plant (ton/day)*
BIOPERCENT	*Ratio of biomass feed to total feed to BTL plant; equals 1 for all BTL cases (dimensionless)*
HHVBIO	*Higher heating value (HHV) of biomass feedstock (MMBtu/ton)*
DIESELFLOW	*Production rate of FT (Fischer-Tropsch) diesel (barrels/day)*

CAP_FAC	*Capacity factor of BTL plant (dimensionless)*
NAPFLOW	*Production rate of naphtha, a co-product (barrels/day)*
CO2SEQFLOW	*Mass capture rate of CO_2 from BTL plant (ton/day)*
CO2FLOW	*CO_2 released to atmosphere from BTL plant (ton/day)*
STACK_OUT	*Volumetric flow rate of stack gas from BTL plant (ft^3/hr)*
PROD_OUT	*Volumetric flow rate product gas from BTL plant (ft^3/hr)*
SOLIDFLOW	*Mass flow rate of solid waste from BTL plant (lb/hr)*
H2OFLOW_IN	*Water input to BTL plant (L/MMBtu)*
H2OFLOW_OUT	*Water output from BTL plant (L/MMBtu)*
H2O_CCS	*Rate at which water use increases with addition of a CCS or CCS+ATR system (dimensionless)*

Tracked Input Flows:

SRWC	*SRWC input to BTL plant*

Tracked Output Flows:

FT Diesel Produced	*1 kg of FT diesel production (the reference flow of this unit process)*
Naphtha Produced	*Mass of naphtha is co-produced per kg of FT diesel production*
CO_2 sent to sequestration	*Mass of CO_2 captured for sequestration per kg of FT diesel production*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage3_O_SRWC_BTL_2010.01.xls*, which provides additional details regarding relevant calculations, data quality, and references.

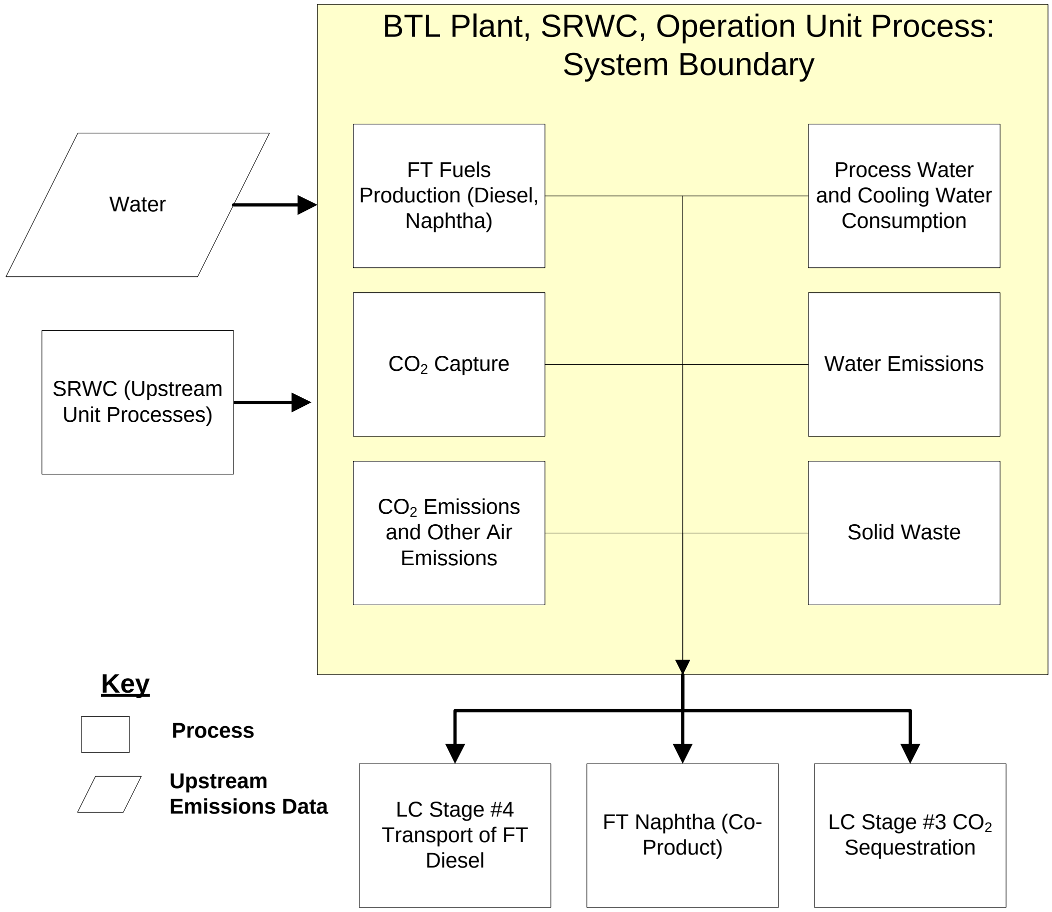
Goal and Scope

This unit process accounts for the operating activities for a BTL plant that uses SRWC as a feedstock. The process is based on the reference flow of 1 kg of FT diesel production. The inputs to the process include water and SRWC. Water is used for cooling and other process-related utilities; water is assumed to enter the boundaries of this unit process having no upstream resource consumption or environmental emissions. SRWC is a biomass feedstock that is converted to diesel via gasification followed by catalyzed synthesis; the resource consumption and emissions associated with the upstream production and delivery of SRWC to the BTL plant are not included in the boundaries of this unit process, but are accounted for by upstream unit processes. The outputs of this unit process are FT diesel (the reference flow of this unit process), naphtha (a co-product of this unit process), water, air emissions, and water emissions.

Boundary and Description

This unit process models the production of diesel fuel via biomass gasification and FT synthesis. The energy inputs and outputs for this process were provided in the NETL CBTL Baseline Report (NETL 2009). This unit process describes activities that occur within Life Cycle (LC) Stage #3 of FT diesel production. The steps that precede this unit process include the production of biomass feedstocks in LC Stage #1, and the transport of biomass feedstocks in LC Stage #2. The step that immediately follows this unit process is the pipeline transport of FT diesel in LC Stage #4. **Figure 1** provides an overview of the boundary of this unit process. Rectangular boxes represent relevant sub-processes, while trapezoidal boxes indicate upstream data that are outside the boundary of this unit process. As shown, upstream resources and emissions associated with the production and delivery of biomass are accounted for outside the boundary of this unit process, while water is assumed to enter the boundary of the unit process with no upstream resources or emissions. The methods for calculating these operating activities are described below.

Figure 1: Unit Process Scope and Boundary



This unit process has 14 adjustable parameters, which enhance its versatility and allow the modeling of several scenarios. Unless noted otherwise, these adjustable parameters are based on data from the NETL baseline report on CBTL plants (NETL 2009). The default values for the adjustable parameters are shown in the DS for this unit process; cases in which a range in a default value is warranted are noted below. “BIOFEED” is an adjustable parameter that is based on NETL data for BTL plants (NETL 2009) and describes the rate at which the BTL plant consumes biomass feedstocks. “BIOPERCENT” is an adjustable parameter that describes the fraction of BTL feedstock that is biomass; it equals 1 for BTL plants, but equals other values for coal and biomass to liquids (CBTL) scenarios. “HHVBIO” is an adjustable parameter that describes the higher heating value of biomass feedstock and is a necessary factor for the normalization of water use rates and stack flow rates, which are expressed on the basis of volume per MMBtu of feedstock input, to the production of one kilogram of FT diesel. “DIESELFLOW” is an adjustable parameter for the production rate of FT diesel and is based on NETL data for BTL plants (NETL 2009). “CAP_FAC” is an adjustable parameter that describes the operating time of the BTL plant and allows an accurate translation between instantaneous and annual flows of the BTL plant; the default value for

"CAP_FAC" is 0.85 (i.e., 85 percent), which is specified in the baseline document for this unit process (NETL 2009) and accounts for interruptions in biomass supply. "NAPFLOW" is an adjustable parameter that represents the mass of naphtha co-produced per kilogram of FT diesel production. "CO2SEQFLOW" and "CO2FLOW" are adjustable parameters that represent the mass of carbon dioxide (CO_2) captured for sequestration and the mass of CO_2 that is released to the atmosphere, respectively. "STACK_OUT" is an adjustable parameter that represents the volumetric flow rate of the stack gas and allows the calculation of sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), and hydrogen chloride (HCl) emissions to air. "PROD_OUT" is an adjustable parameter that represents the volumetric flow rate (in ft^3/hr) of the gas stream that exits the gasifier and is used to calculate hydrogen sulfide (H_2S) emissions from the BTL plant. "SOLIDFLOW" is an adjustable parameter that represents the mass of ash and other solid wastes from the BTL plant. "H2OFLOW_IN" and "H2OFLOW_OUT" are adjustable parameters that are based on NETL data for an integrated gasification combined cycle (IGCC) power facility (NETL 2007) and represent the water consumption of the BTL plant. Finally, "H2O_CCS" is an adjustable parameter that represents the change in water input to the BTL plant when a CCS system is added; this change in water input is also based on the NETL data for an IGCC power facility (NETL 2007).

Naphtha is a co-product of FT diesel. This unit process does not use co-product allocation to apportion environmental burdens between FT diesel and naphtha. Rather, the mass of naphtha per production of one kilogram of FT diesel is shown as an output, and the recommended approach for co-product management is system expansion wherein naphtha co-produced by BTL plants displaces naphtha that is produced by conventional routes. No life cycle data are available for the production of naphtha by conventional routes in the United States. Thus, for the life cycle of BTL fuels, NETL uses life cycle data for jet fuel to represent the conventional naphtha routes that are displaced by FT naphtha. That is, for every kilogram of FT naphtha that is produced by a BTL plant, one kilogram of jet fuel is displaced from the energy supply system. Alternatively, one could use the available GaBi profile for naphtha produced in the European Union. The displacement of conventional routes to naphtha production are outside the scope of this unit process; only the mass of naphtha that is co-produced per unit of FT diesel production is shown in this unit process.

The NETL CBTL baseline (NETL 2009) provides data for CO_2 emissions, H_2S emissions, and slag (solid waste) output. All other impacts were determined by other sources. An LCA study on poplar SRWC gasification was used to characterize SO_X, CO, and HCl emissions (Carpentieri 2005); it is assumed that these emissions do not change significantly with changes in the type of biomass feedstock. Carpentieri (2005) also provides NO_x emission data, but does not provide sufficient information on the extent of environmental controls used to manage NO_x emissions. Thus, NO_x emissions were calculated using environmental targets outlined in the NETL baseline report on fossil energy plants (NETL 2007), which includes data for an IGCC plant) with bituminous coal as a feedstock. The NO_x emissions data for the IGCC plant (NETL 2007) were adjusted downward because co-firing with biomass has been shown to reduce NO_X emissions (Tillman 2000).

Particulate matter (PM) emissions from BTL plants were also estimated from the baseline data for IGCC plants (NETL 2007). This unit process assumes that the BTL plant produces negligible mercury (Hg) emissions; this assumption is supported by a study that shows that Hg in biomass is on the scale of parts per billion (Friedli 2003). Similarly, based on the composition of the BTL feedstock and the extent to which the gas streams of a BTL plant are cleaned, ammonia (NH_3) and lead (Pb) emissions were assumed to be negligible. Because no combustion processes are considered (e.g., no auxiliary boilers or other units are used for onsite energy generation) no other combustion-related emissions are calculated. Air emissions are considered a limitation due to the lack of specific data for BTL plants.

Water use was not given in the NETL CBTL baseline report. An environmental impact statement (EIS) on a smaller CTL plant was used as a data source for water input, consumption, and discharge (DOE 2007). This is noted as a data limitation because the BTL cases have slightly lower gasifier output temperatures and therefore would probably require less water; however, no BTL-specific water use data were available. Water increases due to CCS addition were based on the percent increase reported in the NETL baseline report on fossil energy plants (NETL 2007). This, too, is noted as a data limitation, as no distinction was made between water use increases with CCS and CCS +ATR. Emissions to water were determined based on the calculated water output and effluent water quality data from an IGCC plant (NETL 2002). Water emissions that were calculated as 0.1 ppm (parts per million) or greater were included in the water quality data for this unit process. This includes the waterborne emission of NH_3, cyanide (CN^-), nickel (Ni), selenium (Se), and zinc as significant water outputs. Both the water quantity and quality data are considered data limitations.

Solid waste is dominated by ash created during gasification, which is given in the NETL CBTL baseline report. Additionally, the FT process uses an iron catalyst that would contribute to solid waste as it degrades and is replaced. Data on FT catalyst productivity and loss (degradation) rate was taken from an NREL report of FT production of mixed alcohols from biomass (Phillips *et al.* 2007). When calculated, the loss of catalyst was less than 0.01 percent compared to slag output, and was therefore considered insignificant.

Properties of BTL plants that use SRWC as a feedstock are shown in **Table 1**. **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.

Table 1: Properties of SRWC BTL Plants (NETL 2009)

Property (at 100% capacity)	5,000 BPD BTL, SRWC	5,000 BPD BTL w/ CCS, SRWC	5,000 BPD BTL w/ CCS + ATR, SRWC
Diesel Output (tonne/day)	463	464	464
Naphtha Output (tonne/day)	158	157	157
Biomass Input (tonne/day)	3,539	3,584	3,769
Biomass HHV (MJ/kg)	17.7	17.7	17.7
CO2 Capture (tonne CO2e/day)	0	3,466	4,085
CO2 Emissions (tonne/day)	3,761	449	147
Solid Waste Flow (tonne/day)	222	225	236

Table 2: Unit Process Input and Output Flows

Flow Name*	5,000 BPD BTL, SRWC	5,000 BPD BTL w/ CCS, SRWC	5,000 BPD BTL w/ CCS + ATR, SRWC	Units (Per Reference Flow)
Inputs				
Water (unspecified) [Water]	**34.7**	**37.6**	**39.6**	**kg**
SRWC	**7.64**	**7.72**	**8.12**	**kg**
Outputs				
Fischer-Tropsch diesel (FTD)	1	1	1	kg
Naphtha (NETL) [Organic intermediate products]	0.340	0.337	0.338	kg
Carbon dioxide [Inorganic intermediate products]	0.0	7.5	8.8	kg
Water (returned to receiving body) [Water]	14.5	15.7	16.5	kg
Carbon dioxide [Inorganic emissions to air]	6.90	0.82	0.27	kg
Nitrogen dioxide [Inorganic emissions to air]	3.31E-05	4.07E-05	3.30E-05	kg
Sulphur dioxide [Inorganic emissions to air]	3.71E-05	4.55E-05	3.69E-05	kg
Particulate Matter, unspecified [Other emissions to air]	4.12E-04	4.16E-04	4.38E-04	kg
Hydrogen Sulfide [Other emissions to air]	2.29E-07	2.70E-07	2.52E-07	kg
Carbon monoxide [inorganic emissions to air]	5.29E-07	6.51E-07	5.28E-07	kg
Hydrogen chloride [inorganic emissions to air]	3.62E-04	4.45E-04	3.61E-04	kg
Ammonium / ammonia [Inorganic emissions to fresh water]	1.28E-04	1.38E-04	1.46E-04	kg
Cyanide [Inorganic emissions to fresh water]	2.09E-06	2.26E-06	2.38E-06	kg
Nickel (+II) [Heavy metals to fresh water]	1.65E-06	1.79E-06	1.89E-06	kg
Selenium [Heavy metals to fresh water]	2.00E-06	2.17E-06	2.28E-06	kg
Zinc (+II) [Heavy metals to fresh water]	1.98E-06	2.14E-06	2.26E-06	kg
Solid Waste (unspecified) [Solid Waste]	4.07E-01	4.11E-01	4.33E-01	kg

* **Bold face** clarifies that the value shown *does not* include upstream environmental flows.

Embedded Unit Processes

None.

References

Carpentieri *et al.* 2005	Carpentieri, M., Corti, A., Lombardi, L., 2005. *Life cycle assessment (LCA) of an integrated biomass gasification combined cycle (IBGCC) with CO2 removal.* Energy Conversion and Management 46:1790-1808. http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6V2P-4DXB86Y-3-1&_cdi=5708&_user=2638189&_orig=search&_coverDate=07%2F01%2F2005&_sk=999539988&view=c&wchp=dGLbVlW-zSkzk&md5=9de9d8ed2399fcd4f37324b44282f5a3&ie=/sdarticle.pdf (accessed December 17, 2009).
DOE 2007	DOE, 2007. *Final Environmental Impact Statement for the Gilberton Coal-to-Clean Fuels and Power Project*. U.S. Department of Energy. DOE/EIS-0357. http://www.gc.energy.gov/NEPA/finalEIS-0357.htm (accessed December 17, 2009).
Friedli 2003	Friedli, H.R., *et al*., 2003. *Mercury emissions from burning of biomass from temperate North American forests: laboratory and airborne measurements.* Atmospheric Environment 37:253-267.
NETL 2002.	NETL, 2002. *Major Environmental Aspects of Gasification-Based Power Generation Technologies.* U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory. http://www.netl.doe.gov/technologies/coalpower/gasification/pubs/pdf/final%20env.pdf (accessed December 17, 2009).
NETL 2007	NETL, 2007. *Cost and Performance Baseline for Fossil Energy Plants – Volume 1: Bituminous Coal and Natural Gas to Electricity Final Report*. U.S. Department of Energy, National Energy Technology Laboratory. Pittsburgh, PA. DOE/NETL-2007/1281. http://www.netl.doe.gov/energy-analyses/baseline_studies.html (accessed December 17, 2009).

NETL 2009	NETL, 2009. *Affordable, Low-Carbon Diesel Fuel from Domestic Coal and Biomass*. U.S. Department of Energy, National Energy Technology Laboratory. Pittsburgh, PA. DOE/NETL-2009/1349. January 14, 2009.
Phillips *et al.* 2007	Phillips, S., et al., 2007. *Thermochemical Ethanol via Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass*. National Renewable Energy Laboratory, Golden, CO. NREL/TP-501-41168. http://www.nrel.gov/docs/fy07osti/41168.pdf (accessed December 17, 2009).
Tillman 2000	Tillman, D.A., 2000. "Biomass cofiring: the technology, the experience, the combustion consequences." *Biomass and Bioenergy* 19:365-384. http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6V22-41TN69H-2-58&_cdi=5690&_user=2638189&_orig=search&_coverDate=12%2F31%2F2000&_sk=999809993&view=c&wchp=dGLzVtb-

Section III: Document Control Information

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Section IV: Disclaimer