NETL Life Cycle Inventory Data
Process Documentation File

Process Name: Oil Sands Upgrading

Reference Flow: 1 kg of Synthetic Crude Oil (SCO)

Brief Description: Energy use, feedstock, and emissions from production of 1 kg of synthetic crude oil at an upgrading facility (delayed coker or hydrocracker).

Section I: Meta Data

Geographical Coverage: Canada **Region:** Alberta

Year Data Best Represents: 2010

Process Type: Energy Conversion (EC)

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

Allocation Applied: No

Completeness: All 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	☐ Other
Releases to Water:	☐ Inorganic	☐ Organic Emissions	☐ Other
Water Usage:	☐ Water Consumption	☐ Water Demand (throughput)	
Releases to Soil:	☐ Inorganic Releases	☐ Organic Releases	☐ Other

Adjustable Process Parameters:

Cogen	*[Dimensionless] 0 = Upgrading facility without cogen; 1 = Upgrading facility with cogen*
Upgrade	*[Dimensionless] 0 = Delayed Coking; 1 = Hydrocracker*
Fug_CH4	*[kg/kg] Fugitive emissions from upgrading processes*

Flar_CO2	*[kg/kg] Flared emissions from upgrading processes*
H2_In_Coke	*[m3/m3] Coker hydrogen input*
H2_In_H2	*[m3/m3] Hydrocracker hydrogen input*
NG_In_SMR_H2	*[m3/m3] SMR hydrogen production per unit natural gas input*
Diluent_MU	*[kg/kg] Coker makeup diluent (naphtha) input*
SCO_Bit_Coke	*[kg/kg] Coker SCO output to bitumen input ratio*
SCO_Bit_H2	*[kg/kg] Hydrocracker SCO output to bitumen input ratio*
Elec_req_Coke	*[MWh/kg] Coker electricity required for a unit without cogen*
Elec_prod_Coke	*[MWh/kg] Coker electricity produced for a unit with cogen*
Elec_req_H2	*[MWh/kg] Hydrocracker electricity required for a unit without cogen*
Elec_prod_H2	*[MWh/kg] Hydrocracker electricity produced for a unit with cogen*
NG_NoCo_Coke_St	*[m3/m3] Gas required for boiler steam production - coker*
NG_NoCo_H2_St	*[m3/m3] Gas required for boiler steam production - hydrocracker*
Proc_Gas_Coke	*[m3/m3] Process gas production for coker*
Proc_Gas_H2	*[m3/m3] Process gas production for hydrocracker*
Elec_Cogen_Coke	*[MWh/m3] Electricity produced from coker upgrader with cogen*
Elec_Cogen_H2	*[MWh/m3] Electricity produced from hydrocracker upgrader with cogen*
Gas_Turb_Ef_HHV	*[dimensionless] Gas turbine HHV electricity generation efficiency*
Nat_Gas_HHV	*[MJ/m3] HHV of natural gas*
NG_Density	*[kg/m3] Density of natural gas*

SCO_Density	*[kg/m3] Density of SCO*

Tracked Input Flows:

Natural Gas US Mix - NETL [Natural gas (resource)]	*[Technosphere] Combusted natural gas input*
Naphtha [Organic intermediate products]	*[Technosphere] Naphtha input*
Bitumen plus Diluent [Crude Oil Products]	*[Technosphere] NGL input*
Electricity [Electric Power]	*[Technosphere] Electricity input*

Tracked Output Flows:

SCO [Crude Oil Products]	*Reference flow*
Natural Gas US Mix - NETL [Natural gas (resource)]	*Gas Co-Product*
Electricity [Electric Power]	*Electricity Co-Product*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *Stage1_O_Oil_Sands_Upgrading_2014.01.xlsx*, which provides additional details regarding relevant calculations, data quality, and references.

Goal and Scope

This unit process provides a summary of relevant input and output flows associated with the production of synthetic crude oil from an oil sands upgrading facility. The processes allows the user to choose a facility type (delayed coker or hydrocracker) as well as an option for cogeneration. Units that include cogeneration facilities export electricity. In some cases, the processes also export some process gas if an excess remains. Hydrogen production is included inside the boundary and feed/fuel natural gas is accounted for in the net gas total. The reference flow of this unit process is: 1 kg of Synthetic Crude Oil (SCO).

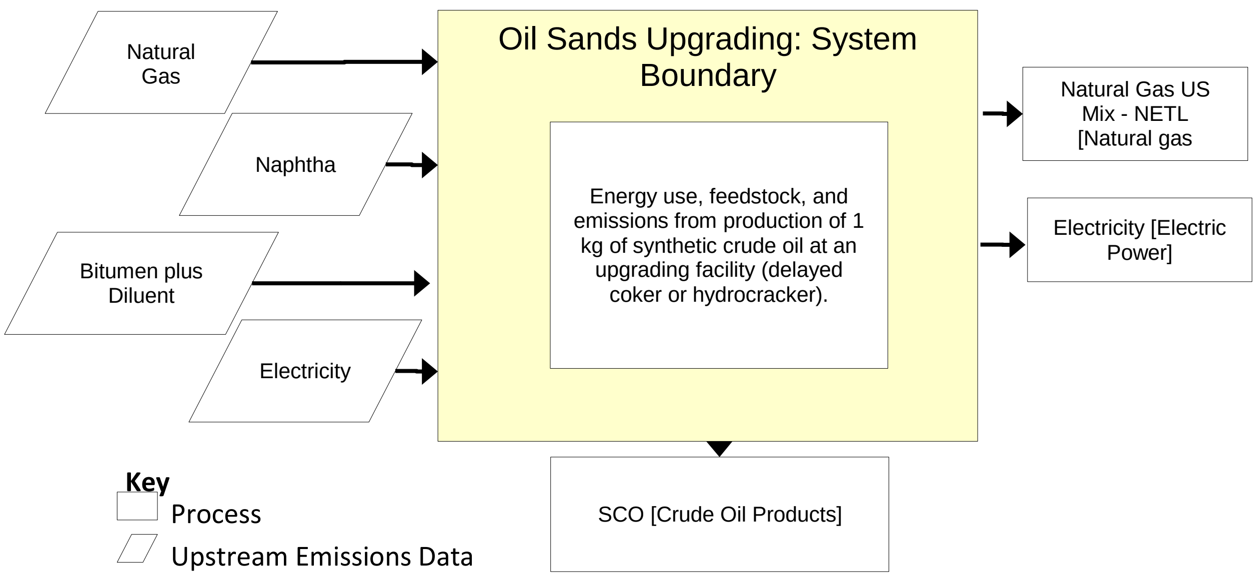
Boundary and Description

There are two primary options for upgrading the bitumen that is produced from oil sands: delayed coking and hydrocracking. This unit process allows the user to choose which technology will be used for upgrading the bitumen that is transported to the upgrader. Bitumen that is produced from either a surface mining or in situ extraction process is diluted with naphtha to all for pipeline transport and delivered to the upgrading facility. The extraction of oil sands and transport of bitumen are outside of the scope of this process.

Delayed coking thermally cracks the long carbon chains contained in the bitumen to produce gas, coke, and SCO (Bergerson et al. 2012). Hydrocracking utilizes hydrogen in the presence of a catalyst to crack the carbon chain and also saturates the newly cracked molecules with hydrogen. Similar to delayed coking, the hydrocracker produces gas and SCO, but no coke.

Figure 1 shows all of the process inputs and outputs, along with the system boundary for the upgrading of bitumen. The parameter values utilized to scale the inputs and outputs are detailed in **Table 1**. The basis for these parameter values is the GreenHouse gas emissions of current Oil Sands Technologies (GHOST) model developed by the Universities of Calgary and Toronto (Bergerson et al. 2012 and Charpentier et al. 2011). GHOST is a life cycle model which tracks greenhouse gas emissions all the way from the extraction of oil sands up to the entrance to a refinery. Both upgrading processes require steam, electricity, and hydrogen. Steam is generated in a boiler by using a combination of the process gas produced by the upgrader and imported natural gas. If there is an excess of process gas, it is assumed to leave the system boundary as a co-product. In the case of delayed coking, the coke byproduct is assumed to be a waste and is not included as a co-product. The hydrogen is produced in an on-site steam-methane reformer (SMR), which uses natural gas as a process and fuel input. The electricity can be generated on-site or imported from the grid.

Figure 1: Unit Process Scope and Boundary



The direct emissions accounted for in this process include the flaring of associated gas as well as fugitive gas emissions (Bergerson et al. 2012). Direct emissions which are part of the overall system, but not accounted for in this unit process include the combustion of natural gas to generate steam for recovery. Indirect emissions which are also part of the overall system, but not accounted for in this process include the supply chain emissions associated with the production of diesel, natural gas, electricity, and the diluent (naphtha, NGLs, or SCO depending on the desired product).

GHOST includes both no cogeneration (boiler only) and cogeneration cases for the upgrading operations. In the no cogeneration case, all of the electricity required for the operation is sourced from the grid. In the cogeneration case, natural gas is imported and combusted in a gas turbine to generated electricity. The exhaust gas is sent to a heat recovery steam generator (HRSG) where the necessary steam is produced. Any excess electricity leaves the boundary as a co-product.

Table 1: Parameter Values for Delayed Coker and Hydrocracker Upgraders (Bergerson et al. 2012, Charpentier et al. 2011)

Parameter	Delayed Coker		Hydrocracker		Units (per m^3 SCO, unless otherwise noted)
	Value	Range	Value	Range	
Process Inputs					
SCO/Bitumen Ratio	0.85	0.78-0.9	1.03	0.95-1.05	m3 SCO/m3 bitumen
SCO/(Bitumen+Diluent) Ratio	0.60	0.55-0.63	0.72	0.67-0.74	m3 SCO/(m3 bitumen + diluent)
Co-produced Process Gas	70	55-115	55	25-115	m^3
Hydrogen Gas	80	65-200	80	75-200	m^3
Makeup Diluent	20	5-30	20	5-30	L
Emissions					
Fugitive Methane	1	0-2	1	0-2	kg CO_2e
Flared Hydrocarbons	6.5	5-10	6.5	5-10	kg CO_2e
No Cogeneration - Utilities					
Total Gas Required	105	55-115	85	55-115	m^3
Natural Gas (Total – Process Gas)	35	-60-60	30	-60-90	m^3
Electricity for Process	55	40-70	100	85-130	kWh
Cogeneration – Utilities					
Electricity for Process	55	40-70	100	85-130	kWh
Gas Turbine Efficiency	30%	N/A	30%	N/A	%
Total Electricity Produced	1,100	220-2,200	2,000	400-4,000	kWh
Gas Input for Hydrogen	35	28-87	35	33-87	m^3
Gas Input for Electricity/Steam	348	70-697	633	127-1,266	m^3
Total Gas Required	383	98-784	668	159-1,353	m^3
Natural Gas (Total – Process Gas)	313	-17-729	613	44-1,328	m^3

Table 2 shows the unit process input and output flows for the case in SCO is produced from a delayed coker with no cogeneration.

Table 2: Unit Process Input and Output Flows

Flow Name	Value	Units (Per Reference Flow)
Inputs		
Natural Gas US Mix - NETL [Natural gas (resource)]	**2.63E-02**	**kg**
Naphtha [Organic intermediate products]	**1.71E-02**	**kg**
Bitumen plus Diluent [Crude Oil Products]	**1.76E+00**	**kg**
Electricity [Electric Power]	**6.14E-05**	**MWh**
Outputs		
SCO [Crude Oil Products]	1.00	kg
Natural Gas US Mix - NETL [Natural gas (resource)]	0.00E+00	kg
Electricity [Electric Power]	0.00E+00	MWh
Carbon dioxide [Inorganic emissions to air]	7.25E-03	kg
Methane [Organic emissions to air (group VOC)]	4.46E-05	kg

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

Embedded Unit Processes

None.

References

Bergerson et al. 2012 — Bergerson, J. A., Kofoworola, O., Charpentier, A. D., Sleep, S., & MacLean, H. L. (2012). Life Cycle Greenhouse Gas Emissions of Current Oil Sands Technologies: Surface Mining and In Situ Applications. Environmental Science & Technology, 46(14), 7865-7874. doi: 10.1021/es300718h

Charpentier et al. 2011 — Charpentier, A. D., Kofoworola, O., Bergerson, J. A., & MacLean, H. L. (2011). Life Cycle Greenhouse Gas Emissions of Current Oil Sands Technologies: GHOST Model Development and Illustrative Application. Environmental Science & Technology, 45(21), 9393-9404. doi: 10.1021/es103912m

Section III: Document Control Information

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