NETL Life Cycle Inventory Data
Process Documentation File

Process Name:	Oil Sands In Situ Extraction
Reference Flow:	1 kg of Recovered and Extracted Dilbit, Synbit, or Upgrader Feed
Brief Description:	Energy use, feedstock, and emissions from production of 1 kg Dilbit, Synbit, or SCO upgrader feed

Section I: Meta Data

Geographical Coverage: Canada **Region:** Alberta

Year Data Best Represents: 2010

Process Type: Energy Conversion (EC)

Process Scope: Cradle-to-Gate Process (CG)

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 = Extraction facility without cogen; 1 = Extraction facility with cogen*
In_Situ	*[Dimensionless] 0 = SAGD; 1 = CSS*

Finished_Prod	*[Dimensionless] Determination of ultimate product; 0 = dilbit; 1 = synbit; 2 = SCO (diluent used for transport)*
Diluent	*[Dimensionless] Diluent used for produced Dilbit; 0 = naphtha; 1 = NGL*
Fug_CH4_SAGD	*[kg/kg] SAGD fugitive emissions from bitumen extraction processes*
Fug_CH4_CSS	*[kg/kg] CSS fugitive emissions from bitumen extraction processes*
Flar_CO2_SAGD	*[kg/kg] SAGD flared emissions from bitumen extraction processes*
Flar_CO2_CSS	*[kg/kg] CSS flared emissions from bitumen extraction processes*
Elec_req_SAGD	*[MWh/kg] SAGD electricity required for a unit without cogen*
Elec_prod_SAGD	*[MWh/kg] SAGD electricity produced for a unit with cogen*
Elec_req_CSS	*[MWh/kg] CSS electricity required for a unit without cogen*
Elec_prod_CSS	*[MWh/kg] CSS electricity produced for a unit with cogen*
Naphtha_Dil_m	*[kg/kg] Naphtha diluent input per unit bitumen*
NGL_Dil_m	*[kg/kg] NGL diluent input per unit bitumen*
SCO_Syn_m	*[kg/kg] SCO diluent input per unit bitumen*
Naphtha_SCO_T	*[kg/kg] Naphtha diluent input per unit bitumen - blended for transport to upgrader*
FW_Temp	*[deg C] Temperature of boiler feedwater*
Soln_Gas_SAGD	*[m3/m3] Solution gas production for SAGD*
Soln_Gas_CSS	*[m3/m3] Solution gas production for CSS*
SOR_SAGD_Dry	*[m3/m3] Steam to oil ratio for SAGD on a dry steam basis*

SOR_CSS_Wet	*[m3/m3] Steam to oil ratio for CSS on a wet steam basis*
NG_HHV	*[kJ/m3] Natural gas HHV*
Boiler_HHV_Eff	*[dimensionless] Boiler efficiency based on HHV*
Elec_Cogen_SAGD	*[MWh/m3] Electricity produced from SAGD extraction with cogen*
Elec_Cogen_CSS	*[MWh/m3] Electricity produced from CSS extraction 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*
Bit_Density	*[kg/m3] Density of bitumen*

Tracked Input Flows:

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

Tracked Output Flows:

In Situ Extracted Bitumen plus Diluent to Upgrader [Crude Oil Products]	*Reference flow*
Dilbit [Crude Oil Products]	*Reference flow*
Synbit[Crude Oil Products]	*Reference flow*
Electricity [Electric Power]	*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_In_Situ_Extraction_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 In Situ extraction of Canadian Oil Sands. The process allows the user to choose either SAGD or CSS In Situ extraction technology. The processes allows the user to choose the type of product produced (i.e. dilbit, synbit, or upgrader feed), which thereby determines the diluent type and amount. Units that include cogeneration facilities export electricity. The reference flow of this unit process is: 1 kg of Recovered and Extracted Dilbit, Synbit, or Upgrader Feed.

Boundary and Description

There are two main techniques for extracting oil sands: surface mining and in situ recovery. This unit process applies specifically to the second technique. In situ recovery can be further subdivided into Steam Assisted Gravity Drainage (SAGD) and Cyclic Steam Stimulation (CSS). SAGD refers to a process by which steam is continuously injected into an upper horizontal well and then the bitumen is collected by a lower well (Charpentier et al. 2011). Conversely, CSS involves injecting steam, allowing the steam to soak the oil sands, and production of the bitumen (Bergerson et al. 2012). The extracted slurry is transported to a recovery facility where the bitumen is separated by utilizing hot water (Bergerson et al. 2012). For both methods, one of the major variables is the Steam-to-Oil Ratio (SOR). The SOR is a measure of the efficiency of the recovery method (i.e. how much steam is required to produce a unit of bitumen). As such, the SOR is a primary driver of the emissions of these extraction processes. As noted in the documentation for GHOST, there are two measures of SOR, instantaneous and cumulative (iSOR and cSOR). As the name implies, iSOR is a short term, usually daily, metric, whereas cSOR is a measure over a longer period of time (Charpentier et al. 2011). SAGD is the newer of the two technologies, so there is not enough sufficient data to calculate a representative iSOR. Therefore, GHOST relies on iSOR data available at the time the model was created.

Following bitumen recovery it can be blended to produce an immediately saleable product or transported to an upgrading facility. Recovered bitumen must be diluted prior to sale or transport to reduce the viscosity to the point where it can be transported via pipeline. The material used to dilute the bitumen is referred to as the diluent. If the desired product is diluted bitumen (or dilbit), then the most common diluents are naphtha and natural gas liquids (NGLs). Conversely, if the producer wishes to produce synthetic bitumen (or synbit), the bitumen is diluted with synthetic crude oil (SCO) from an oil sands upgrading facility. Finally, if the bitumen will be sent to an upgrader, it is blended with naphtha so that it can be transported via pipeline.

Figure 1 shows all of the process inputs and outputs, along with the system boundary for in situ extraction of oil sands. The parameter values utilized to scale the inputs and outputs are detailed in **Table 1** for the scenarios without any cogenerated electricity. 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.

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 in situ injection 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 surface mining recovery 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. **Table 2** provides parameter values utilized to scale the inputs and outputs for the cogeneration cases of SAGD and CSS in situ extraction. 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.

Figure 1: Unit Process Scope and Boundary

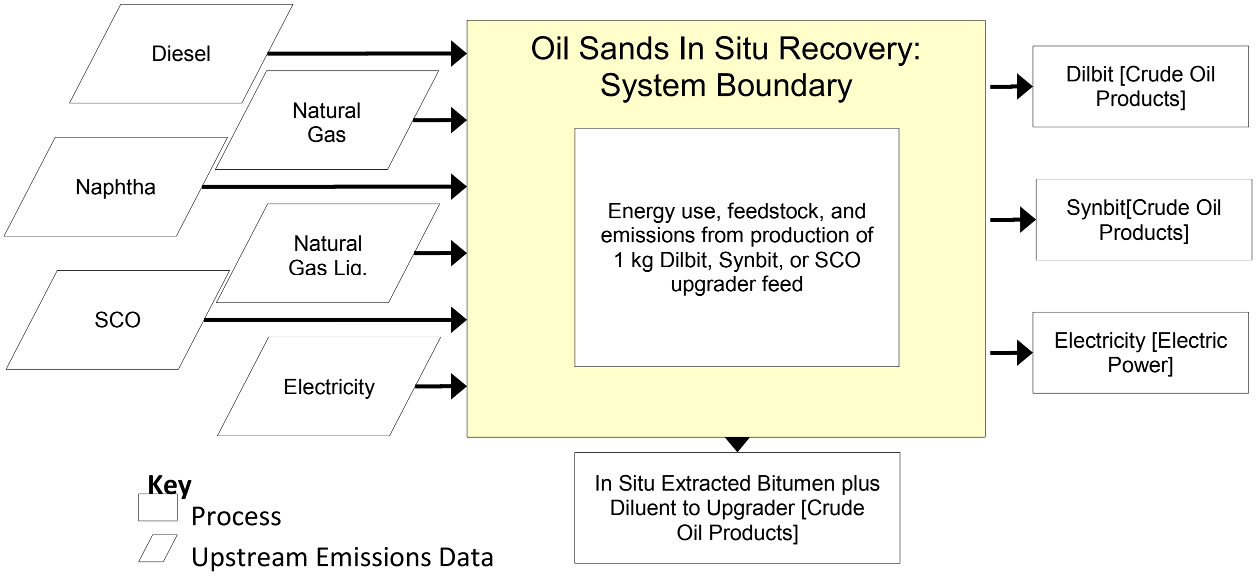

Table 1: Parameter Values for SAGD and CSS No Cogeneration Cases (Bergerson et al. 2012, Charpentier et al. 2011)

Parameter	SAGD		CSS		Units (per m^3 bitumen unless noted)
	Value	Range	Value	Range	
Steam Generation/Injection					
Instantaneous SOR (iSOR dry)	2.6	2.2-3.3	N/A	N/A	m^3 dry steam
Cumulative SOR (cSOR wet)	N/A	N/A	3.5	2.6-5.9	m^3 wet steam
Injected Steam Quality	100%	-	80%	-	%
Produced Steam Quality	80%	-	80%	-	%
Boiler or Co-Gen Feedwater Temperature	150	100-200	150	100-180	Degrees C
Boiler HHV Efficiency	80%	-	80%	-	%
Utility Requirements					
Electricity Used by Process	75	45-120	91	87-99	kWh
Co-produced Solution Gas	5	1-12	51.4	29.2-86.6	m^3
Natural Gas Requirement	192	135-278	158	87-298	m^3
Emissions					
Fugitive Methane	0.5	0.3-1	1.4	0-1.4	kg CO_2e
Flared Hydrocarbons	0.2	0.1-0.6	0.2	0.1-0.6	kg CO_2e
Diluent					
SCO Pathway Transport (naphtha)	30%	30%	30%	30%	% by volume
Dilbit Pathway (NGL or naphtha)	25%	25%	25%	25%	% by volume
Synbit Pathway (SCO)	50%	50%	50%	50%	% by volume

Table 2: Parameter Values for SAGD and CSS Cogeneration Cases (Bergerson et al. 2012, Charpentier et al. 2011)

Parameter	SAGD		CSS		Units (per m^3 bitumen unless noted)
	Value	Range	Value	Range	
Steam/Electricity Generation					
Instantaneous SOR (iSOR dry)	2.6	2.2-3.3	N/A	N/A	m^3 dry steam
Cumulative SOR (cSOR wet)	N/A	N/A	3.5	2.6-5.9	m^3 wet steam
Injected Steam Quality	100%	-	80%	-	%
Produced Steam Quality	80%	-	80%	-	%
Gas Turbine Efficiency	80%	-	80%	-	%
Total Electricity Produced	1,500	300-3,000	1,500	300-3,000	kWh
Utility Requirements					
Electricity Used by Process	75	45-120	91	87-99	kWh
Gas for Electricity/Steam Production	475	95-950	475	95-950	m^3
Co-produced Solution Gas	5	45-120	51.4	29-87	m^3
Natural Gas Import	470	50-830	424	66-863	m^3
Emissions					
Fugitive Methane	0.5	0.3-1	1.4	0-1.4	kg CO_2e
Flared Hydrocarbons	0.2	0.1-0.6	0.2	0.1-0.6	kg CO_2e
Diluent					
SCO Pathaway Transport (naphtha)	30%	30%	30%	30%	% by volume
Dilbit Pathway (NGL or naphtha)	25%	25%	25%	25%	% by volume
Synbit Pathway (SCO)	50%	50%	50%	50%	% by volume

Table 3 shows the unit process input and output flows for the case in which dilbit is produced from a SAGD extraction with no cogeneration.

Table 3: Unit Process Input and Output Flows

Flow Name	Value	Units (Per Reference Flow)
Inputs		
Natural Gas US Mix - NETL [Natural gas (resource)]	**1.02E-01**	**kg**
Naphtha [Organic intermediate products]	**2.01E-01**	**kg**
Natural Gas Liquids [Natural Gas Products]	**0.00E+00**	**kg**
SCO [Crude Oil Products]	**0.00E+00**	**kg**
Electricity [Electric Power]	**5.91E-05**	**MWh**
Outputs		
In Situ Extracted Bitumen plus Diluent to Upgrader [Crude Oil Products]	0.00E+00	kg
Dilbit [Crude Oil Products]	1.00	kg
Synbit[Crude Oil Products]	0.00E+00	kg
Electricity [Electric Power]	0.00E+00	MWh
Carbon dioxide [Inorganic emissions to air]	1.58E-04	kg
Methane [Organic emissions to air (group VOC)]	1.58E-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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Section IV: Disclaimer