NETL Life Cycle Inventory Data
Process Documentation File

Process Name:	Steam injection for oil recovery
Reference Flow:	1 kg of steam injected
Brief Description:	Steam injection by a once-through steam generator (OTSG) for thermally enhanced oil recovery

Section I: Meta Data

Geographical Coverage: World **Region:** N/A

Year Data Best Represents: N/A

Process Type: Extraction Process (EP)

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	☐ 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:

Production_vol	*[bbl/day] Production volume. For all wells in the field. U.S. productivity per well is lower than the world average*
SOR	*[bbl/bbl] Ratio of steam (cold water equivalent) to barrel of produced oil*
h2o_density	*[lbm/bbl] Density of water at 60F and 1 atm*

res_depth	*[ft] Depth of the reservoir. See Figure 3.6. Min and Max represent one standard deviation from the median, which is lower than the mean.*
water_enthalpy	*[btu/lbm] Enthalpy of the incoming water - default assumes 60F and 1 atm*
excess_press	*[dimensionless] Excess steam required to account for distribution losses*
h_sat_water	*[btu/lbm] Enthalpy of saturated water at steam pressure (steam_press)*
h_sat_vapor	*[btu/lbm] Enthalpy of saturated steam at steam pressure (steam_press)*
steam_qual	*[dimensionless] Quality of the steam*
air_mol_wt	*[lbm/lb-mol] Molecular weight of ambient air for combustion*
excess_air	*[dimensionless] Excess oxygen required for combustion over the stoichiometric requirement*
NG_frac	*[dimensionless] Molar fraction of fuel that is natural gas*

Tracked Input Flows:

Natural Gas	*[Tehcnosphere] Natural gas from pipeline*
Associated Natural Gas	*[Technosphere] Associated natural gas produced by the facility*
Water (Unspecified) [Water]	*[Resource] Water is likely sourced from produced water which is treated and recycled*

Tracked Output Flows:

Steam injected	*Reference flow*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage1_O_Steam_injection_2013.01.xlsx*, which provides additional details regarding relevant calculations, data quality, and references.

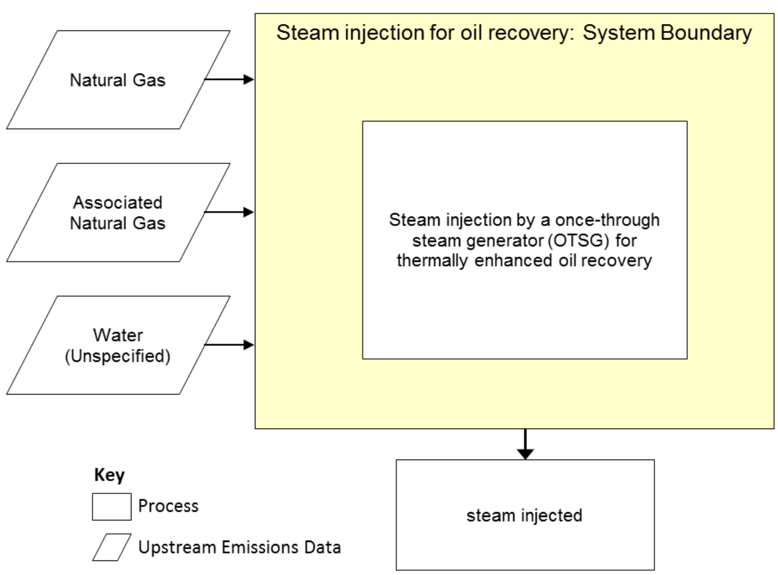
Goal and Scope

This unit process provides a summary of relevant input and output flows associated with steam injection for thermally-enhanced oil recovery using a once-through steam generator. The UP calculates the necessary pipeline natural gas or associated natural gas required for steam production and also the emissions associated with the combustion of those gases. The reference flow of this unit process is: 1 kg of steam injected.

Boundary and Description

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 of the boundary of this unit process. As shown, the upstream emissions from natural or associated gas and water are calculated in another unit process. The methods for calculating these operating activities are described below.

Figure 1: Unit Process Scope and Boundary



The unit process is based on the steam injection calculations in the *Oil Production Greenhouse Gas Emissions Estimator (OPGEE)* (El-Hoijeiri et al., 2013), specifically the calculations using a once-through steam generator (OTSG) for steam production and injection. Steam injection is accomplished using a gas-fired, pressurized OTSG to heat water/steam to the point that the pressure in the generator is great enough to overcome the reservoir pressure. At that point, steam enters the formation to increase recovery rate. On the combustion side, the OTSG inputs consist of the fuel (either natural or associated gas) and air, and combustion products are the output.

The energy required to create the steam and the change in energy from the boiler inputs to the emissions are needed to calculate the required heat input. The energy required to heat the steam is calculated using the steam injection rate and the change in enthalpy, shown in **Equation [1]**.

The change in energy through the combustion side of the OTSG can be calculated by using the change in enthalpy of the inputs to the combustion products and the mass flow rate of each. The inlet air, inlet natural gas, inlet associated gas, and outlet air compositions are set by parameters within the unit process. These parameters are normalized per unit of fuel input, and the default values are taken from OPGEE. The change in enthalpy for each constituent of each stream (i.e., the oxygen in the inlet air and combustion products) is calculated using thermodynamic properties (Lemmon et al., n.d.) and assumed temperatures and pressures. The default inlet temperature is 80.33ºF at 14.7 psia and the outlet temperature is 350ºF at 14.7 psia. Shell losses and other losses are added to the required energy to provide a total energy that must be supplied by the fuel.

The required fuel input is calculated by dividing the weighted average of the lower heating values (LHVs) of the two available fuels – natural gas and associated gas. The LHVs are used to define the energy content of the fuel because the exhaust gas is assumed to be high temperature and not used for any heat recovery which may condense any of the entrained water vapor. The natural gas is assumed to be sourced from an outside pipeline, while associated gas is the co-produced gas from crude extraction. The different sources are used because they represent different upstream burdens.

Equation [1]

$$Q_{steam} = \dot{m}_{steam}[h_{sat\ L} + steam\ quality \cdot (h_{sat\ V} - h_{sat\ L}) - h_{water}]$$

where,
Q_{steam} is the energy required to create the steam
$\dot{m}_{steam}$ is the mass flow rate of steam used for injection
$h_{sat\ L}$ is the enthalpy for saturated water (default is for 1362 psia)
$steam\ quality$ is the quality of steam given as the fraction of steam (default 0.8)
$h_{sat\ V}$ is the enthalpy for saturated steam (default is for 1362 psia)
h_{water} is the enthalpy for the inlet water (default is for 60ºF and 14.7 psia)

The inputs and outputs for this unit process using the default values are shown in **Table 1**.

Table 1: Unit Process Input and Output Flows

Flow Name	Value	Units (Per Reference Flow)
Inputs		
Natural Gas	**1.44E-02**	**kg**
Associated Natural Gas	**4.26E-02**	**kg**
Water (Unspecified) [Water]	1.00E+00	kg
Outputs		
steam injected	**1.00E+00**	**kg**
Carbon dioxide [Inorganic emissions to air]	1.53E-01	kg
Methane [Organic emissions to air (group VOC)]	0.00E+00	kg
Sulphur dioxide [Inorganic emissions to air]	0.00E+00	kg
Carbon monoxide [Inorganic emissions to air]	0.00E+00	kg
Hydrogen sulfide [Inorganic emissions to air]	0.00E+00	kg

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

Embedded Unit Processes

None.

References

El-Hoijeiri et al., 2013	El-Houjeiri, H. M., McNally, S., & Brandt, A. R. (2013). Oil Production Greenhouse Gas Emissions Estimator OPGEE v1.1 DRAFT A: User guide & Technical documentation.
Lemmon et Al, n.d.	Lemmon, E. W., Linden, M. O., & Friend, D. G. (n. d.). Thermophysical Properties of Fluid Systems. National Institute of Standards and Technology. Retrieved September 18, 2012, from http://webbook.nist.gov

Section III: Document Control Information

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Section IV: Disclaimer