NETL Life Cycle Inventory Data
Process Documentation File

Process Name: California Thermal Enhanced Oil Recovery

Reference Flow: 1 kg U.S. Domestic Crude Oil, 2005

Brief Description: Emissions from steam injection processes for extraction of heavy oils in California on the basis of 1 kg U.S. domestic crude oil extracted. Water use for cyclic steam injection, steam flood, and water flood processes for enhanced oil recovery.

Section I: Meta Data

Geographical Coverage: US **Region:** Not Applicable

Year Data Best Represents: 2005

Process Type: Extraction Process (EP)

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

Allocation Applied: No

Completeness: Individual 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:

Natural gas USA [Natural gas (resource)]	*Amount of natural gas used in CA TEOC operations, per kg U.S. domestic crude*

Tracked Output Flows:

U.S. Domestic crude oil, 2005	*Reference Flow*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage1_O_California_Thermal_Enhanced_Oil_Recovery_2010.01.xls*, which provides additional details regarding relevant, calculations, data quality, and references.

Goal and Scope

The scope of this unit process covers the operation of equipment for extraction of heavy oil in California using thermal enhanced oil recovery. The process is used within the extraction of U.S. Domestic crude oil under LC Stage #1. Natural gas is used to power industrial boilers for production of steam, and emissions from combustion of the gas are inventoried. Water inputs to and outputs from the system are also inventoried.

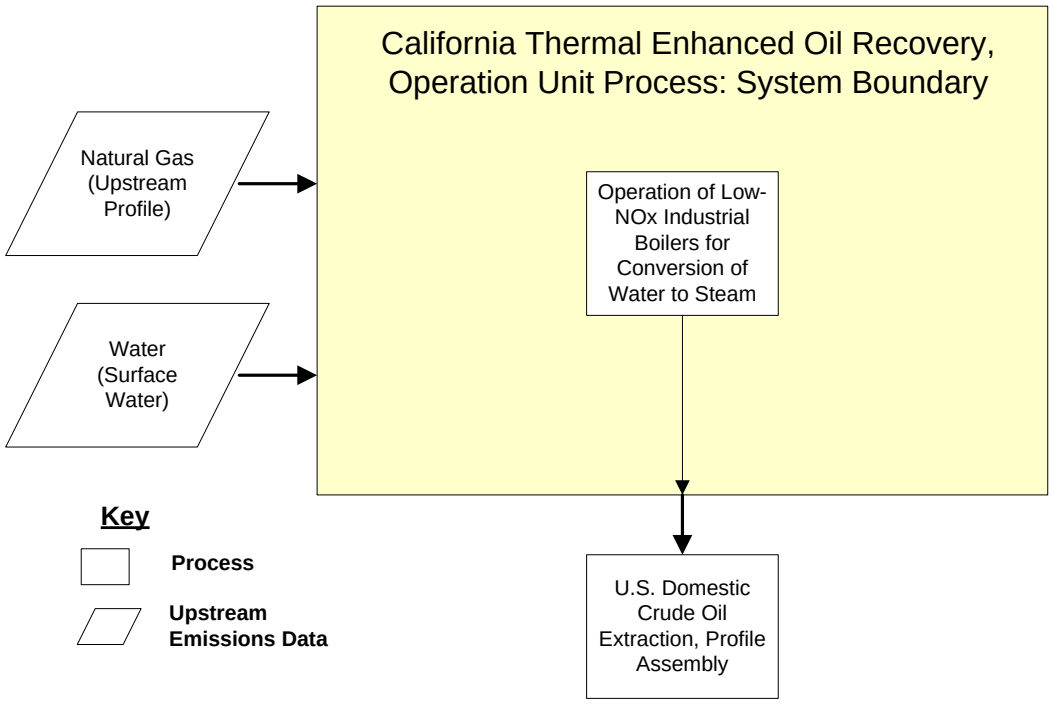
Boundary and Description

Figure 1 provides an overview of the boundary of this unit process. Emissions related to the physical construction and transport of the boilers are not included in this study, and are assumed to be negligible. Upstream emissions from the extraction of natural gas are calculated outside the boundary of this unit process, based on proprietary profiles available within the GaBi model. As shown in Figure 1 and discussed above, this unit process is incorporated into the U.S. Domestic crude oil extraction assembly process for LC Stage #1.

This unit process describes the emissions during extraction of California heavy crude oil using thermal enhanced oil recovery (TEOR) methods of steam injection, otherwise known as “steam flooding” and “cyclic steam”. The inputs and outputs to this process are calculated in terms of 1 kg of U.S. Domestic crude oil, allowing for simple 1-to-1 addition of these emissions to those of the U.S. Domestic crude oil material extraction profile from P.E. America. The P.E. America profile represents a typical crude oil extraction process in the United States.

Heavy oil is very viscous, requiring steam injection (thermal recovery) to overcome its resistance to flow. Production of steam and operation of related surface and subsurface equipment can increase costs of an operation by nearly 4 times (Sarathi and Olsen, 1992), thus it was assumed that an inventory of emissions from these processes might have a significant effect on U.S. Domestic crude oil extraction inventories. Specifically, water and fuel inputs (diesel oil or natural gas) required by steam generation are not present in conventional oil recovery processes. Because the GaBi profile covers all conventional drilling processes for crude oil extraction, this TEOR unit process is tied to the proportion of U.S. Domestic heavy crude originating in California.

Figure 1: Unit Process Inputs, Outputs, and Boundaries



A total of 12.185 percent of 2005 domestic crude production was extracted in California (EIA 2009). Of this quantity, 51 percent is characterized as heavy (average API of 18 degrees or less) (CDC, 2006a). These portions suggest that the California TEOR emissions should be added to 6.21 percent of the domestic crude oil profile.

Crude oil production per barrel of injected steam varies widely. **Figure 2** shows the ratio of heavy oil production to steam injection rates for California between the years of 1991 and 2005.

Figure 2: California Heavy Oil Production Rates and Steam Injection Rates to Produce Heavy Oil (1991-2005) (CDC 2006b)

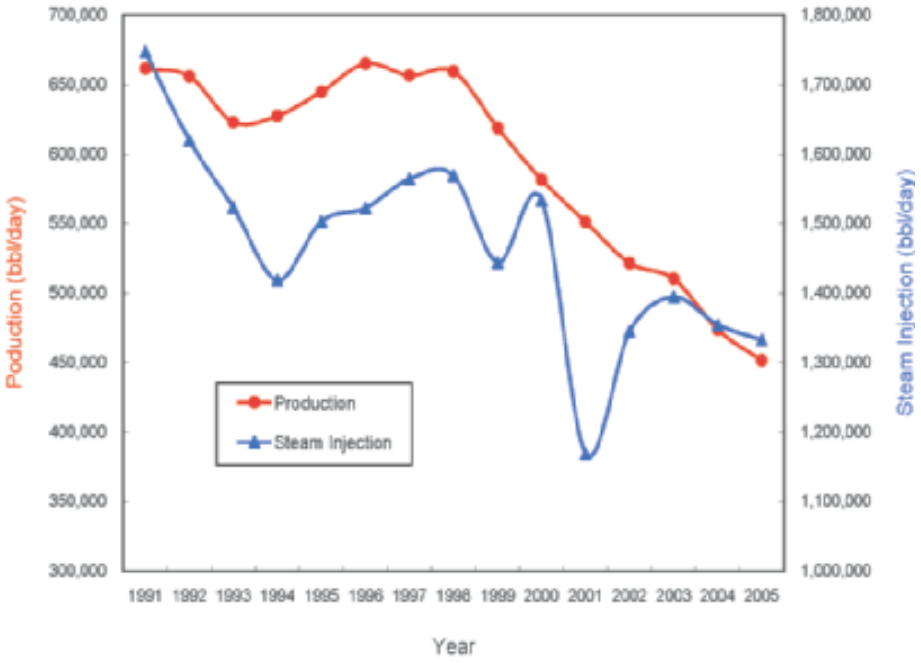


Table 1 shows data used to calculate the energy and water consumption of the process. **Table 2** provides a summary of modeled input and output flows. Additional detail regarding input and output flows, including calculation methods, is contained in the associated DS.

Table 1: Data Used in Calculation of TEOC Energy and Water Use

Description	Value	Reference
Total U.S. domestic crude oil production, 2005 m^3/day (bbl/day)	823236 (5178000)	EIA 2009
California crude oil production, 2005 m^3/day (bbl/day)	100311 (630940)	EIA 2009
Percent of California crude that is heavy oil	51%	CDC 2006a
2005 CA Injection Volume (water) for Cyclic Steam Injection m^3 (bbl)	17907200 (112632896)	CDC 2006b
2005 CA Injection Volume (water) for Steam flood m^3 (bbl)	59406128 (373653294)	CDC 2006b
2005 CA Injection Volume (water) for Water flood m^3 (bbl)	183201896 (1152305224)	CDC 2006b
2005 CA Water Disposal from EOC Processes m^3 (bbl)	73020903 (459287652)	CDC 2006b

Table 2: Unit Process Input and Output Flows

Flow Name*	Value	Units (Per Reference Flow)
Inputs		
Natural gas USA [Natural gas (resource)]	**0.01287436**	**kg**
Water (surface water) [Water]	0.195369414	kg
Outputs		
U.S. Domestic crude oil, 2005	1	kg
water	0.186248995	kg
Carbon dioxide [Inorganic emissions to air]	0.02649386	kg
Carbon monoxide [Inorganic emissions to air]	1.85457E-05	kg
Methane [Organic emissions to air (group VOC)]	5.07799E-07	kg
Nitrous oxide (laughing gas) [Inorganic emissions to air]	1.41301E-07	kg
Lead (+II) [Heavy metals to air]	1.10391E-10	kg
VOC [emissions to air]	1.2143E-06	kg
Nitrogen Oxides [Inorganic emissions to air]	3.09095E-05	kg
Sulphur dioxide [Inorganic emissions to air]	1.32469E-07	kg
Particulate Matter, unspecified [Other emissions to air]	1.67794E-06	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

CDC 2006a — California Department of Conservation. 2006. *Monthly Production and Injection Databases.* California Department of Conservation, Division of Oil, Gas & Geothermal Resources. Sacramento, CA. http://www.conservation.ca.gov/DOG/prod_injection_db/index.htm (Accessed October 1, 2006).

CDC 2006b — California Department of Conservation. 2006. *2005 Annual Report of the State Oil & Gas Supervisor.* California Department of Conservation, Department of Oil, Gas, and Geothermal Resources. Sacramento, CA. ftp://ftp.consrv.ca.gov/pub/oil/annual_reports/2005/PR06_Annual_2005.pdf (Accessed December 18, 2009).

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Section III: Document Control Information

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