NETL Life Cycle Inventory Data
Process Documentation File

Process Name: Crude oil extraction

Reference Flow: 1 kg of extracted crude oil

Brief Description: An assembly of processes used to extract and separate the combination of oil, water, and gas.

Section I: Meta Data

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

Year Data Best Represents: N/A

Process Type: Extraction Process (EP)

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:

API	*[deg API] API of the crude oil being produced. Heavy Venezuelan crude has an API of just over 10, and Bakken crude can be around 42.*
Production_vol	*[bbl/day] Production volume. For all wells in the field. U.S. productivity per well is lower than the world average*

EUR	*[bbl] Total lifetime production of crude oil. The default value is from OPGEE.*
WOR	*[bbl water/bbl oil] Water cut, the ratio of water to oil. A relationship with field age was developed for OPGEE (1.706*EXP(0.036*Field_age)-1.706), which might be low for U.S. fields. The default value is the average of U.S. onshore and offshore from 2007.*
GOR_UI	*[scf/bbl] Ratio of gas to oil; user specified value; otherwise enter 0 for API relationship*
TDS	*[mg/L] Total dissolved solids in the produced water*
bbl_per_well	*[bbl/well-d] The OPGEE default value is for non-US producers (183 bbl/well-d), which have a higher productivity. The default value here is for global production (82 bbl/well-d)*
Num_wells	*[well-d] Number of production wells.*
N2	*Adjustable parameter - mole fraction of nitrogen in associated gas stream*
CO2	*Adjustable parameter - mole fraction of carbon dioxide in associated natural gas stream*
C1	*Adjustable parameter - mole fraction of methane in associated natural gas stream*
C2	*Adjustable parameter - mole fraction of ethane in associated natural gas stream*
C3	*Adjustable parameter - mole fraction of propane in associated natural gas stream*
C4_plus	*Adjustable parameter - mole fraction of butane and higher hydrocarbons in associated natural gas stream*
H2S	*Adjustable parameter - mole fraction of hydrogen sulfide in associated natural gas stream*

AGR	*[boolean] Input 1 if acid gas removal is part of the operations, 0 if it is not*
Dehydrator	*[boolean] Input 1 if gas dehydration is part of the operations, 0 if it is not*
Flare_factor	*[MMscf/bbl] Volume of gas flared per bbl produced. Expected and Min are based on U.S. Continental, Max is for North Dakota*
Venting_ratio	*[scf/bbl] Ratio of venting to oil production*
Dehy_CO2_vfact	*[g/MMscf] Emission factor for venting carbon dioxide from the dehydrator piece*
Dehy_CH4_vfact	*[g/MMscf] Emission factor for venting methane from the dehydrator piece*
AGR_CO2_vfact	*[g/kg] Emission factor for venting carbon dioxide from the acid gas removal per kg of associated gas withdrawn*
Compressor_CO2	*[scf/bbl] Emissions of carbon dioxide from compressor startups and blowdowns*
Compressor_CH4	*[scf/bbl] Emissions of methane from compressor startups and blowdowns*
Gathering_CO2	*[scf/bbl] Emissions of carbon dioxide from gathering pipeline venting and fugitives*
Gathering_CH4	*[scf/bbl] Emissions of methane from gathering pipeline venting and fugitives*
Active_CO2_fact	*[g/piece-year] Emission factor of fugitive carbon dioxide from active wells, calculated using the API*
Active_CH4_fact	*[g/piece-year] Emission factor of fugitive methane from active wells, calculated using the API*
Cellar_CH4_fact	*[g/piece-year] Emission factor of fugitive methane from well cellars, calculated using the API*

Dehy_CO2_fugi	*[scf/day] Fugitive emissions of carbon dioxide from the dehydrator unit*
Dehy_CH4_ffact	*[g/MMscf] Emission factor for fugitive methane from the dehydrator unit*
AGR_CH4_ffact	*[g/MMscf] Emission factor for fugitive methane from the acid gas recovery unit*
Separator_units	*[pieces] Number of associated separator units*
Sep_CO2_ffact	*[g/piece-year] Emission factor of fugitive carbon dioxide from separator units*
Sep_CH4_ffact	*[g/piece-year] Emission factor of fugitive methane from separator units*
Cleanups	*[Events/year] Number of well cleanups*
Clean_CO2_fact	*[g/event] Venting emissions of carbon dioxide from each cleanup event*
Clean_CH4_fact	*[g/event] Venting emissions of methane from each cleanup event*
Gas_lift_ratio	*[scf/bbl liquid] Volume of gas used to lift one bbl of liquid*
Gas_flood_type	*[Integer] Type of gas used for flood operations. 1 = Natural Gas, 2 = Nitrogen.*
Gas_flood_ratio	*[scf/scf-bbl] Ratio of gas used for flooding to the gas-oil ratio when natural gas is used to flood*
N_gas_flood	*[scf/bbl liquid] Volume of nitrogen used for gas flood operations. Based on Maya field in Mexico.*
SOR	*[bbl steam/bbl oil] Steam-to-oil ratio (SOR) when steam flooding is used. Steam is reported as the volume of liquid water. The SOR of some California fields can be as high as 168, but most are below 10 [Reference 2, p 3-23].*
Water_ratio	*[dimensionless] Ratio of water injected to the WOR. Less than 1, some water is*

	released. Greater than 1, water must be imported.
GRI_fraction	*[dimensionless] Fraction of clean gas that is reinjected. If gas flooding is used then the value should be 1.*
CO2F_ratio	*[bbl/tonne] Volume of crude oil produced per metric tonne of carbon dioxide injected*
DHP	*[boolean] A value of 1 indicates the use of a downhole pump*
WRI	*[boolean] A value of 1 indicates the use of water injection*
GRI	*[boolean] A value of 1 indicates the use of gas injection*
GL	*[boolean] A value of 1 indicates the use of gas lift*
GF	*[boolean] A value of 1 indicates the use of gas flood*
SF	*[boolean] A value of 1 indicates the use of steam thermal recovery*
CO2F	*[boolean] A value of 1 indicates the use of carbon dioxide EOR*
Heater_treater	*[boolean] Select 1 if a heater-treater is being used. Can also be used as a fraction for groups of operations.*
Stabilizer	*[boolean] Select 1 if a stabilizer is being used. Can also be used as a fraction for groups of operations.*
Entrained_H2O	*[dimensionless] Volume fraction of entrained water in oil*

Tracked Input Flows:

lifting, downhole pump [Valuable substances]	*[Technosphere] Use of a downhole pump for artificial lift in petroleum production*
Water injected for petroleum extraction [Valuable substances]	*[Technosphere] Use of water reinjection and flooding in petroleum production*

Gas injected for petroleum extraction [Valuable substances]	*[Technosphere] Reinjection of associated gas in petroleum production*
lifting, gas lift of raw petroleum [Valuable substances]	*[Technosphere] Use of gas lift for artificial lift in petroleum production*
Gas injected for petroleum gas flood operations [Valuable substances]	*[Technosphere] Use of gas flooding to maintain reservoir pressure in petroleum production*
Steam injected for thermal petroleum extraction [Valuable substances]	*[Technosphere] Use of steam flooding for enhanced petroleum production*
Carbon dioxide used for EOR operations [Inorganic intermediate products]	*[Technosphere] Use of carbon dioxide injection for enhanced petroleum production*
Natural gas for petroleum gas inject or flood [Intermediate products]	*[Technosphere] Natural gas for injection or lift*
Water for petroleum water inject or flood [Intermediate products]	*[Technosphere] Water for water or steam flooding*
Nitrogen gaseous [Inorganic intermediate products]	*[Technosphere] Nitrogen for flooding*
Production or injection well, drilled	*[Technosphere] Production wells used for oil extraction*
dehydrating, crude oil heater treater [Valuable substances]	*[Technosphere] Heater treater unit for processing crude oil with entrained water*
degassing, crude oil stabilizer column [Valuable substances]	*[Technosphere] Stabilizer column for processing crude oil*
Cleanup venting [Intermediate products]	*[Intermediate Product] Release of associated gas from cleanups*
Workover venting [Intermediate products]	*[Intermediate Product] Release of associated gas from workovers*
Flaring associated gas [Intermediate products]	*[Intermediate Product] Flaring of associated gas from petroleum extraction*
Vented associated gas [Intermediate products]	*[Intermediate Product] Venting of associated gas from petroleum extraction*
Compressor emissions [Intermediate products]	*[Intermediate Product] Emissions of associated gas from compressors*
Active well and cellar emissions [Intermediate products]	*[Intermediate Product] Emissions of associated gas from active wells and well cellars*
Gathering pipeline emissions [Intermediate products]	*[Intermediate Product] Emissions of associated gas from gathering pipelines*
Separator emissions [Intermediate products]	*[Intermediate Product] Emissions of associated gas from separator*

Dehydrator emissions [Intermediate products]	*[Intermediate Product] Emissions of associated gas from dehydrator*
AGR emissions [Intermediate products]	*[Intermediate Product] Emissions of associated gas from AGR*
Associated gas processed in AGR [Valuable substances]	*[Intermediate Product] Mass of associated gas processed by AGR*

Tracked Output Flows:

Crude oil from separator [Valuable substances]	*Reference flow*
Associated gas from separator [Valuable substances]	*Produced gas per kg oil/water/gas mixture produced*
Water, from separator [Water]	*Produced water per kg oil/water/gas mixture produced*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage1_O_Crude_oil_extraction_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 the extraction of oil, water, and gas from a wellhead using a number of different methods. The flow of materials is then sent to a separator. This process includes fugitive emissions associated with operations that take place before and during separation. The default parameter values are not representative of any specific region or geology and should be modified to represent more specific circumstances. The reference flow of this unit process is: 1 kg of extracted crude oil.

Boundary and Description

The extraction of crude oil from a reservoir is a complex process that can take many different forms depending on the reservoir geology, age, and condition. A combination of crude oil, water, and associated gas is extracted from the reservoir through one or more wells. This raw petroleum mixture is separated, and some fraction of the water and/or associated gas is then usually injected back into the reservoir to help maintain its pressure.

This unit process (UP) is part of a petroleum model based on the Oil Production Greenhouse Gas Emissions Estimator (OPGEE) v1.1 DRAFT A (El-Houjeiri *et al.* 2013). The parameters included allow it to represent a wide range of petroleum extraction technologies and reservoir geologies. Energy use for lifting the raw petroleum mixture (crude oil, water, and associated gas) or injecting fluids into the reservoir to maintain pressure is calculated in other processes, such as:

- Downhole pump
- Gas lift
- Water reinjection
- Water flooding
- Gas reinjection
- Gas flooding
- Steam flooding
- Carbon dioxide (CO_2) injection

This UP serves to call those processes when necessary and scales the amount that is used (i.e. the amount of water injected into the reservoir). While the value for some processes is determined by the technology mix and basic geologic factors such as crude API and well depth, in other cases it is more complex than can be calculated within this UP. Because of this, parameters such as the amount of gas used for gas flood operations are considered independent from the volume of raw petroleum mixture extracted, and they must be known in advance by the user.

Artificial lift

The first two processes in the list above (downhole pump and gas lift) both serve to provide artificial lift. This is necessary when the pressure of the reservoir is no longer enough to lift the raw petroleum mixture to the surface at the desired wellhead pressure (El-Houjeiri *et al.* 2013). Both processes are only called for fraction of mass they are responsible for lifting. If the UP is being used to model a single field or well, the two processes should either be off (value of 0) or one of them should be on (value of 1). If the UP is representing a larger number of fields then some fraction may be used to represent the portion of wells that use one or the other lift technologies.

Other field operations

The other processes in the list above are associated with secondary or tertiary production and serve to maintain/increase the pressure of the reservoir or otherwise stimulate additional oil production. Each process refers to the physical amount of the fluid (gas or liquid) that will be injected into the reservoir.

Venting, fugitive, and flaring emissions

To allow the user more insight into the source of venting, fugitive, and flaring (VFF) emissions, the associated environmental flows are included in other processes. Those processes are included as inputs to this UP for better compatibility with life cycle software even though they are used to model environmental outputs.

In a departure from the methodology used in OPGEE, the total amounts of venting and fugitive emissions are calculated using methane emission factors and the composition of associated gas. The mass of associated gas per kg of raw petroleum mixture extracted is calculated:

$$m_i = \frac{CH_{4i} \times D_{CH_4}}{x_{CH_4} \times 16.04} \times \frac{M_{assoc}}{m_{mix}} \left[\frac{kg\ associated\ gas}{kg\ petroleum\ mix}\right]$$

Where m_i = kg of associated gas from source i per kg of raw petroleum mixture; CH_{4i} = volume of methane emissions from source i [scf/day]; D_{CH_4} = density of methane [g/scf]; x_{CH_4} = mole fraction of methane in the associated gas; M_{assoc} = molar mass of associated gas [kg/mol]; m_{mix} = total mass of raw petroleum mixture extracted [kg/day]; and 16.04 is the molar mass of methane.

Petroleum phase separation

The fluid flow extracted from a petroleum well includes a mixture of crude oil, water, and associated gas, which are separated into individual streams as soon as possible. While many different technologies are available for separating the different phases, this unit process assumes that the initial bulk separation is performed with some type of three-phase separator that does not require an energy input. If, however, it is necessary to remove entrained water or light, gaseous hydrocarbons from the crude oil stream, this process links to heater-treater and stabilizer processes. A water treatment process is also included as an input in order to treat the produced water stream, which can then be used for water reinjection or steam flooding.

The mass in each stream exiting the separator is dependent on the history and geology of the reservoir and well. Mass fractions in the unit process are calculated based on the water-to-oil ratio (WOR), gas-to-oil ratio (GOR), the specific gravity of the oil and water fractions (determined using API and the dissolved solids content of the produced water), and the molecular make-up of the associated gas.

Fugitive carbon dioxide and methane emissions from the separator units are calculated using factors developed in El-Houjeiri et al. Emission factors are given in terms of grams per separator per year. The number of separators for a given volume of production is a parameter than can be changed, but the unit process includes a "smart" default formula that estimates an appropriate number.

Figure 1: Unit Process Scope and Boundary

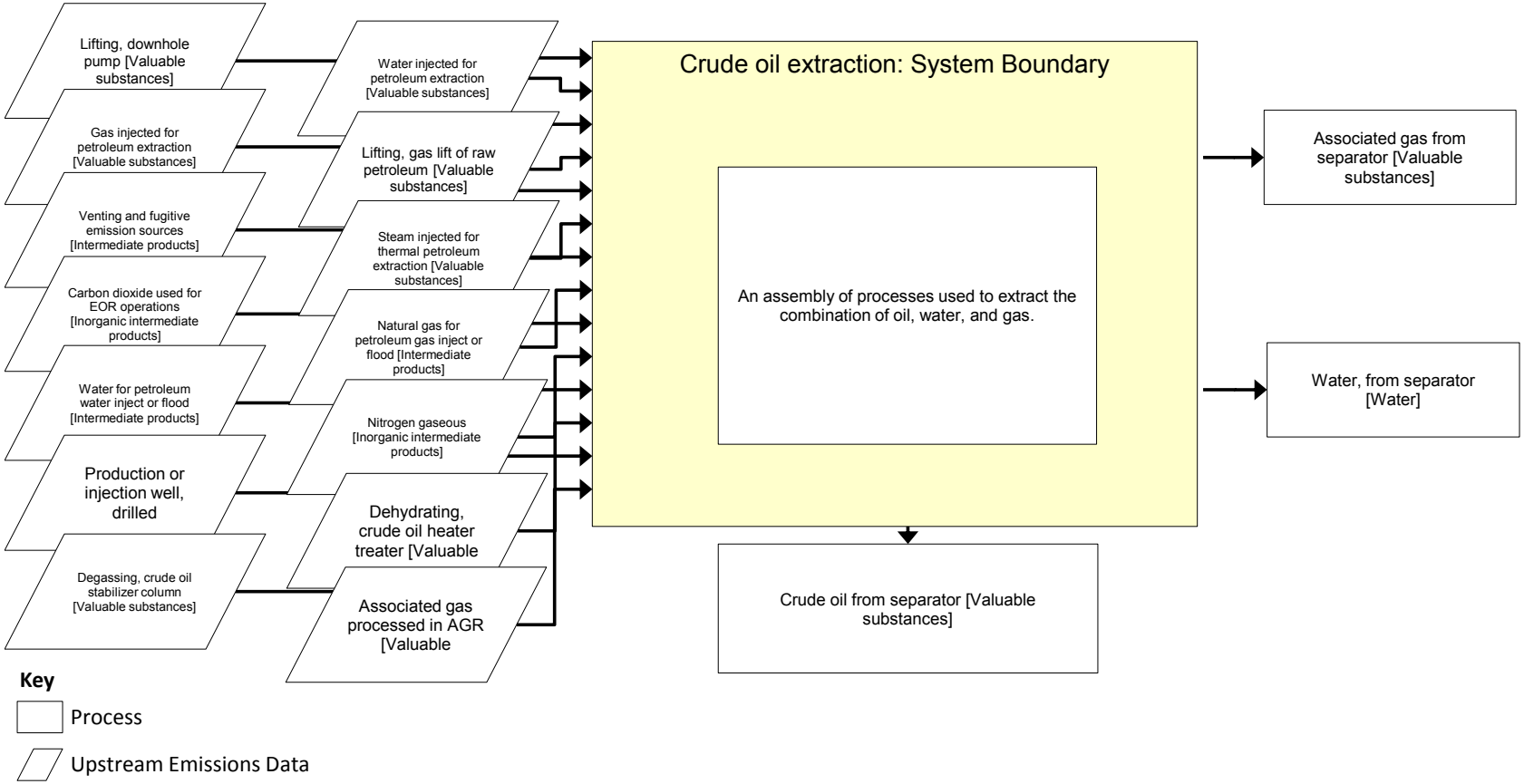

Table 1: Unit Process Input and Output Flows

Flow Name	Value	Units (Per Reference Flow)
Inputs		
lifting, downhole pump [Valuable substances]	7.07E+00	kg
Water injected for petroleum extraction [Valuable substances]	6.07E+00	kg
Gas injected for petroleum extraction [Valuable substances]	5.87E+00	scf
lifting, gas lift of raw petroleum [Valuable substances]	0.00E+00	kg
Gas injected for petroleum gas flood operations [Valuable substances]	0.00E+00	scf
Steam injected for thermal petroleum extraction [Valuable substances]	3.42E+00	kg
Carbon dioxide used for EOR operations [Inorganic intermediate products]	0.00E+00	kg
Natural gas for petroleum gas inject or flood [Intermediate products]	5.87E+00	scf
Water for petroleum water inject or flood [Intermediate products]	3.42E+00	kg
Nitrogen gaseous [Inorganic intermediate products]	0.00E+00	scf
Production or injection well, drilled	5.52E-08	pieces
dehydrating, crude oil heater treater [Valuable substances]	0.00E+00	pieces
degassing, crude oil stabilizer column [Valuable substances]	0.00E+00	pieces
Cleanup venting [Intermediate products]	1.40E-05	kg
Workover venting [Intermediate products]	4.36E-05	kg
Flaring associated gas [Intermediate products]	2.70E-03	kg
Vented associated gas [Intermediate products]	0.00E+00	kg
Compressor emissions [Intermediate products]	3.23E-05	kg
Active well and cellar emissions [Intermediate products]	9.65E-05	kg
Gathering pipeline emissions [Intermediate products]	2.90E-05	kg
Separator emissions [Intermediate products]	5.85E-06	kg
Dehydrator emissions [Intermediate products]	1.43E-04	kg
AGR emissions [Intermediate products]	1.81E-04	kg
Associated gas processed in AGR [Valuable substances]	1.36E-01	kg
Outputs		
Crude oil from separator [Valuable substances]	1.00	kg
Associated gas from separator [Valuable substances]	1.36E-01	kg
Water, from separator [Water]	6.07E+00	kg
Methane [Organic emissions to air (group VOC)]	6.69E-06	kg
Ethane [Group NMVOC to air]	3.89E-07	kg
Propane [Group NMVOC to air]	7.87E-07	kg
iso-Butane [Group NMVOC to air]	2.57E-07	kg
Butane (n-butane) [Group NMVOC to air]	4.11E-07	kg

Flow Name	Value	Units (Per Reference Flow)
Pentane (n-pentane) [Group NMVOC to air]	1.19E-07	kg
Iso-Pentane [Group NMVOC to air]	1.40E-07	kg
Hexane (isomers) [Group NMVOC to air]	8.27E-08	kg
Heptane (isomers) [Group NMVOC to air]	4.74E-08	kg
Octane [Group NMVOC to air]	2.03E-08	kg
Nonane [Group NMVOC to air]	4.89E-09	kg
Benzene [Organic intermediate products]	6.77E-09	kg
Toluene (methyl benzene) [Group NMVOC to air]	6.02E-09	kg
Ethyl benzene [Group NMVOC to air]	3.76E-10	kg
Xylenes (isomers; dimethyl benzene) [Organic emissions to agricultural soil]	1.50E-09	kg

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

Embedded Unit Processes

None.

References

El-Houjeiri *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.

Jacobs 2009 — Jacobs (2009). Life cycle assessment comparison of North American and imported crudes: Alberta Energy Research Institute.

NETL 2009 — NETL. (2009). Produced Water Volumes and Management Practices in the Unites States. Prepared by C.E. Clark and J.A. Veil, Argonne National Laboratory Retrieved July 8, 2013, from http://www.netl.doe.gov/technologies/coalpower/ewr/water/pdfs/anl%20produced%20water%20volumes%20sep09.pdf

API 1998 — API (1998). Publication 4683. Correlation Equations to Predict Reid Vapor Pressure and Properties of Gaseous Emissions for Exploration and Production Facilities

NIST 2011 — NIST. (2011). "Thermophysical Properties of Fluid Systems." Retrieved November 18, 2013, from http://webbook.nist.gov/chemistry/fluid/.

Section III: Document Control Information

Date Created: March 20, 2014

Point of Contact: Timothy Skone (NETL), Timothy.Skone@NETL.DOE.GOV

Revision History:

Original/no revisions

How to Cite This Document: This document should be cited as:

NETL (2013). NETL Life Cycle Inventory Data – Unit Process: Crude oil extraction. U.S. Department of Energy, National Energy Technology Laboratory. Last Updated: July 2013 (version 01). www.netl.doe.gov/LCA (http://www.netl.doe.gov/LCA)

Section IV: Disclaimer

Neither the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) nor any person acting on behalf of these organizations:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this document, or that the use of any information, apparatus, method, or process disclosed in this document may not infringe on privately owned rights; or

B. Assumes any liability with this report as to its use, or damages resulting from the use of any information, apparatus, method, or process disclosed in this document.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by NETL. The views and opinions of the authors expressed herein do not necessarily state or reflect those of NETL.