United States
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Agency

Detailed Study of the Petroleum Refining Category – 2019 Report

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1. INTRODUCTION

This report summarizes information collected and analyzed by the United States Environmental Protection Agency (EPA) as part of a detailed study of the petroleum refining industry. The EPA conducted this study to review discharges from petroleum refineries and to determine whether the current wastewater discharge regulations for these operations should be revised.

The EPA promulgated effluent limitations guidelines and standards (ELGs) for the Petroleum Refining Point Source Category in 1974. The ELGs were challenged in the U.S. Court of Appeals; as a result of the litigation, the EPA made revisions and finalized the ELGs on October 18, 1982. In 1985, EPA revised the Best Available Technology Economically Achievable (BAT) effluent limitations for total chromium, hexavalent chromium, and phenolic compounds (phenols) to reflect additional flow reduction basis and lower attainable concentrations. The EPA also incorporated BAT, Best Practicable Control Technology Currently Available (BPT), and Best Conventional Pollutant Control Technology (BCT) effluent limitations for contaminated runoff, per a 1984 settlement agreement.[1] The regulation applies to discharges from any facility that processes raw petroleum crude into gasoline, fuel oil, jet fuel, heating oils and gases, petrochemicals, and other products. Petroleum refineries are categorized under North American Industry Classification System (NAICS) code 32411 and Standard Industrial Classification code 2911, Petroleum Refineries. Section 2 of this report provides further information on the current ELG. Currently, only biochemical oxygen demand (BOD_5), total suspended solids (TSS), chemical oxygen demand (COD), oil and grease, phenolic compounds, ammonia, sulfide, and chromium are included in the regulation.

The EPA conducted a review of the petroleum refining industry from 1992 to 1996 to determine whether revisions to the ELGs were warranted. For this evaluation, the EPA reviewed data from the Toxics Release Inventory (TRI) and Discharge Monitoring Reports (DMR) included in EPA's Permit Compliance System (PCS). In addition, the EPA collected sampling data during visits to six refineries. The Agency published the results of this review in the *Preliminary Data Summary for the Petroleum Refining Category,* April, 1996. The study provides a general description of the industry, treatment technologies used, water usage, analysis of dioxins in catalytic reformer wastewater, estimates of pollutant discharges, environmental issues, and an economic profile (EPA, 1996). The EPA again reviewed the industry in 2004, using data from the TRI and DMR reporting databases (EPA, 2004). Neither study resulted in recommendations for revisions to the ELGs.

In the *2011 Annual Effluent Guidelines Review Report*, the EPA selected the Petroleum Refining Point Source Category (40 CFR Part 419) for a preliminary category review because it ranked high in toxic-weighted pound equivalents (TWPE) (EPA, 2012a). At that time, the EPA found that the TWPE were largely due to TRI-reported discharges of dioxin and dioxin-like compounds, polycyclic aromatic compounds (PACs), and DMR-reported discharges of sulfides, chlorine, and metals. The EPA reviewed this category during the 2012 Annual Review to verify facilities' discharges and confirmed the results of the 2011 Annual Review. The EPA also reviewed new air pollution control (APC) regulations to identify whether the regulations could result in new wastewater streams.

[1] The 1984 settlement agreement was the result of a petition filed by the Natural Resources Defense Council (NRDC).

The EPA conducted a detailed study of this industry beginning in 2014 to determine if changes to the existing ELGs are needed.

- Changes to the industry may have resulted in new wastewater streams or wastewater characteristics.
- An increase in the number of refineries reporting metals discharges, but only one metal (chromium) is included in the current Petroleum Refining ELG.

The following sections of this report provide an overview of the petroleum refining industry and a summary of the analyses conducted by the EPA as part of the detailed study.

- Section 2 provides an overview of current regulations affecting the petroleum refining industry (air, water, and solid waste).
- Section 3 summarizes the data sources used in this study.
- Section 4 summarizes the industry profile, including details on the petroleum refining population and background on refinery operations and air pollution control devices in place.
- Sections 5.1 through 5.4 summarize the analyses conducted by the EPA as part of the detailed study.

1.1 References

1. EPA. 1996. U.S. Environmental Protection Agency. *Preliminary Data Summary for the Petroleum Refining Category*. Available online at: https://www.epa.gov/sites/production/files/2015-10/documents/petro-refining-elg-study_1996.pdf (April) EPA 821-R-96-015. DCN PR00158.

2. EPA. 2004. U.S. Environmental Protection Agency. Notice of Availability of 2004 Effluent Guidelines Program Plan. Available online at: https://www.federalregister.gov/documents/2004/09/02/04-20040/notice-of-availability-of-2004-effluent-guidelines-program-plan. (2 September) EPA-HQ-OW-2003-0074-1209.

3. EPA. 2012a. U.S. Environmental Protection Agency. *The 2011 Annual Effluent Guidelines Review Report*. Available online at: https://www.regulations.gov/document?D=EPA-HQ-OW-2010-0824-0195. EPA-HQ-OW-2010-0824-0195.

2. PETROLEUM REFINING REGULATION HISTORY

This section summarizes the history of the petroleum refining regulation.

2.1 Effluent Limitation Guidelines

In 1974, the EPA promulgated standards for Best Practicable Control Technology Currently Available (BPT), Best Available Technology Economically Achievable (BAT), New Source Performance Standards (NSPS), Pretreatment Standards for Existing Sources (PSES), and Pretreatment Standards for New Sources (PSNS) for the petroleum refining point source category (40 CFR Part 419). BAT was remanded after legal challenge in 1976, and the EPA continued to study industry treatment practices used in 1976. In 1982, the EPA re-promulgated BAT, setting it equal to BPT (i.e., the 1974 level of control). In 1985, the EPA revised BAT for phenol and chromium, based on additional flow reduction and lower attainable concentrations for these two pollutants. At that time, the EPA also set BCT limits for the industry for biochemical oxygen demand (BOD_5), total suspended solids (TSS), oil and grease, and pH.

BPT limitations are based on both in-plant and end-of-pipe technologies. See Section 4.2 for information on petroleum refining processes.

In-plant technologies

- Sour water strippers to reduce sulfide and ammonia entering treatment plant.
- Elimination of once-through barometric condenser water by using surface condensers or recycle systems with oil water cooling towers.
- Segregation of sewers so that unpolluted storm water and once-through cooling water are not treated with process and other polluted water.
- Elimination of polluted once-through cooling water by monitoring and repairing surface condensers or by use of wet and dry recycle streams.

End-of-pipe technologies

- Equalization and storm water diversion.
- Oil and solids removal (API separator or baffle plate separator).
- Carbonaceous waste removal using biological treatment (activated sludge, aerated lagoons, oxidation ponds, trickling filters, or combination).
- Effluent polishing following biological treatment (polishing ponds or sand, dual-media, or multimedia filter).

The ELGs for petroleum refining consist of five subcategories addressing different levels of processing complexity. Table 2-1 presents applicability details for each subcategory.

Table 2-1. 40 CFR Part 419 Subcategories and Applicability

ELG Subpart	Subpart Name	Applicability
Part 419.10, Subpart A	Topping	Any facility that produces petroleum products by the use of topping and catalytic reforming, whether or not the facility includes any other process in addition to topping and catalytic reforming. However, this subpart does not apply to facilities that include thermal processes (coking, thermal cracking (visbreaking), etc.) or catalytic cracking. Topping refineries separate crude oil by atmospheric and/or vacuum distillation, solvent de-asphalting, and catalytic reforming. Guidelines for the topping subcategory include allowances for ballast water. Ballast is defined as the flow of waters, from a ship, that is treated along with refinery wastewaters in the main treatment system.
Part 419.20, Subpart B	Cracking	Any facility that produces petroleum products by the use of topping and cracking, whether or not the facility includes any process in addition to topping or cracking. However, the provisions of this subpart are not applicable to facilities that include the processes specified in subpart C, D, or E.
Part 419.30, Subpart C	Petrochemical	Any facility that produces petroleum products by the use of topping, cracking, and petrochemical operations whether or not the facility includes any process in addition to topping, cracking, and petrochemical operations. However, the provisions of this subpart are not applicable to facilities that include the processes specified in subpart D or E. Petrochemical operations meet one of two definitions. • Production of second-generation petrochemicals (e.g., alcohols, ketones, cumene and styrene), or • Production of first-generation petrochemicals and isomerization products (e.g., benzene, toluene, xylenes, olefins, and cyclohexane) when 15 percent or more of the total refinery production is as first-generation petrochemicals and isomerization products.
Part 419.40, Subpart D	Lube	Any facility that produces petroleum products by the use of topping, cracking, and lube oil manufacturing processes, whether or not the facility includes any process in addition to topping, cracking, and lube oil manufacturing processes. However, the provisions of this subpart are not applicable to facilities that include the processes specified in subpart C or E.
Part 419.50, Subpart E	Integrated	Any facility that produces petroleum products by the use of topping, cracking, lube oil manufacturing processes, and petrochemical operations, whether or not the facility includes any process in addition to topping, cracking, lube oil manufacturing processes, and petrochemical operations.

Source: 40 CFR Part 419.

Currently, under BPT and BAT, the EPA has established production-based mass limitations for the pollutants included in the ELG. Table 2-3 below presents these limits on a mass-production basis (pounds of pollutant per 1,000 barrels (bbl) of feedstock). The ELG currently regulates BOD_5, TSS, COD, oil and grease, phenolic compounds, ammonia, sulfide, and only one metal (chromium). The regulation outlines stricter NSPS effluent limitations for all pollutants. BCT limits for BOD_5, TSS, oil and grease, and pH are set equal to BPT limits.

Also, each subcategory includes PSES and PSNS for indirect discharges to publicly owned treatment works. For Subparts A, B, C, D, and E, the PSES and PSNS limits are 100 mg/L for both oil and grease and ammonia (as N). The PSNS also include a limit of 1 mg/L for total chromium.

The regulation provides tables of refinery size (based on barrels of feedstock processed per day) and process configuration factors that are used to scale pollutant discharge limits. The regulations establish process configuration factors based on the units present at the refinery. Limits for each parameter must be established by multiplying the limits shown in Table 2-3 by both the size factor and process configuration factor.[2] BAT limitations for phenols, chromium, and hexavalent chromium are calculated by multiplying an effluent limitation factor specific to each process type by the size and process configuration factors.

Process configuration factors are calculated from the unit capacity and the weighting factor established in the regulations. The EPA assigned the following weighting factors by process type.

- Crude processes: 1.
- Cracking and coking processes: 6.
- Lube processes: 13.
- Asphalt processes: 12.

For each process, the capacity relative to total throughput must be calculated and multiplied by the weighting factor for the process group. The Subcategory D regulations show a detailed calculation for a lube plant. Table 2-2 shows an example calculation for crude units. The process configuration factor of 2.48 would be added to the process configuration factors for all other processes at the lube plant. The size factor specified in the regulation for a 125,000 bbl/stream day refinery is 0.97.

Table 2-2. Example Calculation for Crude Units for a 125,000 bbl/Stream Day Refinery

Unit	Capacity	Capacity Relative to Total Throughput	Weighting Factor	Process Configuration Factor
Atmospheric Distillation	125,000	1.0		
Vacuum Distillation	60,000	0.48		
Desalting	125,000	1.0		
Total for Crude		**2.48**	**1**	**2.48**

[2] See 40 CFR Part 419 for size and process configuration factors.

Table 2-3. 40 CFR Part 419 Effluent Limitations in lb per 1,000 bbl of Feedstock

Pollutant or Pollutant Property	Effluent Limit Type	Subpart A[1,2]		Subpart B[2,3]		Subpart C[2,3]		Subpart D[2,3]		Subpart E[2,3]	
		Daily Maximum[4]	30-Day Average[5]	Daily Maximum[4]	30-Day Average[5]	Daily Maximum[4]	30-Day Average[5]	Daily Maximum[4]	30-Day Average[5]	Daily Maximum[4]	30-Day Average[5]
BOD_5	BPT	8.0	4.25	9.9	5.5	12.1	6.5	17.9	9.1	19.2	10.2
	BAT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	BCT	8.0	4.25	9.9	5.5	12.1	6.5	17.9	9.1	19.2	10.2
	NSPS	4.2[6]	2.2[6]	5.8	3.1	7.7	4.1	12.2	6.5	14.7	7.8
TSS	BPT	5.6	3.6	6.9	4.4	8.3	5.25	12.5	8.0	13.2	8.4
	BAT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	BCT	5.6	3.6	6.9	4.4	8.3	5.25	12.5	8.0	13.2	8.4
	NSPS	3.0[6]	1.9[6]	4.0	2.5	5.2	3.3	8.3	5.3	9.9	6.3
COD	BPT	41.2	21.3	74.0	38.4	74.0	38.4	127.0	66.0	136.0	70.0
	BAT	41.2	21.3	74.0	38.4	74.0	38.4	127.0	66.0	136.0	70.0
	BCT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	NSPS	21.7[6]	11.2[6]	41.5	21	47.0	24.0	87.0	45.0	104.0	54.0
Oil and Grease	BPT	2.5	1.3	3.0	1.6	3.9	2.1	5.7	3.0	6.0	3.2
	BAT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	BCT	2.5	1.3	3.0	1.6	3.9	2.1	5.7	3.0	6.0	3.2
	NSPS	1.3[6]	0.70[6]	1.7	0.93	2.4	1.3	3.8	2.0	4.5	2.4
Phenolic Compounds	BPT	0.060	0.027	0.074	0.036	0.088	0.0425	0.133	0.065	0.14	0.068
	BAT	[7]	[7]	[7]	[7]	[7]	[7]	[7]	[7]	[7]	[7]
	BCT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	NSPS	0.031[6]	0.016[6]	0.042	0.020	0.056	0.027	0.088	0.043	0.105	0.051
Ammonia as N	BPT	0.99	0.45	6.6	3.0	8.25	3.8	8.3	3.8	8.3	3.8
	BAT	0.99	0.45	6.6	3.0	8.25	3.8	8.3	3.8	8.3	3.8
	BCT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	NSPS	1.0[6]	0.45[6]	6.6	3.0	8.3	3.8	8.3	3.8	8.3	3.8
Sulfide	BPT	0.053	0.024	0.065	0.029	0.078	0.035	0.118	0.053	0.124	0.056
	BAT	0.053	0.024	0.065	0.029	0.078	0.035	0.118	0.053	0.124	0.056
	BCT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	NSPS	0.027[6]	0.012[6]	0.037	0.017	0.050	0.022	0.078	0.035	0.093	0.042

Table 2-3. 40 CFR Part 419 Effluent Limitations in lb per 1,000 bbl of Feedstock

Pollutant or Pollutant Property	Effluent Limit Type	Subpart A[1,2]		Subpart B[2,3]		Subpart C[2,3]		Subpart D[2,3]		Subpart E[2,3]	
		Daily Maximum[4]	30-Day Average[5]	Daily Maximum[4]	30-Day Average[5]	Daily Maximum[4]	30-Day Average[5]	Daily Maximum[4]	30-Day Average[5]	Daily Maximum[4]	30-Day Average[5]
Total Chromium	BPT	0.122	0.071	0.15	0.088	0.183	0.107	0.273	0.160	0.29	0.17
	BAT	[7]	[7]	[7]	[7]	[7]	[7]	[7]	[7]	[7]	[7]
	BCT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	NSPS	0.064[6]	0.037[6]	0.084	0.049	0.116	0.068	0.180	0.105	0.220	0.13
Hexavalent chromium	BPT	0.01	0.0044	0.012	0.0056	0.016	0.0072	0.024	0.011	0.025	0.011
	BAT	[7]	[7]	[7]	[7]	[7]	[7]	[7]	[7]	[7]	[7]
	BCT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	NSPS	0.0052[6]	0.0025[6]	0.0072	0.0032	0.0096	0.0044	0.022	0.0072	0.019	0.0084
pH[8]	BPT	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0
	BAT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	BCT	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0
	NSPS	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0

Source: 40 CFR Part 419.

[1] Subpart A also includes BPT, BAT and BCT limits for ballast and contaminated runoff water and NSPS limits for ballast water. See 40 CFR Part 419 Subpart A for details.

[2] BPT, BAT, BCT, and NSPS size and process configuration factors, based on facility refining operations, apply. See the comprehensive example in 40 CFR 419.42(b)(3) and the comprehensive example in 40 CFR 419.43(c)(2).

[3] Subpart also contains BPT, BAT, and BCT limits for contaminated runoff water. See 40 CFR Part 419 for details. The ballast water limits from Subpart A also apply.

[4] Daily maximum values are for any reported day.

[5] 30-day average values are for any 30 consecutive reported days.

[6] Units are per 1,000 gallons of flow, not 1,000 bbl of feedstock.

[7] BAT effluent limitation for phenols, total chromium, and hexavalent chromium vary by process type. BAT effluent limitations for these pollutants are calculated by multiplying the limitation factor by the size factor and the process configuration factor. See 40 CFR 419 for the BAT limitation factors for each subpart.

[8] pH limit expressed in units of pH (quantity is dimensionless).

3. DATA SOURCES

This section describes the data sources evaluated by the EPA as part of the petroleum refinery detailed study. The EPA gathered information from publicly available data sources (discussed in Sections 3.1) and collected primary data (discussed in Section 3.2).

3.1 Existing Data Sources

Table 3-1 lists all data sources that the EPA consulted as part of the detailed study. Included in the table is a description of each data source and information on how each is being used for the detailed study.

Table 3-1. Existing Data Sources for Petroleum Refining Detailed Study

Data Source	Description	Use in Detailed Study
Energy Information Administration (EIA) (EIA, 2013; 2014; 2015; 2016; 2017; and 2018)	EIA tracks the number of operating refineries annually. All active refineries are required to complete Form EIA-820 – Annual Refinery Report. Information collected includes capacity, refinery unit processes, capacity for atmospheric crude oil distillation units and downstream units, country of origin of crude oil imports, and production capacity for crude oil and petroleum products. The EPA reviewed the EIA Refinery Utilization and Capacity Reports (2013 through 2018), which present data from EIA Form 820.	Used to establish population of U.S. petroleum refineries and develop industry profile.
National Pollutant Discharge Elimination System (NPDES) Permits (ERG, 2019a)	The EPA obtained copies of NPDES permits and/or permit applications for individual refineries from the following 16 states: AL, AR, CA, CO, DE, IL, IN, KY, LA, MS, NJ, OH, OK, PA, TX, WA. Information contained in permits and permit applications includes refining unit processes, on-site wastewater treatment processes, outfall descriptions, and destinations of wastewater discharges from the refinery (ERG, 2019a).	Used to confirm population of U.S. petroleum refineries and confirm wastewater treatment in-place, discharge locations, and unit operations data.
Discharge Monitoring Report (DMR) Pollutant Loading Tool (ERG, 2019b)	The EPA downloaded Integrated Compliance Information System National Pollutant Discharge Elimination System (ICIS-NPDES) data for 2007 through 2017 from the online Water Pollutant Loading Tool. The data include pollutant discharge information (i.e., concentration and quantity) and discharge flow rate data for refineries operating in the U.S. Refineries are only required to report data for the parameters identified in their NPDES permit.	Used to establish population of U.S. petroleum refineries, evaluate wastewater characteristics, estimate industry loadings, and identify pollutants with permit limitations or monitoring requirements.
1982 *Development Document for Effluent Limitations Guidelines and Standards for the Petroleum Refining Point Source Category* (1982 TDD) (EPA, 1982)	This document outlines the technology options considered and rationale for selecting the technology levels on which the current ELG pollutant limitations are based. The 1982 TDD includes flow rate data and concentration data for toxic, non-conventional, and conventional pollutants from the petroleum refining industry that were collected as part of the 1982 rulemaking.	Used to conduct a preliminary evaluation of wastewater characteristics.
Office of Air and Radiation (OAR) Petroleum Refining Sector Information Collection Request (EPA, 2012b)	The EPA reviewed the publicly available data collected as part of the 2011 survey of refineries conducted by OAR. The 2011 information collection request gathered information on processing characteristics, air emissions, and wastewater generation.	Used to identify process unit operations, wastewater treatment, and air pollution controls at petroleum refineries.
Industrial Wastewater Treatment Technologies (IWTT) Database (EPA, 2018)	The EPA's IWTT database contains information on treatment technology advances identified through the EPA's Annual Reviews. As part of its screening of industrial wastewater discharges, the EPA reviews literature regarding the performance of new and improved industrial wastewater treatment technologies and inputs the data into its IWTT database.	Reviewed data in the IWTT database to identify any new technologies or changes to technologies used at petroleum refineries to treat wastestreams.

Table 3-1. Existing Data Sources for Petroleum Refining Detailed Study

Data Source	Description	Use in Detailed Study
Department of Energy (DOE) Energy and Environmental Profile of the U.S. Petroleum Refining Industry (DOE, 2007)	This November 2007 document describes the petroleum refining industry and refining processes. The document provides an overview of the following refining processes, including their energy requirements, air emissions, effluents, and wastes/by-products: atmospheric and vacuum distillation, cracking and coking, catalytic reforming, alkylation, hydrotreatment, additives and blending components, lubricating oil manufacturing, and other supporting processes (sulfur management, chemical treatment, water treatment, process heating).	Provides background information on the U.S. refining industry, refining processes, and wastewater treatment. Used to identify process unit operations, wastewater treatment, and air pollution controls at petroleum refineries.
Emerging Technologies and Approaches to Minimize Discharges into Lake Michigan (Purdue-Argonne, 2012a)	Report published by Purdue University Calumet Water Institute and Argonne National Laboratory detailing emerging technologies and approaches for minimizing wastewater discharges from a petroleum refinery.	Used to identify any new technologies or management approaches for handling refinery wastewater.

3.2 Primary Data Collection

The EPA collected additional data from the petroleum refining industry through primary data collection activities.

- Site visits to specific refineries of interest (Section 3.2.1).
- Data request to a subset of the industry (Section 3.2.2).
- Industry-submitted data (Section 3.2.3).

3.2.1 Site Visits

The EPA conducted phone calls and site visits with personnel at petroleum refineries to gather information on refinery unit operations, wastewater generated by refineries, and the methods for managing wastewater to allow for recycle, reuse, or discharge. The EPA used information from available data sources to identify refineries for site visits.

In support of the detailed study, the Agency visited 10 petroleum refineries in four states between April, 2015, and September, 2017. Table 3-2 presents the refineries visited, the visit dates, and the document control numbers (DCNs) of any supporting documentation. During site visits, the EPA toured refinery unit operations of interest and wastewater treatment systems.

Table 3-2. Petroleum Refinery Site Visits

Refinery Name	Location	Site Visit Date	Reference(s)
PBF Energy Paulsboro Refinery	Paulsboro, NJ	April 29, 2015	PR00047
Valero Benicia Refinery	Benicia, CA	April 11, 2017	PR00084; PR00085
Phillips 66 San Francisco Refinery	Rodeo, CA	April 10, 2017	PR00125
Chevron Richmond Refinery	Richmond, CA	April 12, 2017	PR00083
Tesoro Martinez Refinery [a]	Martinez, CA	April 13, 2017	PR00082
Shell Martinez Refinery	Martinez, CA	April 14, 2017	PR00086
Marathon Michigan Refinery	Detroit, MI	July 11, 2017	PR00102; PR00123
Shell Convent Refinery	Convent, LA	September 19, 2017	PR00095
Phillips 66 Alliance Refinery	Belle Chasse, LA	September 20, 2017	PR00096
Valero Meraux Refinery	Meraux, LA	September 21, 2017	PR00097; PR00098

a – This refinery is currently operated by Marathon Petroleum Corp.

3.2.2 2017 Data Request

In July 2017, the EPA administered the *Data Request for the Petroleum Refining Industry Detailed Study* (data request) (EPA, 2017) to nine companies (comprising 22 refineries) subject to the Petroleum Refining ELGs to collect information on water use, crude processed, production rates, unit operations, wastewater characteristics, pollution prevention, and wastewater management, treatment, and discharge for calendar year 2016. The memorandum titled *Selecting Recipients for the Petroleum Refining Detailed Study Data Request* (ERG, 2018) describes the EPA's procedure for selecting refineries for the data request.

Twenty-one refineries responded to the data request. EPA excused ExxonMobil's Baytown Refinery from participation due to severe hurricane damage to the facility just after distribution of the request.

See the memorandum *Petroleum Refining Industry Data Request Responses* for the data request responses of the 21 refineries (ERG, 2019c).

3.2.3 Industry-submitted Data

The EPA obtained information on petroleum refinery operations, wastewater discharges, and wastewater characterization from correspondence with trade associations (American Petroleum Institute (API) and American Fuel & Petrochemical Manufacturers (AFPM)), and from submissions received directly from refineries, as shown in Table 3-3. The table includes a description of each data source and how the data are being used for the detailed study.

Table 3-3. Industry-Submitted Data Evaluated for Detailed Study

Data Source	Description	Use in Detailed Study
Refinery Process Water and Wastewater Sampling Data (CBI, 2017)	On December 7, 2017, one refining company provided the EPA with operational and analytical data related to petroleum refinery process water and wastewater streams. The dataset includes analytical and operational data for refineries in the company's fleet collected between October 2015 and July 2016. These data are claimed as confidential business information (CBI).	Used to conduct a preliminary evaluation of wastewater characteristics.
API List of Refineries and Discharge Status (API, 2019)	On March 6, 2019, API provided the EPA with a list of 148 petroleum refineries operating in the U.S., including the parent company, location, discharge status, receiving water, and NPDES permit numbers for each refinery.	Used to augment the list of petroleum refineries in the U.S. and industry profile.

3.3 References

1. API. 2019. American Petroleum Institute and American Fuel and Petroleum Manufacturing. *2019* API List of Refineries and Discharge Status. (6 March) DCN PR00131.

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4. Industry Profile

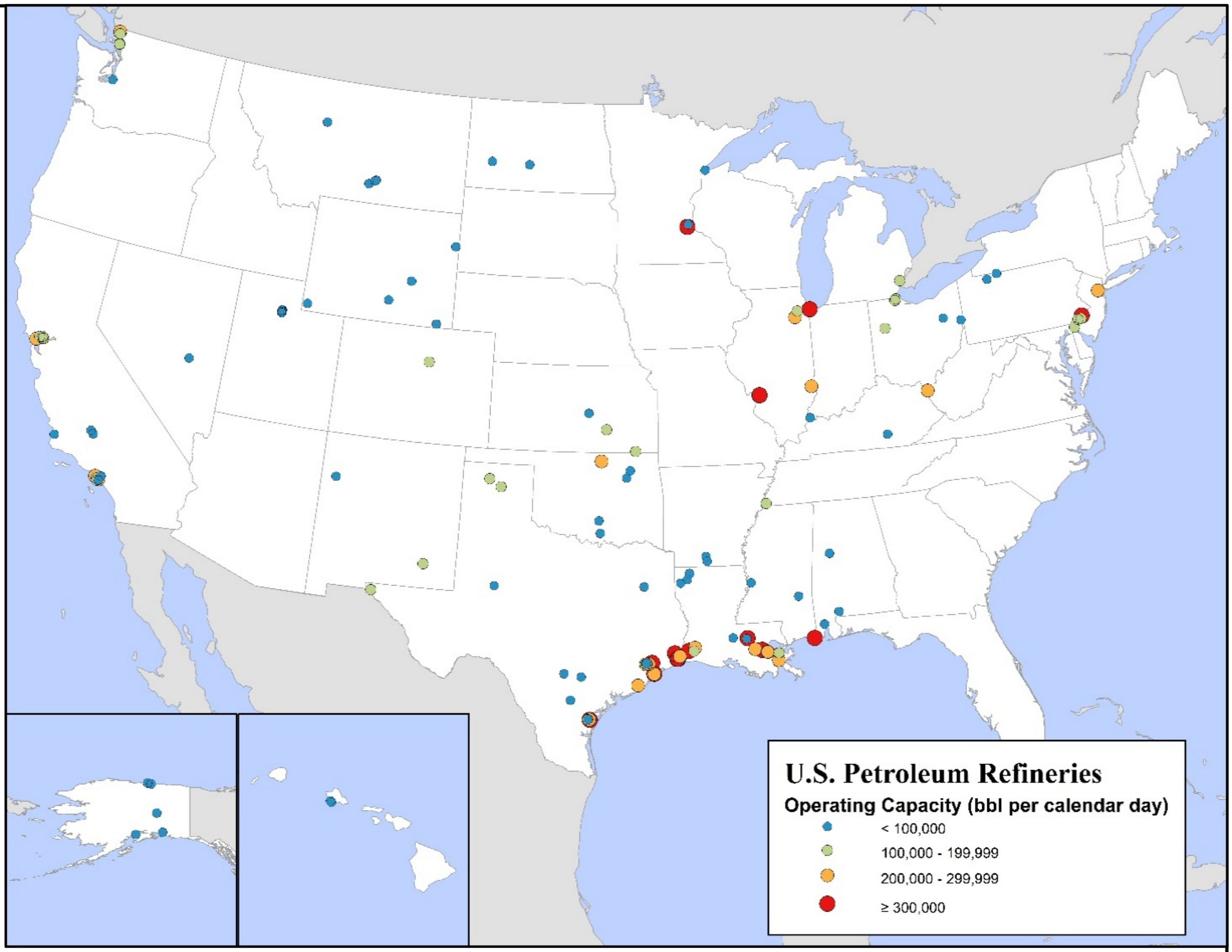
The EPA identified the population of petroleum refineries operating in the U.S. and developed an industry profile to characterize these refineries. The EPA used data from sources described in Section 3 to compile general refinery information (e.g., name, company, location, identification numbers, subcategory) and details such as refinery-specific unit operations, crude and production information, air pollution controls, wastewater treatment systems, and discharge status for each refinery identified in the population. An overview of the petroleum refining industry is provided in Section 4.1 and a description of general process operations within the industry, including air pollution control (APC) and wastewater treatment (WWT) technologies, is provided in Section 4.2.

4.1 Number of Refineries and Location

The EPA identified petroleum refineries operating in the U.S. based on refineries listed in the Energy Information Administration (EIA) Refinery Capacity Report for calendar year 2013 (EIA, 2013). Over the course of the detailed study, the EPA continued to augment the profile as updated information was collected (e.g., additional details on production, discharge type, or updates on closed or reopened refineries) from the following data source.

- EIA Refinery Capacity Report for calendar years 2013 through 2018 (EIA, 2013; 2014; 2015; 2016; 2017; and 2018).
- Publicly available wastewater discharge permits and permit applications.
- Office of Air and Radiation (OAR) Petroleum Refining Sector Information Collection Request.
- Refinery calls and site visits.
- Refinery responses to the 2017 data request.
- API List of Refineries and Discharge Status (API, 2019).

The EPA identified 143 petroleum refineries operating in the U.S. as of January 1, 2019. See Appendix A for the complete list. Figure 4-1 includes a geographic distribution of all U.S. petroleum refineries reported in the 2018 EIA Annual Refinery Report by operating capacity. More than half of the U.S. refineries have operating capacities of less than 100,000 barrels per calendar day. As illustrated in the figure, petroleum refineries are concentrated along the Gulf of Mexico (mainly in Texas and Louisiana) and California. Table 4-1 summarizes the count of refineries in each state.



Operating Capacity (barrels per calendar day)	Number of EIA Refineries Included in the Category	Total Refinery Atmospheric Crude Distillation Capacity (barrels per calendar day)
<100,000	67	3,050,000
100,000-199,999	31	4,680,000
200,000-299,999	20	4,880,000
≥300,000	14	5,960,000
Total	**132[a]**	**18,600,000**

Note: Capacity values are rounded to three significant figures.
a - The EPA's profile references individual refineries by NPDES ID, in some cases these refineries may be listed as two separate refineries in EIA (e.g., an East and West) or some refineries may not have reported production for 2018 or have closed since the population was developed in 2015.

Figure 4-1. Map of United States Petroleum Refineries

Table 4-1. U.S. Refineries by State

State	Number of Refineries
TX	29
CA	20
LA	18
WY	6
WA	5
UT	5
AK	5
OK	5
MT	4
IL	4
MS	4
OH	4
PA	4
KS	3
NJ	3
AL	3
AR	2
HI	2
MN	2
KY	2
NM	2
ND	2
IN	2
TN	1
WI	1
MI	1
DE	1
CO	1
WV	1
NV	1
Total	**143**

The current Petroleum Refining ELGs establish effluent limitations for direct and indirect discharges from refineries and defines five process subcategories of varying complexity. Table 4-2 and Table 4-3 present the distribution of U.S. refineries based on type of discharge and subcategory, respectively.

Table 4-2. U.S. Refineries by Discharge Status

Discharge Status	Number of Refineries
Direct	90
Indirect	30
Direct & Indirect	9
Zero Discharge	2
Unknown	12
Total	**143**

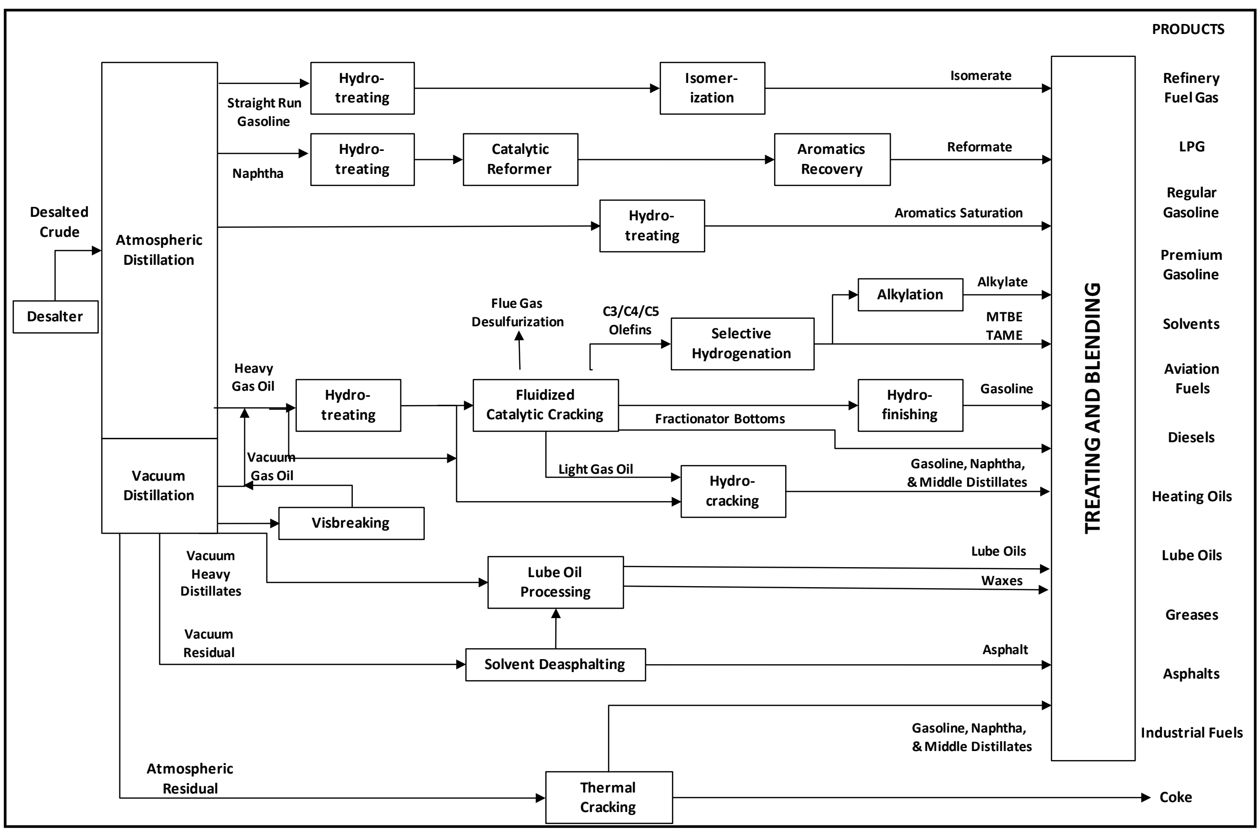
Table 4-3. U.S. Refineries by Subcategory

Topping (Part 419.10, Subpart A)	5
Cracking (Part 419.20, Subpart B)	46
Petrochemical (Part 419.30, Subpart C)	5
Lube (Part 419.40, Subpart D)	4
Integrated (Part 419.50, Subpart E)	6
Unknown	77
Total	**143**

Note: Four refineries were identified as subject to two ELG subcategories, Topping (Subpart A) and Cracking (Subpart B), based on the 2019 detailed study data. In this table, each of these four refineries is counted once, under Cracking (Subpart B).

4.2 General Refinery Operations

Figure 4-2 shows a general refinery process flow diagram. Refineries differ in the number and type of processing units. The physical separation and chemical reaction processes at each refinery depend on the type of raw crude processed and the desired final products.



Source: DOE, 2007.
MTBE: Methyl tertiary butyl ether.
TAME: Tertiary amyl methyl ether.

Figure 4-2. Petroleum Refinery Process Diagram

As discussed in Section 2, the current refinery ELGs define subcategories based on the types of units at the refinery. Table 4-4 shows the general process categories at refineries, the processes included in the category, and a description of the category. All refineries perform distillation operations; however, the extent and variety of processes used to convert distilled fractions into petroleum products varies by refinery.

Table 4-4. Petroleum Refining Process Categories

Process Category	Processes	Description
Topping (separating crude oil)	• Desalting. • Atmospheric distillation. • Vacuum distillation.	Separates crude oil into hydrocarbon groups.
Thermal and Catalytic Cracking	• Thermal Operations. — Delayed coking. — Fluid coking/flexicoking. — Visbreaking. • Catalytic cracking. • Catalytic hydrocracking.	Breaks large, heavy hydrocarbons from topping process into smaller hydrocarbons.
Combining/Rearranging Hydrocarbons	• Alkylation. • Polymerization. • Catalytic reforming. • Isomerization.	Processes hydrocarbons to form desired end products.
Removing Impurities	• Catalytic hydrotreating.	Removes impurities such as sulfur, nitrogen, and metals from products or waste gas streams.
Specialty Products Blending and Manufacturing	• Lube oil. • Asphalt.	Blends product streams into final products or final processing into specialty products.

Source: DOE, 2007.

4.2.1 Refining Unit Operations

Table 4-5 summarizes the typical process operations found at most petroleum refineries and provides the products, wastes, and wastestreams generated.

Table 4-5. Petroleum Refining Processes, Products, Byproducts, and Wastewater Streams

Unit Operation/Processes	Function	Products	Byproducts and Wastes	Wastewater[a]
Crude Desalter	Removes salt from raw crude.	• Desalted crude.	• Desalter sludge.	• High salt wastewater. • Desalter sludge.
Atmospheric Distillation	Separates lighter petroleum fractions.	• Straight-run liquids (gasoline, naphtha, kerosene, gas oil, heavy crude residue). • Products further processed or blended.	• Refinery gas – Light non-condensable fuel gas consisting of methane, ethane, hydrogen sulfide, and ammonia. Refinery gas can be treated and used as fuel in process heaters.	• Oily sour water.
Vacuum Distillation	Separates the heavier portion (bottoms from atmospheric distillation).	• Vacuum gas oil (top of column), heavy pitch (bottom of column), intermediate oil products.	• Refinery gas.	• Oily sour water.
Catalytic Cracking Unit (CCU) (includes fluidized catalytic cracking)	Breaks large hydrocarbons into lighter components using a catalyst.	• Gasoline, fuel oils, light gases.	• Spent catalysts.	• Sour water. • Steam from catalyst regeneration.
Catalytic Hydrocracking	Breaks large hydrocarbons into lighter components using a catalyst and hydrogen.	• Blending stocks for gasoline and other fuels (fuel gas, naphtha, diesel, kerosene, gas oils).	• Spent catalysts. • Sour gas.	• Sour water
Delayed Coking Unit (DCU) (thermal cracking)	Converts low value oils to higher value gasoline and gas oils. Typical feedstock is residual fuel oil from the vacuum distillation column.	• Gasoline, gas oils, fuel gas. • Petroleum coke.	• Coke dust.	• Quench water. • Water from decoking.
Visbreaking (thermal cracking)				• Sour water.
Alkylation	Combines small hydrocarbons to form a gasoline blending stock.	• Alkylate product (for blending). • Propane. • Butane.	• Spent acid. • Neutralization sludge (generated from neutralizing acids).	• Product wash water. • Steam stripper wastewater.
Catalytic Reforming Unit (CRU)	Increase octane rating of products from atmospheric distillation and produces aromatics.	• High octane gasoline. • Aromatics. • Light gases. • Hydrogen.	• Spent catalyst.	• Process wastewater from dehydrogenation of naphthas.
Isomerization	Rearranges molecules to increase octane.	• Isomerization products (converts paraffins to isoparaffins).	• Spent catalysts.	• Sour water from fractionators.

Table 4-5. Petroleum Refining Processes, Products, Byproducts, and Wastewater Streams

Unit Operation/Processes	Function	Products	Byproducts and Wastes	Wastewater[a]
Polymerization	Converts propane and butane to higher octane products.	• Higher octane products.	• Spent acid.	• Feed wash water. • Sour water from fractionators.
Hydrotreating	Removes impurities.	• Products vary by feed and catalysts.	• Light fuel gas. • Hydrogen sulfide. • Ammonia.	• Sour water from fractionators and separators.
Lube and Asphalt Processes	Converts heavy distillates and residuals from vacuum distillation to usable products.	• Lube oils. • Waxes. • Asphalt.	• Spent solvent.	• Sour water from steam stripping. • Solvent recovery wastewater.

Sources: DOE, 2007; Gary and Handwerk, 1994.

[a] Sour water contains sulfides, ammonia, phenols, suspended solids, dissolved solids, and other organic chemical constituents of the crude oil.

4.2.2 Supporting Units

Supporting processes at refineries are used to recover byproducts of refinery production, such as the sulfur and nitrogen compounds removed from raw crude during processing. See Table 4-5 for a list of byproducts and wastes. Table 4-6 lists supporting operations that may be present at refineries, the purpose of the process, and notes whether a wastewater stream is generated. The number, type, and configuration of these units/processes will vary by refinery.

Table 4-6. Petroleum Refining Supporting Processes

Supporting Process	Function	Wastewater Generated?
Hydrogen Production	Produce hydrogen for hydrotreating and hydrocracking operations. Hydrogen can be produced from steam reforming of light products (methane, ethane, propane) or oxidation of heavy hydrocarbons by burning the fuel with oxygen.	Yes.
Amine Treating	Remove hydrogen sulfide and other sulfur compounds from off-gases and fuel gas.	Little to no wastewater generated.
Sour Water Strippers	Remove hydrogen sulfide, ammonia, phenols, and other contaminants from sour water.	Little to no wastewater generated. Treated stripped water is reused within the refinery if possible.
Sulfur Recovery	Recover elemental sulfur from the acid gases from amine units and sour water strippers.	Little to no wastewater generated.
Chemical Treatment	Remove sulfur, nitrogen, or oxygen compounds from final product streams.	Little to no wastewater generated.
Benzene Recovery Unit (BRU)	Remove benzene to meet air regulation requirements.	No.

Sources: DOE, 2007; Gary and Handwerk, 1994.

4.2.3 Air Pollution Control Technologies

Potential air pollutants produced by refineries include volatile organic compounds (VOCs), hazardous air pollutants (HAPs), sulfur oxides (SOx), carbon monoxide, nitrogen oxides (NOx), hydrogen sulfide (H_2S), odors, and particulate matter (PM). The Clean Air Act National Emission Standards for Hazardous Air Pollutants (NESHAPs) and NSPS, state that petroleum refineries must have APC technologies in place. Unit operations that commonly have APC technologies include CCUs, coking units, and CRUs. Common APC devices, the pollutants they control, and any wastewater they may produce are described in Table 4-7.

Table 4-7. Characteristics of Air Pollution Control Technologies

Air Pollution Control	Brief Description	Pollutants Controlled	Wastewater Typically Produced?
Carbon Adsorbers	The gas stream is passed through a cartridge of activated carbon, which attracts and adsorbs gases and vapors.	VOCs and HAPs.	No.
Condensers	In a condenser, gas is condensed to liquid through changes in temperature or pressure. Condensers may be used as preliminary air pollution control devices prior to other devices.	VOCs and HAPs.	Yes.
Electrostatic Precipitators (ESP)	The gas stream is passed through an electrical field, which creates an electrical charge on particles. Collecting plates attract the charged particles. The collecting plates are cleaned either through shaking or tapping the plate or by using water. When water is used, the system is called "wet ESP."	PM.	Wet ESP systems generate wastewater; dry ESP systems do not.
Fabric/Cartridge Filter (Baghouse)	Gas flows through fabric filters, which collect PM. The PM is periodically removed to prevent the filters from clogging.	PM.	No.
Flare	Flares are devices which combust flammable gases, converting the gases to carbon dioxide and water. The waste is evaporated as steam.	VOCs.	No.
Scrubbers	Scrubbers use reagents, slurries, or liquids to remove pollutants from the gas stream. • Dry scrubbers inject or spray reagents or slurries into the gas stream. Acid gases are absorbed by the reagent or slurry and are removed as solids. • Wet scrubbers remove pollutants by spraying or passing a liquid (typically water) into the gas stream. The gas and liquid are mixed, and pollutants absorb onto the liquid and drop out of the gas stream. • LoTOX scrubbers use ozone to react with mercury and NOx to produce water soluble forms of mercury and nitrogen.	PM, vapors, and gases such as SOx and H_2S, corrosive acidic or basic gas streams, solid particles, liquid droplets, soluble mercury.	Wet and LoTOX scrubbers generate wastewater; dry scrubbers do not.
Selective Catalytic Reduction (SCR)	To remove NOx, ammonia is injected into the gas stream which passes into the SCR. The ammonia and NOx react in the SCR to form nitrogen and water. The gas is passed through beds of solid catalytic material where the VOCs are oxidized or reduced.	NOx and VOCs.	SCR can have ammonia slip which could contaminate a scrubber stream. Water contaminated with ammonia is handled as sour water.
Selective Non-Catalytic Reduction (SNCR)	Ammonia is injected into high temperature (1,400 to 2,000° F) gas where it reacts with NOx and reduces them to nitrogen, carbon dioxide, and water.	NOx.	SNCR can have ammonia slip which could contaminate a scrubber stream. Water contaminated with ammonia is handled as sour water.

Table 4-7. Characteristics of Air Pollution Control Technologies

Air Pollution Control	Brief Description	Pollutants Controlled	Wastewater Typically Produced?
Tertiary Cyclone	Cyclones remove PM by whirling the gas stream rapidly inside of a cylinder. Centrifugal force is created, which causes the particles to move to the walls of the cylinder and drop out of the gas stream.	Large PM.	No.
Thermal or Catalytic Incinerator/Oxidizer	Incinerators/oxidizers combust liquid or gaseous wastes. Because these systems operate at very high temperatures (up to 2,000° F), they are expensive to operate and require large quantities of fuel. High-efficiency regenerative thermal oxidizers (regenerators) can recover heat, which reduces costs as compared to typical thermal oxidizers.	VOCs, gases, fumes, hazardous organics, odor, and PM.	No.
Vapor Balancing System	Reduces vapors lost during loading of liquid petroleum into transportation vehicles. As liquid petroleum is being unloaded from vehicles, this system transfers gasses from the top of the bulk tanks into the top of the vehicle.	Vapors.	No.
Water Seal	Water seals can be used in conjunction with other air pollution controls. Water seals are traps filled with water that create a water barrier between the pipe and the atmosphere.	VOCs, gases, hazardous organics, odor, and PM.	Yes.

Sources: A&WMA, 2007; EPA, 1995.

4.2.4 Wastewater Treatment Units

As described in Section 2.1, the technology basis for the current ELGs includes oil/water separation, solids separation, biological treatment, clarification, and polishing steps. These wastewater treatment steps are listed in Table 4-8.

Table 4-8. Wastewater Treatment Processes

Wastewater Treatment Step	General Description	Treatment Methods
Oil/Water Separation	Oil/water separation separates oil and solids from wastewater. Some refineries operate distinct primary and secondary oil/water separation steps. The oil streams removed during primary and secondary oil/water separation are typically reprocessed to recover additional product. Solids are handled separately.	• API separator. • Corrugated plate interceptors. • Parallel plate separators. • Dissolved air flotation (DAF). • Dissolved gas (typically nitrogen). flotation (DGF or DNF). • Induced air flotation (IAF).
Biological Treatment	Biological wastewater treatment systems use microorganisms to consume biodegradable soluble organic contaminants and bind the less soluble portions into flocculant, which is removed from the system.	• Suspended growth. • Attached growth. • Aerated surface impoundment. • Membrane bioreactor (MBR).

Table 4-8. Wastewater Treatment Processes

Wastewater Treatment Step	General Description	Treatment Methods
Filtration/ Adsorption/Polishing	If the refinery needs to meet an effluent limit, it may use a filtration or adsorption unit as the final step in treating wastewater. The specific type of unit often depends on the targeted pollutant and effluent limit.	• Media filtration (e.g., sand filters). • Adsorption (e.g., activated carbon). • Chemical oxidation.
Sludge Handling	Sludge is produced by the oil/water separation units, biological treatment, and some tertiary treatments.	• Aerobic digestion. • Anaerobic digestion. • Sludge dewatering.

4.3 References

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5. Study Analyses

As discussed in Section 1, the focus of the study was to determine if recent changes in the industry have resulted in new wastewater streams or wastewater characteristics, and to investigate the observed increase in the number of refineries reporting metals discharges. The EPA's study analyses included various analyses described in this section.

- Evaluating available data on untreated petroleum refining process wastewater, see Section 5.1.
- Estimating baseline loadings discharged by the petroleum refining industry, see Section 5.2.
- Evaluating available data on wastewater treatments (WWTs) used by the petroleum refining industry and comparing end-of-pipe WWT systems to the current Petroleum Refining ELG technology basis, see Section 5.3.
- Evaluating permits and Discharge Monitoring Report (DMR) data from current petroleum refineries to identify any trends within the industry, see Section 5.4.
- Reviewing information on new WWT technologies and on improvements to established technologies since the current Petroleum Refining ELG was issued, see Section 5.5.

5.1 Wastewater Influent Concentration Analysis

In developing the current Petroleum Refining ELGs, the EPA used effluent from primary oil water separation (OWS) units to characterize untreated petroleum refining process wastewater. For this study, the EPA applied the same approach. Using analytical data collected during the detailed study, the EPA estimated the average concentrations of metals, nutrients, and other pollutants of interest in OWS effluent and compared these concentrations to data available in the *Development Document for Effluent Limitations Guidelines and Standards for the Petroleum Refining Point Source Category* (1982 TDD) to determine if untreated process wastewater characteristics have changed since the previous rulemaking.

The EPA used 2013 DMR data and knowledge of the process to identify 26 pollutants likely to be present in petroleum refining wastewater, including metals, nutrients, organics, and other priority pollutants. Table 5-1 lists the pollutants identified by the EPA and the rationale for selecting each. This listing includes pollutants with high toxicity (high toxic weight factors (TWF)), pollutants identified in the existing Petroleum Refining ELGs or refinery NPDES permits, and pollutants that may be present in wet scrubber purge. The EPA also considered naphthenic acids and alkylated polycyclic aromatic hydrocarbons (PAHs) in the list of pollutants of interest, but the Agency determined that available data are insufficient to determine whether these classes of pollutants warrant further consideration. Hence, they are not included in Table 5-1.

Naphthenic acids are a complex group of cyclic carboxylic acids that are natural components of crude oil and bitumen (Misiti et al., 2012). Naphthenic acids are formed from the bio-oxidation of naphtha fractions in crude oils. Crude oil from older, heavier crude formations are likely to have higher naphthenic acid content (Misiti, 2012). Results from crude oil samples demonstrated that the naphthenic acid content in crude can range from 0.1 percent to 4.0 percent (weight/weight), depending on the source and type of the crude oil (Misiti, 2012; Misiti et al., 2012). Studies show that these pollutants may be transferred to refinery wastewater, mostly through desalting, when water contacts crude oil to remove salts and other contaminants. Studies have also shown that naphthenic acids may undergo some degradation or removal in biological treatment systems, especially those that involve physical/chemical treatment (Misiti et al., 2012; Syvret and Lordo, 2014).

PAHs comprise a group of over 100 different aromatic compounds that may be naturally occurring (e.g., maturation of crude oil and synthesis of certain plant and bacteria) or formed during incomplete combustion of natural and anthropogenic organic substances. Alkylated PAHs are characterized by the total number of alkyl carbon atoms present n the parent PAH compound. Studies have shown that this group of pollutants may be present in crude oil (Andersson and Achten, 2014; Li et al., 2017; Hawthorne et al., 2005). While these pollutants are among the most abundant and persistent toxic constituents in Canadian Oil Sands tailings pond water and water commingling with raw petroleum during the extraction of Canadian Oil Sands, very little information is known about the presence of these pollutants in refinery wastewater (Li et al., 2017).

The EPA will continue to evaluate naphthenic acids and alkylated PAHs in petroleum refining wastewater as data becomes available.

Table 5-1. Pollutants of Interest in Petroleum Refining Wastewater

Pollutant	Rationale
Metals	
Arsenic	Higher toxicity metal (TWF > 1). Reported by 17 refineries in 2013 DMR data. Present in purge from wet scrubbers at coal-fired power plants.
Cadmium	Higher toxicity metal (TWF > 1). Reported by 3 refineries in 2013 DMR data.
Chromium	Included in current ELG. Reported by 39 refineries in 2013 DMR data. Chromium and hexavalent chromium were included in the existing ELG due to their use as cooling water additives. This practice is no longer a concern, but it may be helpful to evaluate concentration and load to determine if the pollutant is still a concern in refinery operations and needs to remain in the ELG.
Copper	Reported by 23 refineries in 2013 DMR data.
Lead	Higher toxicity metal (TWF > 1). Reported by 13 refineries in 2013 DMR data.
Mercury	Higher toxicity metal (TWF > 1). Reported by 21 refineries in 2013 DMR data. Present in purge from wet scrubbers at coal-fired power plants.
Nickel	Reported by 16 refineries in 2013 DMR data.
Selenium	Higher toxicity metal (TWF > 1). Reported by 27 refineries in 2013 DMR data. Present in purge from wet scrubbers at coal-fired power plants.
Uranium-238	Naturally occurring pollutant in some underground areas. Crude extracted from these areas may contain higher concentrations of uranium also. Reported by 1 refinery in 2013 DMR data.
Zinc	Reported by 30 refineries in 2013 DMR data.
Organics	
BOD_5	Included in current ELG. Reported by 81 refineries in 2013 DMR data.
BTEX	Common contaminant of concern in oil spills and occurs in gasoline. Reported by 6 refineries in 2013 DMR data.
COD	Reported by 74 refineries in 2013 DMR data.
Oil & Grease	Included in current ELG. Reported by 75 refineries in 2013 DMR data.
PAH	PAHs are common contaminants of concern in oil spills and some PAHs are known carcinogens. Reported by 2 refineries in 2013 DMR data.
Phenol	Included in current ELG. Reported by 69 refineries in 2013 DMR data.
TOC	Reported by 47 refineries in 2013 DMR data.
Nutrients and Other Priority Pollutants	
Ammonia	Included in current ELG. Reported by 78 refineries in 2013 DMR data.
Cyanide	Reported by 18 refineries in 2013 DMR data.

Table 5-1. Pollutants of Interest in Petroleum Refining Wastewater

Pollutant	Rationale
Nitrate-Nitrite	Refinery production processes such as hydrotreatment are used to remove nitrogen from some petroleum fractions which may lead to transfer of these compounds to wastewater. Ammonia, included in current ELGs, could be oxidized to nitrate or nitrite in refinery processes and/or wastewater treatment. Reported by 4 refineries in 2013 DMR data.
Nitrogen, Total	Combination of ammonia, TKN, nitrate/nitrite, and other individual nitrogen parameters. May be reported by refineries instead of individual nitrogen pollutants.
Phosphorus	Reported by 14 refineries in 2013 DMR data.
TDS	Reported by 12 refineries in 2013 DMR data. Wet gas scrubber purge may contain high TDS.
TKN	Reported by 3 refineries in 2013 DMR data.
TSS	Included in current ELG. Reported by 81 refineries in 2013 DMR data.
Sulfide	Included in current ELG. Reported by 60 refineries in 2013 DMR data.

Acronyms: BTEX (benzene, toluene, ethylbenzene, xylene); COD (chemical oxygen demand); PAH (polycyclic aromatic hydrocarbons); TDS (total dissolved solids); TKN (total Kjeldahl nitrogen); TOC (total organic carbon); TSS (total suspended solids); TWF (toxic weight factor)

Using analytical data available in the 1982 TDD and data collected as part of the 2019 detailed study, the EPA calculated the average, minimum, and maximum concentrations for the 26 pollutants of interest in refinery end-of-pope WWT influent process wastewater.

For each data source, the EPA first reviewed all available information (e.g., refinery configuration diagrams, WWT system data) to identify primary OWS units. For data from the 1982 TDD, the EPA used all analytical data clearly identified as separator or dissolved air flotation (DAF) unit effluent in the analysis. Because WWT configuration details were not included in the TDD, where analytical data were reported for effluent from multiple OWS units at a refinery, all sample results were used (7 refineries). EPA identified 17 petroleum refineries with OWS effluent data in the 1982 TDD which includes short-term monitoring data for 15 petroleum refineries and long-term monitoring data for 2 petroleum refineries. The EPA identified primary OWS effluent data for 19 petroleum refineries collected for the 2019 detailed study.

To estimate average, minimum, and maximum pollutant concentrations for refinery end-of-pipe WWT influent, the EPA first calculated refinery-level average, minimum, and maximum concentrations for each pollutant using the following assumptions.

- Set all nondetect results to zero.[3]
- Set results reported below or above the reporting limit to the reporting limit (e.g., <1 µg/L was set to 1 µg/L and >100 µg/L was set to 100 µg/L).

The EPA then calculated an industry-level average, minimum, and maximum for each pollutant for the 2019 detailed study data and for the 1982 TDD.

Table 5-2 presents the average, minimum, and maximum pollutant concentrations in WWT system influent based on 1982 TDD data and data collected for the 2019 detailed study. The EPA compared the

[3] In this study, all nondetect results are treated as a concentration of zero for the purpose of estimating concentrations because information on detection limits is limited and varies by data source.

average concentrations for 16 pollutants for which analytical data are available from both datasets.[4] Of these 16 pollutants, six have higher average concentrations in the 1982 TDD data and ten have higher average concentrations in the 2019 detailed study data. The higher of the two average concentration values is shaded red while the lower concentration is shown in blue in Table 5-2. The EPA notes the following assumptions and limitations for this analysis.

- The concentrations reported in Table 5-2 are based on a combination of discrete sampling results and average results due to the level of detail included in each data source.
- The 1982 TDD only presents data for pollutants detected at least once. The EPA assumed all pollutants not presented in each 1982 TDD table were nondetect results (i.e., handled as zero for purposes of calculating a refinery-level average).
- The methodology handles all nondetect results as zero and nonquantifiable results above the reporting limit as the reporting limit, potentially underestimating the actual concentrations. This methodology potentially overestimates the actual concentration.
- The sensitivity of methods and detection limits are not known for all data. Analytical methods are not available for all data from the 1982 TDD and the 2019 detailed study.

Table 5-2. Pollutant Concentrations in WWT System Influent

Pollutant	1982 TDD				2019 Detailed Study			
	Refineries with Data	Pollutant Concentration (mg/L)			Refineries with Data	Pollutant Concentration (mg/L)		
		Avg	Min	Max		Avg	Min	Max
Ammonia[a]	15	16.0	1.00	44.0	7	[CBI]	[CBI]	[CBI]
Arsenic	16	0.0301	ND	0.438	5	0.00823	ND	0.0250
BOD_5[a]	15	93.0	12.0	260	2	283	46.5	1080
BTEX	0	No Data	No Data	No Data	0	No Data	No Data	No Data
Cadmium	16	0.00556	ND	0.0200	0	No Data	No Data	No Data
Chromium[a]	17	0.531	0.001	3.42	5	0.00208	ND	0.0120
COD[a]	15	384	83.0	987	9	[CBI]	[CBI]	[CBI]
Copper	15	0.0645	ND	0.286	5	0.0133	ND	0.0290
Cyanide	15	0.170	ND	1.76	0			
Lead	15	0.0635	ND	0.862	5	0.00412	ND	0.0220
Mercury	15	0.00123	ND	0.0100	5	0.000472	ND	0.00710
Nickel	15	0.0131	ND	0.154	5	0.0106	ND	0.0600
Nitrate-Nitrite	0	No Data	No Data	No Data	0	No Data	No Data	No Data
Nitrogen, Total	0	No Data	No Data	No Data	1	12.9	12.0	61.0
Oil & Grease[a]	15	51.0	ND	293	9	[CBI]	[CBI]	[CBI]
PAH	0	No Data	No Data	No Data	0	No Data	No Data	No Data
Phenol[a]	17	2.79	ND	33.5	4	7.01	ND	58.4
Phosphorus	0	No Data	No Data	No Data	0	No Data	No Data	No Data
Selenium	17	0.00712	ND	0.081	5	0.0485	ND	0.186
Sulfide[a]	15	7.03	0.500	27.3	3	11.6	ND	100
TDS	0	No Data	No Data	No Data	1	3320	2080	7820

[4] The calculated average, minimum, and maximum concentrations for ammonia, chemical oxygen demand (COD), and oil & grease based on detailed study data are withheld from this document to protect underlying data claimed as confidential business information (CBI).

Table 5-2. Pollutant Concentrations in WWT System Influent

Pollutant	1982 TDD				2019 Detailed Study			
	Refineries with Data	Pollutant Concentration (mg/L)			Refineries with Data	Pollutant Concentration (mg/L)		
		Avg	Min	Max		Avg	Min	Max
TKN	0	No Data	No Data	No Data	1	8.70	ND	96.3
TOC	15	110	25.0	283	3	150	11.7	738
TSS[a]	15	91.7	11.0	380	6	[CBI]	[CBI]	[CBI]
Uranium-238	0	No Data	No Data	No Data	0	No Data	No Data	No Data
Zinc	17	0.393	0.00900	1.90	5	0.403	0.0500	1.48

Acronyms: CBI (confidential business information); mg/L (milligrams-per-liter); ND (nondetect).
Note: All pollutant concentrations are rounded to three significant figures.
a - Included in current ELG.

5.2 Baseline Loadings Estimate

The EPA used publicly available data to estimate the discharged quantities of the 26 pollutants of interest (listed in Table 5-1). These baseline loadings estimates are calculated using flow rate and pollutant-specific concentrations to determine the amount discharged in pounds per year for each pollutant of interest. Section 5.2.1 describes the method for estimating pollutant-specific concentrations and Section 5.2.2 describes how flow rates at each refinery were determined. The results of the EPA's baseline loadings estimate are discussed in Section 5.2.3.

5.2.1 Effluent Concentrations

The EPA used 2017 Integrated Compliance Information System National Pollutant Discharge Elimination System (ICIS-NPDES) data, data collected for the 2019 detailed study, and data from permits to identify outfalls with WWT effluent. Some permits include multiple outfalls, some of which may discharge various wastestreams (e.g., process wastewater, stormwater, or cooling water, among others). The EPA used publicly available data to identify the subset of outfalls with treated process wastewater for this effluent analysis. The EPA identified outfall data containing WWT effluent, or treated process wastewater, for 91 refineries using the following methods.

- Reviewed WWT diagrams submitted through the Petroleum Refining Data Request and site visits to identify the specific outfall number corresponding to the effluent from the WWT. See Section 2.2 for details on the data request and site visits conducted as part of the detailed study. The EPA matched these outfalls to outfall numbers listed in ICIS-NPDES data to check that these outfalls included at least those pollutants that are included in the current petroleum refining ELG (ammonia, BOD_5, COD, chromium, hexavalent chromium, oil and grease, phenol, sulfide, and TSS).
- Used the process wastewater discharge and permit information provided by the trade associations (API, 2019) to identify refineries that were listed as direct discharge only or direct and indirect discharge and had only one final outfall included in their permit. The EPA assumed these outfalls contained WWT effluent.
- Identified permits for petroleum refineries that included numeric limits for all pollutants listed in the current ELG using 2017 DMR data. Where a permit included only one outfall with limits for all pollutants in the current ELG, the EPA assumed this outfall included

process water and represented the WWT effluent. Eight permits included multiple outfalls with numeric limits for all ELG pollutants; for these, the EPA assumed outfall 1 represented WWT effluent.

The EPA calculated, using the 2017 outfall-specific annual load and flow date estimated from EPA's Water Pollutant Loading Tool, a concentration for the pollutants of interest (annual load divided by annual flow) for 82 refineries with DMR data for outfalls with WWT effluent (ERG, 2019a). These refinery-specific average concentrations were then used to calculate an average concentration for the industry, as shown in Table 5-3.

Table 5-3. Average Effluent Concentrations of Pollutants of Interest at 82 Refineries with DMR Data for Outfalls Discharging WWT Effluent

Pollutant	Number of Refineries with Data	Average Pollutant Concentration (mg/L)
Ammonia as N	76	3.50
Arsenic	15	0.0179
BOD_5	79	8.49
BTEX	3	0.000192
Cadmium	11	0
Chromium	65	0.00245
COD	73	76.1
Copper	19	0.00333
Cyanide	15	0.0122
Lead	17	0.000982
Mercury	25	0.0000860
Nickel	12	0.00547
Nitrate-Nitrite	0	No Data
Nitrogen, Total	5	16.9
Oil & Grease	63	2.16
PAH[a]	0	No Data
Phenol	25	0.00894
Phosphorus	16	0.954
Selenium	26	0.0536
Sulfide	70	0.0296
TDS	7	1440
TKN	8	6.78
TOC	11	11.2
TSS	77	12.9
Uranium-238	0	No Data
Zinc	20	0.0261

Note: All concentrations are rounded to three significant figures.
a – The EPA's analysis includes only data listed as the combined PAH parameter in ICIS-NPDES. Some refineries may collect samples for individual PAH compounds that was not included in this analysis. The EPA determined that comparing concentrations for varying number of individual PAH compounds at different refineries may not be representative.

5.2.2 Wastewater Treatment Effluent Flows

The EPA also estimated WWT-specific effluent flows for all refineries, not just those with DMR data by taking the following steps. [5]

1. Eighteen of the 21 refineries responding to the data request discharge all or part of their WWT effluent to surface water. For each of these 18 refineries, the EPA calculated total 2016 wastewater effluent flow from their WWT to a surface water by (a) assuming that the daily flow values they reported in their data request responses were average daily values; and (b) multiplying by 365 days to calculate an annual flow.
2. The EPA then used the 2016 EIA Refinery Capacities Report operating capacity (EIA, 2016) value in barrels per calendar day to calculate an average WWT flow per barrel per calendar day (data request WWT effluent flow/EIA operating capacity) for these 18 refineries.
3. Finally, the EPA multiplied the average WWT flow per barrel per calendar day from Step 3 by the 2017 EIA operating capacity value in barrels per calendar day to calculate the 2017 WWT effluent flows for all refineries (EIA, 2017).

The EPA calculated the industry-level annual flow rate as the sum of the flow rates of all refineries included in the petroleum refining population that directly discharge any of their process wastewater or where the discharge status is unknown. For nine refineries, 2017 EIA capacity data were not available. For these nine refineries, the EPA assumed an average effluent flow of 1,250 million gallons per year (MGPY), which is the average of all 2017 WWT effluent flows calculated in Step 3 (see above).The EPA estimates the industry-level annual discharge of process wastewater from refineries directly to surface waters at 139,000 MGPY.

5.2.3 Loadings Estimate

For each of the 26 pollutants of interest (see Table 5-1), the EPA estimated the annual load using the following equation.

$$\text{Industry-Level Loading (lb/year)} = \text{Industry-level Annual Flow Rate} \times \text{Concentration in mg/L} \times (2.20462 \text{ lb}/10^6 \text{ mg}) \times (1000 \text{ L}/264.17 \text{ gallons})$$

Where:

Industry-level Annual Flow Rate = 139,000 MGPY
Concentration in mg/L = Concentrations listed in Table 5-3

The EPA's estimated baseline loadings are presented in Table 5-4. These loadings account for the following assumptions.

[5] Flows reported in DMR represent total outfall flows, which can include wastewaters other than treated WWT effluent. In order to estimate only the flow of treated effluent from the WWT, the EPA developed this method based on 2018 detailed study data.

- Loadings estimates do not differentiate by types of WWT installed at individual refineries. With additional data to characterize effluent from treatment systems and data on the types of treatment at each refinery, the EPA would be able to refine these baseline loadings estimates of pollutants being discharged by groups of similar WWT systems.
- Loadings estimates do not include the amount of pollutants discharged by refineries that send all their process wastewater to publicly owned treatment works (POTWs) (i.e., indirect dischargers).

Table 5-4. Estimated 2017 Baseline Loadings

Pollutant	Estimated Loading (lb/yr)
Ammonia as N	4,070,000
Arsenic	20,800
BOD_5	9,870,000
BTEX	223
Cadmium	0
Chromium	2,850
COD	88,500,000
Copper	3,870
Cyanide	14,200
Lead	1,140
Mercury	99.9
Nickel	6,360
Nitrate-Nitrite	No Data
Nitrogen, Total	19,600,000
Oil & Grease	2,510,000
PAH	No Data
Phenol	10,400
Phosphorus	1,110,000
Selenium	62,300
Sulfide	34,400
TDS	1,680,000,000
TKN	7,880,000
TOC	13,000,000
TSS	15,000,000
Uranium-238	No Data
Zinc	30,400

Note: All estimated loadings are rounded to three significant figures.

5.3 Wastewater Treatment-In-Place

The EPA reviewed publicly available data on WWT operated by refineries, including systems treating specific wastestreams upstream of the end-of-pipe WWT system. Section 5.3.1 summarizes the information on WWT prior to the end-of-pipe WWT system, and Section 5.3.2 summarizes end-of-pipe WWT systems.

5.3.1 Wastewater Treatment Prior to End-of-Pipe Treatment

The Petroleum Refining Data Request collected information on specific unit operations and destinations of wastewater generated by these units (see Section 3 for more details on the data request). From the responses to this request, the EPA gathered information from 21 of the 143 refineries on treatment technologies used in 2016. Treatment systems were used to treat a variety of wastewater streams.

- Crude desalter effluent.
- Catalytic cracking unit (CCU) and associated air pollution control (APC) wastewater.
- Catalytic reforming unit (CRU) regenerator and associated APC wastewater.
- Delayed coking unit (DCU) wastewater.
- Sour water stripper (SWS) effluent.
- Benzene removal unit (BRU) effluent.

The EPA notes the following trends based on responses to the request.

- All surveyed refineries generating CCU APC wastewater operate at least one dedicated CCU APC wastewater treatment unit. Most refineries then send treated CCU APC wastewater to end-of-pipe WWT system.
- Dedicated treatment of wastewater from CRU regenerators and associated APCs is not common among surveyed refineries. Most refineries reported sending this stream directly to an end-of-pipe WWT system.

5.3.2 Wastewater Treatment Within End-of-Pipe Wastewater Treatment System

To assess end-of-pipe WWT technologies in-place, the EPA used WWT data collected as part of the data request, site visit reports, and other publicly available data sources, such as 2011 Office of Air and Radiation (OAR) data, NPDES permit and permit application information, and other publicly available studies and reports. See Section 3 for a discussion of these data sources. As part of this assessment, the EPA compared the WWT technologies in place to the technology basis identified as the best available technology (BAT) in the existing ELGs. The end-of-pipe treatment train identified in the BAT ELGs includes the following treatment units.

- Equalization and storm water diversion.
- Primary oil and solids removal.
- Secondary oil and solids removal.
- Biological treatment to reduce BOD and COD.
- Filtration or other final polishing steps following biological treatment.

The EPA made the following assumptions as part of this analysis.

- Where multiple data sources provided wastewater treatment information for a facility, the Agency considered the most current information.
- Technologies were operated in a similar order as the BAT technology basis treatment train.

- Biological treatment includes the following types of systems.
  - Aerobic impoundment or units.
  - Aerated/non-aerated surface impoundments.
  - Aerobic fixed film growth.
  - Aerobic suspended growth.
  - Moving bed bioreactors (MBBR).
  - Membrane bioreactor (MBR).
  - Tank-based activated sludge.
  - ADVENT integral biological system.
  - Biological activated filter.
  - Biosolids flotation unit.
  - Ecoverde.
  - Integrated biox system.

- Final polishing includes the following types of systems.
  - Polishing pond.
  - Chemical oxidation.
  - Chemical addition.
  - Settling unit.
  - Constructed wetland or lagoon.
  - Coagulation and flocculation.

The EPA compiled WWT data for 129 of the 143 petroleum refineries. Table 5-5 summarizes the number of petroleum refineries operating each step of the BAT technology basis. Note that the treatment technologies identified as the final step are split into filtration and other polishing. Both may fulfill the BAT technology basis but comprise different groups of technologies. Refineries need to meet the final effluent limits; they are not required to install the BAT technology basis. Hence, some refineries may be meeting the ELGs with treatment units other than those identified as the technology basis for the ELG.

Table 5-5. WWT Technologies at 129 Petroleum Refineries

	Oil and Solids Removal	Secondary Oil and Solids Removal	Biological Treatment	Effluent Polishing	
				Filtration	Other Polishing
Number of Refineries Operating Technology	121	88	100	24	9
Percent of Total Refineries	94%	68%	78%	19%	7%

Note: The EPA compiled WWT data for a total of 129 of the 143 current petroleum refineries.

Of the 129 refineries with WWT data, the EPA identified 25 refineries that are not subject to the BAT requirements because they discharge process wastewater indirectly or not at all. The EPA also identified eight refineries where the type of process wastewater discharge is unknown, the EPA assumed these refineries are likely subject to the BAT requirements. Therefore, 104 refineries (of the 129 with WWT data) are likely subject to the BAT requirements. Figure 5-1 shows the treatment technologies operated by these 104 refineries. The EPA used the following WWT categories.

- *Beyond BAT*. WWT system includes biological treatment, final polishing (i.e., filtration or other polishing), and some additional type of treatment before discharge.
- *Current BAT*. WWT includes biological treatment system and an effluent polishing unit (i.e., filtration or other polishing).
- *Biological treatment*. WWT includes a biological treatment system, but not an effluent polishing unit. These refineries may or may not operate an oil/water separator.
- *Treatment other than biological treatment*. WWT includes at least one oil/water separator, but not biological treatment.
- *No treatment information available*. WWT information is not available in the sources the EPA reviewed for these refineries.

Appendix B identifies the WWT data for each refinery that the EPA used to categorize each refinery's treatment technology.

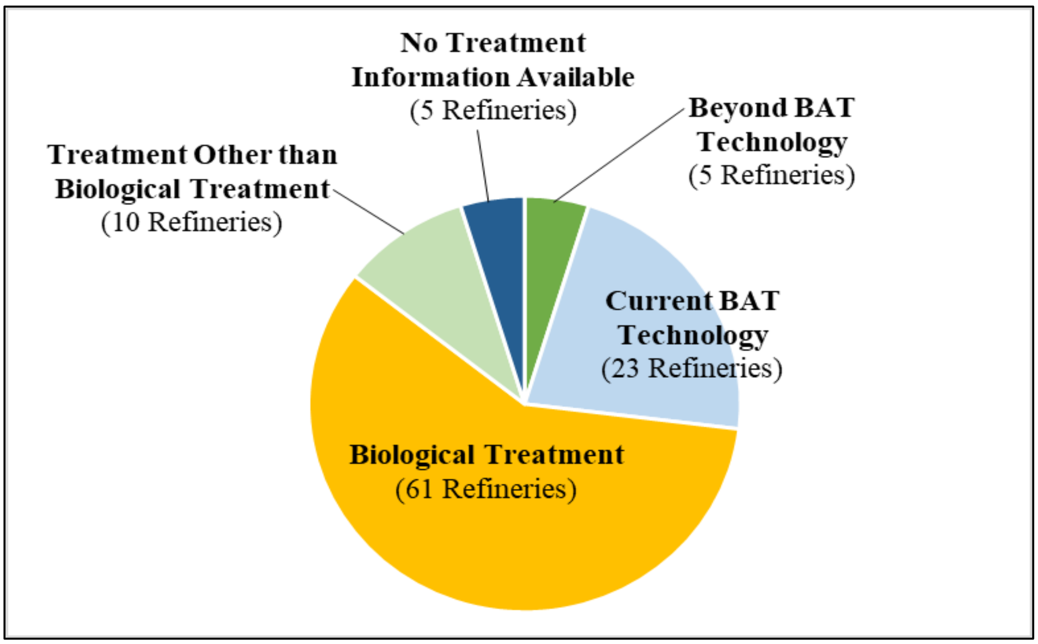

Figure 5-1. WWT Systems at Refineries Subject to BAT Requirements

Of the 104 refineries likely subject to BAT requirements, five refineries were categorized as beyond BAT technology. These refineries employ one of the following in addition to BAT.

- Filtration and a polishing unit.
- Selenium reduction plant.

- Ion exchange.[6]

5.4 Permit Limits Analysis

The EPA reviewed publicly available permit limits and discharge monitoring data to determine the prevalence of limits for the 26 pollutants listed in Table 5-1.

Using 2017 ICIS-NPDES data, the EPA investigated pollutants found in NPDES permits for the petroleum refining industry that are not already included in the existing ELG for petroleum refining. The existing petroleum refining ELG includes limits for ammonia, BOD_5, COD, chromium, hexavalent chromium, oil and grease, phenol, sulfide, and TSS.

The EPA identified data for external outfalls and effluent monitoring locations using DMR data entry codes for parameter feature (EXO and SUM) and monitoring location (1, 2, A, B, or SC). The EPA identified DMR data representing external outfalls or effluent monitoring locations for 106 refineries (115 permits) (ERG, 2019b). Using this subset of DMR data, the EPA further identified which permits include a numeric limit or monitoring requirement for the pollutants of interest.

The EPA found requirements for metals, including arsenic, selenium, copper, mercury, lead, and zinc, in 30 or more permits. Table 5-6 lists the pollutants most commonly found in permits, excluding those pollutants already included in the petroleum ELG. Table 5-7 presents the information by state, with details for zinc, lead, mercury, copper, selenium, arsenic, phosphorus, and nitrogen.

Table 5-6. Pollutants Found in 10 or More Petroleum Refining Permits

Pollutant	Number of Permits Including a Requirement in 2017 DMR Data[a]
TOC	73
Zinc	47
Lead	45
Mercury	44
Copper	42
Cyanide	40
Benzene	40
Whole effluent toxicity	39
Selenium	39
Arsenic	30
Nickel	29
Phosphorus	26
Cadmium	25
TDS	22
Benz[a]anthracene	21
Benzo[a]pyrene	21
Naphthalene	20
Fluoranthene	19
Pyrene	18
BTEX combination	18
Anthracene	18
Chrysene	18

[6] The EPA does not have details as to the role of this technology within the refinery's WWT system.

Table 5-6. Pollutants Found in 10 or More Petroleum Refining Permits

Pollutant	Number of Permits Including a Requirement in 2017 DMR Data[a]
Benzo(b)fluoranthene	17
Benzo[k]fluoranthene	17
Chloride	17
Acenaphthene	17
Nitrogen	13
TKN	11
Dibenz[a,h]anthracene	11
Indeno[1,2,3-cd]pyrene	10

Source: ERG, 2019c
a – Permit requirement refers to either a numeric limit or a monitoring requirement for an individual pollutant.

Table 5-7. Petroleum Refining Permit Requirement Data by State and EPA Region

EPA Region	State	Number of Refineries in State	Number of Permits Included in Analysis	Permits with Monitoring Requirements and/or Numeric Limits							
				Zinc	Lead	Mercury	Copper	Selenium	Arsenic	Phosphorus	Nitrogen
2	NJ	3	3	1	1	1	1	0	0	1	0
3	DE	1	2	1	1	1	1	0	0	0	0
3	PA	4	5	2	2	0	1	1	0	2	0
3	WV	1	1	1	0	0	1	0	1	0	1
4	AL	3	2	1	1	1	1	0	0	2	0
4	KY	2	3	1	1	0	0	0	2	0	0
4	MS	4	4	1	0	0	1	0	0	1	1
5	IL	4	4	2	1	3	1	1	1	1	0
5	IN	2	2	1	2	2	1	1	1	1	0
5	MN	2	2	1	0	2	0	2	0	2	0
5	OH	4	4	1	2	3	1	3	0	3	0
5	WI	1	1	1	1	1	1	1	1	1	0
6	AR	2	2	1	1	1	1	1	0	1	0
6	LA	18	19	3	8	2	3	0	0	3	4
6	OK	5	6	0	1	0	0	1	0	0	0
6	TX	29	25	11	3	3	6	6	2	1	1
7	KS	3	3	3	3	3	3	3	3	2	2
8	CO	1	1	1	1	1	1	1	1	0	0
8	MT	4	4	0	2	2	1	2	3	3	3
8	ND	2	1	0	0	0	0	0	0	0	0
8	UT	5	2	0	0	0	0	0	0	1	0
8	WY	6	1	1	1	1	1	1	1	0	0
9	CA	20	13	10	11	13	12	13	11	0	0
9	HI	2	1	0	0	1	0	0	1	1	1
10	AK	5	1	0	0	1	1	0	0	0	0
10	WA	5	3	3	2	2	3	2	2	0	0
Total		138	115	47	45	44	42	39	30	26	13

Note: Some refineries have more than one permit.

5.5 Review of New Technologies or Improved Performance

The EPA's Industrial Wastewater Treatment Technology Database provides technology performance data from peer-reviewed journals, conference proceedings, and government reports (EPA, 2018). The EPA used this tool to identify articles and performance data related to treatment of petroleum refining wastewater for metals and nutrients.[7] This section summarizes articles focused on filtration or adsorption technologies targeting arsenic, selenium, mercury, and nutrients.

5.5.1 Removal of Selenium in Refinery Effluent with Adsorption Media

A study conducted by MAR Systems Inc., a wastewater treatment technology company, provided data from 2012 on their proprietary adsorbent technology, which uses an activated alumina-based substrate that was tested on petroleum refining wastewater (Hayes and Sherwood, 2012). The technology, Sorbster™ media, uses proprietary chemistries to covalently bond metals and remove them from aqueous streams. Of interest is the media's ability to remove soluble selenium in the form of selenate and selenite, and other forms such as selenium sulfide and selenosulfate. After use, the proprietary media passes the EPA toxicity characteristic leaching procedure tests for disposal in non-hazardous landfills.

The Hayes and Sherwood (2012) study evaluated five refineries, two midwestern and three western refineries, currently with less than 110 parts per billion (ppb) selenium in their final treated effluent. The purpose of the testing was to evaluate whether the Sorbster™ media could remove more selenium, to a concentration of less than 20 ppb. New detection limits for selenium and lower permit limits were cited as potential reasons for these lower selenium concentrations.

For all bench-scale testing, refinery effluent wastewater flowed through a packed column with a contact time of 10 minutes to 25 minutes. Each refinery has existing selenium treatment within the WWT.

- Refinery A – In the Midwest, used final WWT effluent for testing. The WWT includes carbon filtration.
- Refinery B – In the western U.S., used permeate from a fluid bed reactor (FBR)/membrane treatment unit for testing.
- Refinery C – In the Midwest, used final WWT effluent for testing. The WWT includes iron coprecipitation targeting selenium.
- Refinery D – In the western U.S., used final WWT effluent for testing. The WWT includes iron coprecipitation and carbon polishing to target selenium.
- Refinery E – In the western U.S., used final WWT effluent for testing. The WWT includes iron coprecipitation to target selenium.

[7] The EPA used the following search terms to identify articles: Petroleum refining (Industry); Selenium, Mercury, Lead, Arsenic, Nitrogen, Phosphorus, Phosphate, Nitrogen, Total Kjeldahl (TKN), Ammonia, Chromium, Aluminum, Antimony, Barium, Beryllium, Cadmium, Copper, Iron, Magnesium, Manganese, Nickel, Silver, Sodium, Strontium, Thallium, Zinc (Pollutants).

Influent and effluent samples from the columns were sampled using the EPA Method 200.7. The detection limit for selenium is 5 ppb. Table 5-8 presents the influent water quality data from each refinery for the Sorbster™ media testing.

Table 5-8. Bench-Scale Tests of Influent Water Quality at Five Refineries

Pollutant	Concentrations and Speciation at Five Refineries				
	Refinery A	Refinery B	Refinery C	Refinery D	Refinery E
Selenium Concentration	22.8[a]	5.7 ppb	32 ppb	23.0 ppb	109 ppb
Se Speciation	Not known	Selenocyanate then selenite; minor selenate	Selenate, selenite	Not known	Mostly selenite, minor selenate

Source: Hayes and Sherwood, 2012.
a – Units not specified in data source.

The study determined that the Sorbster™ media was able to remove additional selenium from treated WWT effluent. The study does not include precise selenium concentration data, but, based on the non-detect and target concentration results, the sorbent technology achieved greater than 80 percent removal of selenium in all refinery effluent, regardless of upstream selenium treatment technology.

5.5.2 Evaluation of Activated Sludge Microfiltration for Refinery Wastewater Reuse

Coffeyville Resources Refining & Marketing refinery in Coffeyville, Kansas, conducted a pilot test in 2009 to evaluate the performance of side-stream microfiltration for refinery wastewater treatment (Cabral et al., 2010). The pilot had two main objectives.

- Determine if the technology could be used to reduce the load on the clarifiers within the WWT system in place.
- Produce a treated effluent with water quality suitable for reuse. The goal of water reuse would be to reduce river water intake and use treated effluent as reverse osmosis (RO) feed water.

Coffeyville refinery's WWT system included API separation, equalization, DAF, three conventional mix activated sludge (CMAS) basins operated in parallel (hydraulic retention time of approximately one day), two secondary clarifiers operated in parallel, and a final clarifier before discharge.

The piloted microfiltration unit was a modified, immersed MBR, operated without the biological treatment steps. The microfiltration membranes were polyvinylidene fluoride reinforced hollow fiber with 0.4-micron pore size. The microfiltration unit treated effluent from the existing CMAS basins.

The study was conducted in three phases, each evaluating different air flow and flux scenarios (e.g., low air flow and high flux, low air flow and decreased flux, and normal air flow and decreased flux). Table 5-9 presents average influent and effluent concentrations for select pollutants across the entire test period (about three weeks), as well as the calculated percent removal based on laboratory results. Influent samples were collected as wastewater exited the DAF but before entering the CMAS basins; while effluent samples were membrane permeate.

The study demonstrated that the microfiltration technology could alleviate the load on the clarifier and that the microfilter permeate quality can achieve RO feed water requirements. No details on whether the refinery changed the WWT configuration based on this pilot were included in the study.

Table 5-9. Microfiltration Pilot Study Results

Parameter	Average Concentration in Influent (mg/L)	Average Concentration in Effluent (mg/L)	Percent Removed
Ammonia	14.6	0.0	100 %
BOD	198.3	<2.0	100 %
COD	874.8	69.2	92.1 %
Nitrates	0.0	2.0	No data
Oil & grease	169.4	2.00	98.8 %
Phenol	5.1	Non-detect	100 %
TKN	28.7	1.0	96.5 %
TOC	119.8	23.5	80.4 %
Total Phosphorus	0.9	0.3	No data
Total Nitrogen[a]	25.5	3.6	85.9 %
TSS	254.9	<1	99.8 %

Source: Cabral et al., 2010.

a – The study authors removed results on August 27 and 28 for total nitrogen in influent and effluent datasets. These results were 109 mg/L and 113 mg/L average total nitrogen in the influent and 55 mg/L and 83 mg/L average total nitrogen in the effluent. The authors considered these results outliers.

5.5.3 Tertiary Filter Pilot Study for Mercury Removal from Refinery Wastewater

An unidentified refinery conducted a pilot test of filtration technologies for treatment of mercury after receiving a new mercury mass-based permit limit of 8.5 nanograms per liter (ng/L) on an annual average basis. The refinery's effluent mercury concentration was averaging 13.5 ng/L. After determining that source reduction was not feasible and conducting effluent sampling that indicated sample filtration would reduce the effluent mercury concentration, the refinery conducted a six-month pilot study of disk filtration and gravity granular media filtration technologies. The initial pilot study performance goals were to achieve ≤4.1 mg/L TSS and ≤8.5 ng/L mercury in the filtration effluent. The refinery's WWT system consisted of gravity oil-water separation, DAF, tank-based activated sludge (operated at a target sludge age of 25 days), a secondary clarifier, and a final settling basin. Effluent from the secondary clarifier was sent to the filtration technologies for this pilot (Allen and Loete, 2016).

The disk filter had a drum configuration containing 10 micrometer (10 μm) micro-screen panels. Secondary clarifier effluent was routed through a y-strainer before being pumped to a mix tank, where polymer was added to aid with coagulation/flocculation before it went to the disk filter. Effluent routed to an unmixed filtrate tank. Chemical addition only occurred during part of pilot testing and was determined not to have significantly improved mercury removal. Ultimately, the disk filter operated for 64 days when pilot testing was terminated due to insufficient mercury removal. Table 5-10 presents the disk filter performance data for mercury and TSS. The disk filter achieved 8.5 ng/L effluent mercury concentration in about 23 percent of samples (Allen and Loete, 2016).

The granular media filtration columns operated for 138 days. The study tested two columns with different configurations. The first column operated 82 days with mixed media (anthracite, sand, and garnet), and the remaining days with only sand media. The second column operated with dual media (anthracite and sand) for 126 days of the 138-day test period. Table 5-10 presents the granular media filtration performance data for mercury and TSS. While the effluent TSS concentrations did not meet the initial target performance goals for the pilot (≤4.1 mg/L), mercury removal met the pilot goal of 8.5 ng/L and the three granular media filtration configurations performed similarly. All three configurations either achieved or nearly achieved 100 percent of samples with an 8.5 ng/L effluent mercury concentration (Allen and Loete, 2016).

Table 5-10. Mercury and TSS Performance Data for Tertiary Filtration Technologies

Technology	Influent	Effluent	Percent of samples that achieved <8.5 ng/L (%)	Percent Removal (%)
Average TSS				
DF	72.6 mg/L	15.2 mg/L	NA	71
GMF, mixed	111 mg/L	5.3 mg/L	NA	92
GMF, dual	105 mg/L	5.7 mg/L	NA	87
GMF, mono	90 mg/L	6.4 mg/L	NA	78
Average Mercury (unfiltered)				
DF	112 ng/L	16.1 ng/L	23	86[a]
GMF, mixed	146 ng/L	1.8 ng/L	98.5	96
GMF, dual	119 ng/L	1.3 ng/L	100	93
GMF, mono	70 ng/L	1.0 ng/L	100	87

Source: Allen and Loete, 2016.
Acronyms: DF (disk filter); GMF (granular media filtration); NA (not applicable).
a – Value calculated for this report.

A pilot study conducted by Argonne National Labs and Purdue University at the BP Whiting Refinery also evaluated treatment technologies for mercury removal in WWT effluent (Purdue-Argonne, 2012b). The pilot focused on tertiary filters because mercury was in a suspended solid particulate form and not dissolved in the effluent.

5.6 References

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Appendix A –
U.S. Refinery Population

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U.S. Refinery Population

Refinery ID	Refinery Name	City	State	Operating Company	NPDES Permit(s)	Discharge Status	ELGs Subcategory	2018 EIA Refinery Atmospheric Crude Distillation Capacity (barrels per calendar day)
1	Arctic Slope Regional - North Pole	North Pole	AK	Petro Star Inc		Unknown		19,700
2	Arctic Slope Regional - Valdez	Valdez	AK	Petro Star Inc		Unknown		55,000
3	BP - Prudhoe Bay	Prudhoe Bay	AK	BP		Indirect		6,000
4	ConocoPhillips - Prudhoe Bay	Prudhoe Bay	AK	ConocoPhillips		Unknown		15,000
5	Kenai Refinery	Kenai	AK	Marathon Petroleum Corporation	AK0000841	Direct and Indirect		62,700
6	Goodway Refining	Atmore	AL	Goodway Refining LLC		Unknown		4,100
7	Hunt Refining - Tuscaloosa	Tuscaloosa	AL	Hunt Refining Company	AL0000973	Direct	B	46,000
8	Shell Chemical Mobile Site	Saraland	AL	Shell Oil Products US	AL0055859	Direct	A	91,575
9	Lion Oil	El Dorado	AR	Delek US Holdings	AR0000647	Direct		83,000
10	Martin Operating	Smackover	AR	Martin Midstream Partners	AR0000591	Direct		7,500
11	Alon - Bakersfield	Bakersfield	CA	Alon USA Energy, Inc.		Direct		
12	Los Angeles Refinery - Carson	Carson	CA	Marathon Petroleum Corporation	CA0000680, CAS000001	Indirect	B	243,800
13	Los Angeles Refinery - Wilmington	Wilmington	CA	Marathon Petroleum Corporation	CA0003778	Indirect	B	97,500
14	Chevron - Richmond Refinery	Richmond	CA	Chevron Corporation	CA0005134	Direct	E	245,271
15	Chevron - El Segundo Refinery	El Segundo	CA	Chevron Corporation	CA0000337	Direct and Indirect	B	269,000
16	Phillips - SF Refinery Rodeo	Rodeo	CA	Phillips 66	CA0005053	Direct	B	120,200
17	Phillips - SF Refinery Arroyo Grande	Arroyo Grande	CA	Phillips 66	CA0000051	Direct	B	
18	Phillips - LA Refinery Carson	Carson	CA	Phillips 66	CA0063185	Indirect	B	[a]
19	Phillips - LA Refinery Wilmington	Wilmington	CA	Phillips 66	CA0000035, CA0064611	Indirect	B	139,000
20	Torrance Refinery	Torrance	CA	PBF Energy	CA0055387	Indirect	B	160,000
21	Greka	Santa Maria	CA	Greka Integrated		Unknown		9,500
22	Kern Refining	Bakersfield	CA	Kern Oil & Refining Company	CAU000200, CAZ458176	Unknown		26,000
23	South Gate Refinery	South Gate	CA	World Oil Company (d.b.a. World Oil Refining)	CAP000078, CAZ189100	Indirect		8,500
24	Paramount Refinery	Paramount	CA	Alon USA Energy, Inc.	CA0056065	Indirect	B	
25	San Joaquin Refinery	Bakersfield	CA	San Joaquin Refining Co., Inc.	CAZ456330	Indirect		15,000
26	Shell - Martinez Refinery	Martinez	CA	Shell Oil Products US	CA0005789	Direct	B	156,400
27	Martinez Refinery	Martinez	CA	Marathon Petroleum Corporation	CA0004961	Direct	B	166,000
28	Valero - Wilmington Refinery	Wilmington	CA	Valero Energy Corporation		Indirect		85,000
29	Benicia Refinery	Benicia	CA	Valero Energy Corporation	CA0005550	Direct	B	145,000
30	Wilmington Asphalt Plant	Wilmington	CA	Valero Energy Corporation		Indirect		6,300
31	Commerce City Refinery	Commerce City	CO	Suncor	CO0001147	Direct	B	103,000
32	Delaware City Refinery	Delaware City	DE	PBF Energy	DE0000256, DE0050601	Direct		182,200
33	Kapolei Refinery	Kapolei	HI	Par Pacific Holdings, Inc.	HI0000329	Direct		54,000
34	Hawaii Refinery	Kapolei	HI	Par Petroleum Corporation		Indirect	B	93,500
35	Lemont Refinery	Lemont	IL	Citgo Petroleum Corporation	IL0001589	Direct	B	179,265
36	Joliet Refinery	Channahon	IL	ExxonMobil	IL0002861	Direct	B	238,600
37	Marathon - Illinois Refinery	Robinson	IL	Marathon Petroleum Corporation	IL0004073	Direct and Indirect	B	245,000
38	Wood River Refinery	Roxana	IL	Phillips 66	IL0000205	Direct		314,000
39	BP Whiting Refinery	Whiting	IN	BP	IN0000108	Direct	B	413,500
40	CountryMark Refinery	Mt Vernon	IN	CountryMark	IN0002470	Direct		28,800
41	Coffeyville Refinery	Coffeyville	KS	CVR Refining, LP	KS0000248	Direct		132,000
42	El Dorado Refinery	El Dorado	KS	HollyFrontier Corporation	KS0000761	Direct		160,000
43	National CO-OP Refinery	McPherson	KS	CHS Inc	KS0000337	Indirect		97,920
44	Catlettsburg Refinery	Catlettsburg	KY	Marathon Petroleum Corporation	KY0000388, KY0070718	Direct	E	277,000
45	Somerset Refinery	Somerset	KY	Continental Refining Company	KY0003476	Direct		5,500
46	Krotz Springs Refinery	Krotz Springs	LA	Alon USA Energy, Inc.	LA0051942	Direct	C	80,000
47	Calcasieu Refinery	Lake Charles	LA	Calcasieu Refining Company	LA0052370	Direct	A	125,000
48	Calumet - Shreveport Lubricant and Waxes	Shreveport	LA	Calumet Specialty Products Partners LP	LA0032417	Direct	D	57,000
49	Calumet - Princeton Lubricants	Princeton	LA	Calumet Specialty Products Partners LP	LA0088552	Indirect		8,300
50	Calumet - Cotton Valley Lubricants	Cotton Valley	LA	Calumet Specialty Products Partners LP	LA0005312	Direct	A	13,020
51	Citgo - Lake Charles Refinery	Lake Charles	LA	Citgo Petroleum Corporation	LA0005941	Direct	D	418,000
52	Phillips - Lake Charles Refinery	Westlake	LA	Phillips 66	LA0003026, LA0104469	Direct	D	260,000
53	Alliance Refinery	Belle Chasse	LA	Phillips 66	LA0003115	Direct	B	249,700
54	Convent Refinery	Convent	LA	Shell Oil Products US	LA0006041	Direct	B	209,787
55	Shell - Saint Rose Refinery	Saint Rose	LA	Shell Oil Products US	LA0054216	Direct	A	
56	Baton Rouge Refinery	Baton Rouge	LA	ExxonMobil	LA0005584	Direct	E	502,500
57	Chalmette Refinery	Chalmette	LA	PBF Energy	LA0004260	Direct	B	190,000
58	Garyville Refinery	Garyville	LA	Marathon Petroleum Corporation	LA0045683	Direct	B	556,000
59	Norco Refinery	Norco	LA	Shell Oil Products US	LA0003522, LA0005762	Direct	C	218,200
60	Pelican - Lake Charles Refinery	Lake Charles	LA	Pelican Refining Company, LLC	LA0054399	Direct		
61	Placid - Port Allen Refinery	Port Allen	LA	Placid Refining Company, LLC	LA0039390	Direct	B	75,000
62	Valero - New Orleans Refinery	Norco	LA	Valero Energy Corporation	LA0052051, LAG535403	Direct	B	215,000
63	Meraux Refinery	Meraux	LA	Valero Energy Corporation	LA0003646	Direct	B	125,000
64	Michigan Refinery	Detroit	MI	Marathon Petroleum Corporation		Indirect	B	139,000
65	Pine Bend Refinery	Rosemount	MN	Flint Hills Resources	MN0000418	Direct and Indirect		310,000
66	St Paul Refinery	Saint Paul Park	MN	Marathon Petroleum Corporation	MN0000256	Direct		98,515
67	Pascagoula Refinery	Pascagoula	MS	Chevron Corporation	MS0001481	Direct		352,000
68	Ergon Refinery	Vicksburg	MS	Ergon Inc.	MS0034711	Direct		26,500
69	Southland Refinery	Sandersville	MS	Hunt Refining Company	MS0001686	Direct		11,000
70	Vicksburg Petroleum Products	Vicksburg	MS	Vicksburg Petroleum Products	MS0060976	Direct		
71	Laurel Refinery	Laurel	MT	CHS Inc	MT0000264	Direct		59,600
72	Phillips - Billings Refinery	Billings	MT	Phillips 66	MT0000256	Direct and Indirect		60,000
73	Exxon - Billings Refinery	Billings	MT	ExxonMobil	MT0000477, MT0028321	Direct		61,500
74	Montana Refinery	Great Falls	MT	Calumet Specialty Products Partners LP	MTPU00118, MTR000556	Indirect		24,000
75	Dakota Refinery	Dickinson	ND	Marathon Petroleum Corporation	NDR050776	Indirect	A	19,500
76	Mandan Refinery	Mandan	ND	Marathon Petroleum Corporation	ND0000248	Direct	B	73,800
77	Bayway Refinery	Linden	NJ	Phillips 66	NJ0001511, NJ0026662, NJ0026671	Direct	B	258,000
78	Axeon - Paulsboro	Paulsboro	NJ	Axeon Specialty Products	NJ0064921	Direct		
79	PBF - Paulsboro	Paulsboro	NJ	PBF Energy	NJ0005029	Direct	B	160,000

U.S. Refinery Population

Refinery ID	Refinery Name	City	State	Operating Company	NPDES Permit(s)	Discharge Status	ELGs Subcategory	2018 EIA Refinery Atmospheric Crude Distillation Capacity (barrels per calendar day)
80	Navajo Refinery	Artesia	NM	HollyFrontier Corporation		Indirect and Injection		110,000
81	Gallup Refinery	Jamestown	NM	Marathon Petroleum Corporation	NM0031071, NMR053168	Unknown		26,600
82	Foreland Refinery	Ely	NV	Foreland Refining Corp		Unknown		2,000
83	Toledo Refinery	Oregon	OH	BP and Husky Energy (Joint Venture)	OH0002461	Direct	B	155,000
84	Lima Refinery	Lima	OH	Husky Energy	OH0002623	Direct		177,000
85	Ohio Refinery	Canton	OH	Marathon Petroleum Corporation	OH0005657	Direct		93,000
86	Toledo Refinery	Oregon	OH	PBF Energy	OH0002763	Direct		172,800
87	Ponca City Refinery	Ponca City	OK	Phillips 66	OK0000256	Direct	B	206,000
88	Tulsa East Refinery	Tulsa	OK	HollyFrontier Corporation	OK0001309	Direct and Indirect		70,300
89	Tulsa West Refinery	Tulsa	OK	HollyFrontier Corporation	OK0000876	Direct		85,000
90	Ardmore Refinery	Ardmore	OK	Valero Energy Corporation	OK0001295	Direct	B	86,000
91	Wynnewood Refinery	Wynnewood	OK	CVR Refining, LP	OK0000825, OK0046027	Direct		74,500
92	American Refining	Bradford	PA	American Refining Group Inc.	PA0002674	Direct		11,000
93	Trainer Refinery	Trainer	PA	Delta Airlines, Inc.	PA0012637	Direct		190,000
94	Philadelphia Refinery	Philadelphia	PA	Philadelphia Energy Solutions Refining and Marketing LLC	PA0011533, PA0012629	Direct and Indirect		335,000
95	United Refining	Warren	PA	United Refining Company	PA0005304	Direct		65,000
96	Tennessee Refinery	Memphis	TN	Valero Energy Corporation	TNG670074, TNR056522, 5-NN1-029	Indirect	B	180,000
97	Calumet - San Antonio	San Antonio	TX	Calumet Specialty Products Partners LP	TXG670214	Unknown		20,000
98	Big Springs Refinery	Big Spring	TX	Alon USA Energy, Inc.	TX0104515	Direct		73,000
99	Borger Refinery	Borger	TX	Phillips 66 and Cenovus (Joint Venture)	TX0009148	Direct	B	146,000
100	Sweeny Complex	Brazoria	TX	Phillips 66	TX0007536	Direct	C	256,000
101	Citgo - Corpus Christi Refinery	Corpus Christi	TX	Citgo Petroleum Corporation	TX0006211	Direct		157,500
102	Tyler Refinery	Tyler	TX	Delek US Holdings	TX0001449	Indirect		75,000
103	McKee Plant	Sunray	TX	Valero Energy Corporation	TX0115851	Indirect	B	195,000
104	Beaumont Refinery	Beaumont	TX	ExxonMobil	TX0118737	Direct	D	365,644
105	Baytown Refinery	Baytown	TX	ExxonMobil	TX0006271	Direct	E	560,500
106	Flint Hills - Corpus Christi East Refinery	Corpus Christi	TX	Flint Hills Resources	TX0006599	Direct	B	319,000
107	Flint Hills - Corpus Christi West Refinery	Corpus Christi	TX	Flint Hills Resources	TX0006289	Direct	C	[b]
108	LyondellBasell - Houston Refinery	Houston	TX	LyondellBasell	TX0003247	Direct and Indirect	E	263,776
109	Galena Park Crude & Condensate	Galena Park	TX	Kinder Morgan	TX0135640	Indirect		84,000
110	Lazarus Refinery	Nixon	TX	Blue Dolphin Energy Company		Unknown		13,765
111	Marathon - Galveston Bay Refinery	Texas City	TX	Marathon Petroleum Corporation	TX0003522	Direct	B	571,000
112	Marathon - Texas City Refinery	Texas City	TX	Marathon Petroleum Corporation	TX0003697	Direct	B	
113	Pasadena Refinery	Pasadena	TX	Brazilian Petroleum Corporation - Petrobras	TX0004626	Indirect	E	112,229
114	Motiva - Port Arthur Refinery	Port Arthur	TX	Motiva Enterprises - Divested to Saudi Aramco (Q2 2017)	TX0005835	Direct	C	603,000
115	Valero - Port Arthur Refinery	Port Arthur	TX	Valero Energy Corporation	TX0005991	Direct	B	335,000
116	Deer Park Refinery	Deer Park	TX	Shell Oil Products US and Pemex (Joint Venture)	TX0004871, TX0004863	Direct	B	275,000
117	Silsbee Refinery	Silsbee	TX	Texas Oil & Chemical Co	TX0003204	Direct	B	
118	Total Petrochemicals - Port Arthur Refinery	Port Arthur	TX	Total Petrochemicals and Refining USA, Inc.	TX0004201	Direct		225,500
119	Valero - Texas City Refinery	Texas City	TX	Valero Energy Corporation	TX0006009, TXG670007	Direct	B	225,000
120	Valero - Houston Refinery	Houston	TX	Valero Energy Corporation	TX0002976	Direct		199,000
121	Valero - Corpus Christi East Refinery	Corpus Christi	TX	Valero Energy Corporation	TX0006904	Direct		275,000
122	Valero - Corpus Christi West Refinery	Corpus Christi	TX	Valero Energy Corporation	TX0063355	Direct		
123	Three Rivers Refinery	Three Rivers	TX	Valero Energy Corporation	TX0088331	Direct		89,000
124	Western Refinery	El Paso	TX	Marathon Petroleum Corporation		Indirect		135,000
125	Big West Oil Refinery	North Salt Lake	UT	Big West Oil LLC		Unknown		30,500
126	Chevron - Salt Lake City Refinery	Salt Lake City	UT	Chevron Corporation	UT0000175	Direct and Indirect		53,200
127	HollyFrontier - Wood Cross Refinery	Woods Cross	UT	HollyFrontier Corporation	UTG070092, UTR000514	Indirect		39,330
128	Silver Eagle - Wood Cross Refinery	Woods Cross	UT	Silver Eagle Refining	UTR000132, UTR000449	Indirect		15,000
129	Salt Lake City Refinery	Salt Lake City	UT	Marathon Petroleum Corporation		Indirect		58,500
130	Cherry Point Refinery	Blaine	WA	BP	WA0022900	Direct	B	227,000
131	Ferndale Refinery	Ferndale	WA	Phillips 66	WA0002984	Direct		105,000
132	Puget Sound Refinery	Anacortes	WA	Shell Oil Products US	WA0002941	Direct	B	145,000
133	Anacortes Refinery	Anacortes	WA	Marathon Petroleum Corporation	WA0000761	Direct	B	120,000
134	Tacoma Refinery	Tacoma	WA	US Oil & Refining Company	WA0001783, WAR307424	Direct		40,700
135	Superior Refinery	Superior	WI	Calumet Specialty Products Partners LP	WI0003085	Direct		38,000
136	Ergon West Virginia Refinery	Newell	WV	Ergon Inc.	WV0004626	Direct		22,300
137	Antelope Refining	Douglas	WY	Antelope Refining LLC		Indirect		
138	Frontier Refining	Cheyenne	WY	HollyFrontier Corporation	WY0000442	Indirect		48,000
139	Evanston Refinery	Evanston	WY	Silver Eagle Refining		Zero Discharge		3,000
140	Casper Refinery	Casper	WY	Sinclair Oil Corporation		Indirect		24,500
141	Sinclair Refinery	Sinclair	WY	Sinclair Oil Corporation		Zero Discharge		75,000
142	Hermes Consolidated Refinery (d.b.a. Wyoming Refining Company)	Newcastle	WY	Par Pacific Holdings, Inc.		Unknown		18,000
143	BTB Refining LLC	Corpus Christi	TX	Buckeye Partners LP	TX0096474	Direct		60,000

a - The Phillips - LA Refinery Carson Refinery and Phillips - LA Refinery Wilmington Refinery are reflected as one facility in the 2018 EIA Annual Refinery Report. For the purposes of this analysis, the 2018 atmospheric crude distillation capacity for both refineries is listed for Phillips - LA Refinery Wilmington Refinery only.

b - The Flint Hills - Corpus Christi West Refinery and Flint Hills - Corpus Christi East Refinery are reflected as one facility in the 2018 EIA Annual Refinery Report. For the purposes of this analysis, the 2018 atmospheric crude distillation capacity for both refineries is listed for Flint Hills - Corpus Christi East Refinery only.

Appendix B –
Wastewater Treatment in Place at Petroleum Refineries

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Wastewater Treatment in Place at Petroleum Refineries

EPA used WWT data collected as part of the data request, site visit reports, and other publicly available data sources, such as 2011 Office of Air and Radiation (OAR) data, NPDES permit and permit application information, and other publicly available studies and reports to assess end-of-pipe WWT technologies in-place.

Facility Information						Treatment Technologies[a]						Data Source					WWT Categories	
Refinery ID	Refinery Name	Indirect or Direct[f]	City	State	NPDES ID(s)	Oil/water Separation	Second Oil/water Separation Unit	Biological Treatment	Filtration	Effluent Polishing	Description of Effluent Polishing Unit	Data Request for 2016 Data	Site Visit	2011 OAR Information Collection Request	Permit	Other Sources	Categorized by ERG for Petroleum Refining Detailed Study Report	Technologies Identified as "Beyond BAT Technologies"
1	Arctic Slope Regional - North Pole	Unknown	North Pole	AK		No Data	No Data	No Data	No Data	No Data	No Data						No Data	
2	Arctic Slope Regional - Valdez	Unknown	Valdez	AK		No Data	No Data	No Data	No Data	No Data	No Data						No Data	
3	BP - Prudhoe Bay	Indirect	Prudhoe Bay	AK		No Data	No Data	No Data	No Data	No Data	No Data						No Data	
4	ConocoPhillips - Prudhoe Bay	Unknown	Prudhoe Bay	AK		No Data	No Data	No Data	No Data	No Data	No Data						No Data	
5	Kenai Refinery	Direct and Indirect	Kenai	AK	AK0000841	X	X	X						X			Biological Treatment	
6	Goodway Refining	Unknown	Atmore	AL										X			No Treatment Information Available	
7	Hunt Refining - Tuscaloosa	Direct	Tuscaloosa	AL	AL0000973	X	X	X						X	X		Biological Treatment	
8	Shell Chemical Mobile Site	Direct	Saraland	AL	AL0055859	X		X						X	X[b]		Biological Treatment	
9	Lion Oil	Direct	El Dorado	AR	AR0000647	X	X	X	X					X	X		Current BAT Technology	
10	Martin Operating	Direct	Smackover	AR	AR0000591	X								X			Treatment Other than Biological Treatment	
11	Alon - Bakersfield	Direct	Bakersfield	CA		X	X							X			Treatment Other than Biological Treatment	
12	Tesoro Los Angeles Refinery - Carson Operations	Indirect	Carson	CA	CA0000680; CAS000001	X	X					X					Treatment Other than Biological Treatment	
13	Tesoro - LA Refinery Wilmington	Indirect	Wilmington	CA	CA0003778	X	X							X	X		Treatment Other than Biological Treatment	
14	Chevron - Richmond Refinery	Direct	Richmond	CA	CA0005134	X		X	X	X	Constructed wetlands		X				Beyond BAT Technology	Filtration **and** Polishing
15	Chevron - El Segundo Refinery	Direct and Indirect	El Segundo	CA	CA0000337	X	X	X				X					Biological Treatment	
16	Phillips - SF Refinery Rodeo	Direct	Rodeo	CA	CA0005053	X	X	X	X				X				Beyond BAT Technology	Selenium Reduction Plant
17	Phillips - SF Refinery Arroyo Grande	Direct	Arroyo Grande	CA	CA0000051	X	X	X						X	X		Biological Treatment	
18	Phillips - LA Refinery Carson	Indirect	Carson	CA	CA0063185	X	X							X	X		Treatment Other than Biological Treatment	
19	Phillips - LA Refinery Wilmington	Indirect	Wilmington	CA	CA0000035; CA0064611	X	X					X					Treatment Other than Biological Treatment	
20	Exxon - Torrance Refinery	Indirect	Torrance	CA	CA0055387	X		X	X					X	X		Current BAT Technology	
21	Greka	Unknown	Santa Maria	CA				X						X			Biological Treatment	
22	Kern Refining	Unknown	Bakersfield	CA	CAU000200; CAZ458176	X								X			Treatment Other than Biological Treatment	
23	Lunday - Thagard Refinery	Indirect	South Gate	CA	CAP000078; CAZ189100	X	X							X			Treatment Other than Biological Treatment	
24	Paramount Refinery	Indirect	Paramount	CA	CA0056065	X	X		X					X	X		Treatment Other than Biological Treatment	
25	San Joaquin Refinery	Indirect	Bakersfield	CA	CAZ456330	X	X							X			Treatment Other than Biological Treatment	
26	Shell - Martinez Refinery	Direct	Martinez	CA	CA0005789	X	X	X	X				X				Beyond BAT Technology	Selenium Reduction Plant
27	Tesoro - Martinez Refinery	Direct	Martinez	CA	CA0004961	X	X	X	X				X				Current BAT Technology	
28	Valero - Wilmington Refinery	Indirect	Wilmington	CA		X								X			Treatment Other than Biological Treatment	
29	Benicia Refinery	Direct	Benicia	CA	CA0005550	X	X	X	X	X	Chemical addition and settling unit		X				Beyond BAT Technology	Filtration **and** Polishing
30	Wilmington Asphalt Plant	Indirect	Wilmington	CA		X								X			Treatment Other than Biological Treatment	
31	Commerce City Refinery	Direct	Commerce City	CO	CO0001147	No Data	No Data	No Data	No Data	No Data	No Data						No Data	
32	Delaware City Refinery	Direct	Delaware City	DE	DE0000256; DE0050601	X	X	X						X			Biological Treatment	
33	Chevron - Hawaii Refinery	Direct	Kapolei	HI	HI0000329	X	X	X						X			Biological Treatment	
34	Tesoro - Hawaii Refinery	Indirect	Kapolei	HI		X	X	X						X			Biological Treatment	
35	Lemont Refinery	Direct	Lemont	IL	IL0001589	X		X						X	X		Biological Treatment	
36	Joliet Refinery	Direct	Channahon	IL	IL0002861	X	X	X		X	Settling unit and aeration	X					Current BAT Technology	
37	Marathon - Illinois Refinery	Direct and Indirect	Robinson	IL	IL0004073	X	X	X	X			X					Current BAT Technology	
38	Wood River Refinery	Direct	Roxana	IL	IL0000205	X	X	X						X			Biological Treatment	
39	BP Whiting Refinery	Direct	Whiting	IN	IN0000108	X	X	X	X			X					Current BAT Technology	
40	CountryMark Refinery	Direct	Mt Vernon	IN	IN0002470	X	X	X						X			Biological Treatment	
41	Coffeyville Refinery	Direct	Coffeyville	KS	KS0000248	No Data	No Data	No Data	No Data	No Data	No Data						No Data	
42	El Dorado Refinery	Direct	El Dorado	KS	KS0000761	X	X	X						X			Biological Treatment	
43	National CO-OP Refinery	Indirect	McPherson	KS	KS0000337	X	X	X						X			Biological Treatment	
44	Catlettsburg Refinery	Direct	Catlettsburg	KY	KY0000388; KY0070718	X	X	X				X					Biological Treatment	
45	Somerset Refinery	Direct	Somerset	KY	KY0003476			X						X			Biological Treatment	
46	Krotz Springs Refinery	Direct	Krotz Springs	LA	LA0051942	X	X	X						X	X		Biological Treatment	
47	Calcasieu Refinery	Direct	Lake Charles	LA	LA0052370	X	X	X						X	X		Biological Treatment	
48	Calumet - Shreveport Lubricant and Waxes	Direct	Shreveport	LA	LA0032417	X	X	X						X	X		Biological Treatment	
49	Calumet - Princeton Lubricants	Indirect	Princeton	LA	LA0088552	X		X						X			Biological Treatment	
50	Calumet - Cotton Valley Lubricants	Direct	Cotton Valley	LA	LA0005312	X		X						X	X		Biological Treatment	
51	Citgo - Lake Charles Refinery	Direct	Lake Charles	LA	LA0005941	X	X	X						X	X		Biological Treatment	
52	Phillips - Lake Charles Refinery	Direct	Westlake	LA	LA0003026; LA0104469	X	X	X						X	X		Biological Treatment	
53	Alliance Refinery	Direct	Belle Chasse	LA	LA0003115	X	X	X					X				Biological Treatment	
54	Convent Refinery	Direct	Convent	LA	LA0006041	X	X	X					X				Biological Treatment	
55	Shell - Saint Rose Refinery	Direct	Saint Rose	LA	LA0054216	X	X	X	X						X		Current BAT Technology	
56	Baton Rouge Refinery	Direct	Baton Rouge	LA	LA0005584	X		X				X					Biological Treatment	
57	Chalmette Refinery	Direct	Chalmette	LA	LA0004260	X	X	X						X	X		Biological Treatment	
58	Garyville Refinery	Direct	Garyville	LA	LA0045683	X	X	X		X	Effluent settling pond	X					Current BAT Technology	
59	Norco Refinery	Direct	Norco	LA	LA0003522; LA0005762			X		X	Clarifier/settling unit	X					Current BAT Technology	
60	Pelican - Lake Charles Refinery	Direct	Lake Charles	LA	LA0054399	X		X						X			Biological Treatment	
61	Placid - Port Allen Refinery	Direct	Port Allen	LA	LA0039390	X		X	X					X	X		Current BAT Technology	
62	Valero - New Orleans Refinery	Direct	Norco	LA	LA0052051; LAG535403	X	X	X				X					Biological Treatment	
63	Meraux Refinery	Direct	Meraux	LA	LA0003646	X	X	X	X				X				Current BAT Technology	
64	Michigan Refinery	Indirect	Detroit	MI		X	X	X					X				Biological Treatment	
65	Pine Bend Refinery	Direct and Indirect	Rosemount	MN	MN0000418	X	X	X						X			Biological Treatment	
66	St Paul Refinery	Direct	Saint Paul Park	MN	MN0000256	X	X	X						X			Biological Treatment	
67	Pascagoula Refinery	Direct	Pascagoula	MS	MS0001481	X	X	X						X	X[b]		Biological Treatment	
68	Ergon Refinery	Direct	Vicksburg	MS	MS0034711									X	X[b]		No Treatment Information Available	
69	Southland Refinery	Direct	Sandersville	MS	MS0001686	X								X	X[b]		Treatment Other than Biological Treatment	
70	Vicksburg Petroleum Products	Direct	Vicksburg	MS	MS0060976										X		No Treatment Information Available	
71	Laurel Refinery	Direct	Laurel	MT	MT0000264	X	X	X						X			Biological Treatment	
72	Phillips - Billings Refinery	Direct and Indirect	Billings	MT	MT0000256	X	X	X						X			Biological Treatment	
73	Exxon - Billings Refinery	Direct	Billings	MT	MT0000477; MT0028321	X	X	X						X			No Treatment Information Available	
74	Montana Refinery	Indirect	Great Falls	MT	MTPU00118; MTR000556	X	X							X			Treatment Other than Biological Treatment	
75	Dakota Refinery	Indirect	Dickinson	ND	NDR050776	No Data	No Data	No Data	No Data	No Data	No Data						No Data	
76	Mandan Refinery	Direct	Mandan	ND	ND0000248	X		X				X					Biological Treatment	
77	Bayway Refinery	Direct	Linden	NJ	NJ0001511; NJ0026662; NJ0026671	X	X	X						X	X[b]		Biological Treatment	
78	Axeon - Paulsboro	Direct	Paulsboro	NJ	NJ0064921	X	X	X						X			Biological Treatment	
79	PBF - Paulsboro	Direct	Paulsboro	NJ	NJ0005029	X	X	X	X					X	X		Current BAT Technology	
80	Navajo Refinery	Indirect and Injection	Artesia	NM		X	X	X						X			Biological Treatment	
81	Gallup Refinery	Unknown	Jamestown	NM	NM0031071; NMR053168	X		X						X			Biological Treatment	
82	Foreland Refinery	Unknown	Ely	NV		X	X	X						X			Biological Treatment	

Wastewater Treatment in Place at Petroleum Refineries

EPA used WWT data collected as part of the data request, site visit reports, and other publicly available data sources, such as 2011 Office of Air and Radiation (OAR) data, NPDES permit and permit application information, and other publicly available studies and reports to assess end-of-pipe WWT technologies in-place.

Facility Information						Treatment Technologies[a]						Data Source					WWT Categories	
Refinery ID	Refinery Name	Indirect or Direct[f]	City	State	NPDES ID(s)	Oil/water Separation	Second Oil/water Separation Unit	Biological Treatment	Filtration	Effluent Polishing	Description of Effluent Polishing Unit	Data Request for 2016 Data	Site Visit	2011 OAR Information Collection Request	Permit	Other Sources	Categorized by ERG for Petroleum Refining Detailed Study Report	Technologies Identified as "Beyond BAT Technologies"
83	Toledo Refinery	Direct	Oregon	OH	OH0002461	X	X	X	X					X	X		Current BAT Technology	
84	Lima Refinery	Direct	Lima	OH	OH0002623	X	X	X						X			Biological Treatment	
85	Ohio Refinery	Direct	Canton	OH	OH0005657	X	X	X						X			Biological Treatment	
86	Toledo Refinery	Direct	Oregon	OH	OH0002763									X			No Treatment Information Available	
87	Ponca City Refinery	Direct	Ponca City	OK	OK0000256	X		X				X					Biological Treatment	
88	Tulsa East Refinery	Direct and Indirect	Tulsa	OK	OK0001309	X		X						X			Biological Treatment	
89	Tulsa West Refinery	Direct	Tulsa	OK	OK0000876	X	X	X						X			Biological Treatment	
90	Ardmore Refinery	Direct	Ardmore	OK	OK0001295	X		X				X					Biological Treatment	
91	Wynnewood Refinery	Direct	Wynnewood	OK	OK0000825; OK0046027									X			No Treatment Information Available	
92	American Refining	Direct	Bradford	PA	PA0002674	X	X	X						X			Biological Treatment	
93	Trainer Refinery	Direct	Trainer	PA	PA0012637	X	X	X						X	X[b]		Biological Treatment	
94	Philadelphia Refinery	Direct and Indirect	Philadelphia	PA	PA0011533; PA0012629	X		X						X	X[b]		Biological Treatment	
95	United Refining	Direct	Warren	PA	PA0005304	X	X	X						X			Biological Treatment	
96	Tennessee Refinery	Indirect	Memphis	TN	NG670074; TNR056522; 5-NN1-02	X	X					X					Treatment Other than Biological Treatment	
97	Calumet - San Antonio	Unknown	San Antonio	TX	TXG670214	X								X			Treatment Other than Biological Treatment	
98	Big Springs Refinery	Direct	Big Spring	TX	TX0104515	X	X	X	X					X	X		Current BAT Technology	
99	Borger Refinery	Direct	Borger	TX	TX0009148	X	X	X	X					X	X	X[c,d]	Beyond BAT Technology	Ion Exchange
100	Sweeny Complex	Direct	Brazoria	TX	TX0007536	X	X	X		X	Brine tank (coagulation and flocculation)	X					Current BAT Technology	
101	Citgo - Corpus Christi Refinery	Direct	Corpus Christi	TX	TX0006211	X	X	X						X			Biological Treatment	
102	Tyler Refinery	Indirect	Tyler	TX	TX0001449	X		X						X			Biological Treatment	
103	McKee Plant	Indirect	Sunray	TX	TX0115851	X	X	X	X					X	X		Current BAT Technology	
104	Beaumont Refinery	Direct	Beaumont	TX	TX0118737	X	X							X	X		Treatment Other than Biological Treatment	
105	Baytown Refinery	Direct	Baytown	TX	TX0006271	X	X	X		X	Chemical oxidation			X	X		Current BAT Technology	
106	Flint Hills - Corpus Christi East Refinery	Direct	Corpus Christi	TX	TX0006599	X	X	X	X					X	X		Current BAT Technology	
107	Flint Hills - Corpus Christi West Refinery	Direct	Corpus Christi	TX	TX0006289	X	X	X	X			X					Current BAT Technology	
108	LyondellBasell - Houston Refinery	Direct and Indirect	Houston	TX	TX0003247	X								X	X		Treatment Other than Biological Treatment	
109	Galena Park Crude & Condensate	Indirect	Galena Park	TX	TX0135640	No Data	No Data	No Data	No Data	No Data	No Data						No Data	
110	Lazarus Refinery	Unknown	Nixon	TX		No Data	No Data	No Data	No Data	No Data	No Data						No Data	
111	Marathon - Galveston Bay Refinery	Direct	Texas City	TX	TX0003522	X	X	X	X					X	X		Current BAT Technology	
112	Marathon - Texas City Refinery	Direct	Texas City	TX	TX0003697	X	X	X	X			X					Current BAT Technology	
113	Pasadena Refinery	Indirect	Pasadena	TX	TX0004626	X								X	X		Treatment Other than Biological Treatment	
114	Motiva - Port Arthur Refinery	Direct	Port Arthur	TX	TX0005835	X	X	X						X	X		Biological Treatment	
115	Valero - Port Arthur Refinery	Direct	Port Arthur	TX	TX0005991	X	X	X						X	X		Biological Treatment	
116	Deer Park Refinery	Direct	Deer Park	TX	TX0004871; TX0004863	X		X						X	X		Biological Treatment	
117	Silsbee Refinery	Direct	Silsbee	TX	TX0003204	X		X							X		Biological Treatment	
118	Total Petrochemicals - Port Arthur Refinery	Direct	Port Arthur	TX	TX0004201	X	X	X						X	X		Biological Treatment	
119	Valero - Texas City Refinery	Direct	Texas City	TX	TX0006009; TXG670007	X	X	X	X			X					Current BAT Technology	
120	Valero - Houston Refinery	Direct	Houston	TX	TX0002976	X	X	X						X	X		Biological Treatment	
121	Valero - Corpus Christi East Refinery	Direct	Corpus Christi	TX	TX0006904	X								X			Treatment Other than Biological Treatment	
122	Valero - Corpus Christi West Refinery	Direct	Corpus Christi	TX	TX0063355	X								X	X[b]		Treatment Other than Biological Treatment	
123	Three Rivers Refinery	Direct	Three Rivers	TX	TX0088331	X	X	X	X					X	X		Current BAT Technology	
124	Western Refinery	Indirect	El Paso	TX		X								X			Treatment Other than Biological Treatment	
125	Big West Oil Refinery	Unknown	North Salt Lake	UT		X	X							X			Treatment Other than Biological Treatment	
126	Chevron - Salt Lake City Refinery	Direct and Indirect	Salt Lake City	UT	UT0000175	X		X						X			Biological Treatment	
127	HollyFrontier - Wood Cross Refinery	Indirect	Woods Cross	UT	UTG070092; UTR000514	X	X	X						X			Biological Treatment	
128	Silver Eagle - Wood Cross Refinery	Indirect	Woods Cross	UT	UTR000132; UTR000449	X		X						X			Biological Treatment	
129	Salt Lake City Refinery	Indirect	Salt Lake City	UT		No Data	No Data	No Data	No Data	No Data	No Data						No Data	
130	Cherry Point Refinery	Direct	Blaine	WA	WA0022900	X	X	X						X	X		Biological Treatment	
131	Ferndale Refinery	Direct	Ferndale	WA	WA0002984	X	X	X						X		X[c]	Biological Treatment	
132	Puget Sound Refinery	Direct	Anacortes	WA	WA0002941	X	X	X		X	Final pond (chemical addition and settling)	X					Current BAT Technology	
133	Anacortes Refinery	Direct	Anacortes	WA	WA0000761	X	X	X		X	Settling pond	X					Current BAT Technology	
134	Tacoma Refinery	Direct	Tacoma	WA	WA0001783; WAR307424	X	X	X						X			Biological Treatment	
135	Superior Refinery	Direct	Superior	WI	WI0003085	X	X	X						X			Biological Treatment	
136	Ergon West Virginia Refinery	Direct	Newell	WV	WV0004626	X	X	X						X			Biological Treatment	
137	Antelope Refining	Indirect	Douglas	WY		No Data	No Data	No Data	No Data	No Data	No Data						No Data	
138	Frontier Refining	Indirect	Cheyenne	WY	WY0000442	X	X	X						X		X[c,e]	Biological Treatment	
139	Evanston Refinery	Zero Discharge	Evanston	WY		X								X			Treatment Other than Biological Treatment	
140	Casper Refinery	Indirect	Casper	WY		No Data	No Data	No Data	No Data	No Data	No Data						No Data	
141	Sinclair Refinery	Zero Discharge	Sinclair	WY		No Data	No Data	No Data	No Data	No Data	No Data						No Data	
142	Wyoming Refinery	Unknown	Newcastle	WY		X		X						X			Biological Treatment	
143	BTB Refining LLC	Direct	Corpus Christi	TX	TX0096474	No Data	No Data	No Data	No Data	No Data	No Data						No Data	

Note: ERG collected available data about pre-treatment technologies in place at petroleum refineries, including stripping units (*e.g.,* sour water stripper), benzene recovery units, and brine treatment units. Refineries may consider these units part of the refining process and may not report

Note: The technology field is populated in the table if the wastewater treatment technology is incorporated anywhere in the system. For this analysis, if the facility has the technologies associated with BAT bases, ERG assumed they were in the expected order.

Note: ERG presented information based solely on survey or site visit data where available.

a - ERG did not verify if the oil/water separators are operated in series.

b - Although there was permit data for this refinery in the permit database, the permit database did not list any treatment technologies for this refinery. Therefore, the data presented for the refinery are solely based on the 2011 OAR data.

c - Identified treatment in place from the BP and Purdue/Argonne Studies (see Section 7 for list of studies)

d - Identified treatment in place from 2009 report titled *Lessons Learned on Long-Term Operation of MBBR for Refinery WWT* (Cabral, 2009).

e - Identified treatment in place from report titled Enhancing Nitrification in an Oil Refinery WWTP with IFAS (Flournoy, 2008).

f - The data sources used to identify direct or indirect discharge of wastewater is presented and discussed in the Industry Profile Memo.