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Petroleum Coke: Industry and Environmental Issues

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Summary

In early 2013, media outlets around Detroit, Michigan began publishing stories about large piles of petroleum coke stored along the Detroit Riverfront. Petroleum coke (petcoke) is a black-colored solid composed primarily of carbon, and may contain limited amounts of elemental forms of sulfur, metals and non-volatile inorganic compounds. Petcoke is essentially chemically inert. Petcoke exposure is considered to pose few human health or environmental risks, but may present significant nuisance concerns. The material in Detroit was the byproduct of the nearby Marathon Refinery's processing of heavy crude oils derived, in part, from Canadian oil sands deposits. The situation gained national attention with the publication of an article in the *New York Times* ("A Black Mound of Canadian Oil Waste Is Rising over Detroit," *New York Times,* May 17, 2013). The piles of petcoke sparked local concerns over the potential impacts of the material on human health and the environment, and whether these concerns were adequately addressed by local, state, and federal regulations. As petroleum refining is a nationwide commercial industry, these concerns may arise in other regions.

Petcoke is a co-product of several distillation processes used in refining heavy crude oil. Nearly half of U.S. petroleum refineries (56 or more) use a coking process to convert heavy crude oils into refined petroleum products, and more refineries may follow suit to take advantage of the supply of heavy crude oils from Canada's oil sands projects. Although it is a refining co-product, petcoke has economic value as both a heating fuel and raw material in manufacturing. In 2012, the U.S. Energy Information Administration reported that U.S. refineries produced in excess of 56 million metric tons of petcoke, of which 80% was exported.

The U.S. Environmental Protection Agency has surveyed the potential human health and environmental impacts of petcoke through its High Production Volume (HPV) Challenge Program and found the material to be highly stable and non-reactive at ambient environmental conditions. Most toxicity analyses of petcoke find it has a low potential to cause adverse effects on aquatic or terrestrial environments as well as a low health hazard potential in humans, with no observed carcinogenic, reproductive, or developmental effects. Cases of repeated-dose and chronic inhalation of fugitive dust (as generated during petcoke handling and storage) in animal studies do appear associated with respiratory inflammation. Emissions from the combustion of petcoke, however, can have impacts on human health and the environment, including the release of common pollutants, hazardous substances, and high levels of the greenhouse gas, carbon dioxide.

While some federal statutes address certain environmental impacts of petcoke's life-cycle, most regulatory action and oversight has been undertaken at the state and local levels, generally through facility-specific permitting requirements. Federally, petcoke is exempted from classification as either a solid or hazardous waste under the Resource Conservation and Recovery Act (RCRA) and is not considered a hazardous substance under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Petcoke facilities may be regulated under certain provisions of the National Pollutant Discharge Elimination System (NPDES) permit program, as authorized by the Clean Water Act (CWA), if it is determined that runoff from sites where it is stored has the potential to transport the substance to nearby surface waters. The handling of petcoke may also create instances of reduced air quality due to releases of fugitive dust into the atmosphere. Most of the impacts of fugitive dust are localized; and thus, much of the regulatory oversight is implemented at the local and state level. Whether such oversight is providing adequate protection is among the issues that have been raised.

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Background

Some Members of Congress have expressed concern about storage and management of petroleum coke (petcoke) in their districts. Despite a lack of data on observed health impacts, local concerns have included potential human health and environmental impacts of fugitive dusts and runoff into waterways. Broader concerns have also been raised about the carbon dioxide (greenhouse gas) emissions from petcoke combustion.

Petcoke is the co-product of several processes used in petroleum refining to upgrade "residuum" into gasoline and middle distillate-range fuels. Residuum (or resid) remains after refineries initially distill heavy crude oils. Petcoke is a black-colored solid composed primarily of carbon, and may contain limited amounts of elemental forms of sulfur, metals, and non-volatile inorganic compounds.

The petroleum industry and federal regulators characterize petcoke as a "co-product" because it may have some commercial value as a boiler fuel and as a raw material in manufacturing. Nearly half of U.S. petroleum refineries employ "coking" processes. Refineries also produce petcoke as a by-product of catalysis, which refineries later consume as a fuel.

In addition to the existing suite of coking refineries, other refineries may add coking processes to take advantage of increased supplies of heavy crude oils from Canada's oil sand projects. Meanwhile, newly available light crude oil from U.S. unconventional shale projects and the Texas Permian Basin is leading some coking refineries to cut back on coking. At present, it is uncertain whether petcoke production will increase, remain steady or even decline, given the changing slate of U.S. crude oil supplies. Nevertheless, the export and demand for U.S. petcoke has been rising recently.

Community stakeholders have grown concerned over the potential effects on public health and the environment related to the production, storage, transportation, and use of petcoke. Some of these impacts include concerns over air quality due to fugitive dust, water quality due to run-off, and the potential for toxic and other emissions (including greenhouse gas emissions) from its combustion as a fuel source. In light of these concerns, industry, regulators, and compliance officers may be interested in best practices related to the storing, containing, and managing of petcoke.

Petcoke Uses

Petcoke may be combusted as fuel in industrial and power generating plants. Cement plants and power plants are currently the two greatest consumers of petcoke. There is some limited use as space heating and in commercial brick kilns in Europe, and a small but emerging market as a metallurgical coal blending component for the steel industry. In the United States, the high sulfur content may limit the petcoke in a coal/petcoke blend in a plant designed for coal. However, more recently designed Circulating Fluidized Bed (CFB) boilers can accommodate 100% high sulfur coke.[1]

Fuel grade petcoke can substitute for "steam coal" in power plant boilers, having the advantage of a higher heating value (discussed below). Conventional coal-fired boilers can blend petcoke with

[1] Pet Coke Consulting LLC, http://www.petcokeconsulting.com/primer/index.html.

steam coal, and newer boiler designs have replaced steam coal with petcoke entirely.[2] Cement plants consume fuel-grade petcoke in rotary kilns.

Anode grade calcined petcoke is the principal raw material used in manufacturing carbon anodes for use in aluminum smelting. The anodes act as conductors of electricity and as a source of carbon in the electrolytic cell that reduces alumina into aluminum metal. Carbon anode manufacturers, predominantly captive operations of aluminum smelting companies, purchase anode grade calcined petcoke, mix it with pitch binders, press the mixture into blocks, and then bake the mixture to form a finished, hardened carbon anode.

Petcoke Composition

Petcoke is composed primarily of carbon. The specific chemical composition of petcoke depends on the composition of the petroleum feedstock used in refining. Petcoke impurities (i.e., the non-elemental carbonaceous substances) include some residual hydrocarbons left over from processing (referred to as volatiles), as well as elemental forms of nitrogen, sulfur, nickel, vanadium, and other heavy metals. These impurities exist as a hardened residuum captured within coke's carbon matrix. **Table 1** provides an observed range of petcoke properties for green and calcined petcoke.

Table 1. Petcoke Elemental Composition

By Weight Percent

Composition	Green	Calcined
Carbon	89.58–91.80	98.40
Hydrogen	3.71–5.04	0.14
Oxygen	1.30–2.14	0.02
Nitrogen	0.95–1.20	0.22
Sulfur	1.29–3.42	1.20
Ash (including heavy metals such as nickel and vanadium)	0.19–0.35	0.35
Carbon-Hydrogen Ratio	18:1–24:1	910:1

Source: U.S. Environmental Protection Agency, Screening-Level Hazard Characterization, Petroleum Coke Category, June 2011; and H.W. Nelson, *Petroleum Coke Handling Problems*, 1970.

Notes: The process of "calcining" converts green coke to almost pure carbon, with a defined structure to produce carbon anodes for the aluminum industry.

Petcoke Compared to Metallurgical Coke and Coal

Petcoke has a significantly high heating value compared to metallurgical coke (metcoke) and bituminous coals (see **Table 2**). The higher heating value comes at the cost of higher sulfur and nitrogen content, however. Ash content is relatively low, compared to coal, but much of it is in the form of heavy metals. Due to the severe thermal environment in which petcoke forms, there is

[2] Thermal coal is sometimes called "steam coal" because it is used to fire boiler plants that produce steam for electricity generation and industrial uses.

very little combustible volatile material. The low volatile content, in comparison to coal and other fossil fuels, makes petcoke more difficult to ignite and sustain combustion.[3]

Bituminous coal includes two subtypes: thermal and metallurgical.[4] Metallurgical coke is made from low ash, low sulfur bituminous coal, with special coking properties. To produce metcoke, special coke ovens heat metallurgical grade coal at temperatures of 1,000ºF to 2,000ºF to fuse fixed carbon and inherent ash, and drive off most of the volatile matter.[5] Approximately 1.5 tons of metallurgical coal will produce one ton of metcoke. The final product is a nearly pure carbon source with sizes ranging from basketballs (foundry coke) to a fine powder (coke breeze).

Table 2. Petcoke vs. Metcoke and Coal

Heating Value and Price

Fuel	Coal Rank	Btu / lb.	$/Short Ton
Petcoke	n.a.	14,200	See Note
Metcoke	Metallurgic	12,600	171.51
Steam Coal			
Pittsburgh #8	Bituminous	13,000	68.25
Illinois #6	Bituminous	11,000	45.40
Powder River Basin	Sub-bituminous	8,800	10.30

Source: MIT, The Future of Coal Appendices, P5, http://web.mit.edu/coal/The_Future_of_Coal_Appendices.pdf, and EIA, Coal News and markets, http://www.eia.gov/coal/news_markets/.

Notes: Steam Coal Prices as of July 19, 2013. Petcoke prices track steam coal prices, but at a discount that may range from 15% to 85%. Recent prices have been closer to 67% of steam coal prices.

Petcoke Grades

The coking processes described above produce "green coke," which then requires additional thermal processing to remove any residual hydrocarbons (volatile matter) to increase the percentage of elemental carbon. Thermal processing lowers the potential toxicity of the coke. Depending on the coking operation temperatures, length of coking-time, and quality of the crude oil feedstock, one of several grades of petcoke can be produced:

- *sponge coke*, the most common type of regular-grade petcoke, used as a solid fuel (see **Figure 1**);
- *needle coke,* a premium-grade coke made from special petroleum feedstock, used in the manufacture of high-quality graphite electrodes for the steel industry;
- *shot coke,* produced from heavy petroleum feedstock, used as fuel, but less desirable than sponge coke (see **Figure 2**);
- *purge coke*, produced by flexi-coking, used as a fuel in coke-burning boilers; or

[3] Anthony Pavone, "Converting Petroleum Coke to Electricity," Proceedings from the 14th National Industrial Energy Technology Conference, Houston, TX, April 22-23, 1992, http://repository.tamu.edu/bitstream/handle/1969.1/92212/ESL-IE-92-04-47.pdf.

[4] Bituminous coals are mined throughout the eastern United States range but generally have higher sulfur and nitrogen contents than western coals.

[5] Oxbow, *Metallurgical Coke*, http://www.oxbow.com/Products_Industrial_Materials_Metallurgical_Coke.html. Also see Grande Cache Coal, *Met Coke 101*, http://www.gccoal.com/about-us/met-coal-101.html.

- *catalyst coke,* carbon deposited on catalysts, used in various refining processes and burned off and used as a fuel in the refining process; not recoverable in a concentrated form.

Figure 1. Sponge Coke

Source: John D. Elliott, Shot Coke: Design & Operations, http://www.fwc.com/publications/tech_papers/oil_gas/shotcoke.pdf.

Figure 2. Shot Coke

Partially Crushed

Source: John D. Elliott, Shot Coke: Design & Operations, http://www.fwc.com/publications/tech_papers/oil_gas/shotcoke.pdf.

Coking Refineries and Outputs

The fleet of petroleum refineries operating throughout the United States has steadily declined in the past several decades as refining capacity has become concentrated in larger refineries. At present, some 115 refineries (and refinery complexes) produce over 17 million barrels per day of motor fuels and other petroleum products. Nearly half (56) have the coking capacity to convert heavy crude oils[6] (see the **Appendix** to this report).

Coking capacity has been concentrated in refineries operating along the Gulf Coast, the historic refining center of the United States and primary destination for crude oil imports. However, to take advantage of the increasing supply of heavier crude oils from Canada's oil sands projects, several Midwest refineries have added coking conversion capacity.

U.S. refineries have the capacity to process 2.5 million barrels per day of petroleum resid. The Gulf Coast not only represents the greatest refining capacity (9.3 million barrels per day), it also represents also the greatest coking capacity (1.5 million barrels per day).

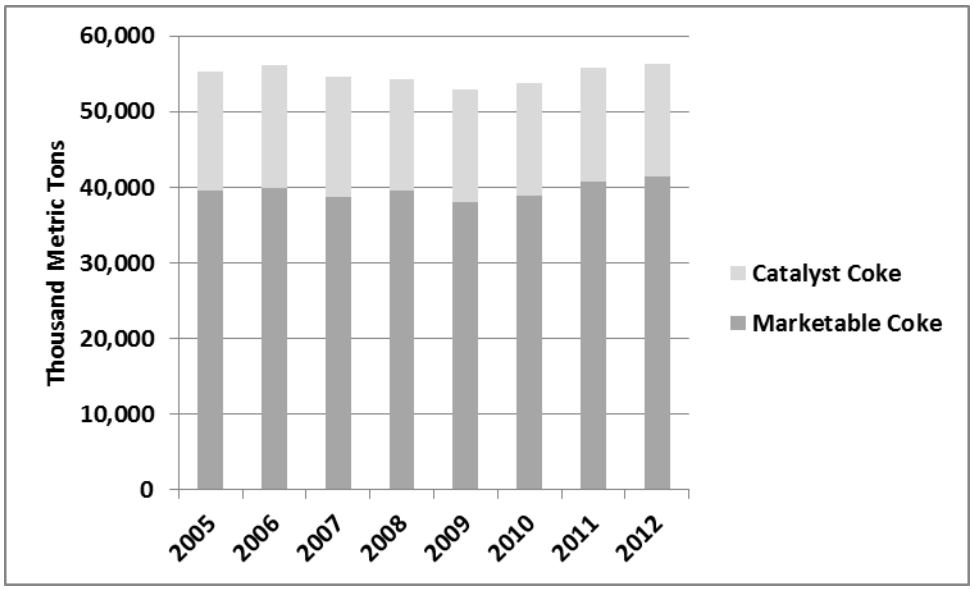
U.S. petcoke production has remained constant over the last decade for the reason that refining capacity has remained constant (see **Figure 3**). In 2012, the U.S. Energy Information Administration (EIA) reported that U.S. refineries produced 42 million metric tons of marketable

[6] For further background on the refining industry, see CRS Report R41478, *The U.S. Oil Refining Industry: Background in Changing Markets and Fuel Policies*, by Anthony Andrews et al.

petcoke and another 15 million metric tons of catalyst coke.[7] For the purpose of comparison, the United States produced 9.3 million tons of coke from metallurgical grade coal[8] and more than 1.2 billion tons of coal in 2012.[9]

Figure 3. U.S. Refinery Net Petcoke Production

Thousand Metric Tons per Year



Source: U.S. Energy Information Administration, U.S. Refinery Net Production, http://www.eia.gov/dnav/pet/pet_pnp_refp2_dc_nus_mbbl_a.htm.

Notes: Catalysts used in various refining processes (e.g., catalytic cracking) become deactivated from the buildup of carbon deposits, In order to reactivate the catalysts; the carbon is burned off and used as a fuel by the refinery. The carbon coke is not recoverable in a concentrated form.

Overall, petcoke production reflects refinery capacity utilization rate, which represents the use of the refinery atmospheric crude oil distillation units. The rate is calculated by dividing the gross input to these units by the operable refining capacity of the units. The utilization rate has averaged from 82% to 88%.[10] U.S. refineries have been producing approximately 40 million metric tons of marketable petcoke annually over the period of 2007 through 2012. Refineries, however, need enough light-heavy price spread (LHS) between coker feedstock (heavy resid) and light products (gasoline, jet, and diesel) to run their coking units profitably. With the rising availability of U.S. produced light-sweet crude oil, however, some refineries may choose to cut back on coking, and thus produce less coke. These and other variables lend uncertainty to whether petcoke production will increase, remain steady or decline in the coming years.

[7] The U.S. Energy Information Administration reported that U.S. refinery net production of petroleum coke in 2012 was 310,481 thousand barrels (U.S. Refinery Net Production, http://www.eia.gov/dnav/pet/pet_pnp_refp2_dc_nus_mbbl_a.htm). 1 metric ton is the equivalent of 5.51 barrels.

[8] American Iron and Steel Institute, *Annual Statistical Report*, 2012, p.80. Production and Consumption of Coke.

[9] U.S. Energy Information Administration, *Monthly Energy Review*, Coal, June 2013, http://www.eia.gov/totalenergy/data/monthly/index.cfm#coal.

[10] U.S. Energy Information Administration, Refinery Utilization and Capacity, http://www.eia.gov/dnav/pet/pet_pnp_unc_dcu_nus_a.htm.

Petcoke Storage Terminals

Refineries temporarily stockpile petcoke on their facilities, but because they generally lack sufficient storage space must transport it regularly to avoid production slowdowns. Typically, coker drums are mounted over railroad tracks so that coke can be discharged directly into open hopper or gondola cars. The rail cars then transport the petcoke to calcining plants or to temporary storage terminals.

A complete accounting of independent terminals that store petcoke exceeds the scope of this report. However, a CRS survey identified at least four companies with petroleum coke as a primary business line: SSM Petroleum Coke LLC, TCP Petroleum coke Corp, DTE Petroleum Coke, LLC, and Kinder Morgan Petroleum Coke Gp LC.[11] SSM Petroleum Coke is an affiliate of Oxbow Carbon LLC (Koch Industries, Inc.). Koch Carbon, LLC specialize in the global sourcing, supply, handling, and transportation of bulk commodities including, but not limited to, petcoke. TCP Petroleum Coke Corporation is a joint venture between CITGO Petroleum Corporation (CITGO) and RWE Power AG, offering a diversified marketing network to over 30 countries. DTE Petroleum Coke is a subsidiary of DTE Energy, a diversified energy company that includes electric/gas utilities. DTE Energy has reportedly removed the petcoke it stored at its Detroit Bulk Storage site along the Detroit River.[12] Kinder Morgan Petroleum Coke L.P. advertises that it is responsible for handling over 10 million tons of petcoke through several terminals located on the Texas Gulf Coast.

Petcoke Market and Exports

Petcoke competes with both coal and metcoke in the international market. Its comparatively higher heating values makes it an economic substitute for steam coal. However, its granular physical properties may add to the cost of material handling, which is reflected in a discounted price compared with coal in the United States. Petcoke prices track coal prices but at discounts in the range of 15% to 85%.[13] Recently U.S. petcoke price have ranged from 67% to 68% of coal prices.

U.S. petcoke exports have steadily increased over the last decade, as the U.S. market has given way to increased demand overseas (see **Figure 4**). In 2012, 80% of marketable (i.e., non-catalyst) petcoke was exported. The largest recipients of U.S. petcoke exports in 2012 were China (14%), followed by Japan (11%), Mexico (9%), and Turkey (7%). China's demand has steadily increased during the last decade.

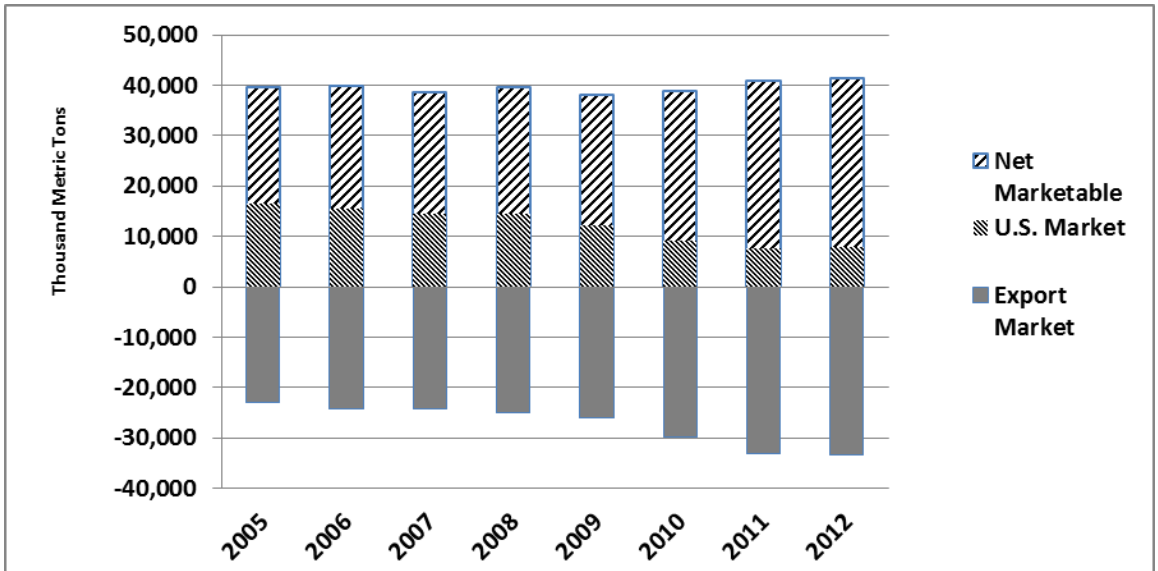
[11] A search through http://www.Manta.com produced six U.S. companies matching "petroleum coke."

[12] "Pet Coke Piles Along Detroit River Clear Away," *CBS Detroit*, August 27, 2013, http://detroit.cbslocal.com/2013/08/27/pet-coke-piles-along-detriot-river-cleared-away/.

[13] Personal communication with Mike Stewart, Jacobs Consultancy/Petroleum Coke Quarterly.

Figure 4. Net Petcoke Production vs. Exports

Thousand Metric Tons per Year



	2005	2006	2007	2008	2009	2010	2011	2012
Net Marketable	39,474	39,818	38,694	39,529	38,105	38,895	40,749	41,376
U.S. Market	16,458	15,577	14,450	14,461	12,185	9,155	7,677	7,952
Export Market	-23,016	-24,241	-24,244	-25,068	-25,920	-29,740	-33,071	-33,424

Source: U.S. Energy Information Administration, U.S. Refinery Net Production, http://www.eia.gov/dnav/pet/pet_pnp_refp2_dc_nus_mbbl_a.htm, and Petroleum Coke Exports by Destination, http://www.eia.gov/dnav/pet/pet_move_expc_a_eppc_eex_mbbl_a.htm.

Potential Health and Environmental Impacts

The recent increase in coking capacity in the United States has raised concerns over the potential impacts of petcoke on both human health and the environment. Local concerns include air quality hazards, water quality hazards, and potential exposure to toxic substances. These impacts may arise during various stages of petcoke's life-cycle, including its production, handling, storage, transportation, combustion, and use. Broader concerns have been raised about the greenhouse gas (i.e., carbon dioxide) emissions from petcoke combustion. The focus of this report, however, is on the impacts of handling and storage, not on end-use combustion.

EPA's Hazard and Toxicity Characterizations

In recent years, the U.S. Environmental Protection Agency (EPA) has surveyed the potential human health and environmental impacts of petcoke through its High Production Volume (HPV) Challenge Program. The HPV Challenge Program, initiated jointly by EPA, Environmental Defense Fund (EDF), American Petroleum Institute (API), and American Chemistry Council (ACC), was instituted for several purposes, including

1. to collect health and environmental effects data on industrial chemicals produced in the United States in high volumes,

2. to provide the public with basic hazard information that would allow for active participation in environmental decision-making at all levels—local, state, and federal, and
3. to provide EPA with valuable hazard and toxicity information to support its mission of protecting human health and welfare.

Companies have sponsored research into more than 2,200 HPV chemicals, with approximately 1,400 administered directly through the HPV Challenge Program and the remainder administered indirectly through international efforts.[14] API sponsored a testing group for the petcoke category,[15] which produced an analysis in December 2007.[16] This analysis was supplemented by EPA, after stakeholder comments, and published in June 2011.[17]

The findings from EPA's hazard characterization of petcoke are summarized in the following sections.

Environmental Fate

Most chemical analyses of petcoke, as referenced by EPA, find it to be highly stable and non-reactive at ambient environmental conditions.

Due to the extreme conditions under which petcoke is produced, qualities such as melting point, boiling point, vapor pressure, and water solubility exist well outside the range of ambient conditions. If released to the environment, petcoke would not be expected to undergo many of the environmental fate pathways which could lead to environmental risks. Depending on the particle size and density of the material, terrestrial releases of petcoke become incorporated into the soil or transported via wind or surface water flow. If released to the aquatic environment, petcoke incorporates into sediment or floats on the surface, depending on the particle size and density in relation to water. Chemically, petcoke is essentially inert. That is, petcoke does not vaporize into the atmosphere, does not react chemically in the presence of water, and does not react chemically in the presence of light. Furthermore, it is not biodegradable, nor does it bio-accumulate substances—such as toxic chemicals—into its structure.[18]

Environmental Toxicity

Most eco-toxicity analyses of petcoke, as referenced by EPA, find it has a low potential to cause adverse effect on aquatic or terrestrial environments.

The environmental effects of petcoke have been tested along various pathways for exposure in the environment, including both aquatic and terrestrial endpoints in plants and animals. Aquatic and terrestrial toxicity tests have been performed to assess the hazard of petcoke releases to

[14] U.S. Environmental Protection Agency's High Production Volume (HPV) Challenge Program, http://www.epa.gov/chemrtk/index.htm.

[15] U.S. Environmental Protection Agency, *Robust Summaries & Test Plans: Petroleum Coke*, http://www.epa.gov/chemrtk/pubs/summaries/ptrlcoke/c12563tc.htm.

[16] The American Petroleum Institute Petroleum HPV Testing Group, Petroleum Coke Category Analysis and Hazard Characterization, submitted to EPA December 28, 2007, http://www.epa.gov/hpv/pubs/summaries/ptrlcoke/c12563rr2.pdf.

[17] U.S. Environmental Protection Agency, Screening-Level Hazard Characterization, Petroleum Coke Category, June 2011, http://www.epa.gov/chemrtk/hpvis/hazchar/Category_Petroleum%20Coke_June_2011.pdf.

[18] Petcoke's volatilization is negligible, its rate of hydrolysis is negligible, and its rate of atmospheric photo-oxidation is negligible. Neither biodegradation nor bioaccumulation is applicable.

representative aquatic organisms and terrestrial soil-dwelling invertebrates and plants. In these studies, petcoke was found to be non-toxic to terrestrial plants and animals, non-toxic to aquatic animals (both vertebrates and invertebrates), and showed only slight effects on aquatic plants at the exposure levels tested (i.e., studies found slight growth inhibition in freshwater algae).[19] (The exposure levels and durations were conducted in accordance with EPA and Organization for Economic Co-operation and Development (OECD) recommendations, although, presumably, these tests could be re-administered at higher dosages or intervals to assess the effects of greater concentrations.)

Human Health Effects

Most toxicity analyses of petcoke, as referenced by EPA, find it has a low health hazard potential in humans, with no observed carcinogenic, reproductive, or developmental effects. Only animal cases studies of repeated-dose and chronic inhalation have shown respiratory inflammation attributed to the non-specific effects of dust particles rather than the specific effects of petcoke.

Inhalation of and skin contact with petcoke were assessed to be the most likely exposure routes to humans. Most repeated-dose inhalation exposure studies (on rats and primates) found cases of irreversible respiratory effects and significantly increased lung weights. These effects were considered to be non-specific responses of the respiratory tract to high concentrations of dust particles rather than compound specific-induced effects. Petcoke was not found to be carcinogenic via inhalation. No excess skin or visceral cancers were observed in a lifetime skin painting study. Petcoke was not found to produce genetic mutations in bacteria and mammalian cells in standard in vitro toxicity tests or to produce chromosome aberrations of bone marrow in standard in vivo toxicity tests. Petcoke was not found to produce any reproductive or developmental effects following repeated inhalation or exposure to the skin.[20]

Reactivity

Petcoke is generally stable under normal conditions; however, the substance has the potential to become flammable or explosive. Emissions from the combustion—either accidentally or purposefully—of petcoke can have impacts on human health and the environment, including the release of common pollutants, hazardous substances, and greenhouse gases.

When petcoke is combusted, common pollutants and hazardous decomposition products may be produced such as carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen oxides, particulate matter, and heavy metals, depending upon the chemical composition of the feedstock (see **Table 1**

[19] Environmental toxicity studies referenced by the EPA analysis include Wildlife International, Ltd., *Petroleum Coke: A 96-Hour Static-Renewal Acute Toxicity Test with the Fathead Minnow (Pimephales promelas), Final Report,* Project No. 472A-1134, 2006; Wildlife International, Ltd., *Petroleum Coke: A 48-Hour Static-Renewal Acute Immobilisation Test with the Cladocern (Daphnia magna), Final Report,* Project No. 472A-112, 2006; Wildlife International, Ltd., *Petroleum Coke: A 96-Hour Toxicity Test with the Freshwater Alga (Selenastrum capricornutum), Final Report,* Project No. 472A-114, 2006; Wildlife International, Ltd., *Petroleum Coke: A 21-Day Toxicity Test to Determine the Effects of the Test Substance on Seedling Emergence and Growth of Terrestrial Plants, Final Report,* Project No. 472-102, 2006; Wildlife International, Ltd., *Petroleum Coke: A 14-Day Acute Toxicity Test with the Earthworm (Eisenia fetida), Final Report,* Project No. 472-101, 2006.

[20] Toxicity studies referenced by the EPA analysis include Huntingdon Life Sciences, Study No. 03-4246, "Petroleum Coke: Reproduction/Developmental Toxicity Screening Study in Rats via Nose-Only Inhalation Exposures," 2006; Klonne, D. R., Burns, J. M., Halder, C. A., Holdsworth, C. E. and Ulrich, C. E., "Two Year Inhalation Study of Petroleum Coke in Rats and Monkeys." *American Journal of Industrial Medicine*, 11:375-389, 1987; and IRDC (International Research & Development Corporation), "Chronic Inhalation Toxicity Study of Petroleum Coke (Delayed Process) in Rats and Monkeys," API Publication number 32-30234, 1985.

for the chemical composition of petcoke). These releases may take place unintentionally, through the natural or unintended combustion of surface or air-borne dust particles, or intentionally, through the combustion of petcoke for electrical power generation or other like purposes.

Petcoke's use as a fuel is criticized because it commonly has higher greenhouse gas emissions relative to the amount of heat it generates when burned. **Table 3** presents potential carbon dioxide (CO_2) emissions for petcoke in comparison to metallurgical coke and several grades of steam coal. When petcoke or coal combust, CO_2 forms from one carbon atom (C) uniting with two oxygen atoms (O).[21] Assuming complete combustion, 1 pound of carbon combines with 2.667 pounds of oxygen to produce 3.667 pounds of carbon dioxide. Petcoke with a carbon content of 90% and a heating value of 14,200 Btu per pound emits about 232 pounds of carbon dioxide per million Btu when completely burned.[22] Comparatively, Powder River Basin coal with a carbon content of 48% and a heating value of 8,800 Btu per pound emits about 202 pounds of carbon dioxide per million Btu when completely burned, or 15% less than petcoke. Because coal has high hydrogen-to-carbon ratio compared to petcoke, part of its energy content comes from the combustion of hydrogen that is emitted as water vapor instead of carbon dioxide.

Table 3. Petcoke vs. Coal: Combustion Emissions

Fuel	Coal Rank	Sulfur %wt.	Btu / lb.	Carbon %wt.	CO_2 lbs./ Million Btu
Petcoke	n.a.	1.5–6.0	14,200	89–92	232
Metcoke	Metallurgic	0.4–0.7	12,600	91–92	266
Steam Coal					
Pittsburgh #8	Bituminous	3.0	13,000	73–74	207
Illinois #6	Bituminous	3.9	11,000	60–61	201
Powder River Basin	Sub-bituminous	0.5	8,800	48–49	202

Source: MIT, The Future of Coal Appendices, p. P5.

Notes: Potential carbon dioxide emissions calculated by percent carbon ÷ Btu per pound x 36,670 = pounds (lbs.) of carbon dioxide per million Btu.

Federal Regulatory Requirements

Various aspects of the production, handling, storage, transportation, combustion, and use of petcoke have been addressed at local, state, and federal levels to protect human health and the environment. While some federal statutes address certain environmental impacts of petcoke's life-cycle, most regulatory action and oversight has been undertaken at the state and local levels, generally through facility-specific permitting requirements. With few exceptions, petcoke is not specifically regulated by local, state, or federal codes.[23] Rather, it is petcoke's potential

[21] B. D. Hong and E. R. Slatick, *Carbon Dioxide Emission Factors for Coal*, U.S. Energy Information Administration, http://www.eia.gov/coal/production/quarterly/co2_article/co2.html.

[22] Potential carbon dioxide emissions can be calculated by use of the following formula: percent carbon ÷ Btu per pound x 36,670 = pounds (lbs.) of carbon dioxide per million Btu.

[23] In a survey of state statutes, conducted by the U.S. Library of Congress's Law Library for this report on August 9, 2013, California was found to be the only state which has passed laws to directly manage the environmental impacts from the handling, storage, and transportation of petcoke. California State Code on petcoke included California Code–HSC Section 40459 (requirements for enclosing piles of petcoke when storing the substance prior to shipment), http://www.leginfo.ca.gov/cgi-bin/displaycode?section=hsc&group=40001-41000&file=40440-40459, and California

contribution to more general hazards (e.g., air and water quality impacts such as haze, fugitive dust, and stormwater runoff) that is monitored and controlled through various permitting and reporting requirements at the state and local levels. This report focuses on the federal response to petcoke and on the rules that may be implemented during the handling, storage, and transportation phases of petcoke's life-cycle. States may also have their own laws or regulations related to the handling, storage, and transportation of petcoke, specifically, or high-production-volume industrial substances like petcoke, more generally; a full review of state and local code is beyond the scope of this report.

Regulatory agencies at all levels of government commonly aim to manage the human health and environmental impacts of industrial materials (e.g., petcoke) based upon thorough assessments of their hazardous exposure pathways. Because of its relative inertness, exposure to petcoke is considered to pose few human health and environmental risks. Thus, federal law generally exempts petcoke from classification as either a solid or hazardous waste. Despite these exemptions, petcoke may nevertheless present significant nuisance concerns. A "nuisance" is the unreasonable, unwarranted and/or unlawful use of property, which causes inconvenience or damage to others, either to individuals or to the general public.[24] A nuisance may not violate any regulatory standard or cause demonstrable environmental or health impacts; however, if a nuisance interferes with a person's use of his or her property, it may be the basis for a lawsuit for damages or an injunction. For example, fugitive dust from petcoke storage piles can be deposited on and in nearby waterways, outdoor areas, or residents' homes, leaving a black- or grey-colored residue. This deposition may result in undesirable and unsightly conditions, interfering with residents' comfort and use of their property. Similarly, dust from coke piles can challenge the operations of commercial or industrial facilities, such as pharmaceutical research and production plants, electronics assembly, or fuel cell membrane manufacturing. Dust from nearby coke piles can increase filtration costs or threaten the integrity of strict quality control standards required for such high technology operations.

In light of these issues, the monitoring and management of petcoke at the federal level is summarized in the following sections.

Waste Classifications

Federal law generally exempts petcoke from classification as either a solid or hazardous waste.

The exemption for petcoke from classification as either a solid or hazardous waste stems from the scope of the statutory term "solid waste" as decided in *American Mining Congress v. U.S. EPA*.[25] In that decision, the court held that materials recycled and reused in an ongoing manufacturing or

Code–VEH Section 23114 (requirements for the transportation of petcoke by vehicle), http://www.leginfo.ca.gov/cgi-bin/displaycode?section=veh&group=23001-24000&file=23100-23135.

[24] A nuisance may be either a private nuisance or a public nuisance. An activity constitutes a *private* nuisance if it is a substantial and unreasonable invasion of another's interest in the private use and enjoyment of land, without involving trespass. Private nuisance actions are brought by the aggrieved landowner. An activity is a *public* nuisance if it creates an "unreasonable" interference with a right common to the general public. Unreasonableness may rest on the activity significantly interfering with, among other things, public health and safety. Public nuisance cases are usually brought by the government rather than private entities, but may be brought by the latter if they suffer special injury.

[25] *American Mining Congress v. U.S. EPA*, 824 F.2nd 1177 (D.C. Cir. 1987). The court held that the EPA exceeded its authority by amending its definition of "solid waste" under the Resource Conservation and Recovery Act (RCRA) to include secondary materials destined for reuse within an industry's ongoing production process. The court held that EPA's interpretation is contrary to RCRA's plain language (§ 1004(5) defines solid waste to include "discarded material"), and that EPA's inclusion of materials retained for immediate use as discarded material strains the everyday usage of that term.

industrial process were not considered to be "discarded," and hence, not considered to be "solid wastes." Furthermore, in 1998, EPA identified a list of petroleum refining wastes that would be subject to federal regulations applicable to the management of hazardous waste established under the Resource Conservation and Recovery Act (RCRA).[26] In this rulemaking, EPA stated that petcoke is not a refining waste, but rather a "co-product" of the refining process.[27] In separate rulemaking, EPA included petcoke among other fuels in its definition of "traditional fuels" (at 40 C.F.R. 241.2). As a result of these determinations, unless or until it is discarded, petcoke would not be subject to federal waste management requirements established under RCRA.

Petcoke would not be subject to the federal cleanup authorities of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, often referred to as Superfund)[28] because of the exclusion of petroleum from the statute. The response authorities of CERCLA specifically apply to the release of hazardous substances, pollutants, or contaminants into the environment. Hazardous substances under CERCLA are broader than hazardous wastes under RCRA and include hundreds of toxic chemicals. However, CERCLA defines a hazardous substance, pollutant, or contaminant to exclude "petroleum, including crude oil or any fraction thereof which is not otherwise specifically listed or designated as a hazardous substance."[29] EPA's interpretation has been that hazardous substances present in petroleum that are naturally occurring or are normally added during the refining process are fractions of the petroleum that would fall within the scope of the exclusion from CERCLA. EPA's position has been that CERCLA may be applied to the cleanup of wastes containing petroleum, if the wastes contain hazardous substances that are not part of the petroleum product itself.[30] Hazardous substances that may leach from a petroleum product into the environment, and therefore no longer be part of the petroleum product, may raise other issues.

Industrial Stormwater Runoff

The handling and storage of petcoke may be regulated under certain provisions of the National Pollutant Discharge Elimination System (NPDES) permit program,[31] as authorized by the Clean

[26] 42 U.S.C. 6901 et seq. For further discussion of the authorities of RCRA, see CRS Report RL30798, *Environmental Laws: Summaries of Major Statutes Administered by the Environmental Protection Agency*, coordinated by David M. Bearden.

[27] See U.S. Environmental Protection Agency, Final Rule, "Hazardous Waste Management System; Identification and Listing of Hazardous Waste; Petroleum Refining Process Wastes; Land Disposal Restrictions for Newly Identified Wastes; and CERCLA Hazardous Substance Designation and Reportable Quantities," August 6, 1998, 63 *Federal Register* 42110. "The coke product itself may best be characterized as a co-product of the coking operation, while the principal products are the light ends that are returned to the refining process. Thus, the Agency is affirming that the conventional coking operation is a production process, resids are normal feedstocks to this process and petroleum coke is a legitimate fuel product." Id, at page 42121.

[28] 42 U.S.C. 9601 et seq. For further discussion of the authorities of CERCLA, see CRS Report R41039, *Comprehensive Environmental Response, Compensation, and Liability Act: A Summary of Superfund Cleanup Authorities and Related Provisions of the Act*, by David M. Bearden.

[29] The definition of the term "hazardous substance" in Section 101 (14) of CERCLA is codified at 42 U.S.C. 9601(14). The definition of the terms "pollutant" and "contaminant" in Section 101(33) of CERCLA is codified at 42 U.S.C. 9601(33).

[30] U.S. Environmental Protection Agency, Office of General Counsel, *Scope of the CERCLA Petroleum Exclusion Under Sections 101(14) and 104(a)(2)*, July 31, 1987. Section 104(a)(2) of CERCLA, as originally enacted in 1980, defined the term "pollutant or contaminant." Section 101(f) of the Superfund Amendments and Reauthorization Act of 1986 re-designated the definition of this term in Section 101(33) of CERCLA, cited above. The full text of the 1987 guidance is available at http://www.epa.gov/compliance/resources/policies/cleanup/superfund/petro-exclu-mem.pdf.

[31] For further discussion on the NPDES Permit Program, see CRS Report 97-290, *Stormwater Permits: Status of EPA's Regulatory Program*, by Claudia Copeland, as well as U.S. Environmental Protection Agency, "National Pollutant

Water Act (CWA),[32] if it is determined that runoff from storage sites due to rain or snowmelt has the potential to transport the substance to nearby surface waters.

Activities that take place at industrial facilities, such as material handling and storage, are often exposed to the weather. As runoff from rain or snowmelt comes into contact with these activities, it can pick up pollutants and transport them to a nearby storm sewer system or directly to a river, lake, or coastal water. Recognition of the water quality problems of stormwater runoff led Congress in 1987—when it last comprehensively amended the CWA—to direct EPA to implement a specific permit program for stormwater discharges from industrial sources and municipalities (P.L. 100-4). These stormwater requirements were incorporated into the National Pollutant Discharge Elimination System (NPDES), a comprehensive permit program authorized in Section 402 of the CWA. Under the act, it is illegal to discharge pollutants from point sources (e.g., industrial plant pipes, sewage treatment plants, or storm sewers) into the nation's waters without a permit. NPDES permits are the fundamental compliance and enforcement mechanism of the law. EPA manages the NPDES stormwater program in four states (Idaho, Massachusetts, New Hampshire, and New Mexico), plus the District of Columbia and most U.S. territories, and has delegated that authority to the remaining 46 states and the Virgin Islands. Therefore, the vast majority of industrial and other facilities obtain NPDES permit coverage for stormwater discharge through their state. Petroleum refining facilities are one of several categories of facilities that are specifically covered under the CWA stormwater regulatory program.

Common requirements for coverage under an industrial stormwater permit include development of a written stormwater pollution prevention plan (SWPPP), implementation of control measures, and submittal of a request for permit coverage, usually referred to as the Notice of Intent (NOI). The SWPPP is a written assessment of potential sources of pollutants in stormwater runoff and control measures that will be implemented at the facility to minimize the discharge of these pollutants in runoff from the site. These control measures include site-specific best management practices, maintenance plans, inspections, employee training, and reporting. The procedures detailed in the SWPPP must be implemented by the facility and updated as necessary, with a copy of the SWPPP kept on-site. The industrial stormwater permit also requires collection of visual, analytical, and compliance monitoring data to determine the effectiveness of implemented best management practices. Stormwater permits are valid for up to five years and must be renewed.

Best management practices for the prevention of industrial stormwater runoff include ensuring adequate storage facilities and equipment, spill detection and repair, and employee training. Many environmental agencies, including EPA, provide extensive summaries of best management practices.[33]

Fugitive Dust

The handling, storage, and transportation of petcoke may create instances of reduced air quality due to weather or activity related releases of fugitive dust into the atmosphere. Most of the

Discharge Elimination System," http://cfpub.epa.gov/npdes/.

[32] 33 U.S.C. §§1251-1387. For further discussion of the authorities of CWA, see CRS Report RL30030, *Clean Water Act: A Summary of the Law*, by Claudia Copeland.

[33] An extensive list of best management practices for stormwater runoff, included under the general categories of "good housekeeping practices," "minimize exposure," "erosion and sediment control," and "management of runoff," can be found in U.S. Environmental Protection Agency, *Industrial Stormwater, Fact Sheet Series, Sector C: Chemical and Allied Products Manufacturing and Refining*, U.S. EPA Office of Water, EPA-833-F-06-018, December 2006, http://www.epa.gov/npdes/pubs/sector_c_chemical.pdf.

impacts of fugitive dust are localized; and thus, much of the regulatory oversight is implemented at the local and state level and generally takes the form of a fugitive dust control program.

Facilities may be required by state or local agencies to develop a fugitive dust control program for many reasons. State and local agencies, based on their own air emission measurements, their own code of regulations, environmental consent orders, or complaints of nuisance, may require a fugitive dust program from any facility if it processes, uses, stores, transports, or conveys bulk materials from a highly emitting dust source. Further, these programs are often a necessary component to any air permitting requirements at the state and local level, including permits to install, operate, or decommission a facility. At the federal level, Clean Air Act (CAA)[34] National Ambient Air Quality Standards (NAAQS) have been set nationwide by EPA for particulate matter (PM).[35] NAAQS are standards for outdoor (ambient) air that are intended to protect public health and welfare from harmful concentrations of pollution. If fugitive dust generation is determined to be an issue at a facility that produces, handles, stores, transports, or uses petcoke, and if the facility is situated in an area that is identified by the EPA as "nonattainment" for PM NAAQS, then it may be possible for state authorities to ask the facility to report on and manage its fugitive dust emissions—if it is not doing so already—within the context of their State Implementation Plans (SIPs).

Whether petcoke storage is considered a significant source of PM depends a number of factors, including how the coke is handled (e.g., number of drops), individual petcoke particle sizes and the size of the overall petcoke piles, as well as the storage method. In some cases, petcoke may have been processed through pulverization that generates dust which could be monitored and controlled at $PM_{2.5}$ (less than 2.5 microns). $PM_{2.5}$ can produce greater health impacts because it is more respirable than "coarse" PM which is larger than 2.5 microns. PM that is greater than about 10 microns is generally considered less of a health risk because it is less respirable. As illustrated in **Figure 1**, most forms of petcoke are comprised of granules orders of magnitude larger than $PM_{2.5}$, and are not likely respirable, but may pose a nuisance concern. Also, in some cases, petcoke storage may be ephemeral because markets support frequent elimination of stored inventories.

The management of fugitive dust commonly involves the submission of a fugitive dust plan to state or local agencies. These plans would include an analysis of the quantity and opacity of fugitive dust from the facility; a determination of the type of fugitive dust control methods that would be the most effective, taking into account the quantity, moisture content, specific gravity, and particle size distribution of the bulk materials on-site; an assessment of the type of control technologies, methods, and equipment to be implemented or installed, and the schedule for implementation or installation; and a report on the level of recordkeeping and maintenance requirements for activities that are implemented under the dust program. Fugitive dust plans commonly set out an operating program designed to significantly reduce emissions to the lowest level that a particular source is capable of achieving by the application of control technology that is both reasonably available and based on technological and economic feasibility. The requirement for fugitive dust plans for a given facility and the plan's enforcement remain at the discretion of the state and local agencies.

[34] 33 U.S.C. §§1251-1387. For further discussion of the authorities of CWA, see CRS Report RL30030, *Clean Water Act: A Summary of the Law*, by Claudia Copeland.

[35] For further discussion of particulate matter, see CRS Report RL34762, *The National Ambient Air Quality Standards (NAAQS) for Particulate Matter (PM): EPA's 2006 Revisions and Associated Issues*, by Robert Esworthy.

Best management practices for the prevention of fugitive dust include ensuring adequate storage facilities and equipment, emission detection and repair, and employee training. Many environmental agencies, including the U.S. EPA, provide extensive summaries of best management practices.[36]

Regulatory Standards for Petcoke Combustion in Power Generation

The combustion of petcoke, and the resulting emissions from this combustion, may be regulated under several different provisions in the CAA and the CWA.

When petcoke is used for industrial or power generating purposes, emissions from its combustion are regulated under the standards set on the respective facilities. For example, some of the federal regulations which may be implemented by the combustion of petcoke at industrial or power generating facilities include EPA's New Source Performance Standards for Electricity Generating Units, Clean Air Interstate Rule (CAIR) for NO_x and SO_2, CAA Title V Permitting Requirements, GHG Reporting Program, Steam Electric Effluent Guidelines, recently finalized Mercury and Air Toxics Standards/Utility MACT, and proposed Coal Combustion Waste Rules, as well as the various state rules under State Implementation Plans.

A full description of these requirements is beyond the scope of this report.

Conclusion

Petcoke production depends on the crude oil demand of operating refineries that in tum depend on the availability of heavy and light crude oils and their comparative cost advantages. The domestic production of petcoke may increase as U.S. refineries continue to add coking capacity to take advantage of competitively priced petroleum produced from Canada's oil sands and other heavy crude oil sources. Conversely, as U.S. light crude oil production increases, U.S. coking refineries may find an economic advantage in switching to lighter crude oils and idle their coking units. If that occurs, the production and export of U.S. petcoke may reverse.

Community stakeholder and regulator concerns about fugitive dust emission into the air and stormwater runoff into waterways are likely to continue in situations where there is not sufficient mitigation and abatement. In some states, permit conditions have been imposed to mitigate the emissions from petcoke storage and handling. The specific permit conditions (e.g., enclosed conveyors and storage silos) are generally based on best management practices as determined by state regulators. At the federal level, Clean Air Act (CAA) National Ambient Air Quality Standards (NAAQS) for outdoor (ambient) air continue to protect public health and welfare from harmful concentrations of particulate matter pollution. If states determine that fugitive dust generation is an issue at a facility that produces, handles, stores, transports, or uses petcoke, and if the facility is situated in an area that is identified by the EPA as "nonattainment" for PM NAAQS, then state authorities may ask the facility to report on and manage its fugitive dust emissions—if it is not doing so already—within the context of their State Implementation Plans (SIPs). States and localities may also have their own regulatory standards for fugitive dust, independent of whether the area is in nonattainment of federal PM NAAQS.

[36] An extensive list of emission control techniques for fugitive dust can be found in U.S. Environmental Protection Agency, *Fugitive Dust Background Document and Technical Information Document for Best Available Control Measures*, U.S. EPA Office of Air and Radiation, EPA-450/2-92-004, September 1992, http://www.epa.gov/oaqps001/lead/pdfs/1992_09_fugitive_dust.pdf.

In light of these concerns, industry, regulators, and compliance officers have shown a continued interest in impact assessment and best practices related to the storing, containing, and managing of petcoke. Two bills have been introduced in the 113th Congress regarding petcoke: H.R. 2298, the Petroleum Coke Transparency and Public Health Study Act (introduced 6/6/2013), and S. 1388, Petroleum Coke Transparency and Public Health Study Act (introduced 7/30/2013). Each would require the Secretary of Health and Human Services, in consultation with the Administrator of the Environmental Protection Agency, to conduct a study on the public health and environmental impacts of the production, transportation, storage, and use of petcoke.

Appendix. Petroleum Refining and Petcoke Production

Petroleum refineries use several key processes to convert crude oil systematically into refined products; these include atmospheric distillation, hydrocracking, hydrotreating, reforming, and ultimately coking. The refinery's atmospheric distillation column initially separates crude oil into lighter streams of hydrocarbons based on their boiling temperatures. The gasoline-range of petroleum distillates condense at the top of the column. Middle distillate fuels (kerosene, jet, and diesel fuels) condense in the middle of the column. The heavier-still range of gas oils condense lower in the column. Residuum, a heavy tar-like material figuratively referred to as the "bottom of the barrel," has such a high boiling temperature that it remains at the bottom of the column.

In order to produce more gasoline, refineries "crack" the heavier distillation products into the gasoline range with heat, pressure, hydrogen, and catalysts. Hydrotreating removes elemental sulfur from gasoline and middle-distillate fuels through a reaction with hydrogen gas.

Coking dates back to the late 1920s, but became an important process for U.S. refineries during the 1980s and 1990s. During this time, refineries faced a dwindling supply of light sweet crude oils favored for making gasoline and distillate fuels. They began switching to increasingly more available, heavy-sour crude oils. The resid that remained after refining heavier crudes initially found use as "ship's bunker fuel" and as boiler fuel in electric power plants. With the implementation of Clean Air Act regulations, power plants switched from boiler fuel to cleaner burning natural gas. During the same era, the demand for gasoline increased, and refineries began adding coking to convert the "resid" into motor fuels.

Coking initially converts petroleum residuum into lighter range hydrocarbons; low-Btu gas that can serve as a fuel in refinery operations; and "green coke."

Refineries commonly employ one of three types of coking processes:

- *delayed coking*—a thermal cracking process that converts residuum into gasified products streams and concentrated carbon coke. It is called "delayed coking" because cracking takes place in a coke drum rather than in a furnace or reactor. The residuum is heated in a furnace first, and then fed into the bottom of the coke drum. The "cracked" light products are drawn off at the top of the drum and sent to a fractionator which separates out gasoline, naphtha, gas oil, and lighter products. The drums are "de-coked" by hydraulic or mechanical cutting processes. In delayed coking, one coking drum is filled while a second is de-coked (emptied). First commercialized in 1928, delayed coking predominates among U.S. refineries that process heavy crude oil. See **Figure A-1**.
- *flexi-coking*—a continuous fluidized-bed thermal cracking process integrated with coke gasification. It converts most of the carbon coke to carbon monoxide (CO), which is then mixed with carbon (C2) and lighter hydrocarbons to produce a low quality fuel gas. The process was commercialized in 1976. See **Figure A-2**.
- *fluid coking*—a variation on flexi-coking that uses a cyclone to separate the coke. The process was commercialized in 1954.

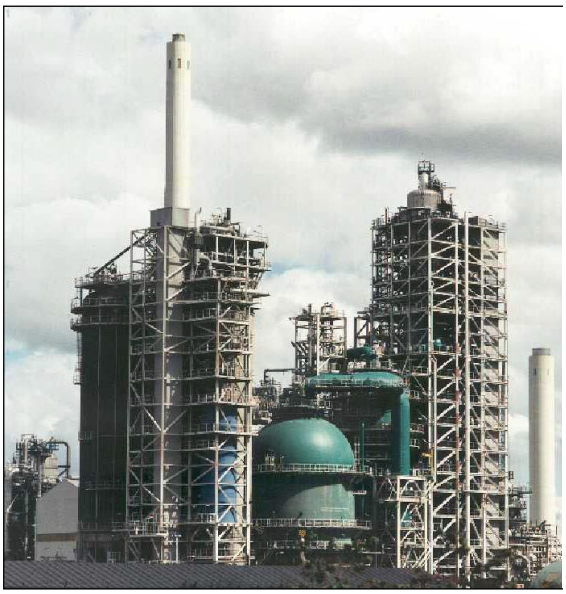
Figure A-1. Shell Delayed Coking Unit

Puget Sound Refinery

Source: Shell.

Figure A-2. ExxonMobil Flexi-Coking Unit

Rotterdam, The Netherlands

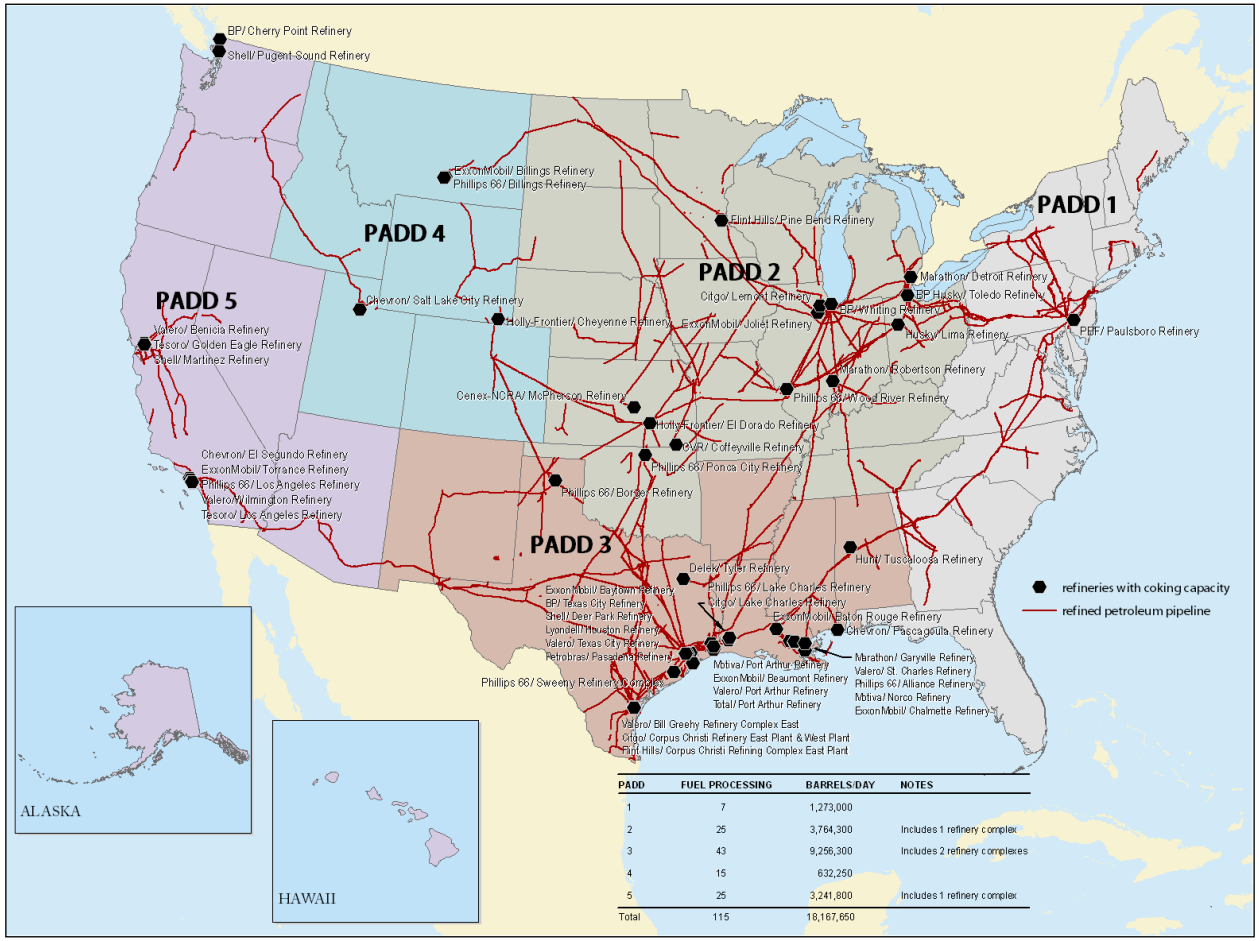


Source: ExxonMobil Research & Engineering Company, Upgrading of Heavy Oils with Flexicoking.

Independent processors convert the green coke into to either fuel grade or anode grade coke depending upon the crude oil refined and the coking process used.

Figure A-3. U.S. Refineries with Coking Capacity

by Petroleum Adminstration for Defense Districts (PADD)

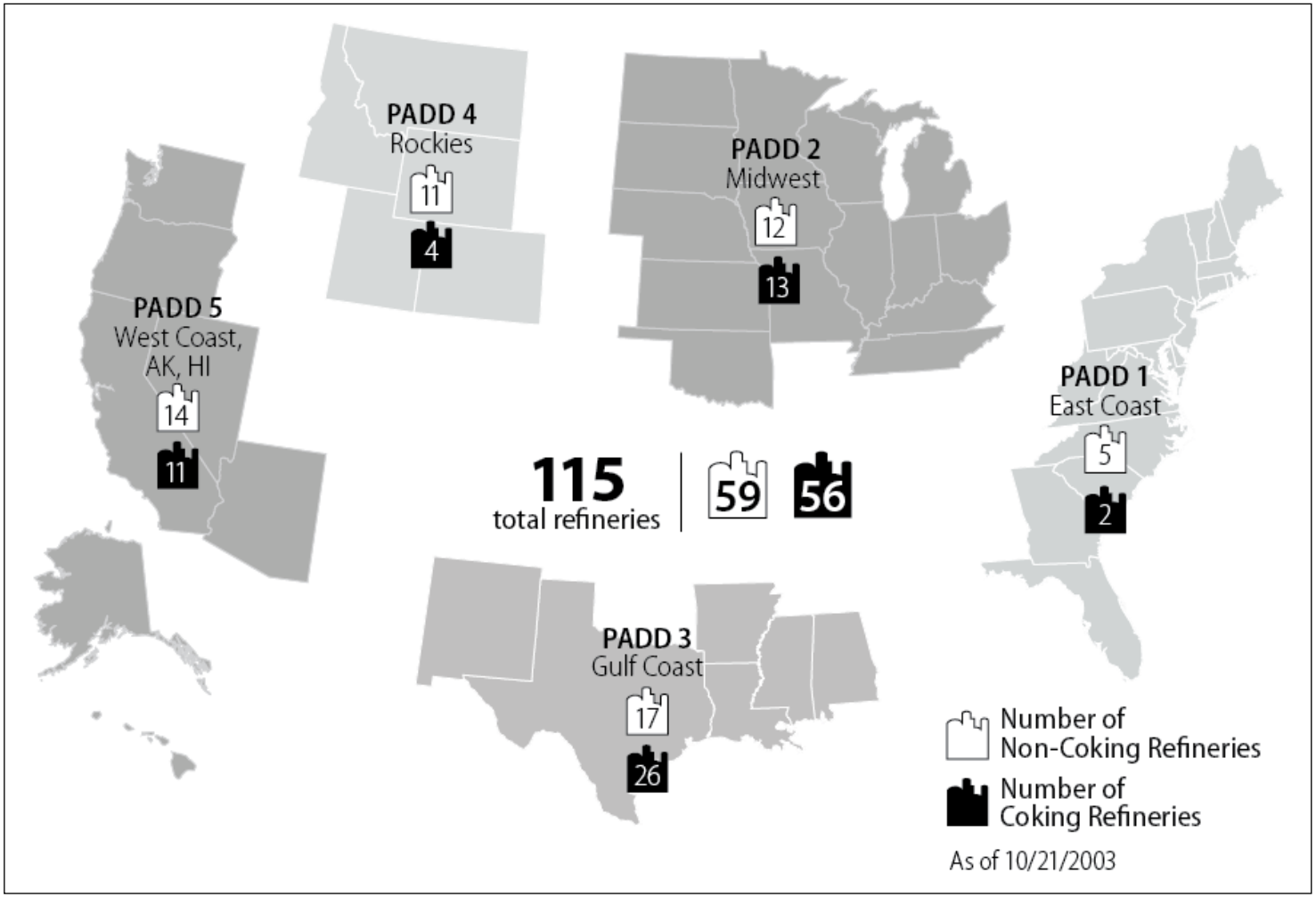


PADD	FUEL PROCESSING	BARRELS/DAY	NOTES
1	7	1,273,000	
2	25	3,764,300	Includes 1 refinery complex
3	43	9,256,300	Includes 2 refinery complexes
4	15	632,250	
5	25	3,241,800	Includes 1 refinery complex
Total	115	18,167,650	

Source: Prepared for CRS by the Library of Congress.

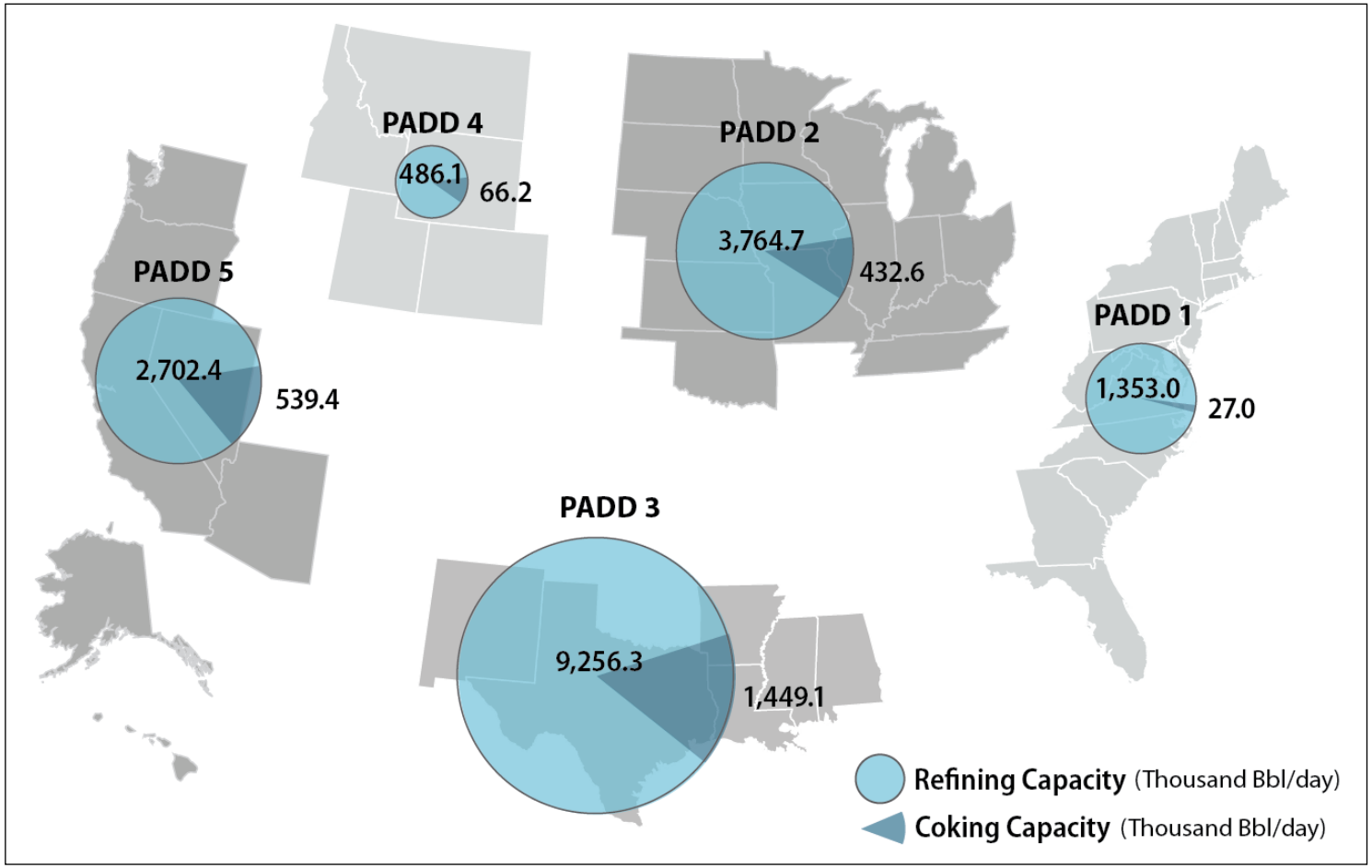
Notes: See **Table A-1** for a list of refineries.

Figure A-4. Coking Refineries by PADD



Source: Compiled by CRS from various sources.

Figure A-5. Refining and Coking Capacity by PADD



Source: Compiled by CRS from various sources.

Notes: Coking capacity denotes the throughput capacity to process petroleum resid.

Table A-1. U.S. Refineries with Coking Capacity

Advertised Refinery Capacity in Barrels per Day (Bbl/D)

PADD	St	City	Zip	Facility	Bbl/D	Congressional District
1	NJ	Paulsboro	08066	PBF/ Paulsboro Refinery	180,000	1st New Jersey
1	DE	Delaware	19706	PBF/Delaware City	190,000	At large Delaware
2	IL	Roxana	62084	Phillips 66/ Wood River Refinery	306,000	12th Illinois
2	IL	Drummond	60410	ExxonMobil/ Joliet Refinery	250,000	16th Illinois
2	IL	Robinson	62454	Marathon/ Robinson Refinery	206,000	15th Illinois
2	IL	Lemont	60439	Citgo/ Lemont Refinery	167,000	3rd Illinois
2	IN	Whiting	46394	BP/ Whiting Refinery	413,000	1st Indiana
2	KS	El Dorado	67042	Holly-Frontier/ El Dorado Refinery	135,000	4th Kansas
2	KS	Coffeyville	67337	CVR Coffeyville Refinery	115,000	2nd Kansas
2	KS	McPherson	67460	Cenex-NCRA/ McPherson Refinery	85,000	1st Kansas
2	MI	Detroit	48217	Marathon/ Detroit Refinery	106,000	13th Michigan
2	MN	Rosemont	55068	Flint Hills/ Pine Bend Refinery	320,000	2nd Minnesota
2	OH	Oregon	43616	BP-Husky/ Toledo Refinery	160,000	9th Ohio
2	OH	Lima	45804	Husky/ Lima Refinery	155,000	4th Ohio
2	OK	Ponca City	74601	Phillips 66/ Ponca City Refinery	187,000	3rd Oklahoma
3	AL	Tuscaloosa	35401	Hunt/ Tuscaloosa Refinery	72,000	7th Alabama
3	LA	Baton Rouge	70805	ExxonMobil/ Baton Rouge Refinery	503,500	2nd Louisiana
3	LA	Garyville	70051	Marathon/ Garyville Refinery	490,000	2nd Louisiana
3	LA	Lake Charles	70601	Citgo/ Lake Charles Refinery	425,000	3rd Louisiana
3	LA	Norco	70079	Valero/ St. Charles Refinery	270,000	6th Louisiana
3	LA	Belle Chasse	70037	Phillips 66/ Alliance Refinery	247,000	1st Louisiana

PADD	St	City	Zip	Facility	Bbl/D	Congressional District
3	LA	Westlake	70669	Phillips 66/ Lake Charles Refinery	239,000	3rd Louisiana
3	LA	St. Charles Parrish	70079	Motiva/ Norco Refinery	234,700	6th Louisiana
3	LA	Chalmette	70043	ExxonMobil/ Chalmette Refinery	192,500	1st Louisiana
3	MS	Pascagoula	39581	Chevron/ Pascagoula Refinery	330,000	4th Mississippi
3	TX	Port Arthur	77641	Motiva/ Port Arthur Refinery	600,000	14th Texas
3	TX	Baytown	77520	ExxonMobil/ Baytown Refinery	573,000	36th Texas
3	TX	Texas City	77590	Marathon/ Texas City Refinery	475,000	14th Texas
3	TX	Beaumont	77703	ExxonMobil/ Beaumont Refinery	365,000	14th Texas
3	TX	Deer Park	77536	Shell/ Deer Park Refinery	340,000	36th Texas
3	TX	Corpus Christi	78407	Valero/ Bill Greehy Refinery Complex East	325,000	27th Texas
3	TX	Port Arthur	77641	Valero/ Port Arthur Refinery	310,000	14th Texas
3	TX	Houston	77017	Lyondell/ Houston Refinery	268,000	29th Texas
3	TX	Sweeny	77463	Phillips 66/ Sweeny Refinery Complex	247,000	14th Texas
3	TX	Texas City	77590	Valero/ Texas City Refinery	245,000	14th Texas
3	TX	Port Arthur	77642	Total/ Port Arthur Refinery	174,000	14th Texas
3	TX	Corpus Christi	78047	Citgo/ Corpus Christi Refinery East & West Plant	165,000	27th Texas
3	TX	Corpus Christi	78408	Flint Hills/ Corpus Christi Refining Complex East Plant	150,000	27th Texas
3	TX	Borger	79007	Phillips 66/ Borger Refinery	146,000	13th Texas
3	TX	Pasadena	77506	Petrobras/ Pasadena Refinery	100,000	29th Texas
3	TX	Tyler	75702	Delek/ Tyler Refinery	60,000	1st Texas
4	MT	Billings	59101	ExxonMobil/ Billings Refinery	60,000	At Large Montana
4	MT	Billings	59101	Phillips 66/ Billings Refinery	58,000	At Large Montana
4	UT	Salt Lake City	84116	Chevron/ Salt Lake City Refinery	45,000	2nd Utah

PADD	St	City	Zip	Facility	Bbl/D	Congressional District
4	WY	Cheyenne	82007	Holly-Frontier/ Cheyenne Refinery	52,000	At Large Montana
5	CA	Paramount	90723	Alon/ California Refineries	70,000	40th California
5	CA	El Segundo	90245	Chevron/ El Segundo Refinery	290,000	33rd California
5	CA	Benicia	94510	Valero/ Benicia Refinery	170,000	5th California
5	CA	Martinez	94553	Tesoro/ Golden Eagle Refinery	166,000	5th California
5	CA	Martinez	94553	Shell/ Martinez Refinery	165,000	5th California
5	CA	Torrance	90509	ExxonMobil/ Torrance Refinery	150,000	43rd California
5	CA	Carson	90745	Phillips 66/ Los Angeles Refinery	139,000	44th California
5	CA	Wilmington	90744	Valero/ Wilmington Refinery	135,000	44th California
5	CA	Wilmington	90744	Tesoro Los/ Angeles Refinery	97,000	44th California
5	WA	Blaine	98230	BP/ Cherry Point Refinery	230,000	1st Washington
5	WA	Anacortes	98221	Shell/ Puget Sound Refinery	145,000	2nd Washington

Source: Various

Notes: Alon operates three units in Bakersfield, Paramount, and Long Beach, CA, as one refinery, but the delayed coker is reported as inactive.

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