BAY AREA
AIR QUALITY
MANAGEMENT
DISTRICT

WORKSHOP REPORT

Draft Amendments to Regulation 6, Rule 5: Particulate Emissions from Petroleum Refinery Fluidized Catalytic Cracking Units

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I. INTRODUCTION

The Bay Area Air Quality Management District (Air District) is developing amendments to Regulation 6: Particulate Matter, Rule 5: Particulate Emissions from Petroleum Refinery Fluidized Catalytic Cracking Units (Rule 6-5). The purpose of these amendments is to address particulate matter from refinery fluidized catalytic cracking units, which are some of the largest individual sources of particulate matter emissions in the San Francisco Bay Area. The Bay Area does not currently attain all state and national ambient air quality standards for particulate matter, and further reductions of particulate matter emissions are needed to ensure progress towards attainment of the standards. Furthermore, exposure to particulate matter has long been understood as a health hazard based on respiratory health effects, and recent studies have linked particulate matter exposure to a wide range of cardiovascular diseases, impacts to cognitive function, and cancer.[1] Compelling evidence also suggests that fine particulate matter is the most significant air pollution health hazard in the Bay Area, and reductions in particulate matter emissions are needed to achieve further clean air and public health benefits.[2]

Fluidized catalytic cracking units (FCCUs) are the largest single source of particulate matter emissions at petroleum refineries. Prior regulation of FCCUs only considered particulate matter that could be captured using filter-based test methods. The evolution in our understanding of particulate formation and measurement methods has shown that this previous approach misses the particulate matter that can form when the emissions from the stack cool upon contact with the atmosphere. In 2010, the United States Environmental Protection Agency completed updates to test methods that can measure total particulate matter emissions from sources such as FCCUs. Application of these updated methods at FCCUs have further indicated that a substantial amount of the total particulate matter can be missed when using only filter-based test methods. The adoption of Air District Rule 6-5 in 2015 marked the first regulatory step in addressing total particulate matter from these fluidized catalytic cracking units in the San Francisco Bay Area. In 2017, the Air District's Clean Air Plan included Control Measure SS1 to evaluate ongoing progress in reducing these emissions, and to further control particulate matter emissions from fluidized catalytic cracking units. In 2018, the Air District adopted the Assembly Bill 617 Industrial Cap-and-Trade Sources Expedited Best Available Retrofit Control Technology (BARCT) Implementation Schedule, which identified potential rule development projects to evaluate and implement Best Available Retrofit Control Technology at certain industrial sector facilities as required by California Assembly Bill 617 (AB 617). The schedule identified that potentially substantial particulate matter emission reductions could be achieved at these fluidized catalytic cracking units, and further rule amendments should be evaluated and considered. This current rule development effort for amendments to Rule 6-5 follows these previous Air District rulemaking and planning actions to address emissions from these sources. These amendments are needed to ensure that Air District regulations are as health protective as possible and consider recent advances in the understanding and control of total particulate matter emissions.

The Air District staff released draft amendments to Rule 6-5 and an Initial Staff Report in May 2020 for public review and comment and presented information on the draft amendments and rule development effort at Air District Stationary Source Committee meetings throughout 2020. Following the release of the draft amendments in May 2020, staff further evaluated other potential control options for these sources, including a more stringent potential control option for assessment and consideration. The Air District staff is releasing this Workshop Report, along with

[1] BAAQMD, 2012. Understanding Particulate Matter: Protecting Public Health in the San Francisco Bay Area. November.

[2] BAAQMD, 2017. Final 2017 Clean Air Plan: Spare the Air – Cool the Climate. April.

two versions of draft amendments to Rule 6-5—the draft amendments released in May 2020 and the draft amendments reflecting a more stringent potential control option. This report includes updated information on the potential control options, including additional discussions on preliminary estimates of associated impacts. Air District staff is soliciting comments on these materials and will consider input received during the public comment period in the further development of these amendments.

II. BACKGROUND

A. Industry Description

Petroleum refineries process crude oil into a variety of products, such as gasoline, aviation fuel, diesel and other fuel oils, lubricating oils, and feedstocks for the petrochemical industry. The processing of crude oil occurs in various process units or plants throughout these facilities, including fluidized catalytic cracking units (FCCUs). Four of the five refineries in the San Francisco Bay Area have fluidized catalytic cracking units: Chevron Products Richmond, PBF Martinez Refinery, Marathon Martinez Refinery, and Valero Benicia Refinery. Note that the Marathon Martinez Refinery announced the temporary idling of their refinery, including the facility's fluidized catalytic cracking unit, in April 2020. In July 2020, Marathon announced that the refinery will remain idled indefinitely with no plans to restart normal operations.

B. Fluidized Catalytic Cracking Units

Fluidized catalytic cracking units are complex processing units at refineries that convert heavy components of crude oil into lighter distillates, including gasoline and other high-octane products. Fluidized catalytic cracking units use a fine powdered catalyst that behaves as a fluid when aerated with a vapor. The fluidized catalyst is circulated continuously between a reaction vessel where the catalyst is used to promote the hydrocarbon cracking process and a regenerator where carbonaceous material deposited on the catalyst is burned off. An illustrative diagram of the fluidized catalytic cracking unit is shown in Figure 1.

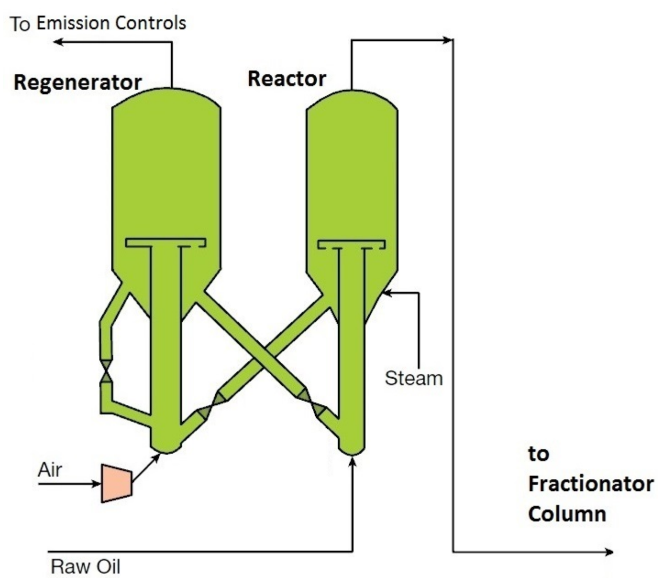

Figure 1 – Petroleum Refinery Fluidized Catalytic Cracking Unit Diagram[3]

[3] Modified from American Institute of Chemical Engineers, 2014. Chemical Engineering Progress (CEP) – An Oil Refinery Walk-Through. May.

Fresh feed is preheated and enters the fluidized catalytic cracking unit at the base of the feed riser, where it is mixed with the heated catalyst. The heat from the catalyst vaporizes the feed and brings the materials up to the desired reaction temperature. The cracking reactions start as the catalyst and hydrocarbon vapor travel up the riser and continue as the materials flow into the reactor. As the cracking reaction progresses, the catalyst surface is gradually coated with carbonaceous material (coke), reducing its efficacy. The cracked hydrocarbon vapors are separated from the catalyst particles by cyclones in the reactor, and the hydrocarbon vapors are sent to a distillation column for separation and further processing.

The spent catalyst is steam stripped to remove remaining oil on the catalyst and cycled to the regenerator. The coke deposited on the catalyst is burned off in a controlled combustion process with preheated air, reactivating the spent catalyst. The catalyst is then recycled to be mixed with fresh hydrocarbon feed. Catalyst regenerators may be designed to burn the coke completely to carbon dioxide (CO_2) (full burn) or to only partially burn the coke to a mixture of carbon monoxide (CO) and carbon dioxide (partial burn). Because the flue gas from partial burn regenerators have high levels of carbon monoxide, the flue gas is vented to a carbon monoxide gas boiler where the carbon monoxide is further combusted to carbon dioxide.

The fluidized catalytic cracking unit regenerator is a substantial source of emissions and fluidized catalytic cracking units are the largest single source of particulate matter emissions at petroleum refineries. During the regeneration process, some of the catalyst becomes entrained in the flue gas that exits the fluidized catalytic cracking unit regenerator. In addition to these “catalyst fines”, the flue gas also contains other pollutants, including sulfur dioxide (SO_2), oxides of nitrogen (NOx), reactive organic gases (ROG), toxic air contaminants, and other particulate matter (PM) generated in the combustion process. This flue gas is then routed through a train of pollutant abatement devices (see Section III.C. for further information on control technologies). In many abatement trains, ammonia (NH_3) is also injected into the flue gas stream to enhance the efficiency of certain types of pollution control equipment. Ammonia that is not fully consumed in the process can also remain in the flue gas stream (also referred to as “ammonia slip”) and may be emitted along with other pollutants in the flue gas. These gaseous pollutants can increase total particulate matter emissions (see discussion of total particulate matter in Section III.A.).

C. Regulatory History

1. Air District Rules/Regulations

The Air District adopted a number of rules that address emissions of particulate matter from fluidized catalytic cracking units. Air District Regulation 6: Particulate Matter, Rule 1: General Requirements (Rule 6-1) contains an opacity limit of 20 percent for all sources, including fluidized catalytic cracking units and carbon monoxide boilers. Opacity is a measurement of the degree to which filterable particulates in an exhaust stream or dust plume obscure the ability of an observer to see through the exhaust stream or dust plume. Opacity can also be measured with instrumentation by a beam of light’s ability to pass through the exhaust stream without being reflected by any particles in the exhaust stream. As such, opacity is a surrogate for more complicated and time intensive source testing (mass-based measurements) of particulate matter emissions. This method is fairly crude but easy to implement and was among the first methods used to measure and limit particulate matter emissions.

The Air District adopted Regulation 6: Particulate Matter, Rule 5: Particulate Emissions from Refinery Fluidized Catalytic Cracking Units (Rule 6-5) in 2015, with the goal of reducing emissions of total particulate matter from fluidized catalytic cracking units at Bay Area refineries. Rule 6-5 established a limit for ammonia slip (unreacted ammonia emitted to atmosphere) of 10 parts per million, volumetric dry (ppmvd) at 3 percent oxygen (O_2), as a daily average. The Rule also provided for an alternative method of compliance for an owner or operator of a fluidized catalytic cracking unit to conduct an ammonia optimization study and establish an enforceable ammonia emission limit based on this optimization. Rule 6-5 was also amended in 2018 for minor clarifications, but no substantive changes were made to these ammonia injection and emission requirements.

Rule 6-5 does not currently contain sulfur dioxide emission limits, but the role of sulfur dioxide as a contributor to total particulate matter emissions (along with ammonia) was recognized during the development and adoption of the Rule in 2015, with the potential of addressing sulfur dioxide in future rule amendments. Air District Regulation 9: Inorganic Gaseous Pollutants, Rule 1: Sulfur Dioxide (Rule 9-1) does contain a sulfur dioxide limit for fluidized catalytic cracking units and prohibits the emission of effluent process gas containing sulfur dioxide in excess of 1,000 ppm by volume from a fluidized catalytic cracking unit. Additionally, Rule 9-1 contains general prohibitions on emissions of sulfur dioxide in quantities that result in ground level sulfur dioxide concentrations in excess of 0.5 ppm (continuously for three minutes), 0.25 ppm (averaged over 60 minutes), or 0.05 ppm (averaged over 24 hours).

In addition to existing regulations, the Air District's programmatic and plan-level efforts have identified and included measures and strategies to further reduce particulate matter emissions from fluidized catalytic cracking units.

a) 2017 Clean Air Plan

In 2017, the Air District adopted its current Clean Air Plan: Spare the Air, Cool the Climate (2017 Clean Air Plan or 2017 Plan). The 2017 Plan describes the Air District's approach to reducing emissions of air pollutants, including total particulate matter. The 2017 Plan includes control measures to protect the public health and reduce particulate matter, including stationary source Control Measure SS1: "Fluid Catalytic Cracking in Refineries." Control Measure SS1 includes establishing emission limits to reduce total particulate matter emissions at fluidized catalytic cracking units, working to conduct source tests and total particulate matter quantification, and evaluating ongoing progress in optimizing ammonia injection to minimize total particulate matter.

b) AB 617 Expedited BARCT Implementation Schedule

Assembly Bill 617 requires each air district that is in nonattainment for one or more air pollutants to adopt an expedited schedule for implementation of best available retrofit control technology (BARCT) by the earliest feasible date, but not later than December 31, 2023. "Best available retrofit control technology" is defined in the California Health and Safety Code as an emission limitation that is based on the maximum degree of reduction achievable, taking into account environmental, energy, and economic impacts by each class or category of source.[4] In December 2018, the Air District's Board of Directors adopted the Expedited Best Available Retrofit Control Technology Implementation Schedule, which identified a number of potential rule development projects to evaluate and implement Best Available Retrofit Control Technology. The Schedule includes a rule development project to control emissions of total particulate matter from fluidized catalytic cracking units and carbon monoxide gas boilers. Staff identified strategies for addressing these emissions through potential amendments to Rule 6-5 that would address components of condensable particulate matter, including ammonia and sulfur dioxide.

[4] California Health and Safety Code, Section 40406.

2. Federal Regulations

Federal rules that address emissions from fluidized catalytic cracking units and carbon monoxide boilers include New Source Performance Standards (NSPS) Subparts J and Ja, and National Emissions Standards for Hazardous Air Pollutants (NESHAP) Subpart UUU. New Source Performance Standards Subpart J contains an emission limit of 1.0 kilograms of filterable particulate matter per megagram (kg/Mg) (2.0 lb/ton) of coke burnoff in the catalyst regenerator and an opacity limit of 30 percent. New Source Performance Standards Subpart Ja has a filterable particulate matter emission limit of 1.0 g/kg of coke burnoff for fluidized catalytic cracking units reconstructed or modified after May 14, 2007, and a limit of 0.5 g/kg of coke burnoff for fluidized catalytic cracking units newly constructed after May 14, 2007. The National Emissions Standards for Hazardous Air Pollutants Subpart UUU includes various particulate matter emission limit options for compliance.

Note that these existing federal particulate matter limits are based on methods for monitoring and measuring filterable particulate matter only. The federal rules do not contain limits for total particulate matter or ammonia slip; however, federal New Source Performance Standards Subpart J contains sulfur dioxide emission limits of 9.8 kg/Mg (20 lb/ton) of coke burnoff, and 50 parts per million by volume (ppmv) sulfur dioxide for a fluidized catalytic cracking unit with an add-on control device. New Source Performance Standards Subpart Ja contains sulfur dioxide emission limits of 50 ppmv on a seven-day rolling average basis and 25 ppmv on a 365-day rolling average basis for fluidized catalytic cracking units constructed, reconstructed, or modified after May 14, 2007.

3. Existing Regulations in Other Districts

Staff identified existing rules in other air districts in California that address emissions of particulate matter from fluidized catalytic cracking units. In 2003, South Coast Air Quality Management District (South Coast AQMD) adopted Rule 1105.1: Reduction of PM_{10} and Ammonia Emissions from Fluid Catalytic Cracking Units. Units subject to Rule 1105.1 must meet one of the following limits for filterable PM_{10}: 3.6 pounds per hour, 0.005 grain per dry standard cubic foot corrected to 3 percent oxygen (O_2), or 2.8 pounds per thousand barrels of fresh feed. Rule 1105.1 also contains a provision that allows an operator to instead comply with a higher filterable PM_{10} emission limit of 0.006 grain per dry standard cubic foot, provided that the operator mitigates the difference in emission reductions between the 0.006 and 0.005 grain per dry standard cubic foot by other alternative methods. Note that these limits are based on methods for monitoring and measuring filterable particulate matter only. However, Rule 1105.1 does contain a limit for ammonia slip (unreacted ammonia emitted to atmosphere) of 10 parts per million, volumetric dry (ppmvd) at 3 percent oxygen (O_2) averaged over 60 consecutive minutes.

III. TECHNICAL REVIEW

A. Particulate Matter

Particulate matter (PM) is a diverse mixture of suspended particles and liquid droplets, also known as aerosols. Particulate matter varies in terms of size, physical state, chemical composition, and toxicity. Particulate matter emissions can originate from anthropogenic stationary and mobile sources, as well as from natural sources. Particulate matter may consist of elements such as carbon and metals; compounds such as nitrates, organics, and sulfates; and complex mixtures such as diesel exhaust, wood smoke, and soil. Unlike other criteria pollutants which are individual chemical compounds, particulate matter includes all particles that can be suspended in the air.

Particulate matter is often characterized and differentiated based on particle size using the following categories:

- **Total Suspended Particulate (TSP)**: Any airborne particulate matter.
- **PM_{10}**: Particulate matter with an aerodynamic diameter equal to 10 microns or less.
- **$PM_{2.5}$**: Particulate matter with an aerodynamic diameter equal to 2.5 microns or less.
- **Ultrafine Particulate Matter**: Particles smaller than 0.1 micron in diameter.

In addition to size ranges, particulate matter is also classified based on how the particles are formed and emitted. Particulate matter can be categorized as "primary" or "secondary" particulate matter. Primary particulate matter refers to particles that are directly emitted in solid or aerosol form, whereas secondary particulate matter refers to particles that are formed in the atmosphere through chemical reactions.

Primary particulate matter includes soot and liquid aerosols from a wide variety of sources, including cars, trucks, buses, industrial facilities, power plants, cooking, and burning wood, as well as dust from construction sites and other ground disturbing operations. Primary particulate matter can be further classified as filterable particulate matter or condensable particulate matter. Filterable particulate matter describes material that is a liquid or solid at the emission point and is released to the atmosphere. Condensable particulate matter describes material that is a gas at the emission point, but immediately condenses to a liquid or solid form when it exits the stack and is exposed to cooler ambient air. This material exists as a gas at the high temperatures that are typically found at stack conditions. As the hot gases leave the stack and are exposed to ambient air, the gas stream is cooled and diluted, and the gaseous compounds are transformed to a liquid or solid state through condensation, nucleation[5], and coagulation processes. The formation of condensable particulate matter can vary based on specific characteristics of the gas stream, such as chemical composition, water vapor concentration, and temperature. Gaseous components such as nitrogen oxides, sulfur oxides, ammonia, and organic compounds can contribute to the formation of condensable particulate matter compounds, including sulfates, nitrates, and organic particles.

Secondary particulate matter may be formed in the atmosphere by gaseous precursors undergoing chemical reactions and physical transformations. In contrast to primary condensable particulate matter, secondary particulate matter can often require minutes, hours, or days to form in the atmosphere. Secondary particulate matter can consist of organic and inorganic compounds that are formed through physical transformations and chemical reactions between precursor gases, including nitrogen oxides, sulfur oxides, ammonia, and organic compounds, that are emitted from various sources.

Even though primary and secondary particulate matter are defined in terms of the processes and sources that produce particulate matter, most individual particles in the atmosphere are in fact a combination of both primary and secondary particulate matter. An individual particle typically begins as a core or nucleus of solid or liquid material, such as carbonaceous material originating from fossil fuels or biomass combustion or geologic dust. Layers of organic and inorganic compounds then condense or deposit onto the particle, causing it to grow in size. These layers are largely comprised of secondary material that is not emitted directly.

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[5] Nucleation is the initial process that occurs in the formation of a crystal from a solution, a liquid, or a vapor, in which a small number of ions, atoms, or molecules become arranged in a pattern characteristic of a crystalline solid, forming a site upon which additional particles are deposited as the crystal grows.

1. Health Impacts of Particulate Matter

Since exposure to ambient particulate matter has long been understood as a health hazard,[6] particulate matter was designated as one of the criteria pollutants in the original 1970 federal Clean Air Act. Concerns about particulate matter were initially based on its respiratory health effects, such as aggravating asthma, bronchitis, and emphysema. However, in recent years, many epidemiological studies have linked particulate matter exposure to a much wider range of negative health effects, including cardiovascular effects such as atherosclerosis (hardening of the arteries), ischemic strokes (caused by obstruction of the blood supply to the brain), and heart attacks. Studies also indicate that exposure to particulate matter may be related to other health effects, including reduction in cognitive function, autism, and increased risk of diabetes. Infants and children, the elderly, and persons with heart and lung disease are most sensitive to the effects of particulate matter. Fetal $PM_{2.5}$ exposures can result in low birth weight, pre-term birth, and changes in gene expression, and brain inflammation from particulate matter exposure can affect both ends of the life spectrum—neurodevelopment and neurodegeneration.[7]

Analysis by Air District staff found that $PM_{2.5}$ is the most significant air pollution health hazard in the Bay Area, particularly in terms of premature mortality.[8] A large and growing body of scientific evidence indicates that both short-term and long-term exposure to fine particles can cause a wide range of health effects, and studies have concluded that reducing particulate matter emissions can reduce mortality and increase average life span.[9] Smaller particles can more easily enter the body than their larger counterparts and penetrate deep into the lungs, and from there into the bloodstream. Small particles, such as $PM_{2.5}$, also have much higher surface area relative to mass than larger particles, enabling them to act as carriers for other potentially harmful substances such as trace metals and organic compounds that collect on their surface. There remains no known threshold for harmful $PM_{2.5}$ health effects.[10] Although the epidemiological evidence that shows strong correlation between elevated particulate matter levels and public health effects is very well documented, scientists are still working to understand the precise biological mechanisms through which particulate matter damages our health. Research studies have indicated several different potential mechanisms through which particulate matter can harm human health, including increases in blood pressure, blood vessel damage, tissue damage from oxidative stress, and DNA damage.[11,12] Recent research also indicates that early life exposure to wildfire smoke particulate matter can permanently damage the immune system and lung structure and function, and that this damage that can be passed to the next generation.[13]

2. Health Benefits Analytical Techniques

The Air District continues to study and evaluate health impacts associated with particulate matter exposure. The Air District developed a multi-pollutant evaluation method (MPEM) to analyze the

[6] The London fogs of the early 1950s that killed thousands of people were primarily caused by particulate matter from coal, which led to the banning of coal burning within the city.
[7] BAAQMD Advisory Council, 2020. Advisory Council Particulate Matter Reduction Strategy Report. December.
[8] BAAQMD, 2017. Final 2017 Clean Air Plan: Spare the Air – Cool the Climate. April.
[9] United States Environmental Protection Agency (EPA), 2018b. Integrated Science Assessment for Particulate Matter. October.
[10] EPA, 2018b. Integrated Science Assessment for Particulate Matter. October.
[11] BAAQMD, 2017. Final 2017 Clean Air Plan: Spare the Air – Cool the Climate. April.
[12] BAAQMD, 2012. Understanding Particulate Matter: Protecting Public Health in the San Francisco Bay Area. November.
[13] Miller, Lisa et al., 2019. "Are Adverse Health Effects from Air Pollution Exposure Passed on from Mother to Child?" University of California, Davis. California Air Resources Board Contract No. 15-303.

benefits of control measures and strategies, such as the 2017 Clean Air Plan.[14] More recently, the Air District has applied the US Environmental Protection Agency's (EPA) Benefits Mapping and Analysis Program, Community Edition (BenMAP-CE) to estimate heath impacts of air pollution and to quantify the benefits of control measures. The BenMAP-CE program calculates the economic value of air quality change using conventional (EPA-approved) valuations, including both "cost of illness" and "willingness to pay" metrics. The techniques are further detailed in Appendix A.2.

3. General Findings of the Advisory Council

In 2019, the Air District and the Air District's Advisory Council began convening a series of symposia on particulate matter and its health effects. The Advisory Council prepared a report of its findings and recommendations on ways to address particulate matter pollution and exposure, which was shared with the Air District Board of Directors during a special joint meeting on December 16, 2020. In its *Particulate Matter Reduction Strategy Report*, the Advisory Council concluded that current ambient air quality standards for particulate matter are not adequately health protective, and that further particulate matter reductions would realize additional health benefits.[15] Furthermore, the Advisory Council report states that the projected increased particulate matter exposure from wildfire smoke due to climate change justifies greater efforts to reduce controllable sources of particulate matter to reduce overall risk. The report also states that particulate matter is the most important health risk driver in Bay Area air quality, and that there is no known threshold for harmful health effects from particulate matter in the form of $PM_{2.5}$. The Advisory Council also found that while some species of particulate matter may be more impactful than others, no particulate matter species can be exonerated from being considered dangerous to human health.

B. Particulate Matter Emissions from Fluidized Catalytic Cracking Units

As described previously, the fluidized catalytic cracking unit regeneration process generates particulate matter emissions through the combustion process and through the loss of catalyst fines. In addition, other pollutants in the regenerator flue gas, including sulfur dioxide, oxides of nitrogen, and ammonia, can increase total particulate matter. When the plume from the stack cools, these components can form various particles, including ammonium nitrates and ammonium sulfates. As the formation of total particulate matter is complex, emission estimates can be informed by a variety of data, including source process parameters, source testing, and monitoring of total particulate matter components. Air District estimates of total particulate matter emissions from fluidized catalytic cracking units in the San Francisco Bay Area for calendar year 2018 are shown in Table 1. The Air District continues to study these emissions and may update or refine estimates as staff gathers additional information. As part of this effort, Air District staff conducted and oversaw further source testing at the PBF Martinez Refinery fluidized catalytic cracking unit from August to October 2020. Preliminary source test results demonstrated reasonable agreement with previous total PM_{10} emission estimates. The Air District anticipates gathering further information from these sources as appropriate. As shown in Table 1, emissions from petroleum refinery fluidized catalytic cracking units total approximately 825 tons per year of PM_{10} and 800 tons per year of $PM_{2.5}$. These emissions contribute to approximately 50 percent of all refinery PM_{10} emissions, represent approximately 17 percent of PM_{10} emissions from all inventoried stationary sources at facilities with Air District permits, and 3 percent of all human-made PM_{10} emissions in the Bay Area.

[14] BAAQMD, 2017. Final 2017 Clean Air Plan: Spare the Air – Cool the Climate. April.

[15] BAAQMD Advisory Council, 2020. Advisory Council Particulate Matter Reduction Strategy Report. December.

Table 1 – Particulate Matter Emissions from Petroleum Refinery Fluidized Catalytic Cracking Units by Facility

Facility	FCCU Fresh Feed Capacity (barrels per day)[16]	PM_{10} (tons per year)	$PM_{2.5}$ (tons per year)
Chevron Products Richmond[a]	80,000	245	229
Marathon Martinez Refinery[b,c]	*70,000*	*190*	*190*
PBF Martinez Refinery[a]	67,400	309	300
Valero Benicia Refinery[d]	72,000	81	81
Total[e]	**289,400**	**825**	**800**

[a] Emissions based on reported 2018 facility emissions inventory for total PM.
[b] Reported 2018 facility emissions inventory only included filterable PM. Emissions shown here are based on average 2020 source test emission rate data for total PM. $PM_{2.5}$ emissions were assumed to be equal to PM_{10} emissions.
[c] The Marathon Martinez Refinery announced the idling of the refinery, including the facility's fluidized catalytic cracking unit, in April 2020. Marathon announced in July 2020 that the facility would remain indefinitely idled with no plans to restart.
[d] Reported 2018 facility emissions inventory only included filterable PM. Emissions shown here are based on average 2016-2019 source test emission rates data for total PM at flue gas scrubber stack, which includes combined emissions from Valero's fluidized catalytic cracking unit and coker unit. $PM_{2.5}$ emissions were assumed to be equal to PM_{10} emissions.
[e] Total figures shown include the Marathon Martinez Refinery, which was idled in April 2020 and remains indefinitely idled.

C. *Emission Control Methods for Particulate Matter from Fluidized Catalytic Cracking Units*

As discussed previously, flue gas components such as sulfur dioxide, oxides of nitrogen, and ammonia can contribute to total particulate matter emissions from fluidized catalytic cracking units. Therefore, many control strategies are available to reduce potential total particulate matter formation through the control of these components.

1. Reduction of Ammonia Injection and Ammonia Slip

Ammonia is commonly used as a conditioning agent to alter the resistivity and cohesiveness of particles in the gas stream, which can improve the effectiveness of electrostatic precipitators (ESP) in capturing catalyst fines. Excess ammonia that is not consumed in this process can remain in the fluidized catalytic cracking unit flue gas stream (this is called "ammonia slip") and can combine with sulfur and nitrogen oxides in the stream to form particulate matter. Therefore, reducing ammonia injection and ammonia slip can reduce emissions of total particulate matter. Potential strategies for achieving these reductions include the optimization of ammonia injection, the use of alternative non-ammonia conditioning agents, and improved removal of particulate matter through electrostatic precipitators or wet gas scrubbing, which may reduce or eliminate the need for ammonia injection. Some of these control strategies may also be used in combination to effectively reduce emissions of total particulate matter.

a) Optimization of Ammonia Injection

The use of ammonia in existing abatement systems can be optimized to minimize the amount of ammonia injection and ammonia slip emissions. Optimization of ammonia injection can be achieved through proper process controls, data collection and monitoring, controls for injection timing, and regular maintenance and servicing of abatement equipment. The efficacy of ammonia

[16] U.S. Energy Information Administration, 2019. Refinery capacity data by individual refinery as of January 1, 2019. https://www.eia.gov/petroleum/data.php.

optimization may be constrained by the capabilities and design of existing abatement equipment, which may vary widely between individual sources. Costs of ammonia optimization may include one-time optimization costs and additional ammonia and process monitoring systems, however reductions in ammonia use could result in long-term cost savings.

b) Use of Alternative Conditioning Agents

Ammonia and ammonia-based compounds (such as urea) are commonly used conditioning agents for improved removal of fluidized catalytic cracking unit catalyst fines at electrostatic precipitators. The use of non-ammonia-based compounds for flue gas conditioning could reduce or eliminate ammonia injection and associated ammonia slip emissions. Non-ammonia based conditioning agents used in other industrial applications include sulfur trioxide, sodium compounds, potassium sulfate, and steam injection. Proprietary chemicals have also been developed for flue gas conditioning in power and electricity generation applications. Costs of alternative conditioning agents are anticipated to be comparable to ammonia injection, although some cost differences between specific injection systems and chemicals would be expected. Limited information exists on the feasibility of alternative conditioning agents in refinery fluidized catalytic cracking unit applications.

c) Electrostatic Precipitator

An electrostatic precipitator (ESP) is a control device designed to remove particulate matter from an exhaust gas stream by using electrical energy. The main components of the electrostatic precipitator include discharge electrodes, collection plates, and a plate cleaning system. Particulate matter is removed from the gas stream through a series of steps inside the electrostatic precipitator: 1) a power supply energizes the discharge electrodes to establish an electric field; 2) the gas stream and particles are ionized and charged as they pass through the electric field; 3) the charged particles migrate out of the gas stream and towards collection plates, which are oppositely charged; and 4) the particles collected on the plates are removed for disposal. The removal of particles from the collection plates can be accomplished using different systems. In a dry electrostatic precipitator system, rapping systems are used to vibrate the collection plates and remove the collected particles. In a wet electrostatic precipitator system, particles are removed from the collection plates by rinsing the plates with water.

Ammonia is often injected into flue gas streams to improve the collection efficiency of the electrostatic precipitators, however excess ammonia in the flue gas stream (ammonia slip) can increase total particulate matter emissions. An electrostatic precipitator system with sufficient collection efficiency and capacity may be able to reduce or eliminate the need for ammonia injection, therefore limiting the amount of potential condensable particulate matter formation. The collection efficiency of an electrostatic precipitator system can be improved by rebuilding the system with additional capacity or by adding additional cells to increase residence time and collection surface area. In addition, advancements in electrostatic precipitator technologies can increase performance of existing systems, especially as these units and components age and degrade. Potential upgrades and replacements include rapping system upgrades, electrode upgrades, and power supply system upgrades. Rapping system upgrades (including rapping scheme optimization and enhanced control systems) can improve plate cleaning, which increases collection area and decreases re-entrainment of particles. Electrode upgrades (including electrode replacement, electrode spacing/configuration upgrades, and use of rigid discharge electrodes) can increase overall collection efficiency. Power supply system upgrades (including high frequency power supplies, switch-mode power supplies, and three-phase power supplies) can deliver higher and more consistent voltage to increase particulate matter collection.

For treatment of high-volume flue gas streams, installations of electrostatic precipitators typically require a large amount of space, although advancements in precipitator design and technology can reduce the size and space needed. Costs of new and expanded electrostatic precipitators can vary based on the specific installation, design, capacity, and other constraints. Costs for component replacements and upgrades to existing electrostatic precipitator systems would be anticipated to be much lower than the costs of a new electrostatic precipitator or electrostatic precipitator expansion. Potential costs and preliminary cost estimates for electrostatic precipitator controls are further discussed in Section V.B.

Potential hazards associated with electrostatic precipitators include risks for fire or explosion, which can occur if flammable hydrocarbons enter the unit and mix with oxygen in the presence of an ignition source. Standard industry practices and vendor safety recommendations, including frequent inspection and maintenance, air filter cleaning, use of hydrocarbon sensors, and electronic controls for process automation can reduce risks from operation of electrostatic precipitators. A well-documented incident involving a refinery electrostatic precipitator explosion occurred in February 2015 at the ExxonMobil Refinery located in Torrance, California. An investigation of the incident by the U.S. Chemical Safety and Hazard Investigation Board identified weaknesses in the refinery's process safety management system and found that a number of standard industry and safety practices were not followed, contributing to the incident.[17]

d) Wet Gas Scrubbing

Wet gas scrubbing is a process that is used to remove liquid or solid particles from a gas stream. The process removes these particles by transferring them to a liquid, which is typically water or a reagent solution. In a typical wet gas scrubbing system, the scrubbing liquid is sprayed into the spray tower, and the flue gas stream enters at the bottom of the tower and flows upwards through the scrubbing liquid. As the gas stream passes through the scrubbing liquid, particles from the stream are collected as they impact the liquid droplets. Some wet gas scrubbing systems are also designed to capture gaseous pollutants that can be absorbed into the scrubbing liquid. The scrubbing liquid is then collected by mist eliminators or separators for treatment and discharge, or for regeneration and further use. Various types of scrubbers exist with different features, such as tower design, spray operations, energy usage level, and liquid collection and regeneration systems. In addition to capturing filterable particulate matter, the wet gas scrubbing process can also remove condensable components, such as ammonia, as well as reduce or eliminate the need for ammonia injection altogether.

Costs of new wet gas scrubbing systems can vary based on specific design and site constraints, as well as additional equipment or infrastructure required for operation. Potential costs and preliminary cost estimates for wet gas scrubbing controls are further discussed in Section V.B.

Because the wet gas scrubbing process uses water or reagent solutions, these systems often require high volumes of water consumption. As the scrubbing liquid is passed through the scrubber, water is evaporated due to the high temperature of the flue gas stream. Spent scrubbing liquid that contains the captured pollutants also needs to be routed for treatment and discharge. Additional makeup water is therefore required to replace this lost water and maintain continued

[17] U.S. Chemical Safety and Hazard Investigation Board, 2017. Investigation Report – ExxonMobil Torrance Refinery Electrostatic Precipitator Explosion, Torrance, California. No. 2015-02-I-CA. May.

wet gas scrubbing operations. Estimated water demand for installations of wet gas scrubbers for fluidized catalytic cracking units in California range from 120,000 to 430,000 gallons per day.[18,19]

Water consumption for each specific wet gas scrubbing system can vary based on a number of factors, including certain designs or technologies that can affect the need for makeup water. Pre-scrubber quench cooling systems can be used to reduce the temperature of the exhaust gas stream prior to entering the wet gas scrubber. This lowered gas temperature can reduce the amount of evaporation that occurs in the wet gas scrubber when the gas comes into contact with the scrubbing liquid. In addition, wet gas scrubbing systems utilizing regenerative technology can reduce the amount of spent scrubbing liquid that is purged and discharged. In a regenerative system, spent scrubbing liquid that contains the captured pollutant is routed to a separate section where the scrubbing liquid is separated from the pollutant and regenerated, typically through heating and condensing. The regenerated scrubbing liquid can then be re-used in the scrubbing system, reducing the amount of liquid purged and reducing the amount of makeup water needed. These types of designs and system elements typically involve increased capital costs and complexity due to additional equipment and space requirements. In addition to these design and technology considerations, water demand requirements can be affected by the availability and use of water supplies other than fresh water, such as reclaimed and/or recycled water. Any other types of water used would still need to meet specific water quality standards required by the individual system design, as wet gas scrubbing equipment may be susceptible to water quality-related issues, such as deposit formation, high solids content and plugging of nozzles, and interferences with reagent chemistry. Therefore, the use of these other types of water stream would be dependent on the specific availability and treatment/infrastructure requirements associated with each individual system.

2. Reduction of Sulfur Dioxide Emissions

As discussed previously, sulfur dioxide emissions generated through the fluidized catalytic cracking unit catalyst regeneration process can also lead to increased total particulate matter emissions. Potential strategies for achieving reductions of sulfur dioxide and total particulate matter include the use and optimization of sulfur dioxide-reduction additives, feed hydrotreating, and removal of sulfur dioxide and particulate matter through wet gas scrubbing. Some of these control strategies may be used in combination to effectively reduce emissions of total particulate matter.

a) Optimization of Sulfur Dioxide-Reducing Additives

Sulfur dioxide-reducing additives are used to remove sulfur oxides from fluidized catalytic cracking unit regenerator flue gas. These additives typically consist of a metal oxide agent, such as a magnesium-based agent, and may contain other catalytic components. The sulfur dioxide removal process occurs through a multi-step mechanism. Sulfur dioxide is formed in the regenerator as coke is burned off the spent catalyst, and a portion of the sulfur dioxide is converted to sulfur trioxide (SO_3) in the presence of excess oxygen. The metal oxide agent chemically bonds with the sulfur trioxide to form a metal sulfate, which recirculates back to the reactor and reacts with hydrogen to form a metal oxide or a metal sulfide and water. The metal sulfide further reacts with steam to form a metal oxide and hydrogen sulfide. The hydrogen sulfide generated is routed for further treatment and sulfur recovery.

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[18] City of Benicia, 2008. Valero Improvement Project – Addendum to VIP EIR, SCH No. 2002042122. June.
[19] South Coast AQMD, 2007. Final EIR for ConocoPhillips Los Angeles Refinery PM_{10} and NOx Reduction Project, SCH No. 2006111138. June.

Optimized use of these additives can reduce sulfur dioxide emissions that contribute to total particulate matter emissions. In addition, advancements in additive technology and process controls may present additional potential for emissions reductions. Costs for optimizing sulfur dioxide-reducing additives may include one-time optimization costs and additional process monitoring and additive handling systems. Costs of different additives are anticipated to be comparable to existing additives, although optimized use of advanced additives may present some long-term cost savings from increased efficiency and reduced additive usage. Potential costs and preliminary cost estimates associated with these additives are further discussed in Section V.B.

b) Feed Hydrotreating

Removal of sulfur compounds in feed material prior to introduction to the fluidized catalytic cracking unit can reduce the amount of sulfur dioxide that is eventually generated through the fluidized catalytic cracking unit process. Refineries remove sulfur and other undesirable compounds from hydrocarbon feedstocks through feed hydrotreating. In the hydrotreatment process (also referred to as hydro-desulfurization), hydrogen is added to a feedstock stream over a bed of catalyst typically containing molybdenum with nickel or cobalt. Sulfur compounds in the feed react with hydrogen to form hydrogen sulfide (H_2S), which is then removed from the stream through an amine treatment system and routed to a sulfur recovery unit.

All refineries employ some form of feed hydrotreating, but additional treating or more severe hydrotreatment can further reduce sulfur content in the feed. The feasibility and costs of upgrades to existing hydrotreating systems can vary widely based on site-specific and operational considerations. These factors can include the condition, design, and capacity of the existing system, as well as the extent of upgrades being implemented. Potential costs and preliminary cost estimates associated with improved hydrotreatment controls are further discussed in Section V.B.

c) Wet Gas Scrubbing

Wet gas scrubbing is described above in Section II.C.1. For wet gas scrubbing systems that are designed to control sulfur dioxide, an alkaline reagent, such as caustic soda (NaOH), soda ash, or lime, is typically added to the scrubbing liquid. These reagents are used to drive sulfur dioxide absorption into the scrubbing liquid. As described previously, spent scrubbing liquid that contains the captured pollutants is then routed for treatment and discharge, or regenerated for further use.

IV. DRAFT RULE AMENDMENTS

The purpose of the draft amendments to Rule 6-5 is to further address particulate matter emissions, including condensable particulate matter emissions, from fluidized catalytic cracking units and associated carbon monoxide boilers. Air District staff reviewed and considered a variety of information in the development of the draft amendments, including existing regulations, industry and academic literature, stakeholder input, emissions and compliance data, and information on control and monitoring technologies.

The Air District staff released draft amendments to Rule 6-5 in May 2020 for public review and comment. These draft amendments are described below as “Control Scenario A”. Following the release of the draft amendments in May 2020, staff further evaluated other potential control options for these sources, including a more stringent potential control option for assessment and consideration. Staff developed draft amendments reflecting this more stringent potential control option, which are described below as “Control Scenario B”.

A. *Draft Rule Amendments Under Control Scenario A—Electrostatic Precipitator*

The draft amendments under Control Scenario A reflect the draft amendments published by the Air District in May 2020. Note that staff received public comments on the draft amendments following their release in May 2020, including comments regarding the stringency of the draft amendments, feasibility of achieving the draft limits, testing and monitoring requirements, implementation timelines, and potential economic, environmental, and health impacts. Staff will continue to evaluate and consider those comments and other comments received during this current comment period in the further development of rule amendments. The discussion below of Control Scenario A draft amendments reflects the draft amendments as presented in May 2020.

The draft amendments under Control Scenario A include new and modified limits on ammonia and sulfur dioxide, as well as a direct limit on total PM_{10}. The draft new and modified limits on ammonia and sulfur dioxide reflect levels of stringency widely achieved at multiple facilities. Control of these pollutants was historically demonstrated and implemented through various federal, state, and regional regulatory programs, and the reduction of these components was shown to reduce total particulate matter emissions. The draft amendments also include a new limit on total PM_{10} emissions. This direct limit on total PM_{10} would ensure that all particulate matter emissions are adequately controlled and that abatement systems are optimized to reduce overall total particulate matter emissions. Previously, some abatement systems were optimized to control only filterable particulate matter, and this inadvertently resulted in higher emissions of total particulate matter. The draft amendments also include modifications to existing rule language to clarify provisions and improve monitoring requirements.

1. Purpose

The draft amendments under Control Scenario A contain requirements to control total particulate matter and reduce flue gas components and pollutants known to increase total particulate matter emissions. The draft amendments also contain testing and monitoring requirements to determine compliance with emission limits and provide further information on particulate matter emissions and control performance.

2. Applicability

Draft amendments to Rule 6-5 under Control Scenario A would apply to fluidized catalytic cracking units and associated carbon monoxide boilers at Bay Area petroleum refineries. Four of the five petroleum refineries in the San Francisco Bay Area have fluidized catalytic cracking units.[20]

3. Exemptions

<u>Section 6-5-111 – Limited Exemption, Emissions Abated by Wet Scrubber</u>: The draft amendments to Rule 6-5 modify the exemption under Section 6-5-111 regarding emissions abated by wet scrubber. Under the currently adopted Rule 6-5, emissions abated by a wet gas scrubber are not subject to any requirements of the rule. Because the draft amendments include new requirements (described in the sections below), Section 6-5-111 is changed to a limited exemption to clarify that emissions abated by a wet scrubber are only exempt from the requirements related to ammonia limits in Section 6-5-301.1. Emissions abated by a wet scrubber would be subject to the additional limits and requirements included in these draft amendments.

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[20] One of these four refineries is Marathon Martinez Refinery, which announced the temporary idling of their refinery, including the facility's FCCU, in April 2020. In July 2020, Marathon announced that the refinery will remain idled indefinitely with no plans to restart normal operations.

Section 6-5-112 – Limited Exemption, Emissions during Startup or Shutdown Periods: The draft amendments to Rule 6-5 clarify the limited exemption under Section 6-5-112 for emissions during startup and shutdown periods. The amendments clarify that the exemption for these periods are only applicable to the short-term daily ammonia limit in Section 6-5-301.1 and short-term seven-day rolling average limit for sulfur dioxide in Section 6-5-301.2.2. Long-term limits in Section 6-5-301 would continue to apply.

Section 6-5-115 – Limited Exemption, Ammonia Optimization: The draft amendments also modify the limited exemption under Section 6-5-115 regarding ammonia optimization. Under the currently adopted Rule 6-5, refinery operators that implement an optimization of ammonia and/or urea injection are exempt from the ammonia emission limit in Section 6-5-301.1. Under the draft amendments, all sources previously exempt under Section 6-5-115 would be subject to the ammonia emission limit in Section 6-5-301.1 effective January 1, 2023.

4. Definitions

Section 6-5-207 – Fluidized Catalytic Cracking Unit (FCCU): The draft amendments clarify language regarding the applicability of the rule requirements to commingled emissions from a fluidized catalytic cracking unit and other sources. Commingled emissions are considered fluidized catalytic cracking unit emissions. This is stated in the current Rule under Section 6-5-101; the draft amendments include this language in the fluidized catalytic cracking unit definition for further clarity.

Section 6-5-212 – Total Particulate Matter 10 Microns or Less in Diameter (Total PM_{10}): The draft amendments to Rule 6-5 define total particulate matter 10 microns or less in diameter (total PM_{10}) in Section 6-5-212 as material emitted to the atmosphere as filterable particulate matter or condensable particulate matter less than 10 microns in diameter. Condensable particulate matter is currently defined in the rule under Section 6-5-203.

Section 6-5-213 – Total Particulate Matter 2.5 Microns or Less in Diameter (Total $PM_{2.5}$): For the purposes of this rule, the draft amendments to Rule 6-5 define total particulate matter 2.5 microns or less in diameter (total $PM_{2.5}$) in Section 6-5-213 as material emitted to the atmosphere as filterable particulate matter or condensable particulate matter less than 2.5 microns in diameter. Condensable particulate matter is currently defined in the Rule under Section 6-5-203.

5. Standards

Section 6-5-301 – Fluidized Catalytic Cracking Unit (FCCU) Emission Limits: The draft amendments to Rule 6-5 establish and modify fluidized catalytic cracking unit emission standards for ammonia slip, sulfur dioxide, and total particulate matter.

Section 6-5-301.1: Under the Control Scenario A draft amendments, the ammonia emission limit of 10 parts per million by volume, dry basis (ppmvd) corrected to 3 percent oxygen on a daily average remains unchanged from the currently adopted rule. As described above in the "Exemptions" section, the draft amendments modify the limited exemption under Section 6-5-115 such that sources previously exempt from the ammonia emission limit in Section 6-5-301.1 would be subject to this limit effective January 1, 2023. The ammonia limit of 10 ppmvd is equivalent to the ammonia limit for fluidized catalytic cracking units adopted by South Coast Air Quality Management District in their Rule 1105.1; this limit was achieved by fluidized catalytic cracking units at multiple refineries using electrostatic precipitators or wet gas scrubbers.

Sections 6-5-301.2.1 and 301.2.2: The draft amendments under Control Scenario A include a new sulfur dioxide limit of 50 ppmvd corrected to zero (0) percent oxygen on a seven-day rolling average basis, and 25 ppmvd corrected to 0 percent oxygen on a 365-day rolling average basis. These limits are equivalent to the sulfur dioxide limits in federal New Source Performance Standards Subpart Ja, which are required for fluidized catalytic cracking units constructed, reconstructed, or modified after May 14, 2007. These sulfur dioxide emission levels have been achieved at multiple refineries throughout California and the US through the implementation of sulfur dioxide-reducing additives and/or wet gas scrubbers. The draft amendments under Control Scenario A include an effective date for the sulfur dioxide limits of January 1, 2023.

Section 6-5-301.3: The draft amendments under Control Scenario A include a new limit for total PM_{10}. The draft amendments require a refinery operator of a fluidized catalytic cracking unit to comply with a total PM_{10} limit of 0.020 grains per dry standard cubic foot (gr/dscf) on a rolling four-quarter average basis. The total PM_{10} limit in the draft amendments is based on the Air District's review of source test data from fluidized catalytic cracking units at refineries throughout California and the US.[21,22] The draft total PM_{10} limit of 0.020 gr/dscf represents an achievable level of control that has been demonstrated to be feasible at multiple facilities through the use of various control technologies, including electrostatic precipitators and wet gas scrubbers. The draft amendments under Control Scenario A include an effective date for the total PM_{10} limit of January 1, 2023.

Under the draft amendments, compliance with the total PM_{10} limits would be determined based on the rolling four-quarter average calculated as the time-weighted average of source tests (which must be performed on at least a quarterly basis). Other emission monitoring systems approved by the Air District would also be allowed for monitoring and compliance demonstration with the total PM_{10} limit.

6. Administrative Requirements

Section 6-5-403 – Ammonia Optimization: The draft amendments under Control Scenario A include clarifications and modifications to the ammonia optimization requirements in Section 6-5-403 to align this section with the provisions and timelines of the draft amendments in Section 6-5-115.1.

Section 6-5-404 – Reporting Requirements: Draft Section 6-5-505 requires monthly reporting of monitoring data collected as required by Sections 6-5-501, as well as quarterly reporting of source test results and data collected as required by Section 6-5-503.

7. Monitoring and Records

The operator of any source subject to the emission limits in Section 6-5-301 must monitor and record all parameters necessary to demonstrate compliance with the applicable standards.

Section 6-5-501 – Ammonia Monitoring: For fluidized catalytic cracking units subject to the ammonia emission limit in 6-5-301.1, ammonia monitoring requirements in Section 6-5-501 remain unchanged from the currently adopted rule.

[21] EPA, 2016. Comprehensive Data Collected from the Petroleum Refining Sector – Petroleum Information Collection Request for Petroleum Refinery Sector New Source Performance Standards and National Emissions Standards for Hazardous Air Pollutants Risk and Technology. July. https://www.epa.gov/stationary-sources-air-pollution/comprehensive-data-collected-petroleum-refining-sector.

[22] EPA, 2015. Compilation of Air Pollutant Emissions Factors (AP-42), Fifth Edition, Volume I, Chapter 5: Petroleum Industry, 5.1 Petroleum Refining. April.

Section 6-5-502 – Sulfur Dioxide Monitoring: Under draft Section 6-5-502, refinery operators that must comply with the draft sulfur dioxide limits in Section 6-5-301.2 must also comply with the continuous emission monitoring requirements of District Regulation 1, Sections 1-520 and 522.

Section 6-5-503 – Total PM_{10} and Total $PM_{2.5}$ Monitoring: Under draft Section 6-5-503, refinery operators that must comply with the total PM_{10} limit in Section 6-5-301.3 must also implement a source testing protocol or other total PM_{10} and total $PM_{2.5}$ emission monitoring system approved by the Air District. The source testing protocol must include at least one source test each calendar quarter for total PM_{10} and total $PM_{2.5}$ emissions in accordance with Sections 6-5-604 and 605.

Section 6-5-504 – Records: The draft amendments to Section 6-5-504 extend the current recordkeeping requirements to include all monitoring records required under Sections 6-5-501, 502, and 503. Section 6-5-504 has also been renumbered accordingly.

8. Manual of Procedures

Section 6-5-601 – Compliance Determination: The draft amendments to Section 6-5-601 include additional provisions regarding the performance of source tests for compliance. Under the draft amendments, source tests must meet the requirements in the District Manual of Procedures, Volume IV, Source Test Policy and Procedures. The draft amendments to Section 6-5-601 also include clarifications to align this section with the draft amendments in Section 6-5-112 pertaining to emissions during startup and shutdown periods. The amendments clarify that the exemption for these periods are only applicable to the short-term daily ammonia limit in Section 6-5-301.1 and short-term seven-day rolling average limit for sulfur dioxide in Section 6-5-301.2.2.

Section 6-5-602 – Determination of Ammonia and Oxygen: The draft amendments to Section 6-5-602 specify additional requirements for Air District approved ammonia monitoring systems. Under the draft amendments, ammonia monitoring systems must meet the requirements of US Environmental Protection Agency Performance Specification 18.[23] Although US Environmental Protection Agency Performance Specification 18 was not specifically developed for use with ammonia monitoring systems, Air District staff has consulted with US Environmental Protection Agency staff and determined this specification to be appropriate for these monitoring systems. The US Environmental Protection Agency strongly encourages that operators of ammonia monitoring systems consider the use of Performance Specification 18.[24] The draft amendments also clarify that compliance with the ammonia limits in Section 6-5-301.1 must be determined by the monitoring systems installed as required by Section 6-5-501.

Section 6-5-603 – Determination of Sulfur Dioxide: Draft Section 6-5-603 states that compliance with the sulfur dioxide limits in Section 6-5-301.2 must be determined by monitoring systems that meet the requirements of District Regulation 1, Section 1-522.

Section 6-5-604 – Determination of Total Particulate Matter 10 Microns or Less in Diameter (Total PM_{10}): Draft Section 6-5-604 states that total PM_{10} must be determined by the summation of filterable PM_{10} as measured by US Environmental Protection Agency Test Method 201A and condensable particulate matter as measured by US Environmental Protection Agency Test Method 202. Compliance with the total PM_{10} limit in Section 6-5-301.3 must be determined by the time-weighted average of all source tests conducted in the preceding four calendar quarters.

[23] EPA, 2019a. Performance Specification 18 – Performance Specifications and Test Procedures for Gaseous Hydrogen Chloride (HCl) Continuous Emission Monitoring Systems at Stationary Sources. January.
[24] EPA, 2019b. Air Emission Measurement Center (EMC) Other Test Methods. May. https://www.epa.gov/emc/emc-other-test-methods.

Section 6-5-605 – Determination of Total Particulate Matter 2.5 Microns or Less in Diameter (Total $PM_{2.5}$): Draft Section 6-5-605 states that total $PM_{2.5}$ must be determined by the summation of filterable $PM_{2.5}$ as measured by US Environmental Protection Agency Test Method 201A and condensable particulate matter as measured by US Environmental Protection Agency Test Method 202.

B. Draft Rule Amendments Under Control Scenario B—Wet Gas Scrubber

Following the release of the draft amendments in May 2020, staff further evaluated other potential control options for these sources, including a more stringent potential control option for assessment and consideration. Staff developed draft amendments reflecting this more stringent potential control option under Control Scenario B.

The draft amendments under Control Scenario B include new and modified limits on ammonia and sulfur dioxide, as well as a direct limit on total PM_{10}, which includes both filterable and condensable particulate matter. The draft new and modified limits reflect levels of stringency that have been achieved at units using wet gas scrubbing controls. The draft amendments also include modifications to existing rule language to clarify provisions and improve monitoring requirements.

1. Purpose

The draft amendments under Control Scenario B contain requirements to control total particulate matter and reduce flue gas components and pollutants that known to increase total particulate matter emissions. The draft amendments also contain testing and monitoring requirements to determine compliance with emission limits and provide further information on particulate matter emissions and control performance.

2. Applicability

Draft amendments to Rule 6-5 under Control Scenario B would apply to fluidized catalytic cracking units and associated carbon monoxide boilers at Bay Area petroleum refineries. Four of the five petroleum refineries in the San Francisco Bay Area have fluidized catalytic cracking units.[25]

3. Exemptions

Section 6-5-111 – Limited Exemption, Emissions Abated by Wet Scrubber: The draft amendments that modify Section 6-5-11 under Control Scenario B are equivalent to those under Control Scenario A, which are described in the previous Section IV.A.

Section 6-5-112 – Limited Exemption, Emissions during Startup or Shutdown Periods: The draft amendments that modify Section 6-5-12 under Control Scenario B are equivalent to those under Control Scenario A, which are described in the previous Section IV.A.

Section 6-5-115 – Limited Exemption, Ammonia Optimization: The draft amendments under Control Scenario B modify the limited exemption under Section 6-5-115 regarding ammonia optimization. Under the currently adopted Rule 6-5, refinery operators that implement an optimization of ammonia and/or urea injection are exempt from the ammonia emission limit in Section 6-5-301.1. Under the Control Scenario B draft amendments, all sources previously

[25] One of these four refineries is Marathon Martinez Refinery, which announced the temporary idling of their refinery, including the facility's FCCU, in April 2020. In July 2020, Marathon announced that the refinery will remain idled indefinitely with no plans to restart normal operations.

exempt under Section 6-5-115 would be subject to the ammonia emission limit in Section 6-5-301.1 effective January 1, 2026.

4. Definitions

The draft amendments to the "Definitions" section of Rule 6-5 under Control Scenario B are equivalent to those under Control Scenario A, which are described in the previous Section IV.A.

5. Standards

Section 6-5-301 – Fluidized Catalytic Cracking Unit (FCCU) Emission Limits: The draft amendments to Rule 6-5 under Control Scenario B establish and modify fluidized catalytic cracking unit emission standards for ammonia slip, sulfur dioxide, and total particulate matter. The draft amendments under Control Scenario B include an effective date for the draft limits of January 1, 2026. Staff anticipates that the draft limits under Control Scenario B would require the installation of wet gas scrubbing systems at the affected refineries (see Section V of this report for a preliminary discussion of potential impacts), which may involve substantial time and effort for the planning, design, scheduling, and construction and/or modifications of such abatement systems. For example, applications for use permits and Air District permits for the installation of the wet gas scrubber at the Valero Benicia Refinery were originally submitted in 2002 as part of the Valero Improvement Project. The Valero Improvement Project involved several components, and construction of the various elements occurred over several years following approval. Construction of the wet gas scrubber abatement train took place from 2008 through 2010, with operation commencing in 2011.[26]

Section 6-5-301.1: Under the Control Scenario B draft amendments, the ammonia emission limit of 10 parts per million by volume, dry basis (ppmvd) corrected to 3 percent oxygen on a daily average remains unchanged from the currently adopted rule. As described above in the "Exemptions" section, the draft amendments modify the limited exemption under Section 6-5-115 such that sources previously exempt from the ammonia emission limit in Section 6-5-301.1 would be subject to this limit effective January 1, 2026.

Sections 6-5-301.2.1 and 301.2.2: The draft amendments under Control Scenario B include a new sulfur dioxide limit of 50 ppmvd corrected to zero (0) percent oxygen on a seven-day rolling average basis, and 25 ppmvd corrected to 0 percent oxygen on a 365-day rolling average basis. These limits are equivalent to the sulfur dioxide limits in federal New Source Performance Standards Subpart Ja, which are required for fluidized catalytic cracking units constructed, reconstructed, or modified after May 14, 2007. These sulfur dioxide emission levels have been achieved at multiple refineries throughout California and the US through the implementation of sulfur dioxide-reducing additives and/or wet gas scrubbers. In addition, the wet gas scrubbing system in operation at the Valero Benicia Refinery is currently subject to comparable sulfur dioxide limits. The draft amendments under Control Scenario B include an effective date for the sulfur dioxide limits of January 1, 2026.

Section 6-5-301.3: The draft amendments under Control Scenario B include a new limit for total PM_{10}. The draft amendments require the operator of a fluidized catalytic cracking unit to comply with a total PM_{10} limit of 0.010 grains per dry standard cubic foot (gr/dscf) on a rolling four-quarter average basis. The total PM_{10} limit in the draft amendments is based on the Air District's review of source test data from fluidized catalytic cracking units at refineries throughout California and the US. The draft total PM_{10} limit of 0.010 gr/dscf represents an achievable level of control that

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[26] Valero Benicia Refinery, 2012. Valero Improvement Project (VIP) Construction Report for the period ending June 30, 2012. August.

has been demonstrated to be feasible at multiple facilities through the use of wet gas scrubbers. The draft amendments under Control Scenario B include an effective date for the total PM_{10} limit of January 1, 2026.

Under the Control Scenario B draft amendments, compliance with the total PM_{10} limits would be determined based on the rolling four-quarter average calculated as the time-weighted average of source tests (which must be performed on at least a quarterly basis). Other emission monitoring systems approved by the Air District would also be allowed for monitoring and compliance demonstration with the total PM_{10} limit.

6. Administrative Requirements

Section 6-5-403 – Ammonia Optimization: The draft amendments under Control Scenario B include clarifications and modifications to the ammonia optimization requirements in Section 6-5-403 to align this section with the provisions and timelines of the draft amendments in Section 6-5-115.1.

Section 6-5-404 – Reporting Requirements: Draft Section 6-5-505 requires monthly reporting of monitoring data collected as required by Sections 6-5-501, as well as quarterly reporting of source test results and data collected as required by Section 6-5-503.

7. Monitoring and Records

Draft amendments to the “Monitoring and Records” section of Rule 6-5 under Control Scenario B are equivalent to those under Control Scenario A, which are described in the previous Section IV.A.

8. Manual of Procedures

Draft amendments to the “Manual of Procedures” section of Rule 6-5 under Control Scenario B are equivalent to those under Control Scenario A, which are described in the previous Section IV.A.

V. PRELIMINARY DISCUSSION OF POTENTIAL IMPACTS

This section discusses preliminary estimates of potential impacts associated with the potential control options described in the draft amendments. Air District staff continues to evaluate and assess these potential impacts and may update or refine estimates as staff conducts additional research and gathers additional information.

A. Preliminary Estimates of Potential Emissions Reductions

Based on staff’s understanding of fluidized catalytic cracking units emissions and performance at the Bay Area petroleum refineries, staff anticipates that under Control Scenario A, fluidized catalytic cracking units at Marathon Martinez Refinery and Valero Benicia Refinery would be able to comply with the draft emission limits without substantial modifications. Therefore, potential emission reductions at these facilities would be minimal. Fluidized catalytic cracking units at Chevron Products Richmond and PBF Martinez Refinery would not meet the draft emission limits under Control Scenario A and staff anticipates that emission reductions would be required at these facilities to comply with these draft limits. Estimates of potential emission reductions associated with Control Scenario A are shown in Table 2.

Under Control Scenario B, staff anticipates that the fluidized catalytic cracking unit at Valero Benicia Refinery would be able to comply with the draft emission limits without substantial modifications, and potential emission reductions at this facility would be minimal. Fluidized catalytic cracking units at Chevron Products Richmond, Marathon Martinez Refinery, and PBF Martinez Refinery would not meet the draft emission limits under Control Scenario B, and staff anticipates that emission reductions would be required at these facilities to comply with these draft limits. Estimates of potential emission reductions associated with Control Scenario B are shown in Table 2. As described previously, Air District staff continues to study these emissions and may update or refine emission reduction estimates as staff gathers additional information.

Table 2 – Estimates of Potential Particulate Matter Emission Reductions Under Control Scenario A and Control Scenario B

Facility	**Estimated PM_{10} Reductions (tons per year)**	
	Control Scenario A	**Control Scenario B**
Chevron Products Richmond	80	160
Marathon Martinez Refinery[a]	*–*	*93*
PBF Martinez Refinery	170	240
Valero Benicia Refinery	–	–
Total Estimated Reductions[b]	**250**	**493**

[a] The Marathon Martinez Refinery announced the idling of the refinery, including the facility's fluidized catalytic cracking unit, in April 2020. Marathon announced in July 2020 that the facility would remain indefinitely idled with no plans to restart.
[a] Total estimated reductions shown include potential reductions at the Marathon Martinez Refinery, which was idled in April 2020 and remains indefinitely idled.

B. Preliminary Estimates of Compliance Cost, Cost Effectiveness, and Incremental Cost Effectiveness

Air District staff reviewed available data on costs and cost estimation tools and methodologies and developed preliminary cost estimates associated with compliance under each potential control scenarios. The development of these preliminary estimates for each control scenario is discussed below. Air District staff continues to assess and gather additional information related to compliance costs and may update or refine these preliminary estimates.

Air District staff also developed preliminary estimates of cost effectiveness for each potential control option, as well as estimates of the incremental cost effectiveness between the control options. Cost effectiveness is calculated by dividing the annual costs by the total number of tons of emission reductions expected each year:

$$\text{Cost-effectiveness} = \frac{\text{Annual cost}}{\text{Emission reduction}}$$

Incremental cost effectiveness is calculated when two (or more) control methods are being considered. Incremental cost effectiveness is then calculated by: 1) calculating the incremental increase in cost between the first control method and the second more stringent control method, and 2) dividing the incremental increase in cost by the incremental increase in emission reductions from the second more stringent control method:

$$\text{Incremental cost-effectiveness} = \frac{\text{Annual cost (B)} - \text{Annual cost (A)}}{\text{Emission reduction (B)} - \text{Emission reduction (A)}}$$

The Air District is required to consider both cost effectiveness and incremental cost effectiveness when adopting any regulation.[27,28]

1. Preliminary Estimates of Compliance Cost and Cost Effectiveness for Control Scenario A

Under Control Scenario A, staff anticipates that additional pollution abatement equipment and modifications would be required at fluidized catalytic cracking units at Chevron Products Richmond and PBF Martinez Refinery. Based on staff's understanding of current performance and emissions at these facilities, staff anticipates that improvements to existing electrostatic precipitator systems or additional electrostatic precipitator capacity would be required to comply with Control Scenario A. Staff anticipates that PBF Martinez Refinery would also be required to improve feed hydrotreatment and sulfur dioxide-reducing additives to comply with the draft limits under Control Scenario A. Preliminary estimates of the total compliance costs and cost effectiveness under Control Scenario A are shown in Table 3. Further information on the development of the preliminary cost estimates are provided in the sections below.

Table 3 – Preliminary Estimates of Compliance Costs and Cost Effectiveness for Control Scenario A

Facility	Estimated Capital Costs	Estimated Total Annual Costs[a]	Estimated Cost Effectiveness
Chevron Products Richmond[b]	$30 MM	$4.4 MM	$55,300/ton
Marathon Martinez Refinery	–	–	–
PBF Martinez Refinery[c]	$80 MM	$14 MM	$84,900/ton
Valero Benicia Refinery	–	–	–

[a] Total annualized costs include amortized capital costs, tax, insurance, general and administrative, and operating and maintenance costs.
[b] Compliance under Control Scenario A at Chevron Products Richmond is assumed to require improvements/expansions to existing electrostatic precipitator systems.
[c] Compliance under Control Scenario A at PBF Martinez Refinery is assumed to require improvements/expansions to existing electrostatic precipitator systems, improvements to existing feed hydrotreatment systems, and optimized/improved sulfur dioxide-reducing additives.

a) Preliminary Cost Estimates for Electrostatic Precipitator Improvements

Staff estimated costs for electrostatic precipitator expansions using control cost methodologies presented in the EPA Air Pollution Control Cost Manual.[29] Staff assumed controls would be applied to an exhaust flow of approximately 550,000 actual cubic feet per minute at Chevron Products Richmond, and applied to three separate exhaust flows of approximately 160,000 actual cubic feet per minute each at PBF Martinez Refinery due to the configuration of the fluidized catalytic cracking system and three carbon monoxide boilers at the refinery. Due to the existing electrostatic precipitator systems at both facilities, staff estimated costs for expansions of these systems based on a half-sized electrostatic precipitator. Additional assumptions, inputs, and model parameters were based on the cost estimates and methodologies presented in the EPA cost analysis for the 2008 Standards of Performance for Petroleum Refineries.[30]

Staff also applied additional adjustments to the results of these methodologies to reflect temporal and geographic differences and changes in market conditions. To adjust for inflation and changes of control costs over time, staff used the Chemical Engineering Plant Cost Index (CEPCI) to adjust

[27] California Health and Safety Code, Section 40703.
[28] California Health and Safety Code, Section 40920.6.
[29] United States Environmental Protection Agency (EPA), 2018a. EPA Air Pollution Control Cost Manual. https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/cost-reports-and-guidance-air-pollution. Updated May 23, 2018.
[30] EPA, 2008. Regulatory Impact Analysis for the Petroleum Refineries NSPS (New Source Performance Standards). EPA-452/R-08-002. April.

cost estimates to 2019 dollars.[31] The Chemical Engineering Plant Cost Index is an index that tracks costs of equipment, construction labor, buildings, and supervision in chemical process industries, and has been used extensively by the US Environmental Protection Agency for escalation purposes.[32] Staff also reviewed information on potential adjustments to account for regional market differences. Staff found that construction costs for projects in the San Francisco Bay Area are approximately 30 percent higher compared to national average costs based on a review of the RSMeans City Cost Index, which allows for comparison of materials, labor, and installation costs across different regions.[33] Although the index is not specific to air pollution control equipment, it provides a reference point for comparison these costs between regional markets.

Preliminary capital cost estimates for electrostatic precipitator improvements and expansions for each facility are shown in Table 4. Staff also estimated total annual costs, which includes amortized capital costs, tax, insurance, general and administrative (G&A) costs, and operating and maintenance (O&M) costs. Amortized capital cost is calculated assuming a project lifetime of 20 years at six percent interest. Operating and maintenance costs were estimated based on the EPA cost estimating methodologies and assumptions described previously. Other annual costs were estimated as a percentage of capital cost, with tax costs of one percent, insurance costs of one percent, and general and administrative costs of two percent. The preliminary estimates of total annual costs, including amortized capital and annual operating costs, are also shown in Table 4.

Table 4 – Preliminary Cost Estimates for Electrostatic Precipitator Improvements/Expansions

Facility	Estimated Capital Costs	Estimated Total Annual Costs[a]
Chevron Products Richmond	$30 MM	$4.4 MM
Marathon Martinez Refinery	–	–
PBF Martinez Refinery	$40 MM	$5.9 MM
Valero Benicia Refinery	–	–

[a] Total annualized costs include amortized capital costs, tax, insurance, general and administrative, and operating and maintenance costs.

Staff also reviewed available cost information reported for electrostatic precipitator improvements and expansions at other facilities. Staff recognizes that costs of specific electrostatic precipitator projects may vary based on a number of factors, including the age, performance, and capacity of existing electrostatic precipitator systems; specific system designs and technologies; and other site-specific constraints. South Coast Air Quality Management District (South Coast AQMD) staff reported on costs of electrostatic precipitator projects at refineries in their jurisdiction following the adoption of South Coast AQMD Rule 1105.1 in 2003.[34] These costs ranged widely, with four refineries reporting total capital costs ranging from $23 million to $121 million, while one refinery reported total capital costs of $340 million. South Coast AQMD staff noted that these costs were higher than previously estimated costs, and some of the factors potentially leading to these discrepancies include the hyperinflation of construction equipment and labor in 2008, compressed construction schedules caused by the Western States Petroleum Association (WSPA) litigation

[31] Chemical Engineering, 2020. The Chemical Engineering Plant Cost Index. https://www.chemengonline.com/pci-home.
[32] EPA, 2018a. EPA Air Pollution Control Cost Manual. https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/cost-reports-and-guidance-air-pollution. Updated May 23, 2018.
[33] Gordian, 2020. RSMeans City Cost Index. https://www.rsmeans.com/rsmeans-city-cost-index.
[34] South Coast AQMD, 2010. Final Staff Report SOx RECLAIM, Part 1: BARCT Assessment & RTC Reductions Analysis. November.

of the rule, and a sharp increase in steel pricing. In addition, South Coast AQMD staff noted that some of the facilities with much higher costs added extraordinary capacity to their existing electrostatic precipitator systems and elected to upgrade a number of other systems at their site in addition to the electrostatic precipitators.

Air District staff also solicited cost estimate information from the potentially affected refineries. Chevron Products Richmond estimated that additional electrostatic precipitator installations at the refinery would result in capital costs of approximately $100 million.

b) Preliminary Cost Estimates for Improved Feed Hydrotreatment and Sulfur Dioxide-Reducing Additives

Staff reviewed information on capital costs for improvements and revamps of fluidized catalytic cracking unit feed hydrotreating systems. Costs for these types of improvement projects may vary based on a number of factors, including the existing equipment train, the specific improvements made, and other site-specific constraints. An industry case study estimated that a hydrotreater revamp project, including the construction of a new product fractionator, would cost $30 million.[35] Other literature also presents capital cost estimate tools for new hydrotreatment systems.[36] Staff also solicited information from PBF Martinez Refinery on potential costs for hydrotreatment improvement projects.

Based on the review of available cost data and tools and stakeholder input, staff developed preliminary cost estimates of hydrotreatment improvements, which are shown in Table 5. Staff also estimated total annual costs, which includes amortized capital costs, tax, insurance, general and administrative (G&A) costs, and operating and maintenance (O&M) costs. Amortized capital cost is calculated assuming a project lifetime of 20 years at six percent interest. Annual costs were estimated as a percentage of capital cost, with tax costs of one percent, insurance costs of one percent, general and administrative costs of two percent, and operating and maintenance costs of five percent. In addition, staff reviewed available cost data for the use of optimized and improved sulfur dioxide-reducing additives from EPA, South Coast AQMD, and industry literature.[37,38,39,40] Based on this review, staff estimated that optimization and improvement of sulfur dioxide-reducing additives would result in an additional annual cost of $1.5 million. The preliminary estimates of total annual costs, including amortized capital and annual operating costs, are also shown in Table 5.

[35] Schwalje, David; Larry Wisdom; and Mike Craig (Axens North America), 2016. Revamp cat feed hydrotreaters for flexible yields. EPTQ (Petroleum Technology Quarterly), Revamps 2016.
[36] Gary, James H.; Glenn Handwerk; and Mark Kaiser, 2007. Petroleum Refining Technology and Economics, Fifth Ed.
[37] EPA, 2008. Regulatory Impact Analysis for the Petroleum Refineries NSPS (New Source Performance Standards). EPA-452/R-08-002. April.
[38] South Coast AQMD, 2003. Final Staff Report for Proposed Rule 1105.1. September.
[39] South Coast AQMD, 2010. Final Staff Report SOx RECLAIM, Part 1: BARCT Assessment & RTC Reductions Analysis. November.
[40] Evans, Martin (Intercat/Johnson Matthey), 2008. Evaluating FCC flue gas emission-control technologies. Digital Refining, 2008 Q1.

Table 5 – Preliminary Cost Estimates for Improvements to Feed Hydrotreatment and Sulfur Dioxide-Reducing Additives

Facility	Estimated Capital Costs	Estimated Total Annual Costs[a]
Chevron Products Richmond	–	–
Marathon Martinez Refinery	–	–
PBF Martinez Refinery	$40 MM	$8.6 MM
Valero Benicia Refinery	–	–

Notes:
[a] Total annualized costs include amortized capital costs, tax, insurance, general and administrative, operating and maintenance costs, and annual costs for optimized and improved sulfur dioxide-reducing additives.

2. Preliminary Compliance Cost Estimates for Control Scenario B

Under Control Scenario B, staff anticipates that additional pollution abatement equipment and modifications would be required at fluidized catalytic cracking units at Chevron Products Richmond, PBF Martinez Refinery, and Marathon Martinez Refinery. Based on staff's understanding of current performance and emissions at these facilities, staff anticipates that wet gas scrubbing systems would be required to comply with Control Scenario B. Preliminary estimates of the total compliance costs, cost effectiveness, and incremental cost effectiveness under Control Scenario B are shown in Table 6. Further information on the development of the preliminary cost estimates are provided in the sections below.

Table 6 – Preliminary Compliance Cost and Cost Effectiveness Estimates for Control Scenario B

Facility	Estimated Capital Costs	Estimated Total Annual Costs[a]	Estimated Cost Effectiveness	Estimated Incremental Cost Effectiveness
Chevron Products Richmond	$241 MM	$39 MM	$239,600/ton	$423,400/ton
Marathon Martinez Refinery[b]	*$235 MM*	*$38 MM*	*$406,400/ton*	–[c]
PBF Martinez Refinery	$255 MM	$40 MM	$165,000/ton	$359,400/ton
Valero Benicia Refinery	–	–	–	–

[a] Total annualized costs include amortized capital costs, tax, insurance, general and administrative, and operating and maintenance costs.
[b] The Marathon Martinez Refinery announced the idling of the refinery, including the facility's fluidized catalytic cracking unit, in April 2020. Marathon announced in July 2020 that the facility would remain indefinitely idled with no plans to restart.
[c] Incremental cost effectiveness is not calculated for the Marathon Martinez Refinery because there is no emission reduction or compliance cost under Control Scenario A to compare to Control Scenario B.

a) Preliminary Cost Estimates for Wet Gas Scrubbing Systems

Staff estimated costs for wet gas scrubbing systems using control cost methodologies presented in the US Environmental Protection Agency Air Pollution Control Cost Manual.[41] Staff assumed non-regenerative wet gas scrubbers would be applied to an exhaust flow of approximately 550,000 actual cubic feet per minute at Chevron Products Richmond; 530,000 actual cubic feet per minute at Marathon Martinez Refinery; and 480,000 actual cubic feet per minute at PBF

[41] United States Environmental Protection Agency (EPA), 2018a. EPA Air Pollution Control Cost Manual. https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/cost-reports-and-guidance-air-pollution. Updated May 23, 2018.

Martinez Refinery.[42] Additional assumptions, inputs, and model parameters were based on the cost estimates and methodologies for non-regenerative wet gas scrubbers presented in the EPA cost analysis for the 2008 Standards of Performance for Petroleum Refineries.[43] Staff also applied additional adjustments to these methodologies to reflect temporal and geographic differences and changes in market conditions. These adjustments and sources are described in Section V.B.1(a) (page 22).

In addition, staff reviewed information from the Valero Benicia Refinery's installation of a regenerative wet gas scrubber to evaluate the performance of the cost estimate methodology and identify other potential adjustments and refinements. The Valero Benicia Refinery installed a regenerative wet gas scrubber to abate emissions from the facility's fluidized catalytic cracking unit and fluid coking unit. This project is the most recent installation of a wet gas scrubber on a fluidized catalytic cracking unit in California, and the only such refinery wet gas scrubber in the San Francisco Bay Area. Valero reported that the cost of the wet gas scrubber equipment train, which also included the replacement of existing furnaces, was approximately $750 million.[44] The cost of the wet gas scrubber installation was estimated to be approximately $525 million.[45] Staff conducted a comparison of this reported cost with cost estimates developed for a comparably sized regenerative wet gas scrubbing system using US Environmental Protection Agency control cost methodologies. Staff's evaluation indicated that reported costs were a factor of 7 higher than the estimates developed using the US Environmental Protection Agency control cost methodologies. Staff applied this additional factor to the preliminary cost estimates.

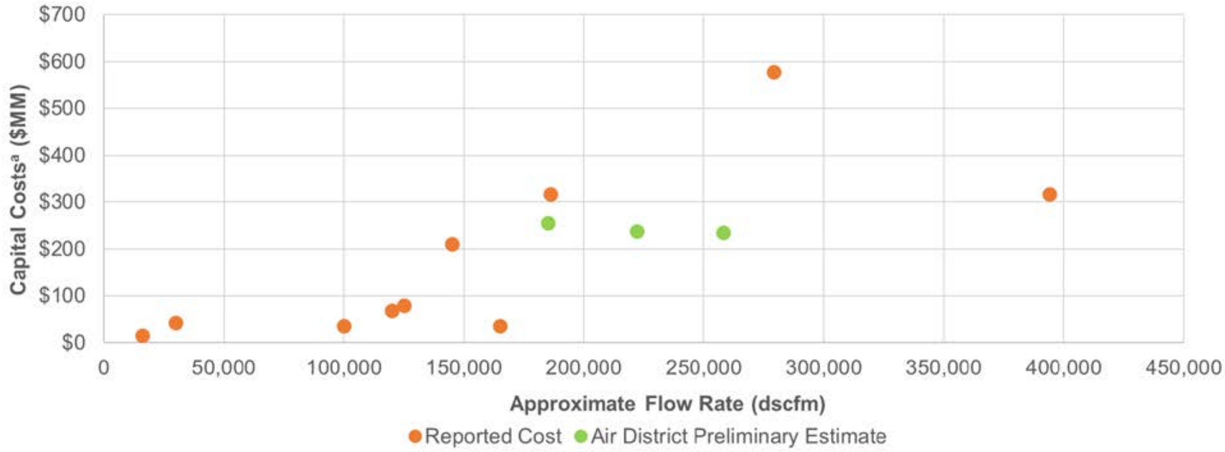
Staff also solicited input from potentially affected refineries on estimated costs related to the installation of a wet gas scrubber. Based on staff's understanding of potential space constraints at PBF Martinez Refinery in the areas around the existing fluidized catalytic cracking unit and carbon monoxide boilers, staff assumes the installation of a wet gas scrubber would require additional costs for the relocation of some equipment. Based on staff's understanding and stakeholder input, staff estimated that this relocation would cost approximately $35 million. Staff included this additional relocation cost in the preliminary cost estimates for the PBF Martinez Refinery.

Preliminary capital cost estimates for wet gas scrubber installations for each facility are shown in Table 6. Staff also estimated total annual costs, which includes amortized capital costs, tax, insurance, general and administrative (G&A) costs, and operating and maintenance (O&M) costs. Amortized capital cost is calculated assuming a project lifetime of 20 years at six percent interest. Operating and maintenance costs were estimated based on the US Environmental Protection Agency cost estimating methodologies and assumptions described previously. Other annual costs were estimated as a percentage of capital cost, with tax costs of one percent, insurance costs of one percent, and general and administrative costs of two percent. The preliminary estimates of total annual costs, including amortized capital and annual operating costs, are also shown in Table 6.

[42] PBF Martinez Refinery is currently configured to exhaust gas through three separate carbon monoxide boilers. Staff assumes that these exhaust streams would be combined and routed to a single wet gas scrubber in this control scenario.
[43] EPA, 2008. Regulatory Impact Analysis for the Proposed Petroleum Refinery New Source Performance Standards, EPA–452/R–07–006.
[44] Valero Benicia Refinery, 2012. Valero Improvement Project (VIP) Construction Report for the period ending June 30, 2012. August.
[45] Gas Prices: Hearing before the U.S. Senate Committee on Energy and Natural Resources, 113th Cong. 22, 2013. (Prepared Statement of William R. Klesse, Chairman of the Board and Chief Executive Officer, Valero Energy Corporation, San Antonio, TX.)

To provide further context for the preliminary cost estimates, staff also reviewed available cost information reported for refinery wet gas scrubber installations at other facilities throughout the US. Staff collected available reported cost information for refinery WGS systems, and applied factors to adjust cost data to 2019 dollars and the California region where appropriate to provide a more standardized basis for comparison. Staff recognizes that there are many other potential factors that can impact capital costs of these systems, including but not limited to specific design and configuration of the source being abated, wet gas scrubbing system design, additional equipment and/or equipment modifications required. Nevertheless, these reported costs can provide information on the types of costs that have been historically incurred. This cost information is shown in Figure 2 and summarized in Table 7, along with approximate flow rates for the wet gas scrubbing units in dry standard cubic feet per minute (dscfm) to provide an indication of the size and capacity of each system. The preliminary cost estimates for Chevron Products Richmond, Marathon Martinez Refinery, and PBF Martinez Refinery are also shown in Figure 2.

Figure 2 – Summary of Refinery Wet Gas Scrubber Capital Costs



[a] Capital costs shown were adjusted to year 2019 dollars and California market cost basis where appropriate.

Table 7 – Adjusted Capital Costs of Refinery Wet Gas Scrubbing System Installations

Installation/ Operational Year	Facility/Unit	Reported Capital Cost, Adjusted[a]	Approximate Flow Rate (dscfm)[b]
2011	HollyFrontier Woods Cross Unit 4 FCCU #1[46]	$16 MM	16,000
2015	HollyFrontier Cheyenne FCCU[47]	$43 MM	30,000
2004	Tesoro Mandan FCCU[48]	$36 MM	100,000
2008	Unspecified SCAQMD Refinery X FCCU[49]	$68 MM	120,000
2006	Shell Puget Sound Refinery FCCU[50]	$79 MM	125,000
2007	CITGO Lemont FCCU[51]	$210 MM	145,000
2004	Shell Deer Park FCCU[52]	$36 MM	165,000
2006	Valero Delaware City Refinery Coker[53]	$316 MM	186,000
2010	Valero Benicia FCCU and Coker[54]	$579 MM	280,000
2006	Valero Delaware City Refinery FCCU[55]	$316 MM	394,000

[a] Capital costs shown were adjusted to year 2019 dollars and California market cost basis where appropriate.
[b] dscfm = dry standard cubic feet per minute

[46] HollyFrontier Corporation, 2011. Form 10-K (Annual Report), Filed 02/25/11 for the Period Ending 12/31/10.
[47] HollyFrontier Cheyenne Refinery, 2015. "Cheyenne Can Breathe Easier." September.
[48] Bismarck Tribune, 2004. "Tesoro installs a new $2[0] million scrubber." October 26.
[49] South Coast AQMD, 2010. Final Staff Report SOx RECLAIM, Part 1: BARCT Assessment & RTC Reductions Analysis. November.
[50] Anacortes Chamber of Commerce, 2012. "Shell Puget Sound Refinery," The Anacortes Communicator. July.
[51] CITGO Petroleum Corporation and PDV Midwest Refining, LLC., v. Illinois Environmental Protection Agency, 2013. Petition for Modification of Variance to Include Additional Conditions for Protection of Aquatic Life Uses. July 10.
[52] Vanya, Rob, 2004. "Shell going to great lengths to meet environmental mandates," Houston Chronicle. September 13.
[53] BAAQMD, 2008. Tesoro Plant No. 14628, Banking Application No. 17798 Engineering Evaluation. November.
[54] Gas Prices: Hearing before the U.S. Senate Committee on Energy and Natural Resources, 113th Cong. 22, 2013. (Prepared Statement of William R. Klesse, Chairman of the Board and Chief Executive Officer, Valero Energy Corporation, San Antonio, TX.)
[55] BAAQMD, 2008. Tesoro Plant No. 14628, Banking Application No. 17798 Engineering Evaluation. November.

Staff also sought input from potentially affected refineries on the potential costs of a wet gas scrubbing system. Based on this input, staff understands that Chevron Products Richmond estimates the installation of a wet gas scrubber would result in total capital costs of approximately $1.48 billion. This estimate is substantially higher than the costs estimated by Air District staff, and is higher than any of the adjusted costs reviewed for other refinery wet gas scrubber installations.

C. Preliminary Estimates of Potential Socioeconomic Impacts

Air District staff contracted with an independent consultant, Applied Development Economics (ADE), to develop preliminary estimates of potential socioeconomic impacts for each potential control option. The Air District is required to assess and consider potential socioeconomic impacts when adopting or amending regulations.[56] The Air District continues to assess and gather additional information related to potential socioeconomic impacts and may update or refine these preliminary estimates.

When analyzing the potential socioeconomic impacts of proposed new rules and amendments, ADE attempts to work closely within the parameters of accepted methodologies discussed in a California Air Resources Board report on the assessment of economic impacts;[57] the methodologies described in this report have also been incorporated by the California Air Resources Board in its own assessment of socioeconomic impacts of rules generated by the California Air Resources Board. One methodology relates to determining a level above which a rule and its associated costs is deemed to have significant impacts. When analyzing the degree to which the impacts are significant or insignificant, the California Air Resources Board employs a threshold of significance that ADE follows. The report states that the California Air Resources Board's use of a ten percent change in return on equity as a threshold for finding no significant adverse impact on competitiveness or jobs seems reasonable or even conservative.

Applied Development Economics estimated sales generated by impacted industries, as well as net profits for each affected industry. To estimate net after tax profit ratios for potentially affected sources, ADE calculated ratios of profit per dollar of revenue for affected industries. The result of the socioeconomic analysis shows what proportion of profits the compliance costs represent. Based on assumed thresholds of significance, these analyses provide preliminary estimates of which impacts are potentially significant or insignificant, and whether the affected sources may reduce jobs as a means of recouping the cost of rule compliance or as a result of reducing business operations. In some instances, particularly where consumers are the ultimately end-users of goods and services provided by the affected sources, ADE also analyzed whether costs could be passed to consumers in the region.

These analyses rely heavily on the most current data available from a variety of sources, including corporate reports filed with the Securities Exchange Commission (SEC), data from the US Census County Business Patterns and Census of Manufactures, the US Internal Revenue Service, and reports published by the California Energy Commission (CEC) that track gasoline prices and cost components as well as refinery production levels. ADE also utilized employment data from the California Employment Development Department – Labor Market Information Division (EDD LMID).

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[56] California Health and Safety Code, Section 40728.5.

[57] Berck, Peter, 1995. "Development of a Methodology to Assess the Economic Impact Required by SB513/AB969." Department of Agricultural and Resources Economics, University of California. California Air Resources Board Contract No. 93-314. August.

1. Preliminary Estimates of Revenues and Net Profits of Potentially Affected Facilities

The crude oil capacity of each potentially affected refinery reported by the California Energy Commission (CEC) is shown in Table 8. ADE also estimated the effective throughput of each refinery (shown in Table 8) based on average utilization rates as provided in the US Census of Manufactures and the average yield of refined product from the California Energy Commission. Table 8 also shows the estimated revenue calculated using a wholesale value of gasoline at $121.04 per barrel, which is based on California Energy Commission estimates for 2019. The net profits were estimated for each refinery as described below.

In its 2019 annual report, Chevron reported $1.559 billion in earnings from its US downstream refining operations and sales of 1.25 million barrels of gasoline and other refined products. ADE estimated that Chevron earned $1,247 per barrel of refined product. Based on capacity and utilization data from the California Energy Commission and the US Census of Manufacturers, ADE estimated an output of approximately 226,820 barrels of refined product at Chevron Products Richmond, resulting in an estimated annual net income of $282.8 million at the refinery. This information is summarized in Table 8.

PBF Energy completed the purchase of the Martinez refinery from Shell in February 2020, so there is no 2019 operating or financial data for the refinery under PBF ownership. Consequently, the operating performance of the Martinez refinery is estimated based on Shell's annual report for 2019. Shell reported downstream refinery net earnings of $6.7 billion for all its refining operations, and indicates that 19 percent of its refined products sales occurred from US operations, resulting in a prorated net earnings of $1.27 billion for US refineries. Shell reported that total US refining capacity was 1,117,000 barrels per day (BPD), which yields a return of $1,136 per BPD capacity, slightly below the comparable figure for Chevron. Based on these factors, it was estimated that the net income from the Martinez refinery was $177.7 million. The 2019 net income represents 2.8 percent of estimated sales revenue.

Marathon does not report net income per barrel in the same way as Chevron and Shell, but its 2019 Annual Report indicates that for all its refineries, sales revenue totaled $106.7 billion and income from operations was $2.367 billion. The net income ratio from these figures is 2.2 percent, which has been applied to the sales estimate in Table 8 to derive the net income figure for that refinery.

Table 8 – Preliminary Estimates of Revenues and Net Profits at Potentially Affected Facilities

Facility	Barrels Per Day Capacity	Effective Barrels Per Day	Estimated Revenues	Estimated Net Profits
Chevron Products Richmond	245,271	226,820	$10.0 billion	$282.8 million
Marathon Martinez Refinery[a]	*161,500*	*149,350*	*$6.6 billion*	*$146.5 million*
PBF Martinez Refinery	156,400	144,600	$6.4 billion	$177.7 million

[a] The Marathon Martinez Refinery announced the idling of the refinery, including the facility's fluidized catalytic cracking unit, in April 2020. Marathon announced in July 2020 that the facility would remain indefinitely idled with no plans to restart.

2. Preliminary Estimates of Potential Socioeconomic Impacts Associated with Control Scenario A

As described in Section V.B.1 (page 22), staff anticipates that Chevron Products Richmond and PBF Martinez Refinery would be required to implement modified or additional controls to comply with Control Scenario A. Table 9 shows the preliminary estimates of the proportion of profits the total annual compliance costs represent. As shown, the estimated compliance costs do not exceed the assumed threshold of ten percent of return on equity that would indicate the potential to create significant adverse socioeconomic impacts.

Table 9 – Preliminary Estimates of Potential Socioeconomic Impacts for Control Scenario A

Facility	Estimated Total Annual Compliance Cost	Estimated Annual Net Income	Estimated Portion of Net Profits
Chevron Products Richmond	$4.4 MM	$282.8 MM	1.6%
Marathon Martinez Refinery[a]	–	*$146.5 MM*	–
PBF Martinez Refinery	$14 MM	$177.7 MM	8.1%

[a] The Marathon Martinez Refinery announced the idling of the refinery, including the facility's fluidized catalytic cracking unit, in April 2020. Marathon announced in July 2020 that the facility would remain indefinitely idled with no plans to restart.

3. Preliminary Estimates of Potential Socioeconomic Impacts Associated with Control Scenario B

As described in Section V.B.2 (page 25), staff anticipates that Chevron Products Richmond, Marathon Martinez Refinery, and PBF Martinez Refinery would be required to implement additional controls to comply with Control Scenario B. Table 10 shows the preliminary estimates of the proportion of profits the total annual compliance costs represent. As shown, the estimated compliance costs at all three facilities exceed the assumed threshold of ten percent of return on equity that would indicate the potential to create significant adverse socioeconomic impacts.

Table 10 – Preliminary Estimates of Potential Socioeconomic Impacts for Control Scenario B

Facility	Estimated Total Annual Compliance Cost	Estimated Annual Net Income	Estimated Portion of Net Profits
Chevron Products Richmond	$39 MM	$282.8 MM	13.7%
Marathon Martinez Refinery[a]	*$38 MM*	*$146.5 MM*	*25.8%*
PBF Martinez Refinery	$40 MM	$177.7 MM	22.3%

[a] The Marathon Martinez Refinery announced the idling of the refinery, including the facility's fluidized catalytic cracking unit, in April 2020. Marathon announced in July 2020 that the facility would remain indefinitely idled with no plans to restart.

Under Control Scenario B, the affected refineries would be expected to attempt to reduce other costs or increase revenues to restore the cost impact below ten percent of net income. The annual amounts necessary to achieve this result are approximately $11 million per year at Chevron Products Richmond, $23 million per year at Marathon Martinez Refinery, and $22 million per year at PBF Martinez Refinery. There are several ways the companies could consider making these adjustments, although it is not clear if any are feasible at these facilities. If the companies reduced labor costs in these amounts, it would be equivalent to reducing employment by 62 jobs at Chevron Products Richmond, 136 jobs at Marathon Martinez Refinery and 128 jobs at PBF Martinez Refinery. Note that the equivalent reductions at Marathon Martinez Refinery and PBF Martinez Refinery would amount to an estimated labor reduction of approximately 19 to 20 percent, and it is not clear whether the facilities could operate at capacity with this level of staff reductions.

On the revenue side, the highest estimated cost impacts are at Marathon Martinez Refinery and PBF Martinez Refinery. At PBF Martinez Refinery, these impacts would amount to approximately

0.62 percent of estimated annual revenue at the facility. Translated to the wholesale price for gasoline, this equals about $0.75 per barrel or $0.02 per gallon. Individual refineries may be limited in their ability to increase prices unilaterally, particularly during periods of falling demand. In addition, an increase in gasoline prices could have multiplier effects in the regional economy as consumers shift spending from other sectors to increased transportation costs.

D. Preliminary Exposure and Health Equity Assessment

Reductions in particulate matter emissions would lead to reductions in ambient concentrations, which result in improvements to the health of exposed populations. Staff used an atmospheric model (see Appendices A.3 and A.4 for further information) to estimate the contribution of baseline emissions of $PM_{2.5}$ to ambient concentrations, and then to estimate changes that would result from expected reductions in emissions (Table 11) as well as changes in stack configurations.

1. Study Area and Modeled Contributions to Ambient $PM_{2.5}$

Figure 3, below, shows the estimated contributions of baseline emissions from modeled sources to ambient $PM_{2.5}$. The outermost contour represents a contribution of +0.1 microgram per cubic meter ($\mu g/m^3$), which as an order-of-magnitude is approximately 1 percent of the total ambient concentration within the general area. It should be noted that 0.1 $\mu g/m^3$ is not a *de minimis* value, as there are potentially significant real-world impacts beyond this. However, the +0.1 $\mu g/m^3$ contour was selected by staff to define a "study area" to assess the exposure and health of a more localized population.

Figure 4 shows the same outermost contour (i.e., study area) from Figure 3, and overlays it with information on the residential population. The modeled population is a forecast of the 2020 population based on 2010 Census data (see Appendices A.1 and A.2 for further information) and consists of approximately one million residents, with a racial/ethnic composition similar to that of the Bay Area as a whole (Appendix A.1): 42 percent white; 26 percent Hispanic/Latino; 21 percent Asian/Pacific Islander; 11 percent African-American/Black, and 0.3 percent Native American/Alaska Native.

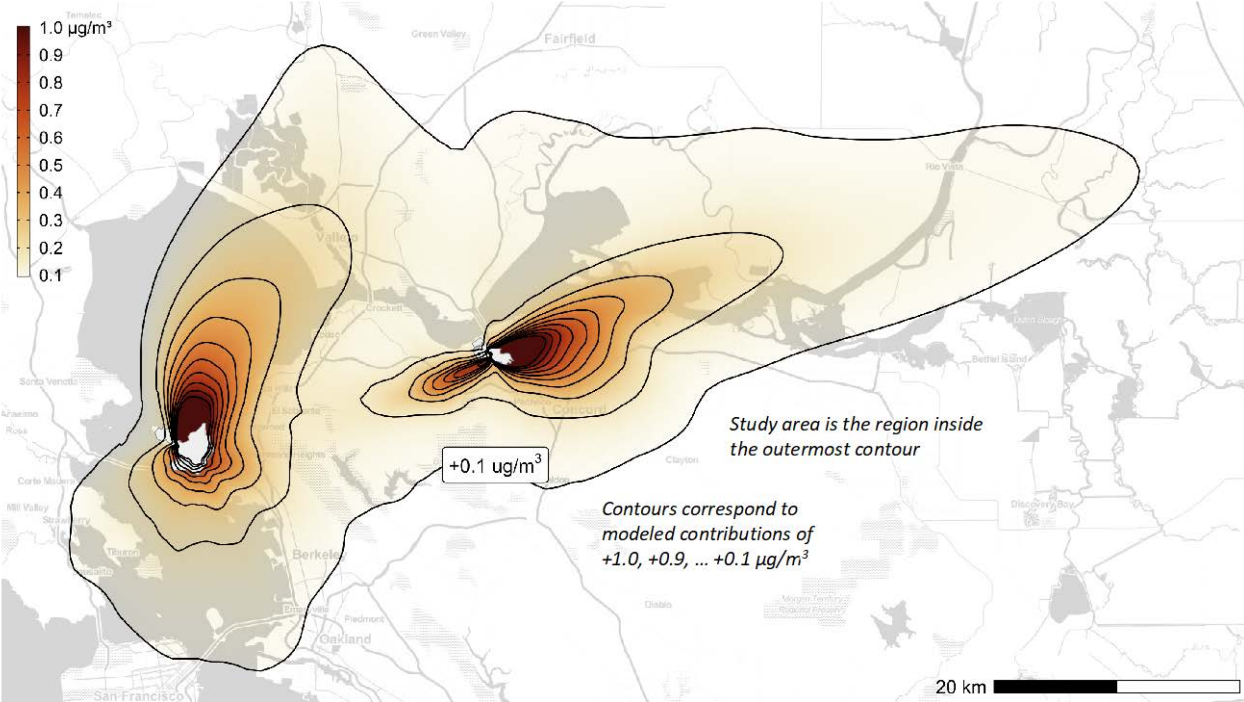

Figure 3 – Contributions of modeled baseline emissions to ambient $PM_{2.5}$

The outermost contour represents a contribution of +0.1 µg/m³, which is approximately 1% of ambient $PM_{2.5}$ within the vicinity. Contributions less than +0.1 µg/m³ (i.e., beyond the study area) are not shown.

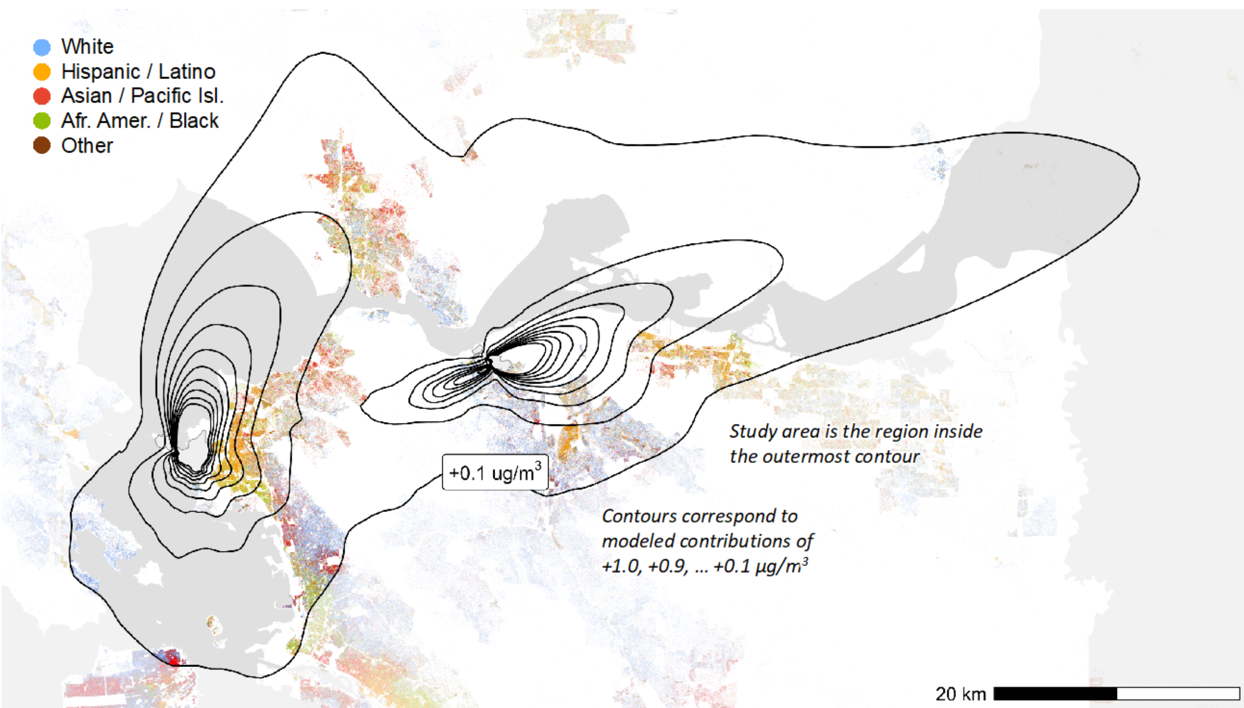

Figure 4 – Residential population

Each dot corresponds to one resident; colors correspond to US Census race/ethnicity categories. Approximately one million people reside in the study area.

2. Equity Assessment: Distributions of Modeled Exposures

Combining the data from Figures 3 and 4 — that is, weighting $PM_{2.5}$ contributions by residential population — provides estimates of attributable exposure (see Appendix A.1 for technical details). Figures 5a through 5c, below, summarize these exposures according to race/ethnicity across all modeled scenarios. As shown, the exposures are not distributed equally, and inequities persist across all modeled scenarios.

Figure 5a shows the estimates of *total population exposure*, which depends both on the intensity of the exposure and on the number of people exposed. On the y-axis of Figure 5a, thirty thousand (30,000) “exposure units” (person-µg/m^3) are equivalent to a city of 100,000 persons exposed to 0.3 µg/m^3, and/or a population of one million persons exposed to 0.03 µg/m^3. A notable finding is that the total population exposure burden attributable to Chevron emissions (top row) for Hispanic and Latino residents (orange) under the baseline scenario (“Base”) is approximately 45,000 person-µg/m^3. This is larger than any other baseline estimate in the top row, and is due to the close proximity of Chevron Products Richmond to neighborhoods that are both densely populated and comprised largely of Hispanic/Latino residents (Figure 4).

In addition to the total population exposure, staff estimated the *exposure intensity* for an “average” or randomly selected resident within a particular racial/ethnic category (or “per capita” exposure). In Figure 5b, the total population exposures from Figure 5a have been divided by the number of persons affected to calculate this “per capita” exposure. These per capita exposure estimates show a number of differences compared to the total population exposure estimates. As an example, again considering Chevron emissions alone (top row), Figure 5a shows that the total population exposure for white residents (blue bars) is higher than for African-American/Black residents (green bars), but Figure 5b shows that the per capita exposure for African-American/Black residents (green bars) is now higher than for white residents (blue bars). This is because, although white residents outnumber African-American/Black residents within the study area, the exposures of African-American/Black residents to $PM_{2.5}$ from Chevron are, on average, nearly twice as high as those of white residents.

Figure 5c shows the combined per capita impacts from both facilities. This figure shows that Hispanic/Latino and African American/Black residents are exposed to more $PM_{2.5}$ in all modeled scenarios per capita. Emissions from modeled sources other than fluidized catalytic cracking units (represented by the lighter portions of the bars in Figures 5a through 5c) drive these disparities and remain significant across all modeled scenarios. The combined impact is mostly attributable to modeled contributions from Chevron emissions, which are responsible for approximately twice as much modeled population exposure as those from PBF emissions (Figure 5a).

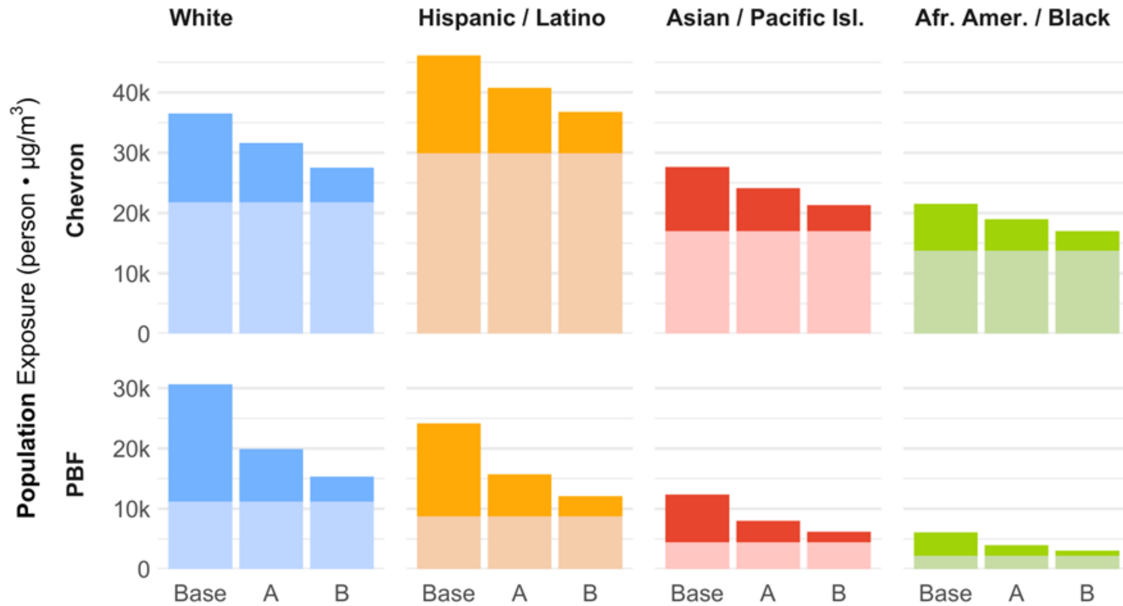

Figure 5a – Modeled estimates of total population exposure (residential impact) within the study area

Within each of the eight panels, there are three bars. The leftmost bar corresponds to the baseline scenario. The middle and rightmost bars correspond to scenarios where emissions from the FCCU have been reduced. Bar heights correspond to total impacts from all modeled sources; the darker portions of the bars correspond to the shares of those impacts that are specifically attributed to FCCU emissions.

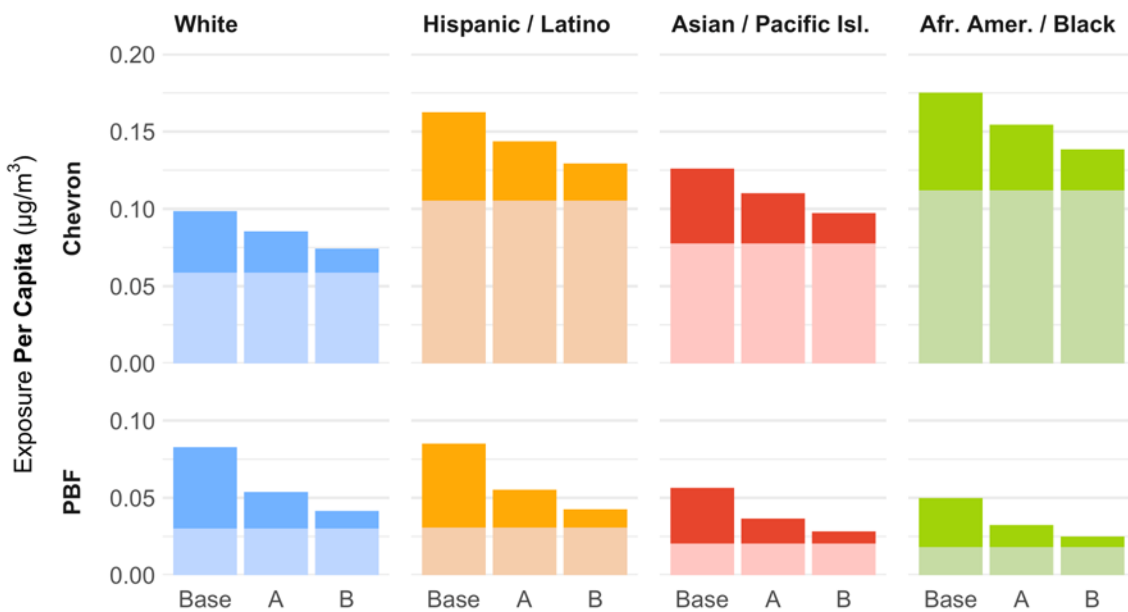

Figure 5b – Modeled estimates of total population exposure (residential impact) within the study area normalized by population

Same as Figure 5a, except that the y-axes have been normalized by population, yielding bar heights that correspond to average (that is, "per capita") impacts.

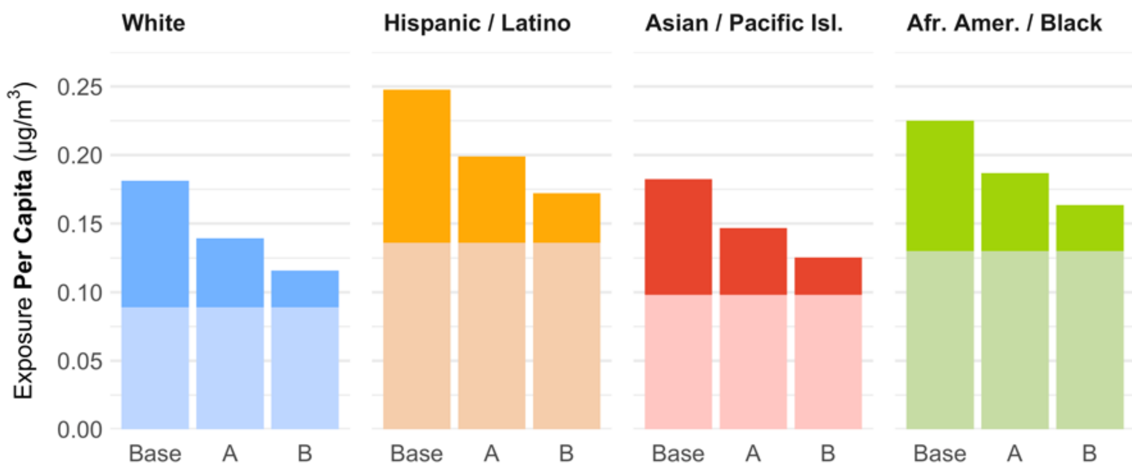

Figure 5c – Combined modeled estimates of total population exposure (residential impact) within the study area normalized by population

Same as Figure 5b, except that impacts from both facilities have been combined.

E. Preliminary Estimates and Valuations of Health Impacts

Staff selected a representative set of health endpoints to assess in light of the modeled exposures described in the previous section. Staff used a methodology and software platform (BenMAP) developed by the US Environmental Protection Agency to calculate:

- baseline impacts of modeled $PM_{2.5}$ emissions on selected health endpoints;
- benefits associated with modeled reductions; and
- conventional (EPA-approved) valuations of both the baseline impacts and the reductions.

For details of the methodology, see Appendix A.2 and EPA's BenMAP.[58]

1. Estimated Health Impacts, Benefits from Reductions, and Valuations

Table 11 provides a summary that is presently scoped to Chevron alone. (A forthcoming draft will contain a joint assessment of Chevron and PBF.) Each row corresponds to a single health impact from among those that were estimated. For health impacts where valuation ranges are presented, the ranges indicate the minimum and maximum estimates derived from multiple studies of the same health endpoint (e.g., premature mortality). The first two columns report the annual impacts, and conventional (EPA-approved) valuations of those impacts, attributed to modeled baseline emissions. The next two columns present reductions—which apply both to those impacts and to their valuations—modeled under Control Scenarios A and B. The final row is the summation of the last two columns, in 2015 US Dollars. In all cases, mortality comprises the vast majority (over 90 percent) of the total valuation. Limitations are described below; for details, see Appendix A.2.

[58] EPA, 2018c. "Environmental Benefits Mapping and Analysis Program Community Edition (BenMAP-CE) Users' Manual, V1.4.8." Office of Air Quality Planning; Standards (OAQPS). Research Triangle Park, NC, July.

Table 11 – Estimated Annual Baseline Health Impacts, Reductions, and Valuations (Annual, All Modeled Sources at Chevron Alone)

Under Baseline Conditions			Potential Benefits	
Health Impact		**Valuation[1]**	**Scenario A**	**Scenario B**
Cardiovascular	0.5–4.3 heart attacks 1.0 hospital admissions	$63k–600k $47k	-13% -13%	-22% -22%
Restricted Activity	4,800 days	$360k	-12%	-21%
Lost Work	820 days	$190k	-12%	-21%
Asthma	200 exacerbations[3] 4 emergency room visits 0.1 hospital admissions	$12k $2k $1k	-12% -12% -12%	-21% -21% -20%
Respiratory Illness[2]	140 upper tract[3] 100 lower tract[3] 8 bronchitis[3] 0.2 chronic lung disease	$5k $2k $4k $5k	-12% -12% -12% -12%	-20% -20% -20% -21%
Mortality	5.1–11.6 deaths[4]	$52.5 MM to $118 MM	-13%	-23%
			$6.8 MM to $15.2 MM/yr	**$12.2 MM to $27.4 MM/yr**

[1] Conventional EPA valuations, in 2015 US dollars
[2] Other than asthma
[3] Subset of pediatric (≤18 years)
[4] Including infant mortality

2. Summary of Estimated Annual Reductions, Benefits, and Costs

Table 12 reproduces the bottom-line valuations from Table 11 alongside the estimates of emissions reductions and associated costs that were reported in previous sections.

Table 12 – Modeled Reductions, Valuations of Benefits, and Costs (Annual, Chevron Alone)

Scenario	Emission Reductions*	Valuation of Assessed Benefits†,‡	Estimated Costs
A	80 ton/yr	$6.8 MM to $15 MM/yr	$4.4 MM/yr
B	160 ton/yr	$12 MM to $27 MM/yr	$39 MM/yr

** PM_{10} from FCCU. Modeled $PM_{2.5}$ / PM_{10} ratio for the Chevron FCCU is approximately 95%.*
† Based on EPA-approved valuations of the health impacts that were assessed.
‡ Valuations are in 2015 US Dollars, calculated using the EPA BenMAP system.

3. Limitations and Comparability

Tables 11 and 12 show estimates of potential benefits and invite comparison with estimated costs. In this context, several important limitations should be noted.

First, the set of reported benefits is limited in scope. It does not include, for example, benefits to reproductive health or neurological health. Including more health endpoints would increase the estimated benefits. Using BenMAP to evaluate a particular health endpoint requires at least one sufficiently reliable “concentration-response” function (linking $PM_{2.5}$ to a measurable outcome) to be available, and at least one valuation function (linking that outcome to dollars) to be available. See Appendix A.2 for details.

Second, there are considerable uncertainties embedded in different parts of the underlying calculations, including: (a) estimated emissions; (b) modeled concentrations; (c) population distributions; and (d) concentration-response functions. These uncertainties were not carried forward in calculating the ranges reported in Tables 11 and 12. Therefore, the true benefits could be much larger, or much smaller, than those ranges suggest.

Finally, the valuation of avoided mortality, which comprises the majority (over 90 percent) of the total reported valuation, is based on willingness-to-pay (WTP). As documented by the EPA,[59] WTP is fundamentally subjective:

The WTP [willingness-to-pay] for a given benefit is likely to vary from one individual to another. In theory, the total social value associated with the decrease in risk of a given health problem resulting from a given reduction in pollution concentrations is generally taken to be the sum of everyone's WTP for the benefits they receive.

VI. RULE DEVELOPMENT / PUBLIC PARTICIPATION PROCESS

The Air District adopted the AB 617 Expedited Best Available Retrofit Control Technology (BARCT) Implementation Schedule in December 2018. As part of the schedule, staff identified potential efforts to develop amendments to Rule 6-5 that would address particulate matter, including condensable particulate matter components such as ammonia and sulfur dioxide. An update on the implementation of currently adopted refinery rules and rule development efforts on amendments to Rule 6-5 was presented at a Board of Directors Stationary Source Committee meeting in April 2019. In September and October 2019, staff convened meetings of the Air District’s Refinery Rules Technical Working Group to engage with stakeholders on technical topics related to the rule development effort for amendments to Rule 6-5. Members of the technical working group, which include representatives from industry, community-based organizations, and regulatory agencies, provided input on control technologies and testing/monitoring methods related to fluidized catalytic cracking units and particulate matter control. Air District staff also conducted site visits to potentially affected refineries to better understand each fluidized catalytic cracking unit operation and site-specific considerations.

[59] EPA, 2018c. “Environmental Benefits Mapping and Analysis Program Community Edition (BenMAP-CE) Users’ Manual, V1.4.8.” Office of Air Quality Planning; Standards (OAQPS). Research Triangle Park, NC, July.

The Air District released draft amendments to Rule 6-5 and an Initial Staff Report in May 2020 for public review and comment. Staff presented information on the draft amendments and rule development effort at Air District Stationary Source Committee meetings in June, July, October, and December 2020, including information on other potential control options that staff have further evaluated following the release of the draft amendments. The Air District is releasing this Workshop Report, the draft amendments originally released in May 2020, and new draft amendments reflecting a more stringent potential control option. Air District staff is soliciting comments on these materials. Staff will continue to evaluate and consider previously received comments and other comments received during this current comment period in the further development of rule amendments.

As part of the rule development process, staff also evaluates potential environmental impacts as required by the California Environmental Quality Act (CEQA), Public Resources Code Section 21000 et seq. Potential environmental impacts related to projects under the AB 617 Expedited Best Available Retrofit Control Technology Implementation Schedule, including amendments to Rule 6-5, were previously analyzed in an Environmental Impact Report (EIR) certified by the Air District Board of Directors in December 2018. In evaluating potential environmental impacts related to the amendments to Rule 6-5, staff will assess the impacts addressed in the certified Environmental Impact Report, and determine if additional analysis of impacts from amendments to Rule 6-5 is required by the California Environmental Quality Act.

Staff will prepare final proposal and staff report, along with other supporting documents, for further review and comment prior to a Public Hearing.

VII. CONCLUSION / RECOMMENDATIONS

The Air District is developing amendments to Rule 6-5 to further address particulate matter emissions, including condensable particulate matter emissions, from petroleum refinery fluidized catalytic cracking units and associated carbon monoxide boilers. Fluidized catalytic cracking units are some of the largest individual sources of particulate matter emissions in the San Francisco Bay Area, and further reductions of particulate matter are needed to ensure progress towards attainment of the ambient air quality standards and reduce public health impacts from particulate matter exposure. The purpose of the amendments is to ensure that Air District regulations are as health protective as possible and consider recent advances in the understanding and control of condensable particulate matter emissions. Air District staff has published this Workshop Report and related materials for public review and encourages interested parties to submit comments for consideration. Air District staff will continue to further develop and evaluate the rule amendments in preparation of presenting final proposed rule amendments for consideration by the Air District Board of Directors.

REFERENCES

American Institute of Chemical Engineers, 2014. Chemical Engineering Progress (CEP) – An Oil Refinery Walk-Through. May.

Anacortes Chamber of Commerce, 2012. "Shell Puget Sound Refinery," The Anacortes Communicator. July.

BAAQMD, 2008. Tesoro Plant No. 14628, Banking Application No. 17798 Engineering Evaluation. November.

BAAQMD, 2012. Understanding Particulate Matter: Protecting Public Health in the San Francisco Bay Area. November.

BAAQMD, 2017. Final 2017 Clean Air Plan: Spare the Air – Cool the Climate. April.

BAAQMD, 2019. Particulate Matter: Spotlight on Health Protection – Symposium Summary: Health Effects and Exposures and Risk. October.

BAAQMD Advisory Council, 2020. Advisory Council Particulate Matter Reduction Strategy Report. December.

Berck, Peter, 1995. "Development of a Methodology to Assess the Economic Impact Required by SB513/AB969." Department of Agricultural and Resources Economics, University of California. California Air Resources Board Contract No. 93-314. August.

Bismarck Tribune, 2004. "Tesoro installs a new $2[0] million scrubber." October 26.

Chemical Engineering, 2020. The Chemical Engineering Plant Cost Index. https://www.chemengonline.com/pci-home.

CITGO Petroleum Corporation and PDV Midwest Refining, LLC., v. Illinois Environmental Protection Agency, 2013. Petition for Modification of Variance to Include Additional Conditions for Protection of Aquatic Life Uses. July 10.

City of Benicia, 2008. Valero Improvement Project – Addendum to VIP EIR, SCH No. 2002042122. June.

EPA, 2008. Regulatory Impact Analysis for the Petroleum Refineries NSPS (New Source Performance Standards). EPA-452/R-08-002. April.

EPA, 2015. Compilation of Air Pollutant Emissions Factors (AP-42), Fifth Edition, Volume I, Chapter 5: Petroleum Industry, 5.1 Petroleum Refining. April.

EPA, 2016. Comprehensive Data Collected from the Petroleum Refining Sector – Petroleum Information Collection Request for Petroleum Refinery Sector New Source Performance Standards and National Emissions Standards for Hazardous Air Pollutants Risk and Technology. July. https://www.epa.gov/stationary-sources-air-pollution/comprehensive-data-collected-petroleum-refining-sector.

EPA, 2018a. EPA Air Pollution Control Cost Manual. https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/cost-reports-and-guidance-air-pollution. Updated May 23, 2018.

EPA, 2018b. Integrated Science Assessment for Particulate Matter. October.

EPA, 2018c. "Environmental Benefits Mapping and Analysis Program Community Edition (BenMAP-CE) Users' Manual, V1.4.8." Office of Air Quality Planning; Standards (OAQPS). Research Triangle Park, NC, July.

EPA, 2019a. Performance Specification 18 – Performance Specifications and Test Procedures for Gaseous Hydrogen Chloride (HCl) Continuous Emission Monitoring Systems at Stationary Sources. January.

EPA, 2019b. Air Emission Measurement Center (EMC) Other Test Methods. May. https://www.epa.gov/emc/emc-other-test-methods.

Evans, Martin (Intercat/Johnson Matthey), 2008. Evaluating FCC flue gas emission-control technologies. Digital Refining, 2008 Q1.

Gary, James H.; Glenn Handwerk; and Mark Kaiser, 2007. Petroleum Refining Technology and Economics, Fifth Ed.

Gas Prices: Hearing before the U.S. Senate Committee on Energy and Natural Resources, 113th Cong. 22, 2013. (Prepared Statement of William R. Klesse, Chairman of the Board and Chief Executive Officer, Valero Energy Corporation, San Antonio, TX.)

Gordian, 2020. RSMeans City Cost Index. https://www.rsmeans.com/rsmeans-city-cost-index.

HollyFrontier Corporation, 2011. Form 10-K (Annual Report), Filed 02/25/11 for the Period Ending 12/31/10.

HollyFrontier Cheyenne Refinery, 2015. "Cheyenne Can Breathe Easier." September.

Miller, Lisa et al., 2019. "Are Adverse Health Effects from Air Pollution Exposure Passed on from Mother to Child?" University of California, Davis. California Air Resources Board Contract No. 15-303.

Schwalje, David; Larry Wisdom; and Mike Craig (Axens North America), 2016. Revamp cat feed hydrotreaters for flexible yields. EPTQ (Petroleum Technology Quarterly), Revamps 2016.

South Coast AQMD, 2003. Final Staff Report for Proposed Rule 1105.1. September.

South Coast AQMD, 2007. Final EIR for ConocoPhillips Los Angeles Refinery PM_{10} and NOx Reduction Project, SCH No. 2006111138. June.

South Coast AQMD, 2010. Final Staff Report SOx RECLAIM, Part 1: BARCT Assessment & RTC Reductions Analysis. November.

South Coast AQMD, 2011. The Challenges of Reducing Particulate Matter and Ammonia Emissions from Fluid Catalytic Cracking Units in the South Coast Air Basin. Paper 2011-A-46-AWMA.

U.S. Chemical Safety and Hazard Investigation Board, 2017. Investigation Report – ExxonMobil Torrance Refinery Electrostatic Precipitator Explosion, Torrance, California. No. 2015-02-I-CA. May.

U.S. Energy Information Administration, 2019. Refinery capacity data by individual refinery as of January 1, 2019. https://www.eia.gov/petroleum/data.php.

Valero Benicia Refinery, 2012. Valero Improvement Project (VIP) Construction Report for the period ending June 30, 2012. August.

Vanya, Rob, 2004. "Shell going to great lengths to meet environmental mandates," Houston Chronicle. September 13.