BAY AREA
AIR QUALITY
MANAGEMENT
DISTRICT

FINAL STAFF REPORT

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

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Prepared By

David Joe, P.E. – Assistant Rule Development Manager
Jacob Finkle – Senior Air Quality Specialist

Table of Contents

I. EXECUTIVE SUMMARY

The Bay Area Air Quality Management District (Air District) is proposing amendments to Regulation 6: Particulate Matter, Rule 5: Particulate Emissions from Petroleum Refinery Fluidized Catalytic Cracking Units (Rule 6-5). This Staff Report has been developed to provide information supporting the proposed amendments to Rule 6-5 and is intended to provide the public with information in advance of a Public Hearing on the proposed amendments in June 2021.

Fluidized catalytic cracking units (FCCUs) are the largest single source of particulate matter (PM) emissions at petroleum refineries and are some of the largest individual sources of PM in the San Francisco Bay Area. Scientific understanding of particulate matter emissions has advanced considerably in recent years. Particulate matter emissions can be divided into two categories. One category consists of "filterable" particulates that can be measured at the exit point of the emissions "stack." The other category consists of "condensable" emissions that convert to particle form only after exiting and cooling in the atmosphere. The phrase "total particulate matter" or "total PM" is commonly used to describe the sum of both filterable and condensable portions. Historically, regulation of particulate matter from FCCUs was based on measurement methods that only detected the filterable portion. It is now understood that the amount of condensable particulate matter that forms upon contact with the atmosphere is significant and needs to be considered in determining how to control emissions from FCCUs.

In 2010, the United States Environmental Protection Agency updated test methods for measuring total particulate matter emissions from sources such as FCCUs. The updated methods have been instrumental in understanding that total particulate matter is a more significant problem than it was previously believed to be when only filterable particulate was measured. The first step taken by the Air District to address this new understanding of total particulate matter was the adoption of Rule 6-5 in 2015, which focused on minimizing particulate matter associated with ammonia injection. In adopting Rule 6-5, the Air District stated that further measures to control particulate matter from FCCUs were being considered. The Air District's 2017 Clean Air Plan (a document periodically issued to forecast future regulations) included as "Control Measure SS1" a stated intention to evaluate further controls from FCCUs.

Apart from required planning to achieve ambient air quality standards, the proposed amendments are also part of the Air District's efforts to meet the requirements of California Assembly Bill 617 (2017) which requires the Air District to implement an expedited schedule for implementing best available retrofit technology (BARCT) at industrial facilities covered by the State's Cap-and-Trade program. The Expedited BARCT Implementation Schedule adopted by the Air District in 2018 identified PM emission reductions at FCCUs as a key area where BARCT controls could have a significant impact.

By addressing PM emissions from FCCUs, the proposed amendments to Rule 6-5 follows through on these commitments under the Clean Air Plan and AB 617. The proposed amendments are "necessary" within the meaning of the California Health & Safety Code because they would help attain and maintain ambient air quality standards. 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 for attainment and maintenance of the standards. The District-wide health benefits of attaining and maintaining compliance with the PM ambient air standards are significant. PM causes adverse respiratory health effects, and recent studies have linked PM exposure to a wide range of cardiovascular diseases, impacts to cognitive function, and cancer.[1] Compelling evidence also indicates 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]

As explained in this Report, reducing particulate matter from FCCUs will also yield health benefits to communities living near refineries. In doing so, it will further the goals of AB 617. California Health & Safety Code Section 44391.2, enacted as a part of AB 617, indicates that BARCT standards are one of the regulatory tools to be used to reduce the impact of "criteria pollutants" (of which PM is one) on disadvantaged communities. The FCCU at the Chevron Richmond Refinery is proximate to a "disadvantaged community" identified through the AB 617 process. Modeling exercises conducted by the Air District and described later in this Report suggest that the emissions impact is substantial. AB 617 created a process for development of community-based emission reductions programs. Although these amendments to Rule 6-5 have not been developed as part of a community emissions reduction program as envisioned by AB 617, the amendments would be a significant step in promoting the goals of that program.

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 more stringent control options for these sources. In January 2021, Air District staff released two versions of draft amendments and a workshop report reflecting two alternative control options. Staff received public comments on the materials and conducted a virtual public workshop in February 2021. Air District staff presented updates on the workshop and materials at an Air District Stationary Source and Climate Impacts Committee meeting in March 2021. In that meeting a majority of Committee members expressed a preference to proceed with development of the more stringent of the two control options issued for comment in January. This Staff Report proposes the Board of Directors consider the more stringent level of control. The Report also includes discussion of the less stringent control option. Air District staff believes discussion of both control options will promote a more informed decision by the Board of Directors and a better understanding by the public.

The proposed amendments to Rule 6-5 include new and modified limits on ammonia and sulfur dioxide. The proposed amendments also include a direct limit on total particulate matter less than 10 microns in diameter (total PM_{10}), which includes both filterable and condensable particulate matter. The proposed amendments would also include modifications to existing rule language to clarify existing provisions and improve monitoring requirements.

The proposed amendments would apply to the four FCCUs in the San Francisco Bay Area at the following refineries: Chevron Products Richmond, PBF Martinez Refinery, Marathon Martinez Refinery, and Valero Benicia Refinery. Staff anticipates that Chevron Products Richmond, PBF Martinez Refinery, and Marathon Martinez Refinery would be required to install wet gas scrubbing systems at their FCCUs to comply with the proposed amendments. The proposed amendments would result in particulate matter emissions reductions of 493 tons per year.[3] An analysis of the

[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.

[3] This emission reduction estimate includes potential reductions at the Marathon Martinez Refinery, which was idled in April 2020 and remains indefinitely idled. Further details on the emission reductions by facility can be found in Section IV.

potential environmental impacts of the proposed amendments concluded that installation of these wet gas scrubbing systems would result in potentially significant air quality impacts during construction of the control equipment, and potentially significant water demand impacts from the operation of the wet gas scrubbers. The proposed amendments may also result in potentially significant socioeconomic impacts due to the estimated cost of the wet gas scrubbing installations.

Air District staff released the Staff Report and proposed amendments to Rule 6-5 for public review and comment. Staff accepted written comments and developed responses to comments for inclusion in the final proposal to the Air District Board of Directors for their consideration at a Public Hearing. At the Public Hearing, the Air District Board of Directors will consider the final proposal and receive public input before taking action. Air District staff recommends the Board of Directors adopt the proposed amendments to Regulation 6, Rule 5.

II. BACKGROUND

A. Industry and Source Description

1. 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 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 FCCU, in April 2020. In July 2020, Marathon announced that the refinery will remain idled indefinitely with no plans to restart normal operations.

2. 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.

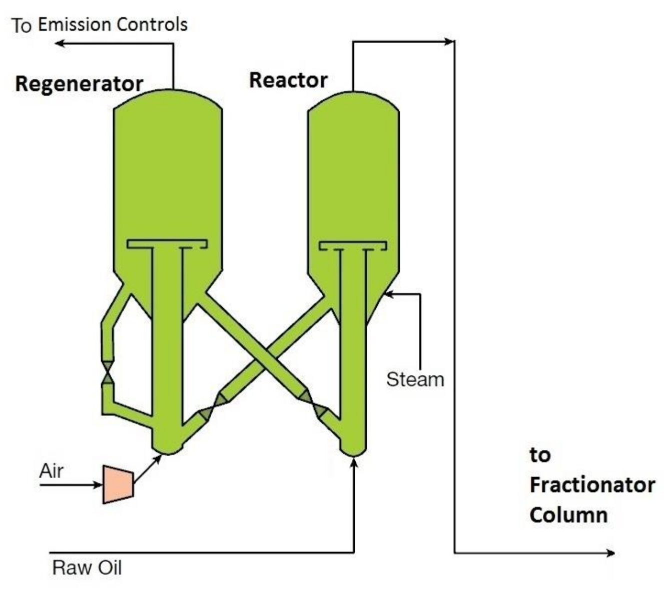

Figure 1 – Petroleum Refinery Fluidized Catalytic Cracking Unit Diagram[4]

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 form carbon dioxide.

3. Pollutants and Emission Sources

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 II.C. for further information on control technologies). In many

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

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.

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.

[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.

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.

b) 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

[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.

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]

c) *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 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 Appendices A.2 and A.3.

d) *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 with the Advisory Council 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 related to climate change justifies greater efforts to reduce controllable sources of particulate matter to reduce overall health risks. 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.

4. Current Emissions Control Technology and Methods

As discussed previously, particulate matter emissions from FCCUs include catalyst fines, particulates formed in the combustion process, and particulate matter formed from various gaseous components through condensation, nucleation, and coagulation processes. Therefore, control of total particulate matter emissions from these sources can depend on a variety of control equipment and methods to address these different components.

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[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.
[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.

At Chevron Products Richmond, PBF Martinez Refinery, and Marathon Martinez Refinery, electrostatic precipitator (ESP) systems with ammonia injection are used at the fluidized catalytic cracking units as the primary control device to capture and remove catalyst fines and other particulate matter generated in the combustion process. In addition, these refineries use feed hydrotreatment and sulfur dioxide-reducing catalyst additives to reduce sulfur dioxide emissions and sulfur components that can contribute to particulate matter formation. At the Valero Benicia Refinery, a regenerative amine wet gas scrubber (WGS) is used at the fluidized catalytic cracking unit as the primary control device to abate particulate matter emissions and sulfur dioxide emissions that can contribute to particulate matter formation. Feed hydrotreatment is also used at the Valero Benicia Refinery. Further information on the operation of these control technologies is provided in Section II.C.

B. Regulatory History

1. Air District Rules/Regulations

The Air District has 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 the degree to which a beam of light can 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 regulate 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.

e) 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.

f) 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."[16] In December 2018, the Air District's Board of Directors adopted the AB 617 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 levels of emission control. 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.

2. Federal Regulations

Federal regulations that address emissions from fluidized catalytic cracking units and carbon monoxide boilers include the New Source Performance Standards (NSPS) Subparts J and Ja, and the National Emissions Standards for Hazardous Air Pollutants (NESHAP) Subpart UUU. The 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. The 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 regulations do not contain limits for total particulate matter or ammonia slip; however, the 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-

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

on control device. The 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 reviewed 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.

C. Technical Review of 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 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 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 cost estimates for wet gas scrubbing controls are further discussed in Section V.A.

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 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]

[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.
[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.

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.[20] 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.

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

[20] Weaver, Edwin H. (BELCO Technologies Corporation), 2006. Evaluating Wet Scrubbers, Petroleum Technology Quarterly, Quarter 3, 2006.

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 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 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.

III. PROPOSED AMENDMENTS

The purpose of the proposed 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 proposed amendments, including existing regulations, industry and academic literature, stakeholder input, emissions and compliance data, and information on control and monitoring technologies.

The proposed amendments 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 proposed new and modified limits reflect levels of stringency that have been achieved at units using wet gas scrubbing controls. The proposed amendments also include modifications to existing rule language to clarify provisions and improve monitoring requirements.

A. Purpose

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

Section 6-5-101 – Description: The proposed amendments to Section 6-5-101 clarify the description of the rule consistent with the new and modified provisions and requirements of the proposed amendments to Rule 6-5 described below. The amendments to Section 6-5-101 also clarify the applicability of Rule 6-5 requirements to commingled emissions of an FCCU and other sources from a single exhaust point, consistent with existing provisions in Air District Regulation 1, Section 1-107. Air District Regulation 1, Section 1-107 states that where air contaminants from two or more sources are combined prior to emission and there are no adequate and reliable means to establish the nature, extent, and quantity of the emissions from each source, Air District regulations apply to the combined emission as if it originated in a single source, with emissions subject to the most stringent limitations and requirements applicable to any of the sources.

B. Applicability

Proposed amendments to Rule 6-5 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.[21]

C. Exemptions

Section 6-5-111 – Limited Exemption, Emissions Abated by Wet Scrubber: The proposed 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 proposed 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 proposed amendments.

Section 6-5-112 – Limited Exemption, Emissions During Startup or Shutdown Periods: The proposed 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 6-5-113 – Limited Exemption, Installation of Wet Scrubber: The proposed amendments to Rule 6-5 remove the language for this limited exemption. This limited exemption currently applies to owners or operators of an installed wet gas scrubber and provided an extension for compliance with the ammonia emission limit. The extension period has passed, and this limited exemption is no longer applicable.

Section 6-5-115 – Limited Exemption, Ammonia Optimization: The proposed amendments to Rule 6-5 modify the limited exemption under Section 6-5-115 regarding ammonia optimization. Under

[21] 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.

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 proposed 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 five years after the date of adoption.

D. Definitions

Section 6-5-212 – Total Particulate Matter 10 Microns or Less in Diameter (Total PM_{10}): The proposed 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 $PM_{2.5}$): The proposed 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.

E. Standards

Section 6-5-301 – Fluidized Catalytic Cracking Unit (FCCU) Emission Limits: The proposed amendments to Rule 6-5 establish and modify fluidized catalytic cracking unit emission standards for ammonia slip, sulfur dioxide, and total particulate matter less than 10 microns in diameter. Under the proposed amendments, the proposed limits would become effective five years after the date of adoption. Staff anticipates that the proposed limits would require the installation of wet gas scrubbing systems at the affected refineries, which may involve substantial time and effort for the planning, design, scheduling, and construction and/or modifications associated with these 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.[22] The ConocoPhillips Los Angeles Refinery (Wilmington) also installed a wet gas scrubber at the fluidized catalytic cracking unit to meet the requirements of South Coast AQMD's Rule 1105.1 adopted in 2003. Construction was reported to have occurred from 2007 through 2008.[23] Construction of a wet gas scrubber at the HollyFrontier Cheyenne Refinery fluidized catalytic cracking unit was reported to have occurred from 2014 through 2015, with planning of the project starting in 2011.[24,25]

Section 6-5-301.1: Under the proposed 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 current Rule. As described above in the "Exemptions" section, the proposed

[22] Valero Benicia Refinery, 2012. Valero Improvement Project (VIP) Construction Report for the period ending June 30, 2012. August.
[23] South Coast AQMD, 2010. Final Staff Report SOx RECLAIM, Part 1: BARCT Assessment & RTC Reductions Analysis. November.
[24] HollyFrontier Cheyenne Refinery, 2015. "Cheyenne Can Breathe Easier." September.
[25] Orr, Becky, 2015. "Massive scrubber at HollyFrontier will cut pollution, stench," Wyoming Tribune Eagle. April 30.

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 five years after the date of adoption. 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 in South Coast AQMD using electrostatic precipitators or wet gas scrubbers.

Sections 6-5-301.2.1 and 301.2.2: The proposed amendments 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 the 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 United States through the implementation of sulfur dioxide-reducing additives, wet gas scrubbers, or both. In addition, the wet gas scrubbing system in operation at the Valero Benicia Refinery is currently subject to comparable sulfur dioxide limits. The proposed amendments include an effective date five years after the date of adoption.

Section 6-5-301.3: The proposed amendments include a new limit for total PM_{10}. The proposed 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) at 5 percent oxygen on a rolling four-quarter average basis. The total PM_{10} limit in the proposed amendments is based on the Air District's review of source test data from fluidized catalytic cracking units at refineries throughout California and the United States. A summary of this data is provided in Appendix B. The proposed total PM_{10} limit of 0.010 gr/dscf at 5 percent oxygen represents an achievable level of control that has been demonstrated to be feasible at multiple facilities through the use of wet gas scrubbers. The proposed amendments include an effective date for the total PM_{10} limit five years after the date of adoption.

Under the proposed 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.

F. Administrative Requirements

Section 6-5-403 – Ammonia Optimization: The proposed amendments 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 proposed amendments in Section 6-5-115.1.

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

G. Monitoring and Records

The owner or 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 Section 6-5-301.1, ammonia monitoring requirements in Section 6-5-501 remain unchanged from the current Rule.

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

Section 6-5-503 – Total PM_{10} and Total $PM_{2.5}$ Monitoring: Under proposed 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 proposed 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.

H. Manual of Procedures

Section 6-5-601 – Compliance Determination: The proposed amendments to Section 6-5-601 include additional provisions regarding the performance of source tests for compliance. Under the proposed amendments, source tests must meet the requirements in the Air District Manual of Procedures, Volume IV, Source Test Policy and Procedures. The proposed amendments to Section 6-5-601 also include clarifications to align this section with the proposed amendments in Section 6-5-112 pertaining to emissions during startup and shutdown periods. The amendments clarify that the exemption for these periods is 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 proposed amendments to Section 6-5-602 specify additional requirements for Air District approved ammonia monitoring systems. Under the proposed amendments, ammonia monitoring systems must meet the applicable requirements for ammonia monitoring in the Air District Manual of Procedures. The Air District is currently evaluating and developing performance specifications that can be applied to ammonia monitoring systems, and any future relevant updates to the Air District Manual of Procedures would be applicable to these monitoring systems. The proposed 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: Proposed Section 6-5-603 requires that compliance with the sulfur dioxide limits in Section 6-5-301.2 be determined by monitoring systems that meet the requirements of Air District Regulation 1, Section 1-522.

Section 6-5-604 – Determination of Total Particulate Matter 10 Microns or Less in Diameter (Total PM_{10}): Proposed Section 6-5-604 requires that total PM_{10} 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.

Section 6-5-605 – Determination of Total Particulate Matter 2.5 Microns or Less in Diameter (Total $PM_{2.5}$): Proposed Section 6-5-605 requires that total $PM_{2.5}$ 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.

IV. EMISSIONS AND EMISSION REDUCTIONS

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 staff 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. Air District staff continues to study these emissions and gather additional information as appropriate. As part of this effort, Air District staff conducted and oversaw further source testing at the PBF Martinez Refinery fluidized catalytic cracking unit from September to October 2020. Source test results demonstrated reasonable agreement with previous total PM_{10} emission estimates.

A. Emissions

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.

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

Facility	FCCU Fresh Feed Capacity (barrels per day)[26]	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.

B. Emission Reductions

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

Table 2 – Estimates of Potential Particulate Matter Emission Reductions under Proposed Amendments

Facility	Estimated PM_{10} Reductions (tons per year)
Chevron Products Richmond	160
Marathon Martinez Refinery[a]	*93*
PBF Martinez Refinery	240
Valero Benicia Refinery	–
Total Estimated Reductions[b]	**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.

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

V. ECONOMIC IMPACTS

A. Cost Effectiveness

The Air District is required to consider cost effectiveness when adopting any regulation.[27] Cost effectiveness is calculated by dividing the annualized costs (amortized capital costs and operating costs) by the total number of tons of emission reductions expected each year:

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

Air District staff reviewed available data on costs and cost estimation tools and methodologies and developed cost estimates associated with compliance under the proposed amendments. Based on these cost estimates, Air District staff estimated cost effectiveness for the proposed amendments. Estimates of the total compliance costs, total annual costs, and cost effectiveness are shown in Table 3. Further information and details on the development of the cost estimates are provided in the following Section V.A.1.

Table 3 – Compliance Cost and Cost Effectiveness Estimates for Proposed Amendments

Facility	Estimated Capital Costs	Estimated Total Annual Costs[a]	Estimated Cost Effectiveness
Chevron Products Richmond	$241 MM	$39 MM	$242,700
Marathon Martinez Refinery[b]	*$235 MM*	*$38 MM*	*$406,400*
PBF Martinez Refinery	$255 MM	$40 MM	$165,000
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.

Air District staff has also reviewed information on cost effectiveness data of previously adopted rules and amendments for particulate matter. This data is provided in Table 4 for additional information and context.

[27] California Health and Safety Code, Section 40703.

Table 4 – Historical Cost Effectiveness Data for Previously Adopted Rules and Amendments

District	Rule/Amendment (Year)	Pollutant	Cost Effectiveness Data (2019 Dollars)
BAAQMD	Rule 6-1 Amendments – General Requirements (2018)	Total Suspended Particulate (TSP)	$2,500/ton - $14,000/ton
BAAQMD	Rule 6-6 – Prohibition of Trackout (2018)	PM_{10}	$4,700/ton
		$PM_{2.5}$	$32,500/ton
SCAQMD	Rule 1105.1 Amendments – FCCUs (2003)	Filterable PM	$19,600/ton - $34,800/ton
		Filterable and Condensable PM	$4,500/ton - $7,600/ton
SCAQMD	Rule 1158 Amendments – Coke/Coal/Sulfur Handling (1999)	PM_{10}	$4,700/ton - $46,700/ton

Note: This table does not list other recent Air District rulemakings that reduced particulate matter that did not have relevant cost effectiveness data. This includes Rule 9-13: Nitrogen Oxides, Particulate Matter, and Toxic Air Contaminants from Portland Cement Manufacturing (2012), Rules 12-13: Foundry and Forging Operations (2013), Rule 6-4: Metal Recycling and Shredding Operations (2013), and Rule 6-5: Particulate Emissions from Refinery Fluidized Catalytic Cracking Units (2015).

1. Development of Compliance Cost Estimates for Proposed Amendments

Under the proposed amendments, 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 the proposed emission limits.

Staff estimated costs for wet gas scrubbing systems using control cost methodologies presented in the US Environmental Protection Agency Air Pollution Control Cost Manual.[28] 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 Martinez Refinery.[29] 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.[30]

Staff also applied additional adjustments to the results of these methodologies to reflect temporal and geographic equipment cost and wage 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 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

[28] 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.

[29] 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.

[30] EPA, 2008. Regulatory Impact Analysis for the Proposed Petroleum Refinery New Source Performance Standards, EPA–452/R–07–006.

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

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 of these costs between regional markets.

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.[34] The cost of the wet gas scrubber installation was estimated to be approximately $525 million.[35] 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 seven higher than the estimates developed using the US Environmental Protection Agency control cost methodologies for the comparable system. Staff applied this additional factor to the compliance cost estimates for the proposed amendments.

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 cost estimates for the PBF Martinez Refinery. Chevron Products Richmond also expressed concerns regarding siting constraints at their refinery, but did not provide further details on specific relocation costs for consideration in staff's analysis.

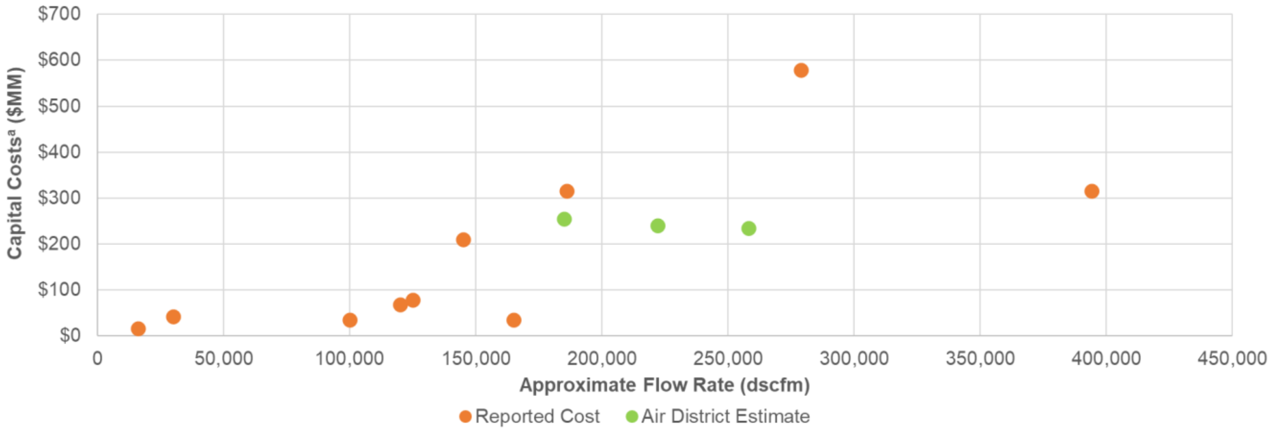
Capital cost estimates for wet gas scrubber installations for each facility are shown in Table 3. Staff also estimated total annual costs, which includes amortized capital costs, tax, insurance, general and administrative (G&A) costs, and operating and maintenance (O&M) costs. Amortized capital cost 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

[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] Valero Benicia Refinery, 2012. Valero Improvement Project (VIP) Construction Report for the period ending June 30, 2012. August.
[35] 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.)

percent, and general and administrative costs of two percent. The estimates of total annual costs, including amortized capital and annual operating costs, are also shown in Table 3.

To provide further context for these 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 wet gas scrubbing 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 5, 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 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 5 – 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[36]	$16 MM	16,000
2015	HollyFrontier Cheyenne FCCU[37]	$43 MM	30,000
2004	Tesoro Mandan FCCU[38]	$36 MM	100,000
2008	Unspecified SCAQMD Refinery X FCCU[39]	$68 MM	120,000
2006	Shell Puget Sound Refinery FCCU[40]	$79 MM	125,000
2007	CITGO Lemont FCCU[41]	$210 MM	145,000
2004	Shell Deer Park FCCU[42]	$36 MM	165,000
2006	Valero Delaware City Refinery Coker[43]	$316 MM	186,000
2010	Valero Benicia FCCU and Coker[44]	$579 MM	280,000
2006	Valero Delaware City Refinery FCCU[45]	$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

[36] HollyFrontier Corporation, 2011. Form 10-K (Annual Report), Filed 02/25/11 for the Period Ending 12/31/10.
[37] HollyFrontier Cheyenne Refinery, 2015. “Cheyenne Can Breathe Easier.” September.
[38] Bismarck Tribune, 2004. "Tesoro installs a new $2[0] million scrubber." October 26.
[39] South Coast AQMD, 2010. Final Staff Report SOx RECLAIM, Part 1: BARCT Assessment & RTC Reductions Analysis. November.
[40] Anacortes Chamber of Commerce, 2012. "Shell Puget Sound Refinery," The Anacortes Communicator. July.
[41] 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.
[42] Vanya, Rob, 2004. "Shell going to great lengths to meet environmental mandates," Houston Chronicle. September 13.
[43] BAAQMD, 2008. Tesoro Plant No. 14628, Banking Application No. 17798 Engineering Evaluation. November.
[44] 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.)
[45] 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. Chevron Products Richmond estimates that the installation of a wet gas scrubber would result in total capital costs of approximately $1.48 billion. PBF Martinez Refinery estimates that the installation of a wet gas scrubber would result in total capital costs of approximately $800 million. These estimates are substantially higher than the costs estimated by Air District staff and are higher than any of the adjusted costs reviewed for other refinery wet gas scrubber installations.

During previous public comment periods for materials related to this rule development effort, staff received many public comments about potential wet gas scrubbing designs and technologies that could reduce potential water usage. As described in Section II.C.1, several technologies are available to reduce wet gas scrubber water usage, but typically result in increased costs and complexity. Due to the increased costs, staff does not anticipate that the affected facilities would elect to implement these designs; nevertheless, staff have developed information on potential costs associated with these types of technologies. Literature suggests that the use of a regenerative wet gas scrubber design would increase initial capital costs compared to a non-regenerative design due to additional equipment required, but would result in some operational cost savings due to the reductions in water use and associated wastewater handling and processing.[46] Applying these capital cost and operating cost adjustments to the non-regenerative cost model, staff estimates that costs for a regenerative wet gas scrubber would be approximately $579 million at Chevron Products Richmond ($76 million total annual cost), $565 million at Marathon Martinez Refinery ($75 million total annual cost), $563 million at PBF Martinez Refinery ($74 million total annual cost). As mentioned, staff does not anticipate that the affected facilities would elect to implement these costlier technologies.

B. Incremental Cost Effectiveness

The California Health and Safety Code requires the Air District to consider incremental cost effectiveness of potential control options identified that meet the emission reduction objectives of the regulation.[47] Incremental cost effectiveness is calculated by: 1) calculating the incremental difference in cost between the identified control methods, and 2) dividing the incremental difference in cost by the incremental difference in emission reductions between each progressively more stringent potential control option:

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

Air District staff identified a potential control option that is less stringent and less costly than the proposed control option and developed associated emission reduction estimates and cost estimates (further information and details on this less stringent control option and associated cost estimates are provided in the following Section V.B.1). Air District staff estimated the incremental cost effectiveness of the proposed amendments compared to this less stringent control option. The results of this incremental cost effectiveness analysis are shown in Table 6.

[46] Weaver, Edwin H. (BELCO Technologies Corporation), 2006. Evaluating Wet Scrubbers, Petroleum Technology Quarterly, Quarter 3, 2006.
[47] California Health and Safety Code, Section 40920.6.

Table 6 – Incremental Cost Effectiveness Analysis for Proposed Amendments and Other Control Options

Facility	Capital Costs	Total Annual Costs[a]	PM_{10} Emission Reductions (tpy)	Cost Effectiveness ($/ton)	Incremental Cost Effectiveness ($/ton)
Proposed Amendments					
Chevron Products Richmond	$241 MM	$39 MM	160	$242,700	$430,200
Marathon Martinez Refinery[b]	*$235 MM*	*$38 MM*	*93*	*$406,400*	*–[c]*
PBF Martinez Refinery	$255 MM	$40 MM	240	$165,000	$359,400
Valero Benicia Refinery	–	–	–	–	–
Less Stringent Control Option					
Chevron Products Richmond	$30 MM	$4.4 MM	80	$55,300	–
Marathon Martinez Refinery[b]	*–*	*–*	*–*	*–*	*–*
PBF Martinez Refinery	$80 MM	$14 MM	170	$84,900	–
Valero Benicia Refinery	–	–	–	–	–

[a] The 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 the less stringent control option to compare to the proposed amendments.

1. Development of Compliance Cost Estimates for Less Stringent Control Option

Air District staff identified a less stringent control option as a potential alternative to the proposed amendments. This less stringent control option was previously discussed as "Control Scenario A" in the Air District's Workshop Report released in January 2021.[48] This control option reflects levels of control that are less stringent than the proposed amendments and have been demonstrated to be feasible through the use of various control technologies, including electrostatic precipitators.

For this analysis, staff assumed that facilities would be required to meet a less stringent total PM_{10} limit of 0.020 grains per dry standard cubic foot (gr/dscf). Based on staff's understanding of fluidized catalytic cracking units emissions and performance at the refineries, staff anticipated that the fluidized catalytic cracking units at Chevron Products Richmond and PBF Martinez Refinery would not meet the this limit, and emission reductions would be required at these facilities. Estimates of these potential emission reductions associated with the less stringent control option are shown in Table 6. Staff anticipated that the fluidized catalytic cracking units at Marathon Martinez Refinery and Valero Benicia Refinery would be able to comply with these emission limits without substantial modifications; potential emission reductions at these facilities would, therefore, be minimal under this less stringent control option.

Staff anticipated 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 anticipated that improvements to existing electrostatic precipitator systems or additional electrostatic precipitator capacity would be required under this control option. Staff anticipated that PBF Martinez Refinery would also be required to improve feed hydrotreatment and sulfur

[48] BAAQMD, 2021. Workshop Report – Draft Amendments to Regulation 6, Rule 5: Particulate Emissions from Petroleum Refinery Fluidized Catalytic Cracking Units. January.

dioxide-reducing additives under this control option. Estimates of the total compliance costs and cost effectiveness under this less stringent control option are shown in Table 7. Further information and details on the development of these cost estimates are provided below.

Table 7 – Estimates of Compliance Costs and Cost Effectiveness for Less Stringent Control Option

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[d]	$14 MM[e]	$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 costs at Chevron Products Richmond include improvements/expansions to existing electrostatic precipitator systems.
[c] Compliance costs at PBF Martinez Refinery include improvements/expansions to existing electrostatic precipitator systems, improvements to existing feed hydrotreatment systems, and optimized/improved sulfur dioxide-reducing additives.
[d] Includes capital costs of $40 million for improvements/expansions to existing electrostatic precipitator systems and $40 million for improvements to existing feed hydrotreatment systems.
[e] Includes annual costs of $5.9 million per year for improvements/expansions to existing electrostatic precipitator systems and $7.1 million per year for improvements to existing feed hydrotreatment systems, and $1.5 million per year for optimized/improved sulfur dioxide-reducing additives.

a) 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.[49] 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.[50] 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.A.1.

Capital costs for electrostatic precipitator improvements were estimated to be $30 million at Chevron Products Richmond and $40 million at PBF Martinez Refinery and are included in the total capital cost estimates in Table 7. 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 total annual costs for the

[49] 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.
[50] EPA, 2008. Regulatory Impact Analysis for the Petroleum Refineries NSPS (New Source Performance Standards). EPA-452/R-08-002. April.

electrostatic precipitator improvements, including amortized capital and annual operating costs, were estimated to be $4.4 million per year at Chevron Products Richmond and $5.9 million per year at PBF Martinez Refinery. These figures are included in the total annual cost estimates shown in Table 7.

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.[51] 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 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. PBF Martinez Refinery estimated that additional electrostatic precipitator installations at the refinery would result in capital costs of approximately $480 million.

b) 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.[52] Other literature also presents capital cost estimate tools for new hydrotreatment systems.[53] 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, capital costs for hydrotreatment improvements at PBF Martinez Refinery were estimated to be $40 million, which is included in the total capital cost estimates shown in Table 7. 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

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[51] South Coast AQMD, 2010. Final Staff Report SOx RECLAIM, Part 1: BARCT Assessment & RTC Reductions Analysis. November.
[52] Schwalje, David; Larry Wisdom; and Mike Craig (Axens North America), 2016. Revamp cat feed hydrotreaters for flexible yields. EPTQ (Petroleum Technology Quarterly), Revamps 2016.
[53] Gary, James H.; Glenn Handwerk; and Mark Kaiser, 2007. Petroleum Refining Technology and Economics, Fifth Ed.

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. The total annual costs for the hydrotreatment improvements at PBF Martinez Refinery, including amortized capital and annual operating costs, were estimated to be $7.1 million per year. 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.[54,55,56,57] 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. These figures are included in the total annual cost estimates shown in Table 7.

C. Socioeconomic Impacts

The Air District is required to assess and consider potential socioeconomic impacts when adopting or amending regulations.[58] Air District staff contracted with an independent consultant, Applied Development Economics (ADE), to develop estimates of potential socioeconomic impacts for the proposed amendments to Rule 6-5 and the less stringent control option identified in Section V.B. The analysis and findings are summarized in this section, and the full report of the socioeconomic impact analysis is available in Appendix C.

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;[59] the methodologies described in this report have also been incorporated by the California Air Resources Board in its own assessment of socioeconomic impacts of regulations adopted 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 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

[54] EPA, 2008. Regulatory Impact Analysis for the Petroleum Refineries NSPS (New Source Performance Standards). EPA-452/R-08-002. April.
[55] South Coast AQMD, 2003. Final Staff Report for Proposed Rule 1105.1. September.
[56] South Coast AQMD, 2010. Final Staff Report SOx RECLAIM, Part 1: BARCT Assessment & RTC Reductions Analysis. November.
[57] Evans, Martin (Intercat/Johnson Matthey), 2008. Evaluating FCC flue gas emission-control technologies. Digital Refining, 2008 Q1.
[58] California Health and Safety Code, Section 40728.5.
[59] 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.

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).

1. 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 per day (BPD) 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 – 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. Estimates of Potential Socioeconomic Impacts Associated with the Proposed Amendments

As described in Section V.A, staff anticipates that Chevron Products Richmond, Marathon Martinez Refinery, and PBF Martinez Refinery would be required to implement additional controls to comply with the proposed amendments. Table 9 shows the estimated 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 9 – Estimates of Potential Socioeconomic Impacts for Proposed Amendments

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 the proposed amendments, 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. While individual refineries may be limited in their ability to increase prices unilaterally, particularly during periods of falling demand, the price increases required to reduce the significance of the emission reduction costs are well within the level of gas price fluctuations that normally occur due to changes in demand and supply factors annually.

Therefore, while the socioeconomic impacts are potentially significant for the affected facilities, it is likely they can be mitigated to less than significant levels. In addition, these impacts and adjustments may have other impacts throughout the region. For example, an increase in gasoline prices could have multiplier effects in the regional economy as consumers shift spending from other sectors to increased transportation costs, but jobs and income created through the installation and construction of the control technologies could offset impacts of the increased gas prices.

3. Estimates of Potential Socioeconomic Impacts Associated with Less Stringent Control Option

As described in Section V.B, staff anticipates that Chevron Products Richmond and PBF Martinez Refinery would be required to modify or install additional controls to comply with the less stringent control option identified. Table 10 shows the estimated proportion of profits the total annual compliance costs represent. As shown, the estimated compliance costs under the less stringent control option 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 10 – Estimates of Potential Socioeconomic Impacts for Less Stringent Control Option

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.

D. 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.4 and A.5 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. Staff conducted this modeling for the Chevron Richmond Products and PBF Martinez Refinery facilities, and evaluated a scenario for the proposed amendments and a scenario for the less stringent control option identified. Throughout this section and Appendices A.1 through A.5, the scenario for the less stringent control option is referred to as "Control Scenario A", and the scenario for the more stringent proposed amendments is referred to as "Control Scenario B".

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 baseline emissions used for the modeling include contributions representative of 2018, the most recent year that emissions have been checked and finalized by

Air District staff, but with changes to reflect significant reductions in non-FCCU sources at Chevron Products Richmond since 2018 (due to the Chevron Refinery Modernization Project[60]).

The outermost contour represents a contribution of +0.1 microgram per cubic meter (µg/m^3), which as an order-of-magnitude is approximately 1 percent of the total ambient concentration within the general area. Note that 0.1 µg/m^3 is not a *de minimis* value, as there are potentially significant real-world impacts beyond this contour. However, the +0.1 µg/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, A.2, and A.3 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.

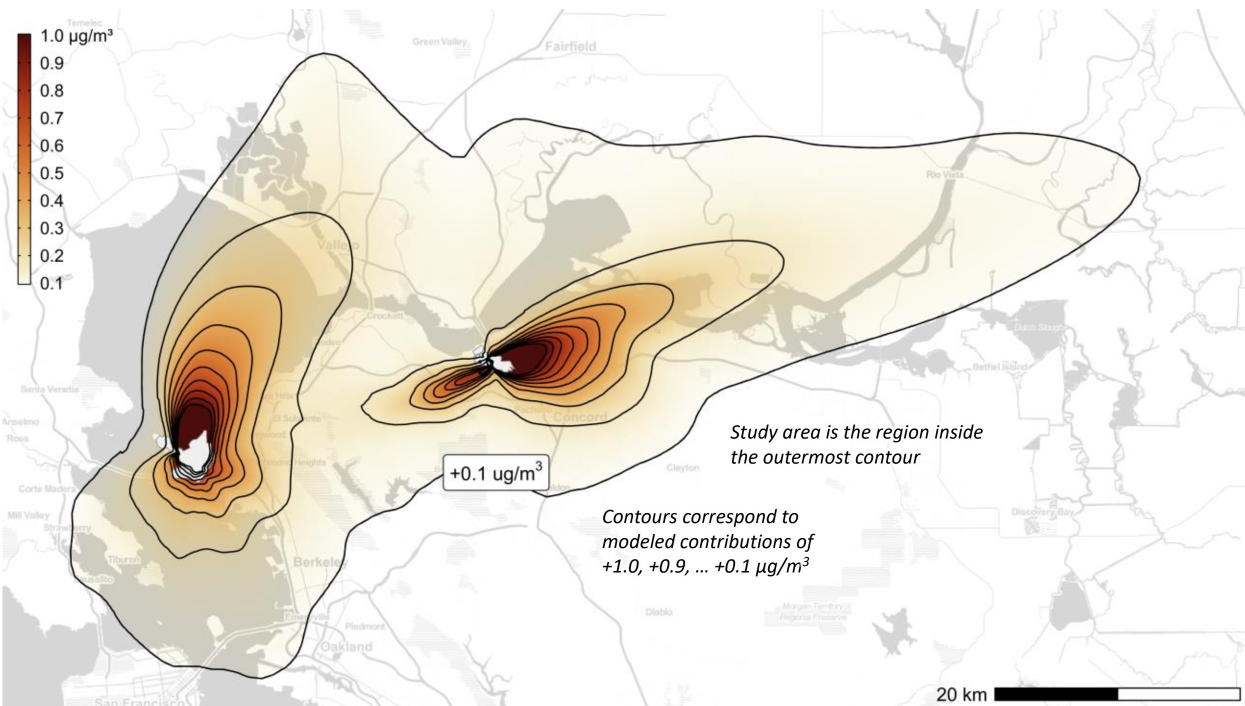

Figure 3 – Contributions of modeled baseline emissions to ambient $PM_{2.5}$

The outermost contour represents a contribution of +0.1 µg/m^3, which is approximately 1 percent of ambient $PM_{2.5}$ within the vicinity. Contributions less than +0.1 µg/m^3 (i.e., beyond the study area) are not shown.

60 City of Richmond, 2015. Chevron Refinery Modernization Project Environmental Impact Report, Consolidated Version Volumes 1 and 2, SCH No. 2011062042. October.

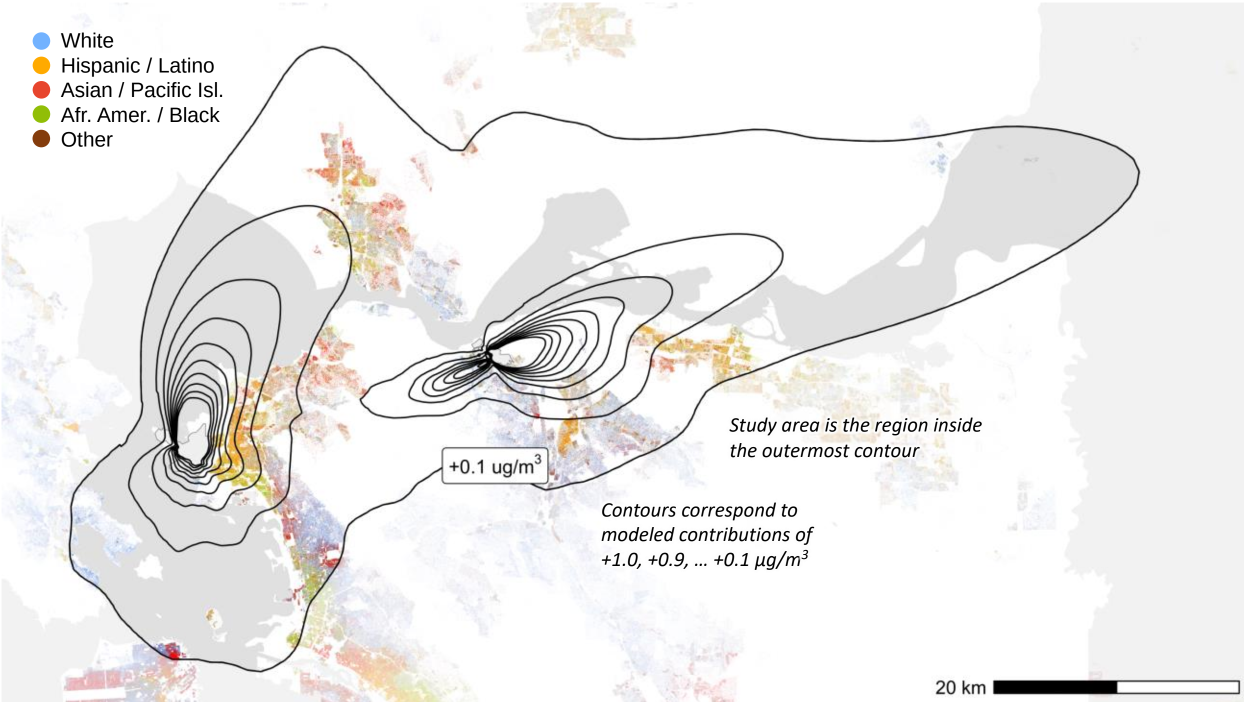

Figure 4 – Residential population

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).

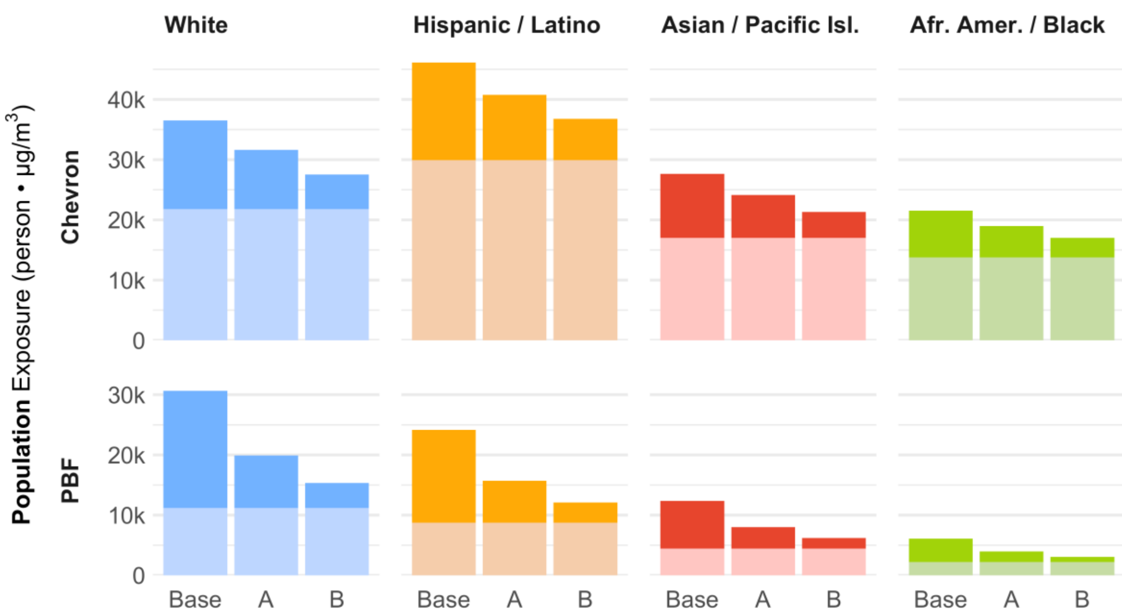

Figure 5a – Modeled estimates of total population exposure (residential impact) within the study area

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 (Scenario A = Less Stringent Control Option; Scenario B = Proposed Amendments). 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.

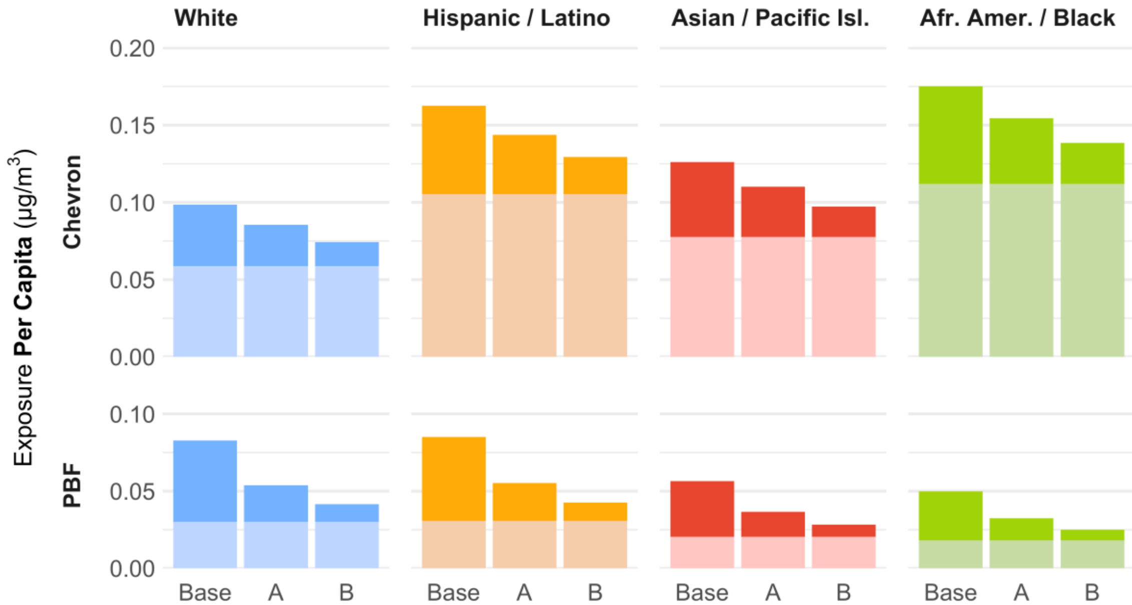

Figure 5b – Modeled estimates of total population exposure (residential impact) within the study area normalized by population

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. Scenario A = Less Stringent Control Option; Scenario B = Proposed Amendments.

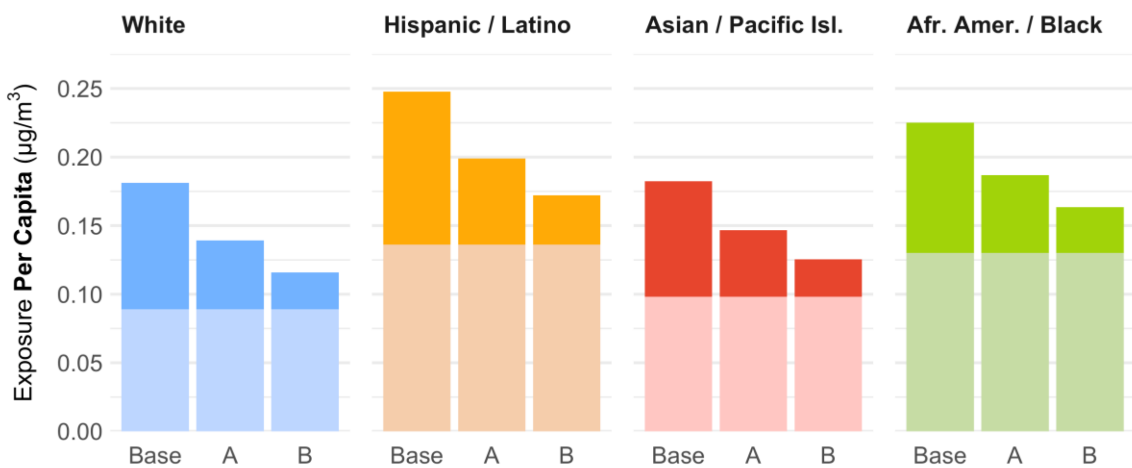

Figure 5c – Combined modeled estimates of total population exposure (residential impact) within the study area normalized by population

Same as Figure 5b, except that impacts from both facilities have been combined. Scenario A = Less Stringent Control Option; Scenario B = Proposed Amendments.

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 Appendices A.2 and A.3 and EPA's BenMAP.[61]

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

Table 11 provides a summary that is scoped to Chevron Products Richmond, and Table 12 provides a summary that is scoped to PBF Martinez Refinery. 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 Scenario A (Less Stringent Control Option) and B (Proposed Amendments). 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 Appendices A.2 and A.3.

[61] 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 Products Richmond Alone)

Under Baseline Conditions			Potential Benefits	
Health Impact		**Valuation[1]**	**Scenario A (Less Stringent Control Option)**	**Scenario B (Proposed Amendments)**
Cardiovascular	0.5–4.3 heart attacks	\$63k–600k	-13%	-22%
	1.0 hospital admissions	\$47k	-13%	-22%
Restricted Activity	4,800 days	\$360k	-12%	-21%
Lost Work	820 days	\$190k	-12%	-21%
Asthma	200 exacerbations[3]	\$12k	-12%	-21%
	4 emergency room visits	\$2k	-12%	-21%
	0.1 hospital admissions	\$1k	-12%	-20%
Respiratory Illness[2]	140 upper tract[3]	\$5k	-12%	-20%
	100 lower tract[3]	\$2k	-12%	-20%
	8 bronchitis[3]	\$4k	-12%	-20%
	0.2 chronic lung disease	\$5k	-12%	-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

Table 12 – Estimated Annual Baseline Health Impacts, Reductions, and Valuations (Annual, All Modeled Sources at PBF Martinez Refinery Alone)

Under Baseline Conditions			Potential Benefits	
Health Impact		**Valuation[1]**	**Scenario A (Less Stringent Control Option)**	**Scenario B (Proposed Amendments)**
Cardiovascular	0.3–2.4 heart attacks	$37k–350k	-35%	-50%
	0.6 hospital admissions	$26k	-35%	-50%
Restricted Activity	2,700 days	$200k	-35%	-50%
Lost Work	460 days	$100k	-35%	-50%
Asthma	110 exacerbations[3]	$7k	-35%	-50%
	2 emergency room visits	$1k	-35%	-50%
	<0.1 hospital admissions	$1k	-35%	-50%
Respiratory Illness[2]	80 upper tract[3]	$3k	-35%	-50%
	50 lower tract[3]	$1k	-35%	-50%
	4 bronchitis[3]	$2k	-35%	-50%
	0.1 chronic lung disease	$3k	-35%	-50%
Mortality	2.8–6.3 deaths[4]	$28.8 MM to $64.9 MM	-35%	-50%
			$10.1 MM to $22.7 MM/yr	**$14.4 MM to $32.4 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 13 reproduces the bottom-line valuations from Table 11 and Table 12 alongside the estimates of emissions reductions and associated costs that were reported in previous sections.

Table 13 – Modeled Reductions, Valuations of Benefits, and Costs (Annual, Chevron Products Richmond and PBF Martinez Refinery)

Facility	Scenario	Emission Reductions*	Valuation of Assessed Benefits†,‡	Estimated Annual Costs
Chevron Products Richmond	Less Stringent Control Option (A)	80 ton/yr	\$6.8 MM to \$15 MM/yr	\$4.4 MM/yr
	Proposed Amendments (B)	160 ton/yr	\$12 MM to \$27 MM/yr	\$39 MM/yr
PBF Martinez Refinery	Less Stringent Control Option (A)	170 ton/yr	\$10 MM to \$23 MM/yr	\$14 MM/yr
	Proposed Amendments (B)	240 ton/yr	\$14 MM to \$32 MM/yr	\$40 MM/yr

** PM_{10} from FCCU. Modeled $PM_{2.5}$ / PM_{10} ratio for the Chevron FCCU is approximately 95%. Modeled $PM_{2.5}$ / PM_{10} ratio for the PBF Martinez FCCU is approximately 97%.*

† Based on EPA-approved valuations of the health endpoints that were assessed for the 1 million people in the study area.

‡ Valuations are in 2015 US Dollars, calculated using the EPA BenMAP system.

3. Limitations and Comparability

Tables 11 through 13 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 the scope of the health endpoints included. 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, reported benefits are scoped to the population included in the defined study area. (See Section V.D.1.) The size of the study area, as we have defined it, is linked to the baseline emission estimates, which means that it inherits uncertainties in those estimates. The baseline emissions represent contributions in 2018 from two of the five Bay Area refineries (with adjustments described in Section V.D.1). If the study area were adjusted to match a +0.1 $\mu g/m^3$ contour estimated from a different set of baseline emissions (including non-FCCU emissions), then it could grow or shrink. For example, the study area would grow if baseline emissions from the Valero Benicia Refinery, which is also subject to this proposed rule, were accounted for. This would increase the estimated total benefits since the covered study population would increase.

Third, 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,[62] 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.

F. District Impacts

Staff anticipates that the proposed amendments may require additional staff time and resources in a number of areas. Air District Engineering resources may be required in the review, processing, and evaluation of permit applications for installations of new air pollution control equipment and abatement devices. Air District Compliance and Enforcement resources may be required for review and documentation of any rule requirements that are not met and may also be required for assistance in the evaluation of permit applications for any air pollution control equipment installations. Air District Meteorology and Measurement resources would be needed to review monitoring and testing reports submitted, and to verify compliance with testing and monitoring procedures. Additional resources would be required to coordinate and conduct testing at the affected facilities. This may involve the procurement of additional equipment, instrumentation, and testing infrastructure, and ongoing costs for additional staffing to conduct testing.

VI. REGULATORY IMPACTS

A regulatory impact analysis is required by California Health and Safety Code Section 40727.2 to compare the proposal to other Air District, State and federal rules addressing the same sources. The following Table 14 provides this regulatory impact analysis.

[62] 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 14 – H&SC Section 40727.2 Regulatory Analysis: Proposed Amendments to Rule 6-5

Section	Description (paraphrased)	Comparable State or Air District Provision	Comparable Federal Provision	Discussion
101	Description	N/A	N/A	No applicable requirements.
111	Limited Exemption, Wet Scrubber	N/A	N/A	Provides exemption from ammonia limit if source is abated by a wet gas scrubber that meets BACT requirements.
112	Limited Exemption, Startup or Shutdown	SCAQMD Rule 1105.1	N/A	Provides limited exemption during shutdown and startup periods, consistent with SCAQMD Rule 1105.1.
113	Deleted, Limited Exemption, Installation of Wet Scrubber	N/A	N/A	No applicable requirements.
114	Limited Exemption, FCCU without Nitrogen-Based Additives	N/A	N/A	Provides exemption from ammonia limit for sources not using ammonia additives.
115	Limited Exemption, Ammonia Optimization	N/A	N/A	Proposed amendments would provide an end date for this limited exemption.
200	Definitions			
212	Total PM_{10}	BAAQMD Regulation 6	N/A	Definition is consistent with BAAQMD Regulation 6.
213	Total $PM_{2.5}$	BAAQMD Regulation 6	N/A	Definition is consistent with BAAQMD Regulation 6.
300	Standards			
301.1	Ammonia slip emission concentration limit	SCAQMD Rule 1105.1	N/A	Proposed ammonia slip limit is consistent with SCAQMD Rule 1105.1 limit.
301.2	Sulfur dioxide emission concentration limits	BAAQMD Rule 9-1 SCAQMD Rule 1105	40 CFR 60 Subpart J (NSPS) 40 CFR 60 Subpart Ja (NSPS)	Proposed sulfur dioxide limits are more stringent than BAAQMD Rule 9-1, SCAQMD Rule 1105, and NSPS Subpart J limits for FCCUs. Proposed sulfur dioxide limits are consistent with NSPS Subpart Ja limits for FCCUs constructed or modified after May 14, 2007.
301.3	Total PM_{10} emission limit	SCAQMD Rule 1105.1	40 CFR 60 Subpart J (NSPS) 40 CFR 60 Subpart Ja (NSPS) 40 CFR 63 Subpart UUU (NESHAP)	Proposed PM limit applies to total PM_{10} emissions. SCAQMD Rule 1105.1 and federal PM emission limits only apply to filterable PM.
400	Administrative Requirements			

Section	Description (paraphrased)	Comparable State or Air District Provision	Comparable Federal Provision	Discussion
403	Ammonia Optimization	N/A	N/A	Administrative requirement.
404	Reporting Requirements	N/A	N/A	Administrative requirement.
500	Monitoring and Records			
502	Sulfur Dioxide Monitoring	BAAQMD Rule 9-1	40 CFR 60 Subpart J (NSPS) 40 CFR 60 Subpart Ja (NSPS)	Proposed sulfur dioxide monitoring requirements are consistent with BAAQMD Rule 9-1 and NSPS Subparts J and Ja requirements.
503	Total PM_{10} and Total $PM_{2.5}$ Monitoring	SCAQMD Rule 1105.1	40 CFR 60 Subpart J (NSPS) 40 CFR 60 Subpart Ja (NSPS) 40 CFR 63 Subpart UUU (NESHAP)	Proposed amendments require monitoring of total PM_{10} and total $PM_{2.5}$ through quarterly testing or other approved methods. NSPS Subparts J and Ja require monitoring for filterable PM only. SCAQMD Rule 1105.1 requires testing for filterable and condensable PM on an annual basis.
504	Records	N/A	N/A	Administrative requirement.
600	Manual of Procedures			
601	Compliance Determination	N/A	N/A	Administrative requirement.
602	Determination of Ammonia and Oxygen	SCAQMD Rule 1105.1	N/A	Proposed amendments specify and clarify performance requirements for continuous or parametric ammonia monitoring. SCAQMD Rule 1105.1 requires annual source test for ammonia emissions.
603	Determination of Sulfur Dioxide	BAAQMD Rule 9-1	40 CFR 60 Subpart J (NSPS) 40 CFR 60 Subpart Ja (NSPS)	Proposed amendments for the determination of sulfur dioxide are consistent with BAAQMD Rule 9-1 and NSPS Subpart J and Ja requirements.
604	Determination of Total PM_{10}	SCAQMD Rule 1105.1	40 CFR 51, Appendix M	Proposed amendments for the determination of total PM_{10} are consistent with Method 201A and Method 202 of Appendix M of 40 CFR 51. SCAQMD Rule 1105.1 requires the use of SCAQMD Source Test Method 5.2.
605	Determination of Total $PM_{2.5}$	N/A	40 CFR 51, Appendix M	Proposed amendments for the determination of total $PM_{2.5}$ are consistent with Method 201A and Method 202 of Appendix M of 40 CFR 51.

VII. ENVIRONMENTAL IMPACTS

The California Environmental Quality Act (CEQA), Public Resources Code Section 21000 et seq., require a government agency that undertakes or approves a discretionary project to consider the potential impacts of that project on all environmental media. Potential environmental impacts related to projects under the AB 617 Expedited Best Available Retrofit Control Technology (BARCT) 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 on December 19, 2018 (State Clearing House Number: 2018082003). The EIR found that implementation of the projects under the AB 617 Expedited BARCT Implementation Schedule would result in significant impacts. The EIR concluded that air quality impacts associated with the construction of air pollution control equipment would be potentially significant after mitigation and cumulatively considerable. Water demand impacts from the operation of air pollution control equipment were found to be potentially significant after mitigation and cumulatively considerable. The Air District incorporates the EIR into the record, and the EIR is attached to this Staff Report as Appendix D.

The proposed amendments to Rule 6-5 do not present substantial changes in the project or circumstances or new information that would require a new analysis. Staff anticipates the proposed amendments to Rule 6-5 would require the installation of up to three wet gas scrubbers at refinery FCCUs, as was anticipated in the EIR. Air quality impacts associated with the construction of this air pollution control equipment and water demand impacts from the operation of this control equipment are not anticipated to be substantially different than the impacts described in the EIR. No subsequent or supplemental EIR is required as there have not been substantial changes in the proposed project that would require major revisions to the EIR, there have not be substantial changes with respect to the circumstances under which the project is being undertaken that would require major revisions to the EIR, and there is no new information available that would change the analysis in the EIR. Therefore, the Air District continues to rely on the EIR pursuant to CEQA section 21166.

VIII. 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.

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. Following the release of the draft amendments in May 2020, staff further evaluated other more stringent control options for these sources. In January 2021, Air District staff released two versions of draft amendments and a workshop report reflecting two alternative control options. Staff conducted a virtual public workshop on the draft amendments on February 4, 2021 and received public comments on the materials through March 1, 2021. The Air District staff presented updates on the workshop, materials, and comments received at an Air District Stationary Source and Climate Impacts Committee meeting in March 2021. In that meeting, a majority of Committee members expressed a preference to proceed with development of the more stringent of the two control options issued for comment in January.

The Air District released the Staff Report and proposed amendments to Rule 6-5 for public review and comment on March 30, 2021. Staff received 47 comment letters from a number of residents, medical professionals, refinery staff, local governments, environmental advocacy groups, affected facilities, and industry associations. Comments were submitted on many topics, including:

- Support for the proposed amendments
- Opposition to the proposed amendments
- Support for other control options
- Compliance costs and cost estimates
- Socioeconomic impacts
- Impacts on fuels markets
- Environmental impacts
- Emissions estimates and test methods
- Air pollution control equipment technical feasibility
- Air quality modeling
- Health impacts modeling
- Health impacts of particulate matter
- Legal and statutory requirements

Air District staff have addressed the submitted comments and prepared a Response to Comments document. At the Public Hearing, the Air District Board of Directors will consider the final proposal and receive public input before taking any action on the proposed amendments to Rule 6-5.

IX. CONCLUSION / RECOMMENDATIONS

Pursuant to the California Health and Safety Code Section 40727, before adopting, amending, or repealing a rule the Board of Directors must make findings of necessity, authority, clarity, consistency, non-duplication and reference. This section addresses each of these findings.

A. Necessity

As stated in California Health and Safety Code Section 40727(b)(1), "'Necessity' means that a need exists for the regulation, or for its amendment or repeal, as demonstrated by the record of the rulemaking authority."

The San Francisco 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 for attainment and maintenance of the standards. The proposed amendments to Rule 6-5 would reduce particulate matter emissions from petroleum refinery fluidized catalytic cracking units, which are among the largest individual sources of particulate matter emissions in the Bay Area. The proposed amendments to Rule 6-5 are needed to ensure attainment and maintenance of these ambient air quality standards for particulate matter and to provide clean air and public health benefits.

The proposed amendments to Rule 6-5 were identified in the Air District's AB 617 Expedited Best Available Retrofit Control Technology (BARCT) Implementation Schedule. AB 617 requires that district adopt an expedited schedule for implementation of best available retrofit control technology by the earliest feasible date, and no later than December 31, 2023. The proposed amendments to Rule 6-5 are needed to implement these BARCT requirements consistent with AB 617 and California Health and Safety Code Section 40920.6(c).

B. Authority

The California Health and Safety Code Section 40727(b)(2) states that "'Authority' means that a provision of law or of a state or federal regulation permits or requires the regional agency to adopt, amend, or repeal the regulation."

The Air District has the authority to adopt these rule amendments under Sections 40000, 40001, 40702, and 40725 through 40728.5 of the California Health and Safety Code.

C. Clarity

The California Health and Safety Code Section 40727(b)(3) states that "'Clarity' means that the regulation is written or displayed so that its meaning can be easily understood by the persons directly affected by it."

The proposed amendments to Rule 6-5 are written so that its meaning can be easily understood by the persons directly affected by them. Further details in the Staff Report clarify the proposals, delineate the affected industry, compliance options, and administrative requirements for the industries subject to this rule.

D. Consistency

The California Health and Safety Code Section 40727(b)(4) states that "'Consistency' means that the regulation is in harmony with, and not in conflict with or contradictory to, existing statutes, court decisions, or state or federal regulations."

The proposed amendments to Rule 6-5 are consistent with other Air District rules and not in conflict with state or federal law.

E. Non-Duplication

The California Health and Safety Code Section 40727(b)(5) states that "'Nonduplication' means that a regulation does not impose the same requirements as an existing state or federal regulation unless a district finds that the requirements are necessary or proper to execute the powers and duties granted to, and imposed upon, a district."

The proposed amendments to Rule 6-5 are non-duplicative of other statutes, rules or regulations.

F. Reference

The California Health and Safety Code Section 40727(b)(6) states that "'Reference' means the statute, court decision, or other provision of law that the district implements, interprets, or makes specific by adopting, amending, or repealing a regulation."

By adopting the proposed amendments to Rule 6-5, the Air District Board of Directors will be implementing, interpreting or making specific the provisions of California Health and Safety Code Sections 40000, 40001, 40702 and 40727.

The proposed amendments to Rule 6-5 have met all legal noticing requirements, have been discussed with the regulated community and other interested parties, and reflect consideration of the input and comments of many affected and interested stakeholders.

G. Recommendations

Air District staff recommends the Air District Board of Directors adopt the proposed amendments to Regulation 6, Rule 5: Particulate Emissions from Petroleum Refinery Fluidized Catalytic Cracking Units.

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