South Coast AQMD

2022 AIR QUALITY MANAGEMENT PLAN

Final Socioeconomic Report Appendices

December 2022

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December 2022

FINAL SOCIOECONOMIC REPORT
APPENDIX 2-A

COMPILATION OF INCREMENTAL COSTS OF CONTROL MEASURES

DECEMBER 2022

The 2022 AQMP includes control strategies for emission reductions from both stationary sources and local mobile sources, as well as broader mobile source control measures proposed by CARB that will contribute to further emission reductions and help the region attain upcoming federal air quality standards.

This appendix consists of two parts. Part I presents the incremental costs of the South Coast AQMD control measures with quantified emission reductions to be committed into the SIP. It also includes a discussion of currently known or available cost information for the South Coast AQMD's stationary source control measures with TBD emission reductions. Part II presents the incremental costs of the state's SIP control strategies. These costs are based on CARB data and assumptions,[1] and they are estimated for those control strategies with quantified emission reductions in the Basin.

Part I – Incremental Costs of the South Coast AQMD Control Measures

(a) Incremental Costs of Control Measures with Quantified Emission Reductions

Direct costs associated with the 2022 AQMP control measures generally include capital expenditures on control or replacement equipment or on research and development to reformulate chemical products. They also include annual operating and maintenance costs such as fuel, utilities, filter replacement, etc.

The present worth value (PWV) of incremental costs by measure was calculated based on a four-percent discount rate which discounts all future stream of costs to year 2021. Conversely, the amortized annual average cost was obtained by amortizing the PWV of the incremental costs over the average equipment life using the same discount rate. The discount rate used for discounting and amortization corresponds to a real interest rate of four percent.[2] As a sensitivity test, a real interest rate of one percent will also be used, which is closer to the prevailing real interest rate.[3]

Notice that the analysis horizon which is used in the macroeconomic impact evaluation in Chapter 4 of this report is from 2022 to 2037, or from the year of the anticipated 2022 AQMP adoption to the year when the 2015 8-hour ozone standard of 70 ppb will need to be achieved. However, many categories of equipment included in the cost analysis will continue to be in operation after year 2037, either because of their long equipment life or because they are expected to come online at a later date. The PWV reported in Table 2-1 of Chapter 2 includes all recurring costs over the entire equipment life; thus, it may

[1] See CARB's Mobile Source Strategy, Appendix A: Economic Impact Analysis (2016a) and the 2022 SIP Strategy, Appendix A: Economic Analysis.

[2] In 1987, South Coast AQMD staff began to calculate cost-effectiveness of control measures and rules using the Discounted Cash Flow method with a discount rate of 4 percent. Although not formally documented, the discount rate is based on the 1987 real interest rate on 10-year Treasury Notes and Bonds, which was 3.8 percent. The maturity of 10 years was chosen because a typical control equipment life is 10 years; however, a longer equipment life would not have corresponded to a much higher rate—the 1987 real interest rate on 30-year Treasury Notes and Bonds was 4.4 percent. Since 1987, the 4 percent discount rate has been used by South Coast AQMD staff for all cost-effectiveness calculations, including BACT analysis, for the purpose of consistency.

[3] See https://www.whitehouse.gov/omb/circulars_a094/a94_appx-c/.

include costs occurring after 2037. In that same table, the amortized annual average cost over the period 2022-2037 is also reported. This cost, in contrast, includes recurring costs up to 2037, and the amortized capital and other upfront costs beyond 2037 are not included. The amortized costs are comparable to the costs reported in the Economic Analysis for the Proposed 2022 State Strategy for the State Implementation Plan.

Cost assumptions and cost breakdown by measure are presented below (see Chapter 4 and Appendices IV-A and IV-B of the 2022 AQMP for the detailed description of each measure). The implementation period for the cost analysis may differ somewhat from the "Implementation Period" listed in the 2022 AQMP Tables 4-20 and 4-21. The implementation period for the cost analysis herein generally refers to the year(s) when the control or replacement equipment will be purchased, installed, and begin operation. The purchase and installation cost of all equipment is assumed to be evenly distributed over the implementation period unless otherwise noted.

Stationary Source Measures (NOx and/or VOC Emission Reductions)

1. *R-CMB-01 (Residential Water Heating)*
2. *R-CMB-02 (Residential Space Heating)*
3. *C-CMB-01 (Commercial Water Heating)*
4. *C-CMB-02 (Commercial Space Heating)*

CARB's 2022 State SIP Strategy has proposed control measures for residential and commercial building space and water heating appliances, which would align with the South Coast AQMD 2022 AQMP Control Measures R-CMB-01 (Residential Water Heating), R-CMB-02 (Residential Space Heating), C-CMB-01 (Commercial Water Heating), and C-CMB-02 (Commercial Space Heating). CARB would design any such standard in collaboration with energy and building code regulators and with air districts to ensure consistency with all state and local efforts and would work carefully with communities to consider any housing cost or affordability impacts, recognizing that reducing emissions and energy demand from these appliances can generate cost-savings and health benefits with properly designed standards. For the cost estimate of control measures R-CMB-01 (Residential Water Heating), R-CMB-02 (Residential Space Heating), C-CMB-01 (Commercial Water Heating), and C-CMB-02 (Commercial Space Heating), this Socioeconomic Report relies on the CARB analysis. All cost assumptions for CARB measures can be found in the Proposed 2022 State Implementation Plan, Appendix A: Economic Analysis.

5. *R-CMB-03 (Residential Cooking Devices)*

R-CMB-03 would achieve NOx reductions from residential cooking devices by replacing conventional gas-fired cooking appliances with zero emissions and low NOx emissions devices such as electric cooking devices, induction cooktops, and low NOx burner technologies. The NOx reductions in this measure would be achieved through a combination of regulatory and incentive approaches. South Coast AQMD estimates 170,000 total cooking devices are installed or replaced each year in new and existing residential buildings within the South Coast Air Basin. The control measure proposes zero emissions devices for 50% of the applicable sources and low NOx burner technologies for the remaining 50% by 2037. Staff expects the first year of implementation to occur in 2029 and to continue through 2037 with 170,000 replacements and new installations per year. Implementation of this control measure can reduce NOx emissions from residential cooking appliances by 65% or 0.79 tons per day by 2037.[4]

The initial phase of R-CMB-03 is a technology assessment including testing of various cooking devices to establish emissions rates. Once emissions rates are defined, the next phase would be future rule development. Emissions limits would affect manufacturers, distributors, and installers. Future rule development would consider incentive funding to encourage use of zero and low NOx emissions technologies for future replacements and new installations of cooking equipment.

For the 50% of applicable sources implementing zero emissions cooking appliances, costs are based on the purchase of equipment for new installations and natural turnover of existing equipment. Induction cooktops have an incremental equipment cost of $840 compared to the gas-fired counterpart. Replacing gas-fired cooking appliances with electric cooking devices results in a cost savings of $270. Infrastructure costs vary depending on the type of equipment installed or replace, the age of the building, energy consumption, if an electric panel upgrade is required, and whether solar panels are installed to offset electrical costs. A 240V electrical outlet installation is assumed for existing buildings with equipment replacements and is estimated to cost about $150 each.[5] Currently, new construction and alterations of existing buildings are subject to the 2019 Title 24 energy code, which mandates these buildings to be electric-ready and to install solar panels. The use of solar panels can partially or fully offset the difference in electric utility costs compared gas utility rates. When compared with natural gas counterparts, the additional incremental utility costs range annually from $0 to $43 for electric cooking devices and from $0 to $35 for induction cooktops.

The remaining 50% of cooking appliances will be replaced with low NOx emissions technologies. Although low NOx burner technologies have been proven in demonstration, the technology is not yet widely available by manufacturers of residential equipment. No costs are available at the time of this analysis, but updated cost information will be pursued during rule development process and discussed at working group meetings.

[4] In 2018, residential cooking devices emitted 1.28 tpd of NOx and are projected to emit 1.21 tpd in 2037.
[5] Installations in existing residences may require electrical panel upgrades that range up to $2,000 per residence, but for the purposes of this analysis was not accounted for due to uncertainty in the number of residences requiring the upgrade.

TABLE 2A-1: COST ASSUMPTIONS FOR R-CMB-03

Equipment Name	Affected Industries (NAICS)	Commercial Electricity Cost per kWh	Per Unit Cost	Per Unit Incentive Amount	Number of units	Years of Equipment Life
Zero Emissions Cooking Devices	Residential Consumers (53)	$0.16	-$270 (savings)	--	42,500	12
Zero Emission Cooktops (induction stove)	Residential Consumers (53)	$0.16	$840	--	42,500	12
Induction Cooktop 240V Outlet	Residential Consumers (53)	--	$150	--	34,000	--

Note: The total quantified costs do not include not-yet-known costs for low NOx options.

The incremental cost is presented below in millions of 2021 dollars:

TABLE 2A-2: INCREMENTAL COSTS FOR R-CMB-03

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[6]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
R-CMB-03: Residential Cooking	2029	$371.6	$19.4

6. R-CMB-04 (Other Residential Combustion Sources)

Control measure R-CMB-04, as residential-others, seeks NOx emission reductions from residential combustion sources using natural gas and liquefied petroleum gas (LPG) that are not water heating (See R-CMB-01), space heating (See R-CMB-02) and cooking equipment (See R-CMB-03). R-CMB-04 sources are miscellaneous, but primarily comprised of swimming pool heaters, laundry dryers, and barbecue grills. Further study is needed to identify other equipment that would be subject to this control measure. Such a study should be included in future rulemaking efforts.

[6] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

Control measurer R-CMB-04 seeks NOx emission reductions from residential other combustion sources by: (1) requiring zero emission technologies through a regulatory approach for some emission sources in both new and existing residences; and (2) allowing near-zero and other lower NOx technologies as an alternative for the rest of emission sources. Mitigation fee may be required for certain lower NOx technology applications which will be evaluated during the future rulemaking process. The mitigation fee collected would be utilized as incentives to accelerate the adoption of zero emission units.

Although the currently available electric laundry dryers (electric resistance heating models) are considered zero NOx emission units, heat pump laundry dryers with a much higher energy efficiency would be the preferred zero-emission technology for incentives. The emerging zero emission technology for heating pools is the swimming pool heat pump. Heat pump pool heaters work efficiently if the outside temperature remains above the 45ºF–50ºF range. The warm climate of South Coast AQMD favors the application of pool heat pumps. With regards to gas grills, the electric-grill market is expected to continue to grow at an average rate of 7 percent a year. A regulatory approach would accelerate the turnover of some gas grills to zero emission grills.

With regards to lower NOx technologies, a low NOx limit may be feasible with current technology or further technology development. Natural gas pool heaters are subject to a 55 ppm NOx limit by Rule 1146.2. Staff reviewed source test results for Rule 1146.2 certifications conducted since 2017 and identified some models showing emissions at 10 to 20 ppm. As burner adjustment for cooking equipment (as proposed by control measure R-CMB-3) would lower the NOx emissions by 70 percent, this technology could potentially be applied to gas grills as well. Further evaluation during future rulemaking will be conducted.

In addition to a regulatory approach, incentives for the purchase and installation of zero emission technology or electric panel upgrade would be considered under this control measure not only for additional emission reductions, but also to encourage further development of future zero emission space heating technology for existing residential buildings. Collected mitigation fee and future allocated funding would be utilized for the incentives. More local agencies are now proposing incentives for retrofitting gas appliances, which may be funding sources for this control measure. For example, the City of Santa Monica is offering a $300-400 rebate for replacing a gas dryer with an electric heat pump clothes dryer, incentives to electric panel upgrade, and rebates to other zero emission appliances.

The target of this regulatory approach is to implement zero emission technologies for fifty percent of the applicable sources and implement lower NOx emission technologies in conjunction with a mitigation fee at the time of replacement for the remaining fifty percent by 2037. The near-zero and other lower NOx technologies could be an alternative to a zero emission requirement. The collected fee could be utilized in an incentive program to offset the emission reduction difference between near-zero and other lower NOx technologies and zero emission technologies.

To implement zero emission technologies for fifty percent of the applicable sources by 2037, ten percent would come from new buildings and forty percent from existing buildings starting in year 2029. Staff recognizes that a unit replacement for existing buildings may occur at the end of the unit lifetime, which creates a natural unit turnover. With an estimated average useful lifetime around 13 years, there would be more than forty percent natural turnover over an eight-year period by 2037 for existing buildings. Additional NOx emission reductions could be achieved with state and local incentive programs that have been launched or proposed. The South Coast AQMD will propose incentives to promote zero emission equipment and will also seek partnerships for implementing the incentives.

For lower NOx technologies in conjunction with a mitigation fee, the emission reductions are estimated based on its implementation for the remaining fifty percent of the sources by 2037, with a consideration of natural turnover by a 13-year average useful lifetime, and seventy percent reduction for each replacement.

With the Title 24 code update for the readiness of new building electrification, the implementation for new buildings could occur earlier (e.g., 2024) than that for existing buildings. However, for a conservative emission reduction estimation, the implementation start year for new buildings would also occur in 2029 as for older buildings.

The overall cost-effectiveness for this control measure will be refined during rulemaking. As this control measure covers miscellaneous sources mainly including laundry dryers, pool heaters, and grills, the cost of each individual source is discussed in this measure. A comprehensive analysis will be conducted during the rulemaking process to ascertain the emission reductions of each type of sources and therefore the final cost-effectiveness for this control strategy.

With regards to the cost of heat pump laundry dryer, the Home Depot website lists one heat pump laundry dryer (24 inch 3.88 cubic feet 240-volt white stackable electric ventless front load heat pump dryer) with a price of $1,094.67. On the same website, electric laundry dryers of equivalent size (3.5 cubic feet) are priced between $300 to $700, and a gas laundry dryer of similar size (5.9 cubic feet which is the smallest size for gas unit listed there) is around $800.

An incentive of $300 or more may offset the higher upfront cost of a heat pump laundry dryer, and thus promote its adoption. As mentioned earlier, some local agencies such as the City of Santa Monica is currently offering $300-400 rebate for each replacement with a heat pump laundry dryer.

Heat pump pool heaters cost more than gas pool heaters, but they typically have much lower annual operating costs because of their higher efficiencies. With proper maintenance, heat pump pool heaters typically last longer than gas pool heaters. Therefore, consumers will eventually save more money. The U.S. Department of Energy estimates the savings of $32 to $300 for every $1,000 in annual pool heating costs using a heat pump pool heater compared to using a gas pool heater.

On the other hand, gas pool heaters certified to meet the 55 ppm NOx limit have been tested at 10 to 20 ppm. This preliminary data indicates the feasibility of a 70 percent emission reduction. Because the reductions would be based on existing technology, the additional cost for lower NOx gas pool heaters technologies should be minimal.

With regards to grills, although gas grills are more popular, electric grills are increasing their market share by 7 percent each year. For the cost, there are websites (for example: barbecuegrillreview.com) stating the purchase cost of electric grills are cheaper, while there are some other websites (For example: diffen.com) stating gas grills are cheaper. Nevertheless, electric grills are a market acceptable technology that is a feasible zero emission solution. For lower emission grills, further evaluation would be required for its cost effectiveness.

Due to insufficient data, the costs for this measure are estimated by applying the weighted average cost-effectiveness of R-CMB-03 and CARB's Zero Emission Standard for Space & Water Heater measure for residential cooking to the 3.09 TPD emission reductions projected for this measure. The assumption is that the replacement equipment would typically have a 13-year equipment life.

Assumptions for cost estimation are listed in the table below:

TABLE 2A-3: COST ASSUMPTIONS FOR R-CMB-04

Source Categories	
Installation at new buildings – zero emission	▪ Implement zero emission for all new buildings. ▪ Start implementation in 2029 (could occur earlier). ▪ Cover ten percent of the universe by 2037. ▪ No additional cost for all electric heat pump installation, operation, and maintenance over its lifetime.
Installation at existing buildings – zero emission	▪ Implement zero emission for certain amount of existing buildings. ▪ Start implementation in 2029. ▪ Cover forty percent of the universe by 2037. ▪ Approximately $2,000 additional cost for electrical panel upgrade as compared to new buildings may be required for older buildings, however it could have been considered by R-CMB-01 or R-CMB-02 as a one-time panel upgrade would benefit all other control measures for residential appliances.
Installation at existing buildings – Other Technologies with Mitigation Fee	▪ Implement lower NOx technologies in conjunction with a mitigation fee. ▪ Start implementation in 2029. ▪ Cover the remaining fifty percent of the universe by 2037.
Incentives	▪ Incentivize heat pump installation and panel upgrade to lower the upfront cost in implementing zero emission at existing buildings. ▪ Funded by mitigation fee collected from implementing lower NOx technologies. ▪ Mitigation fee rate would be evaluated at future rulemaking process, based on the upfront cost difference between zero emission and other technologies.

Estimated Incremental Costs:

TABLE 2A-4: INCREMENTAL COSTS FOR R-CMB-04

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[7]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
R-CMB-04: Residential Other Combustion	2029	$2,588.9	$125.4

7. C-CMB-03 (Commercial Cooking Devices)

C-CMB-03 seeks to achieve NOx reductions from commercial cooking devices including fryers, ovens, stoves, griddles, broilers, and other appliances through a combination of regulatory and incentive approaches. Replacing existing gas burners with zero emissions and low NOx emissions appliances such as electric cooking devices, induction cooktops, or low NOx gas burners can reduce NOx emissions. In 2018, commercial cooking devices contributed 1.31 tons per day of NOx and are projected to emit 0.98 tons per day in 2037. Implementation of this control measure is expected to reduce NOx emissions by 65 percent by 2037, or 0.64 tons per day of NOx.

In contrast to the many studies that evaluate cost associated with the transition from gas to electric cooking devices in residential buildings, such information is more limited in the commercial cooking sector. Fisher-Nickel, Inc. (now Frontier Energy) conducted a study for the California Energy Commission (CEC) from 2008-2009 to characterize various commercial primary cooking equipment in California. The study identified nine major commercial cooking appliance categories and estimated that fryers, ovens, and ranges account for the largest shares of the commercial cooking inventory in the State.[8] The gas cooking equipment inventory within the South Coast Air Basin was estimated using 47 percent of the State's inventory.

The target of this control measure is to implement zero emissions technologies for 50 percent of the applicable sources and implement low NOx burner technologies for the remaining 50 percent by 2037. Staff expects the first year of implementation to occur in 2031. The initial phase of C-CMB-03 is a technology assessment including testing of various cooking devices to establish emissions rates of various cooking appliances. Once emissions rates for applicable appliances are defined, the next phase would be future rule development. Emissions limits would affect manufacturers, distributors, and installers. Future rule development would consider incentive funding to encourage use of zero and low NOx emissions technologies for future replacement and new installations of cooking equipment.

[7] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

[8] California Energy Commission, "Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment" [CEC-500-2014-095] (2014).

For the 50% of applicable sources implementing zero emissions cooking appliances, costs are based on the purchase of equipment for new installations and natural turnover of existing equipment. Costs for purchasing cooking appliances were obtained from distributors of restaurant supplies and equipment,[9][10] and were individually averaged for the fryers, ovens, and ranges categories. For the remaining cooking equipment categories, a weighted average was calculated. Equipment costs vary significantly based on equipment characteristics such as appliance type, burner output, and the number of burners, etc. Induction cooktops have an incremental equipment cost of $3,000 compared to the gas-fired counterpart. For ovens and fryers, switching from gas to electric appliances may add average one-time incremental equipment costs of $2,500 and $1,000, respectively. Other electric appliances may have incremental equipment cost savings due to their simple design and lower ongoing maintenance costs. Many advantages of electric appliances are not quantifiable, such as their easiness to use and clean, increased throughput, and safer work environment with no flames and less heat. Some older commercial buildings may require an electric panel upgrade with an estimated cost of approximately $4,000-$5,000 and/or a 240V outlet upgrade that could add a one-time incremental cost of $150 or more. For new buildings, electrical infrastructure is assumed to be sufficient.

The remaining 50% of cooking appliances will migrate to low NOx emissions technologies. Although low NOx burner technologies have been proven in demonstration, the technology is not yet widely available by manufacturers of commercial equipment. No costs are available at the time of this analysis, but updated cost information will be pursued during rule development process and discussed at working group meetings.

[9] https://www.webstaurantstore.com.
[10] https://www.restaurantsupply.com/commercial-cooking-equipment.

Incremental Costs:

TABLE 2A-5: COST ASSUMPTIONS FOR C-CMB-03

Equipment Name	Affected Industries (NAICS)	Per Unit Cost	Per Unit Incentive Amount	Number of units (total)	Years of Equipment Life	Number of units (annual turnover)
Zero Emission Cooking Devices (induction stoves)	Food Services and Drinking Places (722)	$3,000	--	22,500	15	1,500
Zero Emission Cooktops (fryers)	Food Services and Drinking Places (722)	$1,000	--	35,500	15	2,367
Zero Emission Cooktops (ovens)	Food Services and Drinking Places (722)	$2,500	--	31,000	15	2,067
Zero Emission Cooktops (other commercial cooking equipment)	Food Services and Drinking Places (722)	$-3,000	--	42,500	15	2,833
240V Outlet Upgrade	Food Services and Drinking Places (722)	$150	--	105,200	--	7,013
Electric Panel Upgrade	Food Services and Drinking Places (722)	$1,000	--	105,200	--	7,013

Note: The total quantified costs do not include not-yet-known costs for low NOx options.

The incremental cost is presented below in millions of 2021 dollars:

TABLE 2A-6: INCREMENTAL COSTS FOR C-CMB-03

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[11]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
C-CMB-03: Commercial Cooking	2031	$1,950.1	$71.8

[11] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

8. C-CMB-04 (Small Internal Combustion Engines – Non-Permitted)

C-CMB-04 is a control measure that seeks to use financial incentives and educational and outreach programs to reduce emissions from non-permitted internal combustion engines (ICEs) through replacement with zero or lower-emission technologies, where feasible. Electric and plug-in replacements for this type of equipment are generally widely available, though they may be more expensive. Improved technologies and the resulting future price reductions are anticipated to ease the transition from ICEs to zero-emission alternatives. These non-permitted ICEs are rated less than 50 brake horsepower and are not subject to South Coast AQMD regulations. Prior to developing an emissions reduction program, staff would work with CARB, other regulatory agencies, equipment manufacturers, and other stakeholders to refine the emissions inventory for non-permitted ICEs and costs for zero or lower-emission replacement technologies.

As this type of equipment is not permitted in South Coast AQMD, data for this source category is limited. For the purposes of this analysis, CARB's Small Off-Road Engines (SORE) database was used to estimate the equipment inventory. Five categories of small ICE-driven equipment from the SORE database were used to represent the entire population of non-permitted ICEs: welders, air compressors, pumps, generator sets, and pressure washers. To estimate the number of equipment operating in South Coast AQMD, the state-wide SORE equipment database was apportioned based on the population of South Coast AQMD. Based on the SORE equipment database for South Coast AQMD, it is estimated that approximately 60% of the pieces of equipment in the above categories would be able to be replaced with zero-emission technologies, due to the availability of these types of equipment. Equipment replacement would begin in 2033.

TABLE 2A-7: COST ASSUMPTIONS FOR C-CMB-04

Source Category	
Replacement of Small ICE-Driven Equipment	▪ The range of costs for electric/plug-in equipment are assumed to be: ○ $4,000 to $6,200 for a welder ○ $2,000 for a small air compressor ○ $600 to $2,100 for a pump ○ $7,000 to $24,000 for a battery energy storage system ○ $2,800 to $9,200 for a pressure washer ▪ Equipment life is estimated to be 15 years.

Estimated Incremental Costs:

TABLE 2A-8: INCREMENTAL COSTS FOR C-CMB-04

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[12]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
C-CMB-04: Small Internal Combustion Engines (Non-Permitted)	2033	$3,720.3	$122.5

9. C-CMB-05 (Small Miscellaneous Commercial Combustion Equipment – Non-Permitted)

Control measure C-CMB-05 seeks emission reductions of NOx by replacement with zero and Low NOx emission technologies on miscellaneous unpermitted combustion equipment. This equipment is less than 2 million Btu/hr thus not requiring a South Coast AQMD permit in most instances. Such equipment includes ovens, furnaces, dryers, and other fuel combustion equipment too small to require a permit. The manufacturing and deployment of zero and near-zero emission technologies will help reduce criteria pollutant emissions in the region, accelerate removal of higher-emitting equipment that can otherwise last for many decades, and advance economic development and job opportunities in the region.

This control measure will achieve reductions through point-of-sale regulations, incentives, and reassessment of permit and source specific exemption thresholds. Point-of-sale regulations can be established to require manufacturers of miscellaneous combustion equipment to modify the design to reduce NOx. When equipment was naturally replaced, emissions from the source category would be reduced over time. Incentives could be provided to accelerate the transition to reduced NOx equipment or to equipment that are powered electrically.

Assuming a natural gas price of $8.4 per million Btu and electricity price of $21 per million Btu, additional operational costs are estimated to be approximately $12.2 per million Btu for electrification[1]. Assuming a 1.0 million Btu/hr device is operated eight hours per day, emissions reductions would be 1.6 pounds per device at an additional daily cost of $98 dollars. For 8,500 devices, total additional annual operational costs would be $304.0 million and emission reductions would be 1,551 tons of NOx. Cost effectiveness would be $110,000 per ton of NOx reduced.

[12] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur beyond 2037.

Assumptions for cost estimates of electrification are listed in the table below:

TABLE 2A-9: COST ASSUMPTIONS FOR C-CMB-05

Source Categories	
Replacement of Ovens, Dryers Furnaces, Kilns, and other small fuel combustion equipment	▪ Approximately 8,500 unpermitted ovens, dryers, furnaces, kilns, and other small fuel combustion equipment could be replaced with low NOx or zero-emission equipment. ▪ Equipment life is expected to be 25 years. ▪ No additional capital cost. ▪ Additional operational cost of $12.2 per million Btu (assuming a natural gas price of $8.4 per million Btu and electricity price of $21 per million Btu). ▪ Assuming a 1.0 million Btu/hr device is operated eight hours per day, emissions reductions would be 1.6 pounds per device at an additional daily cost of $98 dollars. ▪ For 8,500 devices, total additional annual operational costs would be $304.0 million. ▪ Cost effectiveness would be $110,000 per ton of NOx reduced.

Estimated Incremental Costs:

TABLE 2A-10: INCREMENTAL COSTS FOR C-CMB-05

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[13]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
C-CMB-05: Miscellaneous Small Commercial Combustion Equipment (Non-Permitted)	2033	$3,489.1	$110.2

10. L-CMB-01 (NOx RECLAIM (formerly CMB-05))

Control Measure L-CMB-01 proposes to reduce NOx emissions by transitioning NOx RECLAIM facilities to a command-and-control regulatory structure requiring Best Available Retrofit Control Technology (BARCT) level controls. This control measure targets NOx emissions from source categories of metal melting and heating furnaces, food ovens, and nitric acid tanks. Emission reductions and costs are based on the following BARCT-based rules:

[13] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

I. Rule 1147.2 – NOx Reductions from Metal Melting and Heating Furnaces (adopted April 1, 2022)
II. Proposed Amended Rule 1153.1 – Emissions of Oxides of Nitrogen from Commercial Food Ovens (PAR 1153.1)
III. Proposed Rule 1159.1 – Control of NOx Emissions from Nitric Acid Tanks (PR 1159.1)

Metal melting and heating furnaces operated at existing RECLAIM facilities are expected to require selective catalytic reduction (SCR) equipment or Low-NOx burners to achieve the proposed NOx emission limits in recently adopted Rule 1147.2. The estimated cost-effectiveness for this control measure is $10,000 per ton of NOx reduced.

In addition to the cost associated with equipment, capital costs included a one-time permitting fee of $4,600 per unit, based on the 2019-2020 Fee Schedule identified in Rule 301 Table 1B which ranges in size from Schedule B for Metal Heat Treating Furnaces to Schedule D for Metal Melting Reverberatory Furnaces. Periodic source testing costs were included and based on a source test frequency of three or five years, determined by the rated heat input and annual BTU usage of the unit, at a cost of $3,000 per source test per furnace over 35 years of assumed burner useful life, or over 25 years of assumed SCR useful life. A one-time cost of $190,000 for a NOx Continuous Emissions Monitoring System (CEMS) was included for cost-effectiveness analyses of SCR installation for those units without a NOx CEMS installed. A one-time cost of $60,000 for a NOx feed-forward analyzer was included for cost-effectiveness analyses of SCR installation for units with batch processes as opposed to steady-state processes.

Low NOx Burner Retrofit Costs for Units < 40 MMBtu/hr
The burner equipment and installation costs were averaged across all units listed in the burner retrofit quote and used to establish a burner retrofit cost curve, shown in Equation 1:

Retrofit Cost ($) = $4,121 * (Rated Heat Input: MMBtu/hr) + $96,921 (Equation 1)

Where retrofits are required sooner than the burners' useful life of 35 years, stranded asset costs are also included in overall compliance costs. These stranded asset costs are based on a ratio of the remaining useful life of the burners to the maximum useful life of 35 years multiplied by the burner retrofit formula in Equation 1.

For all units, regardless of whether burner costs are taken into account or excluded due to units' burner ages exceeding 35 years old, the administrative costs of periodic source testing and one-time permitting are included. No additional costs for ongoing maintenance are assumed relative to a unit's current burners.

SCR Installation Costs for Units ≥ 40 MMBtu/hr
Staff utilized the U.S. EPA's SCR Cost Manual to estimate costs for SCR installation for units in this category. Costs include SCR equipment, electricity, reagent, catalyst, maintenance, and administration. The costs of a NOx CEMS analyzer and a NOx feed-forward analyzer were also added to those costs in the SCR Cost Manual, where applicable depending on whether the unit is already equipped with a NOx CEMS or whether the unit uses a steady-state or batch process.

Cost assumptions:

TABLE 2A-11: COST ASSUMPTIONS FOR L-CMB-01

Equipment Name	Capital and Installation Costs (Millions)	Total O&M Costs (Millions)	Years of Equipment Life
Metal Melting Furnaces	$10.91	NA	35
Metal Heat Treating Furnaces (≤1200°F)	$1.53	NA	35
Metal Heat Treating Furnaces (>1200°F)	$2.64	NA	35
Metal Heating and Forging Furnaces (≤1200°F)	$0.94	NA	35
Metal Heating and Forging Furnaces (>1200°F)	$4.35	NA	35
PR 1147.2 Units with Radiant-Tube Burners	$0.72	NA	35
PR 1147.2 Units ≥40 MMBtu/hr	$10.58	$3.37	25
Commercial Food Ovens	TBD	TBD	TBD
Nitric Acid Tanks	TBD	TBD	TBD

Estimated Incremental Costs:

TABLE 2A-12: INCREMENTAL COSTS FOR L-CMB-01

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[14]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
L-CMB-01: NOx RECLAIM	2033	$25.7	$0.7

11. L-CMB-02 (Boilers and Process Heaters – Permitted)

Control measure L-CMB-02 seeks emission reductions of NOx by replacement or retrofits with zero and low NOx emission technologies on boilers and process heaters with a rated heat input greater than or equal to 2 million BTU/hour which are currently regulated under Rules 1146 and 1146.1. L-CMB-02 is designed to maximize emission reductions utilizing zero emission technologies where and when technically feasible and cost-effective, and low NOx emission technologies in all other applications. This control measure will achieve the committed NOx emission reductions through a combination of regulations and incentives. Currently, zero emission technologies are limited to specific operations and

[14] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

are not feasible or cost-effective for all combustion sources. The strategy for this control measure is to conduct future technology assessments in hopes that technological advances will help to overcome current limitations.

Zero Emission Technologies
For zero emissions technologies, a technology assessment will be needed to better understand what stationary sources will be able to implement zero emission technologies. Currently, zero emission technologies are limited to specific operations and are not feasible or cost-effective for all combustion sources. Large scale implementation of zero emission technologies is also impacted by the higher electricity operating costs for large units.

Low NOx Emission Technologies
Burner technologies such as Low-NOx burner systems (LNB) or ultra-low NOx burner systems (ULNB) are combustion control technologies utilized to lower NOx emissions. A variety of factors impact the NOx emissions with LNB or ULNB, such as burner orientation and arrangement, firebox size, heater type (force or natural draft), and fuel type. Dependent on the burner configuration and operation, additional combustion controls are used to reduce NOx emissions, such as fuel and air premix, staged fuel, staged air, and flue gas recirculation. Several commercially available burner control technologies can be utilized on existing and new boilers and process heaters that can meet a NOx limit below 5 ppmv without the need to add post-combustion control equipment. These emerging burner control technologies will become more widely available at lower costs and be considered when setting new regulatory standards. Ultra-low NOx burner replacement costs are taken from cost estimates from Proposed Amended Rule 1146. Equipment cost is determined using the equation: $5,800x + $9,600 where x = heat input in million Btu/hr. Installation cost is determined using the equation: $1,700x + $25,800 where x = heat input in million Btu/hr. Equipment life is expected to be 25 years. No changes are expected for operational costs.

Selective Catalytic Reduction (SCR) is a well-established and commonly utilized post-combustion control technology that is commercially available to control NOx emissions from boilers and process heaters. NOx emissions are reduced with SCR by converting NOx in the flue gas into nitrogen and water with ammonia over a catalyst. Depending on the operating conditions, SCR can be utilized as a single stage control technology or combined with additional NOx controls, such as ULNB, for further reductions. SCR operating costs are based on the Final Staff Report for the 2019 amendments to Rule 1134. Staff used the U.S. EPA's Air Pollution Control Cost Estimation Spreadsheet for Selective Catalytic Reduction to estimate SCR costs. Equipment life is expected to be 25 years.

Assumptions for cost estimates of LNB installation are listed in the table below:

TABLE 2A-13: COST ASSUMPTIONS FOR L-CMB-02

Source Categories	
Zero Emission Technologies	▪ Future technology assessment.
Low NOx Emission Technologies	▪ Low-NOx and ultra-low NOx burner systems utilizing cost assumptions from Proposed Amended Rule 1146. ▪ Equipment cost is determined using the equation: $5,800x + $9,600 where x = heat input in million Btu/hr. Installation cost is determined using the equation: $1,700x + $25,800 where x = heat input in million Btu/hr. Equipment life is expected to be 25 years. No changes are expected for operational costs. ▪ Selective Catalytic Reduction utilizing U.S. EPA's Air Pollution Control Cost Estimation Spreadsheet for Selective Catalytic Reduction. ▪ SCR operating costs are based on the Final Staff Report for the 2019 amendments to Rule 1134. Staff used the U.S. EPA's Air Pollution Control Cost Estimation Spreadsheet for Selective Catalytic Reduction to estimate SCR costs. Equipment life is expected to be 25 years.

The overall average cost-effectiveness for this control measure is $865,000 per ton of NOx reduced.

Estimated Incremental Costs:

TABLE 2A-14: INCREMENTAL COSTS FOR L-CMB-02

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[15]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
L-CMB-02: Large Boilers and Process Heaters	2033	$2,578.9	$73.4

12. L-CMB-03 (Non-Emergency Internal Combustion Equipment – Permitted)

Control measure L-CMB-03 targets NOx emission reductions from permitted, non-emergency internal combustion engines rated over 50 bhp. Engines subject to this control measure are regulated under Rule 1110.2 – Emissions from Gaseous- and Liquid-Fueled Engines. Rule 1110.2 limits NOx emissions to 11 ppm, corrected to 15% O_2, dry for most engines with few exceptions.

Control measure L-CMB-03 recognizes NOx emission reductions from the transition of higher NOx

[15] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

emitting engines in the RECLAIM program that are not subject to the emission limits established in Rule 1110.2. Additional reductions can be harvested from low NOx and zero emission technologies that are expected to be widely available in the future. Low NOx emission technologies include linear generator technology and installation of exhaust controls such as Selective Catalytic Reductions (SCRs) for lean-burn engines or enhanced 3-way catalysts for rich-burn engines. In addition, where appropriate, conversion to battery cells and the electrification of engines are other options for owners and operators of these engines.

As permitted, non-emergency engines transition from the RECLAIM program to a command-and-control regulatory structure, the NOx emission reductions are estimated to be 0.29 tpd and the cost-effectiveness was calculated to be $321,500 per ton of NOx reduced. Currently, the NOx emissions limit is set at 11 ppm, corrected to 15% O_2, dry for most engines with few exceptions. As technology is developed to lower emission levels and the technology becomes commercially viable, the NOx limit may be reduced.

Staff has identified the following distribution of engines and facilities per industrial disposition:

TABLE 2A-15: DISTRIBUTION OF ENGINES AND FACILITIES PER INDUSTRIAL DISPOSITION

NAICS Code	Number of Engines	Number of Facilities
221112	175	81
221117	2	1
221310	162	74
221320	10	3
486210	33	4
Total	382	163

There are two general engine types currently in service: lean-burn and rich-burn. Based on their operational characteristics, it is anticipated that two different exhaust emission controls would be utilized per engine type.

TABLE 2A-16: TECHNOLOGY AND ASSUMPTIONS PER ENGINE-TYPE

Source Categories		
Engine Type	***Technology***	***Assumptions***

Lean-Burn Engines	SCR	▪ Equipment life assumed to be 25 years.
		▪ Recurring costs include:
		  ▪ Catalyst replacement
		  ▪ Reagent costs

Rich-Burn Engines	3-Way Catalyst	▪ Equipment life assumed to be 25 years. ▪ Recurring costs include: ▪ Catalyst costs

It is unknown the distribution of lean-burn versus rich-burn engines. However, staff utilized the costs identified during the 2019 Rule 1110.2 amendment process to estimate the capital costs and recurring costs should engines be retrofitted to meet possible lower emission targets.

Capital Cost Assumptions:

TABLE 2A-17: CAPITAL COST ASSUMPTIONS FOR L-CMB-03

Engine Type	Technology	Per Unit Cost	Years of Equipment Life
Lean-Burn Engines	SCR	$387,482	25
Rich-Burn Engines	3-Way Catalyst	$34,830	25

Recurring Cost Assumptions:

TABLE 2A-18: RECURRING COST ASSUMPTIONS FOR L-CMB-03

Technology	Technology	Per Unit Cost	Frequency (Years)
Lean-Burn Engine	SCR – Catalyst	$108,750	5
	SCR – Reagent	$8,820	1
Rich-Burn Engine	3-Way Catalyst	$31,330	3-5

The cost-effective analysis is only a demonstration for potential emission reductions through costs for replacement/retrofit or control equipment currently available. Upon implementation and formation of a working group, new zero and near-zero emitting technologies such as linear generators, battery cells and electrification of engines could be identified as well as other sources for potential NOx reductions.

For zero emissions technologies, a technology assessment will be needed to better understand what stationary sources will be able to implement zero emission technologies. Currently, zero emission technologies are limited to specific operations and are typically not feasible or cost-effective for engines regulated by Rule 1110.2. Large scale implementation of zero emission technologies is also impacted by the higher electricity operating costs for large units. As part of this control measure, a 10% inclusion for zero emission technology was added. The cost for zero emission technology was based on analysis conducted for L-CMB-06 for hydrogen fuel cells and then scaled to a comparable engine size.

Estimated Incremental Costs:

TABLE 2A-19: INCREMENTAL COSTS FOR L-CMB-03

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[16]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
L-CMB-03: Large Internal Combustion Prime Engines	2033	$665.2	$14.9

[16] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

13. L-CMB-04 (Emergency Standby Engines – Permitted)

L-CMB-04 is a control measure designed to reduce NOx emissions from emergency standby internal combustion engines (ICEs) using regulatory actions. Emissions reductions are achieved primarily by replacement of older ICEs in the South Coast AQMD and by requiring the use of commercially available lower emission fuels, such as renewable diesel. Facilities replacing ICEs would be required to install zero emission or near-zero emission equipment, such as battery energy storage systems (BESSs) or fuel cells where feasible. If these technologies are unavailable, facilities would be required to install the cleanest ICEs available. As newer technologies become more commonplace and costs decline, it is anticipated that it will be more feasible for facilities to replace ICEs with alternative technologies. A formal rulemaking process would include a cost-effectiveness assessment based on replacement equipment costs and emissions reductions. Staff anticipates many facilities and stakeholders will participate in a formal rulemaking process and contribute to determining the most cost-effective means for phasing out the oldest ICEs in the South Coast AQMD.

South Coast AQMD's tool for the annual emission reporting (AER) program requires reporting emissions at permit unit/equipment/device levels. The reporting tool classifies the type of emission source and requires fuel type, throughput, pollutant, and emission factors. Staff used the AER program data along with the South Coast AQMD CLASS permitting system to identify older and higher emitting ICEs that could be affected by this control measure. There are approximately 5,500 older diesel ICEs that were permitted before 2003 and are expected to be higher emitting.

L-CMB-04's cost analysis was conducted based on replacing older ICEs with BESSs or fuel cells. A cost-effectiveness assessment would be conducted to determine the types of facilities where alternative technologies would be more suitable and to evaluate updated costs as these technologies become more prevalent. The costs for BESSs are estimated based on the battery capacity that would be set aside for emergency use (i.e. not the capacity of the entire system if batteries are also used for energy management like peak shaving). Depending upon a facility's individual backup power needs, BESS costs may vary greatly from the overall cost estimates provided.

TABLE 2A-20: COST ASSUMPTIONS FOR L-CMB-04

Source Category	

Replacement of Tier 1 and older Diesel ICEs	▪ The range of equipment costs are assumed to be:
	  ▪ $630/kWh to $680/kWh for the emergency use portion of a BESS
	  ▪ $4,300/kW to $4,500/kW for hydrogen fuel cells
	  ▪ $2,000/kW to $2,200/kW for natural gas fuel cells
	▪ Equipment life is expected to be 25 years.

Estimated Incremental Costs:

TABLE 2A-21: INCREMENTAL COSTS FOR L-CMB-04

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[17]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
L-CMB-04: Large Internal Combustion Emergency Standby Engines	2033	$7,469.7	$153.3

14. L-CMB-05 (NOx Emission Reductions from Large Turbines)

Control Measure L-CMB-05 proposes to reduce NOx from turbines in the South Coast AQMD subject to Rule 1134 – Emissions of Oxides of Nitrogen from Stationary Gas Turbines (Rule 1134). Fuel cells and electrification are technologies that can be used to shift away from combustion sources generating NOx emissions wherever feasible. As older higher emitting turbines reach the end of their equipment life, it is expected that some facilities will opt to replace turbines with fuel cells or electrify facility operations.

The estimated cost-effectiveness for this control measure is $724,000 per ton of NOx reduced. The estimated cost of this control measure is the difference between the cost of turbine replacement with selective catalytic reduction (SCR) and replacement of turbines with fuel cells. Staff assumed approximately 65 MW of power to be needed when assuming costs for turbine replacement and fuel cells; 65 MW is approximately 10% of the total wattage for Rule 1134 units. Staff assumes 10% of emission reductions from L-CMB-05 will be from zero emission technologies. Staff assumes a 25-year equipment life for fuel cells and for turbines with SCR.

Turbine Replacement and SCR

The cost assumptions for turbine replacement are based on the Final Socioeconomic Assessment for the 2018 amendments to Rule 1135. Staff used the September 2017 Catalog of CHP Technologies, U.S. EPA Combined Heat and Power Partnership to establish turbine replacement costs. For one 20 MW natural gas turbine, staff assumed a capital cost of $19.8 million in equipment cost and $10.2 million in construction and development fees. For one 44 MW natural gas turbine, staff assumed a capital cost of $35.8 million in equipment cost and an additional $17.4 million in construction and development fees.

SCR operating costs are based on the Final Staff Report for the 2019 amendments to Rule 1134. Staff used the U.S. EPA's Air Pollution Control Cost Estimation Spreadsheet for Selective Catalytic Reduction to estimate SCR costs. A turbine rated 43.8 MW had an estimated SCR operating cost of $0.43 million and a turbine rated 21.8 MW had an estimated SCR operating cost of $0.30 million.

[17] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

Fuel Cells

The cost assumptions for fuel cells are based on a vendor quote for 440 kW fuel cells. Staff assumed that approximately 149 440 kW fuel cells are needed to produce 65 MW in power. Staff assumed a capital cost of $1.6 million per unit, an installation cost of $300,000 per unit, and a service contract of $50,000 per year for 2 facilities. Staff assumed a fuel switching cost from natural gas to hydrogen of approximately $131,000 annually per fuel cell.

Cost assumptions:

TABLE 2A-22: COST ASSUMPTIONS FOR L-CMB-05

Equipment Name	Capital and Installation Costs (Millions)	Total O&M Costs (Millions)	Years of Equipment Life
Fuel Cells	$283.27	$19.62	25
Turbine Replacement and SCR	$83.20	$0.73	25

Estimated Incremental Costs:

TABLE 2A-23: INCREMENTAL COSTS FOR L-CMB-05

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[18]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
L-CMB-05: Large Turbines	2037	$281.5	$2.1

15. L-CMB-06 (NOx Emission Reductions from Electricity Generating Facilities)

This control measure seeks NOx emission reductions from electric generating units regulated by Rule 1135 - Emissions of Oxides of Nitrogen from Electricity Generating Facilities (Rule 1135). L-CMB-06 will focus on assessing near-zero and zero emission technologies for power generation as well as other NOx combustion emission reduction technologies. This measure proposes to implement near-zero and zero emission technologies through a regulatory approach at electricity generating facilities.

The overall cost-effectiveness for this control measure is estimated based on the following emission reduction strategies:

- Replacement of 100 percent of boiler sources expected to continue operating after January 1, 2024, with lower-emitting turbines;
- Replacement of 10 percent of gas-fired turbine sources with zero emission fuel cells;

[18] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

- Retrofit of 90 percent of gas-fired turbine sources with new, more-efficient Selective Catalytic Reduction (SCR) systems; and
- Replacement of 40 percent of diesel internal combustion engine sources with near-zero emission fuel cells.

Replacement of Boilers with Lower-Emitting Turbines

Staff estimates that one 45 MW natural gas turbine to replace a MW-equivalent natural gas boiler has capital costs of $35.8 million in equipment costs and $17.4 million in construction and development fees[1]. Staff also estimates that one 200 MW natural gas turbines to replace a MW-equivalent natural gas boiler has capital costs of $86.6 million in equipment costs and $51.9 million in construction and development fees[1]. Recurring costs include: for 45 MW turbines, $10,000 per year in increased ammonia usage and $39,000 every three years in increased catalyst usage; and for 200 MW turbines, $55,000 per year in increased ammonia usage and $215,000 every three years in increased catalyst usage.[2] The incremental cost assumes the cost increase from the boilers installing and operating SCR.

SCR Retrofit

Staff estimates that retrofit of one 30 MW natural gas turbine with new, more efficient SCR system has capital costs of $439,000 in equipment costs, $1.1 million in installation costs, and $165,000 in spent catalyst disposal and administrative fees.[2] Recurring costs for the new SCR system include $1,400 per year in increased ammonia usage and $55,000 every five years for increased catalyst usage.[2] The incremental cost assumes the cost increase from recurring annual ammonia usage and catalyst replacement every 3 years for existing SCR systems.

Zero Emission Fuel Cells

With ten percent of power provided by gas-fired turbines being approximately 1,000 MW, approximately 2,273 440-kW fuel cells (or equivalent level of fuel cells providing this level of power) would be needed as replacement. Staff estimates that one 440-kW fuel cell has capital costs of $1.6 million in equipment costs and $300,000 in installation costs, and recurring cost of $50,000 per year for a service contract for an estimated four facilities.[19] Recurring hydrogen fuel costs to run the fuel cells at 48% efficiency (67 kilograms hydrogen gas per Megawatt-hour) has an incremental cost increase of approximately $213,000, which assumes per kilogram hydrogen cost of $6.50 compared to per MMBtu natural gas cost of $3.22[20] and Megawatt-hours (MWh) generated of approximately 1,200,000 from 1,000 MW worth of randomly sampled existing gas-fired turbines. Overall incremental cost also assumes the cost increase from turbine replacements with fuel cells.

Low NOx Fuel Cells

For an electricity generating facility operating diesel internal combustion engines for primary power, with forty percent of power provided by the engines being 3.8 MW, approximately nine 440-kW would be needed as replacement. Staff estimates the same capital and recurring costs for one fuel cell as previously stated for the zero-emission fuel cell. Recurring natural gas costs to run the fuel cells at 45% efficiency has an incremental cost savings of approximately $78,250, which assumes per MMBtu natural gas cost of

[19] Vendor estimate.

[20] https://www.eia.gov/dnav/ng/ng_cons_heat_a_EPG0_VCOH_btucf_a.htm.

$16.93 compared to per MMBtu diesel gas cost of $18.93[21] and Megawatt-hours (MWh) generated of approximately 12,000 from 3.8 MW worth of diesel engines. Overall incremental cost also assumes the cost increase from diesel engine replacements with fuel cells.

Cost assumptions:

TABLE 2A-24: COST ASSUMPTIONS FOR L-CMB-06

Equipment Name	Affected Industries (NAICS)	Capital and Installation Costs (Millions)	Total O&M Costs (Millions)	Number of Units	Years of Equipment Life
Turbines for Boiler Replacement (45 MW)	Electric Utilities	$106.4	$1.2	2	25
Turbines for Boiler Replacement (200 MW)	Electric Utilities	$554	$12.6	4	25
SCR Retrofit	Electric Utilities	$64.8	$11.33	38	25
Zero Emission Fuel Cells	Electric Utilities	$4,318.7	$521	2,273	25
Near Zero Emission Fuel Cells	Electric Utilities	$17.1	$1.53	9	25

The incremental cost is presented below in millions of 2021 dollars:

TABLE 2A-25: INCREMENTAL COSTS FOR L-CMB-06

Control Measure	Present Value of Remaining Incremental Cost	Present Value of Incentives	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[22]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
L-CMB-06: Electric Generating Facilities	$8,457.1	$0	2033	$8,457.1	$267.1

16. L-CMB-07 (Petroleum Refineries)

Control measure CMB-07 seeks a 20 percent NOx emission reduction from petroleum refineries, primarily from large boilers and process heaters, e.g., units with a maximum rated heat input of 40 MMBtu/hr or larger, as they account for nearly 64 percent of the NOx emissions from petroleum refineries. Refinery

[21] https://www.nrel.gov/docs/fy21osti/76779.pdf.
[22] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

boilers and process heaters are currently regulated under Rule 1109.1 – Emissions of Oxides of Nitrogen from Petroleum Refineries and Related Operations with a NOx limit of 5 ppmv corrected to 3 percent O_2 dry basis for most units. CMB-07 seeks further NOx emissions reductions from these large sources using next generation ULNB, advanced SCR design, and zero-emission technologies.

Control measure L-CMB-07 seeks NOx emission reductions from boilers and process heaters with a rated heat input greater than or equal to 40 MMBtu/hr located at petroleum refineries and will focus on:

- Next Generation Ultra-Low NOx Burners
- Advanced Selective Catalytic Reduction (SCR) systems
- Transition to Zero-Emission Technology

NOx Control technologies used for refinery boilers and process heater applications can be separated into two control techniques: combustion control and post-combustion control. Each control technique will have different degrees of costs, with post-combustion control costing considerably more. Combustion control focus on reducing NOx at the point of formation by reducing the peak flame temperature utilizing various techniques to cool the flame. Combustion control technologies such as ultra-low NOx burners (ULNB) and low-NOx burners (LNB) have been in use for more than 30 years. The technology has evolved and improved to the point where the performance can achieve single digit NOx numbers. Single digit NOx numbers are typically achievable with only post combustion control modifications such as SCR; however, with the advancement of next- generation ULNBs, burner technology can also achieve very low NOx numbers. The cost-effectiveness analysis for CMB-07 focuses on next-generation ULNBs as the primary control technology to achieve further reductions. The other two NOx control options using advanced SCR systems and transition to zero-emission technology will require further assessment at time of rulemaking due to the associated complexities.

Assumptions for cost estimation are listed in the table below:

TABLE 2A-26: COST ASSUMPTIONS FOR L-CMB-07

Source Categories	
Next-Generation Ultra-Low NOx	▪ Existing process heaters greater than or equal to 40 MMBtu/hour retrofitting to next-generation ultra-low NOx burner technology. ▪ Cost of next-generation ultra-low NOx burners quote received form vendor. ▪ Addition of three times contingency to quote from vendor to estimate installation cost. ▪ Burner retrofit cost from vendor was for removal and installation and connection only. Contingency needed to account for third party engineering, procurement, and construction (EPC) – petroleum refineries typically use EPC companies for large capital projects. In addition, refineries are required to hire unionized labor for construction projects so the contingency accounts for the increased cost. ▪ Equipment life assumed to be 25 years. ▪ No additional upkeep or maintenance costs when compared to existing burners.
Second Selective Catalytic Reduction Reactor System	▪ Addition of secondary SCR reactor to existing SCR systems that have already been implemented for Rule 1109.1. ▪ Assessment will need to be conducted at future rulemaking to determine cost-effectiveness and assess feasibility.
Transition to Zero-Emission	▪ Transition to zero emission utilizing electric process heaters and Rondo Energy heat battery system for boilers used in steam generation. ▪ Assessment will need to be conducted at future rulemaking to determine cost-effectiveness and assess feasibility.

Capital Cost Assumptions:

TABLE 2A-27: CAPITAL COST ASSUMPTIONS FOR L-CMB-07

Equipment Name	Affected Industries (NAICS)	Per Unit/Facility Cost	Number of Facilities	Years of Equipment Life
Ultra-Low NOx Burners	Petroleum Refinery	$2,800,000 to $3,000,000	7	25
Selective Catalytic Reduction System	Petroleum Refinery	TBD	7	25
Transition to Zero-Emission	Petroleum Refinery	TBD	7	25

Recurring Cost Assumptions

TABLE 2A-28: RECURRING COST ASSUMPTIONS FOR L-CMB-07

Equipment Name	Affected Industries (NAICS)	Per Unit/Facility Cost	Frequency	Number of Facilities
Ultra-Low/Low NOx Burner Emissions	Petroleum Refinery	$2,000	Every Year	7

Estimated Incremental Costs:

TABLE 2A-29: INCREMENTAL COSTS FOR L-CMB-07

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[23]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
L-CMB-07: Petroleum Refining	2033	$239.2	$7.6

17. L-CMB-08 (NOx Emission Reductions from Combustion Equipment at Landfills and Publicly Owned Treatment Works)

Control Measure L-CMB-08 proposes to reduce NOx emissions through a regulatory approach. The source category for this control measure is biogas fueled combustion equipment – specifically boilers and turbines – regulated by Rule 1150.3 – Emissions of Oxides of Nitrogen from Combustion Equipment at Landfills (Rule 1150.3) and Rule 1179.1 – Emission Reductions from Combustion Equipment at Publicly Owned Treatment Works Facilities (Rule 1179.1). The cost effectiveness of L-CMB-08 is approximately $79,000 per ton of NOx reduced.

Low NOx Burners for Digester Gas Boilers

Staff assumed a 15-year equipment life for low-NOx burners. Existing burners will have reached the end of useful life by 2037 and are expected to be replaced. Staff did not assume any additional costs.

Selective Catalytic Reduction (SCR) and Enhanced Gas Treatment for Digester Gas Turbines

The cost assumptions for SCR and enhanced gas treatment are based on the cost analysis contained in the Final Staff Report of Rule 1179.1. Staff assumed a 25-year equipment life for SCR and enhanced gas treatment. SCR costs were obtained from facilities, U.S. EPA's Air Pollution Cost Estimation Spreadsheet for Selective Catalytic Reduction, two engineering consultants, one catalyst supplier, and applicable costs from the Rule 1110.2 cost analysis for SCR (2012 Technology Assessment). The costs for SCR considered retrofitting three turbines that currently do not utilize SCR.

[23] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

Biogas combustion equipment utilizing SCR requires enhanced gas treatment to protect the SCR catalyst from entrained contaminants such as siloxanes. Costs for gas treatment were obtained from POTWs and landfills within California. Costs reflect gas treatment systems designed to remove siloxanes to < 100 ppb from gas streams that have reported inlet siloxane levels of < 15 ppm. The data used to determine cost-effectiveness to meet 5 ppm at 15 percent oxygen on a dry basis was identified for a gas treatment system that requires treatment of 6,000 scfm of digester gas. The capital cost was $26,250,000 and the annual O&M costs were $250,000.

Turbine Replacement

Staff assumed a 25-year useful life for turbines. Existing turbines rated ≥ 0.3 MW with post- combustion control and firing ≥ 75% landfill gas will have reached the end of their useful life by 2037 and are expected to be replaced. Staff did not assume any additional costs for landfill gas turbine replacement.

The cost-effectiveness for L-CMB-08 includes 5 years of stranded asset costs for 3 digester gas turbines that will not have reached their useful life by 2037. The cost assumptions for turbine replacement for digester gas turbines are based on the cost analysis contained in the Final Staff Report of Rule 1179.1. Costs for new turbines that can meet 15 ppm at 15 percent oxygen on a dry basis were obtained from the U.S. EPA Catalog of CHP Technologies. The U.S. EPA Catalog of CHP Technologies estimates capital costs for new turbines at $1.2 - $1.5 million per megawatt, and annual costs at $0.0092-$0.0093 per kilowatt-hour. The three turbines currently equipped with SCR have a power output capacity of 41.85 MW. The capital cost at $1.5 million/MW is $62,800,000. The annual cost at $0.0093/kwh is $3,400,000.

Cost assumptions:

TABLE 2A-30: COST ASSUMPTIONS FOR L-CMB-08

Equipment Name	Affected Industries (NAICS)	Capital and Installation Costs (Millions)	Total O&M Costs (Millions)	Years of Equipment Life
Rule 1179.1 Boilers with Low NOx Burners	221320	$0	$0	15
Rule 1179.1 Turbines with SCR and Enhanced Gas Treatment	221320	$33.85	$11.07	25
Rule 1150.3 Turbines ≥ 0.3 MW with Post- Combustion Control (Turbine Replacement)	562212	$0	$0	25
Rule 1179.1 Turbines ≥ 0.3 MW (Turbine Replacement)	221320	$12.56	$0	25

Estimated Incremental Costs:

TABLE 2A-31: INCREMENTAL COSTS FOR L-CMB-08

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[24]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
L-CMB-08: Landfills and POTWs	2037	$136.7	$1.0

18. L-CMB-09 (Incinerators)

Control measure L-CMB-09 seeks emission reductions of NOx by replacement or retrofits with zero and low NOx emission technologies on incinerators and other combustion equipment associated with incinerators. Burner technologies such as low NOx burner systems (LNB) or ultra-low NOx burner systems (ULNB) are combustion control technologies utilized to lower NOx emissions. A variety of factors impact the NOx emissions with LNB or ULNB, such as burner orientation and arrangement, firebox size, heater type (force or natural draft), and fuel type. Dependent on the burner configuration and operation, additional combustion controls are used to reduce NOx emissions, such as fuel and air premix, staged fuel, staged air, and flue gas recirculation.

Ultra-low NOx burner replacement costs are taken from cost estimates from Proposed Amended Rule 1146[1]. Equipment cost is determined using the equation: 5800x + 9600 where x = heat input in million Btu/hr. Installation cost is determined using the equation: 1700x + 25800 where x = heat input in million Btu/hr. The three incinerators each have an hourly Btu rating of 96.2 million Btu. Total estimated equipment costs are $1.7 million and installation costs are $0.6 million. Total cost to equip with LNB is $2.3 million. Equipment life is expected to be 25 years. No changes are expected for operational costs.

Assumptions for cost estimates of LNB installation are listed in the table below:

TABLE 2A-32: COST ASSUMPTIONS FOR L-CMB-09

Source Categories	
Installation of LNB at incinerators	▪ Three 96.2 million Btu/hr incinerators. ▪ Total estimated equipment costs are $1.7 million per unit and installation costs are $0.6 million per unit. ▪ Equipment life is expected to be 25 years. ▪ No additional operational cost. ▪ Additional capital cost of $2.3 per million Btu.

[24] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

Estimated Incremental Costs:

TABLE 2A-33: INCREMENTAL COSTS FOR L-CMB-09

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[25]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
L-CMB-09: Incineration	2033	$5.1	$0.2

19. L-CMB-10 (Miscellaneous Permitted Equipment)

Control measure CMB-10 seeks NOx emission reduction from Miscellaneous Permitted Equipment. Miscellaneous permitted equipment is regulated under Rule 1147 – NOx Reductions from Miscellaneous Sources[26] with NOx limits of between 30 to 60 ppm depending on equipment category. Rule 1147 NOx emission limits are corrected to 3% O2 dry basis and does not apply to equipment with rated heat input of less than 325,000 btu/hr. CMB-10 seeks further NOx emissions reductions from these sources with ULNB, LNB, SCR systems, and zero emission technologies.

Control measure CMB-10 seeks NOx emission reductions from miscellaneous permitted equipment greater than or equal to 325,000 btu/hr and will focus on:

- Ultra-Low NOx Burners
- Low-NOx Burners
- Selective Catalytic Reduction (SCR)
- Transition to Zero-Emission Technology

NOx Control technologies used for miscellaneous combustion applications focus on combustion control which refers to reducing NOx at the point of formation by reducing the peak flame temperature utilizing various techniques. NOx control technologies such as ultra-low NOx burners and low-NOx burners have been in use for more than 30 years, but the technology continues to evolve and improve resulting in significant advancements in performance and NOx reduction efficiencies.

[25] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.
[26] South Coast AQMD Rule 1147 – NOx Reductions for Miscellaneous Sources: Proposed Amended Rule 1147 - NOx Reductions from Miscellaneous Sources (http://www.aqmd.gov).

Assumptions for cost estimates are listed in the table below:

TABLE 2A-34: COST ASSUMPTIONS FOR L-CMB-10

Source Categories	
Ultra-Low NOx/Low NOx Burner Retrofit	▪ Existing equipment retrofitting to ultra-low/low NOx burner technology. ▪ Cost of ultra-low NOx burners assumed to be 25% higher than low NOx burners. ▪ Equipment life assumed to be 35 years. ▪ Frequency of emissions monitoring by source testing of between 3 to 5 years. ▪ No additional upkeep or maintenance- costs compared to existing burners.
Installation of Selective Catalytic Reduction System	▪ Equipment life assumed to be 25 years. ▪ Recurring costs include reagent usage and catalyst replacement across life of SCR system.

Capital Cost Assumptions:

TABLE 2A-35: CAPITAL COST ASSUMPTIONS FOR L-CMB-10

Equipment Name	Affected Industries (NAICS)	Per Unit/Facility Cost	Number of Facilities	Years of Equipment Life
Ultra-Low NOx Burners	All Industries	$11,800	2,100	35
Low NOx Burners	All Industries	$9,440	600	35
Selective Catalytic Reduction System	All Industries	$500,000	300	25

Recurring Cost Assumptions:

TABLE 2A-36: RECURRING COST ASSUMPTIONS FOR L-CMB-10

Equipment Name	Affected Industries (NAICS)	Per Unit/Facility Cost	Frequency	Number of Facilities
Ultra-Low/Low NOx Burner Emissions Monitoring	All Industries	$5,000	Every 3 to 5 Years	2,700
Selective Catalytic Reduction System - Reagent	All Industries	$9,440	Annual	300
Selective Catalytic Reduction System - Catalyst	All Industries	$500,000	Every 9 Years	300

The cost-effective analysis is only a demonstration of source categories staff identified for potential emission reductions through costs for replacement/retrofit or control equipment currently available. Upon implementation and formation of a working group, new zero and near-zero emitting technologies could be identified as well as other sources for potential NOx reductions. Staff anticipates many facilities and stakeholders will participate once a working group is established and will identify cost-effective means for achieving emissions reductions.

Estimated Incremental Costs:

TABLE 2A-37: INCREMENTAL COSTS FOR L-CMB-10

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[27]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
L-CMB-10: Miscellaneous Combustion	2033	$251.0	$6.3

Stationary Source Measures (VOC and/or $PM_{2.5}$ Emission Reductions)

20. FUG-01 (Improved Leak Detection and Repair)

Proposed control measure FUG-01 seeks to reduce emissions of volatile organic compounds (VOCs) from fugitive leaks from process and storage equipment from a variety of sources including, but not limited to, oil and gas production, petroleum refining, chemical products processing, storage and transfer, marine terminals, and other sources. Some of these facilities are subject to leak detection and repair (LDAR) requirements established by the South Coast AQMD and the U.S. EPA that include periodic VOC concentration measurements using an approved portable organic vapor analyzer (OVA) to identify leaks. This measure would implement the use of advanced leak detection technologies including optical gas imaging devices (OGI), open path detection devices, and gas sensors for earlier detection of VOC emissions from leaks.

Fugitive emissions are currently regulated under various South Coast AQMD rules. LDAR requirements include monitoring methods and frequency, recordkeeping, reporting, and repair timeframes. These requirements vary between rules. Some rules require self-inspections or inspections conducted by certified personnel such as Rules 462 – Organic Liquid Loading, 463 – Storage of Organic Liquids, 1142 – Marine Vessel Tank Operations, 1148.1 Oil Well Enhanced Drilling, 1173 – Control of Volatile Organic Compound Leaks and Releases from Components at Petroleum and Chemical Plants, 1176 – Sumps and Wastewater Separators, and 1178 – Further Reductions of VOC Emissions from Storage Tanks at Petroleum Facilities.

This control measure will explore the potential for newer leak detection technologies to improve current LDAR requirements and minimize the emissions impact from leaking components and seals. Optical gas imaging devices, open path detection devices, and stationary gas sensors will be assessed. Inspection methods utilizing these technologies will also be assessed and include continuous emissions monitoring, self-inspections, and third-party monitoring services. Implementation of newer technologies will be pursued in a public process allowing interested stakeholders to participate in the rule development process. This control measure will be developed with the review and identification of industries currently

[27] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

subject to LDAR programs and identification of those industries where the new Smart LDAR technology may be utilized. Based on the results, rules regulating VOC emissions may be amended as appropriate to enhance or incorporate an LDAR program to achieve emissions reductions.

Assumptions for cost estimation are listed in the table below:

TABLE 2A-38: COST ASSUMPTIONS FOR FUG-01

Source Categories	
Storage tanks and process equipment	▪ Staff estimates that a tank farm of 22 tanks would require approximately 7 optical gas imaging cameras and corresponding appurtenances including 7 enclosures, 6 pan and tilt systems, 2 control boxes, 7 software systems and 1 computer at a cost of approximately $600,000.[28] The cost for a camera is approximately $86,000. ▪ 1,109 tanks[29] storing petroleum products would require 50 systems at a cost of $30,000,000. ▪ Other process equipment subject to FUG-01 including pumps, valves, compressors and fittings would require the same number of OGI monitoring systems as tank farms at a cost of $30,000,000. ▪ Installation costs are estimated to be approximately 35% of equipment costs[30] for a total of $21,000,000 for 100 systems. ▪ Annual maintenance costs include the replacement of the cooling unit in each camera every 4 years at a cost of $15,000 per replacement.[31] ▪ Annual O&M costs include electricity at a cost of $75 per year[32] per camera totaling $52,500 annually.

Estimated Incremental Costs:

TABLE 2A-39: INCREMENTAL COSTS FOR FUG-01

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[33]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
FUG-01: Improved Leak Detection and Repair	2032	$115.3	$4.4

[28] Optical gas imaging supplier estimate.
[29] From South Coast AQMD issued permits.
[30] From tank retrofit equipment supplier cost estimate.
[31] Optical gas imaging supplier estimate.
[32] From 2016 AQMP Socioeconomic Analysis for FUG-01.
[33] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

21. FUG-02 (Emission Reductions from Cooling Towers)

FUG-02 is a control measure to address VOC emissions from industrial cooling towers. FUG-02 proposes to first assess the need for enhanced leak identification and repair requirements to reduce industrial cooling tower VOC emissions. The assessment will include a review of the emissions inventory, costs for monitoring equipment, and the control requirements established by other governmental agencies. Findings from this assessment will be the basis of potential future rulemaking activities.

22. CTS-01 (Further Emission Reduction from Coatings, Solvents, Adhesives, and Lubricants)

CTS-01 would seek VOC emission reductions by limiting the allowable VOC content in formulations of select coatings, solvents, adhesives and sealants. About 0.5 tons per day (tpd) (2,555 tons over 14 years) of VOC reduction are estimated as emission reductions are conservatively phased in over time. Emission reductions are projected to be 0.5 tpd in 2031 and 0.5 tpd in 2037.

The cost analysis is based on an analysis of Rule 1168 products. Based on the data reported for 2018 through the Quantity and Emissions Reporting (QER) program required by Rule 1168 – Adhesive and Sealant Applications, approximately 1.6 million gallons of product sold will be impacted by the proposed control measure. Due to projected growth[34] over a 19-year period (2018 to 2037), the gallons impacted are likewise expected to grow to 1.8 million gallons by 2037.

An online comparison of over 12 product categories at retail stores between currently compliant products and future compliant products[35] indicates an average price difference of $2.91 per gallon. This figure is used as the estimate of the increase in costs for end-users to purchase future compliant products and is also assumed to be the dollar amount that will be necessary for product manufacturers to recover reformulation related costs. The total annual cost increase is estimated to be proportional to the annual emission reductions projected and will grow to $5.2 million by year 2037. The product survey was not exhaustive and further surveys will be conducted during rule development to further hone cost and cost-effectiveness estimates.

Implementation period for cost analysis[36]: 2024-2037[37]

[34] Southern California Association of Government Adopted 2016-2040 RTP Growth Forecast.
[35] Online cost comparison of potentially impacted products conducted January 2022.
[36] Reformulation costs assumed to occur beginning in 2024.
[37] It is assumed that reformulation cost spending would begin in 2024 to meet compliance requirements.

Reformulation cost assumptions[38]:

TABLE 2A-40: COST ASSUMPTIONS FOR CTS-01

Equipment Name	Affected Industries (NAICS)	Average Cost Increase per Gallon	Incentive Amount	Volume per Year (Gallon)	Years for Cost Recovery
Certain Coating, Adhesive, Solvent, and Sealant Categories	▪ All of 23 (Construction) – end-users affected by reformulation costs ▪ 325520 - Adhesives and sealants (providers of reformulated products)	$2.91	$0	1,800,000	14

The incremental cost is presented below in millions of 2021 dollars:

TABLE 2A-41: INCREMENTAL COSTS FOR CTS-01

Control Measure	Present Value of Remaining Incremental Cost	Present Value of Incentives	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[39]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
CTS-01: Further Emission Reduction from Coatings, Solvents, Adhesives, and Sealants	$51.0	$0	2024	$51.0	$4.7

[38] Incremental cost for VOC measures and rules is typically approximated as the price difference between the existing products that have already met the proposed product standard and those that will need to undergo reformulation to comply with the new proposed standard. The overall incremental cost is then derived from multiplying the incremental cost per unit by the number of potentially affected units. The latter is approximated by the most recent annual sales volume of the existing products that have not met the proposed new standard, multiplied by the years estimated for reformulation cost recovery.

[39] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

South Coast AQMD Mobile Source Measures (NOx and PM2.5 Emission Reductions)

23. MOB-05 (Accelerated Retirement of Older Light-Duty and Medium-Duty Vehicles)

This control measure promotes accelerated retirement of older gasoline- and diesel-powered vehicles with up to 8,500 lbs. gross vehicle weight rating (GVWR), which includes passenger cars, sports utility vehicles, vans, and light-duty pick-up trucks. The South Coast AQMD has been implementing the Replace Your Ride Program (RYR) since 2015 which provides a rebate to low- and moderate-income applicants for replacing their existing cars with newer, cleaner conventionally powered vehicles, plug-in hybrid electric vehicles (PHEVs) or dedicated zero emission vehicles (ZEVs). This measure seeks to retire light- and medium-duty vehicles through continued implementation of the Replace Your Ride Program with incentives up to $9,500, which includes $5,000 for residents in a Disadvantaged Community (DAC) zip code. For plug-in hybrid and battery electric vehicles, an additional incentive of up to $2,000 is also provided for the installation of electric vehicle charging equipment.

Equipment Life:
The equipment life used in this analysis was 3 years which is based on the remaining useful life assumed in the Replace Your Ride program to calculate emissions reductions. Although the actual useful life of new vehicles is longer than 3 years, this approach is taken to quantify SIP-eligible reductions from the RYR-funded replacement projects.

Incremental Cost:
The incremental cost assumed in this analysis ranges from $5,000 for passenger cars (PC) to $20,000 for light-duty trucks (LDTs) in 2023 and it gradually decreases to $2,500 for PCs and $5,000 for LDTs in 2036. These incremental costs were estimated in discussion with CARB staff and they are mostly in line with the incremental cost projected in the CARB's ZEV Technology Assessment,[40] which ranges from low $2,000 to $29,000 in 2026 depending on vehicle type (small car vs pick-up), technology (BEV vs FCEV), and towing package options.

Incentive:
Replace Your Ride offers up to $4,500 in incentive for the purchase of PHEVs or ZEVs depending on income levels. Also, an additional $5,000 is available for residents in the Disadvantaged Community zip codes. The Program also provides up to $2,000 for the installation of electric vehicle charging equipment.

Implementation period for cost analysis: 2023-2037

[40] CARB Advanced Clean Car II ZEV Technology Assessment (2022) Appendix G - ZEV Tech Appendix (ca.gov).

Capital cost assumptions:

TABLE 2A-42: CAPITAL COST ASSUMPTIONS FOR MOB-05

Equipment Name	Affected Industries (NAICS)	Per Unit Cost	Average Per Unit Incentive Amount	Number of Units	Years of Equipment Life
Passenger Cars, SUVs, and Pick-Up Trucks (Replacement)	All Consumers	\$5,000 - \$20,000	\$5,900	32,300	3

Estimated Incremental Costs:

TABLE 2A-43: INCREMENTAL COSTS FOR MOB-05

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incentives[41]	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[42]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
MOB-05: Accelerated Retirement of Older Light-Duty and Medium-Duty Vehicles	2023	\$169	\$169.0	\$14.9

24. MOB-11 (Emission Reductions from Incentive Programs)

MOB-11 seeks to apply an administrative mechanism to quantify and take credit for the emissions reductions achieved through the implementation of District-administered incentive programs for SIP purposes. Traditionally, such emissions reductions have been accounted in the development of historic base year emissions inventories where actual quantifiable emissions reductions have occurred. However, future emissions reductions from incentive-based programs have not been credited towards attainment in the past. The lack of a SIP-creditability mechanism is a constraint in developing future AQMPs since planned reductions cannot be counted in the future year emissions inventories. This proposed measure would provide an administrative mechanism to take SIP credit for future emissions reductions achieved in the Basin from the continued implementation of incentive programs that are administered by South Coast AQMD.

South Coast AQMD has a long history of successful implementation of incentive programs that help fund the accelerated deployment of cleaner engines and vehicles as well as advanced aftertreatment technologies in on-road heavy-duty vehicles and off-road mobile equipment. Such accelerated deployment not only results in early emissions reductions, but also provides a signal for technology providers, engine and vehicle/equipment manufacturers, and academic researchers to develop and

[41] Incentives are expected to fully cover the incremental cost in this analysis.
[42] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.

commercialize the cleanest combustion engines possible and further the efforts to commercialize zero-emission technologies into a wider market. Major incentive programs administered by South Coast AQMD include:

- Carl Moyer Memorial Air Quality standards Attainment Program (Carl Moyer Program)
- Proposition 1B Goods Movement Emission Reduction Program
- Lower Emission School Bus Program
- Community Air Protection Program (CAPP)
- Volkswagen Environmental Mitigation Trust for California

MOB-11 includes two categories of emissions reductions: those from the current contracts where new vehicles/equipment will remain in service through the attainment years of 2031, 2032 and 2037, respectively, and potential reductions that are projected from the implementation of future projects. Since the cost of clean technologies in the first category have already been incurred, they were not included in this analysis.

The future reductions in the second category are estimated based on the projected level of funding for the SCAQMD-administered incentive programs and average emission reductions achieved by the existing projects, discounted by applicable control factors for future years to account for proposed regulations and control strategies. For on-road vehicle sectors (HD trucks and school buses), the Calculator for Spending Incentives (CSI), which is an internally developed model to identify the most cost-effective projects, is used to calculate NOx and PM2.5 emission reductions.

Number of Units:
The assumed project types and the number of units funded based on projected funding levels from 2023 through 2036 are listed below. The actual projects funded may vary depending on applications received at the time funding programs are opened, and the projects that are ultimately awarded.

HD truck (replacement):	14,300 units (>8,500 lbs of Gross Vehicle Weight Rating)
School bus (replacement):	8,500 units
Agricultural equipment: (replacement)	174 units
Construction (repower):	1,330 units
Construction (replacement):	1,040 units
CHE[43], GSE[44] & Others: (replacement)	1,260 units
Marine (repower):	570 units (commercial harbor crafts)
TRU (replacement)	590 units
Locomotive (replacement):	122 units (freight locomotives)

Incremental Cost:
The incremental cost for the off-road sectors is based on the average incentive award amount for the existing projects that were funded from 2018 through 2021. For on-road sectors (HD trucks & school

[43] Cargo handling equipment used at ports, railyards and warehouses to move cargo and containers.
[44] Ground support equipment used at airports to move cargo and baggage.

buses), the incremental cost is based on the CSI model with updates to reflect recent increases in funding caps and cost effectiveness limits in the Carl Moyer Guidelines.

HD truck (replacement):	Up to $410,000 in 2023 and decreases to an average of $8,000 in 2036 for zero emission trucks Up to $160,000 in 2023 and decreases to an average of 95,000 in 2036 for low NOx trucks
School bus (replacement):	Up to $400,000 in 2023 and decreases to $10,000 in 2036 for zero emission buses Up to $220,000 in 2023 and decreases to $160,000 in 2036 for low NOx buses
Agricultural equipment: (replacement)	$136,000
Construction (repower):	$308,000
Construction (replacement):	$286,000
CHE, GSE & Others: (replacement)	$235,000
Marine (repower):	$322,000 (based on the CARB's CHC SRIA[45] cost estimate)
TRU (replacement)	$45,500
Locomotive (replacement):	$1,854,000

Equipment Life:
The equipment life is based on the maximum useful life allowed in the Carl Moyer Guidelines. Although the actual equipment life may be longer than the maximum project life used in this analysis, staff has elected to use the maximum useful life approach to quantify projected SIP-eligible reductions from the implementation of the SCAQMD-administered incentive programs.

HD truck (replacement):	7 years
School bus (replacement):	10 years
Agricultural equipment: (replacement)	10 years
Construction (repower):	7 years
Construction (replacement):	5 years
CHE, GSE and Others: (replacement)	5 years
Marine (repower):	16 years
TRU (replacement)	5 years
Locomotives (replacement):	15 years

[45] CARB Proposed Amendments to the Commercial Harbor Craft Regulation Standardized Regulatory Impact Assessment (2021)(https://ww2.arb.ca.gov/rulemaking/2021/chc2021).

Incentives:
For this analysis, the incentive amount was equal to the estimated incremental cost.

Implementation period for cost analysis: 2023-2037

Capital cost assumptions:

TABLE 2A-44: CAPITAL COST ASSUMPTIONS FOR MOB-11

Equipment Name (Implementation Period)	Affected Industries (NAICS)	Per Unit Incremental Cost	Per Unit Incentive Amount	Number of Units	Years of Equipment Life
On-Road HD Trucks	Truck Transportation (484)	$8,000 - $410,000	$10,000 – $410,000	14,300	7
School Buses	School Buses (485)	$10,000 - $400,000	$10,000 - $400,000	8,500	10
Off-Road Agricultural Equipment	Farms (111-112)	$136,000	$136,000	174	10
Off-Road Construction Equipment (Repower)	Construction (23)	$308,000	$308,000	1,330	7
Off-Road Construction Equipment (Replacement)	Construction (23)	$286,000	$286,000	1,040	5
Cargo Handling Equipment (CHE), Ground Support Equipment (GSE), Other Industrial equipment	Ports (488), Railyards (482), Airports (488), Others	$235,000	$235,000	1,260	5
Commercial Harbor Craft	Ports (488)	$322,000	$322,000	570	16
Transport Refrigeration Unit (TRU)	Specialized Freight Trucking (484)	$45,500	$45,500	590	5
Freight Locomotives	Ports (488), Rail Yards (482)	$1,854,000	$1,854,000	122	15

Estimated Incremental Costs:

TABLE 2A-45: INCREMENTAL COSTS FOR MOB-11

Control Measure	Beginning Year of Measure Implementation for Cost Analysis	Present Value of Incremental Cost Over Equipment Life, Discounted to 2022 (Millions of 2021 dollars)[46][47]	Annual Average of Amortized Cost, 2023-2037 (Millions of 2021 dollars)
MOB-11: Emission Reductions from Incentive Programs	2023	$1,764.4	$155.3

Part II – Incremental Costs of the of the State's SIP Control Strategies

All cost assumptions for CARB measures can be found in the Proposed 2022 State Implementation Plan, Appendix A: Economic Analysis.

[46] Including incremental capital and operating & maintenance (O&M) costs estimated over the entire lifetime of equipment, which may occur well beyond 2037.
[47] Incentives are expected to fully cover the incremental cost in this analysis.

South Coast AQMD

2022 AIR QUALITY MANAGEMENT PLAN

Final Socioeconomic Report Appendix 2-B

Cost-Effectiveness Methodologies

December 2022

FINAL SOCIOECONOMIC REPORT
APPENDIX 2-B

COST-EFFECTIVENESS METHODOLOGIES

DECEMBER 2022

As part of the 2014 independent review of South Coast AQMD's past socioeconomic assessments (2014), the contracted reviewer, Abt Associates examined the cost-effectiveness analysis conducted in recent years. The report concluded that the Discount Cash Flow (DCF) method used by South Coast AQMD is an appropriate choice for regulatory development purposes; however, it is different from the Levelized Cash Flow (LCF) method used by most other agencies and organizations. As a result, the cost-effectiveness estimates produced by South Coast AQMD staff cannot be directly compared to those produced by other agencies. Abt thus recommends South Coast AQMD continue using DCF, and at the same time, conduct a separate analysis using LCF, which could be included in an appendix or juxtaposed with DCF results.

This appendix updates South Coast AQMD's existing documentation regarding cost-effectiveness methodologies. It begins with a review of South Coast AQMD's past and current practice regarding cost-effectiveness analysis. The review is followed by a description of the two methods in question: DCF and LCF. Next, the two cost-effectiveness methodologies are compared in relation to South Coast AQMD's rule development process. Ensuing is a discussion on the sensitivity of cost-effectiveness to key parameters. The final section concludes with staff's recommendations for future practice.

South Coast AQMD's Cost-Effectiveness Analysis: Past and Current Practice

Historical Overview

The South Coast AQMD had previously used the LCF method for the assessment of control measures in the Air Quality Management Plan (AQMP); however, a decision was made in 1987 to switch to the DCF method for two reasons: first, it was then used extensively in major Fortune 500 companies; second, it was more versatile than the LCF method (South Coast AQMD 1989). In 1995, South Coast AQMD began to use DCF in determining compliance of the best available control technology (BACT) for minor sources. DCF has become the cost-effectiveness methodology for rulemaking since 1996.

Furthermore, in 1998, the California Air Pollution Control Officer's Association (CAPCOA) Board approved *Incremental Cost-Effectiveness Calculation Procedures for Rule Adoption* that recognized the importance of using a single cost-effectiveness assessment methodology to maintain consistency when comparing different projects. This guidance document was a collaborative effort among all the air pollution districts in California. Both the Western States Petroleum Association and the California Council for Environmental and Economic Balance participated in the process. 1998 was also the year when the Carl Moyer program began to operate. It is the only program in South Coast AQMD that uses the LCF method to calculate cost-effectiveness with an annually updated discount rate (instead of using a four-percent discount rate). This exception is due to the requirement to follow the statewide *Carl Moyer Program Guidelines*. And it affects mobile sources of air pollution only. Figure 2B-1 summarizes the historical timeline of how South Coast AQMD's cost-effectiveness analysis has evolved.

FIGURE 2B-1: HISTORICAL TIMELINE OF SOUTH COAST AQMD'S COST-EFFECTIVENESS (CE) ANALYSIS

Prior to 1987	Used LCF for AQMPs
1987	Switched to DCF Began using four percent real interest rate as the discount rate
1995	Began using DCF to determine BACT's maximum CE for minor sources
1996	Began using DCF for rulemaking
1998	CAPCOA guideline approved: Use single CE methodology to maintain consistency Carl Moyer program began: the only program in South Coast AQMD that uses LCF with annually updated discount rate (following the statewide Carl Moyer Program Guidelines)

Current Practice

The South Coast AQMD routinely conducts cost-effective analyses regarding proposed rules and regulations that result in the reduction of criteria pollutants (NOx, SOx, VOC, PM, and CO). The analysis is used as a measure of *relative effectiveness* of a proposal. It is generally used to compare and rank rules, control measures, or alternative means of emissions control relating to the cost of purchasing, installing, and operating control equipment in order to achieve the projected emission reductions. The major inputs in a cost-effectiveness analysis include capital and installation costs, operating and maintenance costs, emission reductions, and the key parameters are discount rate and equipment life.

In conducting its analysis of the costs of purchasing, installing, and operating emissions control equipment, staff utilizes, to the extent feasible, data and information provided by equipment manufacturers and also uses actual installation data, where available. In order to derive the control costs by which to examine cost-effectiveness, staff utilizes the capital and annual costs associated with implementing emission reductions. Typically, staff relies on the guidance provided in the Cost Control Manual developed by U.S. EPA's Office of Air Quality and Planning Standards (OAQPS) (U.S. EPA 2002). The U.S. EPA developed the factors used in the Cost Control Manual from vendor quotes. This guidance provides a means by which to estimate direct and indirect capital and annual costs as a ratio of the equipment costs. Indirect costs include other associated costs into the analysis, such as the cost of overhead, property taxes, insurance, shipping, and labor. These costs are all included in the cost-effectiveness equations and can generally be broken out as follows:

- Capital investment, which is usually a one-time cost that's incurred at the beginning of rule implementation. It can be further broken down into total equipment cost, including cost of control device, ancillary equipment, and taxes and freight; the retrofit factor includes installation, and indirect costs including engineering, field expenses, start-up, performance tests, and contingencies;
- Operating and maintenance (O&M) cost, which is a recurring expenditure that's incurred annually. It includes materials, utilities, labor, maintenance, overhead and administration, taxes and insurance.

For the majority of South Coast AQMD regulations, emission reductions are considered as constant over the lifetime of control equipment. It is regarded as a reasonable assumption whether a rule may necessitate the installation of a single piece of control equipment or the simultaneous installation of several pieces of control equipment. However, when the compliance of a regulation is designed to phase in over a number of years, the emissions reduced can increase over this phase-in period and then level off after rule compliance is fully achieved. Therefore, non-constant emission reductions can occur for rules that specify various compliance dates for different types of control equipment or product categories.

As mentioned earlier, an important reason why South Coast AQMD switched from the LCF method to the DCF method back in 1987 was for the latter's versatility. More importantly for South Coast AQMD, the DCF method by design treats constant and non-constant emission reductions unambiguously in the same way. Below, we will discuss the cost-effectiveness methodologies in greater detail.

Cost-Effectiveness Methodologies

The South Coast AQMD's first documented discussion of cost-effectiveness methodologies was dated back to the 1989 AQMP. The 2005 staff report for amendments to the Regional Clean Air Incentives Market (RECLAIM) also included an extensive discussion that compared DCF and LCF methods and the corresponding cost-effectiveness results. The discussion below expands on the existing documentation.

➢ *Discounted Cash Flow (DCF)*

The DCF method converts all costs, including the initial capital investments and the costs that are expected in the present and all future years of equipment life, to a present value. Conceptually, it is as if calculating the amount of funds that would be needed at the beginning of the initial year to finance the initial capital investments and also to set aside to pay off the annual costs as they occur in the future. The fund that's set aside is assumed to be invested and generates a rate of return at the discount rate chosen. The final cost-effectiveness measure is derived by dividing the present value of total costs by the total emissions reduced over the equipment life. Below is the equation used for calculating cost-effectiveness with DCF:

$$CE^{DCF} = \frac{C_0 + \sum_{n=1}^{N} \frac{C_n}{(1+r)^n}}{\sum_{n=1}^{N} E_n} \quad \left(or \ \frac{Present\ Value\ of\ Total\ Costs}{Unweighted\ Sum\ of\ Emission\ Reductions\ Over\ Equipment\ Life} \right) \quad (1)$$

with C_0 denoting the total of initial capital investments; C_n and E_n denoting the costs and emission reductions, respectively, that are anticipated in a future year *n*; *r* denoting the discount rate and *N* the equipment life. As evident in Equation (1), the DCF method aggregates emission reductions over the equipment lifetime regardless of the year when reductions occur. As a result, the DCF treats constant and non-constant emission reductions unambiguously in the same way.

When annual costs and emission reductions are constant, the equation above can be simplified into:

$$CE^{DCF'} = \frac{C_0 + C_n * PVF(r,N)}{E_n * N} \quad \left(or \ \frac{Initial\ Capital\ Investments + (Annual\ O\&M\ Costs \times PVF)}{Annual\ Emission\ Reductions \times Years\ of\ Equipment\ Life} \right) \quad (1')$$

where $PVF(r, N)$ denotes the Present Value Factor, which is a function of the discount rate (r) and equipment life (N).[1]

➢ *Levelized Cash Flow (LCF)*

The LCF method annualizes the present value of total costs as if all costs, including the initial capital investments, would be paid off in the future with an equal annual installment over the equipment life (similar to mortgage amortization).[2] What's less clear, however, is how to deal with non-constant emission reductions when using the LCF method. As stated in the 2014 Abt report, the LCF method is designed to compare the annualized cost with the annual emission reduction that can be potentially achieved by a project; thus implicitly, emission reductions are constant when the LCF method is applied. In van Kooten et al. (2004), however, it is mentioned that there are three main approaches in the literature to account for carbon sequestration:

- Flow summation method, which corresponds to the DCF method described previously.
- Average storage method, which annualizes the present value of all costs (as with the LCF method) and then divides the amount by the mean annual carbon sequestrated.
- Levelization/discounting method, which is similar to the DCF method, but instead of using the unweighted sum of emission reduced, it discounts future carbon sequestration to reflect the preference for earlier emission reductions.[3]

In the following, we will consider that a generalized LCF method, which can handle non-constant emission reductions, corresponds to the average storage method in the carbon sequestration literature. That is, the annualized cost is divided by the average annual emission reduction to arrive at the final cost-effectiveness measure with LCF:[4]

$$CE^{LCF} = \frac{\left(C_0 + \sum_{n=1}^{N} \frac{C_n}{(1+r)^n}\right) * CRF(r,N)}{\left(\sum_{n=1}^{N} E_n\right)/N} \quad \left(or\ \frac{Annualized\ Present\ Value\ of\ Total\ Costs}{Average\ Annual\ Emission\ Reductions}\right) \tag{2}$$

where $CRF(r, N)$ denotes the Capital Recovery Factor, which is used to convert the present value of total costs into annualized payments. It is a reciprocal of $PVF(r, N)$ and therefore also a function of the discount rate (*r*) and equipment life (*N*).[5]

When annual costs and emission reductions are constant, the cost conversion procedure is equivalent to annualizing the initial capital investments only and adding it to the constant annual cost anticipated in any future year. Since emission reductions are constant, the average annual emission reduced is the same in any future year:

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[1] $PVF(r, N) = \frac{(1+r)^N - 1}{r*(1+r)^{(N-1)}}$

[2] The same cost conversion procedure was documented in the 1989 AQMP. It was specifically mentioned in the case of using the LCF method with non-constant annual costs.

[3] With constant emission reductions, the cost-effectiveness calculated using the levelization/discounting method coincides with that obtained with the average storage method.

[4] The formulation can also be rewritten as *(Undiscounted Sum of Annualized Costs ÷ Unweighted Sum of Emission Reductions over Equipment Life)*. When compared to Equation (1), it is clear that emission reductions are treated identically with both the DCF and the generalized LCF method. The only difference stems from cost-conversion.

[5] $CRF(r, N) = \frac{1}{PVF(r,N)} = \frac{r*(1+r)^{(N-1)}}{(1+r)^N - 1}$

$$CE^{LCF'} = \frac{C_0 * CRF(r,N) + C_n}{E_n} \quad \left(or \ \frac{(Initial\ Capital\ Investments \times CRF) + Annual\ O\&M\ Costs}{Annual\ Emission\ Reductions} \right) \qquad (2')$$

This is the formula most often seen for the LCF method.[6]

Comparison between DCF and LCF

➢ Why is the cost-effectiveness value larger with LCF than with DCF?

It's like a mortgage: the lower the down payment, the higher the mortgage costs. The DCF method considers the value of all costs as if they all could be paid off *at present*, or at the time when initial capital investments are made, whereas the LCF method considers the same set of costs as if they all could only be paid off *in future years*. However, by comparing Equations (1) and (2) (or similarly (1') and (2') for the special case of constant emission reductions), it is straightforward to show that one can easily convert, cost-effectiveness computed using the DCF method into that using the LCF method as follows:

$$CE^{LCF} = [N * CRF(r,N)] * CE^{DCF} \qquad (4)$$

Note that this conversion formula stays the same with both constant and non-constant emission reductions. Moreover, the "wedge" between the two cost-effectiveness methods (i.e., $[N * CRF(r,N)]$) is independent of any monetary cost inputs or emission reduction estimates. It depends only on two parameters: equipment life (*N*) and discount rate (*r*). As illustrated in Figure 2B-2, this wedge grows larger with a higher discount rate or a longer equipment life.

To understand better the wedge between LCF and DCF, it is useful to consider the analogous practice of home financing. A typical home buyer usually makes a down payment at the time of purchase and pays off the mortgage over the lifetime of the home loan. The cost conversion made by DCF and LCF methods corresponds to two what-if scenarios respectively when purchasing a home. The cost conversion in DCF is similar to calculating how much the house would cost at the time of purchase if no mortgage is obtained. In comparison, LCF converts costs in a similar fashion as in the scenario when no down payments is made and the purchase is financed completely through a fixed-rate mortgage that needs to be paid off in subsequent years. The wedge between DCF and LCF methods is therefore analogous to the total mortgage payments that need to be made in the latter scenario: they grow larger with a higher interest rate and a greater mortgage length.

However, it should be emphasized that it would not be appropriate to state that the cost-effectiveness derived from the DCF method underestimates the true compliance costs per ton of emission reduced, or conversely, that the cost-effectiveness derived from the LCF method is an overestimation. DCF and LCF

[6] Some regulations proposed by the South Coast AQMD, typically for VOC reductions, may entail the reformulation of chemical products. In this case, a typical cost-effectiveness analysis uses a methodology that mirrors the LCF method with constant emission reductions. First, incremental cost per unit is approximated as the price difference between the existing products that have already met the proposed product standard and those that will need to undergo reformulation to comply with the new proposed standard. The overall incremental cost is then derived from multiplying the unit cost by the number of potentially affected units, which is approximated by the most recent annual sales volume of the existing products that have not met the proposed new standard. Next, emission reductions are measured by aggregating the amount of pollutant reduced across all affected units that were sold in the most recent year. Finally, the cost-effectiveness measure is obtained by dividing the annual incremental compliance costs by the annual emissions reduced.

are simply two different approaches to convert the compliance costs anticipated at various points in time to the same time frame: DCF converts all costs to the present value while LCF annualizes all costs over the equipment life. The conversions are done irrespective of how the compliance costs are actually financed by each affected facility. The difference in cost conversion between DCF and LCF means that the dollar costs of compliance alternatives are expressed at different time periods; therefore, the cost-effectiveness results, albeit both in dollar per ton, are not directly comparable to each other.

FIGURE 2B-2: WEDGE BETWEEN LCF AND DCF

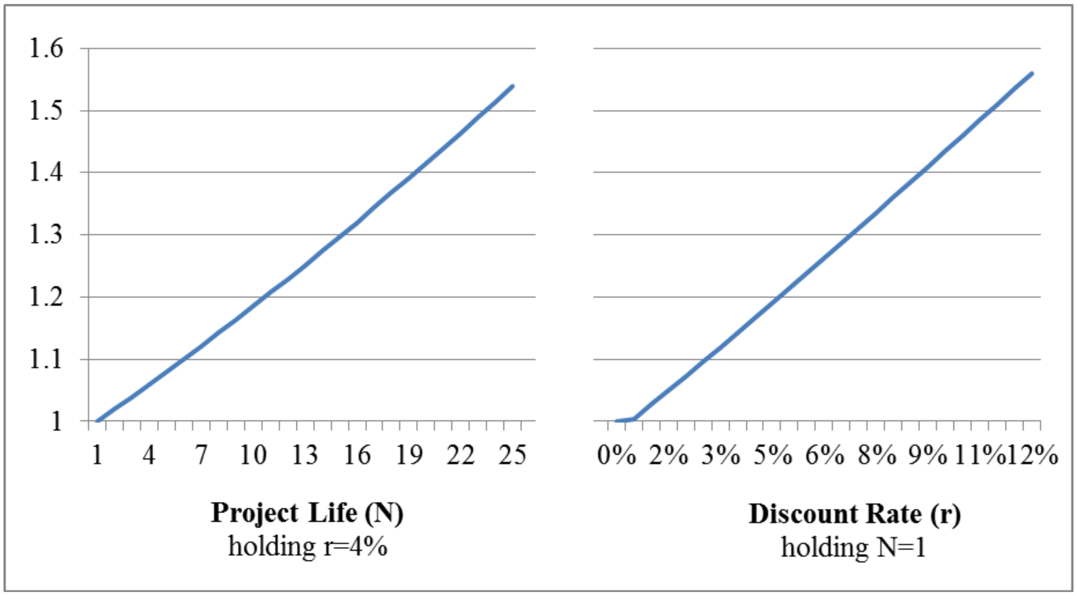


Table 2B-1 summarizes the main methodological differences between DCF and LCF in the case of a one-time capital investment cost made at the initial period and an annually recurring O&M cost, with constant annual emission reductions.

TABLE 2B-1: MAIN METHODOLOGICAL DIFFERENCES BETWEEN DCF AND LCF

Item	DCF	LCF
Time Horizon	Treats all costs (initial capital investments and annual O&M costs) as if they would be paid off *in the initial year*.	Treats the initial capital investment as if they could only be paid off *in future years*, along with the annual O&M costs.
Cost Conversion	Calculates the amount that would be needed to set aside at the initial year to fund the costs as they occur in the future. The fund that's set aside is assumed to be invested and generate a rate of return at the discount rate chosen.	Calculates the amount of annual payments in each future year as if the initial capital investment was entirely financed through a fixed-rate loan and would be paid for in equal annual installments (similar to a home mortgage). The borrowing interest rate is assumed to be the discount rate chosen.
Cost-Effectiveness	Divides the discounted total costs by the unweighted sum of emission reductions that are expected to occur over the equipment life.	Divides the annualized total costs by the amount of emissions reduced at any given year

➢ Can the ranking of alternatives change if LCF, instead of DCF, is used?

The short answer is no. Since the cost-effectiveness analysis is used to compare and rank rules, control measures, or alternative means of emissions control, it is of utmost importance to ascertain whether the ranking of alternatives could be different when a different cost-effectiveness method is chosen. In effect, this is never the case. Suppose there are two such alternatives A and B and that it's already known that alternative A is more cost-effective than alternative B using the DCF method:

$$CE_A^{DCF} < CE_B^{DCF}$$

It automatically implies that alternative A is also more cost-effective than alternative B using the LCF method:

$$CE_A^{LCF} = [N * CRF(r, N)] * CE_A^{DCF} \quad < \quad CE_B^{LCF} = [N * CRF(r, N)] * CE_B^{DCF}$$

This is because, to derive the cost-effectiveness values of both alternatives using the LCF method, we simply need to scale up the DCF results by the same factor, i.e., the wedge between LCF and DCF. Since this factor is always positive, the operation does not change the ordinal ranking of the alternatives.

➢ Will the BACT cost-effectiveness guidelines change when LCF is used instead of DCF?

The short answer is no. The minor source BACT cost-effectiveness guidelines use the DCF method to establish maximum cost-effectiveness criteria, below which a control method is considered cost-effective.[7] The criteria derived using the DCF method are not applicable to the cost-effectiveness results calculated using the LCF method; the criteria must first be converted to their LCF equivalent. As explained earlier, the difference between DCF and LCF in their cost conversion methods implies that the dollar costs of compliance alternatives are expressed in different time frames; thus, their cost-effectiveness results are not directly comparable with each other. (It's as if comparing the value of one US dollar to the value of one Australian dollar, we need to use the proper exchange rate to convert one currency to the other to have a meaningful comparison.)

The left panel of Table 2B-2 reports the current South Coast AQMD BACT cost-effectiveness guidelines for non-major polluting facilities, which were adopted in 1995 and inflation-adjusted to 2014 third quarter dollars. The maximum cost-effectiveness for each criteria pollutant was calculated using the DCF method, with a four-percent discount rate and a 10-year equipment life. The right panel then converted them to the LCF method, by multiplying all amounts in the left panel by a factor of 1.185 (=10*CRF(4%,10)). Again, notice that the conversion from DCF to LCF only involves two parameters: the equipment life and the discount rate that has already been assumed in the computation of cost-effectiveness using the DCF method.

TABLE 2B-2: BACT MAXIMUM COST-EFFECTIVENESS CRITERIA FOR NON-MAJOR POLLUTING FACILITIES

DCF			LCF		
Pollutant	Average (Maximum $ per Ton)	Incremental (Maximum $ per Ton)	Pollutant	Average (Maximum $ per Ton)	Incremental (Maximum $ per Ton)
ROG	28,600	85,800	ROG	33,905	101,715
NOx	27,000	81,000	NOx	32,008	96,025
SOx	14,300	42,900	SOx	16,953	50,858
PM10	6,400	19,000	PM10	7,587	22,524
CO	570	1,630	CO	676	1,932

Note: The cost criteria are based on those adopted by the South Coast AQMD Governing Board in the 2006 BACT Guidelines, adjusted for inflation to third quarter 2014 dollars using the Marshall and Swift Equipment Cost Index.

The left panel of Table 2B-3 replicates the cost-effectiveness of various types of burners that are reported in the 2008 staff report for PR 1147 – NOx Reductions from Miscellaneous Sources (South Coast AQMD 2008).[8] The right panel then converts the amounts to their LCF equivalent using a four-percent discount rate and a 10-year equipment life, as assumed for the DCF method used in the original staff report.[9] When compared against the BACT guidelines in Table 2B-2, none of the burners listed in Table 2B-3 exceed the maximum cost-effectiveness criteria, as long as the comparison is appropriately made using values derived with the same cost-effectiveness method. The reason for this consistency is the same as the

[7] As mentioned earlier, the Carl Moyer program is an exception in that it uses the LCF method to calculate a project's cost-effectiveness, as required by the statewide program guidelines.

[8] Adjusted for inflation to third quarter 2014 dollars.

[9] In the original cost-effectiveness analysis using the DCF method, no discount rate was explicitly used because it was assumed that there was only an initial capital investment cost. Moreover, in the 2011 amendments to Rule 1147, staff used equipment life different than ten years when demonstrating a few more specific examples of cost-effectiveness calculation. The 2008 staff report conducted a more aggregate level of analysis, and an equipment life of ten years was chosen to be on the conservative side.

ranking of alternatives, which as discussed above does not change when LCF is used in lieu of DCF.

TABLE 2B-3: BURNER COST-EFFECTIVENESS FOR RULE 1147

DCF			LCF		
Burner Size (mmBtu/hr)	30 ppm ($ per ton of NOx)	60 ppm	Burner Size (mmBtu/hr)	30 ppm ($ per ton of NOx)	60 ppm
Less than 0.5	21,886	18,887	Less than 0.5	25,946	22,390
1	6,666	6,666	1	7,902	7,902
2.5	4,444	5,555	2.5	5,268	6,585
5	3,333	4,999	5	3,951	5,927
10	3,111	4,444	10	3,688	5,268
20	3,000	3,333	20	3,556	3,951

Note: The original cost-effectiveness were calculated using the 2008 dollar. All amounts in this table have been adjusted for inflation to third quarter 2014 dollars using the Marshall and Swift Equipment Cost Index.

Sensitivity to Key Parameters Chosen

The discussion so far concludes that the choice between DCF and LCF does not change the ranking of alternatives; moreover, a control method that is considered as cost-effective under the current BACT cost-effectiveness guidelines for minor sources will remain cost-effective when calculated with the LCF method. However, the cost-effectiveness analysis can be very sensitive to the key parameters chosen.

➢ Discount Rate

The cost-effectiveness analysis conducted by South Coast AQMD is based on the estimated compliance costs that are expected to be incurred privately by the affected facilities. According to the U.S. EPA's *2010 Guidelines for Preparing Economic Analyses* (2010, section 8.3.1.3), a discount rate that *reflects the industry's cost of capital* should be used. This discount rate is usually higher than that recommended by the Office of Management and Budget in its *Circular A-94 Appendix C* for cost-effectiveness analysis of Federal programs. One of the important reasons for this differential is due to the fact that private facilities generally need to pay an industry-specific risk premium in order to obtain capital. In U.S. EPA's *The Benefits and Costs of the Clean Air Act from 1990 to 2020* (2011), for example, the proprietary data—*Cost of Capital Yearbook* (by Ibbotson Associates)—was used to estimate the private discount rates for each affected industry.

To put it plainly, the most relevant discount rate to South Coast AQMD should be the real interest rate (i.e., borrowing interest rate net of inflation) at which the affected facilities can raise capital to pay for the compliance costs. In the perfect world, this rate should most ideally vary with individual facility, equipment life, and across time. In practice, however, South Coast AQMD staff has been using a real interest rate of four percent since 1987.[10] The 2014 Abt report recommended South Coast AQMD conduct

[10] Although not formally documented, the discount rate is based on the 1987 real interest rate on 10-year Treasury Notes and Bonds, which was 3.8 percent. The maturity of 10 years was chosen because a typical control

sensitivity analysis using, for example, a higher and a lower discount rate.

To demonstrate the sensitivity of cost-effectiveness to the discount rate chosen, we will consider a hypothetical example, where there are two control methods A and B with the following profile:

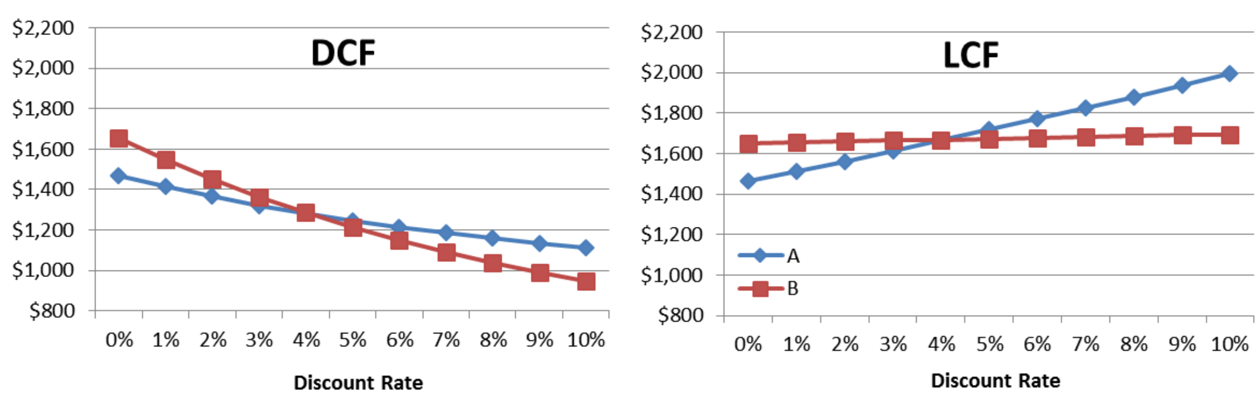
TABLE 2B-4: COST AND EMISSION REDUCTION PROFILE OF TWO HYPOTHETICAL CONTROLS

Year	*0*	*1*	*2*	*…*	*15*	
	Compliance Costs ($)					**Constant Annual Emission Reductions (tons)**
	Initial Capital	**O&M**	**O&M**	**O&M**	**O&M**	
A	2,500	200	200	200	200	0.25
B	200	400	400	400	400	0.25

Figure 2B-3 below shows how cost-effectiveness varies with different discount rates, with the left panel using the DCF method and the right panel the LCF method. Given the same discount rate, it is again verified that the cost-effectiveness ranking of alternatives has nothing to do with the choice between DCF and LCF; that is, if a control method is more cost-effective at a certain discount rate with the DCF method, it's still more cost-effective when calculated using the LCF method with the same discount rate.

FIGURE 2B-3: SENSITIVITY OF COST-EFFECTIVENESS RANKING TO DISCOUNT RATE

(Equipment life is taken to be 15 years)



More importantly, however, it is observed that the ranking of these two alternatives is very sensitive to the discount rate used. Specifically, at a discount rate of less than four percent, control method A is more cost-effective; however, when the discount rate reaches four percent or higher, control method B becomes preferable. This is because a larger share of the overall compliance costs for control method A occurs at the initial year, while for control method B, the majority of the compliance costs are spread out

equipment life was 10 years; however, a longer equipment life would not have corresponded to a much higher rate-- the 1987 real interest rate on 30-year Treasury Notes and Bonds was 4.4 percent. Since 1987, the 4 percent discount rate has been used by South Coast AQMD staff for all cost-effectiveness calculations, including in BACT analysis, to maintain for the purpose of consistency.

into the future. When the discount rate goes up, the costs that are expected to occur further into the future become relatively cheaper than the more imminent costs, thus favoring control method B. In a nutshell, a higher discount rate would generally favor the control methods with a relatively higher annual O&M cost than the initial capital cost because the present value of their total costs are decreased by a proportionally larger amount than the control methods with the opposite cost structure;[11] the converse is true for a lower discount rate.

➢ Equipment Life

The South Coast AQMD determines the equipment life used in its cost-effectiveness analysis through a category-by-category review during AQMP control or rule development, and with input from the stakeholders. When there is a range of estimated equipment life, South Coast AQMD staff usually chooses a representative value that lies on the conservative side. Despite this prudent practice, it is however true that cost-effectiveness can be very sensitive to the equipment life assumed for the analysis. To demonstrate, we will again consider a hypothetical example that is similar to the one analyzed above:

TABLE 2B-5: COST AND EMISSION REDUCTION PROFILE OF TWO HYPOTHETICAL CONTROLS

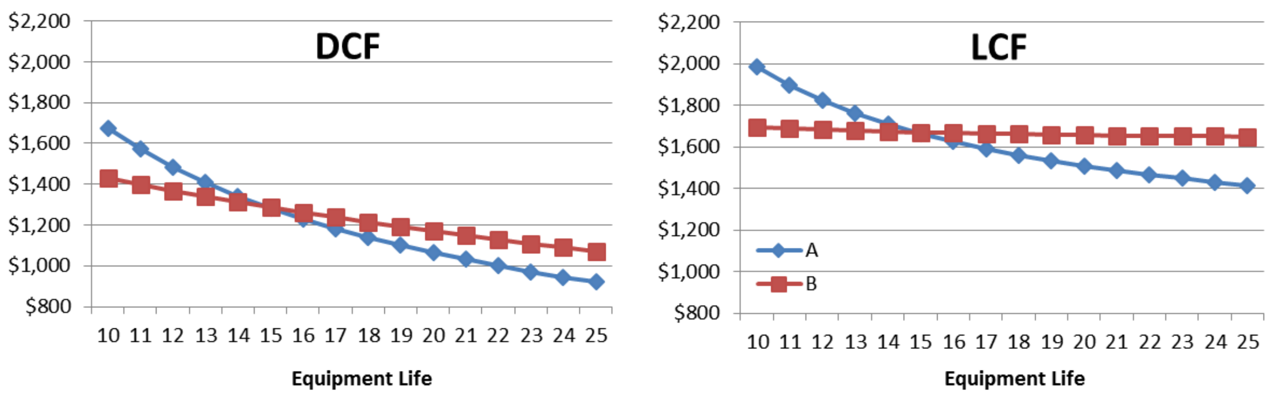
Year	***0***	***1***	***2***	***…***	***N***	
	Compliance Costs ($)					**Constant Annual Emission Reductions (tons)**
	Initial Capital	**O&M**	**O&M**	**O&M**	**O&M**	
A	2,500	200	200	200	200	0.25
B	200	400	400	400	400	0.25

[11] Instead of thinking in terms of present value, we can also reason in terms of annualized costs: a higher discount rate would generally favor the control methods with a relatively higher annual O&M cost than the initial capital cost because the annualized value of their total costs are increased by a proportionally smaller amount than the control methods with the opposite cost structure. The major difference is that, in terms of present value, only the annual costs would be discounted; the higher the discount rate, the lower their present value is. In terms of annualized value however, only the initial capital investments are annualized into future years; the higher the discount rate, the higher the annual installment would become.

Figure 2B-4 below plots the cost-effectiveness of control methods A and B, assuming a four-percent discount rate and varying equipment life. Again, it is shown that the cost-effectiveness ranking of alternatives is consistent between DCF and LCF. However, the ranking of these two alternatives is very sensitive to the equipment life assumed. Specifically, when the equipment life is 15 years or shorter, control method B is more cost-effective, but if the equipment would be in operation for longer than 15 years, control method A becomes preferable. This is because, when the equipment life is longer, the annual O&M cost becomes a more important determinant of the total compliance costs than the initial capital investments. As a result, a longer equipment life lends more favor to the control methods with a lower annual O&M cost, and the opposite is true for a shorter equipment life.

FIGURE 2B-4: SENSITIVITY OF COST-EFFECTIVENESS RANKING TO EQUIPMENT LIFE

(Discount rate is assumed to be 4 percent)



Conclusion

The Cost-effectiveness analysis plays a critical role in South Coast AQMD's rule development process. It is used to compare and rank rules, control measures, or alternative means of emissions control relating to the cost of purchasing, installing, and operating control equipment in order to achieve the projected emission reductions. Regarding the cost-effective methodology, South Coast AQMD switched from LCF to DCF in 1987 and has been using the DCF method since then. It was first used in the 1989 AQMP, and later extended to help determine the maximum BACT cost-effectiveness values, and finally adopted for all rulemaking.

In its final recommendation report for South Coast AQMD's socioeconomic assessments, the independent reviewer Abt Associates suggested South Coast AQMD continue using DCF, but at the same time, conduct a separate analysis using LCF, which could be included in an appendix. By doing so, the cost-effectiveness of South Coast AQMD's control measures can then be directly compared with the cost-effectiveness of similar control measures proposed by other agencies that use the LCF method. Staff has carefully reviewed in this paper both cost-effectiveness methodologies and concludes that:

- The DCF method, by design, does not impose any constraint on a project's time profile of emission reductions. This makes it more versatile than the LCF method, which is conceptually designed to evaluate projects with constant emission reductions. As South Coast AQMD may elect to phase in regulation compliance to allow for reasonable time and flexibility for the regulated community to in this paper both cost-effectiveness methodologies and concludes that:

- The DCF method, by design, does not impose any constraint on a project's time profile of emission reductions. This makes it more versatile than the LCF method, which is conceptually designed to evaluate projects with constant emission reductions. As South Coast AQMD may elect to phase in regulation compliance to allow for reasonable time and flexibility for the regulated community to adapt to the new regulatory requirements, non-constant emission reductions can occur over the initial phase-in period. For this reason, the DCF method is preferred to the LCF method in order to maintain a conceptually consistent cost-effectiveness methodology.
- While maintaining the DCF method, staff also agrees with the 2014 Abt report's recommendation to juxtapose the LCF and DCF results so as to facilitate the comparison with similar control methods proposed by other agencies that use the LCF method. The LCF results can be obtained with the following DCF-LCF conversion formula:

  $$CE^{LCF} = [Equipment\ Life * Capital\ Recovery\ Factor] * CE^{DCF}$$

  The capital recovery factor is jointly determined by the discount rate (*r*) and equipment life (*N*) that are assumed in the cost-effectiveness computation using the DCF method:

  $$CRF(r, N) = \frac{r * (1 + r)^{(N-1)}}{(1 + r)^N - 1}$$

  The CRF value can also be obtained using the Excel function: PMT(r,N,-1, ,1).

Meanwhile, it is worth emphasizing that, although the cost-effectiveness values vary between DCF and LCF (mainly due to different cost conversion procedures), the cost-effectiveness ranking of alternatives does not change with the method used. If a control method is considered as cost-effective under the current BACT minor source guidelines, it will remain so when both the cost-effectiveness value and the BACT guidelines are converted to their LCF equivalent. (For clarity and consistency, the official BACT guidelines for minor sources will continue to be determined using the DCF method.)

However, as discussed in the 2014 Abt report, the cost-effectiveness analysis can be very sensitive to the key parameters chosen, namely the discount rate and the equipment life assumed for the analysis. This paper provides hypothetical examples to demonstrate this point, and it also offers a detailed discussion to explain the reasons behind this sensitivity. For future practice, staff recommends considering consideration of a sensitivity analyses on a case-by-case basis. A sensitivity analysis may be pursued if a reasonable deviation from either the assumed discount rate or the assumed equipment life can impact the cost-effectiveness ranking of a control method or change its cost-effectiveness designation under the BACT minor source guidelines.

South Coast AQMD

2022 AIR QUALITY MANAGEMENT PLAN

Final Socioeconomic Report
Appendix 2-C

Zero-Emission Infrastructure Costs

December 2022

FINAL SOCIOECONOMIC REPORT
APPENDIX 2-C

ZERO EMISSIONS INFRASTRUCTURE COSTS

DECEMBER 2022

The cost of installing zero emissions infrastructure includes many parameters that have not traditionally been considered in air quality plans. As discussed in Chapter 2 of the Final Socioeconomic Report, some zero emissions infrastructure costs are included in the socioeconomic assessment, such as onsite panel upgrades and fuel switching costs (e.g., from natural gas to hydrogen). Details for how zero emissions infrastructure is included for each control measure is discussed in Appendix 2A. Many details are not currently available to estimate total costs from widespread deployment of zero emissions technologies. The cost for these technologies will be due in part to South Coast AQMD control measures. However most of the transition to zero emissions technology for mobile sources, building electrification, and many stationary applications (e.g, power plants) is associated with state policies (e.g., from state legislation, Air Resources Board, Public Utilities Commission, Energy Commission, etc.). The 2022 AQMP relies on these statewide policies to achieve air quality standards. Similarly, state level agencies are also most appropriate to use their expertise to develop methods and analysis of the costs of transitioning to zero emission technology. New methods must be developed to assess these costs, in part due to the rapidly evolving policies being put forth by the state. South Coast AQMD will contribute to developing these cost estimation methods and will continue to update socioeconomic analyses for plans and rules as more information becomes available.

In order to assist in developing an understanding of potential approaches to evaluating zero emission infrastructure costs, South Coast AQMD commissioned Industrial Economics Inc (IEc) to conduct a literature review of studies throughout the country that have explored this topic. A memorandum summarizing this literature as well as some potential next steps is included in this appendix below.

IEc

MEMORANDUM | 25 September 2022

TO Elain Shen, South Coast Air Quality Management District

FROM Derek Ehrnschwender & Jason Price, Industrial Economics, Inc.

SUBJECT Best Practices for Estimating Costs of Zero-Emission Fueling Infrastructure – Task 1: Screening-Level Review and High-Level Methodological Description

INTRODUCTION

The South Coast Air Quality Management District's (AQMD's) 2022 Air Quality Management Plan (AQMP) is likely to rely extensively on the adoption of zero-emission (ZE) technologies. The development of necessary infrastructure to support these technologies is a key component of the transition toward their increased use, in addition to investments in the end-use technologies themselves. The specific expenditures required for ZE supporting infrastructure are wide-ranging, including equipment purchases, property access, installation labor and materials, networking and payments system operations, ongoing hardware maintenance, electricity or ZE fuel supply, electricity capacity investments[1], and any necessary upgrades to the electricity transmission and distribution systems.

Accurately accounting for the costs of these investments in the AQMP poses a number of challenges. The first of these is establishing the level and type of infrastructure investment necessary for ZE technologies. This will depend, in part, on uncertain use patterns for some ZE technologies (e.g., the extent to which EVs charge during the day versus overnight) and the extent to which ZE technologies can use existing infrastructure, which is also uncertain in some cases. In addition, the transition to ZE technologies in the South Coast AQMD is not occurring in a policy or economic vacuum. Various California state agencies are developing rules requiring or incentivizing ZE technologies; the Federal government is also promoting these technologies; and consumers have started to show an increased preference for many of these technologies. These factors, as well as measures included in the AQMP, will contribute to increased ZE infrastructure needs over time. Thus, a key challenge for South Coast AQMD in the context of analyzing the AQMP's costs is determining what ZE infrastructure costs are attributable to the 2022 AQMP. Allocating ZE infrastructure costs to specific policy initiatives will present a particular analytic hurdle not addressed by any of the sources included in this review.

The purpose of this memo is to provide an initial review of past studies that have examined the costs of ZE technology infrastructure and, based on this review, to identify the broad contours of a potential approach for South Coast AQMD to apply in the context of the 2022 AQMP. We first outline the various investments and other expenditures relevant to the development of ZE supporting infrastructure. We then review nine distinct studies that have employed a variety of techniques for assessing and delineating the costs associated with various aspects of supporting infrastructure for ZE technology adoption. Finally, we describe a potential approach for estimating the infrastructure costs associated with ZE technologies implemented pursuant to regulatory initiatives in the 2022 AQMP. To

[1] Capacity investments are related to but separate from costs related to electricity supply. The latter are related to the costs associated with a given MWh produced. By capacity costs, we refer to the investments in excess capacity required to meet CAISO reserve margin requirements, expressed as a specified percentage of the capacity required to meet peak demand.

conclude, we outline next steps for a more detailed review and development of more detailed methodological recommendations.

TYPES OF ZE INFRASTRUCTURE COSTS

This section outlines the various types of infrastructure costs relevant to ZE technologies. These costs include the following, organized into two general segments, **ZE equipment costs** (onsite capital costs such as mobile source charger/refueling hardware and installation, building electrification equipment and electrical system upgrades, stationary source equipment and electrical system upgrades, and operation and maintenance costs) and **energy system costs** (investments in the energy supply, transmission and distribution systems)[2]:

ZE equipment costs:

- **Onsite capital costs,** including the procurement of equipment to be installed, such as battery electric vehicle chargers, as well as any "make-ready" engineering upgrades to the sites in question to support infrastructure installation, such as electrical improvements to parking garages to support fast charging. This category also includes equipment installation labor and materials costs, as well as "soft costs" associated with installation, such as permitting, securing property access, and coordination with the local utilities.
- **Operations costs,** including payment system operations and networking with local utility systems and the relevant ZE technologies to facilitate smart charging.[3]
- **Maintenance costs** associated with ZE supporting infrastructure upkeep, including labor and materials or replacement components.

Energy system costs:

- **Investment costs for expansion of the electric generator fleet** may be incurred to meet the increase in electricity demand associated with electrification. This would include investments in peaking unit capacity to meet CAISO reserve margin requirements if peak demand increases due to electrification.
- **Investment costs for expansion of the transmission and/or distribution systems,** including investments in transmission/distribution lines as well as substations.

The above costs will be influenced by several factors specific to the given context. These include the characteristics of the ZE infrastructure in question (such as the type of battery electric vehicle charger, the number of ports, the installation location), as well as regional differences affecting the costs of fuel and electricity, property access, labor, and transmission and distribution grid upgrades. Another key parameter is the scale and timing of the ZE infrastructure to be installed, as energy consumption per vehicle and the ratio of chargers/fueling stations to the ZE vehicle stock may vary over time. Each of these additional factors (as well as others) will contribute to the total costs associated with ZE infrastructure development and may warrant specific consideration through parameterization or sensitivity analysis in any cost estimation.

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[2] ZE equipment costs are generally experienced first by utility customers for improvements on their side of the onsite electric meter, whereas energy system costs are generally experienced first by electric utilities for improvements on the utility side of the meter.

[3] The cost of electricity or ZE fuel specifically would need to be accounted for either at the generator or utility level or the customer level, to avoid double counting.

REVIEW OF PRIOR ANALYSES

Based on our initial review of the literature, few studies examine costs across all of the categories specified above. Any method employed by South Coast AQMD to capture costs across all of these categories would need to draw from the various methods employed across different past analyses. In the following section, we review nine relevant studies and their methods for estimating aspects of the costs associated with ZE supporting infrastructure.

PNNL'S "ELECTRIC VEHICLES AT SCALE: HIGH EV ADOPTION IMPACTS ON THE WESTERN U.S. POWER GRID"

Phase I of a U.S. Department of Energy-commissioned analysis by the Pacific Northwest National Lab assesses whether there are sufficient resources in the U.S. power grid to provide the electricity for a growing battery electric vehicle (EV) fleet, and what recommended operational changes (such as managed charging practices) might be implemented to accommodate the growing EV fleet.[4] The analysis used the National Renewable Energy Laboratory's electric vehicle infrastructure projection (EVI-Pro) tool to develop load profiles specific to the light-duty EV fleet using both home and public chargers. The analysis assumes that medium-duty vehicle use resembles a delivery business with trucks charged after a single day shift's worth of deliveries. For heavy-duty vehicles, researchers developed a transportation simulation model using Bureau of Transportation Statistics and Federal Motor Carrier Safety Administration data to approximate a simplified U.S. highway network and charging network. The combined light-, medium-, and heavy-duty vehicle load profiles combine to make an aggregate charging load specific to the Western Electricity Coordinating Council (WECC) grid context.

PNNL used the WECC Transmission Expansion Planning Policy Committee's (TEPPC's) 2028 planning model as the base case for future generation and transmission assets, as well as generating capacity retirements.[5] The researchers calculate what they term the "EV resource adequacy" in the WECC, or the amount of light-duty EV deployments where reliability issues would begin, under different scenarios including a "managed charging" scenario where EV customers have a price incentive to shift charging to off-peak times. The researchers investigated whether generation capacity or the transmission system is likely to be the limiting factor on delivering power to serve the EV load and found that the WECC, as a complete system, has enough generation capacity, but given the transmission system's limitations the generating capacity is not located in the right places to serve all EVs. The modeling also allows for the calculation of electricity production costs resulting from EV loads, in $/MWh. A state-level analysis of EV penetration in Washington state allows for region-specific inputs, allowing for the development of locational marginal pricing estimates as a function of EV deployment in each region, though these estimates do not account for additional investments in transmission and distribution. Phase II of this analysis focuses on impacts to the transmission and distribution system.[6] This second report evaluates scenarios of widespread light duty vehicle adoption and tests new modeling routines on a specific distribution circuit in Southern California Edison

[4] "Electric Vehicles at Scale – Phase I Analysis: High EV Adoption Impacts on the Western U.S. Power Grid," (2020). Pacific Northwest National Laboratory.

[5] The TEPPC 2028 model is developed using ABB GridView, a production cost simulation software.

[6] "Electric Vehicles at Scale – Phase II: Distribution System Analysis" (2022). Pacific Northwest National Laboratory

territory. The analysis showed that impacts to the distribution system may require both distribution system infrastructure upgrades as well as smart charging management to address load impacts.

CALIFORNIA'S 2022 CLIMATE CHANGE DRAFT SCOPING PLAN UPDATE

California's 2022 Scoping Plan outlines the state's pathways to achieving carbon neutrality by 2045, incorporating modeling of four scenarios across sectors including transportation. The strategy examined for achieving carbon neutrality includes ZE technologies such as those contemplated by South Coast AQMD, as well as a suite of other investments such as the transition of the power sector to increased reliance on renewables. To evaluate the investments required through 2045, CARB used E3's PATHWAYS model and its identification of necessary technology stocks, fuel consumption, energy sources and infrastructure. The costs captured in the PATHWAYS modeling include initial equipment investments as well as expenditures on energy, operations and maintenance, levelized to arrive at an annualized cost. Fuel savings and resulting cost savings are included as a result of this analysis. The results of the modeling include costs specific to the general category of ZEV deployment and reduced driving demand, but the study does not specify how ZE infrastructure costs and the associated changes in the transportation fuel mix are reflected in these costs.[7]

CALIFORNIA'S 2022 STATE IMPLEMENTATION PLAN

The California Air Resources Board (CARB) describes in the 2022 State Strategy for the State Implementation Plan (SIP) its strategy and commitments to reduce emissions from State-regulated sources in order to meet the state's 70 parts per billion (ppb) 8-hour ozone standard. This report expands on the scenarios reflected in the 2020 Mobile Source Strategy, CARB's multi-pollutant planning effort. Measures included in the 2022 State SIP Strategy are developed in parallel with the 2022 Climate Change Scoping Plan Update. The State SIP Strategy references CEC's AB 2127 Electric Vehicle Charging Infrastructure Assessment, which includes a biannual report assessing the charging needs of California's ZE fleet by 2030. This analysis used vehicle stock scenarios from the 2020 Mobile Source Strategy to estimate future charging station requirements, informed by the following models and analytical tools: NREL's EVI-Pro 2 (intraregional EV travel), EVI-RoadTrip (long-distance interregional EV travel), WIRED (ride hailing EVs), HEVI-Load (MD/HD EVs), and CARB's California Hydrogen Infrastructure Tool (CHIT) which models FCEV infrastructure deployment. The 2022 State SIP Strategy does not present total anticipated costs associated with the buildout of ZE infrastructure (chargers or electricity generating, transmission, and distribution capacity), though it does report average per-charger costs from data collected by the CEC's CALeVIP incentive program for light-duty charging infrastructure.[8]

The 2022 State SIP Strategy outlines near-term planned ZE charger capacity intended to address the progress necessary to meet infrastructure development needs, though it does not compare planned charger capacity against any estimates of the charger capacity needed. The SIP Strategy also indicates that CARB staff also intend to use the REMI Policy Insight Plus to estimate the macroeconomic impacts of the State SIP Strategy on the California economy. More specifically, CARB staff intend to use the direct costs of the Strategy as inputs in the model and report annual changes in employment,

[7] "2022 Draft Scoping Plan Update and Appendices." (2022). California Air Resources Board.

[8] "AB 2127 Electric Vehicle Charging Infrastructure Assessment." (2021). California Energy Commission.

output, fiscal impacts, and other metrics requiring the development of assumptions around the level at which costs are applied (consumer spending, purchase and production costs).[9]

CALIFORNIA'S SB 100 JOINT AGENCY REPORT AND 2045 FRAMING STUDY

A 2021 joint agency report from CEC, CARB, and the CPUC—developed in pursuit of SB 100—provides a review of the policy necessary to meet 100 percent of California's retail and state electricity demand with renewable and zero-carbon resources by 2045. While the focus of this study differs from South Coast AQMD's interest in understanding the implications of increased ZE technology adoption, it applies analytic tools similar to those that would be used to assess the electricity system costs associated with ZE technologies. The report does not assess ZE equipment costs or costs related to distribution system improvements, but it does include capacity expansion modeling of changes anticipated to meet both new demand and regulatory goals. The SB 100 analysis builds on prior work in the CPUC Integrated Resource Planning (IRP) 2045 Framing Study for the 2019-21 IRP cycle.

The 2045 Framing Study adopts a version of E3's RESOLVE California capacity expansion model with updates, such as accounting for all balancing authorities in California, adding hydrogen fuel cells to the candidate resource options, and expanding out-of-state and offshore wind potential. The input scenarios include hourly load profiles for a set of representative days and account for the demand response capabilities of the ZE infrastructure load. The modeling's primary inputs are hourly loads for a representative set of days over the time horizon to 2045, accounting for policy constraints and changes in resource costs. The annual total resource cost for each scenario includes operating costs and fixed costs including levelized new capital investments in generation, storage, and transmission. The modeling does not assign specific costs to the transportation sector or associated ZE infrastructure individually.[10]

NYSERDA'S BENEFIT-COST ANALYSIS OF EV DEPLOYMENT IN NEW YORK

A 2019 benefit-cost analysis commissioned by the New York State Energy Research and Development Authority (NYSERDA) assessed expected impacts associated with largescale adoption of ZE battery electric vehicles in the State of New York.[11] The core of the analysis was a per-vehicle comparison of overall costs versus benefits, with supporting infrastructure (in this case, the deployment and operation of battery electric vehicle chargers) playing a key role. The analysis uses scenarios to assess the impacts of customer charging behavior (charging when convenient versus the use of financial incentives to shift charging behavior to off-peak times), as well as a "high infrastructure" case assuming a greater degree of direct current (DC) fast charger deployment and use. The modeling also divided New York into three subregions: the New York Metropolitan area, Long Island, and Upstate New York, across which the research considered cost differences in electricity generation and distribution, property, labor, and materials.

The NYSERDA analysis made use of real-world cost information where available. For Level 2 and DC Fast Chargers, the analysis accounted for capital costs including make-ready site improvements, charger procurement, and installation using data collected by NYSERDA from prior deployment initiatives, while assuming a low cost of $50 for residential Level 1 charger deployment. To determine

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[9] "Draft 2022 State Strategy for the State Implementation Plan." (2022). California Air Resources Board.

[10] "2021 SB 100 Joint Agency Report - Achieving 100 Percent Clean Electricity in California: An Initial Assessment." (2021). California Air Resources Board, California Energy Commission, California Public Utilities Commission.

[11] "Benefit-Cost Analysis of Electric Vehicle Deployment in New York State," (2019). New York Energy Research and Development Authority.

the scale of Level 1 and Level 2 charger deployment, the analysis relied on survey data of existing charger deployments for each region, making use of simplifying assumptions around DC fast charger deployment due to the more nascent nature of this technology. The analysis accounted for the increased maintenance and operations costs of public chargers only through assuming a 50 percent increase in cost to the customer for use of public chargers, assuming all of these costs would be passed through to ZE vehicle operators.

For modeling ZEV-related electric load, the study used charger use information from one surrogate utility in each region to develop charging load profiles associated with each scenario, the costs of charging to customers, and utility revenues. To estimate the electricity generation and capacity costs associated with additional ZEV-related load requirements, the analysis relied on other existing studies. For generation costs, the analysis relied on production simulation modeling informed by NYISO's Congestion Assessment and Resource Integration Study (CARIS), which includes the projected value of energy for each utility in New York. For capacity costs, the study applied forecasted installed capacity (ICAP) prices from the New York Department of Public Service (DPS). However, these projections of generation and capacity costs from CARIS and DPS, respectively, do not account for the degree to which new EV-related loads will affect marginal generation costs or capacity costs. To calculate incremental transmission and distribution costs, the analysis relied on each utility's marginal costs of service studies, adjusted by expected peak-load additions due to EV deployment.

RMI'S "REDUCING EV CHARGING INFRASTRUCTURE COSTS" REPORT

A 2020 report from the Rocky Mountain Institute provides a more detailed look at the costs associated with specific components of battery electric vehicle charging infrastructure.[12] The study uses the delineation of cost components to identify opportunities for future cost reductions. The analysis used literature, public utility procurement filings, and a survey of a different stakeholders to identify a range of costs associated with charger procurement, data and networking contracts, credit card readers, and cabling. The study also breaks out installation costs between labor, materials, permitting, and relevant taxes and shows the evolution of these costs over time. For distribution utility infrastructure and make-ready site upgrades, the study uses the National Renewable Energy Laboratory's (NREL's) 2019 Distribution System Upgrade Unit Cost Database to identify components and costs that may be required for distribution upgrades to support EV charger installation, such as line extension or transformer upgrades, depending on the context of the given site.

The RMI study also includes an informative discussion of what they term "soft costs:" process costs, marketing costs, site acquisition, meeting local building codes, obtaining local building permits, obtaining utility interconnections, and the costs of delays in permitting. Survey respondents noted the frustrating and unpredictable nature of many of these costs, especially as regulations and codes around ZE supporting infrastructure continue to evolve.

E3'S "DISTRIBUTION GRID COST IMPACTS DRIVEN BY TRANSPORTATION ELECTRIFICATION" REPORT

A 2021 report from Energy + Environmental Economics, GridLab, and the U.C. Berkeley Goldman School of Public Policy assessed electric utility distribution upgrade costs for two categories of upgrades relevant to the deployment of power system infrastructure that may support ZE technologies: marginal additions from EV charging (coincident peak load) and secondary distribution costs driven

[12] "Reducing EV Charger Infrastructure Costs," (2020). Chris Nelder and Emily Rogers, Rocky Mountain Institute.

by the interconnection of EV chargers (connected load). While incremental costs associated with new connected load are less than 10 percent of per kW costs associated with coincident peak load, the magnitude of connected load (total connected charger capacity) is substantially larger than forecasted coincident peak load (expected maximum coincident demand drawn by connected chargers).

The study's method for estimating marginal costs for new capacity-related distribution investments relies on an aggregation of all relevant investments made or planned by the utility divided by the load growth that is driving those investments, using high-level aggregated costs by category from rate cases or FERC reports. These $/kW estimates can then be applied to forecasted expansions in both coincident peak load and total connected load to obtain total additional cost estimates. To calculate forecasted changes in load, E3 identified residential and public EV charging occurring during peak load times and scaled these load estimates with the vehicle adoption scenarios defined in UC Berkeley's 2035 Report 2.0. [13,14]

MASSACHUSETTS EEA'S TECHNICAL PATHWAYS MODELING FOR THE CLEAN ENERGY AND CLIMATE PLAN OF 2025 AND 2030

To support the development of the Massachusetts Office of Energy and Environmental Affairs' Clean Energy and Climate Plan for 2025 and 2030, Evolved Energy Research (EER) modeled a multi-strategy pathway for achieving the decarbonization goals outlined in the Massachusetts 2050 Decarbonization Roadmap. These strategies include, among other elements, increased penetration of renewables, building electrification, electrification of the transport sector, and various working lands initiatives.

While the analysis identifies the additional electricity system investments expected under the decarbonization pathway scenario, it does not allocate these costs to individual elements of the decarbonization pathway. To determine changes in energy system costs, EER used its EnergyPATHWAYS stock accounting model to develop bottom-up estimates of energy demand across a wide range of sectors and energy types under the decarbonization scenario. The totaled hourly energy demands from EnergyPATHWAYS are used as inputs to EER's Regional Investment and Operations (RIO) capacity expansion and resource allocation model, which identified least-cost supply-side pathways for the electricity sector, inclusive of investments in new transmission infrastructure. Costs associated with changes to the energy supply system are assessed at a system-wide level and are not assigned to specific demand categories, such as ZE vehicles.[15,16]

The outputs from EER's analysis also served as inputs into an analysis conducted by BW Research and Industrial Economics of the economic impacts associated with the Clean Energy and Climate Plan. Using the IMPLAN input-output model, the analysis examined employment impacts associated with increased clean energy investment.

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[13] "2035 Report 2.0: Distribution Grid Cost Impacts Driven by Transportation Electrification," (2021). Energy + Environmental Economics.

[14] "2035 Report 2.0: Transportation." 2021. Goldman School of Public Policy, University of California Berkeley.

[15] "Energy Pathways to Deep Decarbonization: A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study." (2020). Massachusetts Executive Office of Energy and Environmental Affairs.

[16] "Appendices to the Massachusetts Clean Energy and Climate Plan for 2025 and 2030." (2022). Massachusetts Executive Office of Energy and Environmental Affairs.

NYSERDA'S INTEGRATION ANALYSIS FOR THE NYS CLIMATE ACTION COUNCIL'S DRAFT SCOPING PLAN

Pursuant to New York's Climate Leadership and Community Protection Act (CLCPA), New York's Climate Action Council developed a Draft Scoping Plan and Integration Analysis in 2021 to model the sectoral transformations that must take place to achieve the GHG emissions reductions set forth by the CLCPA. Similar to the Massachusetts EEA analysis, the Integration Analysis estimates changes in electricity system investment and operational costs associated with multiple changes to the state's energy systems, including building electrification, EV adoption, increased penetration of renewable generating capacity, building shell improvements, and the investments necessary to support electrification. The study examines electricity system cost impacts for all of these changes collectively (rather than individually).

To assess impacts on New York's electricity system, the analysis developed load forecasts for each scenario and relied on an integrated suite of electricity system models to assess the impacts of both changes in load and decarbonization of electricity supply. The analysis used historical hourly system load shapes across a range of end uses (including ZE transportation), along with annual forecasted electricity demand by end use, to create hourly end use load shapes in forecasted years. These forecasts took into account both load increases (such as from vehicle electrification) and load decreases (such as from building shell improvements). For the hourly load curve specific to light duty transportation, the analysis used E3's RESHAPE tool, designed to capture the diversity of housing stock and incorporate geographically distinct weather data. To determine the capability of New York's electric supply infrastructure to meet forecasted demand, the analysis used resource adequacy and capacity expansion models, RECAP and RESOLVE. RECAP performs loss-of-load probability simulations to determine the adequacy of resource portfolios to reliably meet demand. RESOLVE combines capacity expansion decisions with production cost information to determine least-cost approaches to meeting load requirements, including both generation and transmission investments. RESOLVE accounts for the flexible load and demand response characteristics of the vehicle charging and buildings sectors, and it uses a zonal transmission scheme to simulate power flows within New York and its neighbors. Costs associated with changes to the energy supply system to meet future demand were assessed at a system-wide level and were not assigned to specific demand categories, such as ZE vehicles.[17]

POTENTIAL APPROACH AND NEXT STEPS

This section outlines a potential approach for estimating costs associated with ZE supporting infrastructure. Note that this approach is informed by the preliminary review of the above studies, but it is not meant to be a specific recommendation. We also describe potential next steps for additional research.

Potential method for estimating ZE infrastructure costs

Costs associated with ZE infrastructure can be segmented into two categories that have the potential to be quantified at an early stage, and an additional category that may not be quantifiable until more information becomes available. The first two categories include **ZE equipment costs**, including hardware, installation, operation and maintenance costs associated with chargers and refueling stations, building electrification, and stationary source ZE equipment and **energy system costs**, including improvements to energy supply and transmission and distribution infrastructure to support

[17] "New York State Climate Action Council Draft Scoping Plan: Integration Analysis Technical Supplement." (2021). New York State Energy Research and Development Authority.

vehicle refueling and recharging. The third category includes 'soft costs' that are not readily quantifiable, but may have significant costs for many sites, as described in the RMI report. These 'soft costs' include factors such as land use costs (site acquisition, existing site re-designs, easements, etc.), opportunity costs (permitting delays, etc.), marketing, employee training, future-proofing (e.g., overbuilding electrical infrastructure for potential future changes), and stranded asset costs (e.g., equipment that is turned over before its useful life due to subsequent advances in technology). In many instances these 'soft costs' are unknown going into a specific project and can present significant hurdles. These 'soft costs' are often not quantifiable when considering the broad transition to zero emissions technology. Additional research will be needed as more zero emissions infrastructure is installed to develop estimates for these costs. The following discussion addresses potential methods for approaching the estimation of each of the first two categories.

To estimate ZE equipment costs, an initial step will require determining the scale of ZE-related equipment to be installed.[18] These projections can be based on vehicle deployment goals or projections, and would helpfully be segmented by type (e.g., Level 2 versus DC Fast Charging) and location (e.g., workplace, public, highway corridor). This magnitude of ZE infrastructure deployment would then serve as the initial input for calculating costs according to each of the ZE equipment cost categories denoted above. A stock rollover approach would facilitate capturing retirements and replacements as a part of new stock additions. New additions to the infrastructure stock would be multiplied by the estimated unit costs for each procurement and installation cost component. The total stock is relevant for the purposes of capturing ongoing operations and maintenance costs. California-specific data is often well-represented in national studies summarizing these cost inputs. Region-specific estimates for variables such as necessary make-ready improvements, labor, property, permitting and other soft costs should be prioritized where available.[19, 20]

For the purposes of calculating energy system costs, it will be necessary to jointly consider the electricity load (demand) and supply-side effects of ZE technologies. With respect to electricity loads, the adoption of ZE technologies will affect both overall loads and load shape (i.e., the temporal profile of loads). To capture these changes in load patterns in the context of electrification, it is important to assess how changes in the stock of electric vehicles and the charging behavior of vehicle operators will change over time. The former can be projected based on projected electric vehicle sales and typical vehicle turnover, but the latter is more uncertain, as the timing of charging will depend on the pattern of charger infrastructure development, the prevalence of managed charging policies, and the performance of chargers. For example, if charging infrastructure development is centered more on home chargers, charging is likely to be more concentrated in the evening/overnight hours. However, if charging infrastructure is more available in public spaces and a full charge takes only a few minutes, charging may be more concentrated in the daytime hours. For the purposes of assessing the cost implications of increased load, understanding whether these new loads are coincident with peak

[18] Examples of site-specific considerations can be found in: "Electric Public Charging Toolkit for Heavy-Duty Trucks: Guidance for Businesses" (2022). Port of Long Beach.

[19] CARB has assessed the regional variability of the need for make-ready infrastructure upgrades and associated costs. See: "EV Charging Infrastructure: Nonresidential Building Standards," (2020). California Air Resources Board.

[20] For a comparison of California-specific ZE infrastructure costs compared against the rest of the U.S., see: "Estimating Electric Vehicle Charging Infrastructure Costs Across Major U.S. Metropolitan Areas," (2019). Michael Nicholas, The International Council on Clean Transportation.

demand will be critical to accurately assessing the investments in electricity system capacity necessary to accommodate ZE technologies.

To assess the cost implications of these changes in electricity load and load shape, ideally an electricity capacity expansion model would be paired with a reliability model. A capacity expansion model would project the additional capacity investments that would most cost-effectively meet projected loads, inclusive of transmission investments and accounting for the timing and overall magnitude of loads. Pairing the capacity expansion model with a system reliability model would ensure that the projected capacity investments planned by the capacity expansion model are sufficient to meet system reliability requirements (estimated according to metrics such as the loss of load expectation). The outputs of the capacity expansion model would include the change in system investment and operational costs associated with the changes in load. Because such an analytic exercise would understandably incorporate a degree of uncertainty, we recommend incorporating sensitivity analysis for key parameters. Cost projections would ideally be presented as a potential range.

Assessing the infrastructure costs related to ZE technologies fueled with hydrogen (or hydrogen-derived fuels) would be similarly complicated. Because hydrogen has not been widely used as a fuel in the U.S., an analysis of the costs associated with hydrogen deployment would need to consider the costs of establishing a robust supply chain. This would include investments in hydrogen production capacity, storage systems, transmission and distribution networks, and investments in hydrogen-using equipment. Across this supply chain, it would be important to address a number of uncertainties, such as the mix of technologies used to produce hydrogen (e.g., electrolysis or methane reformation); the degree to which additional electric generating capacity investment would be required to support hydrogen production; whether existing infrastructure could be used for storage, transmission, and distribution; and the extent to which different end uses would require the transformation of hydrogen (e.g., liquefaction or the production of ammonia from hydrogen).

To the extent that California's energy systems are already undergoing transformation to accommodate ZE equipment due to statewide policy initiatives, attribution of the associated infrastructure investment costs to the state versus South Coast AQMD will likely pose challenges. Accurate allocation of costs between the state and South Coast AQMD would require statewide energy system modeling with some degree of regional detail within the state. In addition, it would require a baseline projection of how the energy system in the state and in the South Coast AQMD is likely to change over time under current state policies. Separate energy system modeling with South Coast AQMD requirements layered on top of state policy would then assess the impacts of the state and South Coast AQMD policies combined. The difference between the cost outputs generated for this scenario and outputs from the baseline scenario would isolate impacts attributable to the South Coast AQMD.

From a regional economic impact perspective, the changes to the energy system would involve a number of countervailing effects. The adoption of ZE technologies would involve investments that would have a stimulative effect on the regional economy, but the transition away from fossil fuels would reduce economic activity among fossil fuel producers and the network of industries associated with them (e.g., engineering support, fuel distributors). Capturing the full breadth of these effects and their broader impacts across the economy requires an integrated analysis that pairs energy system modeling with economic impact modeling. Energy system modeling will need to capture not only changes in the electricity system but also impacts to fuel markets. The outputs from energy system modeling will include investments to support ZE technologies, disinvestment associated with reduced fossil fuel demand, and changes in the use of both ZE and conventional (fossil fuel-based) technologies. To understand the economic impacts of these changes across the supply chain, the outputs from energy system modeling may serve as the basis for inputs for a model of the regional economy, such as IMPLAN or REMI. This approach has been applied in a number of statewide and national analyses. For example, at the state level, the Massachusetts EEA analysis and NYSERDA Integration Analysis described above both paired energy system modeling with IMPLAN to assess the economic impacts of decarbonization.

Additional considerations and recommendations for future research

Based on the review presented above, additional considerations for future investigation include the following:

- None of the studies initially reviewed attribute a share of ZE infrastructure costs to specific policy initiatives, as South Coast AQMD is interested in for the purposes of AQMP development. Many of the studies reviewed above used vehicle deployment projections as a starting input for their cost analyses, so if a share of future vehicle adoptions and other ZE equipment were attributable to South Coast AQMD's policies, it may be possible to assign a share of costs from a state-wide study to specific regulatory initiatives in the 2022 AQMP.
- We note the temporal variability of many of the key input variables discussed above. As the ZE market continues to expand, component costs are anticipated to continue to decline as production and distribution continues to scale. Similarly, the ratio of ZE refueling infrastructure availability to ZE vehicle deployment will likely not remain constant as ZE vehicles grow in use.[21]
- The studies reviewed above focus mostly on ZE infrastructure specific to battery electric vehicles, which dominate the current ZE market. Accounting for future increases in the deployment and use of hydrogen fuel cell technology would require the collection of additional parameters specific to that industry's costs. Some key differences exist, such as differences in the make-ready infrastructure necessary for hydrogen refueling stations and impacts to local utilities, which would lean on pipelines and trucking for distribution as opposed to the electric grid.
- The extent to which charging behavior is managed to minimize grid impacts will also affect total costs in response to ZE infrastructure development. Tools such as time-of-use pricing, utility smart charging programs, and the potential addition of vehicle-to-grid energy storage technologies will impact utilities' ability to leverage ZE technologies for grid benefits.

[21] AB 2127 mandated an analysis of potential charging needs to meet California's vehicle deployment goals, which was completed in 2021. See: "Electric Vehicle Charging Infrastructure Assessment," (2021). California Air Resources Board.

South Coast AQMD

2022 AIR QUALITY MANAGEMENT PLAN

Final Socioeconomic Report
Appendix 3-A

Weight of Evidence Descriptions for Causal Determination

December 2022

FINAL SOCIOECONOMIC REPORT
APPENDIX 3-A

WEIGHT OF EVIDENCE DESCRIPTIONS FOR CAUSAL DETERMINATION

DECEMBER 2022

DETERMINATION	WEIGHT OF EVIDENCE
Causal Relationship	Evidence is sufficient to conclude that there is a causal relationship with relevant pollutant exposures (e.g., doses or exposures generally within one or two orders of magnitude of recent concentrations). That is, the pollutant has been shown to result in health effects in studies in which chance, confounding, and other biases could be ruled out with reasonable confidence. For example: (1) controlled human exposure studies that demonstrate consistent effects; or (2) observational studies that cannot be explained by plausible alternatives or that are supported by other lines of evidence (e.g., animal studies or mode of action information). Generally, the determination is based on multiple high-quality studies conducted by multiple research groups.
Likely To Be Causal Relationship	Evidence is sufficient to conclude that a causal relationship is likely to exist with relevant pollutant exposures. That is, the pollutant has been shown to result in health effects in studies where results are not explained by chance, confounding, and other biases, but uncertainties remain in the evidence overall. For example: (1) observational studies show an association, but co-pollutant exposures are difficult to address and/or other lines of evidence (controlled human exposure, animal, or mode of action information) are limited or inconsistent or (2) animal toxicological evidence from multiple studies from different laboratories demonstrate effects but limited or no human data are available. Generally, the determination is based on multiple high-quality studies.
Suggestive Of, But Not Sufficient To Infer, A Causal Relationship	Evidence is suggestive of a causal relationship with relevant pollutant exposures, but is limited, and chance, confounding, and other biases cannot be ruled out. For example: (1) when the body of evidence is relatively small, at least one high-quality epidemiologic study shows an association with a given health outcome and/or at least one high-quality toxicological study shows effects relevant to humans in animal species or (2) when the body of evidence is relatively large, evidence from studies of varying quality is generally supportive but not entirely consistent, and there may be coherence across lines of evidence (e.g., animal studies or mode of action information) to support the determination.
Inadequate To Infer The Presence Or Absence Of A Causal Relationship	Evidence is inadequate to determine that a causal relationship exists with relevant pollutant exposures. The available studies are of insufficient quantity, quality, consistency, or statistical power to permit a conclusion regarding the presence or absence of an effect.
Not Likely To Be A Causal Relationship	Evidence indicates there is no causal relationship with relevant pollutant exposures. Several adequate studies, covering the full range of levels of exposure that human beings are known to encounter and considering at-risk populations and lifestages, are mutually consistent in not showing an effect at any level of exposure.

(Adapted from U.S. EPA 2019)

South Coast AQMD

2022 AIR QUALITY MANAGEMENT PLAN

Final Socioeconomic Report

Appendix 3-B

Quantification of Public Health Benefits

December 2022

FINAL SOCIOECONOMIC REPORT
APPENDIX 3-B

QUANTIFICATION OF PUBLIC HEALTH BENEFITS

DECEMBER 2022

Implementation of the2022 Air Quality Management Plan will result in improved air quality, including lower ozone and PM2.5 concentrations in the South Coast AQMD four-county region. Research in epidemiology and health economics has shown that reduced exposure to air pollutants reduces incidence of mortality and morbidity endpoints. The effect of these air quality improvements on the number of various health endpoints is quantified in these analyses, and valuation methods are used to monetize these quantified public health effects to arrive at the overall value of public health benefits. This appendix describes the methodology and data inputs used. More detailed results, including breakdowns by county and by each health endpoint evaluated, are provided as well.

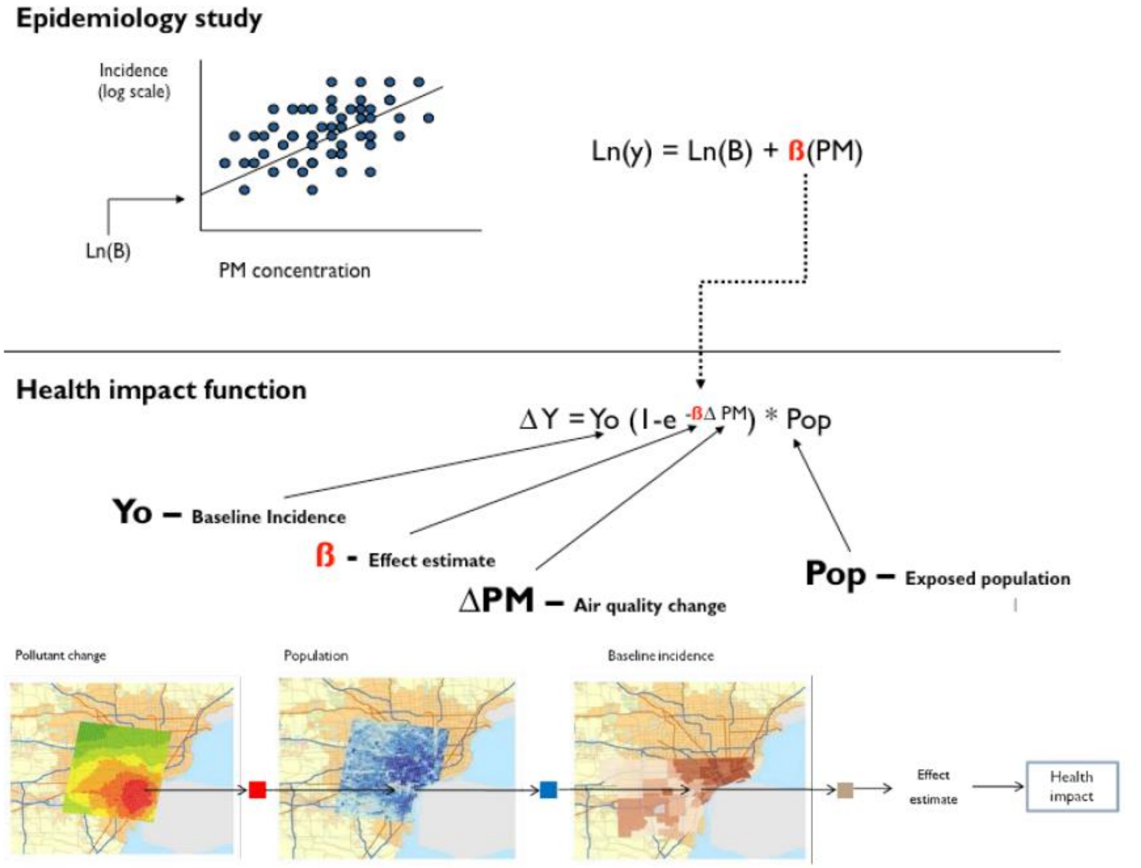
Methodology

The methodology employed to quantify public health benefits consists of several components. The first component is the health impact analysis (see Figure 3B-1). This analysis is based on the use of a health impact function to estimate the change in incidence of a particular endpoint. The variables in the analysis include: the change in air quality concentrations, baseline incidence, population exposed to the particular health risk, and an effect estimate. The effect estimate is derived from epidemiology studies, which use health and air quality data to estimate Concentration-Response (C-R) functions which relate the concentration of a particular pollutant to a mortality or morbidity endpoint. With all of these data taken together, the health impact function can be evaluated to estimate the health effect for a given geographic unit. In the case where there are multiple different C-R functions in epidemiology literature that need to be taken into account, a pooling method can be used. Pooling allows for a calculation of change in incidence of particular endpoint using multiple effect estimates from different epidemiology studies combined together. Once the health impacts have been estimated (pooled or un-pooled), a valuation function is applied, which places a monetary value on the change in incidence of a given endpoint which is either a scalar value or a distribution of values for a given type of incidence. The valuation function can also be pooled together to account for differences among valuation studies.

This methodology is implemented in the Environmental Benefits Mapping and Analysis Program - Community Edition (BenMAP-CE) application, which is used for this analysis. BenMAP-CE is a free and open-source application maintained by the U.S. EPA. Earlier editions of BenMAP were used to quantify the public health benefits of the 2007, 2012, and 2016 AQMPs, as well as for numerous other studies.[1]

[1] U.S. EPA lists examples of these studies at: https://www.epa.gov/benmap/benmap-ce-applications-articles-and-presentations.

FIGURE 3B-1: HEALTH IMPACT METHODOLOGY



Source: BenMAP CE User's Manual, U.S. EPA

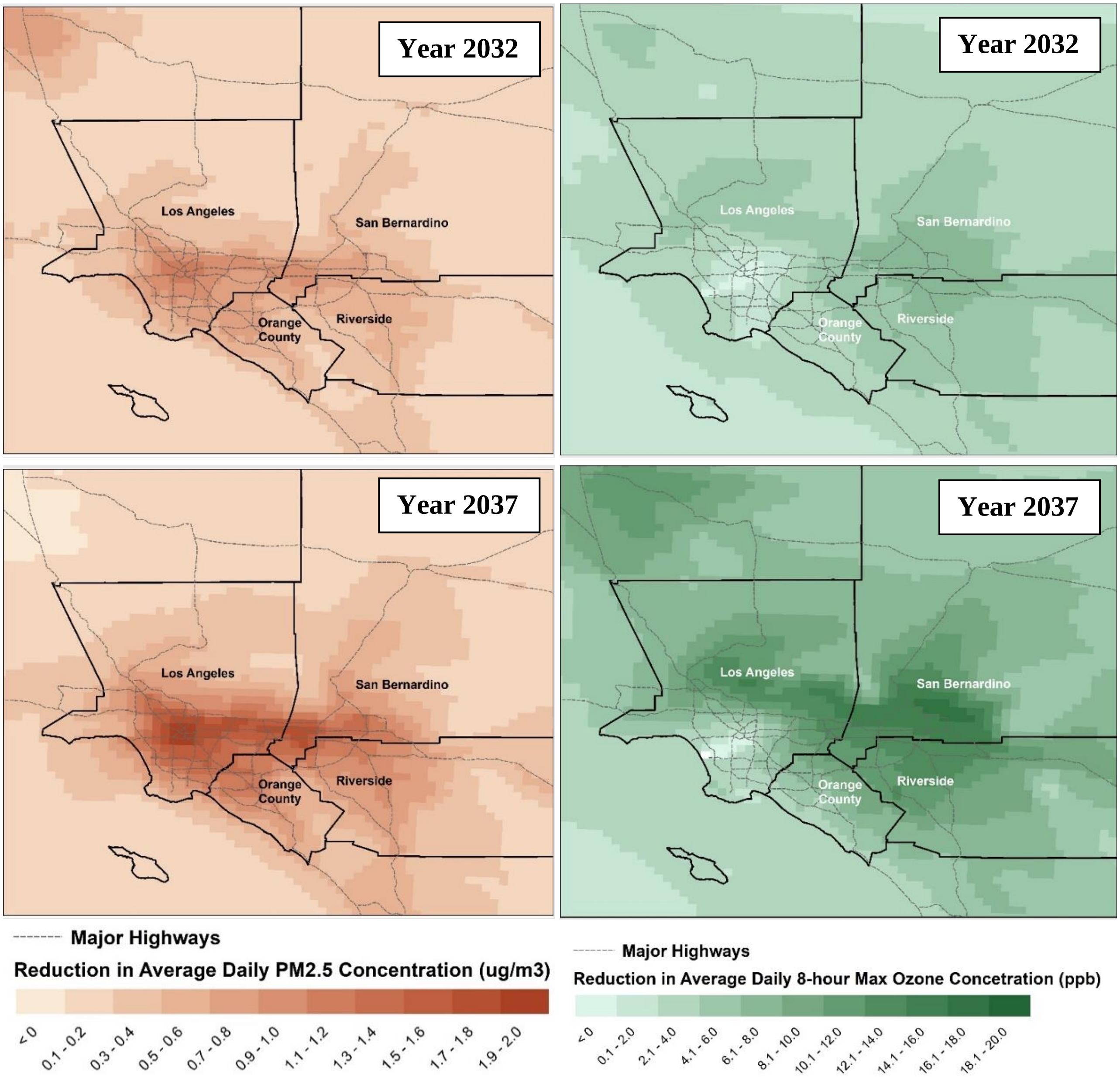
Data

The first input into the health impact calculation is the projected changes in air quality for a particular pollutant, which are derived from the difference between the "baseline" and the "control" air quality scenarios, or the scenarios without and with the 2022 AQMP respectively. The projected baseline and control air quality scenarios are the result of emission inventories (see Appendix III of the 2022 AQMP) and air quality simulations based on these emission inventories and other variables (see Appendix V of 2022 AQMP).[2] These air quality projections are produced at the level of a 4km x 4km grid for the Basin. The projections are hourly for each modeled year and consist of 365 days for both PM2.5 and ozone. These hourly data are converted into daily metrics of air quality changes for each pollutant (daily 8-hour max for ozone and daily 24-hour mean for PM2.5), then loaded into BenMAP-CE for analysis. The average of the daily changes for each pollutant in 2032 and 2037 is illustrated in Figure 3B-2. As shown in panels (b) and (d), the control measures result in decreases in average ozone concentration levels throughout the region, with the largest decreases located around the western portions of San Bernardino and Riverside Counties. Panels (a) and (c), illustrate the changes in average PM2.5 concentration levels, which decrease throughout the region, with the largest

[2] Changes in ozone and PM2.5 concentrations used in the health benefits analysis are based on a slightly different version of air quality modeling data than included in the 2022 AQMP. However, the difference has a negligible impact on the changes in pollutant concentrations, and therefore, the health benefits analysis was not re-run.

decreases concentrated in central Los Angeles County.

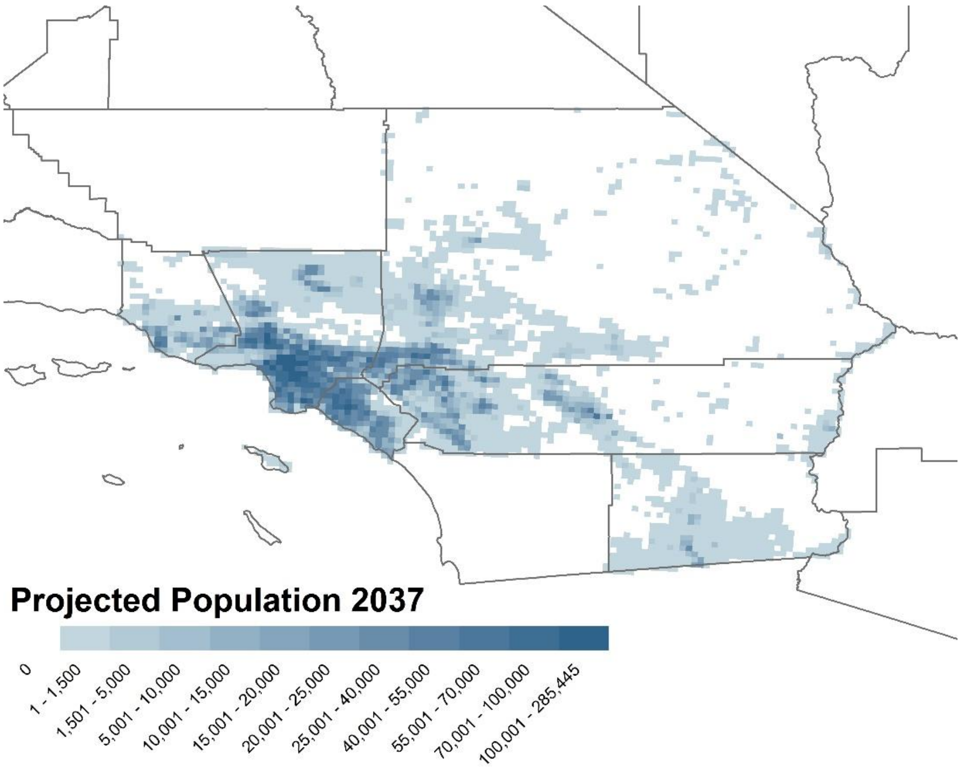
FIGURE 3B-2: AIR QUALITY REDUCTIONS FROM 2022 AQMP MEASURES, 2032 AND 2037



Note: Ozone concentarations shown here are the summer planning period average of daily 8-hour maxima, whereas $PM_{2.5}$ concentrations are the annual average of 24-hour means.

The population projections in 2032 and 2037 (Figure 3B-3) are based on the 2020 RTP/SCS Growth Forecast (SCAG 2020) and were provided by SCAG staff at the 4km x 4km grid-cell level. For the purposes of this analysis, SCAG staff converted the population forecast, originally modeled at the level of Transportation Analysis Zones (TAZs), to the 4km x 4km grid-cell used for air quality modeling.

FIGURE 3B-3: PROJECTED POPULATION IN 2037



Baseline all-cause mortality incidence rates are provided by the California Department of Finance (DoF) at the county level, by five-year age group, for the base year 2018 and projected through 2032 and 2037. Historical baseline respiratory mortality incidence rates are collected from the U.S. Centers for Disease Control and Prevention (CDC)'s WONDER database at the county level, by five-year age group. Historical rates are projected to 2032 and 2037 using an adjustment factor based on the DoF all-cause mortality projection. Baseline incidence for hospital admissions and emergency department visits are based on incidence rates provided by the California Department of Health Care Access and Information (HCAI) at the zip-code and county-level. County-level estimates of baseline incidence for nonfatal myocardial infarctions and ischemic stroke are obtained from the CDC Interactive Atlas of Heart Disease and Stroke. Baseline incidence rates for new onset of asthma in children are provided by IEc for the Los Angeles area for 2002-2005 from the Children's Health Study cohort (McConnell et al. 2010). Baseline incidence for all other endpoints not discussed here are based on the data included with BenMAP-CE.[3]

The effect estimates for each health impact function are from C-R functions as described in Table 3B-1. Local estimates in the South Coast AQMD four-county region were selected whenever available and meeting other selection criteria recommended by IEc (see Appendix 3C). The health effect is often estimated as a relative risk (RR), which is the ratio of the probability of an incidence of a particular endpoint in an exposed group to the probability of it occurring in an unexposed group. The RRs from the recommended study for respiratory mortality from long-term ozone exposure is 1.120 from Turner et al. (2016). The RRs from the recommended studies for all-cause mortality from long-term PM2.5 exposure are: 1.14 (Jerrett et al. 2005), 1.104 (Jerrett et al. 2013), 1.17 and 1.14 from Krewski et al. (2009)'s kriging and land-use regression estimates, respectively.

[3] BenMAP-CE User's Manual is available at https://www.epa.gov/sites/default/files/2015-04/documents/benmap-ce_user_manual_march_2015.pdf.

TABLE 3B-1: C-R FUNCTIONS, STUDY POPULATIONS AND VALUATION FUNCTIONS BY ENDPOINT GROUP

Endpoint	C-R Function	C-R Function Study Population	Valuation Function ($2015)[1]
Long-Term Exposure to Ozone			
Mortality, Respiratory	Turner et al. (2016)	> 30 years	VSL (Robinson and Hammitt 2016). $9.2 million ($4.3-$14.2 million)[1]
Incidence, Asthma	Pooling of: Tetreault et al. (2016); Garcia et al. (2019)	0-17 years	$17,232 (Belova et al. 2020)
Short-Term Exposure to Ozone			
School Loss Days, All Cause	Gilliland et al. (2001)	5-17 years	$106/day (BLS, 2015)
Minor Restricted Activity Days	B. D. Ostro and Rothschild (1989)	18-65 years	$70/day (Tolley et al. 1986)
Emergency Room Visits, All Respiratory	Malig et al. (2016)	All ages	$875/visit (HCUP 2016)
Emergency Room Visits, Asthma	Pooling of: Malig et al. (2016); Gharibi et al. (2019)	All ages	Average of: $447/visit (Standford et al. 1999); $534/visit (Smith et al. 1997)
Hospital Admissions, Asthma	Moore et al. (2008)	0-17 years	$6,564 (HCUP 2014)
Asthma Symptoms (chest tightness, cough, wheeze, shortness of breath)	Lewis et al. (2013)	5-17 years	$219/day (Dickie and Mesmen 2005)

TABLE 3B-1: C-R FUNCTIONS (CONTINUED), STUDY POPULATIONS AND VALUATION FUNCTIONS BY ENDPOINT GROUP

Endpoint	C-R Function	C-R Function Study Population	Valuation Function ($2015)[1]
Long-Term Exposure to PM2.5			
Mortality, All Cause	Pooling of: LA-specific estimates (Jerrett et al. 2005; Jerrett et al. 2013), Kriging and LUR (Krewski et al. 2009), Woodruff et al. 2008 (infants only, not pooled).	<1 year; > 30 years	VSL (Robinson and Hammitt 2016). $9.2 million ($4.3-$14.2 million)
Incidence, Asthma	Pooling of: Tetreault et al. (2016); Garcia et al. (2019)	0-17 years	$17,232 (Belova et al. 2020)
Incidence, Hay Fever/Rhinitis	Parker et al. (2009)	3-17 years	$600 (Soni 2008)
Incidence, Lung Cancer	Gharibvand et al. (2016)	> 30 years	$33,809 (Kaye et al. 2018)
Hospital Admissions, Alzheimer's Disease	Kioumourtzoglou et al. (2016)	> 65 years	Average of: $156,920 (Alzheimer's Association 2020); $184,500 (Jutkowitz et al., 2017)
Hospital Admissions, Parkinson's Disease	Kioumourtzoglou et al. (2016)	> 65 years	$567,285 (Yang et al. 2020)

TABLE 3B-1: C-R FUNCTIONS (CONTINUED), STUDY POPULATIONS AND VALUATION FUNCTIONS BY ENDPOINT GROUP

Endpoint	C-R Function	C-R Function Study Population	Valuation Function ($2015)
Short-Term Exposure to PM2.5			
Minor Restricted Activity Days	B. D. Ostro and Rothschild (1989)	18-64 years	$70/day (Tolley et al. 1986)
Hospital Admissions, All Cardiac Outcomes	Pooling of: 7 study location-specific risk estimates (all from Talbott et al. 2014)	All ages	$16,045 (HCUP 2016)
Hospital Admissions, All Respiratory	Zanobetti et al. (2009); Ostro et al. (2009)	0-17 years; >64 years	$9,075 to $35,402 depending on age (HCUP 2016, Chestnut et al. 2006)
Emergency Room Visits, All Cardiac Outcomes	Ostro et al. (2016)	All ages	$1,161 (HCUP 2016)
Emergency Room Visits, All Respiratory	Ostro et al. (2016)	All ages	$875 (HCUP 2016)
Incidence, Ischemic Stroke	Shin et al. (2014)	>65 years	$33,962 (Mu et al. 2017)
Incidence, Out of Hospital Cardiac Arrest	Ensor et al. (2013)	> 18 years	$35,753 (O'Sullivan et al. 2011)
Emergency Hospital Admissions, Asthma	Delfino et al. (2014)	0-17 years	$6,564 (HCUP 2014)
Emergency Room Visits, Asthma	Ostro et al. (2016)	All ages	Average of: $447/visit (Standford et al. 1999); $534/visit (Smith et al. 1997)
Asthma Symptoms, Albuterol Use	Rabinovitch et al. (2006)	6-17 years	$0.35/inhaler use (derived from Epocrates.com and goodrx.com)
Work Loss Days	Ostro (1987)	18-64 years	$167/day (BLS, 2015)
Acute Myocardial Infarction, Nonfatal	Wei et al. (2019)	>65 years	$48,796 to $162,112 depending on age (Sullivan et al. 2011)

Notes:

1. The values presented in this Appendix are in 2015$, consistent with the current base year / dollar year in BenMAP-CE. As such, the VSL estimates reported in this Appendix appear to differ from the VSL estimates reported in Chapter 3 (in $2021). We rely on BenMAP-CE to adjust all benefits estimates to 2021$.
2. Since the ozone health impact analyses were preformed using air quality data representative of the ozone season (May 1st - September 30th), the C-R functions based on long-term ozone exposure incorporate a correction factor equal to the ratio of the ozone full-year annual average to the ozone seasonal average.

The valuation functions associated with each endpoint are also described in Table 3B-1. The highest valued endpoint is premature mortality. Avoided premature deaths are valued using the concept of the Value of Statistical Life (VSL). VSL is a measure of the willingness-to-pay (WTP) of a society to reduce the risk of a mortality, aggregated up to the amount of risk reduction required to avoid one statistical death over the population. A range of VSL is recommended by IEc (2016) from $4.3 to $14.2 million, with a midpoint of $9.3 million, all of which are expressed in 2015 dollars and reflect 2013 income levels. These are subsequently adjusted to reflect growth in real income through 2032 and 2037. This range is found in Robinson and Hammitt (2016), and falls within the range of Viscusi (2015). Avoided morbidity conditions are valued primarily based on the concept of cost of illness (COI) avoided, which includes the cost of healthcare and the cost of lost productivity, though a few endpoints do include a WTP component. The COI and WTP valuations functions for morbidity endpoints are based on recommendations from the IEc report (2016). It is also recommended that WTP valuations be adjusted for income growth, based on the concept that the income elasticity of VSL is positive. The recommended income elasticity for VSL is $\varepsilon_I = 1.1$ based on Viscusi (2015), with $\varepsilon_I = 0$ and $\varepsilon_I = 1.4$ for sensitivity analyses, while $\varepsilon_I = 0.5$ is recommended for WTP portions of morbidity endpoints.[4]

Per-capita income growth data for historical years 2013-2021 and projections for 2022-2025 are from the California Department of Finance (DOF). The DOF publishes forecasts total personal (nominal) income growth, a forecast of the consumer-product index (CPI-U)[5], and a population forecast. Using the inflation forecast to adjust the nominal income forecast and the population forecast, a forecast of real per-capita income growth to 2025 was derived. The post-2025 per-capita income growth is estimated based on the forecasted 2025 total income growth rate and the DOF's population forecast, resulting in an average annual growth rate of per-capita income of 1.4 percent.

Results

The health impacts are calculated according to the methodology and data described above. The health impacts are categorized into three different types of exposure: short-term ozone exposure, short-term PM2.5 exposure, and long-term PM2.5 exposure. Annual health impacts from short-term ozone exposure are calculated as the sum of the daily impacts for the Summer Planning season. Health impacts from off-season short-term ozone exposure are not calculated here due to data limitations. Thus, the health impacts shown can be interpreted as conservative estimates of the annual health impact, only representing daily impacts of less than half of a year. Annual health impacts from short-term PM2.5 exposure are calculated as the sum of daily impacts for 365 days of a year.[6] Annual health impacts for long-term PM2.5 exposure are calculated based on the annual average of the mean daily concentrations.

Annual health impacts for all endpoints are estimated with no threshold effects for all types of pollutant exposure. This practice is recommended by Industrial Economics, Inc. and based on the latest scientific evidence, including those summarized in the Integrated Science Assessments (U.S. EPA 2019; U.S. EPA 2020).

Pooling methods are used to calculate the annual health impact from pollutant exposure for endpoints where multiple C-R functions are recommended as described in Table 3B-1. The pooling method used here for overlapping C-R functions is either Fixed Effects or Random Effects as implemented in BenMAP-CE. The choice

[4] The income elasticity adjustment is done according to the formula $VSL_{t+n} = VSL_t \left(\frac{income_{t+n}}{income_t}\right)^{\epsilon_I}$, where *n* is the number of years of income growth.

[5] The forecast of CPI-U All Items is used.

[6] In leap-years, February 29th is excluded from health impact calculation due to limitations of BenMAP-CE.

between using Fixed Effects or Random Effects for pooling is made automatically by BenMAP-CE based on a test statistic evaluated at an alpha of 5% (RTI International, 2015).[7] The independent sum pooling method is used for C-R functions with non-overlapping age-groups.

The health impacts of mortality based on the recommended C-R functions are shown in Table 3B-2. The effect of reduced long-term ozone exposure will result in a reduction of 339 respiratory-related premature deaths per year in the year 2032 and 744 per year in the year 2037. The effect of ozone improvements on mortality reduction is significant at the 95% confidence level as shown by the confidence intervals (CI).[8] The effect of reduced long-term PM2.5 exposure on all-cause mortality incidence is much larger than from ozone; reduced long-term PM2.5 levels result in a reduction of 1,280 premature deaths per year in 2032 and 2,287 premature deaths per year in year 2037.

TABLE 3B-2: ANNUAL MORTALITY AND MORBIDITY HEALTH EFFECT ESTIMATES

Endpoint	2032	2037
PREMATURE DEATHS AVOIDED, ALL CAUSES		
Long-Term Ozone Exposure[1]	339	744
	(236; 437)	(521; 955)
Long-Term PM2.5 Exposure	1,280	2,287
	(200; 2,375)	(359; 4,231)

[7] The test statistic used by BenMAP-CE is $Q_w = \sum_i \left[\left(\frac{1}{v_i}\right)\left(\beta_{fe} - \beta_i\right)^2\right]$, where v_i is the variance of study i, β_{fe} is the weighted parameter from fixed-effects estimation, β_i is the beta coefficient of study i. Q_w is chi-squared distributed with n-1 degrees of freedom.

[8] A 95% Confidence Interval (CI) is found from the 2.5 percentile and 97.5 percentile of an empirical distribution resulting from Monte Carlo simulation.

TABLE 3B-2 (CONTINUED): ANNUAL MORTALITY AND MORBIDITY HEALTH EFFECT ESTIMATES

Endpoint	2032	2037
REDUCED MOTBIDITY INCIDENCE		
Long-Term Ozone Exposure[1]		
Asthma, New Onset	4,506 (3,901; 5,100)	9,501 (8,282; 10,681)
Short-Term Ozone Exposure[1]		
Asthma Symptoms (Chest Tightness, Cough, Shortness of Breath, Wheeze)	795,164 (-99,961; 1,633,686)	1,741,652 (-223,660; 3,528,868)
Emergency Room Visits (ED), Asthma	286 (65; 504)	649 (149; 1,136)
ED Visits, All Respiratory Minus Asthma	655 (199; 1,088)	1,501 (455; 2,492)
HA, Asthma	8,244 (4,104; 12,233)	18,292 (9,107; 27,142)
Minor Restricted Activity Days	318,008 (127,508; 499,986)	710,412 (286,098; 1,112,271)
School Loss Days, All Cause	96,176 (-13,921; 197,094)	208,938 (-31,033; 418,157)
Long-Term PM2.5 Exposure		
Asthma, New Onset	1,903 (1,830; 1,979)	3,280 (3,155; 3,411)
HA, Alzheimer's Disease	131 (99; 161)	239 (182; 291)
HA, Parkinson's Disease	54 (28; 79)	100 (52; 144)
Incidence, Hay Fever/Rhinitis	9,024 (2,187; 15,555)	15,726 (3,824; 27,022)
Incidence, Lung Cancer (non-fatal)	107 (33; 177)	191 (59; 314)

TABLE 3B-2 (CONTINUED): ANNUAL MORTALITY AND MORBIDITY HEALTH EFFECT ESTIMATES

Endpoint	2032	2037
REDUCED MOTBIDITY INCIDENCE		
Short-Term *PM2.5 Exposure*		
Acute Myocardial Infarction, Nonfatal	18 (11; 26)	35 (20; 49)
Asthma Symptoms, Albuterol use	316,362 (-154,374; 767,243)	554,968 (-271,320; 1,343,489)
ED Visits, Asthma	66 (11; 119)	117 (19; 210)
ED Visits, All Cardiac Outcomes	138 (-53; 322)	255 (-98; 594)
ED Visits, All Respiratory Minus Asthma	325 (72; 698)	582 (129; 1,246)
Emergency Hospitalizations (EHA), Asthma	3 (0; 7)	6 (0; 12)
HA, All Cardiac Outcomes	47 (-324; 233)	87 (-602; 432)
HA, All Respiratory	132 (71; 191)	245 (132; 354)
Incidence, Ischemic Stroke	73 (22; 131)	138 (41; 247)
Incidence, Out-of-Hospital Cardiac Arrest	13 (1; 23)	23 (3; 42)
Minor Restricted Activity Days[2]	430,241 (349,092; 508,201)	755,830 (613,815; 892,034)
Work Loss Days[2]	73,341 (61,857; 84,389)	129,022 (108,869; 148,392)

[1] Health effects of ozone exposure are quantified for summer planning period only (i.e., May 1 to September 30). There are potentially more premature mortalities and morbidity conditions avoided outside the ozone peak season.
[2] Expressed in person-days. Minor Restricted Activity Days (MRAD) refer to days when some normal activities are avoided due to illness.
(Note: Parentheses are a 95% CI.)

Figure 3B-4 maps the location of the avoided premature deaths by pollutant type in 2037. Ozone exposure reductions result in relatively small reductions in mortality throughout the basin, with concentrations in western Riverside and San Bernardino counties, and central Los Angeles County. The reduced PM2.5 exposure results in much more significant reductions in premature mortality, which are concentrated in central Los Angeles County.

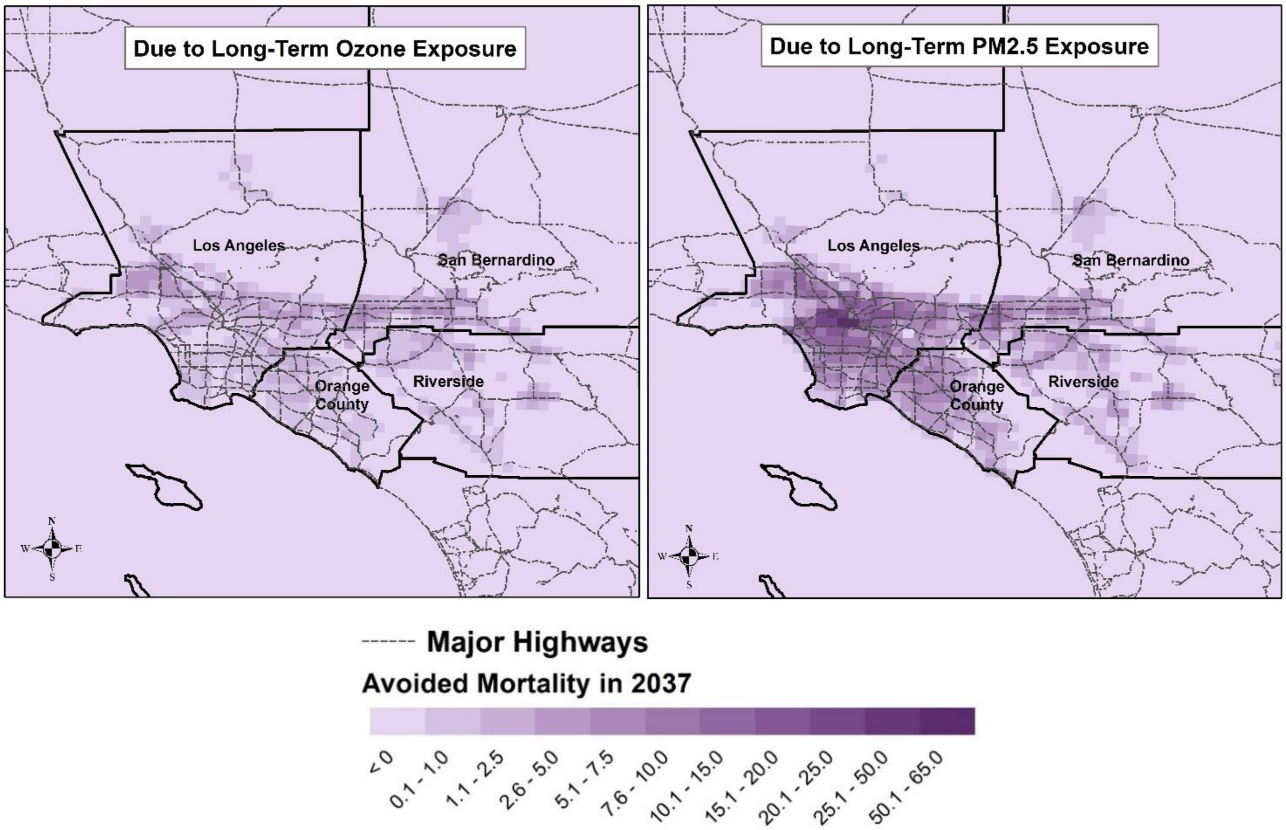
The sensitivity of the long-term PM2.5 mortality-related health impacts shown in Table 3B-2 to the C-R functions used is examined by considering C-R functions from non-local studies. As recommended by IEc (see Appendix 3C), staff estimates the health impacts based on the pooling of two sets of non-local CR functions: (1) two California studies are pooled (Thurston et al. 2016; Jerrett et al. 2013) which have a RRs of 1.03 and

1.01, respectively, and (2) two National study estimates are pooled (Lepeule et al. 2012; Krewski et al. 2009) which have RRs of 1.03 and 1.01, respectively.

TABLE 3B-3: PM2.5-RELATED DEATHS AVOIDED ESTIMATES FROM DIFFERENT CR FUNCTIONS

Scenarios	Health Impacts (premature deaths avoided per year)	
	2032	2037
Main Scenario (L.A. Studies)	1,280	2,287
	(200; 2,375)	(359; 4,231)
California Studies	238	429
	(-50; 803)	(-89; 1,438)
National Studies	783	1,404
	(450; 1,310)	(812; 2,340)

FIGURE 3B-4: CHANGE IN ALL-CAUSE MORTALITY FROM LONG-TERM OZONE EXPOSURE AND LONG-TERM PM2.5 EXPOSURE IN 2037



The change in incidence of specific morbidity endpoints as a result of air quality improvements are also shown in Table 3B-2. There are different sets of morbidity endpoints for different pollutant exposures, but both reductions in ozone and PM2.5 exposures result in fewer school loss days, fewer hospital admissions related to all respiratory causes, and fewer asthma-related emergency room visits.

The valuation of reduced mortality and morbidity incidence is based on the valuation functions described in Table 3B-4, along with an income elasticity and cessation lag where applicable. The valuation of avoided premature deaths is based on the recommended VSL and income elasticity as described above, along with a 20-year cessation lag for long-term PM2.5 exposure. Cessation lag describes how the avoided premature deaths from annual exposure are lagged over time. The 20-year cessation lag as recommended by IEc (2016a) assigns 30% of the reduction to the first year, 13% for years 2-5, and 1% for all following years.[9] The valuation estimates for reduced premature mortality incidence are shown in Table 3B-3, along with lower and upper bounds resulting from sensitivity analysis. The results of this analysis show that the annual public health benefits from avoided premature deaths have a midpoint estimate of $19.3 billion in 2032 and $39.1 billion in 2037 (expressed in 2021 dollars), based on a base VSL of $9.2 million and an income elasticity ε_I of 1.1. The lower- (upper-) bound shows the value of public health benefits if the base VSL is at $4.3 million ($14.2 million) and $\varepsilon_I = 0$ ($\varepsilon_I = 1.4$), this represents an extreme bound of the valuation of the mean health impact and shows

[9] Consistent with the rest of the Final Socioeconomic Report, a four-percent discount rate is applied to the valuation of avoided premature mortalities lagged over the 20-year period.

the sensitivity of the results to the assumptions of the analysis.[10] The annual public health benefits due to avoided premature deaths range from $6.2-$32.5 billion in 2032 and $11.6 -$67.3 billion in 2037. From 2022 to 2037, the mid-point estimate of mortality-related benefits amounts to an average of $19.4 billion per year. As expected from the health impact results, the largest public health benefits are derived from the reduction in PM2.5 concentration in the basin.

TABLE 3B-4: MONETIZED PUBLIC HEALTH BENEFITS

	Monetized Public Health Benefits (Billions 2021$ per year)					
	2032			2037		
	Lower Bound ($4.3M, ε_I=0)	Midpoint ($9.2M, ε_I=1.1)	Upper Bound ($14.2M, ε_I=1.4)	Lower Bound ($4.3M, ε_I=0)	Midpoint ($9.2M, ε_I=1.1)	Upper Bound ($14.2M, ε_I=1.4)
Morality, All Cause	$6.2	**$19.3**	$32.5	$11.6	**$39.1**	$67.3
Ozone	$1.3	**$4.0**	$6.8	$2.8	**$9.6**	$16.5
Los Angeles	$0.5	**$1.5**	$2.5	$1.2	**$4.0**	$6.9
Orange	$0.2	**$0.6**	$1.0	$0.3	**$1.1**	$1.9
Riverside	$0.3	**$1.0**	$1.7	$0.6	**$2.1**	$3.7
San Bernardino	$0.3	**$1.0**	$1.7	$0.7	**$2.4**	$4.1
PM	$4.9	**$15.3**	$25.7	$8.7	**$29.5**	$50.8
Los Angeles	$3.1	**$9.8**	$16.5	$5.6	**$19.0**	$32.7
Orange	$0.7	**$2.2**	$3.7	$1.1	**$3.9**	$6.7
Riverside	$0.5	**$1.5**	$2.6	$0.9	**$3.0**	$5.2
San Bernardino	$0.6	**$1.7**	$2.9	$1.1	**$3.6**	$6.2

Notes:

1. The values presented in this Appendix are in 2015$, consistent with the current base year / dollar year in BenMAP-CE. As such, the VSL estimates reported in this Appendix appear to differ from the VSL estimates reported in Chapter 3 (in 2021$). We rely on BenMAP-CE to adjust all benefits estimates to 2021$.

The monetary benefits of avoided morbidity incidence are shown in Table 3B-5. The greatest benefit from ozone exposure reductions is from reduced asthma symptoms and new-onset asthma valued at $201.4 million and $201.2 million, respectively, in 2032 and valued at $457.1 million and $424.3 million, respectively, in 2037. The greatest benefits from PM2.5 exposure is from reduced new-onset asthma valued at $85 million in 2032 and $146.5 million in 2037 and avoided Parkinson's Disease valued at $30.6 million in 2032 and $56.5 million in 2037.

[10] The values presented in this Appendix are in 2015$, consistent with the current base year / dollar year in BenMAP-CE. As such, the VSL estimates reported in this Appendix appear to differ from the VSL estimates reported in Chapter 3 (in $2021). We rely on BenMAP-CE to adjust all benefits estimates to 2021$.

TABLE 3B-5: MONETIZED ANNUAL MORBIDITY BENEFITS (MILLIONS OF 2021 DOLLARS)

Morbidity Endpoint by Exposure	2032	2037	Average Annual (2025 -2037)
Long-Term Ozone Exposure (Total)	**$201.2**	**$424.3**	**$198.5**
Asthma, New Onset	$201.2	$424.3	$198.5
Short-Term Ozone Exposure (Total)	**$292.8**	**$662.0**	**$299.2**
Asthma Symptoms (Chest Tightness, Cough, Shortness of Breath, Wheeze)	$201.4	$457.1	$206.2
Emergency Room Visits (ED), Asthma	$0.1	$0.3	$0.1
ED Visits, All Respiratory	$0.7	$1.6	$0.7
HA, Asthma	$54.1	$120.1	$54.8
Minor Restricted Activity Days	$26.2	$60.8	$27.1
School Loss Days, All Cause	$10.2	$22.1	$10.2
Long-Term PM2.5 Exposure (Total)	**$145.5**	**$257.1**	**$132.1**
Asthma, New Onset	$85.0	$146.5	$76.3
HA, Alzheimer's Disease	$22.3	$40.7	$20.6
HA, Parkinson's Disease	$30.6	$56.5	$28.3
Incidence, Hay Fever/Rhinitis	$5.4	$9.4	$4.9
Incidence, Lung Cancer (non-fatal)	$2.2	$3.9	$2.0
Short-Term PM2.5 Exposure (Total)	**$56.9**	**$103.3**	**$52.3**
Acute Myocardial Infarction, Nonfatal	$1.0	$1.8	$0.9
Asthma Symptoms, Albuterol use	$0.1	$0.2	$0.1
ED Visits, Asthma	$0.03	$0.1	$0.029
ED Visits, All Cardiac Outcomes	$0.2	$0.3	$0.1
ED Visits, All Respiratory	$0.3	$0.6	$0.3
Emergency Hospitalizations (EHA), Asthma	$0.02	$0.04	$0.02
HA, All Cardiac Outcomes	$0.8	$1.5	$0.7
HA, All Respiratory	$3.9	$7.4	$3.7
Incidence, Ischemic Stroke	$2.5	$4.7	$2.3
Incidence, Out-of-Hospital Cardiac Arrest	$0.4	$0.8	$0.4
Minor Restricted Activity Days	$35.5	$64.6	$32.7
Work Loss Days	$12.1	$21.3	$11.0
Total Morbidity Benefits	**$696.4**	**$1,446.6**	**$682.0**

The total of the monetized public health benefits from avoided premature deaths and reduced morbidity conditions are the sum values from Tables 3B-4 and 3B-5. The total annual public health benefits of the emission reductions resulting from implementation of the 2022 AQMP are $20 billion in 2032 and $40.5 billion in 2037. The majority of the public health benefits are derived from avoided premature deaths, with the remaining amount coming from reduced incidence of morbidity conditions.

Sensitivity and Uncertainty Analyses

It should be emphasized that, as with all scientific studies and evaluations, there are various sources of uncertainty surrounding the estimated public health benefits, including the uncertainty embedded in data inputs, uncertainty of the C-R functions chosen, and uncertainty of valuation. Given the significant contribution of mortality-related benefits, staff conducted several sensitivity and uncertainty analyses regarding three major sources of uncertainties in public health benefits estimations.

Sensitivity Analysis using Different Sets of VSL and Income Elasticity

The first sensitivity analysis considers alternative VSL and income elasticities. The base VSL of $11.1 million represents the mid-point of the recommended VSL range of $5.2 million to $16.9 million, adjusted for inflation (Industrial Economics and Robinson 2016a). This VSL range is based on a review of peer-reviewed studies on the value of mortality risk reductions and considered as reasonable for regulatory analysis (Robinson and Hammitt 2016). In addition, a lower income elasticity of 0 (i.e., VSL does not change with income level) and a higher income elasticity of 1.4 (i.e., a one percent income growth increases VSL by 1.4 percent) were also recommended to be used in the sensitivity analysis, based on a study by Viscusi (2015). Table 3B-6 shows the range of monetized public health benefits, where the lower bound assumes a VSL of $5.2 million and an income elasticity of 0 while the upper bound assumes a VSL of $16.9 million and an income elasticity of 1.4. In 2037, the range of benefits is from $11.6 to $67.3 billion. The lower bound is about 31 percent of the mid-point benefits, while the upper bound is about 170 percent of the mid-point estimate.

TABLE 3B-6: SENSITIVITY ANALYSIS OF MORTALITY EFFECTS VALUATION

Monetized Public Health Benefits (Billions of 2021 dollars)						
	2032			2037		
	Lower Bound	Mid-Point	Upper Bound	Lower Bound	Mid-Point	Upper Bound
Base VSL*	$5.2	$11.1	$16.9	$5.2	$11.1	$16.9
Income Elasticity	0	1.1	1.4	0	1.1	1.4
Mortality-related benefits	**$6.2**	**$19.3**	**$32.5**	**$11.6**	**$39.1**	**$67.3**
* The base VSL is expressed in millions of 2021 dollars and based on 2013 income levels.						

Sensitivity Analysis using C-R Functions from Different Study Locations and Endpoints

To test the sensitivity of mortality-related health benefits to the recommended C-R functions for long-term exposure to PM2.5, two alternative sets of C-R functions estimated for different geographies and incidence data were used, based on recommendations by Industrial Economics (2016a). The sets of pooled C-R functions include those estimated from California data, and those estimated from national data. The two sets of C-R functions consider studies conducted at progressively larger geographic scales, usually with larger sample sizes.

Table 3B-7 shows the results of the sensitivity analysis for both health impacts and monetized benefits in milestone years 2032 and 2037. The quantified public health benefits appear to be lower under both alternative sets of C-R functions, ranging from about 61 percent for the national estimates to 19 percent for the California estimates. However, it should be noted that only the national estimates are directly comparable to the main estimates because of similar study populations. The key difference between the main estimates and the national estimates stem from the estimated magnitude of how mortality risk responds to a change in PM2.5 concentration, which is lower in the national studies used. The other two sensitivity tests also have different magnitudes of concentration-response relationship, but there are additional differences. The sensitivity test based on California estimates consists of the pooling of two studies which have a large variance in their estimated C-R relationships. The pooling method based on IEc's recommendation weighs the study with the smaller magnitude of mid-point estimate (Thurston et al. 2016) much more than the other study with a larger magnitude mid-point estimate (Jerrett et al. 2013); if an equal weighting pooling method would have been applied to these two studies, it would result in greater health impact estimates.

TABLE 3B-7: SENSITIVITY ANALYSIS OF PREMATURE DEATHS AVOIDED AND MONETIZED BENEFITS ASSOCIATED WITH REDUCED LONG-TERM EXPOSURE TO PM2.5

Scenarios	Premature Deaths Avoided (Annual Impacts)		Monetized Benefit (Billions of 2021$ per Year)	
	2032	2037	2032	2037
Main Scenario (L.A. Studies)	1,280	2,287	$15.3	$29.5
California Studies	238	429	$2.8	$5.5
National Studies	783	1,404	$9.3	$18.1

Distribution of PM2.5 Mortality-related Health Impacts by Lowest Measured Level

While the U.S. EPA concluded that, for both ozone and PM2.5, the current scientific evidence does not support the existence of a threshold concentration level below which no health impacts occur (U.S. EPA 2009; U.S. EPA 2013), various different health impact analysis have included a threshold, particularly for PM2.5, for the purpose of addressing the issue of statistical uncertainty at very low concentration levels (U.S. EPA 2012; U.S. EPA 2015b; CARB 2010). In these analyses, a threshold was determined by the lowest measured level (LML) of PM2.5 concentration in the study where the selected C-R function was estimated.

To address the uncertainty associated with this topic, a sensitivity analysis was conducted on the public health benefits of the 2022 AQMP, using a threshold of 5.8 $\mu g/m^3$ based on the LML for national data and 9.5 $\mu g/m^3$ based on the LML for Los Angeles data, both from Krewski et al. (2009). However, we note that alternative epidemiological studies measure significantly lower PM2.5 levels than 5.8 $\mu g/m^3$. For example, Crouse et al. (2011) assessed the relationship between PM2.5 and mortality with a LML of 1.9 $\mu g/m^3$. We found that 6.3 percent and 0.04 percent of the premature deaths avoided reported in Table 3B-3 for 2037 are associated with PM2.5 concentrations that were reduced to 5.8 $\mu g/m^3$ and 9.5 $\mu g/m^3$, respectively (see Table 3B-8).

The results of various sensitivity and uncertainty analyses conducted were consistent with the initial analysis. While it is important to recognize the uncertainties regarding valuation parameters, which specific function is most appropriate to use, and the extrapolation of concentration-response results to very low levels of pollution concentration, the sensitivity analyses continued to demonstrate the significant contribution of cleaner air to public health improvements, specifically from avoided premature deaths due to lower air pollution-related health risk.

TABLE 3B-8: DISTRIBUTION OF MORTALITY-RELATED HEALTH IMPACTS BY LML SCENARIO IN 2037

	Avoided Premature Deaths		
LML Scenario	Above LML Threshold	Below LML Threshold	Percent Above Threshold
5.8 µg/m^3	144	2,143	6.3%
9.5 µg/m^3	1	2,286	0.04%

South Coast AQMD

2022 AIR QUALITY MANAGEMENT PLAN

Final Socioeconomic Report

Appendix 3-C

IEc Memoranda on the Health Benefits Literature Review

December 2022

FINAL SOCIOECONOMIC REPORT
APPENDIX 3-C

IEC MEMORANDA ON THE HEALTH BENEFITS LITERATURE REVIEW

DECEMBER 2022

IEc

MEMORANDUM | October 31, 2022

TO Elaine Shen, South Coast Air Quality Management District

FROM William Raich, Melanie Jackson, and Henry Roman, Industrial Economics, Incorporated

SUBJECT Review of Mortality and Morbidity Risk Reduction Valuation Estimates for 2022 Socioeconomic Assessment

In its role as the air pollution control agency for the South Coast Air Basin, the South Coast Air Quality Management District (South Coast AQMD) develops air pollution control plans to help this portion of California achieve compliance with Federal and State air quality standards. As part of the development of the regional Air Quality Management Plan (AQMP), South Coast considers its socioeconomic impacts, including its expected benefits and costs. The resulting AQMP Socioeconomic Analysis includes a detailed assessment of the benefits of reducing air pollutant concentrations, which requires the use of several datasets covering a wide array of information including, but not limited to, baseline rates of disease, demographic data, concentration-response data, and valuation data.

For the 2016 AQMP Socioeconomic Analysis, South Coast updated its methods and inputs for calculating the benefits to society resulting from air pollution strategies to ensure all inputs were both scientifically- and economically-defensible. In this memorandum, we summarize updated valuation estimates for mortality and morbidity risk reductions associated with implementation of the 2022 AQMP. For a conceptual framework for the valuation approach, see the 2016 valuation memoranda.[1,2,3] Updated valuation estimates include several newer morbidity valuation estimates used in recent

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[1] For the 2016 mortality valuation review, see: http://www.aqmd.gov/docs/default-source/clean-air-plans/socioeconomic-analysis/iecmemos_november2016/scmortalityvaluation_112816.pdf?sfvrsn=6

[2] For the 2016 morbidity valuation review, see: http://www.aqmd.gov/docs/default-source/clean-air-plans/socioeconomic-analysis/iecmemos_november2016/scmorbidityvaluation_112816.pdf?sfvrsn=6

[3] The 2016 materials were derived from substantial previous work conducted by Ms. Robinson in collaboration with Dr. James K. Hammitt of Harvard University. Examples include: Robinson, L.A. and J.K. Hammitt. 2013. "Skills of the Trade: Valuing Health Risk Reductions in Benefit-Cost Analysis." *Journal of Benefit-Cost Analysis*. 4(1): 107-130; and Robinson, L.A. and J.K. Hammitt. 2015a. "Valuing Reductions in Fatal Illness Risks: Implications of Recent Research." *Health Economics*. Early View. The former article can be freely download from: http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=9456622&fulltextType=RA&fileId=S2194588800000518. The latter is included as an attachment to this memorandum for ease of reference. Note that circulation of the attachment is subject to copyright restrictions.

EPA regulatory analyses and VSL estimates updated to reflect inflation and growth in real income.

MORTALITY VALUATION

We recommend that South Coast continue applying a range of VSL estimates suggested in the 2016 review by Robinson and Hammitt. We conducted a supplemental review of the mortality risk literature and identified no new research that would lead to a substantively different conclusion than that of Robinson and Hammitt. When updated for inflation and growth in real income, these values include a central estimate of $9.2 million (2015 dollars, 2013 income levels) and a sensitivity ranging from $4.3 million to $14.3 million. We suggest that these values be adjusted to reflect the expected growth in population-average real income over time, as well as the cessation lag that characterizes the time stream of benefits associated with decreases in long-term $PM_{2.5}$ exposures.

To adjust values for inflation and real income, we recommend using California-specific datasets, specifically the California Department of Finance's historical and projected per-capita income growth and consumer product index. For income growth adjustments, a central elasticity estimate of 1.1 should be applied, alongside sensitivity analyses using elasticities of 0.0 and 1.4 if it appears that real income growth is likely to significantly affect the analytic conclusions. Finally, we recommend continued application of a mortality cessation lag structure consistent with the U.S. EPA Science Advisory Board-recommended 20-year lag.[4] The VSL should be discounted over the lag period at the same rate as used to discount other regulatory impacts.

MORBIDITY VALUATION

Limited willingness-to-pay (WTP) estimates are newly available in the peer-reviewed literature since IEc's 2016 review of available estimates. To update existing valuation estimates and develop estimates for new health endpoints we recommend applying the valuation functions recently updated by EPA and applied in its economic analysis of the Revised Cross-State Air Pollution Rule.[5] These estimates, in addition to the VSL estimates described above, are summarized in Table 1 below. Many of the hospitalization and emergency room visit valuations were developed by IEc using data from the Healthcare Cost and Utilization Project (HCUP). For hospitalizations, these estimates include both medical expenditures and lost wages associated with the length of hospital stay. For emergency room visits, these estimates include only medical expenditures.

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[4] Hammitt, JK and Bailar, J. (2010). Letter from James Hammitt, Chair, Advisory Council on Clean Air Compliance Analysis and John Bailar , Chair, Health Effects Subcommittee, to Administrator Lisa Jackson. Re: Review of EPA's Draft Health Benefits of the Second Section 812 Prospective Study of the Clean Air Act (June 2010). EPA-COUNCIL-10-001. Office of the Administrator, Science Advisory Board, U.S. EPA H.Q., Washington, DC.

[5] See https://www.epa.gov/sites/default/files/2021-03/documents/revised_csapr_update_ria_final.pdf.

TABLE 1. SUMMARY OF RECOMMENDED VALUATION ESTIMATES

Endpoint	C-R Function	C-R Function Study Population	Valuation Function ($2015)
Long-term Exposure to Ozone			
Mortality, Respiratory	Turner et al. (2016)	> 30 years	VSL (Robinson and Hammitt 2016). $9.2 million ($4.3-$14.2 million)[1]
Incidence, Asthma	Pooling of: Tetreault et al. (2016); Garcia et al. (2019)	0-17 years	$17,232 (Belova et al. 2020)
Short-term Exposure to Ozone			
School Loss Days, All Cause	Gilliland et al. (2001)	5-17 years	$106/day (BLS, 2015)
Minor Restricted Activity Days	B. D. Ostro and Rothschild (1989)	18-65 years	$70/day (Tolley et al. 1986)
Emergency Room Visits, All Respiratory	Malig et al. (2016)	All ages	$875/visit (HCUP 2016)
Emergency Room Visits, Asthma	Pooling of: Malig et al. (2016); Gharibi et al. (2019)	All ages	Average of: $447/visit (Standford et al. 1999); $534/visit (Smith et al. 1997)
Hospital Admissions, Asthma	Moore et al. (2008)	0-17 years	$6,564 (HCUP 2014)
Asthma Symptoms (chest tightness, cough, wheeze, shortness of breath)	Lewis et al. (2013)	5-17 years	$219/day (Dickie and Messman 2005)

Endpoint	C-R Function	C-R Function Study Population	Valuation Function ($2015)
Long-term Exposure to $PM_{2.5}$			
Mortality, All Cause	Pooling of: LA-specific estimates (Jerrett et al. 2005; Jerrett et al. 2013), Kriging and LUR (Krewski et al. 2009), Woodruff et al. 2008 (infants only, not pooled).	<1 year; > 30 years	VSL (Robinson and Hammitt 2016). $9.2 million ($4.3-$14.2 million)
Incidence, Asthma	Pooling of: Tetreault et al. (2016); Garcia et al. (2019)	0-17 years	$17,232 (Belova et al. 2020)
Incidence, Hay Fever/Rhinitis	Parker et al. (2009)	3-17 years	$600 (Soni 2008)
Incidence, Lung Cancer	Gharibvand et al. (2016)	> 30 years	$33,809 (Kaye et al. 2018)
Hospital Admissions, Alzheimer's Disease	Kioumourtzoglou et al. (2016)	> 65 years	Average of: $156,920 (Alzheimer's Association 2020); $184,500 (Jutkowitz et al., 2017)
Hospital Admissions, Parkinson's Disease	Kioumourtzoglou et al. (2016)	> 65 years	$567,285 (Yang et al. 2020)

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IEc

MEMORANDUM | October 31, 2022

TO Elaine Shen, South Coast Air Quality Management District

FROM Henry Roman, William Raich, Caroline Borden, and Melanie Jackson, Industrial Economics, Incorporated

SUBJECT Review of Air Pollution-Related Health Endpoints and Concentration-Response Functions for Particulate Matter and Ozone

Every four to six years, the South Coast Air Quality Management District (South Coast AQMD) updates the regional Air Quality Management Plan (AQMP) for Los Angeles, Orange, Riverside, and San Bernardino Counties in southern California. As part of the development of this Plan, South Coast AQMD considers the socioeconomic impacts of the AQMP. These estimated benefits and costs are detailed in a Socioeconomic Report that accompanies the AQMP.

A key analysis in the Socioeconomic Report is an assessment of the health benefits of the AQMP on residents of these four counties. This assessment of health impacts relies on data describing the baseline incidence of mortality and morbidity endpoints, the estimated change in air pollution concentrations, population data, and the relationship between exposure and health outcomes. South Coast AQMD draws this latter input from population-based epidemiological studies. These studies provide information on which health endpoints are associated with exposure to air pollutants, and the mathematical relationship between exposure and the outcome. This report presents our review of recent studies of the health impacts associated with exposure to particles less than 2.5 micrometers in diameter ($PM_{2.5}$) and ozone (O_3) and provides recommendations to inform South Coast AQMD's decisions regarding which health endpoints to include in its benefits analysis of the 2022 AQMP and which mathematical functions should be used to evaluate each endpoint.

METHODS

Our approach consisted of three steps. First, we identified the endpoints and studies used in South Coast AQMD's 2016 Socioeconomic Analysis. Second, we reviewed the current evaluation of PM and ozone effects by the U.S. Environmental Protection Agency (U.S. EPA) in its most recent Integrated Science Assessment (ISA) documents (U.S. EPA, 2019, 2020, 2022). Finally, we conducted a supplemental review of the health literature published since the PM and O3 ISA documents.

IEc sought to identify the health endpoint categories and health studies used to evaluate the health benefits of the 2016 AQMP. IEc based its findings of the 2016 categories and inputs based on review of the 2016 Socioeconomic Report and appendices, additional background documentation provided by South Coast AQMD, and our knowledge of the standard BenMAP functions typically used at the time of the last assessment.

U.S. EPA INTEGRATED SCIENCE ASSESSMENTS

In addition to our literature review, we also reviewed the most recent Integrated Science Assessment for PM published by the U.S. EPA in 2019, the Supplement to the 2019 Integrated Science Assessment for Particulate Matter published by the U.S. EPA in 2021, and the Integrated Science Assessment for Ozone and Related Photochemical Oxidants published by the U.S. EPA in 2020. The comprehensive assessment of the health literature presented in the ISAs provides U.S. EPA's current assessment of the strength of the evidence linking PM and ozone exposures with an array of health endpoint categories and thus serves as a suitable baseline against which we can compare the findings of recent research.

SUPPLEMENTAL LITERATURE REVIEW

In order to ensure South Coast AQMD uses the most current science when evaluating the health impacts of air pollution control, we conducted a literature review of mortality and morbidity impacts of exposure to $PM_{2.5}$ and ozone O_3. We searched PubMed and Google Scholar for peer-reviewed articles on $PM_{2.5}$ from March 2021 onward and articles on O_3 from March 2018 onward, using search terms "[pollutant] AND mortality AND California" and "[pollutant] AND morbidity AND California," where [pollutant] was $PM_{2.5}$ or ozone. We prioritized studies to evaluate for inclusion in the 2022 Socioeconomic Report by evaluating them using the criteria described in our Evaluation Criteria Memo to South Coast AQMD dated March 3, 2022; these criteria are summarized in Exhibit 1. Our criteria serve as guidance for evaluating studies and weighing their strengths and limitations. No one study is likely to meet all criteria listed.

EXHIBIT 1. CRITERIA FOR EVALUATING EPIDEMIOLOGICAL STUDIES

GENERAL:

1. Study is peer-reviewed.
2. Study is written in English.
3. Study measures exposure to at least one of the following pollutants: O_3, $PM_{2.5}$.
4. Preference given to studies or groups of studies that significantly advance our understanding of the relationship between air pollution exposures and mortality and morbidity endpoints, including those endpoints previously quantified by the South Coast AQMD in its Air Quality Management Plans as well as new endpoints.
5. Study was published after IEc's previous socioeconomic review (2016 - present)[1]

GEOGRAPHY AND STUDY POPULATION:

6. Study measures exposures at or near ambient levels found in the South Coast Air Basin. Order of preference of study location:
    a. South Coast Air Basin (Los Angeles, Orange, Riverside, and San Bernardino Counties)
    b. Within State of California
    c. Within Western United States
    d. Within United States or Canada
7. Study uses study population with similar characteristics as found in Los Angeles, Orange, Riverside, and San Bernardino counties.

STUDY DESIGN:

8. Study is population-based, preferably using cohort and case-control epidemiological study designs. Controlled human exposure studies may be evaluated for supporting evidence. Animal and in-vitro studies excluded.
9. Study controls for factors that may obscure the true concentration-response relationship, including selection bias, misclassification, recall bias, confounding (including by other pollutants), effect modification, mortality displacement, loss to follow-up, etc.
10. Study appropriately assesses any potential lag between exposure and outcomes.
11. Study appropriately assesses any potential exposure thresholds for health outcomes.
12. Study clearly presents information about uncertainty in results to facilitate evaluation and comparison with other studies.
13. Prefer studies that assess changes in the risk of incidence of disease, rather than exacerbation of existing cases or changes in symptoms.
14. Prefer studies that characterize pollutant exposure using advanced air quality models that fuse data from multiple sources (e.g., monitors, satellite sensors).

[1] While we focused our search on studies published after IEc's previous socioeconomic review, we also recommend several studies that were published prior to 2016. This is largely due to the evolution of U.S> EPA's focus, as reflected in the most recent ISAs, which includes an emphasis on broader categories of health impacts and the inclusion of new health endpoints.

RESULTS

In this section, we present the results of our research, first presenting baseline information on endpoints and functions used previously and current weight of evidence determinations about causality by U.S. EPA, and then presenting the results of our supplemental literature review. Exhibit 2 summarizes our recommended endpoints and epidemiological studies for deriving health impact functions for use in the benefits analysis of the 2022 AQMP.

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EXHIBIT 2 RECOMMENDED PM2.5 AND OZONE HEALTH ENDPOINTS AND STUDIES

POLLUTANT	ENDPOINT GROUP	ENDPOINT	FIRST AUTHOR	YEAR	AGES	AREA STUDIED	ICD-9 CODES	NEW STUDY?	REPLACES
$PM_{2.5}$	Mortality	Mortality, All Cause*	Krewski	2009	30-99	California	N/A	No	N/A
			Jerrett	2005	30-99	California	N/A	No	N/A
			Jerrett	2013	30-99	California	N/A	No	N/A
			Woodruff	2008	0-0	US counties with >250,000 residents	N/A	Yes	Woodruff et al., 1997
	Cardiovascular	Emergency Room Visits, All Cardiac Endpoints	Ostro	2016	0-99	California (8 metropolitan areas, including Los Angeles, Riverside)	390-459	Yes	Moolgavkar 2003; Moolgavkar 2006b
		Hospital Admissions, All Cardiac Outcomes	Talbott	2014	0-99	Seven US states (FL, MA, NH, NJ, NM, NY, WA)	390-459	Yes	Moolgavkar 2003; Moolgavkar 2006b
		Acute Myocardial Infarction, Nonfatal	Wei	2019	18-99	Continental US	NR	Yes	Pope et al. 2006, Sullivan et al. 2005, Zanobetti et al. 2009, Zanobetti & Schwartz 2006
		Hospital Admissions, Ischemic stroke	Shin	2014	65-99	16 short-term studies (metaanalysis)	433-434	No	N/A
		Incidence, Out of Hospital Cardiac Arrest	Ensor	2013	18-99	Houston, TX	N/A	Yes	N/A (New endpoint)
	Nervous System	Hospital Admissions, Alzheimers Disease	Kioumourtzoglou	2016	65-99	50 northeastern US cities	331	Yes	N/A (New endpoint)
		Hospital Admissions, Parkinsons Disease	Kioumourtzoglou	2016	65-99	50 northeastern US cities	332	Yes	N/A (New endpoint)
	Respiratory	Emergency Room Visits, Respiratory	Ostro	2016	0-99	California (8 metropolitan areas, including Los Angeles, Riverside)	460-519	Yes	Zanobetti et al. 2009

POLLUTANT	ENDPOINT GROUP	ENDPOINT	FIRST AUTHOR	YEAR	AGES	AREA STUDIED	ICD-9 CODES	NEW STUDY?	REPLACES
		Hospital Admissions, Respiratory	Ostro	2009	0-17	California (6 counties, including Riverside)	460-519	Yes	N/A
			Zanobetti	2009	65-99	26 US communities	460-519	No	
		Emergency Room Visits, Asthma	Ostro	2016	0-99	California (8 metropolitan areas, including Los Angeles, Riverside)	493	Yes	Delfino et al. 2014
		Hospital Admissions, Asthma	Delfino	2014	0-17	California (Orange County)	493	No	N/A
		Incidence, Asthma	Tetreault	2016	0-17	Quebec, Canada	N/A	Yes	N/A (New endpoint)
			Garcia	2019	5-17	California (12 southern CA communities)	N/A	Yes	
		Asthma Symptoms, Albuterol use	Rabinovitch	2006	6-17	Denver, CO	N/A	Yes	Ostro et al. 2001, Mar et al. 2004, Young et al. 2014
		Incidence, Hay Fever / Rhinitis	Parker	2009	3-17	Nationwide US	N/A	Yes	N/A (New endpoint)
		Minor Restricted Activity Days	Ostro	1989	18-64	Nationwide US	N/A	No	N/A
		Incidence, Lung Cancer	Gharibvand	2016	18-99	Nationwide US and five Canadian provinces	C34.0-C34.9 (ICD-10)	Yes	N/A (New endpoint)
	Other	Work loss days	Ostro	1987	18-64	Nationwide US	N/A	No	N/A
Ozone	Mortality	Mortality, Respiratory*	Turner	2016	30-99	Nationwide US	460-519	Yes	N/A (New endpoint)
	Respiratory	Emergency Room Visits, Respiratory	Malig	2016	0-99	California	460-519	Yes	Katsouyanni et al. 2009
			Malig	2016	0-99	California	493	Yes	

POLLUTANT	ENDPOINT GROUP	ENDPOINT	FIRST AUTHOR	YEAR	AGES	AREA STUDIED	ICD-9 CODES	NEW STUDY?	REPLACES
		Emergency Room Visits, Asthma	Gharibi	2019	0-99	California (San Joaquin Valley)	493	Yes	Mar and Koenig 2009, Meng et al. 2009
		Hospital Admissions, Asthma	Moore	2008	0-17	California (South Coast Air Basin)	493	No	N/A
		Incidence, Asthma	Tetreault	2016	0-17	Quebec, Canada	N/A	Yes	McConnell et al. 2010
			Garcia	2019	5-17	California (12 southern CA communities)	N/A	Yes	
		Asthma Symptoms, Chest Tightness	Lewis	2013	5-17	Detroit, MI	N/A	Yes	N/A (New endpoint)
		Asthma Symptoms, Cough	Lewis	2013	5-17	Detroit, MI	N/A	Yes	N/A (New endpoint)
		Asthma Symptoms, Shortness of Breath	Lewis	2013	5-17	Detroit, MI	N/A	Yes	N/A (New endpoint)
		Asthma Symptoms, Wheeze	Lewis	2013	5-17	Detroit, MI	N/A	Yes	N/A (New endpoint)
		Minor Restricted Activity Days	Ostro	1989	18-64	Nationwide US	N/A	No	N/A
	Other	School loss days	Gilliland	2001	5-17	California (communities within 200 miles of Los Angeles)	N/A	No	N/A

* Represents changes in annual mortality from long-term exposures

U.S. EPA CAUSALITY DETERMINATIONS FROM INTEGRATED SCIENCE ASSESSMENTS FOR PM AND OZONE

U.S. EPA's Integrated Science Assessments (ISAs) for PM and O_3 (published in 2019 and 2020, respectively) and Supplement to the ISA for PM (published in 2022) discuss the weight of evidence of PM and O_3's role in causing the mortality and morbidity endpoints. U.S. EPA uses the definitions in Exhibit 3 for its causality determinations.

EXHIBIT 3. U.S. EPA WEIGHT OF EVIDENCE FOR CAUSALITY DETERMINATIONS (U.S. EPA 2020)

Table II Weight of evidence for causality determinations.

	Health Effects	Ecological and Other Welfare Effects
Causal relationship	Evidence is sufficient to conclude that there is a causal relationship with relevant pollutant exposures (e.g., doses or exposures generally within one to two orders of magnitude of recent concentrations). That is, the pollutant has been shown to result in health effects in studies in which chance, confounding, and other biases could be ruled out with reasonable confidence. For example: (1) controlled human exposure studies that demonstrate consistent effects, or (2) observational studies that cannot be explained by plausible alternatives or that are supported by other lines of evidence (e.g., animal studies or mode of action information). Generally, the determination is based on multiple high-quality studies conducted by multiple research groups.	Evidence is sufficient to conclude that there is a causal relationship with relevant pollutant exposures. That is, the pollutant has been shown to result in effects in studies in which chance, confounding, and other biases could be ruled out with reasonable confidence. Controlled exposure studies (laboratory or small- to medium-scale field studies) provide the strongest evidence for causality, but the scope of inference may be limited. Generally, the determination is based on multiple studies conducted by multiple research groups, and evidence that is considered sufficient to infer a causal relationship is usually obtained from the joint consideration of many lines of evidence that reinforce each other.
Likely to be a causal relationship	Evidence is sufficient to conclude that a causal relationship is likely to exist with relevant pollutant exposures. That is, the pollutant has been shown to result in health effects in studies where results are not explained by chance, confounding, and other biases, but uncertainties remain in the evidence overall. For example: (1) observational studies show an association, but copollutant exposures are difficult to address and/or other lines of evidence (controlled human exposure, animal, or mode of action information) are limited or inconsistent, or (2) animal toxicological evidence from multiple studies from different laboratories demonstrate effects, but limited or no human data are available. Generally, the determination is based on multiple high-quality studies.	Evidence is sufficient to conclude that there is a likely causal association with relevant pollutant exposures. That is, an association has been observed between the pollutant and the outcome in studies in which chance, confounding, and other biases are minimized but uncertainties remain. For example, field studies show a relationship, but suspected interacting factors cannot be controlled, and other lines of evidence are limited or inconsistent. Generally, the determination is based on multiple studies by multiple research groups.
Suggestive of, but not sufficient to infer, a causal relationship	Evidence is suggestive of a causal relationship with relevant pollutant exposures but is limited, and chance, confounding, and other biases cannot be ruled out. For example: (1) when the body of evidence is relatively small, at least one high-quality epidemiologic study shows an association with a given health outcome and/or at least one high-quality toxicological study shows effects relevant to humans in animal species, or (2) when the body of evidence is relatively large, evidence from studies of varying quality is generally supportive but not entirely consistent, and there may be coherence across lines of evidence (e.g., animal studies or mode of action information) to support the determination.	Evidence is suggestive of a causal relationship with relevant pollutant exposures, but chance, confounding, and other biases cannot be ruled out. For example, at least one high-quality study shows an effect, but the results of other studies are inconsistent.
Inadequate to infer a causal relationship	Evidence is inadequate to determine that a causal relationship exists with relevant pollutant exposures. The available studies are of insufficient quantity, quality, consistency, or statistical power to permit a conclusion regarding the presence or absence of an effect.	Evidence is inadequate to determine that a causal relationship exists with relevant pollutant exposures. The available studies are of insufficient quality, consistency, or statistical power to permit a conclusion regarding the presence or absence of an effect.
Not likely to be a causal relationship	Evidence indicates there is no causal relationship with relevant pollutant exposures. Several adequate studies, covering the full range of levels of exposure that human beings are known to encounter and considering at-risk populations and lifestages, are mutually consistent in not showing an effect at any level of exposure.	Evidence indicates there is no causal relationship with relevant pollutant exposures. Several adequate studies examining relationships with relevant exposures are consistent in failing to show an effect at any level of exposure.

Exhibit 4 reproduces the tables from the 2020 ISA for ozone the U.S. EPA Supplement to the 2019 ISA for PM. It summarizes U.S. EPA's findings of causality for each ozone and PM health endpoint evaluated. It shows that short-and long-term exposure to ozone causes a range of respiratory effects, including mortality. It similarly shows both short- and long-term $PM_{2.5}$ exposure causes effects to the cardiovascular system, increases mortality, likely affects the respiratory system, and likely impacts cancer risk.

EXHIBIT 4. SUMMARY OF USEPA'S CAUSAL DETERMINATIONS FOR OZONE AND PM2.5 EXPOSURE

Health Category	Causal Determination	Quantified ?
Short-Term Exposure to Ozone		
Total Mortality	*Suggestive of a causal relationship*	N
Cardiovascular Effects	*Suggestive of a causal relationship*	N
Respiratory Effects	**Causal relationship**	**Y**
Central Nervous System Effects	*Suggestive of a causal relationship*	N
Metabolic Effects	**Likely to be a causal relationship**[1]	N
Effects on Cutaneous and Ocular Tissues	*Inadequate to infer a causal relationship*	N
Long-Term Exposure to Ozone		
Total Mortality	*Suggestive of a causal relationship*	N
Cardiovascular Effects	*Suggestive of a causal relationship*	N
Respiratory Effects (including respiratory mortality)[2]	**Likely to be a causal relationship**	**Y**
Reproductive and Developmental Effects	*Suggestive of a causal relationship*	N
Central Nervous System Effects	*Suggestive of a causal relationship*	N
Cancer	*Inadequate to infer a causal relationship*	N
Short-Term Exposure to PM2.5		
Mortality	**Causal relationship**[3]	N
Cardiovascular Effects	**Causal relationship**	**Y**
Respiratory Effects	**Likely to be a causal relationship**	**Y**
Central Nervous System Effects	*Suggestive of a causal relationship*	N
Long-Term Exposure to PM2.5		
Mortality	**Causal relationship**	**Y**
Cardiovascular Effects	**Causal relationship**[4]	N

Health Category	Causal Determination	Quantified ?
Respiratory Effects	**Likely to be a causal relationship**	**Y**
Central Nervous System Effects	**Likely to be a Causal Relationship**	**Y**
Reproductive and Developmental Effects	*Suggestive of a causal relationship*	N
Cancer, Mutagenicity, Genotoxicity	***Likely to be a causal relationship***	**Y**

Notes:

1. The ISA determination of likely causal for metabolic effects is based on a synthesis of evidence from toxicology studies in animals, controlled human exposure studies, and epidemiological studies. Due to the more limited epidemiological evidence currently available, the USEPA has not yet identified a suitable epidemiological study from which to derive a health impact function for use in a domestic air quality benefit analysis.
2. The ISA includes cause-specific respiratory mortality as a subset of the respiratory effects category.
3. We do not quantify mortality due to short-term exposure to PM2.5 since mortality due to long-term exposure to PM2.5 is expected to be inclusive of any short-term exposure impacts.
4. Although we do not quantify cardiovascular morbidity effects using risk models with long-term exposure to PM2.5 a number of cardiovascular effects modeled based on short-term exposure to PM2.5 are likely to have chronic impacts following the initial event (e.g., stroke, out-of-hospital cardiac arrest, and AMI). Our valuation of the short-term cardiovascular endpoints reflects long-term, multi-year costs-of-illness.

Source: USEPA ISAs (2019; 2020)

PM2.5 AND O3 LITERATURE REVIEW FINDINGS

In the following section, we discuss the results of our supplemental literature review for health effects of $PM_{2.5}$ published since March 2021 and O3 published since March 2018. A summary table listing details on all studies found in our review can be found in Appendix A.

We identified seven studies conducted in California that assessed the relationship between exposure to $PM_{2.5}$ and/or O_3 and a potentially relevant health endpoint. Six of these studies were excluded from further consideration because they did not adequately satisfy our criteria (see Exhibit 1) due to the specific endpoint studied or experimental design. The remaining study is summarized below.

Gharibi et al. (2019) investigated the association between short-term exposure to O3 and emergency department (ED) visits due to asthma in the San Joaquin Valley, California from June to September, 2015. The authors identified 1,101 asthma ED visits during the study period and obtained the maximum daily 8-hour average O_3 concentration from 18 sampling stations throughout the San Joaquin Valley. The mean 8-hour average O_3 concentration during the study period was 50.7 ppb, and the maximum was 94.5 ppb. They employed a time-stratified case-crossover design, assigning ozone exposures to each patient based on zip code of residence and comparing the exposure of each patient on the day of or during the days prior to their ED visit to their exposures on several referent days. The authors fit conditional logistic regression models, controlling for temperature, $PM_{2.5}$, NO_2, and CO. In a multi-pollutant model, the authors report an odds ratio of 1.066 (1.032 - 1.082) associated with an 18.1 ppb increase in 3-day lagged O_3.

RECOMMENDATIONS

Exhibit 5 summarizes our recommended PM- and O_3-related health endpoints for the 2022 Socioeconomic Analysis. In summary, we propose evaluation of the same $PM_{2.5}$-related endpoints evaluated in 2016, plus cardiovascular and respiratory emergency room visits, out of hospital cardiac arrest, hospital admissions for Alzheimer's and Parkinson's disease, and incidence of asthma, asthma symptoms, hay fever/rhinitis, and lung cancer. We propose evaluation of O_3-related hospital admissions and emergency department visits for asthma, minor restricted activity days, and school-loss days as evaluated in 2016, plus respiratory mortality, respiratory emergency room visits, and asthma incidence. We also are expanding certain endpoint categories to include additional age groups from the studies we identified. Exhibit 5 uses shading to indicate new study recommendations comparted to the 2016 Socioeconomic Report.

EXHIBIT 5. RECOMMENDED $PM_{2.5}$- AND O_3-RELATED HEALTH ENDPOINTS

ENDPOINT	POLLUTANT	STUDY	AGES STUDIED	STUDY LOCATION
PM2.5-RELATED HEALTH ENDPOINTS				
PREMATURE MORTALITY				
Mortality, All Cause	$PM_{2.5}$ (annual avg)	Krewski et al. 2009;	30-99	Los Angeles, CA
		Jerrett et al. 2005	30-99	Los Angeles, CA
		Jerrett et al. 20013	30-99	Los Angeles, CA
		Woodruff et al. 2008	0-0	US counties with >250,000 residents
CARDIOVASCULAR MORBIDITY				
ER Visits, All Cardiac Endpoints	$PM_{2.5}$ (24-hour avg)	Ostro et al. 2016	0-99	8 metropolitan areas in California
HA, All Cardiac Outcomes	$PM_{2.5}$ (24-hour avg)	Talbott et al. 2014	0-99	Seven US states (FL, MA, NH, NJ, NM, NY, WA)
Acute Myocardial Infarction, Nonfatal	$PM_{2.5}$ (24-hour avg)	Wei et al. 2019	18-99	Continental US
HA, Ischemic stroke	$PM_{2.5}$ (24-hour avg)	Shin et al. 2014	65-99	Varies (meta-analysis)
Incidence, Out of Hospital Cardiac Arrest	$PM_{2.5}$ (24-hour avg)	Ensor et al. 2013	18-99	Houston, TX
NERVOUS SYSTEM MORBIDITY				
HA, Alzheimers Disease	$PM_{2.5}$ (annual avg)	Kioumourtzoglou et al. 2016	65-99	50 northeastern US cities
HA, Parkinsons Disease	$PM_{2.5}$ (annual avg)	Kioumourtzoglou et al. 2016	65-99	50 northeastern US cities

ENDPOINT	POLLUTANT	STUDY	AGES STUDIED	STUDY LOCATION
RESPIRATORY MORBIDITY				
ER Visits, All Respiratory	$PM_{2.5}$ (24-hour avg)	Ostro et al. 2016	0-99	8 metropolitan areas in California
HA, All Respiratory	$PM_{2.5}$ (24-hour avg)	Ostro et al. 2009	0-17	6 counties in California
		Zanobetti et al. 2009	65-99	26 US communities
ER Visits, Asthma	$PM_{2.5}$ (24-hour avg)	Ostro et al. 2016	0-99	8 metropolitan areas in California
HA, Asthma	$PM_{2.5}$ (24-hour avg)	Delfino et al. 2014	0-17	Orange County, CA
Incidence, Asthma	$PM_{2.5}$ (annual avg)	Tetreault et al. 2016	0-17	Quebec, Canada
		Garcia et al. 2019	5-17	12 southern California communities
Asthma Symptoms, Albuterol use	$PM_{2.5}$ (24-hour avg)	Rabinovitch et al. 2006	6-17	Denver, CO
Incidence, Hay Fever/Rhinitis	$PM_{2.5}$ (annual avg)	Parker et al. 2009	3-17	Nationwide US
Incidence, Lung Cancer	$PM_{2.5}$ (monthly avg)	Gharibvand et al. 2017	18-99	Nationwide US
Minor Restricted Activity Days	$PM_{2.5}$ (24-hour avg)	Ostro and Rothschild 1989	18-64	Nationwide US and 5 Canadian provinces
OTHER ENDPOINTS				
Work Loss days	$PM_{2.5}$ (24-hour avg)	Ostro et al. 1987	18-64	Nationwide US
OZONE-RELATED HEALTH ENDPOINTS				
RESPIRATORY MORTALITY				
Mortality, Respiratory	O_3 (annual avg)	Turner et al. 2016	30-99	Nationwide US
RESPIRATORY MORBIDITY				
ER Visits, Respiratory	O_3 (1-hour max)	Malig et al. 2016	0-99	California
ER Visits, Asthma	O_3 (1-hour max)	Malig et al. 2016	0-99	California
	O_3 (8-hour max)	Gharibi et al. 2019	0-99	San Joaquin Valley, California
HA, Asthma	O_3 (8-hour max)	Moore et al. 2008	0-17	South Coast Air Basin, California
Incidence, Asthma	O_3 (8-hour max)	Tetreault et al. 2016	0-17	Quebec, Canada
	O_3 (8-hour max)	Garcia et al. 2019	5-17	12 southern California communities
Asthma Symptoms, Chest Tightness	O_3 (8-hour max)	Lewis et al. 2013	5-17	Detroit, MI
Asthma Symptoms, Cough	O_3 (8-hour max)	Lewis et al. 2013	5-17	Detroit, MI
Asthma Symptoms, Shortness of Breath	O_3 (8-hour max)	Lewis et al. 2013	5-17	Detroit, MI
Asthma Symptoms, Wheeze	O_3 (8-hour max)	Lewis et al. 2013	5-17	Detroit, MI
Minor Restricted Activity Days	O_3 (8-hour max)	Ostro and Rothschild 1989	18-64	Nationwide uS
OTHER ENDPOINTS				
School Loss Days, All Cause	O_3 (8-hour max)	Gilliland et al. 2001	5-17	California communities within 200 miles of Los Angeles
ER = Emergency Room, HA = Hospital Admissions				

PM MORTALITY

We found insufficient evidence to warrant changing the recommended main studies for the PM mortality analysis for adults. Evidence from more recent large sample studies bolsters the relationship between PM and mortality, but none were conducted specifically in California. We do recommend updating the main infant mortality study to the latest published by Woodruff et al., in 2008.

PM MORBIDITY

In general, our recommendations mirror those of EPA in its recent RIAs, such as the Cross-State Air Pollution Rule, with the exception of using a more recent study. Wei et al, 2019, for quantifying acute myocardial infarctions, and pooling a local California study of asthma incidence (Garcia et al., 2019) with the larger Tetreault study recommended by U.S. EPA. These changes reflect the updated causality determinations in the ISAs, emphasize broader endpoints for effects such as hospital admissions and emergency department visits (to minimize double counting concerns), and favor studies capturing broader age groups. Where possible, we emphasized local studies that also follow these trends.

Summaries for most of the recommended studies can be found in the Technical Support document for the Cross-State Air Pollution Rule, or in the Appendices to the User Manual for EPA's BenMAP tool.[2] There are two studies we recommend not summarized in these two sources at present. The first is a study by Wei et al, 2019 for quantifying acute myocardial infarctions; this is a larger and much more current study that we believe can replace the previous estimates of several pooled studies used previously.

Wei et al. (2019) Acute Myocardial Infarction, Nonfatal

Wei et al. (2019) evaluated the relationship between short-term PM2.5 exposure and hospital admissions for 214 mutually exclusive disease groups, including acute myocardial infarction, in a time-stratified, case-crossover analysis of over 95 million Medicare inpatient hospital claims from 2000-2012. The authors estimated daily PM2.5 levels at a 1-km2 grid cell level using a satellite based, neural network model that was calibrated using monitor data and assigned 0-1 day lagged PM2.5 exposure to each participant by zip code of residence. For each disease group, Wei et al. (2019) created a case crossover dataset that controlled for individual level and zip code level variables,

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[2] See https://www.epa.gov/sites/default/files/2021-03/documents/estimating_pm2.5-_and_ozone-attributable_health_benefits_tsd.pdf and https://www.epa.gov/sites/default/files/2015-04/documents/benmap-ce_user_manual_march_2015.pdf

day of the week, seasonality, and long-term time trends. They used conditional logistic regression models to estimate associations between PM2.5 exposure and risk of hospital admission and found positive associations for numerous rarely studied and numerous well-studied disease groups.

In a single-pollutant model, the coefficient and standard error are estimated from a reported relative increase in risk (0.11%) and 95% confidence interval (0.07%-0.16%) associated with a 1 ug/m3 increase in 0-1 day lagged PM2.5 exposure (Wei et al. 2019, Figure 3, CCS 100 Acute Myocardial Infarction).

OZONE MORTALITY

Based on the updated finding of the most recent U.S. EPA ISA document finding a causal relationship with long-term ozone exposures and respiratory effects including respiratory mortality, we recommend adding this endpoint to the 2022 AQMP Socioeconomic Analysis. We identified two studies, one nationwide (Turner et al, 2016) and one California-specific (Jerrett et al, 2013). We recommend applying the Turner study because it has a much larger sample size and an exposure period both wider and more recent than Jerrett, despite Jerrett's locational advantage. For a summary of the Turner study, please consult the Appendices to the User Manual for U.S. EPA's BenMAP tool. We do not recommend quantifying respiratory mortality related to short-term ozone to avoid double-counting with the long-term estimate.

OZONE MORBIDITY

In general, our recommendations mirror those of U.S. EPA in its recent RIAs, such as the Cross-State Air Pollution Rule, with the exception of pooling Garcia et al, 2019 with the Tetreault study of asthma onset in children, as was done for PM; recommending the pooling of local California studies of ED respiratory visits for asthma by Malig et al., 2016 and Gharibi et al., 2016; and using Malig et al., 2016 for all respiratory ED visits. These changes reflect the updated causality determinations in the ISAs, emphasize broader endpoints for effects such as hospital admissions and emergency department visits (to minimize double counting concerns), and favor studies capturing broader age groups. Where possible, we emphasized local studies that also follow these trends.

Summaries for most of the recommended studies can be found in the Technical Support document for the Cross-State Air Pollution Rule, or in the Appendices to the User Manual for U.S. EPA's BenMAP tool.[3] There are two studies we recommend not summarized in these two sources at present. The first is a study by Gharibi et al, 2019 of ER visits for asthma, described above; the second is the study of ED visits for respiratory endpoints and asthma by Malig et al., 2016. We recommend pooling of these studies to

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[3] Ibid.

generate a single estimate for asthma ED visits for the 0-99 age group, and we recommend subtracting these visits from the ED visits for all respiratory causes, to avoid double counting.

Malig et al. (2016) ED visits All Respiratory and Asthma

Malig et al. (2016) evaluated the relationship between short-term (1 hour-max) ozone exposure and Emergency Department (ED) visits for asthma and for all respiratory causes in a multi-site time-stratified, case-crossover analysis of over 3.7 million ED visit records from 2005-2008 among California residents living withing 20 km of an ozone monitor. The authors controlled for temperature and relative humidity effects using and extensive network of meteorological observations throughout the state.The authors used a conditional logistic regression to estimate effects by climate zone, which were then pooled using random effects meta-analysis. Effects controlled for temperature, relative humidity, season, monitor difference, and additional socioeconomic variables.

In the all respiratory model, the coefficient and standard error are estimated from a reported relative increase in risk (0.27%) and 95% confidence interval (0.10%-0.44%) associated for ED visits for all ages with a 10 ppb increase in 1-hour max ozone (full-year estimate). In the asthma model, the coefficient and standard error are estimated from a reported relative increase in risk (1.41%) and 95% confidence interval (0.68%-2.15%) for all age ED visits associated with a 10 ppb increase in 1-hour max ozone (full-year estimate).

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MEMORANDUM | November 2, 2022

TO Elaine Shen, South Coast Air Quality Management District

FROM Melanie Jackson, William Raich, and Henry Roman, Industrial Economics, Incorporated

SUBJECT Review of Baseline Incidence Rate Estimates for Use in 2022 Socioeconomic Assessment

In its role as the air pollution control agency for the South Coast Air Basin, the South Coast Air Quality Management District (SCAQMD) develops air pollution control plans to help this portion of California achieve compliance with Federal and State air quality standards. As part of the development of the regional Air Quality Management Plan (AQMP), SCAQMD considers its socioeconomic impacts, including its expected benefits and costs. The resulting AQMP Socioeconomic Analysis includes a detailed assessment of the benefits of reducing air pollutant concentrations, which requires the use of several datasets covering a wide array of information including, but not limited to, data on health condition incidence, demographics, concentration-response relationships, and economic values.

As it prepares for the 2022 AQMP Socioeconomic Analysis, SCAQMD needs to ensure that it is applying the most up-to-date, scientifically-defensible methods and inputs for calculating the benefits to society resulting from air pollution strategies. In this memorandum, we provide our recommendations for the baseline incidence rate data to be used in the BenMAP benefits analysis to support the 2022 Socioeconomic analysis of the 2022 AQMP.

BACKGROUND

Development of appropriate baseline incidence values is a key step in assessing the potential health benefits of air quality strategies. In most cases, the concentration-response (C-R) functions that relate exposure with health outcomes express the change in incidence of a health endpoint as proportional to the baseline incidence of that endpoint. As a result, the use of local data, where available, is preferred for benefits analyses conducted at regional or metropolitan scales, especially where health incidence data is known or expected to exhibit significant spatial variability.

Appropriate selection of baseline incidence values involves obtaining data that best match characteristics such as the health endpoint of interest, the study location, the population of interest, and the time period of the analysis. For example, studies of hospital admissions endpoints may include a range of diagnoses that fall within a particular diagnostic category, expressed in terms of their International Classification of Diseases (ICD) 9 or ICD 10 codes. ICD codes, published by the World Health Organization, allow medical professionals to consistently classify conditions and diseases using numeric or alphanumeric diagnosis codes.[1] Baseline incidence data collected for these endpoints should be based on queries for the same ICD codes specified in the study on which the C-R function is based. Baseline data should be location-specific; obtained at a geographic level appropriate to the analysis; and specific to the characteristics of the study population, if possible. Where baseline incidence estimates need to be generated for future years, they should be based on published projections where available.

ANALYTIC APPROACH AND RESULTS

This section describes our approach to developing baseline incidence data inputs for use in the 2022 Socioeconomic Analysis. For each of the health endpoints we have recommended for inclusion in the 2022 analysis, we searched the Internet for publicly available data and considered whether existing databased in USEPA's BenMAP-CE program would be applicable. Exhibit 1 presents our recommendations for sources of baseline incidence data for each of the health endpoints recommended for use in the 2022 Socioeconomic Analysis.

Mortality Rates

To establish baseline mortality rates at the county level for the SCAQMD analysis, we used California Department of Finance (DoF) projections of all-cause death rates in SCAB counties to obtain age- and county-specific death rates in 2032 and 2037 (California Department of Finance, personal communication). Although the DoF projections are preliminary, the groups most likely to be affected by future changes in the projection method are children and adolescents; the projections of adults are not expected to change. Because the bulk of impacts of air pollution mortality are estimated for adults, we believe these data are reasonable to use despite this caveat, and we prefer the use of DoF projections over U.S. Census-based projections because the former allows SCAQMD to estimate mortality impacts using local, county-level estimates that capture trends specific to the SCAB.

To establish baseline respiratory mortality rates at the county level, we collected historical baseline respiratory mortality rates, stratified by age, for the four counties within SCAQMD's jurisdiction from the U.S. Centers for Disease Control and Prevention (CDC's) WONDER database. Historical rates are projected to 2032 and 2037 using an adjustment factor based on the DoF all-cause mortality projection. We then used the CA DoF projection data for total mortality rates in the SCAB to obtain age-specific ratios of deaths in 2018 to deaths in 2032 and 2037. We applied these adjustments to the average SCAB county cardiovascular death rates to obtain estimated age-specific baseline cardiovascular death rates by county in 2032 and 2037.

Morbidity Rates

[1] ICD codes may also be used to indicate causes of death.

Zip-code specific baseline incidence rates of hospital admissions and emergency department visits were developed from zip-code and county-level data provided by the California Department of Health Care Access and Information (HCAI).

For nonfatal myocardial infarctions, we obtained county-level incidence rate estimates from the CDC Interactive Atlas of Heart Disease and Stroke (http://nccd.cdc.gov/DHDSPAtlas), an online mapping tool that allows users to create county-level maps of heart disease and stroke incidence rates for Medicare beneficiaries aged 65 and older by race/ethnicity, gender, and age group. Hospitalization data in the atlas come from Centers for Medicare and Medicaid Services Medicare Provider Analysis and Review (MEDPAR) file, Part A. Deaths data come from the National Vital Statistics System maintained by the National Center for Health Statistics. Hospitalization data for acute myocardial infarction are adjusted for the percentage of fatal outcomes reported in the atlas to net out the non-fatal hospital admissions rate for this endpoint.

For the endpoint of new onset asthma incidence in children, we recommended using the baseline rate of new asthma incidence in the Los Angeles area for 2002-2005 from the Children's Health Study cohort, reported in Table 1 of the study by McConnell et al., 2010. For prevalence estimates of asthma in California, we used results from the American Lung Association (2010b) report summarizing data from NHIS.

For all other endpoints listed in Exhibit 1, current local baseline data were not readily available from publicly available sources, so we recommended that SCAQMD use the baseline incidence data included in BenMAP-CE for these endpoints. These data can be found in the Other Incidence (2000) and Other Incidence (2014) databases included in the United States setup (U.S. EPA, 2022).

EXHIBIT 1. PROPOSED BASELINE INCIDENCE RATES (PER DAY UNLESS OTHERWISE SPECIFIED)

HEALTH ENDPOINT[a] (AGE RANGE)	PROJECTED RATE PER PERSON 2032	PROJECTED RATE PER PERSON 2037	LOCATION	SOURCE
Mortality, All Cause (per year)				
0	2.71E-03	2.41E-03	Los Angeles	California Department of Finance (CDOF)
1-4	1.09E-04	9.65E-05	Los Angeles	CDOF
5-9	7.79E-05	7.57E-05	Los Angeles	CDOF
10-14	9.94E-05	9.48E-05	Los Angeles	CDOF
15-19	3.11E-04	2.97E-04	Los Angeles	CDOF
20-24	6.79E-04	6.76E-04	Los Angeles	CDOF
25-29	7.00E-04	6.79E-04	Los Angeles	CDOF
30-34	8.17E-04	8.04E-04	Los Angeles	CDOF
35-39	9.76E-04	9.22E-04	Los Angeles	CDOF
40-44	1.20E-03	1.11E-03	Los Angeles	CDOF
45-49	1.89E-03	1.78E-03	Los Angeles	CDOF
50-54	3.25E-03	3.13E-03	Los Angeles	CDOF

HEALTH ENDPOINT[a] (AGE RANGE)	PROJECTED RATE PER PERSON 2032	PROJECTED RATE PER PERSON 2037	LOCATION	SOURCE
55-59	5.10E-03	4.95E-03	Los Angeles	CDOF
60-64	7.93E-03	7.78E-03	Los Angeles	CDOF
65-69	1.12E-02	1.09E-02	Los Angeles	CDOF
70-74	1.61E-02	1.55E-02	Los Angeles	CDOF
75-79	2.49E-02	2.36E-02	Los Angeles	CDOF
80-84	4.10E-02	3.86E-02	Los Angeles	CDOF
85-89	6.95E-02	6.61E-02	Los Angeles	CDOF
90-94	1.27E-01	1.21E-01	Los Angeles	CDOF
95-99	2.21E-01	2.10E-01	Los Angeles	CDOF
0	2.16E-03	1.89E-03	Orange	CDOF
1-4	1.24E-04	1.14E-04	Orange	CDOF
5-9	8.32E-05	7.93E-05	Orange	CDOF
10-14	9.97E-05	9.66E-05	Orange	CDOF
15-19	2.92E-04	2.76E-04	Orange	CDOF
20-24	6.00E-04	5.92E-04	Orange	CDOF
25-29	7.13E-04	7.26E-04	Orange	CDOF
30-34	7.45E-04	7.39E-04	Orange	CDOF
35-39	9.41E-04	9.19E-04	Orange	CDOF
40-44	1.13E-03	1.11E-03	Orange	CDOF
45-49	1.75E-03	1.72E-03	Orange	CDOF
50-54	2.60E-03	2.53E-03	Orange	CDOF
55-59	3.87E-03	3.69E-03	Orange	CDOF
60-64	6.15E-03	5.94E-03	Orange	CDOF
65-69	8.86E-03	8.50E-03	Orange	CDOF
70-74	1.33E-02	1.26E-02	Orange	CDOF
75-79	2.29E-02	2.16E-02	Orange	CDOF
80-84	4.11E-02	3.89E-02	Orange	CDOF
85-89	7.73E-02	7.38E-02	Orange	CDOF
90-94	1.41E-01	1.35E-01	Orange	CDOF
95-99	2.23E-01	2.12E-01	Orange	CDOF
0	3.23E-03	2.95E-03	Riverside	CDOF
1-4	1.67E-04	1.55E-04	Riverside	CDOF
5-9	8.72E-05	8.41E-05	Riverside	CDOF
10-14	8.50E-05	7.95E-05	Riverside	CDOF
15-19	3.10E-04	2.86E-04	Riverside	CDOF
20-24	6.93E-04	6.53E-04	Riverside	CDOF
25-29	7.85E-04	7.42E-04	Riverside	CDOF
30-34	1.16E-03	1.17E-03	Riverside	CDOF
35-39	1.25E-03	1.21E-03	Riverside	CDOF
40-44	1.33E-03	1.24E-03	Riverside	CDOF
45-49	2.16E-03	2.05E-03	Riverside	CDOF
50-54	3.66E-03	3.51E-03	Riverside	CDOF
55-59	5.76E-03	5.54E-03	Riverside	CDOF
60-64	8.83E-03	8.56E-03	Riverside	CDOF
65-69	1.22E-02	1.17E-02	Riverside	CDOF
70-74	1.83E-02	1.78E-02	Riverside	CDOF
75-79	2.70E-02	2.57E-02	Riverside	CDOF
80-84	4.64E-02	4.43E-02	Riverside	CDOF

HEALTH ENDPOINT[a] (AGE RANGE)	PROJECTED RATE PER PERSON 2032	PROJECTED RATE PER PERSON 2037	LOCATION	SOURCE
85-89	7.89E-02	7.65E-02	Riverside	CDOF
90-94	1.44E-01	1.39E-01	Riverside	CDOF
95-99	2.27E-01	2.20E-01	Riverside	CDOF
0	4.70E-03	4.45E-03	San Bernardino	CDOF
1-4	1.89E-04	1.74E-04	San Bernardino	CDOF
5-9	8.00E-05	7.29E-05	San Bernardino	CDOF
10-14	1.00E-04	9.28E-05	San Bernardino	CDOF
15-19	3.63E-04	3.35E-04	San Bernardino	CDOF
20-24	6.61E-04	6.22E-04	San Bernardino	CDOF
25-29	8.52E-04	8.12E-04	San Bernardino	CDOF
30-34	1.27E-03	1.24E-03	San Bernardino	CDOF
35-39	1.34E-03	1.28E-03	San Bernardino	CDOF
40-44	1.70E-03	1.64E-03	San Bernardino	CDOF
45-49	2.62E-03	2.50E-03	San Bernardino	CDOF
50-54	4.38E-03	4.24E-03	San Bernardino	CDOF
55-59	6.62E-03	6.32E-03	San Bernardino	CDOF
60-64	9.43E-03	8.91E-03	San Bernardino	CDOF
65-69	1.39E-02	1.30E-02	San Bernardino	CDOF
70-74	2.12E-02	2.03E-02	San Bernardino	CDOF
75-79	3.49E-02	3.38E-02	San Bernardino	CDOF
80-84	5.52E-02	5.31E-02	San Bernardino	CDOF
85-89	9.02E-02	8.82E-02	San Bernardino	CDOF
90-94	1.65E-01	1.61E-01	San Bernardino	CDOF
95-99	2.60E-01	2.54E-01	San Bernardino	CDOF
Mortality, Respiratory (per year)				
25-34	1.11E-05	1.08E-05	Los Angeles	CDC WONDER
35-44	2.11E-05	1.98E-05	Los Angeles	CDC WONDER
45-54	7.48E-05	7.13E-05	Los Angeles	CDC WONDER
55-64	3.25E-04	3.17E-04	Los Angeles	CDC WONDER
65-74	1.24E-03	1.20E-03	Los Angeles	CDC WONDER
75-84	3.81E-03	3.61E-03	Los Angeles	CDC WONDER
85-99	1.21E-02	1.15E-02	Los Angeles	CDC WONDER
25-34	1.78E-05	1.78E-05	Orange	CDC WONDER
35-44	2.39E-05	2.33E-05	Orange	CDC WONDER
45-54	6.19E-05	6.04E-05	Orange	CDC WONDER
55-64	2.41E-04	2.32E-04	Orange	CDC WONDER
65-74	9.50E-04	9.08E-04	Orange	CDC WONDER
75-84	3.85E-03	3.64E-03	Orange	CDC WONDER
85-99	1.17E-02	1.12E-02	Orange	CDC WONDER
25-34	1.91E-05	1.87E-05	Riverside	CDC WONDER
35-44	2.51E-05	2.38E-05	Riverside	CDC WONDER
45-54	9.92E-05	9.46E-05	Riverside	CDC WONDER
55-64	4.49E-04	4.34E-04	Riverside	CDC WONDER
65-74	1.51E-03	1.46E-03	Riverside	CDC WONDER
75-84	4.42E-03	4.22E-03	Riverside	CDC WONDER
85-99	1.20E-02	1.16E-02	Riverside	CDC WONDER
25-34	2.57E-05	2.48E-05	San Bernardino	CDC WONDER
35-44	3.95E-05	3.79E-05	San Bernardino	CDC WONDER

HEALTH ENDPOINT[a] (AGE RANGE)	PROJECTED RATE PER PERSON 2032	PROJECTED RATE PER PERSON 2037	LOCATION	SOURCE
45-54	1.51E-04	1.45E-04	San Bernardino	CDC WONDER
55-64	5.88E-04	5.59E-04	San Bernardino	CDC WONDER
65-74	2.05E-03	1.94E-03	San Bernardino	CDC WONDER
75-84	5.68E-03	5.48E-03	San Bernardino	CDC WONDER
85-99	1.43E-02	1.40E-02	San Bernardino	CDC WONDER
Hospital Admissions, All Cardiac Outcomes				
0-99	3.10E-05	3.10E-05	Los Angeles	CA HCAI
0-99	2.53E-05	2.53E-05	Orange	CA HCAI
0-99	3.13E-05	3.13E-05	Riverside	CA HCAI
0-99	3.11E-05	3.11E-05	San Bernardino	CA HCAI
Incidence, Ischemic Stroke				
65-99	1.92E-05	1.92E-05	Los Angeles	CA HCAI
65-99	1.75E-05	1.75E-05	Orange	CA HCAI
65-99	1.85E-05	1.85E-05	Riverside	CA HCAI
65-99	1.88E-05	1.88E-05	San Bernardino	CA HCAI
Hospital Admissions, All Respiratory				
0-99	1.63E-05	1.63E-05	Los Angeles	CA HCAI
0-99	1.27E-05	1.27E-05	Orange	CA HCAI
0-99	1.56E-05	1.56E-05	Riverside	CA HCAI
0-99	1.68E-05	1.68E-05	San Bernardino	CA HCAI
Hospital Admissions, Asthma				
0-17	3.05E-06	3.05E-06	Los Angeles	CA HCAI
0-17	1.91E-06	1.91E-06	Orange	CA HCAI
0-17	2.11E-06	2.11E-06	Riverside	CA HCAI
0-17	2.64E-06	2.64E-06	San Bernardino	CA HCAI
Emergency Hospital Admissions, Asthma				
0-17	3.05E-06	3.05E-06	Los Angeles	CA HCAI
0-17	1.91E-06	1.91E-06	Orange	CA HCAI
0-17	2.11E-06	2.11E-06	Riverside	CA HCAI
0-17	2.64E-06	2.64E-06	San Bernardino	CA HCAI
Hospital Admissions, Alzheimer's Disease				
65-99	1.39E-06	1.39E-06	Los Angeles	CA HCAI
65-99	1.01E-06	1.01E-06	Orange	CA HCAI
65-99	8.16E-07	8.16E-07	Riverside	CA HCAI
65-99	1.26E-06	1.26E-06	San Bernardino	CA HCAI
Hospital Admissions, Parkinson's Disease				
65-99	1.03E-06	1.03E-06	Los Angeles	CA HCAI
65-99	7.82E-07	7.82E-07	Orange	CA HCAI
65-99	4.93E-07	4.93E-07	Riverside	CA HCAI
65-99	5.57E-07	5.57E-07	San Bernardino	CA HCAI
Acute Nonfatal Myocardial Infarction				
65-99	2.21E-05	2.21E-05	Los Angeles	CDC Atlas of Heart Disease and Stroke
65-99	1.78E-05	1.78E-05	Orange	CDC Atlas of Heart Disease and Stroke

HEALTH ENDPOINT[a] (AGE RANGE)	PROJECTED RATE PER PERSON 2032	PROJECTED RATE PER PERSON 2037	LOCATION	SOURCE
65-99	2.21E-05	2.21E-05	Riverside	CDC Atlas of Heart Disease and Stroke
65-99	3.01E-05	3.01E-05	San Bernardino	CDC Atlas of Heart Disease and Stroke
Emergency Department Visits, All Cardiac Outcomes				
0-99	4.18E-05	4.18E-05	Los Angeles	CA HCAI
0-99	3.73E-05	3.73E-05	Orange	CA HCAI
0-99	4.87E-05	4.87E-05	Riverside	CA HCAI
0-99	5.09E-05	5.09E-05	San Bernardino	CA HCAI
Emergency Department Visits, All Respiratory				
0-99	9.54E-05	9.54E-05	Los Angeles	CA HCAI
0-99	6.52E-05	6.52E-05	Orange	CA HCAI
0-99	1.05E-04	1.05E-04	Riverside	CA HCAI
0-99	1.27E-04	1.27E-04	San Bernardino	CA HCAI
Emergency Department Visits, Asthma				
0-17	1.24E-05	1.24E-05	Los Angeles	CA HCAI
0-17	7.27E-06	7.27E-06	Orange	CA HCAI
0-17	1.11E-05	1.11E-05	Riverside	CA HCAI
0-17	1.47E-05	1.47E-05	San Bernardino	CA HCAI
Asthma Incidence, New Cases				
0-17	5.01E-05	5.01E-05	South Coast Area	CHS Cohort
Incidence, Hay Fever/Rhinitis				
3-17	1.92E-01	1.92E-01	South Coast Area	BenMAP-CE
Incidence, Out of Hospital Cardiac Arrest				
18-99	5.08E-07	5.08E-07	South Coast Area	BenMAP-CE
Incidence, Lung Cancer (per year)				
30-99	3.77E-04	3.77E-04	South Coast Area	BenMAP-CE
Asthma Exacerbation				
5-17	1.07E-01 (prevalence, applies to cough, shortness of breath, wheeze, and albuterol use)	1.07E-01 (prevalence, applies to cough, shortness of breath, wheeze, and albuterol use)	California	American Lung Association (2010b)
Minor Restricted Activity Days				
18-64	2.14E-02	2.14E-02	United States	Ostro and Rothschild 1989
Work Loss Days				
18-64	5.82E-03	5.82E-03	United States	Adams et al. 1999
School Loss Days (per school day)				
5-17	2.06E-02	2.06E-02	Western United States	National Health Interview Survey

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South Coast AQMD

2022 AIR QUALITY MANAGEMENT PLAN

Final Socioeconomic Report

Appendix 4-A

REMI Baseline Adjustments

December 2022

FINAL SOCIOECONOMIC REPORT
APPENDIX 4-B

REMI MODELING ASSUMPTIONS

DECEMBER 2022

This appendix consists of two parts. Part I presents the REMI Model's framework and the assumptions embedded in the model. The second part covers the detailed REMI modeling assumptions used by staff for each control measure analyzed in this report.

Part I – REMI Modeling Framework and Assumptions

(a) REMI Model Framework

In an effort to expand socioeconomic impact assessments for proposed rules, rule amendments, and AQMPs, the South Coast AQMD has been using a computerized economic model from Regional Economic Models, Inc. (REMI) to assess the socioeconomic impacts on the four-county economy since 1990. The structure and assumptions of the model are briefly described below.

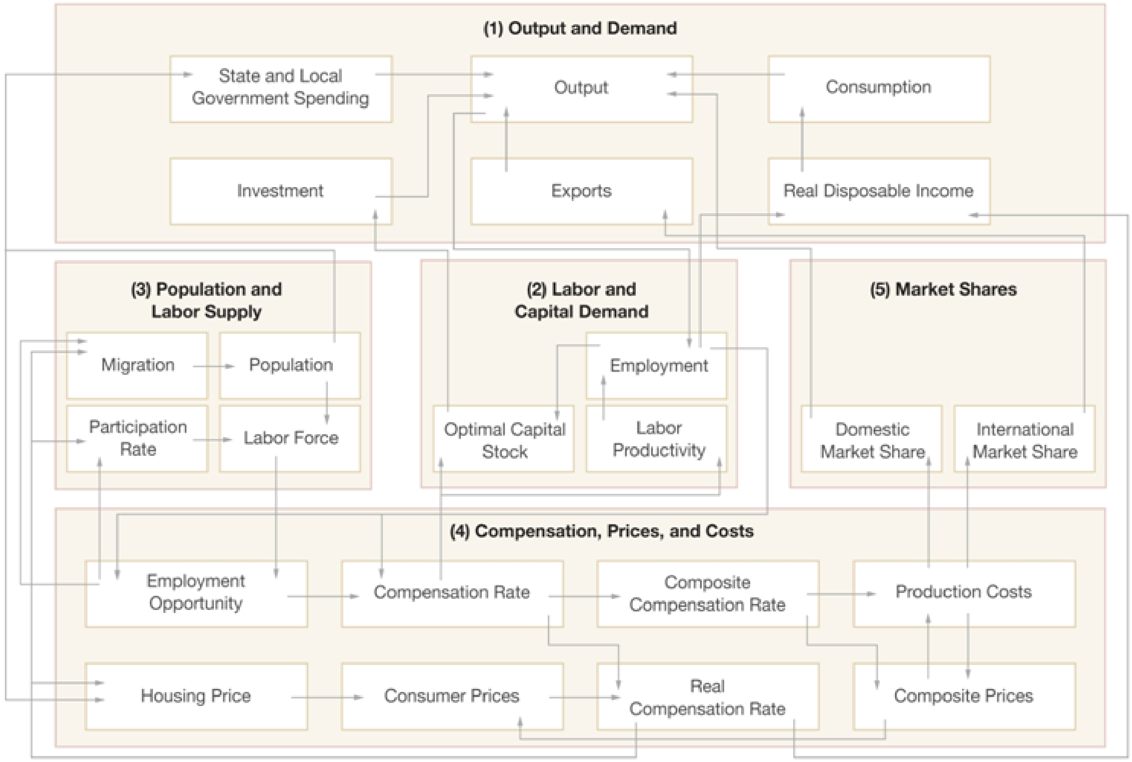
The REMI model customized for the South Coast AQMD's use links the economic activities in the 21 sub-counties within the four-county region of Los Angeles, Orange, Riverside, and San Bernardino. There are 11 sub-county regions in Los Angeles County, four in Orange County, three in Riverside County, and three in San Bernardino County. The division of the sub-regions was originally developed in 1996 and has been updated to reflect the 2020 Census, reflecting the politically, socially, economically, and geographically diversified structure of the Southern California economy.

The REMI model for each sub-region is comprised of a five block structure that includes (1) output and demand, (2) labor and capital, (3) population and labor force, (4) compensation, prices and costs, and (5) market shares. These five blocks are interrelated and the linkages are shown in Figure 4B-1. Each block is built upon a two-step process. First, producers and consumers throughout all regions of the country are assumed to have similar behavioral characteristics. Because of these similarities, statistical techniques are used to estimate economic responses based on studies performed throughout the U. S. The second step of the modeling process is region specific, and involves calibration of the model based on region-specific historical data.

The standard structure has 66 private non-farm industries (3-digit NAICS), three government sectors and a farm sector, 95 occupations, and 88 final demand sectors. The demographic/migration component captures population changes due to births, deaths, migration, and changes to special population (e.g., prisoners and college students); and has 808 age/gender/race/ethnicity cohorts. The input-output module contains detailed inter-industry relationships for 403 sectors and is used to assess the detailed inter-industry effect of a policy change. Results from the input-output module are fed through population, price and economic geography equations to produce a complete economic and demographic assessment.

Figure 4B-1 depicts the framework of the REMI model.

FIGURE 4B-1: REMI MODEL COMPONENTS



(b) Verification of the Model

The REMI model for the Southern California geography was independently evaluated by the University of Pittsburgh in 1989, MIT in 1992, and Abt Associates in 2014 to determine its forecasting and simulation capabilities. The model's performance was judged to meet accepted standards of practice (Cassing and Giarratani, 1992). Abt Associates (2014) recommended that staff continue using the REMI model for macroeconomic impact assessment while evaluating other tools and models to supplement the REMI analysis, particularly when impacts are expected to be at a relatively small scale or when the proposed policies and regulations would affect mainly small businesses or very specific industries.

Part II – REMI Modeling Assumptions for the 2022 AQMP Socioeconomic Impact Assessment

The costs and benefits of the 2022 AQMP are expected to alter, to various degrees, the economic decisions made by households, businesses, and other economic actors. Some businesses would see production costs go up while other businesses would benefit from a greater demand for their services and technologies. For consumers who consider purchasing or replacing household appliances, for example, the proposed control strategies would also in some cases change or widen the range of product, that differ in fuel types, energy efficiencies, effective unit prices, and thus potentially payback periods. In the meantime, improved public health would contribute to higher labor productivity and reduce healthcare-related expenditures. All these direct effects would then cascade through the regional economy and produce indirect and induced macroeconomic impacts. The immediate and subsequent effects may not just occur in the short-term, but some of them may also have lasting impacts that would subside only after a long period of time.

These direct, indirect, and induced macroeconomic impacts were assessed through the customized REMI model.[1] The macroeconomic impacts associated with the 2022 AQMP were simulated and projected relative to the baseline forecast of the regional economy, which is absent the 2022 AQMP and without the implementation of the proposed control strategies. The modeling assumptions used in the analysis are discussed below.

(a) Incremental Costs and Incentives

As discussed in Chapter 2, costs associated with the 2022 AQMP represent the cost difference between a baseline path and an alternative path as proposed by the 2022 AQMP to reach the attainment target. The total incremental cost includes costs incurred by the affected entities, including businesses and consumers, as well as limited incentives assumed to be provided by state and local governments. Total incremental costs are calculated as the sum of incremental capital costs (e.g., equipment purchases and installation costs) and future incremental recurring costs over the equipment's expected lifetime that are associated with operation and maintenance (e.g., filter replacement and fuel costs/savings).

General speaking, the industry-specific "Production Cost" policy variable is used to model increased costs of doing business (and in some cases, cost-savings) for the affected industries. The associated spending on control device and clean technologies is modeled with the industry-specific "Exogenous Final Demand" policy variables to account for increases in sales volume for the equipment and technology suppliers. For the consumers, the "Consumer Spending" policy variable is used in conjunction with "Consumer Spending Reallocation" to model impacts resulting from changes in consumer behavior. For the government incentives, it was assumed that all incentive programs would be funded by existing revenue sources. This is modeled using either the "State Government Spending" or "Local Government Spending" policy variable which would result in government budget reallocation and affect provision of public services.

Table 4B-1 at the end of this appendix lists the industry sectors modeled in REMI that would either incur costs or benefit from the compliance expenditures. It should be noted that, although staff may be able to make reasonable assumptions about the geographical location of directly affected industries based on the review of South Coast AQMD permits and other existing data, the same could not be achieved for the businesses from which the affected facilities would purchase control equipment and services. As a result, staff adopted the ad-hoc assumption that only a portion of these purchases would be from local suppliers, and this portion was based on the national distribution of industry-specific statistics that REMI summarizes in its embedded "regional purchase coefficient" parameters.

(b) Public Health Benefits

Public Health Benefits were valued using two general types of methodologies: willingness-to-pay (WTP) to reduce health risk and avoided cost of illness (COI), based on the 2016 IEc recommendations.[2]

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[1] REMI Policy Insight Plus (PI+) South Coast Sub County Model v3.0.0 (Build 6083). For a full description of the REMI methodology, please refer to the REMI documentation available at http://www.remi.com/products/pi.

[2] Industrial Economics Memo: "Review of Mortality Risk Reduction Valuation Estimates for 2016 Socioeconomic Assessment" March, 2016.

The morbidity-related health benefits were valued by a combination of COI and WTP. The directly avoided COI or the WTP for reduced risk of various morbidity symptoms were modeled as reduced consumer spending on healthcare-related goods and services and a corresponding reallocation of consumer spending from healthcare to other goods, services, and savings. The indirectly avoided COI, which was valued by the lost work time due to absences from work to recover or take care of ill dependents, were assumed to increase labor productivity for all industries.

The mortality-related health benefits valued based on WTP were modeled using the "Non-Pecuniary Amenity Aspects" policy variable which would result in increases in attractiveness of the region relative to the rest of the nation and would induce economic migration into the region. The basic concept of this policy variable is that prospective economic migrants consider a list of factors, including but not limited to location-specific amenities and wages, when making their location choice. An increase in the amenity of a region increases a location's attractiveness even when wages remain the same, such that an individual from outside the region would be willing to migrate to the region despite no changes in the (pre-migration) wage differential between the individual's current residence and the location where the amenity is enhanced. This is because amenity, although non-pecuniary, can in concept be converted as an increase in an individual's total compensation, on top of the individual's market wages.

This change in economic migration then leads to a change in the local labor supply and regional population, and subsequently the post-migration wages and housing prices, which have impacts that cascade through the regional economy. These impacts will eventually lead to a change in regional GDP and the number of jobs.

Following is a technical description of how the change in amenity values enter into the REMI model. REMI's equation for economic migration is as follows (REMI 2022):

$$ECMIG_t^l = \left[\lambda^l + \beta_1 \ln\left(REO_t^l\right) + \beta_2 \ln\left(RWR_t^l\right) + \beta_1 \ln\left(MIGPROD_t^l\right)\right] * LF_{t-1}^l,$$

where *ECMIG* is economic migration, and it is a function of a number of variables including the location-specific amenity (λ^l) and the relative real compensation rate (*RWR*). β_1 and β_2 are the econometrically estimated coefficients and, LF_{t-1}^l is the regional labor force of the previous year. According to REMI staff, an increase in amenity raises λ^l by the amount $\beta_2 \ln\left(1 + \frac{a}{w}\right)$, where a is the amount REMI users would enter into REMI via the "Non-Pecuniary Amenity Aspects" policy variable and w is the total wage and salary disbursement in the location. This increase, in terms of affecting economic migration, can be shown to be equivalent to the effect of raising the relative real compensation rate (*RWR*) by a factor of $\left(1 + \frac{a}{\mathrm{w}}\right)$ so that the change in economic migration ($dECMIG_t^l$) as a result of the increased amenities is calculated by the following differential equation:

$$dECMIG_t^l = \frac{\beta_2 LF_{t-1}^l}{RWR_t^l} dRWR_t^l = \beta_2 \ln\left(1 + \frac{a}{w}\right) LF_{t-1}^l.$$

This change in economic migration cascades through the regional economy according to the model structure described above.

To evaluate and further understand the amenity modeling mechanism employed in the REMI model, South Coast AQMD commissioned a third-party study by Michael Lahr (2016). One of the recommendations of this study was to conduct a sensitivity analysis of the amenity values evaluated in

REMI. This sensitivity analysis is included below.

TABLE 4B-1: ANNUAL REGIONAL JOB IMPACTS OF QUANTIFIED PUBLIC HEALTH BENEFITS (SENSITIVITY ANALYSIS)

	Jobs		Average Annual (2023-2037)	
Primary Scenario (25%)	**2032**	**2037**	**Jobs**	**% Change**
Quantified Public Health Benefits	13,848	31,945	11,490	0.11%
Mortality-Related Benefits	12,866	30,104	10,695	0.10%
Morbidity-Related Benefits	981	1,840	793	0.01%
Sensitivity Analysis (50%)				
Quantified Public Health Benefits	26,701	62,026	22,171	0.20%
Mortality-Related Benefits 50%	25,717	60,180	21,375	0.19%
Morbidity-Related Benefits	981	1,840	793	0.01%
Sensitivity Analysis (100%)				
Quantified Public Health Benefits	52,354	122,307	43,509	0.39%
Mortality-Related Benefits 100%	51,368	120,447	42,711	0.38%
Morbidity-Related Benefits	981	1,840	793	0.01%

FIGURE 4B-2: ANNUAL REGIONAL JOB IMPACTS OF QUANTIFIED PUBLIC HEALTH BENEFITS (SENSITIVITY ANALYSIS)

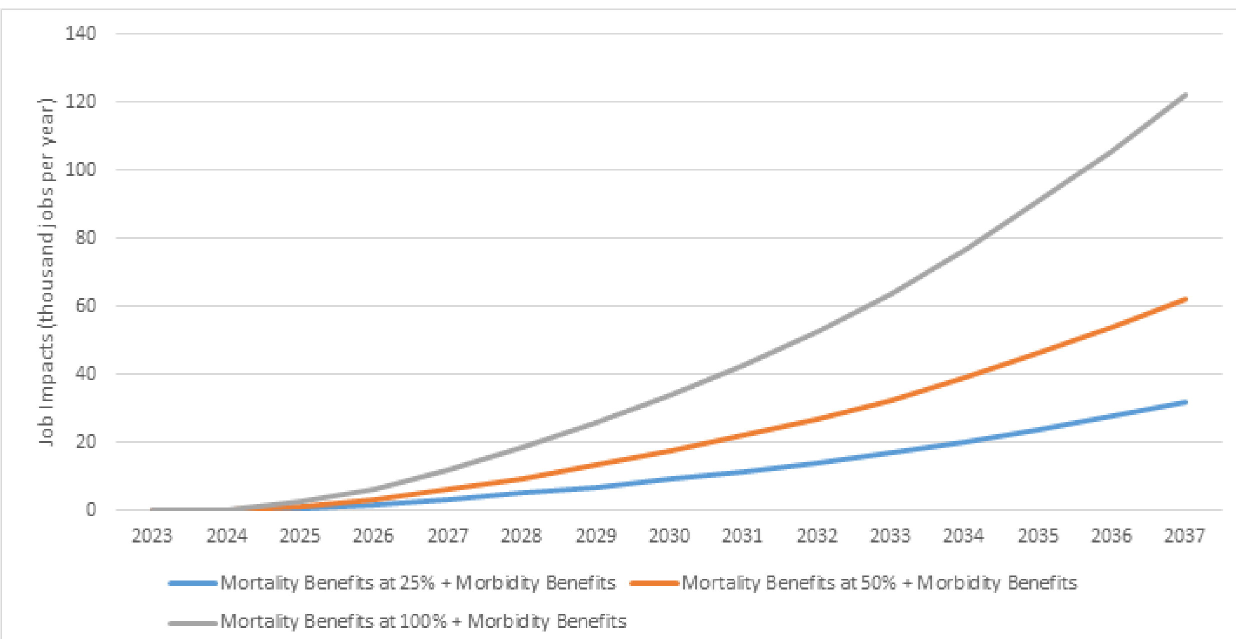

Table 4B-2 presents the nationwide median weekly wage rates for 70 industries or sectors. The data is derived from the 2021 Current Population Survey (CPS), a monthly survey of households administered by the Bureau of Labor Statistics (BLS). Several hundred occupation designations are aggregated into 95 general occupation categories within REMI, which are in turn distributed across 70 private and public sectors depending on the industry. For example, construction trade workers constitute nearly half of Construction industry jobs, but the industry also contains financial clerks and other occupations to lesser degrees. This weighted occupation matrix is used to determine the industry's average wage. The wage rates are ranked in ascending order, and then divided into five groups. The quintiles and the comprising industries are skewed by extremes in wages. For example, many jobs in forestry, fishing, and hunting are seasonal or part-time, thus skewing downwards when projected out to an annual wage. These and others, such as transit – which includes rideshare contractors – include part-time work and workers with multiple jobs. On the other extreme, broadcasting, data processing, and petroleum manufacturing are capital intensive and populated by highly specialized workers and executives, thus skewing upwards.

TABLE 4B-2: AVERAGE WEEKLY EARNINGS BY INDUSTRY SECTOR

Quintile	Sector/Industry Title	Average Weekly Earnings
1	113-114 - Forestry and Logging; Fishing, hunting and trapping	$163
1	485 - Transit and ground passenger transportation	$201
1	814 - Private households	$464
1	812 - Personal and laundry services	$555
1	624 - Social assistance	$626
1	213 - Support activities for mining	$708
1	722 - Food services and drinking places	$710
1	115 - Support activities for agriculture and forestry	$853
1	721 - Accommodation	$996
1	492 - Couriers and messengers	$1,058
1	561 - Administrative and support services	$1,065
1	44-45 - Retail trade	$1,076
1	623 - Nursing and residential care facilities	$1,090
1	711 - Performing arts, spectator sports, and related industries	$1,118
2	523, 525 - Securities, commodity contracts, other investments; Funds, trusts, other financial vehicles	$1,141
2	61 - Educational services; private	$1,156
2	531 - Real estate	$1,165
2	NA - Federal Military	$1,176
2	493 - Warehousing and storage	$1,218
2	337 - Furniture and related product manufacturing	$1,281
2	313-314 - Textile mills; Textile product mills	$1,294
2	315-316 - Apparel manufacturing; Leather and allied product manufacturing	$1,336
2	111, 112 - Farm	$1,342

TABLE 4B-2 (CONTINUED): AVERAGE WEEKLY EARNINGS BY INDUSTRY SECTOR

Quintile	Sector/Industry Title	Average

Quintile	Sector/Industry Title	Average Weekly Earnings
2	712 - Museums, historical sites, and similar institutions	$1,363
2	323 - Printing and related support activities	$1,377
2	813 - Religious, grantmaking, civic, professional, and similar organizations	$1,409
2	811 - Repair and maintenance	$1,482
2	211 - Oil and gas extraction	$1,501
3	321 - Wood product manufacturing	$1,579
3	621 - Ambulatory health care services	$1,588
3	311 - Food manufacturing	$1,615
3	332 - Fabricated metal product manufacturing	$1,639
3	326 - Plastics and rubber products manufacturing	$1,671
3	23 - Construction	$1,712
3	312 - Beverage and tobacco product manufacturing	$1,719
3	212 - Mining (except oil and gas)	$1,760
3	562 - Waste management and remediation services	$1,809
3	331 - Primary metal manufacturing	$1,826
3	327 - Nonmetallic mineral product manufacturing	$1,844
3	322 - Paper manufacturing	$1,949
3	484 - Truck transportation	$1,999
3	325 - Chemical manufacturing	$2,070
4	487-488 - Scenic and sightseeing transportation; Support activities for transportation	$2,072
4	339 - Miscellaneous manufacturing	$2,081
4	54 - Professional, scientific, and technical services	$2,092
4	42 - Wholesale trade	$2,109
4	532, 533 - Rental and leasing services; Lessors of nonfinancial intangible assets	$2,112
4	NA - State and Local Government	$2,334
4	511 - Publishing industries, except Internet	$2,346
4	713 - Amusement, gambling, and recreation industries	$2,380
4	335 - Electrical equipment, appliance, and component manufacturing	$2,424
4	622 - Hospitals; private	$2,431
4	334 - Computer and electronic product manufacturing	$2,526
4	NA - Federal Civilian	$2,603
4	3361-3363 - Motor vehicles, bodies and trailers, and parts manufacturing	$2,645
4	55 - Management of companies and enterprises	$2,653
5	333 - Machinery manufacturing	$2,694
5	517 - Telecommunications	$2,717
5	524 - Insurance carriers and related activities	$2,717

TABLE 4B-2 (CONTINUED): AVERAGE WEEKLY EARNINGS BY INDUSTRY SECTOR

		Weekly Earnings
5	512 - Motion picture and sound recording industries	$2,849
5	481 - Air transportation	$2,978
5	521, 522 - Monetary authorities - central bank; Credit intermediation and related activities	$3,067
5	482 - Rail transportation	$3,081
5	3364-3369 - Other transportation equipment manufacturing	$3,084
5	483 - Water transportation	$3,137
5	486 - Pipeline transportation	$4,063
5	22 - Utilities	$5,743
5	324 - Petroleum and coal products manufacturing	$5,909
5	518, 519 - Data processing, hosting, and related services; Other information services	$6,209
5	515 - Broadcasting, except Internet	$7,630

South Coast AQMD

2022 AIR QUALITY MANAGEMENT PLAN

Final Socioeconomic Report
Appendix 4-B

REMI Modeling Assumptions

December 2022

FINAL SOCIOECONOMIC REPORT
APPENDIX 4-B

REMI MODELING ASSUMPTIONS

DECEMBER 2022

This appendix consists of two parts. Part I presents the REMI Model's framework and the assumptions embedded in the model. The second part covers the detailed REMI modeling assumptions used by staff for each control measure analyzed in this report.

Part I – REMI Modeling Framework and Assumptions

(a) REMI Model Framework

In an effort to expand socioeconomic impact assessments for proposed rules, rule amendments, and AQMPs, the South Coast AQMD has been using a computerized economic model from Regional Economic Models, Inc. (REMI) to assess the socioeconomic impacts on the four-county economy since 1990. The structure and assumptions of the model are briefly described below.

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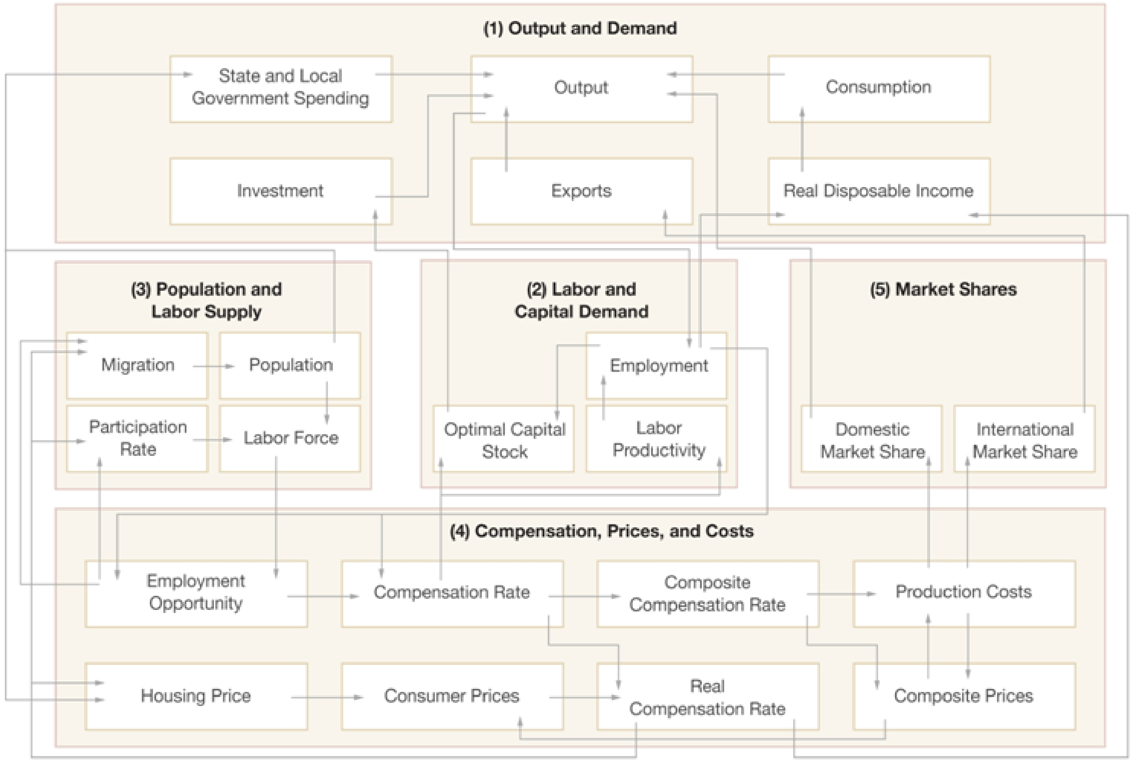
The standard structure has 66 private non-farm industries (3-digit NAICS), three government sectors and a farm sector, 95 occupations, and 88 final demand sectors. The demographic/migration component captures population changes due to births, deaths, migration, and changes to special population (e.g., prisoners and college students); and has 808 age/gender/race/ethnicity cohorts. The input-output module contains detailed inter-industry relationships for 403 sectors and is used to assess the detailed inter-industry effect of a policy change. Results from the input-output module are fed through population, price and economic geography equations to produce a complete economic and demographic assessment.

Figure 4B-1 depicts the framework of the REMI model.

FIGURE 4B-1: REMI MODEL COMPONENTS



(b) Verification of the Model

The REMI model for the Southern California geography was independently evaluated by the University of Pittsburgh in 1989, MIT in 1992, and Abt Associates in 2014 to determine its forecasting and simulation capabilities. The model's performance was judged to meet accepted standards of practice (Cassing and Giarratani, 1992). Abt Associates (2014) recommended that staff continue using the REMI model for macroeconomic impact assessment while evaluating other tools and models to supplement the REMI analysis, particularly when impacts are expected to be at a relatively small scale or when the proposed policies and regulations would affect mainly small businesses or very specific industries.

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The costs and benefits of the Final 2022 AQMP are expected to alter, to various degrees, the economic decisions made by households, businesses, and other economic actors. Some businesses would see production costs go up while other businesses would benefit from a greater demand for their services and technologies. For consumers who consider purchasing or replacing household appliances, for example, the proposed control strategies would also in some cases change or widen the range of product, that differ in fuel types, energy efficiencies, effective unit prices, and thus potentially payback periods. In the meantime, improved public health would contribute to higher labor productivity and reduce healthcare-related expenditures. All these direct effects would then cascade through the regional economy and produce indirect and induced macroeconomic impacts. The immediate and subsequent effects may not just occur in the short-term, but some of them may also have lasting impacts that would subside only after a long period of time.

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(a) Incremental Costs and Incentives

As discussed in Chapter 2, costs associated with the Final 2022 AQMP represent the cost difference between a baseline path and an alternative path as proposed by the Final 2022 AQMP to reach the attainment target. The total incremental cost includes costs incurred by the affected entities, including businesses and consumers, as well as limited incentives assumed to be provided by state and local governments. Total incremental costs are calculated as the sum of incremental capital costs (e.g., equipment purchases and installation costs) and future incremental recurring costs over the equipment's expected lifetime that are associated with operation and maintenance (e.g., filter replacement and fuel costs/savings).

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Public Health Benefits were valued using two general types of methodologies: willingness-to-pay (WTP)

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where *ECMIG* is economic migration, and it is a function of a number of variables including the location-specific amenity (λ^l) and the relative real compensation rate (*RWR*). β_1 and β_2 are the econometrically estimated coefficients and, LF_{t-1}^l is the regional labor force of the previous year. According to REMI staff, an increase in amenity raises λ^l by the amount $\beta_2 \ln\left(1 + \frac{a}{w}\right)$, where a is the amount REMI users would enter into REMI via the "Non-Pecuniary Amenity Aspects" policy variable and w is the total wage and salary disbursement in the location. This increase, in terms of affecting economic migration, can be shown to be equivalent to the effect of raising the relative real compensation rate (*RWR*) by a factor of $\left(1 + \frac{a}{\mathrm{w}}\right)$ so that the change in economic migration ($dECMIG_t^l$) as a result of the increased amenities is calculated by the following differential equation:

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This change in economic migration cascades through the regional economy according to the model

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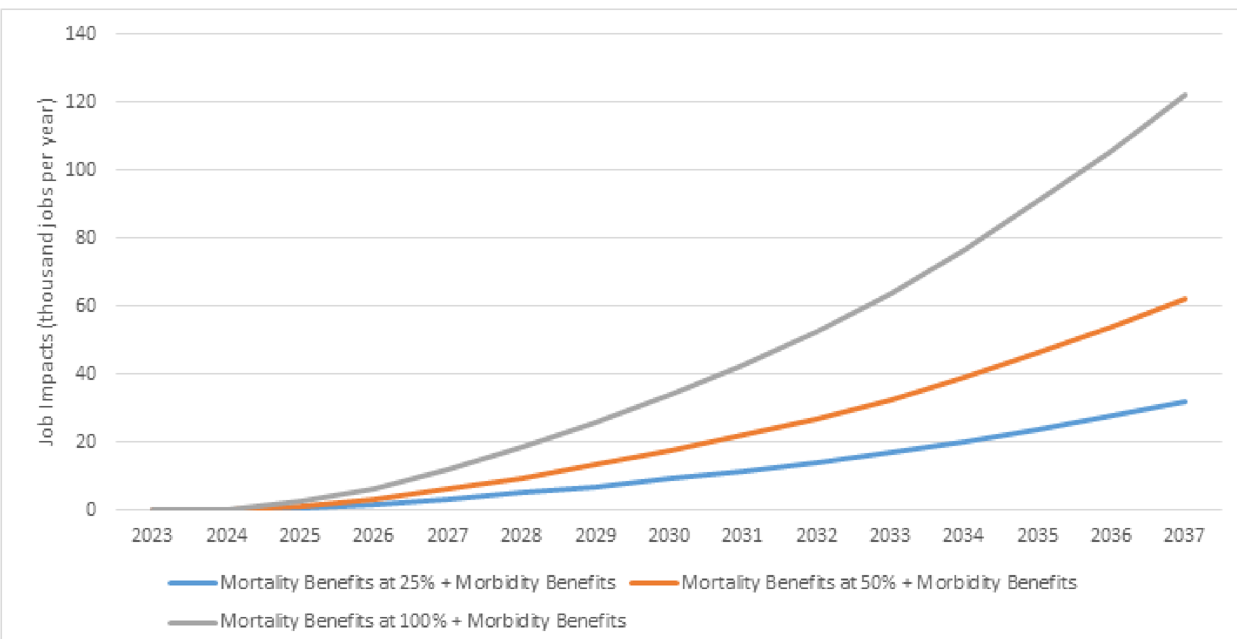

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1	115 - Support activities for agriculture and forestry	$853
1	721 - Accommodation	$996
1	492 - Couriers and messengers	$1,058
1	561 - Administrative and support services	$1,065
1	44-45 - Retail trade	$1,076
1	623 - Nursing and residential care facilities	$1,090
1	711 - Performing arts, spectator sports, and related industries	$1,118
2	523, 525 - Securities, commodity contracts, other investments; Funds, trusts, other financial vehicles	$1,141
2	61 - Educational services; private	$1,156
2	531 - Real estate	$1,165
2	NA - Federal Military	$1,176
2	493 - Warehousing and storage	$1,218
2	337 - Furniture and related product manufacturing	$1,281
2	313-314 - Textile mills; Textile product mills	$1,294
2	315-316 - Apparel manufacturing; Leather and allied product manufacturing	$1,336
2	111, 112 - Farm	$1,342

TABLE 4B-2 (CONTINUED): AVERAGE WEEKLY EARNINGS BY INDUSTRY SECTOR

Quintile	Sector/Industry Title	Average Weekly Earnings
2	712 - Museums, historical sites, and similar institutions	$1,363
2	323 - Printing and related support activities	$1,377
2	813 - Religious, grantmaking, civic, professional, and similar organizations	$1,409
2	811 - Repair and maintenance	$1,482
2	211 - Oil and gas extraction	$1,501
3	321 - Wood product manufacturing	$1,579
3	621 - Ambulatory health care services	$1,588
3	311 - Food manufacturing	$1,615
3	332 - Fabricated metal product manufacturing	$1,639
3	326 - Plastics and rubber products manufacturing	$1,671
3	23 - Construction	$1,712
3	312 - Beverage and tobacco product manufacturing	$1,719
3	212 - Mining (except oil and gas)	$1,760
3	562 - Waste management and remediation services	$1,809
3	331 - Primary metal manufacturing	$1,826
3	327 - Nonmetallic mineral product manufacturing	$1,844
3	322 - Paper manufacturing	$1,949
3	484 - Truck transportation	$1,999
3	325 - Chemical manufacturing	$2,070
4	487-488 - Scenic and sightseeing transportation; Support activities for transportation	$2,072
4	339 - Miscellaneous manufacturing	$2,081
4	54 - Professional, scientific, and technical services	$2,092
4	42 - Wholesale trade	$2,109
4	532, 533 - Rental and leasing services; Lessors of nonfinancial intangible assets	$2,112
4	NA - State and Local Government	$2,334
4	511 - Publishing industries, except Internet	$2,346
4	713 - Amusement, gambling, and recreation industries	$2,380
4	335 - Electrical equipment, appliance, and component manufacturing	$2,424
4	622 - Hospitals; private	$2,431
4	334 - Computer and electronic product manufacturing	$2,526
4	NA - Federal Civilian	$2,603
4	3361-3363 - Motor vehicles, bodies and trailers, and parts manufacturing	$2,645
4	55 - Management of companies and enterprises	$2,653
5	333 - Machinery manufacturing	$2,694
5	517 - Telecommunications	$2,717
5	524 - Insurance carriers and related activities	$2,717

TABLE 4B-2 (CONTINUED): AVERAGE WEEKLY EARNINGS BY INDUSTRY SECTOR

Quintile	Sector/Industry Title	Average Weekly Earnings
5	512 - Motion picture and sound recording industries	$2,849
5	481 - Air transportation	$2,978
5	521, 522 - Monetary authorities - central bank; Credit intermediation and related activities	$3,067
5	482 - Rail transportation	$3,081
5	3364-3369 - Other transportation equipment manufacturing	$3,084
5	483 - Water transportation	$3,137
5	486 - Pipeline transportation	$4,063
5	22 - Utilities	$5,743
5	324 - Petroleum and coal products manufacturing	$5,909
5	518, 519 - Data processing, hosting, and related services; Other information services	$6,209
5	515 - Broadcasting, except Internet	$7,630

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Competitiveness Impacts

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COMPETITIVENESS IMPACTS

DECEMBER 2022

Regional economic competitiveness depends on various interrelated factors. A primary factor is the cost of operating a business in a region, which varies from industry to industry. Some industries may rely heavily on local market demand while others export goods and services to other regions. Businesses in some industry sectors tend to physically cluster with their competitors, as well as upstream and downstream firms, to foster network effects and create economies of agglomeration. In contrast, in other industries, businesses need not locate in close proximity to competitors or upstream/downstream firms to be competitive. Besides the industry-specific factors, the health and productivity of the region's workforce is another important determinant, and both cost of living and quality of life play a role in the size and makeup of a region's labor pool. Additionally, regional economic competitiveness can be also affected by policy decisions and public investment, such as the adequacy and conditions of regional infrastructure, as well as the regulatory environment and enforcement. As discussed in previous sections, the 2022 AQMP will potentially affect regional economic competitiveness through three major channels: (1) by increasing costs or introducing cost-savings for regional businesses, consumers, and the public sector as a result of the proposed control strategies; (2) by reducing air pollution-related health risk for the workforce and their dependents; and 3) by enhancing quality of life for the region's residents via public health and other clear air-related benefits that would improve the residents' well-being.

Having analyzed the job impacts associated with incremental costs and public health benefits in Chapter 4, this appendix additionally analyzes net competitiveness impacts as a result of implementing the 2022 AQMP.[1] The REMI model, used to estimate potential job impacts of the 2022 AQMP, also projects impacts on industry gross domestic product (GDP), cost of production, prices of locally manufactured goods, as well as exports and imports.

[1] There are existing concurrent policies such as Regional Housing Needs Allocation (RHNA) that could have a positive impact on the South Coast region's competitiveness, however, it is not explicitly accounted for in the REMI baseline projections.

Impacts on Industry GDP

Industry GDP is the gross output of an industry less the value of its intermediate inputs. Table 4C-1 shows the percent change of industry GDP from the baseline. The impacts associated with incremental costs only are mostly negative, and the impacts associated with public health benefits only are mostly positive. The overall impacts of the 2022 AQMP on industry GDP are largely negative; however, the magnitude of these impacts are negligible, with a combined cost/benefit impact of either far less than or around one percent for the majority of industries. Exceptions are utilities with a nearly 10 percent increase and agriculture and forestry with an 8 percent decrease.

TABLE 4C-1: IMPACTS ON INDUSTRY GDP

(Relative to Baseline)

Industry	Incremental Costs			Health Benefits			Combined Costs and Benefits		
	2023	2032	2037	2023	2032	2037	2023	2032	2037
Agriculture, Forestry, Fishing, Other	-0.14%	-12.54%	-8.15%	0.00%	0.08%	0.19%	-0.14%	-12.49%	-8.00%
Mining, Oil and Gas Extraction	-0.10%	-1.01%	-1.77%	0.00%	0.12%	0.24%	-0.10%	-0.89%	-1.53%
Utilities	-0.01%	4.03%	9.27%	0.00%	0.17%	0.40%	-0.01%	4.20%	9.65%
Construction	-0.11%	0.28%	-0.14%	0.00%	0.46%	0.91%	-0.11%	0.74%	0.76%
Manufacturing	0.08%	-0.41%	-0.85%	0.00%	0.07%	0.15%	0.08%	-0.34%	-0.71%
Wholesale Trade	-0.01%	-0.21%	-0.16%	0.00%	0.07%	0.17%	-0.01%	-0.14%	0.01%
Retail Trade	-0.03%	-0.26%	-0.49%	0.00%	0.13%	0.30%	-0.03%	-0.14%	-0.19%
Transportation and Warehousing	-0.02%	-1.23%	-1.30%	0.00%	0.07%	0.17%	-0.02%	-1.16%	-1.14%
Information	-0.02%	-0.16%	-0.28%	0.00%	0.03%	0.08%	-0.02%	-0.13%	-0.21%
Finance and Insurance	-0.02%	-0.25%	-0.42%	0.00%	0.06%	0.14%	-0.02%	-0.19%	-0.28%
Real Estate, Rental, and Leasing	-0.04%	-0.24%	-0.46%	0.00%	0.19%	0.43%	-0.04%	-0.05%	-0.03%
Professional and Technical Services	-0.01%	-0.18%	-0.17%	0.00%	0.08%	0.17%	-0.01%	-0.10%	0.00%
Management of Companies & Entr.	0.01%	-0.16%	-0.24%	0.00%	0.03%	0.06%	0.01%	-0.14%	-0.18%
Administrative and Waste Services	-0.01%	-0.30%	-0.46%	0.00%	0.09%	0.21%	-0.01%	-0.21%	-0.25%
Educational Services	-0.02%	-0.25%	-0.49%	0.00%	0.11%	0.26%	-0.02%	-0.14%	-0.23%
Health Care and Social Assistance	-0.03%	-0.23%	-0.45%	0.00%	0.07%	0.18%	-0.03%	-0.17%	-0.27%
Arts, Entertainment and Recreation	-0.03%	-0.23%	-0.37%	0.00%	0.03%	0.08%	-0.03%	-0.19%	-0.29%
Accommodation and Food Services	-0.02%	-0.32%	-0.62%	0.00%	0.18%	0.42%	-0.02%	-0.13%	-0.20%
Other Services (ex. Government)	-0.03%	-0.96%	-1.49%	0.00%	0.09%	0.22%	-0.03%	-0.87%	-1.28%

Impacts on Cost of Production

Table 4C-2 shows the percent change in cost of production relative to the rest of the United States, as a result of implementing the 2022 AQMP. The impacts associated with incremental costs are mostly negative in 2032. Due to limited information on the location of potential clean technology providers, the modeling approach assumes that the increased demand for clean technologies would benefit manufacturers and their suppliers based on the existing industry input-output structure in the U.S. It means that we conservatively assume that the increased spending on clean technologies in the region due to the implementation of 2022 AQMP control measures would not necessarily benefit local suppliers, therefore limiting the magnitude of potential job generating impacts.

In the meantime, about ten percent of the overall annual incremental costs between 2023 and 2037 are assumed to be incentives funded by either state or local governments. No additional revenues are assumed to be raised to fund the proposed incentives, the incentive payouts from government would necessitate a decrease in public spending in other function areas. These spending decreases would reduce local demand for goods and services across many industry sectors, thereby also reducing their demand for capital, labor, and other inputs. With lower demands for these inputs, their price would drop and therefore reduce the cost of production.

The impacts associated with public health benefits mainly decrease production costs, but overall have a negligible impact compared to incremental costs. By attracting more economic migrants into the region via improved quality of life, population growth would increase demand for housing and drive up land costs as well. This will eventually translate into higher capital costs, and therefore increasing production costs. It should be noted that increased economic migration would also increase labor supply and lower wage rates. However, in the REMI model built for the four-county region, the improved amenity, or quality of life, exerts more upward pressure on capital costs than downward impacts on wages, thus increasing the overall costs of production.

Overall, the agricultural sector is projected to experience the highest increase (16 percent in 2032 and 8 percent in 2037) as a result of implementing the 2022 AQMP, with utilities in a close second in 2037 with almost 6 percent due to many proposed stationary, area, and mobile source control measures that would affect both the sector's production cost and the demand for its output. All the remaining sectors will experience a smaller magnitude of production cost impacts. All of these changes are relatively small when compared with the overall size of the four-county economy.

TABLE 4C-2: IMPACTS ON COST OF PRODUCTION BY INDUSTRY

(Relative to Baseline)

Industry	Incremental Costs			Health Benefits			Combined Costs and Benefits		
	2023	2032	2037	2023	2032	2037	2023	2032	2037
Agriculture, Forestry, Fishing, Other	0.39%	15.50%	7.94%	0.00%	-0.02%	-0.06%	0.39%	15.48%	7.88%
Mining, Oil and Gas Extraction	0.48%	0.13%	1.22%	0.00%	0.02%	0.05%	0.48%	0.15%	1.27%
Utilities	0.04%	0.60%	5.67%	0.00%	0.02%	0.04%	0.04%	0.62%	5.72%
Construction	0.09%	0.13%	0.19%	0.00%	-0.01%	-0.01%	0.09%	0.12%	0.18%
Manufacturing	0.03%	0.10%	0.40%	0.00%	0.00%	-0.01%	0.03%	0.10%	0.39%
Wholesale Trade	0.02%	0.07%	0.09%	0.00%	0.00%	0.00%	0.02%	0.06%	0.09%
Retail Trade	0.02%	0.04%	0.05%	0.00%	0.00%	0.00%	0.02%	0.04%	0.05%
Transportation and Warehousing	0.04%	1.51%	1.24%	0.00%	-0.01%	-0.02%	0.04%	1.50%	1.22%
Information	0.03%	0.04%	0.15%	0.00%	0.00%	0.00%	0.03%	0.04%	0.15%
Finance and Insurance	0.03%	0.00%	0.06%	0.00%	0.00%	0.00%	0.03%	0.00%	0.06%
Real Estate, Rental, Leasing	0.05%	-0.06%	-0.04%	0.00%	0.03%	0.07%	0.05%	-0.03%	0.04%
Professional and Technical Services	0.02%	0.04%	0.10%	0.00%	-0.01%	-0.02%	0.02%	0.03%	0.08%
Management of Companies and Entr.	0.01%	0.01%	0.04%	0.00%	-0.01%	-0.02%	0.01%	0.00%	0.02%
Administrative and Waste Services	0.03%	0.06%	0.16%	0.00%	-0.01%	-0.02%	0.03%	0.05%	0.14%
Educational Services	0.02%	0.02%	0.20%	0.00%	0.00%	0.00%	0.02%	0.02%	0.19%
Health Care and Social Assistance	0.02%	0.02%	0.10%	0.00%	-0.01%	-0.02%	0.02%	0.01%	0.07%
Arts, Entertainment and Recreation	0.03%	-0.01%	0.04%	0.00%	0.01%	0.02%	0.03%	0.00%	0.06%
Accommodation and Food Services	0.02%	0.13%	0.40%	0.00%	0.00%	0.00%	0.02%	0.13%	0.40%
Other Services (ex. Government)	0.02%	0.50%	0.87%	0.00%	0.00%	-0.01%	0.02%	0.50%	0.85%

Impacts on Delivered Prices

Changes in production costs will affect prices of goods produced locally. The relative delivered price of a good is based on its production cost and the transportation cost of delivering the good to where it is consumed or used. Thus, the impact of implementing the 2022 AQMP on the delivered price mimics the cost of production. A lower cost of production translates to lower delivered prices, and *vice versa*. Table 4C-3 summarizes the results

TABLE 4C-3: IMPACTS ON DELIVERED PRICES BY INDUSTRY

(Relative to Baseline)

Industry	Incremental Costs			Health Benefits			Combined Costs and Benefits		
	2023	2032	2037	2023	2032	2037	2023	2032	2037
Agriculture, Forestry, Fishing, Other	0.11%	2.92%	1.78%	0.00%	0.00%	0.00%	0.11%	2.92%	1.78%
Mining, Oil and Gas Extraction	0.03%	0.01%	0.06%	0.00%	0.00%	0.00%	0.03%	0.01%	0.07%
Utilities	0.05%	0.62%	3.85%	0.00%	0.01%	0.03%	0.05%	0.63%	3.88%
Construction	0.09%	0.12%	0.18%	0.00%	-0.01%	-0.01%	0.09%	0.12%	0.17%
Manufacturing	0.03%	0.09%	0.30%	0.00%	0.00%	-0.01%	0.03%	0.08%	0.30%
Wholesale Trade	0.02%	0.06%	0.09%	0.00%	0.00%	0.00%	0.02%	0.06%	0.09%
Retail Trade	0.02%	0.03%	0.05%	0.00%	0.00%	0.00%	0.02%	0.03%	0.05%
Transportation and Warehousing	0.04%	1.34%	1.09%	0.00%	-0.01%	-0.02%	0.04%	1.33%	1.08%
Information	0.03%	0.02%	0.10%	0.00%	0.00%	0.01%	0.03%	0.03%	0.10%
Finance and Insurance	0.02%	0.00%	0.03%	0.00%	0.00%	0.00%	0.02%	0.00%	0.04%
Real Estate, Rental, and Leasing	0.05%	-0.06%	-0.04%	0.00%	0.03%	0.07%	0.05%	-0.03%	0.03%
Professional and Technical Services	0.02%	0.04%	0.10%	0.00%	-0.01%	-0.02%	0.02%	0.03%	0.08%
Management of Companies and Entr.	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%
Administrative and Waste Services	0.03%	0.05%	0.15%	0.00%	-0.01%	-0.02%	0.03%	0.05%	0.13%
Educational Services	0.02%	0.02%	0.15%	0.00%	0.00%	0.00%	0.02%	0.02%	0.15%
Health Care and Social Assistance	0.02%	0.02%	0.09%	0.00%	-0.01%	-0.02%	0.02%	0.01%	0.07%
Arts, Entertainment and Recreation	0.03%	-0.01%	0.03%	0.00%	0.01%	0.02%	0.03%	0.00%	0.05%
Accommodation and Food Services	0.02%	0.11%	0.34%	0.00%	0.00%	0.00%	0.02%	0.11%	0.34%
Other Services (ex. Government)	0.02%	0.47%	0.81%	0.00%	0.00%	-0.01%	0.02%	0.46%	0.80%

Impacts on Imports and Exports

Table 4C-4 summarizes the combined impact of the incremental cost of control measures and the public health benefits on the region's exports and imports relative to the baseline projections. Changes in exports reflect the changes in relative cost of production and delivered prices, thus its impact would mimic the impacts discussed above. On the other hand, as a result of population increase in the region, imports are expected to increase. As shown in the table below, all of these changes are relatively small when compared with the overall size of the four-county economy.

TABLE 4C-4: IMPACTS ON IMPORTS AND EXPORTS

($Millions/Percent Change Relative to Baseline)

Category	2023		2032		2037	
Exports	-$32	-0.01%	-$2,062	-0.29%	-$4,014	-0.51%
Imports	$454	0.09%	-$617	-0.11%	$747	0.12%

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Appendix 6-A

Environmental Justice Community Screening Method

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ENVIRONMENTAL JUSTICE COMMUNITY SCREENING METHOD

DECEMBER 2022

South Coast AQMD identifies disadvantaged communities (DACs) within the South Coast Air Basin in accordance with California Senate Bill (SB) 535, with the latest DAC designation published in May 2022.[1] The current DACs are designated based on geographic areas that include:

1) Census tracts that receive the highest 25% of overall scores in CalEnviroScreen4.0 (CES),
2) Census tracts that lack overall scores in CES but receive the highest 5% of CES cumulative pollution burden scores,
3) Census tracts identified in the 2017 DAC designation as disadvantaged, regardless of their current CES4.0 score,
4) Lands under the control of federally recognized Tribes.

The SB 535-designated DACs that fall within the Basin are considered environmental justice (EJ) communities by South Coast AQMD.

For this analysis, we analyzed alternative EJ community definitions in contrast with the SB 535 definition. Alternative EJ definitions considered are derivatives of the CES method. The CES method produces an overall percentile ranking of census tracts within California, based on a formula that combines percentile rankings of numerous sociodemographic and environmental indicators.[2]

EJ Screening Methodology

The CES method focuses on two categories of indicators: sociodemographic (or “population characteristics”) and environmental (or “pollution burden”). The “sensitive populations” and “socioeconomic factors” components are multiplied to calculate the “population characteristics” score; “exposures” and “environmental effects” components are multiplied to calculate the “pollution burden” score. Note that the “environmental effects” score is given half weight compared to the “exposures” score. The indicators that make up each of these components are provided in Table 6-1 in Chapter 6, followed by the general steps and mathematical formula used to produce the overall percentile ranking of census tracts under each alternative EJ definition.

Alternative EJ definitions were updated from the 2016 Socioeconomic Analysis to be consistent with updates within CalEnviroScreen4.0 and the EJ definition currently applied by South Coast AQMD.[3] Definition 1 includes poverty and air quality indicators; Definition 2 includes poverty, as well as other socioeconomic indicators, sensitive health indicators, and additional air quality exposure information; Definition 2a is the same as Alternative Definition 2 but includes a race and ethnicity indicator as part of the socioeconomic variables; Definition 3 is consistent with the SB 535 designation method; and Definition 3a is the same as Definition 3 but also includes a race and ethnicity indicator as part of the socioeconomic variables. For Definitions 1, 2, and 2a, we review EJ communities defined as the top 25 and top 50 percent of ranked CES scores; Definitions 3 and 3a include the top 25% of CES scores, plus additional census tracts consistent with the latest designation of SB 535 DAC. All percentiles were calculated at the state level, then census tracts within the Basin are selected from that set.

[1] See the SB 535 disadvantaged community definition for more details, available at https://calepa.ca.gov/envjustice/ghginvest/.

[2] See the final report of CES 4.0 for more information, available at https://oehha.ca.gov/media/downloads/calenviroscreen/report/calenviroscreen40reportf2021.pdf.

[3] CES 4.0 removed the age variable and added traffic impacts, cardiovascular disease, and housing burden.

The calculations for each definition involved the following steps:

Step 1): For each individual indicator, every census tract in California was percentile ranked based on the raw value of each indicator, such as pollutant concentrations or share of vulnerable populations.

Step 2): For each census tract, a weighted average of its percentile rankings across all indicators was derived for each of the two categories: population characteristics (PC) and pollution burden (PB).[4]

Step 3): For each census tract, its average percentile under each of the two categories was normalized by the highest average percentile among all statewide census tracts. The normalized ranking was then multiplied by ten to arrive at an interim "component score" for each category.

Step 4): For each census tract, the two "component scores" (one for each category) were multiplied to estimate an overall EJ screening score and re-ranked. A high score would place a census tract in the top ranks, which means a more adverse cumulative impact; therefore, the worst impacted tracts are ranked among the top one percent while the least impacted tracts are ranked among the bottom 99 percent.

Step 5): Depending on the threshold specified in the EJ definition, if a census tract within the Basin had an overall score that was high enough to be ranked above the threshold, then it was designated as an EJ area. In this report, for Alternative Definitions 1, 2, and 2a, the threshold was set at either top 25 percent or top 50 percent of CES scores within the state of California; therefore, a census tract within the Basin with an overall score ranked among the top 1st to 25th percentile is designated as an EJ area under either threshold.

For Alternative Definitions 3 (SB 535 definition) and 3a (SB 535 definition plus race/ethnicity), since the first SB 535 criteria is to select census tracts that receive the top 25 percent of CES scores within the state, the threshold for these definitions was set for census tracts within the Basin that meet any of the SB 535 criteria. Therefore, a census tract within the Basin with a CES score ranked among the top 26th to 50th percentile that does not meet any of the other SB535 criteria was not considered an EJ area under Alternative Definitions 3 and 3a.

Step 6): There were several instances for Alternative Definitions 1, 2, and 2a in which census tracts returned a score of "NA." This can be attributed to either low census tract population or missing indicator data required to produce a component score. For these census tracts, pursuant to the SB 535 designation criteria, we assigned an EJ area designation if the census tract contained a pollution burden component score within the top 5 percent of all statewide scores. All remaining "NA" census tracts within the Basin that did not fulfill this criterion were re-assigned as non-EJ areas.

The formula used to calculate CES_i, the overall EJ screening score for census tract *I*, is:, the for the category of pollution burden for census tract *i* be PB_i, the component score for the category of population characteristics for census tract *i be* PC_i, and *I* the set of all statewide census tracts. Then the overall EJ screening score can be written as:

$$CES_i = PB_i \times PC_i,$$

[4] Race and ethnicity are not included in CES, so Alternative Definitions 2a and 3a include percent minority data from ACS 2019 5-year estimates as one of the socioeconomic indicators.

where PB_i and PC_i are the component scores for pollution burden and population characteristics, respectively, normalized to the maximum average rank in the state. Mathematically,

$$PB_i = 10 \times \frac{AvgPB_i}{\max_i\{AvgPB_i\}} \text{ and } PC_i = 10 \times \frac{AvgPC_i}{\max_i\{AvgPC_i\}},$$

where

$$AvgPB_i = \frac{\sum_j^J E1rank_{i,j} + 0.5\sum_l^L E2rank_{i,l}}{J + 0.5L} \text{ and } AvgPC_i = \frac{\sum_k^K S1rank_{i,k} + \sum_m^M S2rank_{i,m}}{K + M},$$

with *J* denoting the set of environmental indicators that measure pollutant exposure; L the set of environmental indicators that is recognized to contribute less to possible pollution burden than other exposure-related environmental indicators (and thus given half weight); *K* the set of population characteristic indicators that address sensitive populations; *M* the set of population characteristic indicators that address socioeconomic factors, $E1rank_{i,j}$ is the percentile rank of exposure-related environmental indicator *j* for census tract *;*, $E2rank_{i,l}$ is the percentile rank of the environmental indicator *l* in census tract *i*, $S1rank_{i,k}$ is the percentile rank of sensitive population indicator *k* in census tract *i*, and $S2rank_{i,m}$ is the percentile rank of socioeconomic factor indicator *m* in census tract *i*.

From this formula, we can see that the set of pollution burden and population characteristics indicators are given equal weight in the overall EJ screening score. The addition of an indicator to either set will change the average for that group but does not change the weighting of either group in calculating the screening score. The EJ screening score is a continuous variable that does not itself indicate whether a census tract should be designated as an EJ area or not.

EJ Screening Example

Table 6A-2 provides an illustrative example of two census tracts to demonstrate how to use the CES method to calculate the overall EJ screening score and assess EJ status. This example uses two EJ definitions: Alternative Definition 1 which focuses on air quality indicators for pollution burden and poverty status for socioeconomic vulnerability; and Alternative Definition 3a, which builds upon the SB 535 DAC definition and incorporates race and ethnicity as part of the socioeconomic vulnerability component.

Table 6A-1: EJ Screening Example

		Census Tract A		Census Tract B	
		Def 1	Def 3a	Def 1	Def 3a
Step 1: Indicator Percentile					
Exposure Indicators					
PM2.5		81.9	81.9	73.6	73.6
Ozone		26.7	26.7	35.2	35.2
Diesel PM		-	95.2	-	21.1
Drinking water		-	94.2	-	95.6
Lead		-	87.7	-	72.8
Pesticide		-	67.8	-	0
Toxic Release		-	99.9	-	85.0
Traffic		-	92.8	-	40.0
Environmental Effects Indicators					
Cleanup Sites		-	77.5	-	27.5
Groundwater Threats		-	92.5	-	47.4
Hazardous Waste		-	99.1	-	28.3
Impaired Water Bodies		-	0	-	0
Solid Waste		-	96.5	-	37.6
Sociodemographic Indicators					
Poverty		75.1	75.1	30.5	30.5
Asthma		-	78.7	-	97.4
Education		-	74.3	-	44.9
Linguistic Isolation		-	83.4	-	13.3
Low Birth Weight		-	71.3	-	93.0
Unemployment		-	87.4	-	94.7
Cardiovascular Disease		-	58.0	-	69.5
Housing Burden		-	84.5	-	83.0
Percent Minority		-	78.0	-	69.6
Step 2: Weighted Average Percentile					
Pollution Burden (PB)		54.6	78.2	53.7	44.7
Population Characteristics (PC)		73.4	75.1	30.5	71.3
Step 3: Component Score					
Max PB		98.1	98.1	81.9	81.9
PB Component Score = (PB/Max PB) x 10		5.5	9.6	5.5	5.5
Max PC		100	100	95.0	95.0
PC Component Score = (PC/Max PC) x 10		7.5	7.8	3.0	7.5
Step 4: Overall EJ Screening Score					
EJ Score = PB Component x PC Component		41.5	74.8	16.8	40.7
EJ Percentile		73.4	99.6	41.7	76.2
Step 5: EJ Designation					
EJ Designation	50% threshold	EJ	EJ	Non-EJ	EJ
	25% threshold	Non-EJ		Non-EJ	

Note: A zero value for an indicator means that there was no impact from that source in the given census tract, thus the percentile rank is 0.

An EJ designation for a census tract can be sensitive to both the definition and designation threshold chosen. As shown in the table, under Definition 1, Census Tract A is designated as an EJ area because it ranks among the top 50 percent most impacted census tracts, though it is not in the top 25 percent most impacted census tracts. Census Tract A is also identified as an EJ area based on Definition 3a, which is the SB 535 definition with race and ethnicity (percent minority) additionally included as one of the socioeconomic indicators. Census Tract B is an EJ community according to Definition 3a, but not according to Definition 1. Both example census tracts have relatively high percentile rankings for many of the additional environmental and sociodemographic indicators, which raise both component scores and cause the overall EJ screening score to increase from Alternative Definition 1 to 3a.

South Coast AQMD

2022 AIR QUALITY MANAGEMENT PLAN

Final Socioeconomic Report

Appendix 6-B

Data and Detailed Results of the Environmental Justice Distributional Analysis

December 2022

FINAL SOCIOECONOMIC REPORT
APPENDIX 6-B

DATA AND DETAILED RESULTS OF THE ENVIRONMENTAL JUSTICE DISTRIBUTIONAL ANALYSIS

DECEMBER 2022

Health Risk Data

Distributional analysis methods were derived based on recommendations from Industrial Economics Inc., Levy and, Harper (2016), following the method used by Fann et al. (2011). This method utilized the air quality data, population projections, baseline incidence of health endpoints, and epidemiological concentration-response functions as described in Appendix 3-B. We estimated pollution exposure related health risk and examined its distribution for the EJ analysis under baseline and policy scenarios separately. Inequality statistics characterizing the statistical dispersion of each distribution were then compared to evaluate whether inequality of health risk would be decreased or exacerbated as a result of implementing the 2022 AQMP. The distribution of exposure related health risk was estimated using the modeled ambient air quality concentrations under each scenario using the health impact methodology as described in Appendix 3-B; however, the exposure-related health risk accounts for exposure to all emission sources of the pollutant, whether anthropogenic or biogenic, under both baseline and policy scenarios. The estimated health risk is defined as the implied health impact based on exposure to ambient air quality concentrations divided by the affected population.

The conversion of air quality, health impacts, and population data from the four kilometer by four kilometer grid cell to census tract, which can either be an aggregation of multiple grid cells, disaggregation of a grid cell, or a combination of both, was done using the geoprocessing methods of BenMAP-CE, which applies an area-weighting approach.

The summary statistics for the health risk distributions utilized here are described in Table 6B-1. All distributions consist of data points for each of the 3,447 census tracts in the Basin that are examined. The 2022 AQMP policies decrease the mean health risk for both PM2.5 and ozone exposure on mortality, asthma ED visits, and asthma incidence.

TABLE 6B-1: SUMMARY STATISTICS OF HEALTH RISK DISTRIBUTIONS

Distribution	Scenario	Mean	Standard Deviation	Coefficient of Variation	Median	25th Percentile	75th Percentile	Inter-Quartile Range
PM2.5-related mortality risk	Baseline	0.143%	0.042%	0.29	0.139%	0.115%	0.174%	0.059%
	Policy	0.126%	0.036%	0.29	0.123%	0.102%	0.151%	0.050%
Ozone-related mortality risk	Baseline	0.038%	0.010%	0.27	0.037%	0.031%	0.044%	0.013%
	Policy	0.034%	0.008%	0.24	0.034%	0.028%	0.040%	0.011%
PM2.5-related asthma ED visits risk	Baseline	0.005%	0.003%	0.56	0.004%	0.003%	0.006%	0.003%
	Policy	0.004%	0.002%	0.56	0.004%	0.003%	0.005%	0.003%
Ozone-related asthma ED visits risk	Baseline	0.024%	0.010%	0.42	0.023%	0.016%	0.030%	0.014%
	Policy	0.022%	0.009%	0.43	0.021%	0.015%	0.026%	0.012%
PM2.5-related asthma incidence risk	Baseline	0.536%	0.108%	0.20	0.547%	0.461%	0.622%	0.161%
	Policy	0.481%	0.095%	0.20	0.491%	0.413%	0.557%	0.143%
Ozone-related asthma incidence risk	Baseline	1.104%	0.071%	0.06	1.099%	1.046%	1.162%	0.116%
	Policy	1.036%	0.044%	0.04	1.040%	1.002%	1.070%	0.067%

Distributional Analysis Method

To evaluate the Atkinson and Kolm-Pollack inequality indices for health risk (a "bad") rather than income (a "good"), we transformed health risk using its complement (1 minus health risk) to understand the percent of the population that is not expected to experience premature death or illness due to the 2022 AQMP. The complement of health risk is directly interpretable as a "good," in that an increase in the value of this metric is a reduction in health risks. This metric is also a percentage, and thus on the same scale as health risk, it therefore does not violate the scale invariance of the Atkinson Index (Sheriff and Maguire 2013).

The computation of the decomposed Atkinson and Kolm-Pollack Index values were accomplished through the use of statistical software. The Atkinson Index is calculated using the Stata package *ineqdeco* (Jenkins 2015). The formula for the Atkinson Index is as follows:

$$A_\epsilon = \begin{cases} 1 - \frac{1}{\mu}\left(\frac{1}{N}\sum_{i=1}^{N} y_i^{1-\epsilon}\right)^{\frac{1}{1-\epsilon}} & for\ 0 \leq \epsilon \neq 1 \\ 1 - \frac{1}{\mu}\left(\prod_{i=1}^{N} y_i\right)^{\frac{1}{N}} & for\ \ \epsilon = 1, \end{cases}$$

where, y_i is the health risk for census tract i, μ is the average health risk, N is the number of census tracts, and ϵ is the inequality aversion parameter. The Atkinson index can be decomposed in within- and between-group components and a residual term. The between-group measure is given as:

$$A_B = 1 - \left[\frac{1}{j}\sum_{j=1}^{J}\left(\frac{\overline{y_j}}{y}\right)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}},$$

where y_j now represents the average health risk of group j (Harper and Lynch 2016). The formula for within-group inequality is somewhat more complicated as is given by Cowell (2011).

The Kolm-Pollack Index was calculated by staff using R software according to the following formula:

$$K(\alpha)_T = K(\alpha)_W + K(\alpha)_B = \left[\sum_{j=1}^{J} p_j K(\alpha)_j\right] + \left[\sum_{j=1}^{J} p_j \zeta_j - \zeta\right],$$

where $K(\alpha)$ is the Kolm-Pollack index, with an inequality aversion parameter α and subscripted by *T, W, and B* to denote the total, within-group, and between-group inequalities. J is the set of groups, and there are two groups examined in the EJ analysis: EJ and non-EJ communities based on the geographical unit of census tracts. p_j is the share of group *j* among all census tracts. ζ_j is the average health risk for group j, and ζ is the equally distributed health risk (Harper and Lynch 2016).

Distributional Analysis Results

We provide comprehensive results of the inequality analysis. Tables 6B-2 through 6B-7 provide results based on the Atkinson and Kolm-Pollack indices (inequality aversion=0.5) for each of the alternative EJ definitions. The within-group value is a measure of the average of the inequality within the EJ and non-EJ communities, respectively. The between-group value is a measure of average inequality between EJ and non-EJ communities. Throughout these tables, the aim is to *decrease* inequality both between EJ and non-EJ communities, and within EJ and non-EJ communities. Increases in inequality are shown in bold text across Tables 6B-2 through 6B-7. For all PM2.5-related health endpoints, we see decreases in inequality both within and between EJ communities, which is both expected and desired from a policy-making standpoint. We see increases in inequality *between* groups for ozone-related mortality in Definitions 1 and 2a and in ozone-related asthma incidence risk in Definitions 2 and 3, including Definitions 2a and 3a. Notably, we see large increases in the percentage of ozone-related asthma incidence risk between EJ and non-EJ communities according to Definitions 3 and 3a.

TABLE 6B-2: INEQUALITY INDICES OF PM2.5 EXPOSURE-RELATED MORTALITY RISK

		Atkinson		Kolm-Pollack	
Definition	Scenario	Within	Between	Within	Between
Def. 1: Top 25%	Baseline	4.31E-08	7.76E-10	4.30E-08	7.74E-10
	Control	3.22E-08	3.98E-10	3.21E-08	3.97E-10
	Change	-1.10E-08	-3.78E-10	-1.09E-08	-3.77E-10
	% Change	-25%	-49%	-25%	-49%
Def. 1: Top 50%	Baseline	4.28E-08	1.17E-09	4.26E-08	1.17E-09
	Control	3.19E-08	6.67E-10	3.18E-08	6.65E-10
	Change	-1.08E-08	-5.06E-10	-1.08E-08	-5.04E-10
	% Change	-25%	-43%	-25%	-43%
Def. 2: Top 25%	Baseline	4.30E-08	9.60E-10	4.28E-08	9.57E-10
	Control	3.20E-08	5.76E-10	3.19E-08	5.74E-10
	Change	-1.10E-08	-3.84E-10	-1.09E-08	-3.83E-10
	% Change	-26%	-40%	-26%	-40%
Def. 2: Top 50%	Baseline	4.20E-08	1.94E-09	4.19E-08	1.94E-09
	Control	3.14E-08	1.21E-09	3.13E-08	1.20E-09
	Change	-1.06E-08	-7.35E-10	-1.06E-08	-7.32E-10
	% Change	-25%	-38%	-25%	-38%
Def. 2a: Top 25%	Baseline	4.29E-08	9.74E-10	4.28E-08	9.71E-10
	Control	3.20E-08	5.84E-10	3.19E-08	5.82E-10
	Change	-1.10E-08	-3.90E-10	-1.09E-08	-3.89E-10
	% Change	-26%	-40%	-25%	-40%
Def. 2a: Top 50%	Baseline	4.21E-08	1.83E-09	4.20E-08	1.83E-09
	Control	3.14E-08	1.13E-09	3.14E-08	1.12E-09
	Change	-1.06E-08	-7.10E-10	-1.06E-08	-7.07E-10
	% Change	-25%	-39%	-25%	-39%
Def. 3: EJ (DAC Tracts (including Top 25%))	Baseline	4.28E-08	1.16E-09	4.26E-08	1.15E-09
	Control	3.18E-08	7.66E-10	3.17E-08	7.64E-10
	Change	-1.10E-08	-3.91E-10	-1.09E-08	-3.89E-10
	% Change	-26%	-34%	-26%	-34%
Def. 3a: EJ (DAC Tracts (including Top 25%))	Baseline	4.27E-08	1.22E-09	4.26E-08	1.22E-09
	Control	3.18E-08	8.09E-10	3.17E-08	8.07E-10
	Change	-1.09E-08	-4.11E-10	-1.09E-08	-4.10E-10
	% Change	-26%	-34%	-26%	-34%

TABLE 6B-3: INEQUALITY INDICES OF OZONE EXPOSURE-RELATED MORTALITY RISK

		Atkinson		Kolm-Pollack	
Definition	Scenario	Within	Between	Within	Between
Def. 1: Top 25%	Baseline	2.55E-09	**1.47E-14**	2.54E-09	**1.30E-14**
	Control	1.76E-09	**8.37E-14**	1.76E-09	**8.52E-14**
	Change	-7.81E-10	**6.91E-14**	-7.80E-10	**7.22E-14**
	% Change	-31%	**471%**	-31%	**556%**
Def. 1: Top 50%	Baseline	2.54E-09	2.95E-12	2.54E-09	2.94E-12
	Control	1.76E-09	1.07E-12	1.76E-09	1.07E-12
	Change	-7.79E-10	-1.88E-12	-7.78E-10	-1.87E-12
	% Change	-31%	-64%	-31%	-64%
Def. 2: Top 25%	Baseline	2.52E-09	2.30E-11	2.52E-09	2.30E-11
	Control	1.75E-09	1.60E-11	1.75E-09	1.60E-11
	Change	-7.74E-10	-7.03E-12	-7.73E-10	-7.02E-12
	% Change	-31%	-31%	-31%	-31%
Def. 2: Top 50%	Baseline	2.54E-09	1.17E-12	2.54E-09	1.16E-12
	Control	1.76E-09	1.12E-12	1.76E-09	1.12E-12
	Change	-7.81E-10	-4.34E-14	-7.80E-10	-4.24E-14
	% Change	-31%	-4%	-31%	-4%
Def. 2a: Top 25%	Baseline	2.52E-09	2.73E-11	2.52E-09	2.73E-11
	Control	1.75E-09	1.93E-11	1.74E-09	1.93E-11
	Change	-7.73E-10	-7.97E-12	-7.72E-10	-7.96E-12
	% Change	-31%	-29%	-31%	-29%
Def. 2a: Top 50%	Baseline	2.54E-09	**1.62E-12**	2.54E-09	**1.63E-12**
	Control	1.76E-09	**1.78E-12**	1.76E-09	**1.77E-12**
	Change	-7.81E-10	**1.57E-13**	-7.80E-10	**1.47E-13**
	% Change	-31%	**10%**	-31%	**9%**
Def. 3: EJ (DAC Tracts (including Top 25%))	Baseline	2.48E-09	6.17E-11	2.48E-09	6.17E-11
	Control	1.73E-09	3.57E-11	1.73E-09	3.57E-11
	Change	-7.55E-10	-2.60E-11	-7.54E-10	-2.60E-11
	% Change	-30%	-42%	-30%	-42%
Def. 3a: EJ (DAC Tracts (including Top 25%))	Baseline	2.48E-09	6.29E-11	2.48E-09	6.29E-11
	Control	1.73E-09	3.59E-11	1.73E-09	3.59E-11
	Change	-7.54E-10	-2.71E-11	-7.53E-10	-2.70E-11
	% Change	-30%	-43%	-30%	-43%

TABLE 6B-4: INEQUALITY INDICES OF PM2.5-RELATED EMERGENCY DEPARTMENT VISIT RISK

		Atkinson		Kolm-Pollack	
Definition	Scenario	Within	Between	Within	Between
Def. 1: Top 25%	Baseline	1.47E-10	3.54E-11	1.47E-10	3.54E-11
	Control	1.13E-10	2.53E-11	1.13E-10	2.53E-11
	Change	-3.39E-11	-1.00E-11	-3.39E-11	-1.00E-11
	% Change	-23%	-28%	-23%	-28%
Def. 1: Top 50%	Baseline	1.48E-10	3.47E-11	1.48E-10	3.47E-11
	Control	1.13E-10	2.54E-11	1.13E-10	2.54E-11
	Change	-3.46E-11	-9.34E-12	-3.46E-11	-9.33E-12
	% Change	-23%	-27%	-23%	-27%
Def. 2: Top 25%	Baseline	1.29E-10	5.30E-11	1.29E-10	5.30E-11
	Control	9.92E-11	3.92E-11	9.92E-11	3.92E-11
	Change	-3.02E-11	-1.37E-11	-3.02E-11	-1.37E-11
	% Change	-23%	-26%	-23%	-26%
Def. 2: Top 50%	Baseline	1.37E-10	4.49E-11	1.37E-10	4.49E-11
	Control	1.05E-10	3.32E-11	1.05E-10	3.32E-11
	Change	-3.22E-11	-1.18E-11	-3.22E-11	-1.18E-11
	% Change	-23%	-26%	-23%	-26%
Def. 2a: Top 25%	Baseline	1.26E-10	5.65E-11	1.26E-10	5.65E-11
	Control	9.66E-11	4.19E-11	9.65E-11	4.19E-11
	Change	-2.94E-11	-1.46E-11	-2.94E-11	-1.46E-11
	% Change	-23%	-26%	-23%	-26%
Def. 2a: Top 50%	Baseline	1.37E-10	4.58E-11	1.37E-10	4.58E-11
	Control	1.05E-10	3.38E-11	1.05E-10	3.38E-11
	Change	-3.20E-11	-1.20E-11	-3.20E-11	-1.20E-11
	% Change	-23%	-26%	-23%	-26%
Def. 3: EJ (DAC Tracts (including Top 25%))	Baseline	1.15E-10	6.76E-11	1.15E-10	6.76E-11
	Control	8.76E-11	5.09E-11	8.76E-11	5.09E-11
	Change	-2.73E-11	-1.67E-11	-2.73E-11	-1.67E-11
	% Change	-24%	-25%	-24%	-25%
Def. 3a: EJ (DAC Tracts (including Top 25%))	Baseline	1.14E-10	6.86E-11	1.14E-10	6.86E-11
	Control	8.68E-11	5.16E-11	8.68E-11	5.16E-11
	Change	-2.70E-11	-1.69E-11	-2.70E-11	-1.69E-11
	% Change	-24%	-25%	-24%	-25%

TABLE 6B-5: INEQUALITY INDICES OF OZONE-RELATED ASTHMA EMERGENCY DEPARTMENT VISITS RISK

		Atkinson		Kolm-Pollack	
Definition	Scenario	Within	Between	Within	Between
Def. 1: Top 25%	Baseline	1.97E-09	6.07E-10	1.97E-09	6.07E-10
	Control	1.65E-09	4.88E-10	1.65E-09	4.88E-10
	Change	-3.22E-10	-1.19E-10	-3.21E-10	-1.19E-10
	% Change	-16%	-20%	-16%	-20%
Def. 1: Top 50%	Baseline	1.97E-09	6.04E-10	1.97E-09	6.04E-10
	Control	1.65E-09	4.86E-10	1.65E-09	4.86E-10
	Change	-3.23E-10	-1.17E-10	-3.23E-10	-1.17E-10
	% Change	-16%	-19%	-16%	-19%
Def. 2: Top 25%	Baseline	1.86E-09	7.18E-10	1.86E-09	7.18E-10
	Control	1.52E-09	6.16E-10	1.52E-09	6.15E-10
	Change	-3.39E-10	-1.02E-10	-3.38E-10	-1.02E-10
	% Change	-18%	-14%	-18%	-14%
Def. 2: Top 50%	Baseline	1.94E-09	6.39E-10	1.94E-09	6.39E-10
	Control	1.60E-09	5.32E-10	1.60E-09	5.32E-10
	Change	-3.34E-10	-1.06E-10	-3.34E-10	-1.06E-10
	% Change	-17%	-17%	-17%	-17%
Def. 2a: Top 25%	Baseline	1.82E-09	7.61E-10	1.82E-09	7.61E-10
	Control	1.48E-09	6.53E-10	1.48E-09	6.52E-10
	Change	-3.33E-10	-1.08E-10	-3.32E-10	-1.08E-10
	% Change	-18%	-14%	-18%	-14%
Def. 2a: Top 50%	Baseline	1.92E-09	6.58E-10	1.92E-09	6.57E-10
	Control	1.59E-09	5.46E-10	1.59E-09	5.46E-10
	Change	-3.29E-10	-1.12E-10	-3.29E-10	-1.12E-10
	% Change	-17%	-17%	-17%	-17%
Def. 3: EJ (DAC Tracts (including Top 25%))	Baseline	1.79E-09	7.88E-10	1.79E-09	7.87E-10
	Control	1.42E-09	7.14E-10	1.42E-09	7.14E-10
	Change	-3.67E-10	-7.37E-11	-3.67E-10	-7.36E-11
	% Change	-21%	-9%	-20%	-9%
Def. 3a: EJ (DAC Tracts (including Top 25%))	Baseline	1.78E-09	7.94E-10	1.78E-09	7.94E-10
	Control	1.41E-09	7.22E-10	1.41E-09	7.22E-10
	Change	-3.69E-10	-7.22E-11	-3.68E-10	-7.21E-11
	% Change	-21%	-9%	-21%	-9%

TABLE 6B-6: INEQUALITY INDICES OF PM2.5-RELATED ASTHMA INCIDENCE RISK

		Atkinson		Kolm-Pollack	
Definition	Scenario	Within	Between	Within	Between
Def. 1: Top 25%	Baseline	2.69E-07	2.60E-08	2.66E-07	2.57E-08
	Control	2.12E-07	1.73E-08	2.10E-07	1.71E-08
	Change	-5.66E-08	-8.69E-09	-5.58E-08	-8.58E-09
	% Change	-21%	-33%	-21%	-33%
Def. 1: Top 50%	Baseline	2.65E-07	2.99E-08	2.62E-07	2.96E-08
	Control	2.09E-07	2.05E-08	2.07E-07	2.03E-08
	Change	-5.58E-08	-9.45E-09	-5.50E-08	-9.32E-09
	% Change	-21%	-32%	-21%	-31%
Def. 2: Top 25%	Baseline	2.54E-07	4.06E-08	2.52E-07	4.01E-08
	Control	2.00E-07	2.98E-08	1.98E-07	2.95E-08
	Change	-5.45E-08	-1.07E-08	-5.38E-08	-1.06E-08
	% Change	-21%	-26%	-21%	-26%
Def. 2: Top 50%	Baseline	2.49E-07	4.63E-08	2.46E-07	4.58E-08
	Control	1.97E-07	3.32E-08	1.95E-07	3.29E-08
	Change	-5.21E-08	-1.32E-08	-5.14E-08	-1.30E-08
	% Change	-21%	-28%	-21%	-28%
Def. 2a: Top 25%	Baseline	2.52E-07	4.32E-08	2.49E-07	4.27E-08
	Control	1.98E-07	3.18E-08	1.96E-07	3.15E-08
	Change	-5.39E-08	-1.14E-08	-5.31E-08	-1.12E-08
	% Change	-21%	-26%	-21%	-26%
Def. 2a: Top 50%	Baseline	2.48E-07	4.71E-08	2.45E-07	4.66E-08
	Control	1.96E-07	3.36E-08	1.94E-07	3.33E-08
	Change	-5.18E-08	-1.35E-08	-5.11E-08	-1.33E-08
	% Change	-21%	-29%	-21%	-29%
Def. 3: EJ (DAC Tracts (including Top 25%))	Baseline	2.43E-07	5.21E-08	2.40E-07	5.15E-08
	Control	1.89E-07	4.02E-08	1.88E-07	3.99E-08
	Change	-5.34E-08	-1.19E-08	-5.27E-08	-1.17E-08
	% Change	-22%	-23%	-22%	-23%
Def. 3a: EJ (DAC Tracts (including Top 25%))	Baseline	2.42E-07	5.34E-08	2.39E-07	5.28E-08
	Control	1.89E-07	4.12E-08	1.87E-07	4.08E-08
	Change	-5.31E-08	-1.22E-08	-5.24E-08	-1.20E-08
	% Change	-22%	-23%	-22%	-23%

TABLE 6B-7: INEQUALITY INDICES OF OZONE-RELATED ASTHMA INCIDENCE RISK

		Atkinson		Kolm-Pollack	
Definition	Scenario	Within	Between	Within	Between
Def. 1: Top 25%	Baseline	1.24E-07	5.57E-09	1.22E-07	5.45E-09
	Control	4.33E-08	5.25E-09	4.24E-08	5.15E-09
	Change	-8.11E-08	-3.17E-10	-7.93E-08	-3.03E-10
	% Change	-65%	-6%	-65%	-6%
Def. 1: Top 50%	Baseline	1.24E-07	5.59E-09	1.22E-07	5.47E-09
	Control	4.36E-08	4.99E-09	4.27E-08	4.89E-09
	Change	-8.08E-08	-5.97E-10	-7.90E-08	-5.77E-10
	% Change	-65%	-11%	-65%	-11%
Def. 2: Top 25%	Baseline	1.29E-07	**1.16E-09**	1.26E-07	**1.14E-09**
	Control	4.62E-08	**2.40E-09**	4.52E-08	**2.35E-09**
	Change	-8.27E-08	**1.24E-09**	-8.08E-08	**1.21E-09**
	% Change	-64%	**106%**	-64%	**107%**
Def. 2: Top 50%	Baseline	1.27E-07	**2.82E-09**	1.24E-07	**2.75E-09**
	Control	4.54E-08	**3.19E-09**	4.44E-08	**3.13E-09**
	Change	-8.18E-08	**3.79E-10**	-7.99E-08	**3.75E-10**
	% Change	-64%	**13%**	-64%	**14%**
Def. 2a: Top 25%	Baseline	1.29E-07	**1.21E-09**	1.26E-07	**1.18E-09**
	Control	4.61E-08	**2.44E-09**	4.52E-08	**2.39E-09**
	Change	-8.27E-08	**1.23E-09**	-8.08E-08	**1.21E-09**
	% Change	-64%	**102%**	-64%	**102%**
Def. 2a: Top 50%	Baseline	1.27E-07	**3.29E-09**	1.24E-07	**3.22E-09**
	Control	4.51E-08	**3.48E-09**	4.41E-08	**3.41E-09**
	Change	-8.16E-08	**1.90E-10**	-7.98E-08	**1.90E-10**
	% Change	-64%	**6%**	-64%	**6%**
Def. 3: EJ (DAC Tracts (including Top 25%))	Baseline	1.30E-07	**3.26E-12**	1.27E-07	**3.19E-12**
	Control	4.76E-08	**9.47E-10**	4.66E-08	**9.27E-10**
	Change	-8.24E-08	**9.44E-10**	-8.05E-08	**9.24E-10**
	% Change	-63%	**28923%**	-63%	**28967%**
Def. 3a: EJ (DAC Tracts (including Top 25%))	Baseline	1.30E-07	**6.51E-12**	1.27E-07	**6.37E-12**
	Control	4.76E-08	**9.63E-10**	4.66E-08	**9.43E-10**
	Change	-8.24E-08	**9.57E-10**	-8.05E-08	**9.37E-10**
	% Change	-63%	**14699%**	-63%	**14717%**