SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

Final Socioeconomic Report
Appendices

2016 AIR QUALITY MANAGEMENT PLAN

March 2017

FINAL SOCIOECONOMIC REPORT
APPENDIX 2-A

COMPILATION OF INCREMENTAL COSTS OF CONTROL MEASURES

MARCH 2017

The Final 2016 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 SCAQMD 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 SCAQMD'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 SCAQMD Control Measures

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

Direct costs associated with the Final 2016 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 and so on.

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 2017. 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 2017 to 2031, or from the year of the anticipated 2016 AQMP adoption to the year when the 2008 8-hour ozone standard of 75 ppb will need to be achieved. However, many categories of equipment included in the cost analysis will continue to be in operation after year 2031, 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

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

[2] In 1987, SCAQMD 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 SCAQMD 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 2031. In that same table, the amortized annual average cost over the period 2017-2031 is also reported. This cost, in contrast, includes recurring costs up to 2031, and the amortized capital and other upfront costs beyond 2031 are not included. The amortized costs are comparable to the costs reported in the Economic Analysis for the Proposed 2016 State Strategy for the State Implementation Plan.

Cost assumptions and cost breakdown by measure are presented below (see Chapter 4 and Appendixes IV-A and IV-B of the Final 2016 AQMP for the detailed description of each measure). All costs presented herein are expressed in 2015 dollars, with conversion based on the Marshall and Swift Index of equipment costs. It should be noted that the implementation period for the cost analysis may differ somewhat from the "Implementation Period" listed in the Final 2016 AQMP Table 4-2 on page 4-10. 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. It is assumed that the purchase and installation of all equipment is evenly distributed over the implementation period unless otherwise noted.

Finally, the control measures that recognize co-benefit ozone emission reductions from other programs will not have incremental costs. They include *ECC-02 (Co-benefits from existing residential and commercial building energy efficiency measures)* which has quantified NOx emission reductions, *ECC-01 (Co-benefit emission reductions from GHG programs, policies, and incentives)* and *ECC-04 (Reduced ozone formation and emission reductions from cool roof technology)*, both with TBD NOx emission reductions. Also, the Further Development of Cleaner Technologies: On-Road Light-Duty control measure is primarily designed to reduce GHG emissions and therefore is recognized as providing NOx and VOC reductions as a co-benefit. These measures are part of federal, state, and local programs and are being implemented across multiple energy sectors and are generally mandated by law, regardless of whether the Final 2016 AQMP is adopted. Therefore, their costs are not a result of the proposed control measures.

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

❖ *CMB-01 (Transition to zero, near-zero emission technologies for stationary sources)*

CMB-01 is an incentive program based control measure and seeks emission reductions of NOx from traditional combustion sources (non-power plant) through facility modernization or replacement of old higher emitting equipment. Higher emitting equipment or facilities will be modernized by replacing or putting in technologies with zero or near-zero NOx emissions such as the usage of electrification, battery storage, alternative process changes, efficiency measures, or fuel cells for combined heat and power. These combustion sources include, but are not limited to, engines, turbines, microturbines, and boilers that generate power for electricity for distributed generation, facility power, process heating, and/or steam production. Another type of combustion source identified for equipment replacement includes ovens, kilns, and furnaces. New businesses can be required or incentivized to install and operate zero-emission equipment, control equipment, technology and processes beyond the current BACT requirements. Fuel cells are also an alternative to traditional combustion methods, resulting in a reduction of NOx emissions with the co-benefit of reducing other criteria air pollutants and greenhouse gases (GHGs). Incentives may be used towards alternative process changes, such as biogas cleanup, or encourage facilities to change out equipment sooner. This would help modernize a facility towards zero and near-zero technologies. This control measure would also seek energy storage systems and smart grid control technologies that provide a flexible and dispatchable resource with zero emissions. Grid based storage systems can replace the need for new peaking generation, be coupled with renewable energy generation, and reduce the need for additional energy infrastructure. Mechanisms will be explored to incentivize businesses to choose the cleanest technologies as they replace equipment and upgrade facilities, and to provide incentives to encourage businesses to move into these zero and near-zero emission technologies sooner. Over the anticipated timeline of this Plan, as emerging technologies become more widely available and costs decline, the SCAQMD will undergo rulemaking to require zero emission equipment be installed where economically feasible and near-zero emission equipment in all other applications.

SCAQMD'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 (e.g., external combustion, internal combustion, coatings, tanks, etc.) and requires fuel type, throughput, pollutant and emission factors. Using this tool, staff identified the largest non-RECLAIM NOx emitting facilities. Sixty six facilities were identified consisting of municipal solid waste (MSW) incinerators, landfill gas, and wastewater treatment facilities, and together these facilities emit 2.3 tons per day of NOx. These facilities will be analyzed to determine where the greatest emissions reductions could be achieved and replaced with zero or near-zero equipment or emission technology including the diversion of waste streams to be cleaned up or processed, or biogas routed to pipelines or used for transportation fuels. Staff also used the AER program along with SCAQMD CLASS permitting system to identify categories with combustion sources that are older and higher emitting and could be replaced with zero and near-zero technologies including fuel cells, low emitting NOx equipment, equipment modification, control equipment, and/or process changes. The combustion source category with the largest amount of emissions is from internal combustion engines (ICEs), because of the volume of ICEs being used in the Basin. Other smaller categories identified include ovens and low use fuel natural gas (NG) boilers.

The cost effective analysis is only a demonstration of source categories staff identified for potential emission reductions through incentive funding and costs for replacement 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 come forth to participate in the incentive program and, once a working group is established, will determine the most cost-effective means for distribution of funds to achieve emissions reductions.

Assumptions[4] for cost estimates are listed in the table below:

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[4] AER System and CLASS permitting system.

Source Categories	
Tier 2 and Lower Diesel ICE Replacement	• The average unit cost of an ICE (meeting at a minimum Tier 4 standards) is assumed to be $155,000[5] per engine (including installation). • It is assumed the replacement of these ICEs (Tier 2 and lower) will have a 96 percent reduction for NOx. • Approximately 6,300 diesel ICEs were permitted before 2010 and are expected to be higher emitting. It is expected about 40 percent will be replaced to reduce NOx emissions. • No additional operational or maintenance costs are expected with this replacement. • Equipment life is expected to be 25 years.
NG Engines to Zero and Near-Zero Replacement[6]	• NG engines being replaced must be less than 670 brake horsepower (bhp) (500 kilowatt (kW)) to use this technology. • NG engines being replaced must be used for power generation to use this technology. • This technology would replace the existing NG rich-burn engines and includes controls. It is assumed 25 percent of NG engines identified from past survey[7] responses could be replaced with this technology. • The average bhp of the engines used in the cost analysis is assumed to be 548 bhp. • It is assumed each engine operates for 6,000 hours per year. • Operation and maintenance costs are assumed at a rate of $0.013 per bhp-hour (bhp-hr). • Equipment life is expected to be 25 years.
NG Engines Retrofitted with Control equipment[3]	• This technology involves retrofitting NG engines with a catalyst to reduce NOx emissions. • The average bhp rating of the engines used in the cost analysis is 344 bhp. • It is assumed each engine operates for 6,000 hours per year. • Operation and maintenance costs are assumed at a rate of $0.013 per bhp-hr. • Equipment life is expected to be 25 years.
Replacement of ICEs to Fuel Cells (Cell Towers)[8]	• Roughly 400 permitted engines could be located at cellular communication sites. Of these, it is estimated 25 percent could be replaced with fuel cells. • Operational and maintenance costs are expected to be minimal; therefore, it is assumed to be five percent of the capital costs. • Equipment life is expected to 20 years.
Retrofitting Diesel ICEs to NG Bi-Fuel Systems[9]	• It is assumed one percent of diesel ICEs permitted before 2010 could be converted to bi-fuel systems that utilize NG to reduce NOx emissions by 30 percent. • No additional operational or maintenance costs are expected with this retrofit. • Equipment life is expected to be 25 years.

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[5] Industry stakeholder cost estimates from Rule 1470 amendment and internal cost data.

[6] Email from W. Martini (Industry Stakeholder) to K. Orellana. September 1, 2016.

[7] 2008 Rule 1110.2 Amendment Survey Data.

[8] Email from C. Vita (Industry Stakeholder) to D. Thai.

[9] Email from J. Villa (Industry Stakeholder) to D. Thai. August 24, 2016.

Source Categories	
Replacement of Ovens/Furnaces/Kilns	• Approximately 1,000 unpermitted ovens, furnaces, and kilns could be replaced with low NOx equipment. • No additional operational or maintenance costs are expected with this replacement. • Equipment life is expected to be 25 years.
Replacement of Low Fuel use NG Boilers[10,11]	• 133 low fuel use NG boilers were identified ranging from five to 75 million British thermal units (MMBtu) per hr to be replaced. Six of these boilers are larger boilers. • No additional operational or maintenance costs are expected with this replacement. • Equipment life is expected to be 25 years.
Facility Modernization by Sector	
Landfills and Wastewater Treatment	• Costs are based only on biogas cleanup. • Biogas cleanup can include cleanup of siloxanes, hydrogen sulfides, oxygen, water (removal), nitrogen, and trace constituents[12]. • Cleanup cost is estimated from the total throughput (in cubic feet per minute) from all the facilities for each category (landfills or wastewater treatment) and not based on each individual facility. • Infrastructure for pipelines is expected to be the highest portion of costs for facility modernization. These are not included in the costs, because it has not been determined which facilities will be participating in the incentive program and their respective distances to pipeline access. Location distance plays a large factor in interconnection costs. • Equipment for biogas cleanup is expected to have an equipment life of 25 years.
Municipal Solid Waste	• Costs are based on using a selective catalytic reduction (SCR)[13] system for a boiler at MSW facilities to lower NOx emissions. • SCRs are expected to have an equipment life of 25 years.

Implementation period for cost analysis: 2018-2031

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[10] Best Available Control Technology (BACT) – Internal Documents (2008).

[11] Final Staff Report. Proposed Amended Rule 1146 – Emissions of Oxides of Nitrogen from Industrial, Institutional, and Commercial Boilers, Steam Generators, and Process Heaters. August 2008.

[12] Black & Veatch Biogas Upgrading. April 29, 2016. Email from N. Taylor to D. Thai. September 1, 2016.

[13] NOx RECLAIM Staff Report – December 4, 2015.

Capital cost assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit/Facility Cost	Per Unit/Facility Incentive Amount	Number of Units	Years of Equipment Life
Tier 2 and Lower Diesel ICEs Replacement	All Industries	$155,000	$43,105	2,420	25
NG Engines to Zero and Near-Zero Replacement	All Industries	$3,781,200	$896,972	60	25
NG Engines Retrofitted with Control equipment[3]	All Industries	$182,320	$43,250	528	25
Replacement of ICEs to Fuel Cells (Cell Towers)	All Industries	$180,000	$44,901	95	20
Retrofitting Diesel ICEs to NG Bi-Fuel Systems	All Industries	$38,000	$13,470	63	25
Replacement of Ovens/Furnaces/Kilns	All Industries	$40,000	$33,300	1,000	25
Replacement of Low Fuel use NG Small Boilers	All Industries	$404,457	$74,749	127	25
Replacement of Low Fuel use Larger NG Boilers	All Industries	$1,178,556	$217,813	6	25
Facility Modernization (Bio Gas Clean up-Landfills)	Landfills (562)	$21,365,000	$1,862,069	29	25
Facility Modernization (Bio Gas Clean up-Waste Water Treatment)	Waste Water Treatment (221)	$6,730,000	$771,429	35	25
Facility Modernization (with SCR)	Landfills (562)	$3,732,800	$13,500,000	4	25

Additional operating and maintenance costs for the NG engines to zero and near-zero and NG engines retrofitted with control equipment were assumed to be catalyst replacements every five years at an estimated cost of $42,744 and $26,832, respectively. Additional operating and maintenance costs for facility modernization of bio gas cleanup for landfills and waste water treatment facilities were assumed to be carbon adsorption replacements at an estimated cost of $1,500,000 and $700,000, respectively. Also, an additional cost of $255,600 for ammonia usage was assumed annually for the units with new SCR.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
CMB-01	$1,883.0	+	$275.5	=	$2,158.6	$89.8

❖ *CMB-02 (Emission reductions from commercial and residential space and water heating)*

CMB-02 would incentivize replacement of older water heaters, boilers and steam generators in commercial establishments and multifamily residential buildings. Initially, incentives would accelerate replacement of older units with new units using existing technology whose NOx emissions are significantly lower than applicable rule limits (e.g., 12 ppm NOx instead of 20 ppm for Rule 1146.2 equipment). A second phase would replace units with near zero emission technologies including, but not limited to, solar thermal, electric, solar electric, heat pumps, and fuel cell technologies. The number of units that can potentially be replaced with newer low emission units or technologies is based on an equipment inventory developed for Rule 1146.2 adoption. Incentive programs are proposed to start by 2018 and potential future rules in support of these programs can have implementation dates starting in 2020.

Cost of equipment are estimated using the following sources of information:

- Prices on Type 1 and Type 2 Rule 1146.2 units based on Information in the 2006 Staff Report for Rule 1146.2[14]
- Prices of Type 1 Rule 1146.2 units were updated based on listed prices on websites of equipment supply companies including but not limited to Home Depot, Lowes, and Grainger
- Prices of heat pump water heaters are based on listed prices on websites of equipment suppliers
- Prices of solar technologies based on information from U.S. EPA, California Energy Commission and web based cost analysis and tools available from companies providing solar heating and electric systems

The price difference between a standard model and a low-NOx emitting model is the basis of the total incremental cost for this control measure. To take into account the potentially larger cost associated with early replacement instead of natural equipment turnover, it is further assumed that the cost of early replacement is equivalent to one third of the price difference. In order to obtain emission reduction credits for the early replacement, it is assumed that units are replaced at two thirds of their useful life (e.g., at 10 out of 15 years) for a commercial water heater. It is also assumed that the installation cost is identical for both models. Therefore, the total incremental cost for a particular type of equipment is assumed to be equal to 1.33 times of the estimated price difference.

Incentives are proposed to partially offset the incremental cost, and the incentives range from $1,000 to $10,000 per unit, depending on the type of equipment purchased. The SCAQMD has committed to achieving emission reductions through an approved program meeting U.S. EPA requirements that will be in place by 2020. However, the incentive programs under this control measure will begin earlier and

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[14] Staff Report for SCAQMD Rule 1146.2 – Emissions of Oxides of Nitrogen from Large Water Heaters and Small Boilers and Process Heaters, May 5, 2006

achieve emission reductions starting in 2018.

Implementation period for cost analysis: 2018-2031[15]

Capital cost assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit Cost	Per Unit Incentive Amount	Number of Units	Years of Equipment Life
Various Categories of Water Heater/Boiler	All Industries	$1,400-$15,000	$1,000-$10,000	2,000-50,000	15-25

No additional operating and maintenance costs were assumed.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
CMB-02	$699.0	+	$503.5	=	$1,202.4	$51.6

❖ *CMB-03 (Emission reductions from non-refinery flares)*

CMB-03 proposes to reduce NOx and VOC emissions from gas handling at non-refinery sources such as organic liquid loading stations, tank farms, oil and gas facilities, landfills, and wastewater treatment facilities. This control measure would create a source specific rule for non-refinery flares based on two potential approaches (certain applications may warrant both approaches):

1) Cleaning the gas that would typically be flared and using it as follows:
    a. Capturing the gas that would typically be flared and converting it into an energy source (e.g. transportation fuel, fuel cells, facility power generation), or if not feasible,
    b. Directing it to equipment that can be converted to power and/or heat.
2) If all other options are infeasible, requiring the installation of newer flares implementing the best available control technology.

Facilities were identified from the following source categories: oil and gas production, landfills, and wastewater treatment facilities. Using SCAQMD's permitting systems, roughly 250 flares were identified. Cost data was based on estimates for new flares with clean enclosed burners (CEB) installed at existing SCAQMD permitted facilities. Facilities can choose a number of options to reduce NOx emissions instead of flaring such as using microturbines and boilers for power generation or routing waste streams to pipelines for transportation fuel. Waste gas that would otherwise be flared can be directed to microturbines or boilers that use organic rankine cycle (ORC) technology to provide power to the facility. Newer power producing technologies, such as the ORC, have shown the ability to consume the gas that would otherwise be flared and provide a co-benefit by producing power. This technology utilizes heat

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[15] Depending on the category of water heater/boilers, some are assumed to be evenly phased in between 2018 and 2023, some between 2018 and 2031, and others between 2023 and 2031.

recovery from gas combustion to operate the ORC loop to make power. Regenerative thermal oxidation with microturbine technology to produce power can be utilized at landfills with low quality, low methane content landfill gas to make power with ultra-low criteria pollutant emissions and without expensive biogas cleanup. Incorporating newer technologies such as energy storage along with biogas development, distributed energy resources, and improved efficiencies can reduce the need for redundant energy infrastructures, provide for greater grid reliability (less possibility for blackouts), and reduce the need for new fossil-based generation. Better utilization of waste streams, such as biogas, will provide sources of energy, can help supply near-zero emission transportation technologies, improve the Basin's NG infrastructure, and provide carbon neutral fuels.

The cost analysis was based on the worst-case scenario where all facilities could not implement all other options and, as a result, had to purchasing a newer lower emitting flare, as specified in Point 2) above. One of the reasons why a facility could not implement all other options may be due to economic feasibility concerns. Pipeline injection can be costly based on pipeline infrastructure and biogas cleanup. Facilities can be identified that are closer to pipelines with corresponding lower costs for pipeline injection infrastructure. Depending on the type of technology or equipment receiving biogas, biogas cleanup could mean removal of nitrogen, siloxanes, hydrogen sulfides, high levels of oxygen, and other trace constituents. Incentives for infrastructure and biogas cleanup can help these sources find beneficial uses with co-benefits for these waste streams. It is expected that advancements in technology will continue and allow zero and near-zero technology to become more cost-effective once established. Staff also anticipates technology will evolve to address waste streams for facilities that produce low levels of biogas. Facilities may qualify under other programs such as the Low Carbon Fuel Standard (LCFS) in California and the federal Renewable Fuel Standard Program. Under these programs, credits are generated for the sale of renewable transportation fuels and, depending on market prices, have provided funding for equipment and lower fuel costs. This may help offset costs.

The cost estimates presented here could be considered as an upper bound for the likely range of incremental costs associated with this measure.

Assumptions[16] for cost estimates include:

Replacement of existing flares with newer flares utilizing CEB (<15 ppm)	• A new flare with CEB for oil and gas production and landfill facilities, was estimated to cost $700,000 and $250,000, respectively (including installation). • New flares with CEB to process digester gas were estimated to cost $475,000 (the average between the high and low estimates of other categories). • Annual operation and maintenance costs are assumed to be 7.2 percent of the capital cost of the equipment. • It is assumed a facility will operate 24 hours a day and 365 days per year. • Equipment life is expected to be 25 years. • Compliance date is expected to be 2020. • The annual average emission reductions of 1.3 tons per day are expected to be achieved for all the non-refinery flares.

Implementation period for cost analysis: 2020

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[16] Costs estimated on data received from Industry Stakeholders.

Capital cost assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit Cost	Incentive Amount	Number of Units	Years of Equipment Life
Clean Enclosed Burners (meeting ≤5 ppmv)	Oil and Gas (211),	$700,000	$0	43	25
	Landfills (562) Landfills, Utilities (221),	$250,000	$0	52	25
	Waste Water Treatment (221),Chemical Manufacturing (325), Transportation Equipment Manufacturing (336), Pipeline Transportation (486), Support Activities for Transportation (488),	$475,000	$0	33	25

Additional annual operating and maintenance costs were estimated at $50,000 per unit for Oil and Gas, $18,000 per unit for landfill units, and $34,000 per unit for other units.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
CMB-03	$113.4	+	$0	=	$113.4	$6.3

❖ *CMB-04 (Emission reductions from restaurant burners and residential cooking)*

CMB-04 would incentivize purchases of new lower emission commercial cooking appliances including, but not limited to, fryers, griddles, ovens and broilers. This control measure proposes to incentivize early replacement or retrofit of up to 250,000 commercial cooking appliances. This equipment number is based on an estimate of 264,000 units in the Basin assuming 47% of the equipment in the commercial cooking inventory developed for the California Energy Commission is in the Basin (population weighted). Not all of the equipment in the Basin would be retrofit or replaced because emissions vary depending upon type and size of unit. Currently, there are more units in the Basin than are proposed to be replaced. In addition, if larger units are the focus of the program, fewer units would need to be replaced.

A cost of $10,000 per unit is used as the average cost for a new commercial cooking appliance and for this analysis all units are assumed to be replaced. The cost for new equipment varies widely from less than $1,000 to much more than $10,000 per unit. This cost is in the middle of the range of costs provided by the following sources of information:

- Southern California Gas Company staff at the Gas Company Energy Resource Center
- Prices listed on websites of restaurant equipment sales companies

The cost increase for purchase of units with lower NOx emissions will also vary. Some individual units in an equipment category may already have lower emissions and there would be no increase in cost to purchase the unit. Lower NOx emissions in other categories of equipment may require a different type of burner in order to reduce emissions.[17] Based on cost increases for low NOx technologies in other

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

appliances used in residential and commercial settings and because of this variability, staff estimates that the average increase in cost for a low NOx unit will be about 20%, or $2,000 per unit. To take into account the potentially larger cost associated with early replacement instead of natural equipment turnover, it is further assumed that the cost of early replacement is equivalent to one third of this cost increase. Therefore, the incremental cost per unit is assumed to be equal to 1.33 times of $2,000, or $2,667 per unit.

An incentive of $1,000 per unit is proposed to partially offset the incremental cost. Incentive programs are proposed to start by 2018 and potential future rules in support of these programs can have implementation dates starting in 2020.

The SCAQMD has committed to achieve emission reductions through an approved program meeting U.S. EPA requirements that will be in place by 2020. However, the incentive programs under this control measure will begin earlier and achieve emission reductions starting 2018.

Implementation period for cost analysis: 2018-2031

Capital cost assumptions:

Equipment Name	**Affected Industries (NAICS)**	**Per Unit Cost[18]**	**Per Unit Incentive Amount**	**Number of Units**	**Years of Equipment Life**
Restaurant Burners	Restaurants (722)	$2,666	$1,000	250,000	15

No additional operating and maintenance costs were assumed.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	**Present Value of Remaining Incremental Cost**		**Present Value of Incentives**		**Present Worth Value of Total Incremental Cost**	**Amortized Annual Average (2017-2031)**
CMB-04	$320.6	+	$192.4	=	$512.9	$30.7

❖ *CMB-05 (Further NOx reductions from RECLAIM assessment)*

CMB-05 proposes to reduce NOx emissions from RECLAIM facilities, which include a wide range of equipment such as fluid catalytic cracking units, boilers, heaters, furnaces, ovens, kilns, coke calciners, internal combustion engines, and turbines that are major sources of NOx or SOx emissions. A proposed method of control is to perform additional or more frequent BARCT assessments and adjust NOx RECLAIM Trading Credit (RTC) allocations as control technologies improve and are implemented in practice. However, another approach under serious consideration is to sunset the program and transition to a traditional command-and-control structure. This would be predicated on whether more creditable SIP reductions and/or actual emission reductions can be achieved in a command-and-control regulatory regime instead of the RECLAIM program. Since the possible sunsetting of the RECLAIM program would be

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[18] Sources: Southern California Gas Company and industry representatives.

a long-term process, the cost assumptions for this control measure must be based on a subsequent BARCT assessment. That is, there would be sufficient time for control technologies to further mature. Thus, such a BARCT assessment would take into consideration equipment controls far enough out in the future that would be determined as feasible and cost-effective. The overall average cost-effectiveness for the December 4, 2015 RECLAIM amendment was $9,000 to $14,000 per ton of NOx reduced[19]. It is assumed that further reductions would be achieved from already controlled equipment, and it is expected that the cost-effectiveness for this control measure would be about 50 percent higher or $13,500–$21,000 per ton.

The cost assumptions were based on distributing the 5 tons per day of emission reductions in the same manner as the 8.77 tons per day of incremental NOx reductions were applied for the December 2015 amendments across the same source categories, which included:

- Refinery Fluid Catalytic Cracking Units (FCCU)
- Refinery Boilers and Heaters
- Refinery Gas Turbines
- Coke Calciner
- Sulfur Recovery Units/Tail Gas Incinerators
- Glass Melting Furnaces
- Sodium Silicate Furnace
- Metal Heat Treating Furnaces Above 150 MMBTU/hr
- Non-Refinery Gas Turbines
- Non-Refinery Internal Combustion Engines

The increase in costs would result from the installation of more sophisticated controls in the future for these source categories to achieve the incremental emission reductions. The cost analysis for CMB-05 assumes negligible cost impact on structural buyers, and at the same time, also omits the potential financial gain of selling surplus credits for those facilities that are assumed to install additional controls.

Implementation period for cost analysis: 2026-2031

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[19] SCAQMD, 2015. Final Staff Report for Amendments to Regulation XX – NOx RECLAIM.

Cost assumptions:[20]

Equipment Name	**Affected Industries (NAICS)**	**Capital and Installation Costs (Millions)**	**Total O& M Costs (Millions)**	**Years of Equipment Life**
Fluid Catalytic Cracking Units (FCCUs)	Petroleum and Coal Products(324)	$227.01	$10.86	25
Gas Turbine	Petroleum and Coal Products(324)	$15.64	$3.67	25
Coke Calciner	Petroleum and Coal Products(324)	$50.84	$2.58	25
Boilers/Heaters	Petroleum and Coal Products(324)	$201.0	$2.42	25
Sulfur Recovery Units	Petroleum and Coal Products(324)	$114.62	$0.64	25
Glass Melting Furnaces	Nonmetallic Mineral Product Manufacturing(327)	$5.68	$0.47	25
Sodium Silicate Furnace	Chemical Manufacturing (325)	$2.0	$0.13	25
Metal Heat Treating Furnace	Primary Metal Manufacturing (331)	$2.8	$0.32	25
Non-Refinery Gas Turbines	Oil and Gas(211), Paper Manufacturing (322), and Support Activities for Transportation (488)	$17.06	$2.36	25
Non-Refinery ICEs	Utilities (221)	$36.2	$2.72	25

No additional operating and maintenance costs were assumed.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	**Present Value of Remaining Incremental Cost**		**Present Value of Incentives**		**Present Worth Value of Total Incremental Cost**	**Amortized Annual Average (2017-2031)**
CMB-05	$856.4	+	$0	=	$856.4	$19.3

- *ECC-03 (Additional enhancements in reducing existing residential building energy use)*

ECC-03 would incentivize advanced highly efficient appliance technologies focused on existing residences. Implementation of smart grid technology and other energy efficiency weatherization measures including: heat pump water heaters and storage systems, pool heater and covers, solar thermal water heating, weatherization, and clothes dryers. The replacements will reduce end use energy consumption and

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[20] Source: 2015 Amendments to the NOx RECLAIM.

provide overall emission reductions. The cost of the incentive program is dependent on the type and number of equipment replacements, available incentives, efficiency gains, and energy prices.

Assumptions

Equipment Cost and Existing Incentives – Equipment cost for proposed technologies and existing incentives currently available were gathered from various websites including: Energy Upgrade California, Energy Star, Energy Wise EPA, Lawrence Berkeley National Lab, U.S. Department of Energy, Southern California Edison, Southern California Gas, and Los Angeles Department of Water and Power.

Number of Units - California Energy Commission Residential Energy Use Summary 2009 Residential Appliance Saturation Survey was used to estimate the number of appliance units in the Basin which could participate in program.

Incentive Amounts – Incentives/reimbursement amounts range from $100 to $300 based on equipment type and cost, existing incentives already available, and cost effectiveness of technology.

Estimated Annual Cost/Savings - For estimated annual cost/savings various scenarios were analyzed including cost savings from reduced natural gas usage[21] (estimated $1.10 cents/therm), and the anticipated expense if the technology uses electricity[22] ($0.16 per kWh for electricity). It should be noted that all residences would be eligible for funding; however, homes with solar panels will have higher savings and lower cost since they have lower electricity cost[23] ($0.06 per kWh). For households with solar panels, it is assumed that a large majority of them, or about 161,000 households,[24] will participate in the program and utilize at least one type of the proposed technologies. This number may be a conservative estimate. As solar panels become more affordable, the number of participants with solar panels will likely also increase to benefit from the higher cost-savings. Other non-utility operation and maintenance costs are assumed to be equivalent to a standard equipment; therefore, no additional costs are associated.

Timeline and Equipment Life - The ECC-03 program is anticipated to begin in 2018, and for the purpose of this cost analysis, end in 2031. Equipment lifetime information was gathered from similar websites as the equipment cost.[25,26,27] It should be noted that equipment life is variable and several factors contribute to the number of years a piece of equipment is operational. Since this program will provide incentives for various types of equipment, assumptions also need to be made regarding the percent distribution of ECC-03's emission reduction targets among different equipment. The equipment life and percent distribution assumptions are listed in the table below.

Technology Type	Equipment Life Assumed	% Distribution for Emission Reduction Targets in ECC-03
Electric Heat Pump	14	40%
Pool Cover	6	16%
Electric Dryer	14	20%
Pool Heat Pump	14	24%

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[21] U.S. Bureau of Labor Statistics, Los Angeles Area

[22] CEC Average Price of Electricity to Ultimate Customers by End-Use Sector

[23] U.S. Department of Energy Sunshot Initiative

[24] Based on latest figure compiled by the California Solar Statistics.

[25] Energy Star Market & Industry Scoping Report - Residential Clothes Dryers - Nov 2011

[26] http://energy.gov/eere/wipo/what-weatherization

[27] Lawrence Berkeley National Lab - National Survey Data to Estimate Lifetimes of Residential Appliances

Implementation period for cost analysis: 2018-2031

Capital cost assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit Cost	Per Unit Incentive Amount	Number of Units	Years of Equipment Life
Water Heater (Electric Heat Pump)	Consumers	$400	$200	1,690,530	14
Pool Heater (Cover)	Consumers	$500	$200	469,328	6
Dryer (Electric)	Consumers	$250	$100	1,079,936	14
Pool Heat Pump (Electric Heat Pump)	Consumers	$1,500	$200	240,586	14

Annual operating and maintenance net cost/(savings) assumptions:[28]

Equipment Name	Per Unit Cost No Solar	Per Unit Cost With Solar
Water Heater (Electric Heat Pump)	$15	$(132)
Pool Heater (Cover)	$(170)	N/A
Dryer (Electric)	$30	$(10)
Pool Heat Pump (Electric Heat Pump)	$(229)	$(238)

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
ECC-03	$246.6	+	$406.9	=	$653.5	$37.8

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

❖ *BCM-10 (Emission reductions from greenwaste composting)*

BCM-10 proposes composting Best Management Practices (BMPs) as a control method to reduce potential VOC and ammonia emissions from chipped and ground but uncomposted mulch that is presumably directly applied to the land after chipping and grinding (chip/grind). Specifically, the proposed control method requires for the 15 days of active phase composting during which chipped and ground mulch piles would be covered by finished compost (or compost overs) only one time and then watered

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[28] $0.09 per kWh for electricity is the Federal average price in the U.S; $0.93 per therm for gas is the Federal average price in the U.S.; $1.107 cents/therm for Los Angeles area (Source: US Bureau of Labor Statistics http://www.bls.gov/regions/west/news-release/averageenergyprices_losangeles.htm.)

before turning up to five times during the 15 day period.[29] In the Basin, 21 affected (8 composting and 13 chip/grind) mulch producing facilities are proposed to be subject to this control method.

Thirteen chip/grind facilities would need to purchase cover material (finished compost or compost overs) from local composting facilities. To reduce the cover material purchasing cost, which could be highly dependent on the size of mulch throughput, it is assumed that they would purchase it only for the first year and then would produce finished compost on-site in the following years. Therefore, material cost (and pick-up trip cost) is considered a one-time cost, annualized over 15 years of a facility's lifetime. In addition to the cover material cost, watering, covering, and recordkeeping costs are also included.

Eight composting facilities would also need to do compost covering and watering. However, since the cover material is readily available on-site, the cover material will not need to be purchased. Recordkeeping is also not considered because it is already required in SCAQMD Rule 1133.3, which applies to the facilities.

Assumptions[29,30] for cost estimates include:

Compost Covering (Labor & Equipment) [a]	• A mulch windrow is 16 ft. wide, 7 ft. high, 200 ft. long, and 132 tons in mass. • Approximately 457,500 tons of chipped and ground mulch throughput. • Operating cost for labor and a front-end loader is $180 per hour. • On a per ton of throughput basis, approximately 0.0044 hours of front-end loader time is needed to apply compost cover to each mulch windrow only one time. • Front-end loader needs 5 gallons of diesel per hour at a rate of $3.50 per gallon. • On a per ton of throughput basis, 0.022 gallons of diesel is needed to operate a front-end loader.
Watering (Labor & Water) [a]	• The wage rate for watering is $20 per hour. • On a per ton of throughput basis, approximately 0.0165 hours of labor are needed to water the windrow five times. • Water costs $0.0024 per gallon (conservatively assumed affected facilities use potable water). • On per ton of throughput basis, 95 gallons of water are needed to water windrow five times.
Compost Cover (Material & Pick-up) [b]	• Approximately 176,700 tons of chipped and ground mulch throughput. • On per ton of throughput basis, approximately 0.167 tons of finished compost are needed to cover mulch windrow.[31] • Bulk finished compost costs approximately $50 per ton.[32] • A 20-ton truck travels 30 roundtrip miles to pick up bulk finished compost at a local composting facility. • Diesel fuel for a truck costs approximately $0.45 per mile.[33]
Recordkeeping [b]	• The wage rate for recordkeeping labor is $25 per hour. • Approximately 78 hours of recordkeeping time are needed per facility.

[a] Apply to 21 affected facilities; [b] Apply to 13 chip/grind facilities

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[29] SCAQMD, 2011. Final Staff Report for Proposed Amended Rule 1133.1 and Proposed Rule 1133.3.

[30] SCAQMD, 2011. Socioeconomic Assessment for Proposed Amended Rule 1133.1 and Proposed Rule 1133.3.

[31] CalRecycle, 2007. Emissions Testing of VOC from Greenwaste Composting at the Modesto Compost Facility in the San Joaquin Valley.

[32] Finished Compost Sale Price: http://www.sunshinegrowersnursery.com. Accessed in May 2016.

[33] Weekly California No. 2 Diesel Retail Prices: https://www.eia.gov. Accessed in May 2016.

Implementation period for cost analysis: 2020-2031

Annual capital and operating and maintenance cost assumptions[34]:

Affected Facilities (Types of Operations)	**Affected Industries (NAICS)**	**Annual Cost**	**Per Unit/Facility Incentive Amount**	**Number of Units**
Facility A (Landscaping& Nursery)	Flower, Nursery Stock, and Florists' Supplies Merchant Wholesalers (424930)	$10,936	$0	1
Facility B (Legislative Bodies)	Refuse Services (921120)	$45,154	$0	1
Facility C (Recycle Wood Products)	Other Miscellaneous Durable Goods Merchant Wholesalers (423990)	$47,527	$0	1
Facility D (Chipping and Grinding)	Landscaping Services (561730)	$26,544	$0	1
Facility E (Green Waste Operation)	Farm Supplies Merchant Wholesalers (424910)	$18,983	$0	1
Facility F (Landscape Operations)	Landscaping Services (561730)	$2,393	$0	1
Facility G (Disposal Services)	Other Waste Collection (562119)	$52,662	$0	1
Facility H (Landscape Operations)	Other heavy and civil engineering construction (237990)	$17,483	$0	1
Facility I (Other Wood Product Manufacturing)	Cut Stock, Resawing Lumber, and Planing (321912)	$39,476	$0	1
Facility J (Solid Waste Management)	Solid waste landfill (562212)	$55,863	$0	1
Facility K (Nursery and Garden Supplies)	Nursery, Garden Center, and Farm Supply Stores (444220)	$19,133	$0	1
Facility L (Landscape Operations)	Landscaping Services (561730)	$2,446	$0	1

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[34] http://www.sunshinegrowersnursery.com for compost covering and material pickups; https://www.eia.gov/ for water and gasoline retail Prices; SCAQMD, Socioeconomic Assessment for PAR 1133.1 & PR 1133.3, July 2011; SCAQMD, Final Staff Report for PAR 1133.1 & PR 1133.3, July 2011; CalRecycle, Emissions Testing of VOC from Greenwaste Composting at the Modesto Compost Facility in the San Joaquin Valley, October 2007.

Affected Facilities (Types of Operations)	Affected Industries (NAICS)	Annual Cost	Per Unit/Facility Incentive Amount	Number of Units
Facility M (Solid Waste Management)	Other Waste Collections (562119)	$67,911	$0	1
Facility N(Solid Waste Management)	Legislative Bodies (Refuse System) (921120)	$75,523	$0	1
Facility O (Nursery)	Nursery and Garden Supplies (444220)	$53,110	$0	1
Facility P (Solid Waste Management	Material Recovery Facility(562920)	$1,187	$0	1
Facility N(Farm Supplies)	Farm Supplies Wholesalers (424910)	$8,797	$0	1
Facility Q(Nursery)	Nursery, Garden Center, and Farm Supply Stores (444220	$6,935	$0	1
Facility R(Recycle Materials)	Recycle Materials Wholesalers (423930)	$20,154	$0	1
Facility S(Recycle Materials)	Recycle Materials Wholesalers (423930)	$173,662	$0	1
Facility T(Landscape Operations)	Landscaping Services (561730)	$61,342	$0	1

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
BCM-10	$7.0	+	$0	=	$7.0	$0.6

❖ *FUG-01 (Improved leak detection and repair)*

FUG-01 would utilize more efficient and effective leak detection systems known as advanced remote sensing techniques (Smart LDAR), such as Fourier transform infrared spectroscopy (FTIR), Ultraviolet Differential Optical Absorption Spectroscopy (UV-DOAS), Solar Occultation Flux (SOF) and infrared cameras, that can identify, quantify, and locate VOC leaks in real time, allowing for faster repair in a manner that is less time consuming and labor intensive than traditional LDAR.

Costs for the various types of equipment are provided below:

- Infrared cameras – state of the art IR camera with cooled detector – provides visualization of VOC emissions, no speciation, no concertation or emission flux determination - ~$100K[35]

- Fourier transform infrared spectroscopy (FTIR) – for monitoring of alkanes, CH4, CO, CO2, some toxics, CFC's – commercial Open Path FTIR (OP-FTIR) systems range between $150 – 250K[36]
- Ultraviolet Differential Optical Absorption Spectroscopy (UV-DOAS) – for monitoring of BTEX, NO2, SO2, HCHO, O3, NO3 - between $100 - $150K [37]
- Solar Occultation Flux (SOF) – for emission flux measurements of alkanes - ~$300K[38]
- Fully equipped mobile laboratory containing SOF (for emission flux measurements of alkanes); zenith-looking DOAS (for emission flux measurements of NO2, SO2, HCHO), DOAS white cell (for ground concentration mapping and emission fluxes of BTEX and O3), extractive FTIR (for ground concentration mapping and emission fluxes of CH4, ammonia, and VOC speciation) - ~$1.1M

Staff is using the SOF technology to determine potential costs. SOF technology requires a full-time technician to operate the equipment resulting in a labor cost of $50,000 per unit per year. Each unit also requires approximately $25,000 in maintenance annually and consumes $75 dollars in electricity.[39]

Staff further estimates that 33 SOF units (with corresponding labor, maintenance and electrical annual costs) would be necessary to implement FUG-01. The number of units is based on the number of large oil and gas production facilities (27) and petroleum refining and chemical products processing (6).

Implementation period for cost analysis: 2022

Capital cost assumptions:[40]

Equipment Name	Affected Industries (NAICS)	Per Unit Cost	Incentive Amount	Number of Units	Years of Equipment Life
Advanced LDAR	Oil and Gas Production (211), Petroleum and Coal Products Manufacturing (342)	$300,000	$0	33	10

An additional annual cost of $75 for electricity and an additional annual maintenance labor cost of $50,000 of labor and $30,000 of materials were assumed for the affected facilities.

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[35] https://www3.epa.gov/airquality/oilandgas/2014papers/Attachment_GG_EDF.pdf

[36] https://archive.epa.gov/nrmrl/archive-etv/web/pdf/01_vr_ail.pdf

[37] http://www.spectroscopyonline.com/minidoas-low-cost-high-performance-contactless-ammonia-measurements-0

[38] http://www.aqmd.gov/docs/default-source/Agendas/Governing-Board/2015/2015-oct2-010.pdf

[39] https://www3.epa.gov/ttnemc01/guidlnd/gd-052.pdf

[40] http://www.aqmd.gov/docs/default-source/Agendas/Governing-Board/2014/may-specsess-10.pdf

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
FUG-01	$26.5	+	$0.0	=	$26.5	$2.5

- *CTS-01 (Further emission reductions from coatings, solvents, adhesives, and sealants)*

CTS-01 would seek VOC emission reductions by limiting the allowable VOC content in formulations of coatings, adhesives, and solvents. Between 1 and 2 tons per day (tpd) (5,698 tons over 14 years) of VOC reduction are estimated as emission reductions are conservatively phased in over time. Emission reductions are projected to be 1.0 tpd in 2023 and 2.0 tpd in 2031.

Based on the 2012 survey data of adhesive products[41], between 2.5 million and 2.8 million gallons of product sold will be impacted by the proposed control measure. Due to projected growth[42] over a 19 year period (2012 to 2031), the gallons impacted are likewise expected to grow to 3.0 million to 3.3 million by 2031.

An online comparison of over 23 product categories at retail stores between currently compliant products and future compliant products[43] indicates an average price difference of $1.76 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 $5.8 million by year 2031. 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[44]: 2018-2031[45]

Reformulation cost assumptions:[46]

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	Specialty Trade Contractors (238110)	$1.76	$0	3,300,000	14

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[41] Proposed Amended Rule 1168 Adhesive and Sealant 2012 Product Sales Survey (August 2013)

[42] Southern California Association of Governments Adopted 2012 RTP Growth Forecast

[43] Online cost comparison of potentially impacted products conducted December 2015

[44] Reformulation costs assumed to incur beginning in 2018

[45] It is assumed that reformulation cost spending would begin in 2018 to meet compliance requirements.

[46] 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

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
CTS-01	$31.6	+	$0.0	=	$31.6	$3.0

Stationary Source Measures (PM2.5 Emission Reductions)

❖ *BCM-01(Further emission reductions from commercial cooking)*

BCM-01 is a contingency control measure which would seek PM reductions from commercial under-fired charbroilers if the PM2.5 annual average standards are not met by 2025. If necessary to meet contingency control measure requirements, a tiered program could be developed that targets higher efficiency controls for under-fired charbroilers at large volume restaurants, with more affordable, lower efficiency controls at smaller restaurants.

Assumptions for cost estimates include:

Estimated number of potentially affected facilities[47]	• 1,000 large restaurants • 7,000 average restaurants
Control Device Cost Estimates[48]	• Large restaurants - Electrostatic precipitator (ESP) $31,000 device cost, $9,500 installation and $8,000 (O&M) • Average restaurants – Vent hood cartridge and filter $2,500 device cost, $500 installation[49], and $1,200[50] (O&M)

Implementation period for cost analysis: 2025

Capital cost assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit Cost	Incentive Amount	Number of Units	Years of Equipment Life
Electrostatic Precipitator (ESP)	Restaurant Operations (722513)	$40,500	$0	1,000	10
Vent hood cartridge + filter	Restaurant Operations (722513)	$3,000	$0	7,000	10

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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.

[47] Derived from SCAQMD PAR 1138 Preliminary Draft Staff Report. August, 2009 and Pacific Environmental Services, A Detailed Survey of Restaurant Operations in the South Coast Air Basin, Contract Number 98089; February 5, 1999.

[48] Air Quest (ESP), 2015 and Streivor air systems (Vent hood cartridge and filter), 2016.

[49] SCAQMD staff estimates

For large restaurants, an additional annual maintenance cost of $8,000 per electrostatic precipitator is assumed. For smaller restaurants, an annual cost of $1,200 for vent hood cartridge maintenance, based on an assumption of 52 hours of labor at $10/hour and 72 filter replacements at $8.50/unit.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
BCM-01	$143.1	+	$0.0	=	$143.1	$10.8

❖ *BCM-04 (Emission reductions from manure management strategies)*

BCM-04 proposes manure management to reduce ammonia, a PM2.5 precursor, from livestock waste. These control strategies can be applied on a year-round basis, or seasonally or episodically to minimize costs. BCM-04 also proposes lowering the applicability thresholds of SCAQMD Rule 223 - Emission Reduction Permits for Large Confined Animal Facilities. The proposed thresholds are 500 milk cows and 400,000 birds. As a result, 36 dairy farms and no chicken farm would be impacted by the proposal. The feasibility of lowering the applicability threshold is evaluated.

The anticipated incremental costs that would be incurred by the 36 impacted dairy farms include the additional cost of disposing manure though composting compared to disposing manure by land application, and the cost of more frequent corral cleaning (4 instead of 2 times per year per farm).

The cost of corral cleaning would be approximately $204.50 per cleaning. The analysis assumes that 119,732 tons of manure is sent to fabric in-vessel (FIV) composting operations, which would cost approximately $31 per ton of manure. In the absence of the composting facilities, the base case assumes that manure will be land spread in the Basin (least costly option currently available, which is approximately $10.20 per ton of manure)[50]. The incremental compliance cost per year is estimated as below:

- *Incremental Annual Compliance Cost = ((FIV cost/ton – In-basin spreading* $_{cost/ton}$*) x tons manure) + extra corral cleaning costs*
  = (($31 – $10.2) x 119,732) + (204.50 x 2 x 36)
  =$2.5 million

The implementation period for cost analysis is 2020-2031.

An estimated average annual cost of $69,444 for cost of corral cleaning and sending the manure to FIV composting facilities was assumed for each dairy farm.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
BCM-04	$16.4	+	$0	=	$16.4	$2.0

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[50] Unit costs are based on data from Rule 1127 Staff Report and inflated to 2016 dollars.

SCAQMD Mobile Source Measures (NOx and/or VOC, PM2.5 Emission Reductions)

- *MOB-10 (Extension of the SOON provision for construction/industrial equipment)*

In 2016, nearly all applications were for replacement equipment. Replacement equipment eligible for SOON funding can cost from under $100,000 to over $1,000,000. The applications were typically for rubber tire loaders, the most common type of mobile off-road equipment. Incentive funding averaged $134,380 per equipment and average equipment cost was $444,521. For replacement equipment, SOON incentives can be up to 80% of actual cost but generally are lower due to cost effectiveness limits. For 2016 applications, SOON paid approximately 30% of actual price ($134,380/$444,521 = 30.2%). Most SOON replacement projects, including those that are not funded, offer incentives between 10% and 50% of actual cost.

Equipment Life:
Most heavy duty equipment remains in operation for many years. Tier 0 equipment replaced or repowered was built before 1996 and is at least 20 years old. The equipment life used for analysis was 20 years.

Operating & Maintenance Cost:
Fuel and maintenance costs are assumed to be the same for new equipment and engines compared to the equipment they replaced. An additional cost is urea for the SCR systems which was estimated at 3% of diesel fuel usage based on engine manufacturer guidance:

200 gallons fuel/week x 52 weeks x 3% = 312 gallons urea/year

Urea cost ranges from $2 to $4 per gallon depending on source, volume and delivery charge. Most heavy construction equipment is refueled at job sites and urea would be delivered by the refueling truck. A conservative estimate for urea cost was $4/gal.

312 gallons per year x $4/gal = $1,248

Incremental Cost:
The SOON program is administered according to Carl Moyer Program guidelines which considers 80% of actual cost to be the incremental cost of replacement equipment and 85% of actual cost to be the incremental cost of engine repowers. The remainder (15% for repower and 20% for replacement) is considered the overhaul and maintenance expense that would be incurred to keep the old engine/equipment operational. For this cost analysis, an incremental cost of $155,000 was selected reflecting the highest average incentive in the SOON program.

Incentive:
The SOON incentive amount for each project in 2014-2016 was based on the difference in emissions of the old and new equipment and a cost effectiveness limit. For many projects, particularly equipment replacement, the incentive amount is less than the 80% nominal incremental value. For this cost analysis the incentive amount of $155,000 was selected reflecting the highest average incentive in the SOON program.

Implementation period for cost analysis: 2017-2022

Capital cost assumptions:[51]

Equipment Name	Affected Industries (NAICS)	Per Unit Cost	Per Unit Incentive Amount	Number of Units	Years of Equipment Life
Off-Road Construction Equipment (Repower)	Construction (283110)	$180,226	$155,000	135	20
Off-Road Construction Equipment (Replacement)	Construction (283110)	$444,521	$155,000	315	20

An additional annual cost of $1,248 for urea usage was assumed for each repower or replacement engine.[52]

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
MOB-10	$7.2	+	$63.4	=	$70.6	$4.6

❖ *MOB-11 (Extended exchange program)*

MOB-11 is an incentive based control measure similar to the Carl Moyer Program focusing on the small off-road engines (SORE) less than 25 hp. These engines are used in handheld equipment, portable equipment, recreational equipment/vehicles, and mobile off-road equipment. This measure specifically addresses commercial 5-25 hp diesel- and gasoline-fueled lawn and garden equipment including garden tractors, riding mowers, and other commercial turf equipment. Commercial diesel-fueled equipment were included because they have the highest NOx emissions per vehicle and therefore are very cost effective compared to gasoline-fueled equipment.

Since 2003, SCAQMD has sponsored lawn mower buyback programs for residential users of old lawn mowers. This program has resulted in over 55,000 high polluting gasoline-powered lawn mowers taken out of service from 2003 to today. In addition to the lawn mower exchange program, SCAQMD has recently sponsored a gasoline-powered leaf blower exchange program targeted at commercial operators. The leaf blower buyback program has resulted in over 12,000 older leaf blowers being exchanged for cleaner combustion leaf blowers.

While the residential lawnmower and commercial hand-held leaf blower exchange programs are important programs, additional emission reductions will be needed from larger commercial lawn and garden equipment such as riding lawnmowers. Zero-emission commercial lawn and garden equipment are currently commercially available from a number of vendors. The SCAQMD is currently sponsoring a

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[51] Source: SOON program, 2014-2016.

[52] Urea (DEF) cost of $1,248/truck/year = 3% x 200 gal fuel/week x 52 weeks/year.

zero-emission commercial lawn and garden equipment loaner program to test and evaluate equipment performance in a various commercial applications. Many of these test units have been well received by users.

MOB-11 achieves emission reductions of NOx from diesel- and gasoline-fueled mobile lawn and garden equipment through their replacement with similar zero or near zero emission equipment. The most stringent regulations for these engines became effective before 2008 meaning that most commercial equipment already meets the most stringent emission standards.

The information for the analysis was based on the 2023 emission inventory of lawn and garden equipment, the 2023 population estimate of lawn and garden equipment from CARB's OFFROAD2007 inventory model, and a limited internet search of pricing for lawn and garden equipment.

Number of Units/Objects:

There are over 7,000,000 pieces of lawn and garden equipment, most of which are either handheld equipment or residential mowers with a total emission inventory of 6 tpd of NOx. In reviewing the population and emission estimates by equipment type and horsepower, the 5-25 hp diesel lawn tractor and 15-25 hp diesel turf equipment categories were the highest NOx categories of lawn and garden equipment. The next highest category was 5-25 hp gasoline turf equipment. These three categories represent nearly half of the lawn and garden source category and total 33,000 units. For simplicity, it was assumed that all units would be replaced by near zero hybrid or zero emission equipment. During implementation, any commercial lawn and garden equipment in these horsepower ranges would be eligible for replacement.

Fuel Type	HP range	Number[53]	NOx tpd reduction[54]	Unit Costs	Cost Used in Analysis
Diesel	15-25	14,550	1.8	\$9,000 - \$20,000	\$12,000
Diesel	5-15	11,600	0.6	\$4,000 - \$12,000	\$8,000
Gasoline	5-25	7,500	0.5	\$2,000 - \$10,000	\$4,000

Equipment Life:

The OFFROAD2007 model includes age-based population distribution factors. The nominal useful life is shown as 5 or 7 years for commercial diesel tractors or turf equipment depending on equipment hp and equipment type. For gasoline tractors or turf equipment, the nominal life is 1 or 4 years. The nominal useful life represents half of the actual age distribution in the model. For diesel equipment, that is either 10 or 14 years and for gasoline equipment is either 2 or 8 years.

For this cost analysis, 10 years was assumed for 15-25 hp diesel equipment, 14 years for 5-15 hp for diesel equipment and 8 years for gasoline equipment.

Operating & Maintenance Cost:

Electrical usage, battery replacement cost, and other operating and maintenance expenses are not quantified due to lack of data. Although fuel and maintenance costs are expected to be lower, for this

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[53] CARB OFFROAD2007 Inventory model – 2023

[54] 2023 AQMP Inventory dated 1/7/2016

analysis no increased operating and maintenance costs or savings were included.

Incremental Cost:
Electric equipment is estimated to have 25% incremental cost over combustion engine equipment due to lower sales volume and higher costs of the battery electrical storage, charging, and drive system compared to combustion engine designs.

Incentive:
For this cost analysis[55], the incentive amount of 25% of average cost was selected to offset the estimated incremental cost.

Manufacturer	Equipment	Model	Fuel	HP	Price	EV Premium
John Deere	Riding Mower	Z-TRACK 997	Diesel	37	$23,765	
Green Machine	Riding Mower	CRX60	EV	36	$22,799	0.96
John Deere	Utility Truck	Gator 4x2 TS	Gas	13	$6,969	
John Deere	Utility Truck	Gator 4x2 EV	EV	6	$11,379	1.63
Toro	Stand-on Mower	74518	Gas	23	$10,388	
Green Machine	Stand-on Mower	48”	EV	24	$13,299	1.28
					AVERAGE	**1.29**

For this analysis, an incremental capital cost of 25% was used. Moreover, EV versions of lawn and turf equipment are available in only a few categories, and EV and combustion engine equipment are not exactly equivalent in performance and configurations.

Internet search for gas/diesel equipment (10/14/2016):

Manufacturer	Equipment	Model	Fuel	HP	Price
Husqvarna	Utility tractor	YTH24K54	Gas	24	$2,100
John Deere	Utility truck	Gator 4x2 TS	Gas	13	$6,969
Kubota	Walk behind mower	WHF-19-52	Gas	13	$7,519
Toro	Stand-on mower	74518	Gas	23	$10,388
Kubota	Utility tractor	BX25D-1	Diesel	18	$9,971
John Deere	Utility tractor	1023E	Diesel	22	$12,002
John Deere	Utility tractor	3025E	Diesel	25	$17,325
John Deere	Riding mower	1550	Diesel	24	$18,420

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[55] Internet search for EV premium 10/14/2016

Implementation period for cost analysis: 2018-2022

Capital cost assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit Incremental Cost	Per Unit Incentive Amount	Number of Units	Years of Equipment Life[56]
Replace Commercial Diesel Equipment 15-25 HP with T4 or Cleaner	Landscaping Services (561730)	$3,000	$3,000	14,550	10
Replace Commercial Diesel Tractors 5-15 HP with T4 or Cleaner	Landscaping Services (561730)	$2,000	$2,000	11,600	14
Replace Commercial Gasoline Equipment 5-25 HP with Cleanest or Zero Emission Equipment	Landscaping Services (561730)	$1,000	$1,000	7,500	8

No operating and maintenance costs were assumed.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
MOB-11	$0.0	+	$66.2	=	$66.2	$7.6

- *MOB-14 (Emission reductions from incentive programs)*

MOB-14 will develop a rule so that emission reductions generated through incentive programs can be credited in State Implementation Plan (SIP) emission inventories. Such emission reductions have been accounted in the development of historic base year emissions inventories where actual quantifiable emission reductions have occurred. Future emission reductions from adopted regulations can be credited towards attainment of air quality standards. However, future emissions reductions as a result of incentive-based programs cannot be credited towards attainment without a demonstration and commitment that the reductions are real, surplus, enforceable, and permanent (for mobile sources to the extent of their useful life). The lack of a SIP-creditability mechanism is now a major constraint in developing future AQMPs since planned reductions cannot be counted in the future year emission inventories. This proposed measure would provide a new administrative mechanism to take SIP credit for future emission reductions achieved in the Basin through incentive programs administered by SCAQMD, CARB, or U.S. EPA.

SCAQMD has a long history of successful implementation of incentive programs that help fund the accelerated deployment of cleaner engines and aftertreatment technologies in on-road heavy-duty

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[56] Based on CARB Offroad2007 model AgeDist table (used all years in age distribution).

vehicles and off-road mobile equipment. Such accelerated deployment not only results in early emission reductions, but also provides a signal for technology providers, engine and automobile manufacturers, and academic researchers to develop and commercialize the cleanest combustion engines possible and further the efforts to commercialize zero-emission technologies into a wider market. Major incentive programs administered by SCAQMD include:

- CARB Carl Moyer Memorial Air Quality standards Attainment Program (Carl Moyer Program)
- CARB Proposition 1-B Air Quality Improvement Fund
- CARB Lower Emission School Bus Program
- U.S. EPA Diesel Emission Reduction Act (DERA) Program
- Old vehicle scrap programs (light duty vehicles)
- Lawn and garden equipment exchange programs.

MOB-14 includes two categories of emission reductions: those from current contracts where new equipment will remain in service through 2023, and those from projects which have been approved but not contracted and funding is reasonably expected to be available. Since the vehicle replacement costs in the first category have already been incurred, they were not included in this analysis.

Number of Units/Objects:
Four project types have been included In MOB14 between 2017 and 2023:

School bus replacements:	600 based on anticipated future funding levels and typical annual school bus replacements from 2010 through 2016.
Cargo handling equipment:	68 units awarded in 2017 Carl Moyer Program funding.
Freight locomotives:	10 units awarded in 2017 Carl Moyer Program funding.
HD On-road vehicles:	7,500 vehicles based on Proposition 1B and Low Carbon Transportation and Fuels Program's funding commitments.

Unit Costs:

School bus replacements:	Based on actual cost of recent replacements projects ($197,000).
Cargo handling equipment:	Based on quote ($300,000) for electric yard trucks awarded in 2016.
Freight locomotives:	Based on quote ($3,000,000) for freight locomotives awarded in 2016.
HD On-road vehicles:	Based on estimated $125,000 for day cab on-road tractors with diesel engines.

Equipment Life:
School bus and heavy duty trucks – 15 years
Locomotives – 30 years
Electric Yard Trucks – 12 years

Operating and Maintenance Cost:

CNG school bus:	Fuel cost savings – 20% of diesel fuel cost: 10,000 gallons/year x $4/gal x20% = $8,000 savings/year/truck.
Locomotives:	No change in O&M cost.
Electric Yard Trucks:	Fuel cost savings – 80% diesel fuel cost: 2,600 gallons/year x $4/gal x 80% = $8,320 savings/year/truck.

HD On-road Trucks:	Cost of urea for SCR systems - 3% diesel fuel cost: 200 gal/wk x 52 wk/yr x $4/gal x 3% = $1,248/year/truck.

Incremental Cost:

CNG school bus:	The incremental cost of replacing existing diesel buses with new natural gas buses was 80% of new vehicle cost. The balance (20% of new vehicle cost) was the estimated cost of maintaining the existing vehicles in operation). Incremental cost = $175,000.
Locomotives:	The incremental cost of replacing old Tier 0/1 locomotives with new Tier 4 locomotives was 85% of the new locomotive cost with the remainder considered the cost of maintaining the existing locomotives in operation. Incremental cost = $2,550,000.
Electric Yard Trucks:	The incremental cost of replacing old diesel yard trucks with new electric yard trucks was the cost difference between new Tier 4 diesel yard trucks and electric yard trucks as shown in the application. Incremental cost = $100,000.
HD On-road Trucks:	The incremental cost of replacing old diesel on-road trucks with new near-zero trucks was the cost difference between new Tier 4 diesel yard trucks and near-zero natural gas yard trucks. Incremental cost = $50,000 for engine/aftertreatment and natural gas fuel system.

Incentive:

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

Implementation period for cost analysis: 2017-2023

Capital cost assumptions:

Equipment Name (Implementation Period)	Affected Industries (NAICS)	Per Unit Incremental Cost	Per Unit Incentive Amount	Number of Units	Years of Equipment Life
CNG School Buses (2017-2023)	Transit Buses (485)	$175,000	$175,000	600	15
Tier 4 Freight Locomotives (2017)	Rail Yards (482)	$2,550,000	$2,550,000	10	30
Electric Cargo Handling Equipment (2017-2019)	Ports (488)	$100,000	$100,000	68	15
0.02 g/bhp-hr On-Road Heavy-Duty Trucks (2017-2023)	Truck Transportation (484)	$50,000	$50,000	7,500	12

An annual fuel cost-savings of $8,000 were assumed for each of the 600 school buses.[57] An annual fuel

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[57] Fuel cost-savings: 20% of diesel fuel cost = 10,000 gal/year x $4/gal x 20%.

cost-savings of $8,320 were assumed for each of the 68 electric cargo handling equipment.[58] An additional annual cost of $1,248 for urea usage was assumed for each of the 7,500 heavy-duty trucks.[59]

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
MOB-14	$26.7	+	$460.1	=	$486.7	$43.1

(b) SCAQMD Control Measures with TBD Emission Reductions

The control measures listed below are not part of the Final 2016 AQMP's attainment demonstration. SCAQMD staff will conduct further assessments to the quantify cost and emission reductions for these measures as data becomes available. Currently available, but limited, cost information is provided below for each measure:

- *BCM-02 (Emission reductions from cooling towers)*

SCAQMD Rule 219(d) exempts cooling towers that do not contain chromium compounds from permitting requirements. As such, the universe of equipment that may benefit from the cost effectiveness of the use of high efficiency drift eliminators is currently unavailable and would be addressed during rule development, if rulemaking is determined to be necessary.

- *BCM 03 (Further emission reductions from paved road dust sources)*

A street sweeping and wheel washing system can be leased for about $3,000 per month with one-time installation/removal, including a transportation cost of about $14,000. However, the number of facilities and local jurisdictions that may participate and benefit from the use of these additional programs are unknown at this time and would be subject to a rule development effort, if rulemaking is determined to be necessary.

- *BCM-05 (Ammonia emission reductions from NOx controls)*

The purpose of this control measure is to seek reductions of ammonia from NOx controls such as SCR and Selective Non-Catalytic Reduction (SNCR). The use of these control systems can result in potential ammonia emissions that slip past the equipment and into the atmosphere. Ammonia is a precursor for PM. Recent advances in catalyst technology have resulted in the development of ammonia slip catalysts that selectively convert ammonia into nitrogen. These catalysts could be installed post-SCR and would result in less ammonia slip. Based on a recent estimate from Ammonia Slip Catalyst (ASC) vendor, an ASC equipment adder (which includes ASC catalyst and a means of loading it into the SCR reactor) is estimated to cost about 6 percent to 12 percent over the cost of SCR emission system equipment. Further cost analysis will be addressed during rule development, if rulemaking is determined to be necessary.

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[58] Fuel cost-savings: 80% of diesel fuel cost = 2,600 gal/year x $4/gal x 80%.

[59] Urea (DEF) cost of $1,248/truck/year = 3% x 200 gal fuel/week x 52 weeks/year.

- *BCM-06 (Emission reductions from abrasive blasting operations)*

The California Health and Safety Code Section 41904 prohibits local districts from requiring emission and performance standards more or less stringent that the state regulation. SCAQMD Rule 1140 – Abrasive Blasting has been developed to conform to the 17 CCR §§92000 et seq (Abrasive Blasting). Due to this pre-emption, this control measure proposes only a voluntary application of limited possible air pollution control methods by providing incentives. The inherent uncertainty in operator preferences limits the ability to forecast resultant emission reductions and costs at this time. As a result, the cost analysis will be addressed during rule development, if rulemaking is determined to be necessary.

- *BCM-07 (Emission reductions from stone grinding, cutting and polishing operations)*

SCAQMD Rule 219(g) exempts from permitting requirements machining equipment exclusively used for polishing, cutting, surface grinding, etc. The universe of affected facilities under this control measure is not fully developed and needs assessment outside of the permitting arena. Due to the absence of operational data at existing facilities, the emissions, potential reductions and associated costs are not available and would be addressed during rule development, if rulemaking is determined to be necessary.

- *BCM-08 (Further emission reductions from agricultural, prescribed and training burning)*

Changes to prescribed burning programs are anticipated to have minimal direct costs as burning would likely be shifted to other times of the year, although training and fire suppression issues would take precedence. Incentivizing or requiring burning alternatives (e.g., chipping/grinding with land application) could increase costs to the agricultural community although 90 percent of agricultural burning occurs in the Coachella Valley portion of the Salton Sea Air Basin which, unlike the Basin, is currently classified as a PM2.5 unclassifiable/attainment area and would not be targeted as part of an attainment demonstration.

- *BCM 09 (Further emission reductions from wood-burning fireplaces and wood stoves)*

Increasing the number of no burn days would result in relatively few direct cost increases to the impacted community as regional residential wood burning is primarily for aesthetic purposes. Based on results of the current and former SCAQMD incentive programs, a basic gas log set can be purchased at a local retailer and installed by a contractor into a home with an existing wood burning fireplace plumbed for natural gas for approximately $400 to $500. The average cost associated with removal and replacement of conventional (uncertified) wood heaters with a U.S. EPA Phase II-certified device has been estimated at $4,000 per unit. The devices are unpermitted and the total number is market and consumer driven. Wood heater upgrades are allowed under the current targeted incentive program but participation has been low due to the small eligible geographic area, whereas, over 10,000 gas log sets have been voluntarily installed into traditional wood-burning fireplaces under various incentive programs implemented since 2008. As a result, the cost analysis will be addressed during rule development, if rulemaking is determined to be necessary.

- *FLX-01 (Improved education and public outreach)*

This proposed control measure seeks to provide education, outreach, and incentives for consumers to contribute to clean air efforts. Examples include consumer choices such as the use of energy efficient products, new lighting technology, “super-compliant” coatings, tree planting, transportation choices, and the use of lighter colored roofing and paving materials which reduce energy usage by lowering the ambient temperature. Potential cost of this control measure cannot be quantified at this time due to the fact that the number of individuals, facilities, and public entities that may participate and benefit from the use of these additional programs are unknown at the present. As a result, the cost analysis will be addressed during rule development, if rulemaking is determined to be necessary.

- *FLX-02 (Stationary source VOC incentives)*

This control measure would seek to incentivize VOC emission reductions from various stationary and area sources through incentive programs for the use of clean, low emission materials or processes. Facilities would be able to qualify for incentive funding if they utilize equipment or material, or accept permit conditions which result in cost-effective emission reductions that are beyond existing requirements. The decision regarding when to replace existing equipment can vary; some facilities may replace equipment or reformulate material when it is no longer operable or outdated, while other facilities may replace equipment or material well before it reaches that point. Predicting VOC emission reductions from these voluntary activities is challenging as the availability and amount of incentives would directly affect the level of VOC emission reductions achieved. Emission benefits from incentives can be quantified based on program participation, technology/material penetration, and other assessment and inventory methods.

The cost and cost-effectiveness of this measure cannot be determined at this time, given the potential variety of programs and projects that will be developed. As a result, the cost analysis will be addressed during rule development, if rulemaking is determined to be necessary.

- *MCS-01 (Improved breakdown procedures and process re-design)*

SCAQMD Rule 430 – Breakdown Provisions, applies to breakdowns that result in a violation of any rule or permit conditions, with some exceptions, and stipulates reporting requirements. This control measure would introduce improved breakdown procedures and/or process re-designs that would apply to breakdowns from all emission sources, providing pollutant concentration, work practice, and/or incidence limits to comply with U.S. EPA's Startup, Shutdown, and Maintenance (SSM) policy. This would apply to combustion equipment that can be tested readily with a portable analyzer such as boilers, engines, and some ovens and furnaces, along with associated control equipment such as SCR. Due to the nature of this control measure, the cost-effectiveness cannot be calculated. The inherent uncertainty in operator preferences limits the ability to forecast resultant emission reductions and costs at this time. As a result, the cost analysis will be addressed during rule development, if rulemaking is determined to be necessary.

- *MCS-02 (Application of all feasible measures)*

This control measure serves as a placeholder for any future control measures that may become feasible, prior to subsequent SIP revisions, through technology advances and/or cost decreases. The SCAQMD staff continually monitors evolving control technologies, price changes, and the actions of other air quality agencies to determine the feasibility of implementing additional controls to achieve emission reductions.

For example, almost all processes in the pulp and recycled paper mills (e.g., pulping machines, press and dryers to convert waste-paper –newspaper, cardboard, etc. – back into cardboard paper) are sources of fugitive VOC emissions, yet currently very high air flow of vent gases makes it impractical and not cost-effective to vent the exhaust gas to a control device. Similarly, breweries, wineries, distillers and other similar operations that store and process grains, ferment, age, store and package the spirits (beer, wine, whiskey, etc.,) and treat the wastewater on-site generate VOC and PM emissions.

Cost and cost-effectives for this control measure cannot be determined because there is currently no known feasible control potentially available for fugitive VOC emissions generated by these type of sources. As a result, the cost analysis will be addressed during rule development, if rulemaking is determined to be necessary.

- *Local mobile source TBD control measures*

SCAQMD staff analyzed the need to accelerate the penetration of cleaner engine technologies and assist in implementing CARB's proposed mobile source strategy. Specifically, there are several measures under the proposed State SIP Strategy that are titled "Further Deployment of Cleaner Technologies" (see 2016 AQMP Appendix IV-B), which identify SCAQMD as an implementing agency along with CARB and U.S. EPA. CARB indicated that the implementation of the "Further Deployment" measures is based on a combination of incentive funding, development of regulations, and quantification of emission reduction benefits from operational efficiency actions and deployment of autonomous vehicles, connected vehicles, and intelligent transportation systems. As such, the proposed SCAQMD mobile source measures will facilitate local implementation of the State SIP control strategy's further deployment of advanced technology measures proposed by CARB. The SCAQMD measures propose a process to also identify voluntary actions that could potentially result in additional NOx emission reductions beyond the state's emission reduction commitments. Since these actions are not specifically identified at this time and will be voluntary in nature, staff does not presume that the affected industries and businesses would voluntarily incur any costs above what has been quantified for CARB's "Further Deployment" measures.

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

To arrive at the cost of the Mobile Source Strategy, CARB has estimated the incremental costs of zero and near-zero emission technologies compared to their conventional counterparts. These incremental costs include capital, fueling infrastructure, and annual operation and maintenance costs associated with each mobile source type. These cost differentials are used to calculate the costs over a vehicle or equipment population generated by the Vision model.

CARB proposed four categories of mobile source measures: On-road light-duty, On-road heavy-duty, Off-Road Federal and International, and Off-Road Equipment.

Vision Model

CARB staff used the Vision model, version 2.1, to estimate the emission reductions as outlined in the State Mobile Source Strategy. Vision 2.1 is an estimation tool that can analyze multiple potential technology and fuel pathways for individual emission sources while collectively considering multiple sectors, fuels, and technologies in comprehensive scenarios to study different pathways to meeting California's air quality and climate goals (CARB 2015). Vision 2.1 incorporates updated CARB inventory work including EMFAC2014, and reflects currently adopted policies.[60] In addition, Vision 2.1 scenarios illustrate the type of technology transformation that would be required to meet the kinds of deadlines and goals that California faces. In this model, a typical user can define penetration rates and technology availability and receive outputs such as greenhouse gas emissions, criteria pollutant emissions, and energy mix.

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[60] Mobile Source Emissions Inventory: http://www.arb.ca.gov/msei/categories.htm

Vision is used to estimate turnover such that the emissions profile of the future fleet of light-duty vehicles, heavy-duty vehicles, locomotives, ships, and off-road vehicles will achieve the goals outlined in the Mobile Source Strategy (for more details see CARB (2016b)).

For control measures where CARB staff has provided the change in the quantity of energy expected by measure, SCAQMD staff used the energy price projections for the Pacific region from U.S. Department of Energy, Energy Information Administration's Annual Energy Outlook 2015 (2015) to calculate costs or savings.

(a) On-Road Light-Duty

❖ *Advanced Clean Cars* 2

This proposed measure is designed to ensure that zero and near-zero emission technology options continue to be commercially available, with range improvements to address consumer preferences for greater ease of use, and maximize electric vehicle miles travelled (eVMT). The regulation may include lowering fleet emissions further beyond the super-ultra-low-emission vehicle standard for the entire light-duty fleet through at least the 2030 model year, and options for improving real world emissions through implementation programs. Additionally, new standards would be considered to further increase the sales of zero-emission vehicles (ZEVs) and plug-in hybrid electric vehicles (PHEVs) beyond the levels required in 2025. The Advanced Clean Cars 2 program is expected to result in price increases (mainly borne by consumers) for new vehicles, while also leading to reduced operating and fuel costs (electricity and hydrogen versus gasoline).

Implementation period for cost analysis: 2026-2031

Cost Assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit/Facility Cost ($)	Per Unit/Facility Incentive Amount ($)	Number of Units	Years of Equipment Life
BEV(Battery) Electric Vehicles	Consumers	$11,237	$0	176,200	14
PHEV(Plug-in-Hybrid Electric Vehicles)	Consumers	$10,676	$0	392,100	14
FCEV(Fuel Cell/Battery Electric Vehicles)	Consumers	$8,788	$0	116,600	14

Additional annual operating savings of $126 was assumed for each of the affected vehicles. Moreover, the additional savings from fuel/energy demand is presented in table below in millions of 2015 dollars:

Years	**Gasoline (Billions of Gallons)**	**Price of Gasoline ($/ Gallon)**	**Diesel (Billions of Gallons)**	**Price of Diesel ($/Gallon)**	**Quantity of Electricity (MWhs)**	**Electricity Price ($/ MWh)**	**Quantity of Hydrogen (kg)**	**Price of Hydrogen ($/ kg)**
2026	-0.022	$3.29	-0.0002	$3.54	77,000	$137.9	1250,000	$6.00
2027	-0.041	$3.34	-0.0003	$3.59	139,000	$138.0	2410,000	$6.00
2028	-0.057	$3.41	-0.0004	$3.67	189,000	$137.4	3190,000	$6.00
2029	-0.069	$3.47	-0.0005	$3.73	235,000	$136.8	3950,000	$6.00
2030	-0.079	$3.52	-0.0006	$3.78	267,000	$136.8	450,0000	$6.00
2031	-0.077	$3.58	-0.0005	$3.85	228,000	$136.7	3,900,000	$6.00

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	**Present Value of Remaining Incremental Cost**		**Present Value of Incentives**		**Present Worth Value of Total Incremental Cost**	**Amortized Annual Average (2017-2031)**
Advanced Clean Cars 2	($2,648.0)	+	$0	=	($2,648.0)	($90.8)

(b) On-Road Heavy-Duty

❖ *Low-NOx Engine Standard-California Action*

This proposed measure is designed to require near-zero emission engine technologies that will substantially lower NOx emissions from on-road heavy-duty vehicles. CARB will begin development of a new heavy-duty low-NOx emission standard in California in 2017, with Governing Board action expected in 2019. A California-only low-NOx standard would apply to all vehicles with new heavy-duty engines sold in California starting in 2023. CARB will develop a heavy-duty low-NOx engine standard in California, and may petition U.S. EPA to establish new federal emission standards for heavy-duty engines. SCAQMD has already petitioned the U.S. EPA to establish a national new low-NOx standard.

Implementation period for cost analysis: 2023-2027

Cost Assumptions:

Equipment Name	**Affected Industries (NAICS)**	**Per Unit/Facility Cost ($)**	**Per Unit/Facility Incentive Amount ($) up to 20124**	**Number of Units 2026-2027**	**Years of Equipment Life**
ZEVs/PHEVz	Truck Transportations (484)	$1,500	$0	140,600	10

No additional annual operating savings or fuel savings were assumed.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
Low NOx Engine Standard-California Action	$154.3	+	$0	=	$154.3	$11.7

❖ *Low-NOx Engine Standard-Federal Action*

The proposed measure includes a new-NOx standard that would be applied to all new heavy-duty engines sold nationwide starting in 2024 or later through a national standard. Conceptually, this measure would ensure that all heavy-duty vehicles traveling within California would eventually be equipped with an engine meeting the low-NOx standard. This proposed measure is necessary to achieve emission reductions from Class 7 and 8 vehicles as many are purchased outside of California. If U.S. EPA begins the regulatory development by 2017, CARB will coordinate its California feet rulemaking efforts with the federal regulation.

Implementation period for cost analysis: 2024-2031

Cost Assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit/Facility Cost ($)	Per Unit/Facility Incentive Amount ($) up to 20124	Number of Units 2024-2031	Years of Equipment Life
ZEVs/PHEVz	Truck Transportations (484)	$1,500	$0	282,600	10

No additional annual operating savings or fuel savings were assumed.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
Low NOx Engine Standard-Federal Action	$281.9	+	$0	=	$281.9	$15.1

❖ *Advanced Clean Transit*

This measure is designed to continue the transition of transit fleets to cleaner technologies to support NOx and GHG emission reduction goals. The measure will consider a variety of approaches to enhance the deployment of advanced clean technology and increase the penetration of the first wave of zero-emission heavy-duty technology into transit applications that are well suited to its use. CARB staff will develop and propose an Advanced Clean Transit measure with a combination of incentives, and/or other methods that would result in transit fleets purchasing advanced technology buses during normal replacement and using renewable fuels when contracts are renewed. Based on currently available information including fuel price projections, the operating and maintenance costs and fuel savings for this measure are expected to more than offset the incremental cost of electric or CNG or fuel cell, and infrastructure buses. Transit bus fleets are well suited for introducing zero-emission buses and other advanced technologies because they operate in urban centers, have stop and go driving cycles, and are centrally maintained and fueled.

Implementation period for cost analysis: 2018-2031

Cost Assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit/Facility Cost ($)	Per Unit/Facility Incentive Amount ($)	Number of Units by 2031	Years of Equipment Life
BEV(Battery) Electric Vehicles	Transit and Ground Transportation (485)	$89,445-$211,122	$89,445-$211,122	1,600	12
Low-NOx	Transit and Ground Transportation (485)	$50,000	$50,000	1,210	12
FCEV(Fuel Cell/Battery Electric Vehicles)	Transit and Ground Transportation (485)	$255,000-$605,000	$255,000-$605,000	270	12

Additional annual operating and costs/savings and additional infrastructure costs are presented in the tables below in millions of 2015 dollars:

Incremental Operating and Maintenance Costs/Savings	2018-2020	2021-2031
BEB (slow charge)	($18,000)	($18,000)
FCEB	$16,000	($7,000)

Infrastructure	Unit Cost	2018	2025
Slow charging (cost per bus)	$20,000		
H2 Station	$5,000,000	$15,000,000	$15,000,000

Additional change in energy and fuel demand are presented in the table below in millions of 2015 dollars:

Years	Gasoline (Billions of Gallons)	Diesel (Billions of Gallons)	Electricity (MWh)	Natural Gas (Bcf)	Hydrogen (kg)
2018	-0.00045	-0.00037	0.0083	-0.0225	0.00001
2019	-0.00056	-0.00016	0.0086	-0.0496	0.00002
2020	-0.00056	-0.00016	0.0087	-0.0498	0.00002
2021	-0.00056	-0.00015	0.0089	-0.0493	0.00003
2022	-0.00056	-0.00015	0.0092	-0.0493	0.00003
2023	-0.00053	-0.00014	0.0092	-0.0476	0.00003
2024	-0.00051	-0.00013	0.0091	-0.0454	0.00003
2025	-0.00076	-0.00019	0.0141	-0.0692	0.00004
2026	-0.00102	-0.00025	0.0188	-0.0945	0.00005
2027	-0.00129	-0.00031	0.0234	-0.1206	0.00007
2028	-0.00128	-0.0003	0.0229	-0.1195	0.00007
2029	-0.00125	-0.00029	0.0220	-0.1169	0.00006
2030	-0.0026	-0.0006	0.0452	-0.2453	0.00012
2031	-0.00267	-0.00049	0.0454	-0.3410	0.00002

Corresponding price forecast from the above energy categories are listed below.[61]

Years	Gasoline Price ($/ Gallon)	Diesel Price ($/Gallon)	Electricity Price ($/MWh)	Natural Gas Price ($/MMBtu)	Hydrogen Price ($/kg)
2018	$2.97	$3.39	$123.04	$9.86	$6.00
2019	$2.98	$3.44	$122.13	$10.28	$6.00
2020	$3.03	$3.50	$122.24	$10.71	$6.00
2021	$3.07	$3.56	$122.55	$11.01	$6.00
2022	$3.10	$3.63	$122.62	$11.18	$6.00
2023	$3.15	$3.70	$121.84	$11.35	$6.00
2024	$3.20	$3.76	$121.28	$11.44	$6.00
2025	$3.24	$3.82	$121.66	$11.69	$6.00
2026	$3.29	$3.89	$122.28	$11.91	$6.00
2027	$3.34	$3.95	$122.31	$11.92	$6.00
2028	$3.41	$4.03	$121.42	$11.81	$6.00
2029	$3.47	$4.10	$120.38	$11.79	$6.00
2030	$3.52	$4.15	$120.09	$11.82	$6.00
2031	$3.58	$4.23	$119.70	$11.92	$6.00

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[61] U.S. DOE EIA (2015)

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
Advanced Clean Transit	($521.5)	+	$312.2	=	($209.2)	($6.6)

- *Last Mile Delivery*

This measure is designed to increase the penetration of the first wave of zero-emission heavy-duty technology into applications that are well suited to its use. This proposed measure will require the use of low-NOx engines and the purchase of zero-emission trucks for certain Class 3-7 last mile delivery trucks in California starting in 2020, with a low fraction initially and gradually ramping up to a higher percentage of the fleet at time of normal replacement through 2030. This control measure would affect truck transportation and couriers and messengers.

Implementation period for cost analysis: 2020-2031

Cost Assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit/Facility Cost ($)	Per Unit/Facility Incentive Amount ($)	Number of Units 2020-2031	Years of Equipment Life
BEV(Battery) Electric Vehicles	Truck Transportation (484)	$31,000	$0	9,800	10
Fuel Cell (FCET)	Couriers and Messengers (492)	$90,000	$0	1,100	10

Cost assumption for the infrastructure is presented below.

Truck Type/Infrastructure	Population	Incremental Capital Cost
FCEV Infrastructure	73	$2,000,000
BEV Infrastructure	980	$20,000

No additional annual operating savings or fuel savings were assumed.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
Last Mile Delivery	$411.5	+	$0	=	$411.5	$29.2

- *Further Deployment of Cleaner Technology On-Road Heavy-Duty Vehicles (SCAQMD Scenario)*

The control strategies targeting Light- and Medium-Heavy-Duty Trucks and Heavy-Heavy-Duty Trucks in Tables 4-20 (a) and 4-20 (b) of the Final 2016 AQMP reflect incentive-based control programs to facilitate market penetration of near-zero technologies for diesel trucks with GVWR of 10,001 pounds and heavier. These control strategies represent an alternative emission control scenario for the mobile source sector with a focus on potentially achieving increased emission reductions from higher-emitting vehicles and pieces of equipment, resulting in a greater cost-effective use of funding. The purpose of the alternative scenario is to present a potentially more effective use of incentive funds compared to the use of these funds by CARB. The amount of incentive funding is assumed to be sufficient to cover the incremental capital cost of purchasing a cleaner vehicle versus a vehicle that the fleet would normally be expected to purchase considering applicable state and local rules. Table 4-20 (a) represents the 2023 attainment scenario, while Table 4-20 (b) represents the 2031 attainment scenario which is built upon the 2023 attainment scenario. The cost assumptions are consistent with the Final 2016 AQMP Tables 4-20 (a) and 4-20 (b). Assumptions utilized for emissions benefit and cost estimation are detailed in the tables below.

Assumptions for Table 4-20 (a):

Source Categories	
Light and Medium Heavy-Duty Trucks	• Affected vehicle categories: - Light heavy-duty diesel trucks with a GVWR of 10,001 to 14,000 pounds - Medium heavy-duty diesel trucks with a GVWR of 14,001 to 33,000 pounds • Affected vehicle model years: the oldest through 2015 model year • Replacement vehicles are assumed to be zero or near zero emission (0.02 g/bhp-hr) • Average unit cost of replacement truck is assumed to be $90,000 per truck • No additional operational or maintenance costs are expected with this measure • Equipment life is expected to be 15 years • Average incentive funding is assumed to be $15,000 per truck
Heavy Heavy-Duty Trucks	• Affected vehicle categories: - Heavy heavy-duty diesel trucks with a GVWR of over 33,000 pounds • Affected vehicle model years: 1997 model year and newer (1997 through 2016 model years: replacement; 2017 to 2023 model years: new purchase) • Replacement / new purchase vehicles are assumed to be zero or near zero emission (0.02 g/bhp-hr) • Average unit cost of replacement/new purchase truck is assumed to be $160,000 per truck • No additional operational or maintenance costs are expected with this measure • Equipment life is expected to be 15 years • Average incentive funding is assumed to be $25,000 per truck

Assumptions for Table 4-20 (b):

Source Categories	
Light and Medium Heavy-Duty Trucks	• Affected vehicle categories: - Light heavy-duty diesel trucks with a GVWR of 10,001 to 14,000 pounds - Medium heavy-duty diesel trucks with a GVWR of 14,001 to 33,000 pounds • Affected vehicle model years: 2016 and 2017 model years • Replacement vehicles are assumed to be zero or near zero emission (0.02 g/bhp-hr) • Average unit cost of replacement truck is assumed to be $90,000 per truck • No additional operational or maintenance costs are expected with this measure • Equipment life is expected to be 15 years • Average incentive funding is assumed to be $35,000 per truck
Heavy Heavy-Duty Trucks	• Affected vehicle categories: - Heavy heavy-duty diesel trucks with a GVWR of over 33,000 pounds • Affected vehicle model years: 2024 through 2027 model year (new purchase) • New purchase vehicles are assumed to be zero or near zero emission (0.02 g/bhp-hr) • Average unit cost of new truck is assumed to be $160,000 per truck • No additional operational or maintenance costs are expected with this measure • Equipment life is expected to be 15 years • Average incentive funding is assumed to be $50,000 per truck

Implementation period for cost analysis: 2017-2031

Cost Assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit/Facility Incremental Cost ($) (2023/2031)	Per Unit/Facility Incentive Amount ($)	Number of Units 2023/2031	Years of Equipment Life
LHD/MHD Trucks	Truck Transportations (484)	$15,000/$35,000	$15,000	68,860/35,100	15
HHD Trucks	Truck Transportations (484)	$25,000/$50,000	$25,000	82,300/18,600	15

No annual operating savings or fuel savings were quantified for this control measure.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
Further Deployment of Cleaner Technology for On-Road Heavy-Duty Vehicles	$0	+	$4191.5	=	$4,191.5	$269.8

❖ *Heavy Duty Fuel (Aggregate Fuel Changes)*

CARB has provided an overall aggregate of fuel and energy demand changes from all the on-road heavy duty control measures as listed below.

Implementation period for cost analysis: 2018-2031

Cost Assumptions:

Calendar Year	Gasoline Billion Gallons	DSL Billion Gallons	CNG (Bcf)	Electricity (MWh)	Hydrogen (Kg)
2018	N/A	-0.0007	N/A	N/A	N/A
2019	N/A	-0.0016	N/A	200	700
2020	-0.0001	-0.0035	-0.0014	5,400	17,900
2021	-0.0006	-0.0099	-0.033	11,600	38,600
2022	-0.0013	-0.0190	-0.068	27,600	91,800
2023	-0.0023	-0.0302	-0.054	48,700	162,100
2024	-0.003	-0.050	0.96	72,000	240,000
2025	-0.005	-0.075	2.33	98,100	326,800
2026	-0.006	-0.101	3.85	124,600	415,100
2027	-0.008	-0.127	5.28	150,500	501,300
2028	-0.009	-0.154	6.79	175,800	585,700
2029	-0.010	-0.183	8.34	200,600	668,400
2030	-0.012	-0.213	10.11	225,200	750,300
2031	-0.013	-0.245	12.08	248,800	828,900

Source: Vision 2.1 Model

The overall aggregate fuel cost increase or savings, including the total increase in cost of electricity and Fuel cell Hydrogen as well as other fuel savings are presented below.

Calendar Year	Gasoline (million $)	Diesel (million $)	CNG (million $)	Electricity (million $)	Hydrogen (million $)
2018	$0.00	($2.37)	$0.00	$0.00	$0.00
2019	$0.00	($3.10)	$0.00	$0.02	$0.00
2020	($0.30)	($6.65)	($0.02)	$0.64	$0.10
2021	($1.54)	($22.76)	($0.36)	$0.76	$0.12
2022	($2.17)	($33.08)	($0.40)	$1.96	$0.32
2023	($3.15)	($41.40)	$0.16	$2.57	$0.42
2024	($2.24)	($74.45)	$11.93	$2.83	$0.47
2025	($6.49)	($95.60)	$16.47	$3.18	$0.52
2026	($3.29)	($101.03)	$18.60	$3.24	$0.53
2027	($6.69)	($102.58)	$17.54	$3.17	$0.52
2028	($3.41)	($108.94)	$18.27	$3.07	$0.51
2029	($3.47)	($118.81)	$18.82	$2.99	$0.50
2030	($7.05)	($124.60)	$21.56	$2.95	$0.49
2031	($3.58)	($135.34)	$24.12	$2.82	$0.47

Source: Vision 2.1

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
Heavy-Duty (aggregated fuel change)	($542.7)	+	$0.0	=	($542.7)	($55.5)

(c) Off-Road Federal & International

- *More Stringent National Locomotive Emission Standards*

This proposed measure is designed to reduce emissions from new and remanufactured locomotives. CARB would petition U.S. EPA for both new Tier 5 national locomotive emission standards for new locomotives and for more stringent national requirements for remanufactured locomotives. CARB staff estimates that the U.S. EPA could require manufacturers to implement the new locomotive emission regulations as early as 2023 for remanufactured locomotives, and 2025 for newly manufactured locomotives. A new federal standard could also facilitate development and deployment of zero-emission track mile locomotives and zero-emission locomotives by building incentives for those technologies into the regulatory structure. This analysis looks at the incremental costs and benefits above Tier 4 standards. Under this measure, CARB would petition U.S. EPA to begin the process of developing new Tier 5 locomotive emissions standards for newly manufactured locomotives, and more stringent national requirements for remanufactured locomotives for criteria pollutants, toxics, and GHG emissions by 2018.

It is assumed that the rail sector would bear the total capital cost for the purchases of locomotives with the compact SCR and Diesel Oxidation Catalyst (DOC) after-treatment system and on-board battery capabilities and for the construction of urea infrastructure required to transition to the Tier 5 standard. Additionally, the rail transportation industry would incur incremental costs related to the operating and maintenance, including those for urea consumption.

Implementation period for cost analysis: 2024-2031

Cost Assumptions:

Equipment Name	**Affected Industries (NAICS)**	**Per Unit/Facility Cost ($)**	**Per Unit/Facility Incentive Amount ($)**	**Number of Units 2017-2031**	**Years of Equipment Life**
Tier 5	Rail Transportations (482)	$1,000,000	$0	4,680	15
Remanufacture		$250,000	$0	3,840	15

Annual operating costs/savings are presented below in millions of 2015 dollars:

Incremental Annual Operating and Maintenance Savings	
Tier 5	$60,000
Remanufacture	$21,600
Fuel Savings (Tier 5 only)	($135,000)

In addition, urea infrastructure for a one-time cost of $1,500,000 is assumed.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	**Present Value of Remaining Incremental Cost**		**Present Value of Incentives**		**Present Worth Value of Total Incremental Cost**	**Amortized Annual Average (2017-2031)**
More Stringent National Locomotive Emission Standards	$308.2	+	$0	=	$308.2	$12.0

- *Tier 4 Vessel Standards*:

The goal of this measure is to reduce emissions from ocean going vessels. CARB would work with international partners and advocate for the International Maritime Organization to establish new Tier 4 NOx and PM standards, plus efficiency targets for existing vessels in Ship Energy Efficiency Management Plans for International Maritime Organization Action. The water transportation sector is expected to bear the costs of the transition to the Tier 4 technology. These costs include the incremental cost above the Tier 3 Exhaust Gas Recycling (EGR) to the Tier 4 SCR technology.

Implementation period for cost analysis: 2025-2031

Cost Assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit/Facility Cost ($)	Per Unit/Facility Incentive Amount ($)	Number of Units 2015-2031	Years of Equipment Life
Tier 4 OGV	Water Transportations (483)	$467,000	$0	504	20

The additional annual cost of urea usage of is estimated to be $147,000 per each Tier 4 OGV.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
Tier 4 Vessel Standards	$133.7	+	$0	=	$133.7	$3.9

❖ *At-Berth Regulation Amendments*

This measure is designed to further reduce emissions from ships auxiliary engines while at-berth. CARB would investigate expanding the current At-Berth Regulation to include smaller fleets and/or additional vessel types (including roll-on/roll-off vehicle carriers, bulk cargo carriers, and tankers) in the requirements for shore power. The proposed measure would increase costs for fleet operators and potentially for terminal operators. In addition, to the extent these costs are passed on to the businesses that own the goods shipped to and from California seaports, the added costs are expected to impact the cargo and business owners that purchase these goods.

Implementation period for cost analysis: 2022

Cost Assumptions:

Cost Incurred by Ports	Affected Industries (NAICS)	Per Unit/Facility Cost ($)	Per Unit/Facility Incentive Amount ($)	Number of Units 2018-2031	Years of Equipment Life
Aggregate Vessel Equipment (bulk, general cargo, tanker vessels)	Water Transportations (483)	$10,000,000	$0.0	11	20

No additional operating and maintenance costs were assumed.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	**Present Value of Remaining Incremental Cost**		**Present Value of Incentives**		**Present Worth Value of Total Incremental Cost**	**Amortized Annual Average (2017-2031)**
At-Berth Regulation	$90.4	+	$0	=	$90.4	$5.2

❖ *Further Deployment of Cleaner Technology: Off-Road Federal and International Sources (SCAQMD Scenario)*

Off-road Federal Sources include aircraft, locomotives, and ocean going vessels (OGVs). The SCAQMD and CARB do not have authority to regulate these sources. As a result, the only control method available is an incentive program to encourage use of the lowest emission equipment available. The purpose of this measure is obtain emission reductions earlier than would otherwise occur by natural turnover of fleets through incentive programs.

The SCAQMD has a long history of successful implementation of incentive programs to fund the accelerated deployment of cleaner engines and after-treatment technologies in on-road heavy-duty vehicles and off-road mobile equipment. Such accelerated deployment not only results in early emission reductions, but also provides a signal for technology providers, engine and automobile manufacturers, academic researchers to develop and commercialize the cleanest combustion engines and zero-emission technologies. Major incentive programs administered by SCAQMD include:

- CARB Carl Moyer Memorial Air Quality Standards Attainment Program (Carl Moyer Program)
- CARB Proposition 1-B Air Quality Improvement Fund
- CARB Lower Emission School Bus Program
- U.S. EPA Diesel Emission Reduction Act (DERA) Program
- Old vehicle scrap programs (light duty vehicles)
- Lawn and garden equipment exchange programs.

Specific technologies were not evaluated in this analysis. Rather, an example of control strategies to address aircraft, locomotive, and OGV emission sources are presented. In its plan, CARB had determined an emission reduction goal of 40 tpd in 2023 and additional 8 tpd in 2031 from further deployment of cleaner technologies for all Federal and international sources. Specific NOx emission reduction targets for aircraft, locomotive, and OGV emission sources were based on SCAQMD staff's judgement as to the relative feasibility of achieving emission reductions considering the emission inventories, state of technology development, and regulatory requirements. An estimate of the cost of incentives needed to attain the target emission reductions was calculated using the Carl Moyer Program[62] methodologies as follows.

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[62] Carl Moyer Program Guidelines, available at https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm.

Cost of Reduction = Emission Reduction x Cost Effectiveness limit/Cost Recovery Factor
Where: NOx Emission Reduction target in tpy
Cost Effectiveness Limit = \$30,000/ton NOx[63]
Cost Recovery Factor (annualized cost over program life)

The cost of the target emission reductions was then divided by the estimated cost per unit to determine the number of units affected by the measure.

Aircraft

This strategy is to encourage early use of the newest and lowest emission aircraft available by providing incentives to airlines that commit to operate aircraft built after 2010 at LAX. Commercial aircraft servicing the Southern California region range in age from essentially new to over 20 years old. The average age of aircraft using LAX has not been determined but the national commercial fleet is approximately 11 years old with the dominant airlines operating at LAX having fleets with average age up to 15 years old[64]. Aircraft engine standards were first adopted in 1992 and revised to reduce NOx emissions in 1998, 2004, and 2010. If the average aircraft is 11-15 years old, then the average emission level is equivalent to the CAEP/4 standard adopted in 1998. The CAEP/8 standard adopted in 2010 provides approximately 30% lower NOx emissions compared to the CAEP/4 standard. Further improvements resulting in additional emission reductions are anticipated in the near future. An 2016 emission reduction goal of at least 50% compared to CAEP/4 was established and has been demonstrated as achievable over a range of engine designs, but has not yet been adopted as a formal standard.[65]

Parameter	**2023**	**2031**
NOx Emission inventory:	16.0 tpd	17.0 tpd
Target Emission Reduction:	5.9 tpd	3.0 tpd
Aircraft useful life:	20 years	20 years
Incentive program life:	10 years	10 years
10 year CRF at 2% interest:	0.111	0.111
Incentive program cost effectiveness limit:	\$30,000/ton	\$30,000/ton
Cost of Emission Reduction:		
2023: (5.9 tpd x 365 dpy x \$30,000/ton) / 0.111	\$600,000,000	
2031: (3.0 tpd x 365 dpy x \$30,000/ton) / 0.111	--	\$289,500,000
Per aircraft incremental cost (engine/air frame improvements):	\$1,500,000	\$1,500,000
Number of aircraft (cost of reduction/incremental cost):	388	197
Operating and Maintenance Cost: (unquantified)	no change	no change

Locomotives

This strategy is to encourage early use of Tier 4 or cleaner freight locomotives by providing incentives to purchase and operate the locomotives in Southern California. Tier 4 locomotives are just now entering service. Locomotives have long useful lives and go through multiple overhaul cycles. As a result, locomotives operating in the Southern California region range in age and emission characteristics. On

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[63] Proposed 2017 cost effectiveness limit

[64] From www.AirFleets.net

[65] N. Dickson, "Local Air Quality and ICAO Engine Emissions Standards," International Civil Aviation Organization Environmental Bureau, Workshop presentation, 2014, available at http://www.icao.int/Meetings/EnvironmentalWorkshops/Documents/2014-Kenya/4-1_LAQ-Technology_notes.pdf

average, the freight locomotive line-haul fleet is reported by ARB to have average emissions equal to Tier 2[66]. The emission reduction from Tier 2 to Tier 4 is approximately 75% per locomotive replaced.

Parameter	2023	2031
NOx Emission inventory:	22.9 tpd	3.6 tpd
Target Emission Reduction:	17.2 tpd	2.4 tpd
Locomotive useful life:	30 years	30 years
Incentive program life:	12 years	12 years
12 year CRF at 2%:	0.095	0.095
Incentive program cost effectiveness limit:	$30,000/ton	$30,000/ton
Cost of Emission Reduction:		
2023: (17.2 tpd x 365 dpy x $30,000/ton) / 0.095	$1,979,644,737	--
2031: (2.4 tpd x 365 dpy x $30,000/ton) / 0.095	--	$236,756,757
Incremental cost/locomotive (replace vs maintain old):	$3,500,000	$3,500,000
Number of locomotives (cost of reduction/incremental cost):	566	79
O&M Cost (3% increase in cost for fuel (non-SCR) or urea (SCR))		
100,000 gal/year x $4/gal x 3%	$12,000	$12,000
Incentive (equal to estimated incremental cost):	$3,500,000	$3,500,000

Ocean Going Vessels

Ocean Going Vessels (OGVs) visiting the Southern California ports range in age and emission characteristics. On average, the average vessel calling at the ports in 2013 was 10 years old (built in 2003) and was subject to Tier 1 emission standards.[67,68] Tier 3 NOx standards are approximately 80% lower than Tier 1 and became effective for vessels with keels laid in 2016. The first Tier 3 vessels will enter service in 2017. This measure is to incentivize the use of the cleanest available ships or propulsion engine retrofit technologies when calling at Southern California ports.

Parameter	2023	2031
NOx Emission inventory:	23.0 tpd	14.6 tpd
Target Emission Reduction:	17.3 tpd	3.0 tpd
Vessel useful life:	30 years	30 years
Incentive program life:	per visit	per visit
1 year CRF at 2%:	1.02	1.02
Incentive program cost effectiveness limit:	$30,000/ton	$30,000/ton
Cost of Emission Reduction:		
2023: (17.3 tpd x 365 dpy x $30,000/ton) / 1.02	$150,000,000	--
2031: (3.0 tpd x 365 dpy x $30,000/ton) / 1.02	--	32,500,000
Per visit incremental cost (technology cost):	$50,000	$50,000
Number of visits (cost of reduction/incremental cost):	3,714	644
Operating and Maintenance Cost (Unquantified):	no change	no change

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[66] CARB website posting that 1998 MOU target had been met. Available at https://www.arb.ca.gov/railyard/1998agree/1998agree.htm

[67] Air Emissions Inventory – 2013, Port of Long Beach, June 2014

[68] Inventory of Air Emissions for Calendar Year 2013, Port of Los Angeles, July 2014.

Implementation period for cost analysis: 2017-2031

Cost Assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit Capital Costs ($)	Per Unit/Facility Incentive Amount ($)	Number of Units 2017-2023 /2024-2031	Years of Equipment Life
Low Emission Air Craft	Air Transportation (481)	$1,500,000	$1,500,000	388/197	20
Low Emission Locomotives	Rail Transportations (482)	$3,500,000	$3,500,000	566/79	30
Low Emission OGV Credits*	Water Transportation (483)	N/A	$50,000	3,714/644	N/A

*Credits to docking fee for Tier 4 vessels

Additional operating and maintenance costs of $12,000 per Tier 4 freight locomotive for urea costs is included.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
Further Deployment of Cleaner Technology: Off-Road Federal and International	$120.3	+	$3,707.0	=	$3,827.2	$221.0

(d) Off-Road Equipment

❖ *Low-Emission Diesel Fuel Requirement*

This measure is designed to reduce emissions from the portion of the heavy-duty fleet that will continue to operate on internal combustion engines. This measure would put into place standards for Low-Emission Diesel, and would require that diesel fuel providers sell steadily increasing volumes of Low-Emission Diesel until it comprises 50 percent of total diesel sales by 2031.

Additional cost of Low-Emission Diesel was distributed evenly among sectors of Rail Yards (NAICS 483) and Water Transportations (NAICS 488).

Implementation period for cost analysis: 2023-2031

Cost Assumptions:

Years	Costs in Millions
2023	$76.8
2024	$107.1
2025	$131.8
2026	$150.9
2027	$164.0
2028	$170.7
2029	$171.1
2030	$165.4
2031	$165.4

No additional operating and maintenance costs are assumed.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
Low-Emission Diesel Requirement (All Off-Road)	$867.7	+	$0	=	$867.7	$86.9

- Zero-Emission Off-Road Forklift Regulation Phase I

This measure is designed to increase the penetration of ZEVs in off-road applications, advance ZEV commercialization, and to send a market signal to technology manufacturers and investors. CARB staff would develop and propose a regulation with specific focus on forklifts with lift capacities equal to or less than 8,000 pounds for which zero-emission technologies have already gained appreciable customer acceptance and market penetration.

Implementation period for cost analysis: 2023-2030

Cost Assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit capital Costs ($)	Per Unit/Facility Incentive Amount ($)	Number of Units	Years of Equipment Life
ZEVs Forklift	Truck Transportations (484), Water Transportations (488), Production Cost - Fruit and Vegetable Preserving and Specialty Food Manufacturing (311), Wholesale (423)	$12,700	$0	3,670	10

Additional electricity cost/fuel and maintenance savings are listed below.

Incremental Annual Operating and Maintenance Costs, per unit	
Electricity	$1,253
Fuel (savings)	$(7,495)
Maintenance (Savings)	$(1,560)

Additional savings are expected to offset the incremental capital cost, resulting in an overall savings for this control measure.

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
Zero-Emission Off-Road Forklift Regulation	($134.8)	+	$0	=	($134.8)	($8.5)

❖ *Zero-Emission Airport Ground Support Equipment*

This measure is designed to increase the penetration of the first wave of zero-emission heavy-duty technology in applications that are well suited to its use, and to facilitate further technology development and infrastructure expansion. CARB would develop and propose a regulation to accelerate the transition of diesel and large spark ignition airport ground support equipment to zero-emission technology. Additional costs are assumed to be incurred evenly by the air transportation and scenic and sightseeing transportation and support activities industries, respectively.

Implementation period for cost analysis: 2023-2031

Cost Assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit capital Costs ($)	Per Unit/Facility Incentive Amount ($)	Number of Units	Years of Equipment Life
Zero-emission GSE Equipment	Scenic And Sightseeing Transportation And Support Activities (488), Air Transportation (481)	$7,733	$0	320	10
Electrical Infrastructure		$800	$0	320	10
Battery Replacement (every 5 years)		$7,773	$0	320	10
Engine Replacement, savings (every 5 years)		$(6,950)	$0	320	10

Additional electricity cost/fuel and maintenance savings are listed below.

Incremental Annual Operating and Maintenance Costs, per unit	
Electricity	$1,238
Fuel (savings)	$(7,409)
Annual Parts savings	$(1,538)
Maintenance (Savings)	$(1,330)

Additional savings are expected to offset the incremental capital cost, resulting in an overall savings for this control measure.[69]

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
Zero-Emission Ground Support Equipment	$3.3	+	$0	=	$3.3	$0.2

- *Small Off-Road Engines*

This measure is designed to reduce emissions from Small Off-Road Engines (SORE), and to increase the penetration of zero-emission technology. SORE that are subject to CARB regulations are used in residential and commercial lawn and garden equipment, and other utility applications. CARB will develop and propose tighter exhaust and evaporative emission standards, encourage increased use of zero-emission equipment, and enhance enforcement of current emission standards for SORE.

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[69] Fuel and O&M savings for this measure have not yet been incorporated in the calculation of PWV.

Implementation period for cost analysis: 2023-2031

Costs Assumptions:

Equipment Name	Affected Industries (NAICS)	Per Unit/Facility Cost ($)	Per Unit/Facility Incentive Amount ($)	Number of Units	Years of Equipment Life
Lawn movers (incremental)	Consumers	$74	$0	24,276	10
String Trimmers (incremental)	Consumers	$41	$0	24,276	10
Exhaust emission controls 80-225 cc (incremental)	Consumers	$28	$0	24,276	10
Exhaust emission controls 225 cc+ (incremental)	Consumers	$97	$0	24,276	10

Additional electricity costs and fuel savings per unit are presented below.[70]

Incremental Annual Operating and Maintenance Costs, per unit	
Electricity	$2
Fuel (savings)	$24

The incremental cost is presented below, all in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
Small Off-Road Engines	$20.4	+	$0	=	$20.4	$2.1

❖ *Further Deployment of Cleaner Technologies: Off-Road Equipment (SCAQMD Scenario)*

These off-road sources include mobile construction, industrial, portable, lawn and garden, and TRU equipment and are represented in CARB's expected emission reductions in the Basin by Further deployment of Cleaner Technologies beyond those achieved by existing and proposed regulations. New engine standards are established by U.S. EPA and CARB. In addition, CARB has established in-use fleet rules for many of these categories. Incentives are used to encourage replacement of these equipment sooner or using cleaner equipment than is required to comply with the fleet rules.

The SCAQMD has a long history of successful implementation of incentive programs to fund the accelerated deployment of cleaner engines and after-treatment technologies in on-road heavy-duty vehicles and off-road mobile equipment. Such accelerated deployment not only results in early emission reductions, but also provides a signal for technology providers, engine and automobile manufacturers,

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[70] Cost estimates from CARB staff (Mallory.Albright@arb.ca.gov)

academic researchers to develop and commercialize the cleanest combustion engines and zero-emission technologies. Major incentive programs administered by SCAQMD include:

- CARB Carl Moyer Memorial Air Quality Standards Attainment Program (Carl Moyer Program)
- CARB Proposition 1-B Air Quality Improvement Fund
- CARB Lower Emission School Bus Program
- U.S. EPA Diesel Emission Reduction Act (DERA) Program
- Old vehicle scrap programs (light duty vehicles)
- Lawn and garden equipment exchange programs.

The 2023 and 2031 emission inventories were consulted to determine the largest contributors. Four strategies for obtaining emission reductions equivalent to the Off-Road were evaluated as described in the following pages. CARB emission models[71] were used to predict the NOx emission inventory and number of equipment in future years by Tier, fuel type, and HP categories. The emission reduction and number of equipment needed to be replaced with cleaner technology was determined from the inventories by assuming the oldest equipment and highest NOx emission equipment was replaced first.

Off-Road Diesel Construction Equipment Replacement

Off-road diesel construction equipment is subject to turn-over requirements according to CARB's In-Use Off-Road Diesel-Fueled Equipment Regulation[72]. The regulation requires fleet turnover (replacement, repower, or retirement) to meet a gradually decreasing fleet average emission target. This strategy is to encourage early use of Tier 4 or cleaner off-road equipment by providing incentives to fleets that commit to purchase and operate the cleaner equipment to replace all Tier 0, Tier 1, and Tier 2 equipment by 2023 and all Tier 3 and Tier 4 Interim equipment with Tier 4 Final equipment and 15% of Tier 4 Final equipment with zero emission equipment by 2031.

Parameter	**2023**	**2031**
NOx Emission inventory:	17.8 tpd	10.4 tpd
Target Emission Reduction:	9.6 tpd	2.3 tpd
Equipment useful life:	20 years	20 years
Number of Equipment:	10,100	15,100
Average Unit Cost ($444,521)[73]	$450,000	$450,000
Average Incremental cost[74]:	$155,000	$150,000
Operating and Maintenance Cost (Urea = 3% of fuel usage)[75]:	$682	$682
Incentive (equal to estimated incremental cost):	$155,000	$150,000

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[71] Off-road equipment inventory models available at https://www.arb.ca.gov/msei/categories.htm#offroad_motor_vehicles

[72] https://www.arb.ca.gov/msprog/ordiesel/reglanguage.htm

[73] Average unit costs from 2014/2015 SOON and 2014 Carl Moyer programs

[74] Incremental unit costs from 2014/2015 SOON and 2014 Carl Moyer programs from amounts actually paid based on cost effectiveness criteria

[75] Urea for SCR systems = 3% x 6,500 gallons fuel/year x $3.50/gal = $682/year

Industrial, Commercial (Portable), TRU, GSE

Off-road diesel-fueled mobile industrial and ground support equipment (GSE) is also subject to the turn-over requirements according to CARB's In-Use Off-Road Diesel-Fueled Equipment Regulation. Transportation Refrigeration Units (TRUs) are subject to the TRU Air Toxics Control Measure[76] which uses an equipment replacement schedule based on original equipment model year. Certain industrial equipment powered by spark ignition engines are subject to CARB's Large Spark-Ignition (LSI) Engine Requirements Regulation[77] which requires equipment turn-over to meet fleet average emission targets. Under these various fleet rules, most equipment already meets the most stringent requirements. This strategy is to incentivize fleets to replace all Tier 0 through Tier 4 Interim and 45% of Tier 4 Final diesel fueled equipment with zero emission equipment by 2023; and replace 42% of remaining Tier 4 Final equipment with zero emission equipment by 2031.

Parameter	2023	2031
NOx Emission inventory:	16.3 tpd	8.4 tpd
Target Emission Reduction:	9.7 tpd	2.7 tpd
Equipment useful life:	15 years	15 years
Number of Equipment:	90,000	42,000
Average Unit Cost[78]:	$130,000	$130,000
Average Incremental cost[79]:	$25,000	$25,000
O&M Cost (Savings)[80]:	($1,000)	($1,000)
Incentive (equal to estimated incremental cost):	$25,000	$25,000

Commercial Small Off-Road Engines (SORE)

The small off-road engine (SORE) category consists of off-road spark-ignition engines that produce 19 kilowatts gross power or less (less than 25 horsepower), including lawn and garden, industrial, logging, airport ground support, and commercial utility equipment, golf carts, and specialty vehicles. CARB's SORE category does not include compression-ignition engines, watercraft, or recreational vehicles. However, for the purpose of this analysis, remaining compression-ignition lawn and garden equipment are included in the inventory and target emission reduction. SORE engines are subject to new engine standards but there are no in-use fleet regulations. This strategy is to incentivize equipment owners to replace all diesel fueled equipment and all spark ignition commercial mowers and tractors between 2 and 50hp (270,000 units) with zero emission equipment by 2023; and replace 36,000 remaining spark-ignition engines with zero emission equipment by 2031.

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[76] https://www.arb.ca.gov/diesel/tru/tru.htm

[77] https://www.arb.ca.gov/msprog/offroad/orspark/lsireglang.htm

[78] Average unit costs based on limited on-line search of lift trucks comparing similar capacity diesel and electric trucks

[79] Incremental costs based on limited on-line search of lift trucks comparing similar capacity diesel and electric trucks

[80] O&M Savings based on 80% of fuel cost representing reduced fuel cost less electric power charge – 1,080 gal/yr x $3.50/gal x 80% = $3,024/year

Parameter	2023	2031
NOx Emission inventory:	8.9 tpd	5.5 tpd
Target Emission Reduction:	3.1 tpd	0.3 tpd
Equipment useful life:	7 years	7 years
Number of Equipment:	270,000	36,000
Average Unit Cost[81]:	$2,000	$2,000
Average Incremental cost[82]:	$500	$500
O&M Cost (Savings)[83]:	($840)	($840)
Incentive (equal to estimated incremental cost):	$500	$500

Locomotives

Locomotives are regulated by EPA. However, a number of passenger locomotives operating in Southern California are old and replacing them with new Tier 4 locomotives or repowering them with Tier 4 engines would reduce NOx emissions at least 75% per locomotive (difference between Tier 2 and Tier 4). This strategy will incentivize railroads owners to replace or repower older 12 passenger locomotives with Tier 4 locomotives or engines by 2023.

Parameter	2023
NOx Emission inventory:	4.5 tpd
Target Emission Reduction:	2.0 tpd
Equipment useful life:	30 years
Number of Equipment:	12
Average Unit Cost[84]:	$6,300,000
Average Incremental cost[85]:	$2,000,000
Operating and Maintenance Cost[86]:	$10,500
Incentive (equal to estimated incremental cost):	$2,000,000

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[81] Average unit costs based on limited on-line search of 10 hp equipment versus electric equipment.

[82] Incremental costs based on limited on-line search of 10 hp equipment versus electric equipment

[83] O&M Savings based on 80% of fuel cost representing reduced fuel cost less electric power charge – 300 gal/yr x $3.50/gal x 80% = $840/year

[84] Average unit costs based on prior Moyer funded project for Metrolink

[85] Incremental costs based on prior Moyer funded project for Metrolink

[86] O&M cost based on SCR urea costs if equipped with SCR or fuel penalty if based on high rate EGR: 100,000 gal/yr x $3.50/gal x 3% = $10,500/year

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
Further Deployment of Cleaner Technology: Off-Road Equipment	$(2,453.2)	+	$4,435.5	=	$1,982.2	($18.8)

❖ *Consumer Products*

The proposed Consumer Products measure includes a wide variety of consumable goods including deodorants, hair spray, cleaning products and other products. The cost assumptions are based on CARB estimates[87]. The cost associated with this measure is estimated at $3.61 per pound of VOC reduced[88]. It is also assumed that half of the estimated 10 tpd of VOC emission reductions for the state in 2031 would occur in the Basin. Staff further assumed that 5 tpd of VOC emission reductions from the baseline inventory would occur annually from 2024 to 2031, after implementation begins in 2020 and becomes fully implemented by the end of 2023.

Implementation period for cost analysis: 2023-2031

The incremental cost is presented below in millions of 2015 dollars:

Control Measure	Present Value of Remaining Incremental Cost		Present Value of Incentives		Present Worth Value of Total Incremental Cost	Amortized Annual Average (2017-2031)
Consumer Products Program	$70.1	+	$0	=	$70.1	$7.0

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[87] CARB. 2016. "Proposed 2016 State Strategy for the State Implementation Plan. Appendix A: Economic Analysis." Sacramento, CA: California Air Resources Board (CARB).

[88] CARB. 2016. "Proposed 2016 State Strategy for the State Implementation Plan. Appendix A: Economic Analysis." Sacramento, CA: California Air Resources Board (CARB).

FINAL SOCIOECONOMIC REPORT
APPENDIX 2-B

COST-EFFECTIVENESS METHODOLOGIES

MARCH 2017

As part of the 2014 independent review of SCAQMD'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 SCAQMD 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 SCAQMD staff cannot be directly compared to those produced by other agencies. Abt thus recommends SCAQMD 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 SCAQMD's existing documentation regarding cost-effectiveness methodologies. It begins with a review of SCAQMD'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 SCAQMD'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.

SCAQMD's Cost-Effectiveness Analysis: Past and Current Practice

Historical Overview

The SCAQMD 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 (SCAQMD 1989). In 1995, SCAQMD 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 SCAQMD 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 SCAQMD's cost-effectiveness analysis has evolved.

FIGURE 2B-1: HISTORICAL TIMELINE OF SCAQMD'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 SCAQMD that uses LCF with annually updated discount rate (following the statewide Carl Moyer Program Guidelines)

Current Practice

The SCAQMD 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 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 SCAQMD 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 SCAQMD switched from the LCF method to the DCF method back in 1987 was for the latter's versatility. More importantly for SCAQMD, 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 SCAQMD'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]

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

- *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]

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

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:

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

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

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 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

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[6] Some regulations proposed by the SCAQMD, 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.

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

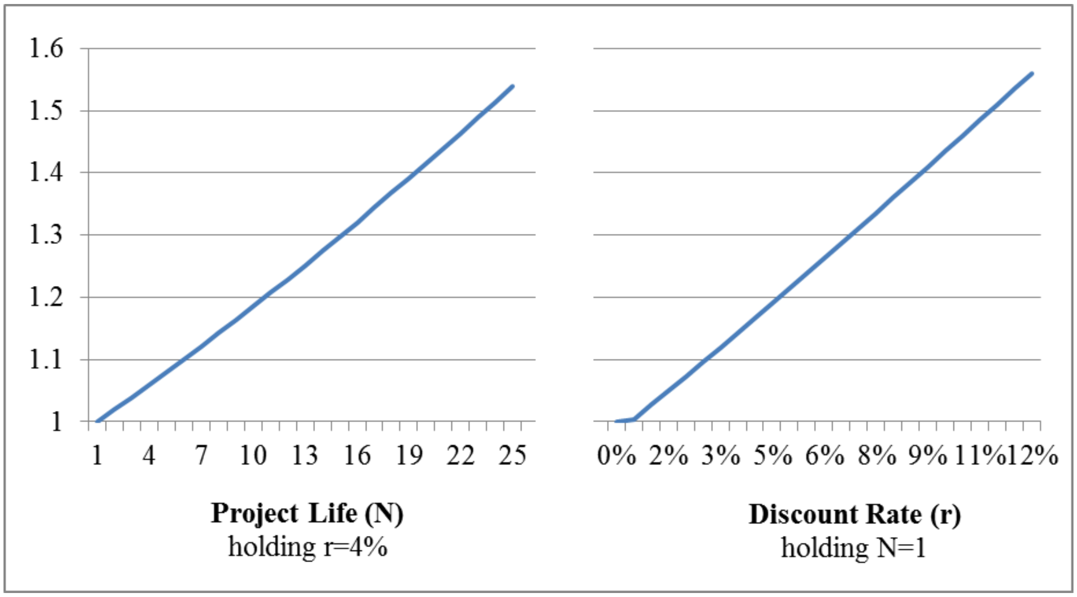

Table 2B-1 summarizes the main methodological differences between DCF and LCF in the case of a one-time capital investment cost made at the initial period and an annually recurring O&M cost, with constant annual emission reductions.

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 SCAQMD 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.

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[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.

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 SCAQMD 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 (SCAQMD 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 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.

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[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.

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 SCAQMD 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 SCAQMD 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, SCAQMD staff has been using a real interest rate of four percent since 1987.[10] The 2014 Abt report recommended SCAQMD conduct 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:

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

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[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 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 SCAQMD staff for all cost-effectiveness calculations, including in BACT analysis, to maintain for the purpose of consistency.

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.

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 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.

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

(Equipment life is taken to be 15 years)

- <u>Equipment Life</u>

The SCAQMD 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, SCAQMD 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

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[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.

a hypothetical example that is similar to the one analyzed above:

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

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 SCAQMD'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, SCAQMD 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 SCAQMD's socioeconomic assessments, the independent reviewer Abt Associates suggested SCAQMD 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 SCAQMD'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 SCAQMD 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.

FINAL SOCIOECONOMIC REPORT
APPENDIX 3-A

WEIGHT OF EVIDENCE DESCRIPTIONS FOR CAUSAL DETERMINATION

MARCH 2017

DETERMINATION	WEIGHT OF EVIDENCE
Causal Relationship	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 health effects in studies in which chance, bias, and confounding could be ruled out with reasonable confidence. For example: (a) controlled human exposure studies that demonstrate consistent effects; or (b) observational studies that cannot be explained by plausible alternatives or are supported by other lines of evidence (e.g., animal studies or mode of action information). Evidence includes replicated and consistent high-quality studies by multiple investigators.
Likely To Be A Causal Relationship	Evidence is sufficient to conclude that a causal relationship is likely to exist with relevant pollutant exposures, but important uncertainties remain. That is, the pollutant has been shown to result in health effects in studies in which chance and bias can be ruled out with reasonable confidence but potential issues remain. For example: (a) 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 (b) animal toxicological evidence from multiple studies from different laboratories that demonstrate effects, but limited or no human data are available. Evidence generally includes replicated and high-quality studies by multiple investigators.
Suggestive Of A Causal Relationship	Evidence is suggestive of a causal relationship with relevant pollutant exposures, but is limited because chance, bias, and confounding cannot be ruled out. For example, at least one high-quality epidemiologic study shows an association with a given health outcome 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.
Not Likely To Be A Causal Relationship	Evidence is suggestive of 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 susceptible populations, are mutually consistent in not showing an effect at any level of exposure.

(Adapted from U.S. EPA 2009)

FINAL SOCIOECONOMIC REPORT
APPENDIX 3-B

QUANTIFICATION OF PUBLIC HEALTH BENEFITS

MARCH 2017

Implementation of the 2016 Air Quality Management Plan will result in improved air quality, including lower ozone and PM2.5 concentrations in the SCAQMD 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 are 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 and 2012 AQMPs, as well as for numerous other studies.[1]

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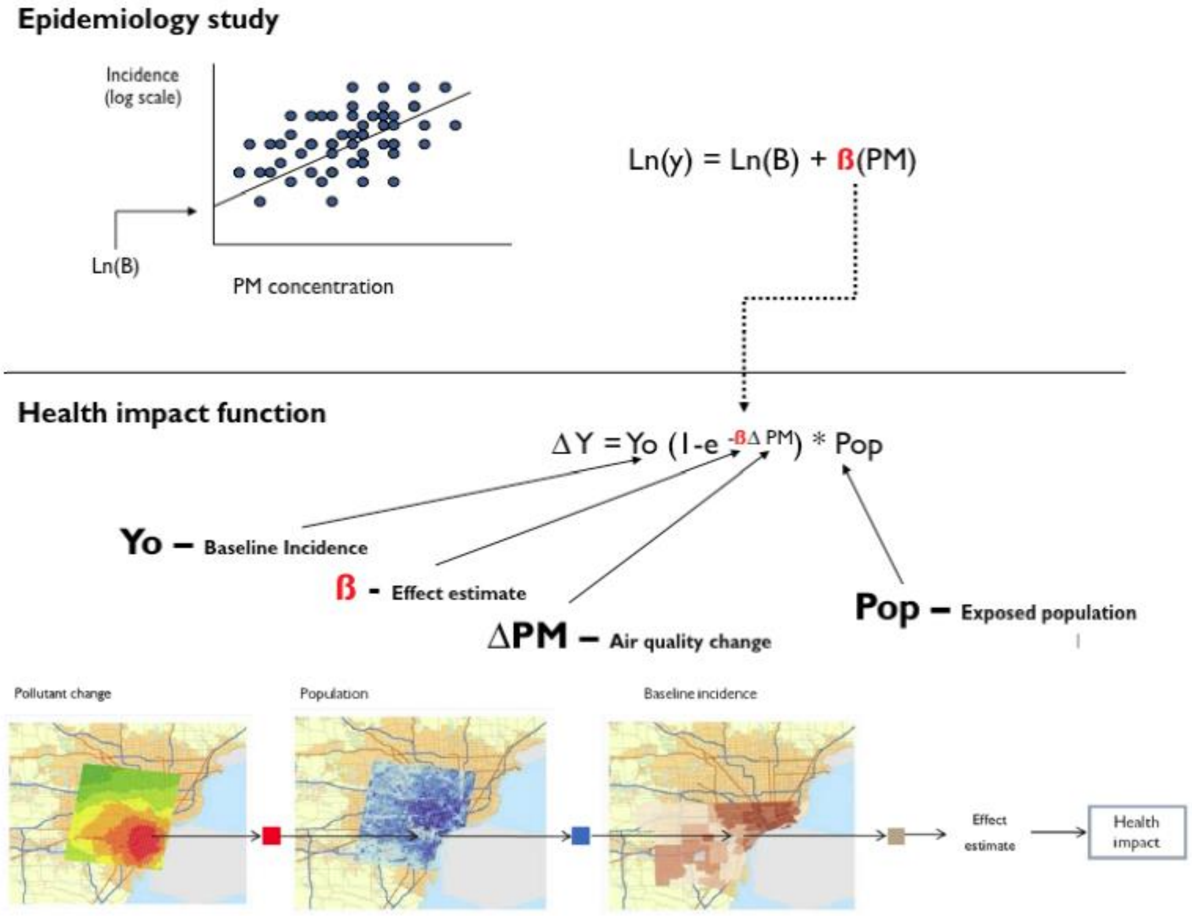
[1] U.S. EPA lists examples of these studies at: https://www.epa.gov/benmap/benmap-ce-applications-articles-and-presentations

FIGURE 3B-1: HEALTH IMPACT METHODOLOGY



Source: BenMAP CE User's Manual 2015, 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 Final 2016 AQMP respectively. The projected baseline and control air quality scenarios are the result of emission inventories (see Appendix III of the Final 2016 AQMP) and air quality simulations based on these emission inventories and other variables (see Appendix V of the Final 2016 AQMP). 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 PM2.5 and 153 days during the Summer Planning Season for 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 for analysis. The average of the daily changes for each pollutant in milestone years 2023 and 2031 is illustrated in Figure 3B-2. As shown in panels (a) and (b), the control measures result in decreases in average ozone concentration levels throughout the region for both years, with the largest decreases located around the western portions of San Bernardino and Riverside Counties. Panels (c) and (d) illustrate the changes in average

PM2.5 concentration levels, which decrease throughout the region for both years, with the largest decreases concentrated in central Los Angeles County.

FIGURE 3B-2: AIR QUALITY CHANGE FROM FINAL 2016 AQMP MEASURES, 2023 & 2031

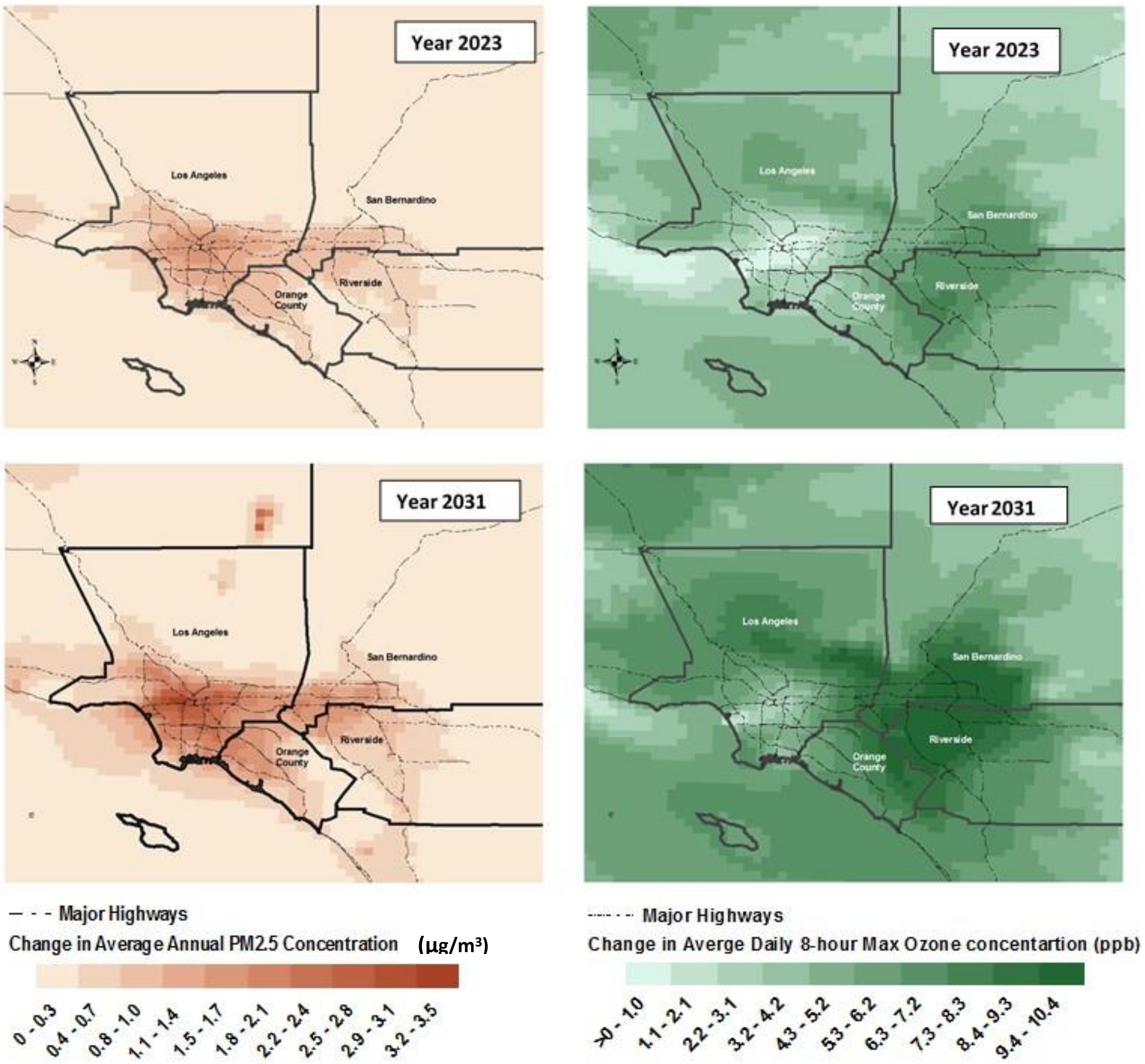
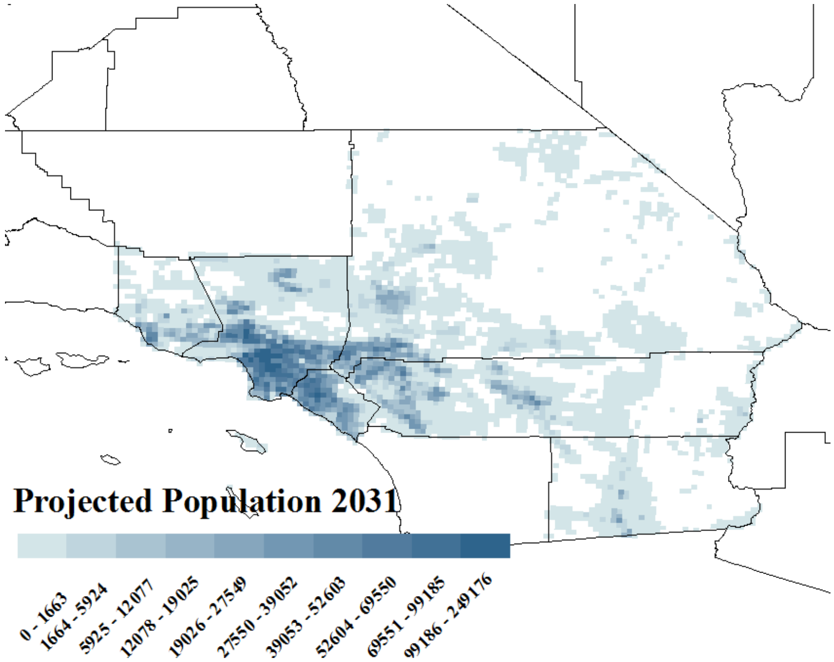


FIGURE 3B-3: PROJECTED POPULATION IN 2031



The population projections in 2031 (Figure 3B-3) are based on the 2016 RTP/SCS Growth Forecast (SCAG 2016) 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.

The baseline incidence rates for mortality and morbidity used are provided by Industrial Economics, Inc. (IEc), based on recommendations from their report (2016) at the county level, by five-year age group. Baseline mortality incidence rates for the base year 2012 are collected for historical years 2011-2013 from the California Department of Public Health and averaged to account for year to year variation. Projected baseline mortality rates for future years are based on the projected trend of U.S. crude death rates, which is available from the U.S. Census Bureau. This U.S. trend was applied to the base year local mortality rates, by age group, to obtain the projected mortality rates for all future years for each county.[2] Baseline incidence for hospital admissions and emergency department visits are based on the publicly accessible database from the Health Care Utilization Project (HCUP). County-level estimates of baseline incidence for nonfatal myocardial infarctions and ischemic stroke are obtained from U.S. Center for Disease Control's 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-

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[2] Staff is looking into procuring more local mortality rate projections and will update the analysis based on these new data once they are obtained.

CE (RTI International 2015).

The effect estimates for each health impact function are from C-R functions as described in Table 3B-1. Local estimates in the SCAQMD four-county region were selected whenever available and meeting other selection criteria recommended by IEc (Industrial Economics, 2016a and 2016b). 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 studies for all-cause mortality from short-term ozone exposure are 1.0035 (National Morbidity and Mortality Air Pollution Study) and 1.005 (meta-analysis) from Bell et al. (2005). 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.

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
Short-term Exposure to Ozone			
Mortality, All Cause	Pooling of: LA-specific NMMAPS and meta-analysis (Bell, Dominici, and Samet 2005)	All ages	VSL (Robinson and Hammitt 2016). $9 million ($4.2-$13.7 million)
School Loss Days All Cause	Gilliland, et al. (2001)	5-17 years	$217/day (BLS, 2012)
Hospital Admissions (HA), All Respiratory	Katsouyanni et al. (2009)	>64 years	$21,509 (HCUP, (Chestnut et al. 2006)
Minor Restricted Activity Days	B. D. Ostro and Rothschild (1989)	18-65 years	$17-$294/day (Brandt, Vásquez Lavín, and Hanemann 2012; Dickie and Hubbell 2004)
Emergency Room Visits, Asthma	Mar and Koenig (2009)	0-19 years and >19 years	HA: $9,131 (Chestnut et al. 2006) ED: $519 (Smith et al. 1997; Stanford, McLaughlin, and Okamoto 1999; Meng et al. 2010)
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)	> 30 years	VSL (Robinson and Hammitt 2016). $9 million ($4.2-$13.7 million)
Acute Bronchitis	Dockery et al. (1996)	8-12 years	$17-$294/day (Brandt, Vásquez Lavín, and Hanemann 2012; Dickie and Hubbell 2004)

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

Endpoint	C-R Function	C-R Function Study Population	Valuation Function
Short-term Exposure to PM2.5			
Minor Restricted Activity Days	B. D. Ostro and Rothschild (1989)	18-64 years	$17-$294/day (Brandt, Vásquez Lavín, and Hanemann 2012; Dickie and Hubbell 2004)
Lower Respiratory Symptoms	Schwartz and Neas (2000)	7-14 years	
Upper Respiratory Symptoms	Pope et al. (2015)	9-11 years	
Asthma Exacerbation (Wheeze, Cough, Shortness of Breath)	Pooling of: Ostro et al. (2001) (cough, wheeze, shortness of breath) and Mar et al. (2004) (cough, shortness of breath)	6-18 years	
HA All Cardiovascular (less Myocardial Infarctions)	Moolgavkar (2000)	>20-64 years	$23,469 (Chestnut et al. 2006)
HA, All Respiratory	Zanobetti et al. (2009) and Moolgavkar (2000)	>64 years	$21,509 (HCUP, (Chestnut et al. 2006)
HA, Ischemic Stroke	(Shin et al. 2014)	>65 years	$61,384 (Lee et al. 2007)
HA and ED Visits, Asthma	Delfino et al. (2014)	0-18 years	HA: $9,131 (Chestnut et al. 2006) ED: $519 (Smith et al. 1997; Stanford, McLaughlin, and Okamoto 1999; Meng et al. 2010)
Asthma, New Onset (Wheeze)	Young et al. (2014)	>34 years	No valuation function applied.
Work Loss Days	Ostro (1987)	18-64 years	$217/day (BLS, 2012)
Acute Myocardial Infarction, Nonfatal	Pooling of (Pope et al. 2015; Zanobetti and Schwartz 2006; Zanobetti et al. 2009; Sullivan et al. 2005).	Adults (>18 years)	$106,293 to $223,214 depending on age (Cropper and Krupnick 1990; Russell et al. 1998; Wittels, Hay, and Gotto 1990)

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 $4.2 to $13.7 million, with a midpoint of $9 million, all of which are expressed in 2013 dollars and based on 2013 income levels. 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.[3]

Per-capita income growth data for historical years 2013-2015 and projections for 2016-2019 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)[4], 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 2019 was derived. The post-2019 per-capita income growth is estimated based on the forecasted 2019 total income growth rate and the DOF's population forecast, resulting in an average annual growth rate of per-capita income of 1.1 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.[5] 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.

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[3] 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.

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

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

EPA 2009; U.S. EPA 2013).

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 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).[6] 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 short-term ozone exposure will result in a reduction of 45 all-cause premature deaths per year in the year 2023 and 89 per year in the year 2031 (both these numbers represent point estimates of a statistical distribution of possible outcomes). The effect of ozone improvements on mortality reduction is significant at the 95% confidence level as shown by the confidence intervals (CI).[7] 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 1,394 premature deaths per year in year 2023 and 2,716 per year in year 2031, both point estimates as well. The rate of change of reduced premature mortalities from year 2023 to 2031 is about 95 percent for both ozone and PM2.5 exposure.

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[6] 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.

[7] 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: ANNUAL MORTALITY AND MORBIDITY HEALTH EFFECT ESTIMATES

Endpoint	**2023**	**2031**
Premature Deaths Avoided, All Cause		
Short-Term Ozone Exposure[1]	45	89
	(5; 85)	(10; 168)
Long-Term PM2.5 Exposure	1,394	2,716
	(221; 2595)	(433; 5029)
Short-Term PM2.5 Exposure[2]	100	194
	(77; 122)	(150; 239)
Reduced Morbidity Incidence		
Short-Term Ozone Exposure[1]		
Hospital Admissions, All Respiratory	68	148
	(-20; 155)	(-44; 338)
Hospital Admissions (HA), Asthma	64	119
	(33; 95)	(61; 178)
Emergency Room Visits, Asthma	2,209	4,154
	(803; 3195)	(1546; 5963)
Minor Restricted Activity Days	327,312	610,075
	(135625; 516446)	(253230; 960949)
School Loss Days, All Cause	100,034	184,781
	(-11927; 205680)	(-22255; 376275)
PM2.5 Exposure		
Acute Bronchitis	1,039	1,890
	(-247; 2281)	(-455; 4099)
Acute Myocardial Infarction, Nonfatal	33	71
	(12; 88)	(26; 190)
Asthma Exacerbation (Wheeze, Cough, Shortness of Breath)	2,956	5,577
	(-1368; 6838)	(-2631; 12680)
Asthma, New Onset (Wheeze)	23,321	42,780
	(-1440; 50795)	(-2641; 93113)
HA, All Cardiovascular (less Myocardial Infarctions)	164	337
	(110; 204)	(226; 419)
HA, All Respiratory (less Asthma)[3]	136	290
	(83; 174)	(176; 372)
HA, Ischemic Stroke	79	171
	(24; 143)	(52; 309)
HA and ED Visits, Asthma	142	260
	(-24; 377)	(-44; 687)
Lower Respiratory Symptoms	12,268	22,387
	(4713; 19614)	(8637; 35646)

TABLE 3B-2: ANNUAL MORTALITY AND MORBIDITY HEALTH EFFECT ESTIMATES (CONT'D)

Endpoint	2023	2031
Upper Respiratory Symptoms	528,869	961,248
	(431337; 625725)	(784383; 1136704)
Minor Restricted Activity Days[4]	24,342	44,720
	(4421; 44141)	(8126; 81066)
Work Loss Days[4]	91,689	166,826
	(77650; 105650)	(141320; 192177)

[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] Premature deaths avoided due to short-term exposure to PM2.5 are likely to partially overlap with those due to long-term PM2.5 exposure. Therefore, the total premature deaths associated with PM2.5 will be lower than simply summing across mortality effects from both short-term and long-term exposure (Industrial Economics and Thurston 2016a; Kunzli et al. 2001).

[3] This is the pooled estimate of two health endpoints: HA, Chronic Lung Disease (less Asthma) (18-64 years old) and HA, All Respiratory (65 or older).

[4] Expressed in person-days. Minor Restricted Activity Days (MRAD) refer to days when some normal activities are avoided due to illness.

(Note: Parenthesis are a 95% CI.)

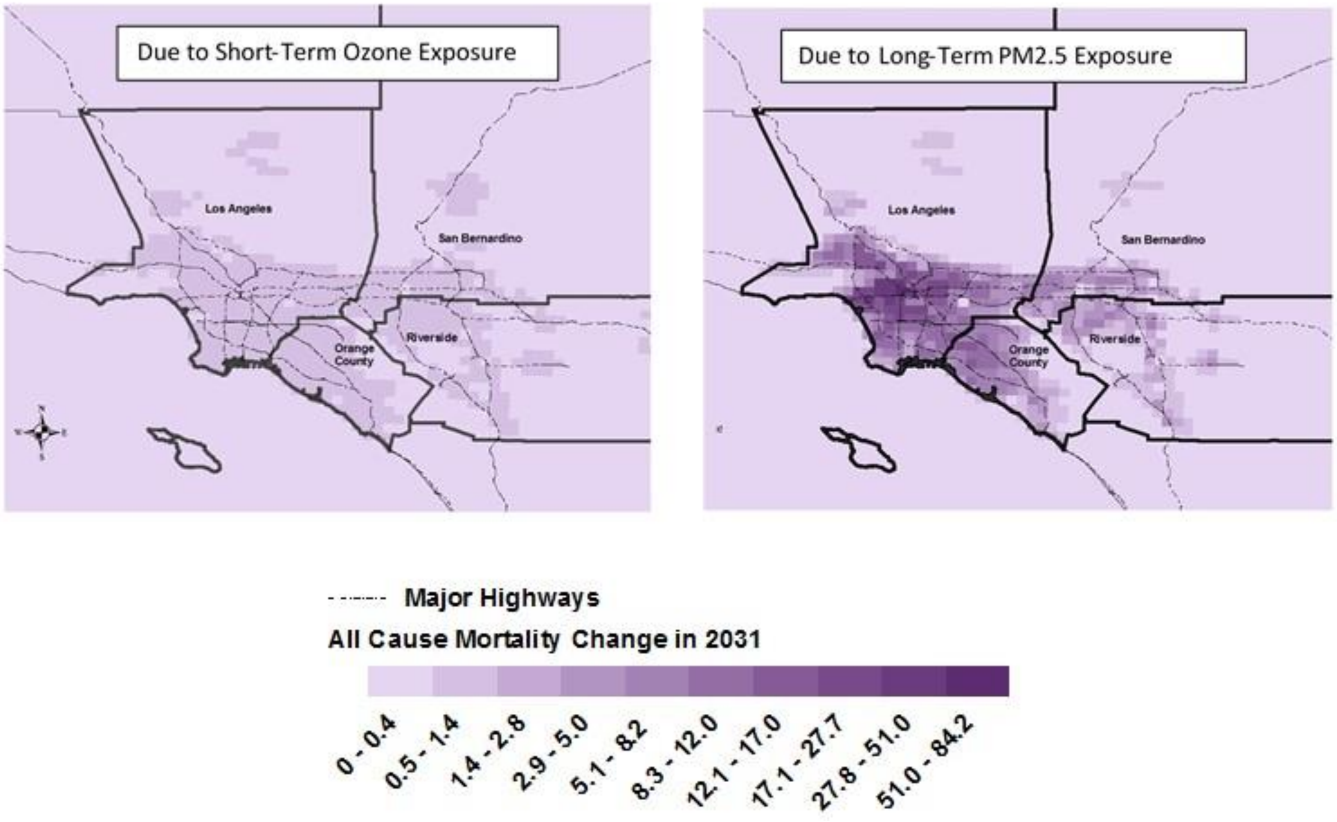
Figure 3B-4 maps the location of the avoided premature deaths by pollutant type in 2031. Ozone exposure reductions result in relatively small reductions in mortality throughout the basin, with concentrations in western Riverside and San Bernardino counties, and central Los Angeles County. The reduced 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 (2016), staff estimates the health impacts based on the pooling of three 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, (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, and (3) three estimates based on CVD-related mortality are considered (Jerrett et al. 2013; Thurston et al. 2016), which have RRs of 1.11, 1.11, and 1.04.

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

Scenarios	Health Impacts (premature deaths avoided per year)	
	2023	2031
Main Scenario (L.A. Studies)	1,394	2,716
	(221; 2595)	(433; 5029)
California Studies	258	509
	(-48; 877)	(-95; 1712)
National Studies	918	1,790
	(409; 1862)	(800; 3617)
CVD (L.A. and CA Studies)	339	663
	(151; 609)	(298; 1183)

FIGURE 3B-4: CHANGE IN ALL-CAUSE MORTALITY FROM SHORT-TERM OZONE EXPOSURE AND LONG-TERM PM2.5 EXPOSURE IN 2031



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.[8] 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 $14.2 billion in 2023 and $30.5 billion in 2031 (expressed in 2015 dollars), based on a base VSL of $9 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 $4.2 million ($13.7 million) and $\varepsilon_I = 0$ ($\varepsilon_I = 1.4$), this represents an extreme bound of the valuation of the mean health impact and shows the sensitivity of the results to the assumptions of the analysis. The annual public health benefits due to avoided premature deaths range from $5.6-$22.7 billion in 2023 and $10.9-$49.9 billion in 2031. From 2017 to 2031, the mid-point estimate of mortality-related benefits amounts to an average of $16.2 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.

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[8] 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.

TABLE 3B-4: MONETIZED PUBLIC HEALTH BENEFITS

	Monetized Public Health Benefits (Billions 2015$ per year)					
	2023			**2031**		
	Lower Bound ($4.2M, $\varepsilon_I=0$)	**Midpoint ($9M, $\varepsilon_I=1.1$)**	**Upper Bound ($13.7M, $\varepsilon_I=1.4$)**	**Lower Bound ($4.2M, $\varepsilon_I=0$)**	**Midpoint ($9M, $\varepsilon_I=1.1$)**	**Upper Bound ($13.7M, $\varepsilon_I=1.4$)**
Morality, All Cause	$5.6	**$14.2**	$22.7	$10.9	**$30.5**	$49.9
Ozone	$0.2	**$0.5**	$0.8	$0.4	**$1.1**	$1.8
Los Angeles	$0.1	**$0.2**	$0.3	$0.2	**$0.5**	$0.8
Orange	$0.0	**$0.1**	$0.2	$0.1	**$0.2**	$0.3
Riverside	$0.0	**$0.1**	$0.2	$0.1	**$0.2**	$0.3
San Bernardino	$0.0	**$0.1**	$0.1	$0.1	**$0.2**	$0.3
PM	$5.4	**$13.7**	$21.9	$10.5	**$29.4**	$48.1
Los Angeles	$3.8	**$9.7**	$15.4	$7.4	**$20.7**	$33.8
Orange	$0.8	**$2.1**	$3.4	$1.6	**$4.5**	$7.3
Riverside	$0.3	**$0.9**	$1.4	$0.7	**$2.1**	$3.4
San Bernardino	$0.4	**$1.0**	$1.6	$0.8	**$2.2**	$3.6

The monetary benefits of avoided morbidity incidence are shown in Table 3B-5. The greatest benefit from short-term ozone exposure reductions is from reduced minor restricted activity days valued at $103.3 million in 2031 and avoided productivity loss from school loss days valued at $40.5 million in 2031. The greatest benefits from short-term PM2.5 exposure is from reduced minor restricted activity days valued at $175.9 million in 2031 and avoided work loss day valued at $36.6 million in 2031. From 2017 to 2031, the morbidity-related benefits amount to an average of $230 million per year.

TABLE 3B-5: MONETIZED ANNUAL MORBIDITY BENEFITS (MILLIONS OF 2015 DOLLARS)

Morbidity Endpoint by Exposure	2023	2031	Average Annual (2017-2031)
Short-term Ozone Exposure (Total)	***$78.3***	***$150.5***	***$84.3***
Emergency Room Visits, Asthma	$1.1	$2.2	$1.2
Hospital Admissions (HA), All Respiratory	$1.5	$3.4	$1.8
Hospital Admissions (HA), Asthma	$0.6	$1.2	$0.7
Minor Restricted Activity Days[4]	$53.1	$103.3	$57.5
School Loss Days, All Cause[4]	$21.9	$40.5	$23.1
Long-Term PM2.5 Exposure (Total)	**$3.3**	**$6.2**	**$3.5**
Acute Bronchitis	$3.3	$6.2	$3.5
Short-term PM2.5 Exposure (Total)	**$133.1**	**$254.4**	**$142.9**
Acute Myocardial Infarction, Nonfatal	$1.7	$3.6	$1.9
Asthma Exacerbation (Wheeze, Cough, Shortness of Breath)	$0.6	$1.1	$0.6
HA, All Cardiovascular (less Myocardial Infarctions)	$4.1	$8.4	$4.5
HA, All Respiratory (less Asthma)[3]	$3.1	$6.6	$3.5
HA, Ischemic Stroke	$5.1	$11.0	$5.9
HA and ED Visits, Asthma	$0.2	$0.4	$0.3
Lower Respiratory Symptoms	$2.0	$3.8	$2.1
Upper Respiratory Symptoms	$3.6	$6.9	$3.9
Minor Restricted Activity Days[4]	$92.7	$175.9	$99.1
Work Loss Days[4]	$20.1	$36.6	$21.0
Total Morbidity Benefits	***$214.7***	***$411.1***	***$230.7***

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 Final 2016 AQMP are $14.4 billion in 2023 and $30.9 billion in 2031. The majority of the public health benefits are derived from premature deaths avoided, with the remaining amount coming from reduced incidence of morbidity conditions.

FINAL SOCIOECONOMIC REPORT
APPENDIX 3-C

REVIEW OF BenMAP OPERATION

MARCH 2017

memorandum

Date	September 1, 2016
To	Elaine Shen/SCAQMD
From	Jin Huang
Subject	Review of the SCAQMD's BenMAP Operation for its Health Benefits Analysis (Final Version)

Background and Objective

The South Coast Air Quality Management District (SCAQMD) is preparing its Socioeconomic Analysis for the 2016 Air Quality Management Plan (AQMP). The District staff is using BenMAP-CE[1] for the health benefits analysis (as part of the AQMP Socioeconomic Analysis).

Under Contract #15577, I was tasked to review the SCAQMD's BenMAP operation and to make sure the District technical staff performs BenMAP tool in an appropriate manner for the health benefits analysis. Note that I did not review any raw data or data sources.

In this memorandum, I document my review process as well as my comments and recommendations.

Review process

BenMAP Audit Trail Reports

My review process started with checking BenMAP audit trail reports generated from the SCAQMD's preliminary health benefits analysis.[2] Audit Trail Reports summarize the assumptions underlying each of five types of files generated by BenMAP-CE:

- Air Quality Grids (with the ".aqgx" extension),
- Incidence Configurations (with the ".cfgx" extension),
- Incidence Configuration Results (with the ".cfgrx" extension),
- Aggregation, Pooling, and Valuation Configurations (with the ".apvx" extension), and
- Aggregation, Pooling, and Valuation Results (with the ".apvrx" extension).

I reviewed the audit trail reports provided to me (i.e., the $PM_{2.5}$ and Ozone health impact quantification and valuation in year 2031) and provided my comments back to the District staff.[3]

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[1] Environmental Benefits Mapping and Analysis Program - Community Edition (BenMAP -CE)

[2] The District technical staff Anthony Oliver provided the audit trail reports to me via email attachments on August 2, 2016.

[3] My comments and notes were sent to Elaine Shen and Anthony Oliver via email on August 8 and were discussed in a face-to-face meeting with Tony on August 9.

Customized BenMAP Datasets

To further evaluate the SCAQMD's BenMAP operation in the health benefits analysis, a face-to-face meeting between District technical staff and me was held on August 9, 2016 (from 10:00AM to 5:00PM) in Mountain View, CA. Using his laptop, the District staff showed me the upload process of customized datasets used in their analysis, including air quality data, population data, health incidence data, health impact functions (HIF), inflation dataset, and income growth factors. I looked into each dataset uploaded to BenMAP, checked data format and identified potential problems with creating and loading the data (see Table 1).

BenMAP Runs

During the face-to-face meeting, the District technical staff performed two complete BenMAP runs, one for $PM_{2.5}$ health benefits and the other is for Ozone health benefits, both using projected 2031 data. I have monitored each step during the runs as well as every option chosen (e.g., health impact function pooling, valuation function pooling).

Intermediate and Final Results

Finally, I reviewed the intermediate and final results generated from the above two BenMAP runs, including

- Maps of air quality change in the study area
- Changes in health incidence
- Aggregated and pooled incidence results, and
- Pooled valuation results

Review Results

Summary

Based on the BenMAP audit trail reports and in-person demonstration of BenMAP runs provided by the SCAQMD, the BenMAP operation for the SCAQMD's health benefits analysis was generally appropriate: the data upload was conducted properly; the customized BenMAP runs were performed correctly; and the intermediate and final results both looked fine. The SCAQMD technical staff has been trained to conduct BenMAP analysis; he is familiar with technical details in BenMAP setup and runs.

Detailed Review Results

The detailed evaluation results, including specific comments and suggestions on different aspects of BenMAP datasets/operation, are listed in Table 1 below.

Table 1. Comments and Suggestions on the SCAQMD BenMAP Operation

BenMAP Operation Steps /Datasets	Comment	Suggestion
SCAG population projection data	Data upload process is correct. Since the incidence rate data is not based on SCAG population (probably based on Census population data), BenMAP would calculate *incidence_count= incidence_rate*SCAG_pop*, that is, *incidence_count/Census_pop * SCAG_pop*. If SCAG and Census	Compare the SCAG and Census population data used in the analysis.

	population data are similar, this would not be a problem; if the population data are quite different, the incidence estimate would not be accurate.	
Incidence rates	Some morbidity incidence rates are not county specific; they are equal for all the four counties.	Incidence rates should be updated to be county- specific when county-level data are available.[4]
Inflation dataset	No inflation dataset is needed for SCAQMD's analysis but a dataset was uploaded in the inflation databox in BenMAP setup. The District staff used this shortcut to adjust income growth for valuation functions that include both willingness-to-pay and cost of illness components.	Document clearly the shortcut used in an internal report to avoid confusion (it might not be necessary to describe it in the public socioeconomic report).
Discount factor	4% is historically used, and 1% will be additionally used in the 2016 AQMP Socioeconomic analysis. It is a good practice to use a low and high discount rate.	Provide sufficient rationale for using 4% and 1% discount rate.[5]
Ozone season	Standard ozone season (May 1 – September 30) is used.[6]	Consider whether extended ozone season is more appropriate for the region.[7]
Health impact function (HIF) pooling	For the "Advanced Pooling Method", the option of "Round weights to two digits" was chosen.	Use "exact weights" option rather than "round weights to two digits".
Valuation function pooling	1) In the $PM_{2.5}$ BenMAP run for respiratory hospitalization, HIF for different age groups (18-64 and 65+) were pooled, but valuation function for 18-64 was then used. 2) Similar problem in the Ozone run for asthma emergency department visits: HIF for 0-17 and 18+ age groups were pooled but valuation function for 0-17	If different age groups were pooled in the HIF pooling step (e.g., 18-64 and 65+), the valuation function for the aggregated age group (e.g., 18+) should be used.[8]

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[4] I was told that the SCAQMD's contractor is working on updating the rates.

[5] Since USEPA and other federal agencies usually use 3% and 7% discount rate in their regulatory analysis (as recommended by OMB in Circular A-4, section "Discount Rates"), the District needs to provide sufficient rationale for using different discount rates.

[6] This may be due to data limitation, that is, the regional air quality modeling focused on summer season only.

[7] If an extended ozone season is more appropriate but air quality data is not currently available, this can be considered as a long-term enhancement.

[8] This suggestion is based on my past practice with BenMAP. The BenMAP user manual does not seem to have details about such pooling.

	was used in the valuation step. See screenshots in Appendix II.	
Health impact function summary		This is out of my review scope; but for District record, it would be good to keep a summary of selected C-R functions/HIFs (A sample is provided in Appendix I).

Appendix I: Sample Summary of Health Impact Studies and Functions

Hospital Admission

Effect	Author	Year	Location	Age	Co-Poll	Metric	Beta	Std. Err.	Functional Form	Notes
All Respiratory	Fung et al.	2006	Vancouver, Canada	65-99		D24Hour Mean	0.003285	0.001707	Log-linear	
Asthma	Linn et al.	2000	Metropolitan Los Angeles	0-29		D24Hour Mean	0.002400	0.000800	Log-linear	
Asthma	Linn et al.	2000	Metropolitan Los Angeles	30-99		D24Hour Mean	0.001400	0.000500	Log-linear	
All Respiratory	Luginaah et al.	2005	Windsor, Ontario	0-14		D1Hour Max	0.006747	0.003628	Log-linear	Female
All Respiratory	Luginaah et al.	2005	Windsor, Ontario	0-14		D1Hour Max	-0.002878	0.003132	Log-linear	Male
All Respiratory	Luginaah et al.	2005	Windsor, Ontario	15-64		D1Hour Max	0.007139	0.004353	Log-linear	Female
All Respiratory	Luginaah et al.	2005	Windsor, Ontario	15-64		D1Hour Max	0.000746	0.005879	Log-linear	Male
All Respiratory	Luginaah et al.	2005	Windsor, Ontario	65-99		D1Hour Max	0.001238	0.002961	Log-linear	Female
All Respiratory	Luginaah et al.	2005	Windsor, Ontario	65-99		D1Hour Max	-0.001435	0.004295	Log-linear	Male
Chronic Lung Disease	Moolgavkar S.H.	2003	Los Angeles County, CA	65-99		D24Hour Mean	0.001800	0.000188	Log-linear	
Chronic Lung Disease	Moolgavkar S.H.	2003	Cook County, CA	65-99		D24Hour Mean	0.002400	0.000803	Log-linear	
All Respiratory	Yang et al.	2003	Vancouver, Canada	65-99	SO_2, O_3, CO, COH	D24Hour Mean	0.008759	0.003069	Logistic	
Chronic Lung Disease (less Asthma)	Yang et al.	2005	Vancouver, Canada	65-99	O_3	D24Hour Mean	0.020605	0.006637	Log-linear	

1. Fung et al. (2006)

Fung et al. (2006) assessed the impact of ambient gaseous pollutants (SO_2, NO_2, CO, and O_3) and particulate matters (PM_{10}, $PM_{2.5}$, and $PM_{10-2.5}$) as well as the coefficient of haze (COH) on recurrent respiratory hospital admissions (ICD-9 codes 460-519) among the elderly in Vancouver, Canada, for the period of June 1, 1995, to March 31, 1999, using a new method proposed by Dewanji and Moolgavkar(2000; 2002). The associations were conducted at current day, 3-day, 5-day, and 7-day moving averages. The strongest association between NO_2 and hospital admissions was observed at 3-day lag (RR = 1.018, 95% CI: 1.000-1.037). For SO_2, significant associations were found between admissions and 3-day, 5-day, and 7-day moving averages of the ambient SO_2 concentrations, with the strongest association observed at the 7-day lag (RR = 1.044, 95% CI: 1.018-1.070). The authors found $PM_{10-2.5}$ for 3-day and 5-day lag to be significant, with the strongest association at 5-day lag (RR = 1.020, 95% CI: 1.001-1.039). No significant associations with admission were found with current day exposure.

Hospital Admissions, All Respiratory (ICD-9 codes 460-519)
In a single-pollutant model the coefficient and standard error are estimated from the relative risk (1.018) and 95% confidence interval (95% CI: 1.000-1.037) for a 5.431 ppb increase in 3-day moving average of NO_2 (Fung, et al., 2006, Table 4).

Emergency Room Visits

Effect	Author	Year	Location	Age	Co-Poll	Metric	Beta	Std. Err.	Functional Form	Notes
Asthma	Ito et al.	2007	NYC	0-99		D24HourMean	0.005460	0.000933	Log-linear	
Asthma	Jaffe et al.	2003	Cincinnati and Cleveland, Ohio	5-34		D1HourMax	0.003000	0.002041	Log-linear	Asthmatics; Warm season
Asthma	NYDOH	2006	Bronx, NYC	0-99	O_3	D24HourMean	0.002264	0.001178	Log-linear	
Asthma	Peel et al.	2005	Atlanta, GA	0-99		D1HourMax	0.002296	0.000901	Log-linear	
Asthma	Villeneuve et al.	2007	Edmonton, Canada	75-99		D24HourMean	0.013505	0.005345	Logistic	

1. Ito et al.(2007)

Ito et al.(2007) assessed associations between air pollution and asthma emergency department visits in New York City for all ages. Specifically they examined the temporal relationships among air pollution and weather variables in the context of air pollution health effects models. The authors compiled daily data for $PM_{2.5}$, O_3, NO_2, SO_2, CO, temperature, dew point, relative humidity, wind speed, and barometric pressure for New York City for the years 1999-2002.The authors evaluated the relationship between the various pollutants' risk estimates and their respective concurvities, and discuss the limitations that the results imply about the interpretability of multi-pollutant health effects models.

Emergency Room Visits, Asthma (ICD-9 code 493)
In a single-pollutant model, the coefficient and standard error are estimated from the relative risk (1.14) and 95% confidence interval (1.09-1.19) for a 24 ppb increase in the average of 0- and 1-day lag of NO_2 (Ito, et al., 2007, p. S52).

Asthma Exacerbation

Effect	Author	Year	Location	Age	Co-Poll	Metric	Beta	Std. Err.	Functional Form	Notes
One or More Symptoms	Delfino et al.	2002	Southern Califormia	9-18		D8Hour Max	0.019939	0.011443	Logistic	
One or More Symptoms	Delfino et al.	2003	Los Angeles	10-16		D8Hour Max	0.240337	0.115256	Logistic	Hispanic asthmatics
One or More Symptoms	Mortimer et al.	2002	7 urban areas (US)	4-12	O_3, SO_2	D4Hour Mean	0.013501	0.011179	Logistic	Warm season; Adjusted age
Cough	Ostro et	2001	Central Los	4-12		D1Hour	0.000591	0.000595	Logistic	African-

Effect	Author	Year	Location	Age	Co-Poll	Metric	Beta	Std. Err.	Functional Form	Notes
	al.		Angeles, CA			Max				Americans; Adjusted age
Cough (New Cases)	Ostro et al.	2001	Central Los Angeles, CA	4-12		D1Hour Max	0.002267	0.001098	Logistic	African-Americans; Adjusted age
Shortness of Breath	Ostro et al.	2001	Central Los Angeles, CA	4-12		D1Hour Max	0.001539	0.000896	Logistic	African-Americans; Adjusted age
Shortness of Breath (New Cases)	Ostro et al.	2001	Central Los Angeles, CA	4-12		D1Hour Max	0.002621	0.001429	Logistic	African-Americans; Adjusted age
Wheeze	Ostro et al.	2001	Central Los Angeles, CA	4-12		D1Hour Max	0.001539	0.000612	Logistic	African-Americans; Adjusted age
Wheeze (New Cases)	Ostro et al.	2001	Central Los Angeles, CA	4-12		D1Hour Max	0.002444	0.000897	Logistic	African-Americans; Adjusted age
One or More Symptoms	Schildcrout et al.	2006	Eight U.S. cities	4-12		D24HourMean	0.004309	0.001406	Logistic	Adjusted age

1. Delfino et al.(2002)

Delfino et al.(2002) examined the association between air pollution and asthma symptoms among 22 asthmatic children (9-19 years of age) followed March through April 1996 (1,248 person-days) in Southern California. Air quality data for PM_{10}, NO_2, O_3, fungi and pollen were used in a logistic model with control for temperature, relative humidity, day-of-week trends and linear time trends. The odds ratio (95% confidence interval) for asthma episodes in relation to lag0 20 ppb changes in 8-hr max NO_2 is 1.49 (0.95-2.33). The authors also considered subgroups of asthmatic children who were on versus not on regularly scheduled anti-inflammatory medications and found that pollutant associations were stronger during respiratory infections in subjects not on anti-inflammatory medications.

Asthma Exacerbation, One or More Symptoms

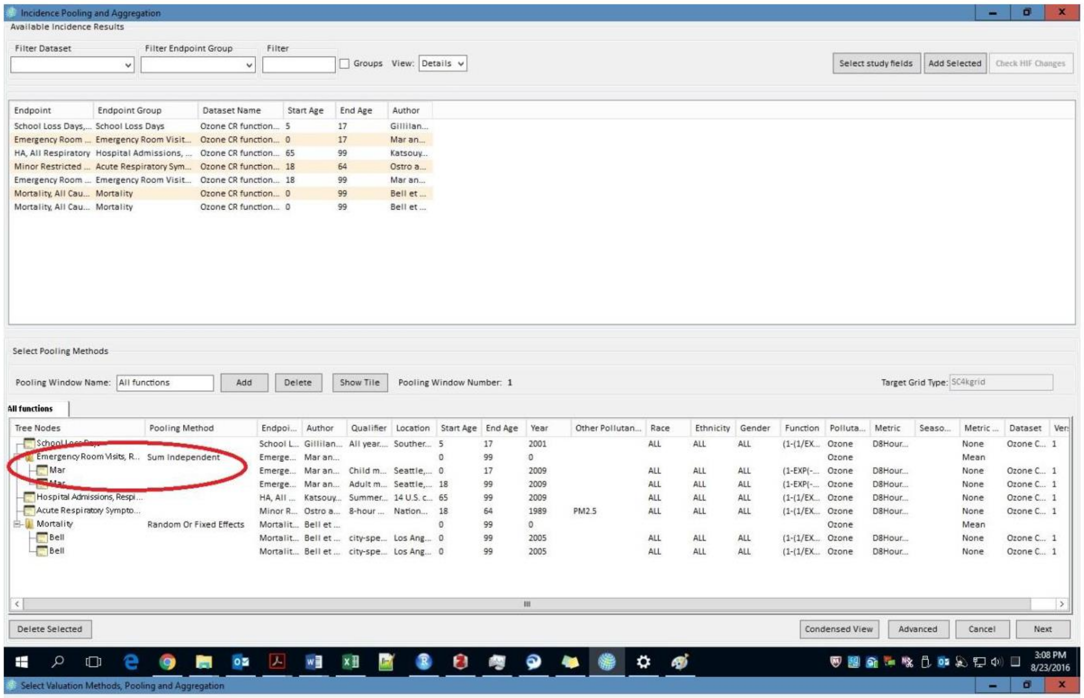
In a single-pollutant model, the coefficient and standard error are estimated from the odds ratio (1.49) and the 95% confidence interval (0.95-2.33) for a 20 ppb increase in 8-hr max NO_2 (Delfino, et al., 2002, Table 4).

Incidence Rate: Delfino et al.(2002, Table 1) reported asthma episodes in the 22 asthmatic children. Asthma episodes are defined as having asthma symptoms that interfered with daily activities (symptom sore >2). The incidence rate is calculated as the ratio of number of person-days that symptom sore >2 and the total number of person-days, i.e., daily asthma episodes incidence rate = 196/1248=0.157

Population: The study population includes asthmatics from 9 to 18 years of age. We treat these as two groups based on the available information from American Lung Association (2002, Table 7). Asthmatic population ages 9 to 17 = 5.67% of population ages 9 to 17 and asthmatic population age 18 = 3.71% of population age 18. The American Lung Association (2002, Table 7) estimates asthma prevalence for children 5- 17 and 18-44 at 5.67% and 3.71% respectively (based on data from the 1999 National Health Interview Survey).

Reference:

Appendix II: Health Impact Function and Valuation Function Pooling



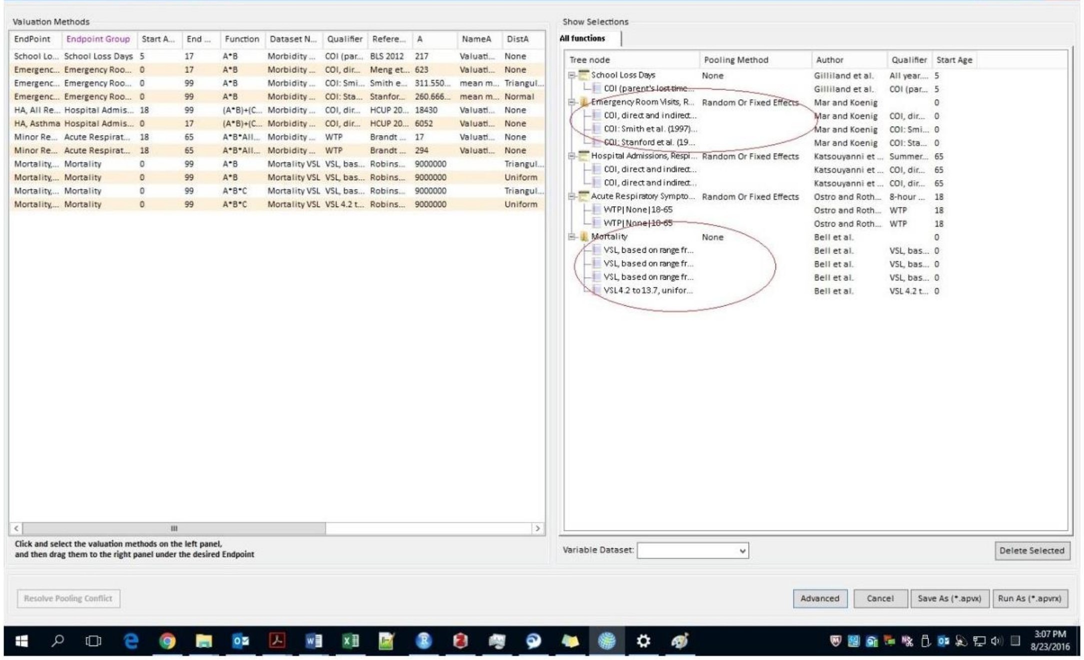
Endpoint	Endpoint Group	Dataset Name	Start Age	End Age	Author
School Loss Days,...	School Loss Days	Ozone CR function...	5	17	Gillilan...
Emergency Room ...	Emergency Room Visit...	Ozone CR function...	0	17	Mar an...
HA, All Respiratory	Hospital Admissions, ...	Ozone CR function...	65	99	Katsouy...
Minor Restricted ...	Acute Respiratory Sym...	Ozone CR function...	18	64	Ostro a...
Emergency Room ...	Emergency Room Visit...	Ozone CR function...	18	99	Mar an...
Mortality, All Cau...	Mortality	Ozone CR function...	0	99	Bell et ...
Mortality, All Cau...	Mortality	Ozone CR function...	0	99	Bell et ...

Pooling Window Name: All functions

Pooling Window Number: 1

Target Grid Type: SC4kgrid

Tree Nodes	Pooling Method	Endpoi...	Author	Qualifier	Location	Start Age	End Age	Year	Other Pollutan...	Race	Ethnicity	Gender	Function	Polluta...	Metric	Seaso...	Metric ...	Dataset	Ver
School Loss Days		School L...	Gillilan...	All year....	Souther...	5	17	2001		ALL	ALL	ALL	(1-(1/EX...	Ozone	D8Hour...		None	Ozone C...	1
Emergency Room Visits, R...	Sum Independent	Emerge...	Mar an...			0	99	0						Ozone			Mean		
Mar		Emerge...	Mar an...	Child m...	Seattle,...	0	17	2009		ALL	ALL	ALL	(1-EXP(-...	Ozone	D8Hour...		None	Ozone C...	1
Mar		Emerge...	Mar an...	Adult m...	Seattle,...	18	99	2009		ALL	ALL	ALL	(1-EXP(-...	Ozone	D8Hour...		None	Ozone C...	1
Hospital Admissions, Respi...		HA, All ...	Katsouy...	Summer...	14 U.S. c...	65	99	2009		ALL	ALL	ALL	(1-(1/EX...	Ozone	D8Hour...		None	Ozone C...	1
Acute Respiratory Sympto...		Minor R...	Ostro a...	8-hour ...	Nation...	18	64	1989	PM2.5	ALL	ALL	ALL	(1-(1/EX...	Ozone	D8Hour...		None	Ozone C...	1
Mortality	Random Or Fixed Effects	Mortalit...	Bell et ...			0	99	0						Ozone			Mean		
Bell		Mortalit...	Bell et ...	city-spe...	Los Ang...	0	99	2005		ALL	ALL	ALL	(1-(1/EX...	Ozone	D8Hour...		None	Ozone C...	1
Bell		Mortalit...	Bell et ...	city-spe...	Los Ang...	0	99	2005		ALL	ALL	ALL	(1-(1/EX...	Ozone	D8Hour...		None	Ozone C...	1

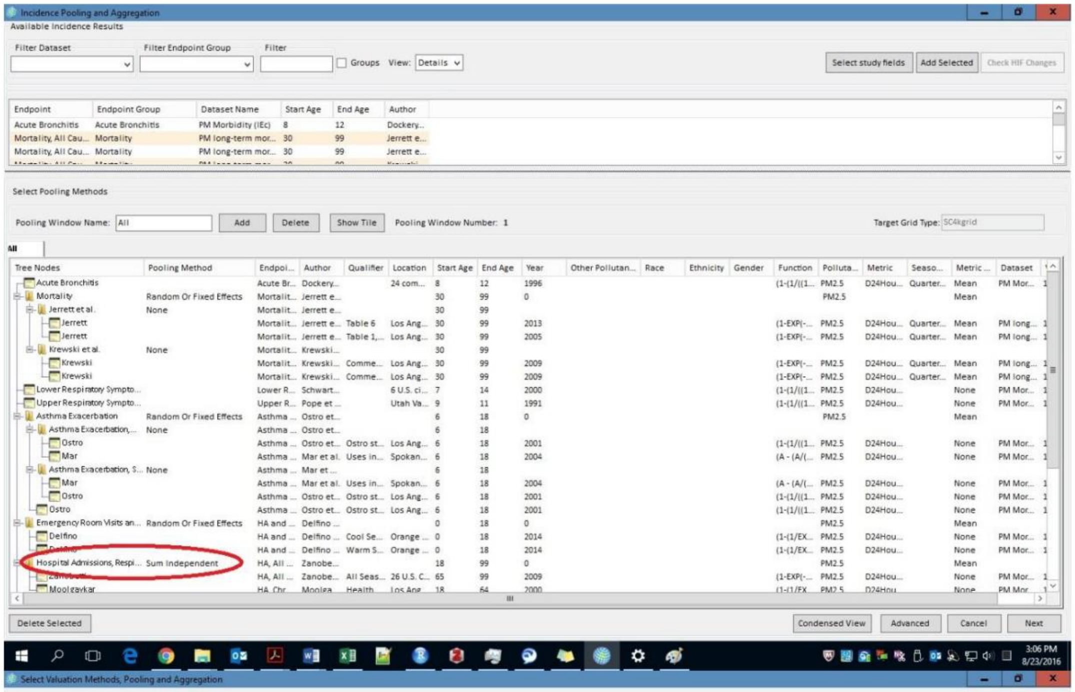


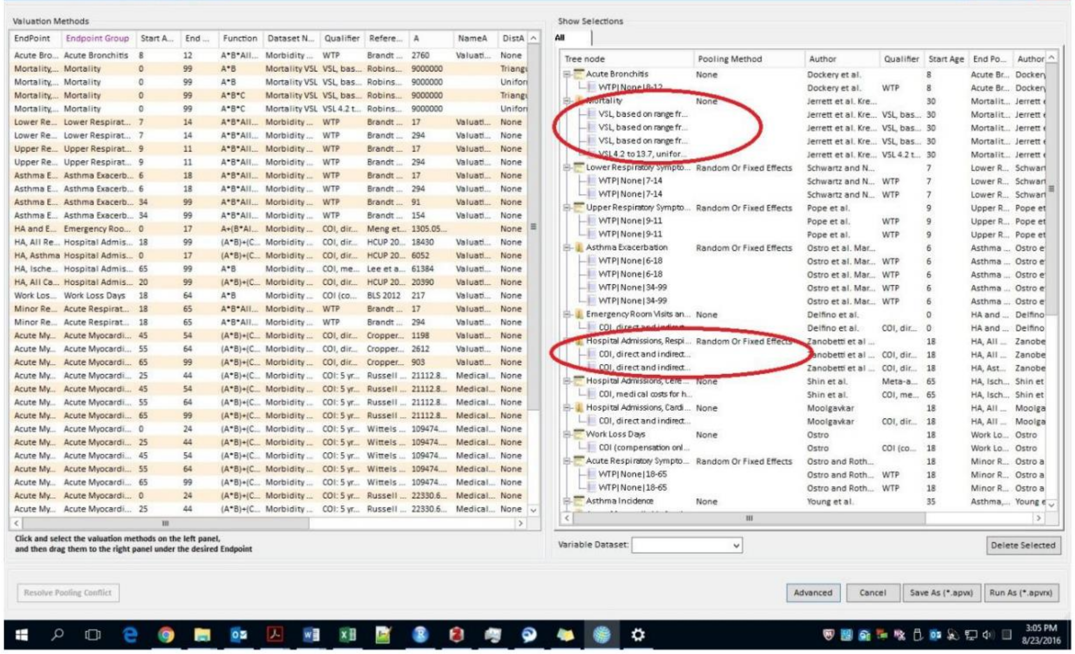
EndPoint	Endpoint Group	Start A...	End ...	Function	Dataset N...	Qualifier	Refere...	A	NameA	DistA
School Lo...	School Loss Days	5	17	A*B	Morbidity ...	COI (par...	BLS 2012	217	Valuati...	None
Emergenc...	Emergency Roo...	0	17	A*B	Morbidity ...	COI, dir...	Meng et...	623	Valuati...	None
Emergenc...	Emergency Roo...	0	99	A*B	Morbidity ...	COI: Smi...	Smith e...	311.550...	mean m...	Triangul...
Emergenc...	Emergency Roo...	0	99	A*B	Morbidity ...	COI: Sta...	Stanfor...	260.666...	mean m...	Normal
HA, All Re...	Hospital Admis...	18	99	(A*B)+(C...	Morbidity ...	COI, dir...	HCUP 20...	18430	Valuati...	None
HA, Asthma	Hospital Admis...	0	17	(A*B)+(C...	Morbidity ...	COI, dir...	HCUP 20...	6052	Valuati...	None
Minor Re...	Acute Respirat...	18	65	A*B*All...	Morbidity ...	WTP	Brandt ...	17	Valuati...	None
Minor Re...	Acute Respirat...	18	65	A*B*All...	Morbidity ...	WTP	Brandt ...	294	Valuati...	None
Mortality,...	Mortality	0	99	A*B	Mortality VSL	VSL, bas...	Robins...	9000000		Triangul...
Mortality,...	Mortality	0	99	A*B	Mortality VSL	VSL, bas...	Robins...	9000000		Uniform
Mortality,...	Mortality	0	99	A*B*C	Mortality VSL	VSL, bas...	Robins...	9000000		Triangul...
Mortality,...	Mortality	0	99	A*B*C	Mortality VSL	VSL 4.2 t...	Robins...	9000000		Uniform

Click and select the valuation methods on the left panel, and then drag them to the right panel under the desired Endpoint

Tree node	Pooling Method	Author	Qualifier	Start Age
School Loss Days	None	Gilliland et al.	All year....	5
COI (parent's lost time...		Gilliland et al.	COI (par...	5
Emergency Room Visits, R...	Random Or Fixed Effects	Mar and Koenig		0
COI, direct and indirect...		Mar and Koenig	COI, dir...	0
COI: Smith et al. (1997)...		Mar and Koenig	COI: Smi...	0
COI: Stanford et al. (19...		Mar and Koenig	COI: Sta...	0
Hospital Admissions, Respi...	Random Or Fixed Effects	Katsouyanni et ...	Summer...	65
COI, direct and indirect...		Katsouyanni et ...	COI, dir...	65
COI, direct and indirect...		Katsouyanni et ...	COI, dir...	65
Acute Respiratory Sympto...	Random Or Fixed Effects	Ostro and Roth...	8-hour ...	18
WTP| None|18-65		Ostro and Roth...	WTP	18
WTP| None|10-65		Ostro and Roth...	WTP	18
Mortality	None	Bell et al.		0
VSL, based on range fr...		Bell et al.	VSL, bas...	0
VSL, based on range fr...		Bell et al.	VSL, bas...	0
VSL, based on range fr...		Bell et al.	VSL, bas...	0
VSL4.2 to 13.7, unifor...		Bell et al.	VSL 4.2 t...	0

Variable Dataset:


Incidence Pooling and Aggregation
Available Incidence Results
Filter Dataset
Filter Endpoint Group
Filter
Groups
View: Details
Select study fields
Add Selected
Check HIF Changes
Select Pooling Methods
Pooling Window Name: All
Add
Delete
Show Tile
Pooling Window Number: 1
Target Grid Type: SC4kgrid
Hospital Admissions, Respi... Sum Independent
Delete Selected
Condensed View
Advanced
Cancel
Next
3:06 PM
8/23/2016


Select Valuation Methods, Pooling and Aggregation
Valuation Methods
Show Selections
Click and select the valuation methods on the left panel,
and then drag them to the right panel under the desired Endpoint
Variable Dataset:
Delete Selected
Resolve Pooling Conflict
Advanced
Cancel
Save As (*.apvx)
Run As (*.apvrx)
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FINAL SOCIOECONOMIC REPORT
APPENDIX 4-A

REMI BASELINE ADJUSTMENTS FOR THE 2016 AQMP

MARCH 2017

Introduction

The 2016 AQMP uses SCAG's 2016 Growth Forecast of jobs, population, output, and other socioeconomic variables as inputs for baseline emissions inventories. To simulate the potential socioeconomic impacts of air pollution control policies, SCAQMD staff use the Regional Economic Models Inc. (REMI) model, which is embedded with its own demographic and economic forecasts. The REMI jobs and population projections are consistent with SCAG at the national level, but differ for the four-county region of Los Angeles, Orange, Riverside, and San Bernardino. For consistency with other AQMP analyses, the sub-county jobs and population forecasts by SCAG for the four-county region are used to adjust and update the REMI baseline forecast for the 2016 AQMP socioeconomic impact assessment. The following sections describe the data and methods used to accomplish the updates in the REMI model, as well as the updated results and any potential implications due to the updates performed.

REMI Baseline Update: Background and Assessment

A 1992 audit of the SCAQMD's socioeconomic analysis methods by Massachusetts Institute of Technology (MIT) recommended further evaluation of the inconsistency between the REMI and SCAG forecasts and the method used to resolve it (Polenske et al. 1992). The biggest source of inconsistency comes from the use of different jobs data for the forecast, where SCAG relies on the Bureau of Labor Statistics (BLS), REMI uses data from the Bureau of Economic Analysis (BEA). The MIT report observed that job impacts predicted by the model could differ significantly between the default REMI and the adjusted REMI models and that this was undesirable. The suggestions offered were: (1) use the default version of REMI model if legally permissible, (2) if SCAG data best suits SCAQMD's needs, negotiate with REMI for a model based on BLS data if feasible, and (3) if the adjusted REMI model is used, the issue of differing job impacts would need to be considered during analysis.

Following the MIT audit, SCAQMD staff chose option (3) and commissioned a study from the Center for the Continuing Study of the California Economy (CCSCE) to determine the sources of inconsistency between these forecasts (Levy 1994). A three-step process was recommended to ensure consistency between REMI and SCAG forecasts: (1) they should use the same U.S. projections for population and jobs, (2) they should use the same birth rates by age cohort; and (3) they should use similar rates of growth for jobs projections. Since the completion of the CCSCE report, REMI and SCAG forecasts have converged in the data sources used for their respective national projections: the BLS Employment Outlook was primarily used for national job projections, and the U.S. Census Bureau's national population projections was the basis for national population projections (REMI 2015a). As with the most recent AQMP socioeconomic reports (Lieu, Dabirian, and Kwon 2007; Lieu, Dabirian, and Hunter 2012), it was determined by SCAQMD staff that no further adjustment to the REMI U.S. forecast is needed.

In this report, SCAQMD staff took the recommendations by both MIT and CCSCE into consideration when conducting an update of the REMI model baseline (i.e., "Regional Control") with SCAG jobs and population forecasts. As described in detail in the following sections, staff found that the REMI employment update achieved similar job growth rates, by county and also for each of the 21 sub-county regions, to SCAG's forecast for the 2016-2031 analysis horizon. We also found that, by using the REMI Population Update function, the REMI population forecast was updated to be identical to SCAG's.

Having achieved the goals set forth by the CCSCE study, staff further investigated, based on the MIT recommendation, the effect of the update on the key parameter of labor productivity, which is the primary parameter in predicting the job impacts of a policy, as described below. Staff found that these updates did not significantly alter labor productivity parameters from the REMI default values; the values changed by less than one percent for the majority of sectors. Based on these findings, staff concluded that the updated REMI model, which was used for the socioeconomic analysis of the 2016 AQMP, acceptably reflected the population and job growth rates forecasted by SCAG. Furthermore, the update did not result in significant changes to the key model parameter of labor productivity, and thus job impact predictions are not expected to differ significantly from what would have been predicted using the default REMI model.

Employment Baseline Adjustment

Data

The jobs forecast in the REMI model and that from SCAG differ both in their data sources and their job forecast up to 2031. The REMI model uses jobs data from BEA, supplemented by compensation data from the same source, for its historical job distribution pattern in the 21 sub-county regions contained in the model. For job projections, REMI bases its national forecast on the 2012-2022 Employment Outlook published by the BLS, along with short-term final demand forecast by the Research Seminar in Quantitative Economics (RSQE). The national forecast is then converted to regional forecasts using historical patterns (REMI 2015a). In comparison, SCAG's jobs forecast is based on data published by the California Employment Development Department (EDD) and the BLS. The base year of SCAG's forecast is 2012. The 2012 job counts is benchmarked to the corresponding historical data in the Current Employment Statistics (CES), and the forecasts for all future years were projected based on a shift-share calculation of national jobs forecasts and refined by inputs provided to SCAG by their local jurisdictions.

There are several differences between the BEA and the EDD/BLS CES data. The BEA jobs data uses additional data sources to estimate jobs in the farm sector, private households, private schools, and other sectors such as railroad operations. The BEA data also include federal military jobs and estimates of self-employment based on tax records. In contrast, the BLS data report only civilian payroll jobs. For transportation modeling purposes, SCAG arrived at its total jobs projections by adding self-employment by sector based on the American Community Survey's Public Use Microdata Samples (ACS PUMS). This method results in much lower estimates of the self-employed than reported in the BEA data, as indicated by a comparison of the 2012 data.

Method

Based on the 2016 Final RTP/SCS (SCAG 2016), SCAG staff provided forecasted job counts by sector for each of the 21 sub-county regions used within the REMI model, for 11 years between 2016 and 2031, in addition to the 2012 base year.[1] The provided data were based on a conversion from SCAG's jobs forecast, which was for 13 industry sectors by Transportation Analysis Zone (TAZ),[2] to the REMI 70-sector model by 21 sub-county regions that was customized for the SCAQMD. The conversion was performed in consultation with SCAQMD staff so that the industry sectors and geographical boundaries are aligned with

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[1] The years of jobs and population data provided are 2012, 2016-2023, 2025, 2026, and 2031. The base year of 2012 was used in the analysis for both the 2016 AQMP and the 2016 RTP/SCS. Other years, except 2016, are the milestone years for air quality attainment demonstration.

[2] TAZs are generally equivalent to census block groups, and there are a total 11,267 TAZs in all of the SCAG counties except Catalina Island.

those in the REMI model. As part of this conversion, SCAG provided a forecast of the Public Administration sector (NAICS 92), which included federal civilian jobs,[3] local and state government jobs, as well as public school jobs. In the REMI model, however, this sector has two separate categories for federal civilian jobs and local and state government jobs, with public school jobs included within the latter category. In order to obtain an applicable growth rate for the REMI model, the Public Administration job counts provided by SCAG was allocated into federal civilian and state and local government categories based on the relative share of jobs annually as implied by the REMI default forecast. Military and private household jobs forecasts were not provided by SCAG; therefore, SCAQMD staff used the default forecast in REMI. Finally, for those years that are missing from the provided forecast, linear interpolation was used to estimate job counts for these in-between years.

From these jobs data, the yearly growth rate was calculated between 2013 and 2031 for each sub-county and each industry sector. These SCAG job growth rates are then multiplied by the corresponding REMI job counts in 2013, the last year of historical data in the REMI model. This results in a jobs forecast which begins with REMI's base-year job counts in 2013, and grows at the rate forecasted by SCAG. This adjusted jobs forecast is entered into the REMI model using the Employment Update function. As illustrated in Figure 4A-3, the overall growth rate is nearly identical between the SCAG and the adjusted REMI forecasts. At the same time, the SCAG, and hence the adjusted REMI, job growth is considerably more optimistic than the default REMI forecast. By 2031, the difference in the adjusted and default levels of overall job counts in REMI reaches 15 percentage points.

It should be noted that there are several technical constraints to directly applying SCAG's projected job counts in REMI's Employment Update function. First, there are large differences in estimates of self-employment between those obtained from ACS PUMS and those from BEA. Secondly, regional allocation of jobs from aggregation of SCAG's TAZs and REMI's method may differ. These resulted in significant differences in the job counts between REMI and SCAG forecasts. These large differences caused errors in the REMI model when SCAG job counts were directly used in the Employment Update function. The job growth rate method adopted here follows what was done in the previous AQMP (Lieu, Dabirian, and Hunter 2012), but is enhanced to include detailed growth rates by 21 sub-county regions and 70 industry sectors based on statistics directly projected by SCAG. Additionally, growth rates were calculated annually instead of for five-year periods.

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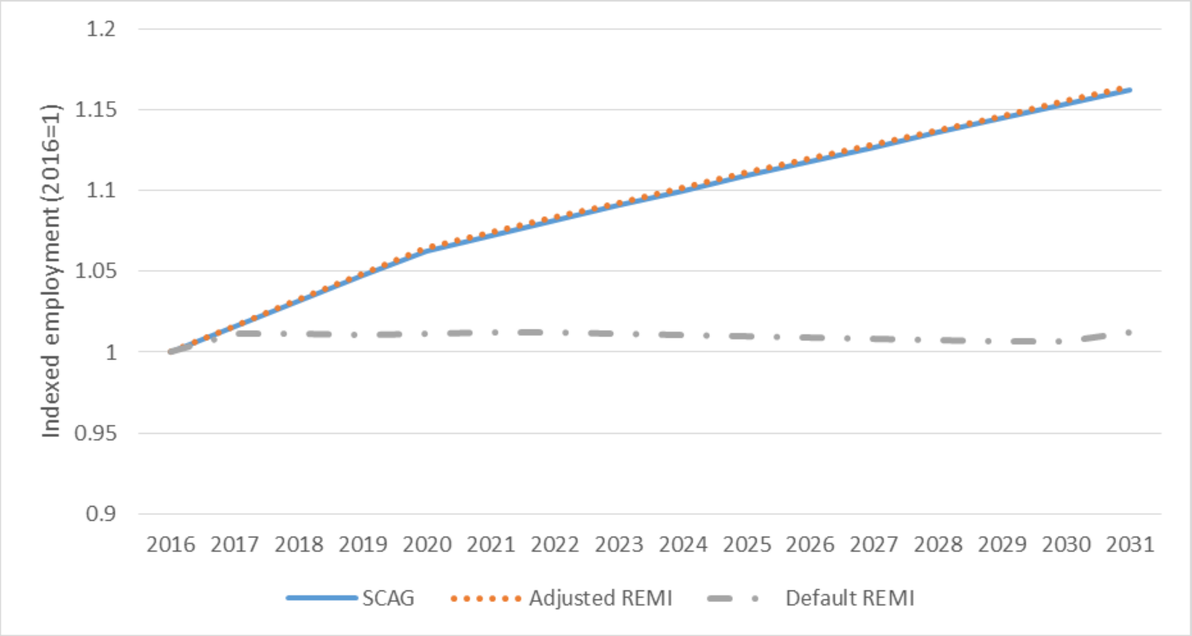
[3] Post office workers (NAICS 491) are also included here.

FIGURE 4A-3: JOB GROWTH, FOUR-COUNTY REGION, 2016-2031



Results and Implications

The 2016-2031 job growth rates by county and by sector can be found in Tables 4A-1 and 4A-2, respectively. On average, the SCAG job growth rate is greater than that of the REMI default rate over the 2016-2031 time period. While SCAG projected the four-county region to grow at an average annual rate of 0.9 percent, the REMI defaults forecasted a mere 0.1 percent. Examining Table 4A-2, it is also observed that the REMI default jobs forecast differs from SCAG's projections by industry sector, and significantly so for a number of sectors such as telecommunications and apparel manufacturing sectors. The adjusted REMI baseline forecast of jobs more closely reflects the SCAG-projected rates of growth for most sectors.

TABLE 4A-1: AVERAGE ANNUAL JOB GROWTH RATES BY COUNTY, 2016-2031

County	Default REMI	SCAG	Adjusted REMI
Los Angeles	0.0%	0.7%	0.7%
Orange	0.1%	0.8%	0.8%
Riverside	0.3%	2.0%	2.0%
San Bernardino	0.1%	1.3%	1.5%
Four-county region	**0.1%**	**0.9%**	**1.0%**

TABLE 4A-2: AVERAGE ANNUAL JOB GROWTH RATES BY INDUSTRY FOR THE FOUR-COUNTY REGION, 2016-2031

Industry	Default REMI	SCAG	Adjusted REMI
Utilities	-2.1%	0.9%	0.8%
Construction	1.8%	1.9%	1.9%
Wholesale trade	-0.4%	0.9%	0.8%
Professional, scientific, and technical services	0.9%	1.1%	1.1%
Management of companies and enterprises	-1.2%	1.0%	1.0%
Educational services	0.2%	1.0%	1.0%
Agriculture and forestry support activities	-0.9%	0.2%	0.0%
Oil and gas extraction	0.7%	0.0%	0.0%
Mining (except oil and gas)	0.2%	0.0%	0.0%
Support activities for mining	1.5%	0.0%	-0.1%
Food manufacturing	-0.6%	0.1%	0.1%
Beverage and tobacco product manufacturing	-0.4%	0.1%	0.4%
Wood product manufacturing	0.3%	0.1%	0.1%
Paper manufacturing	-1.6%	-0.2%	-0.4%
Printing and related support activities	-1.7%	0.1%	0.1%
Petroleum and coal products manufacturing	-1.2%	-0.1%	-0.3%
Chemical manufacturing	-1.9%	-0.3%	-0.1%
Plastics and rubber product manufacturing	-1.9%	-0.2%	-0.3%
Nonmetallic mineral product manufacturing	0.8%	0.1%	0.0%
Primary metal manufacturing	-2.4%	-0.1%	0.1%
Fabricated metal product manufacturing	-0.5%	-0.2%	-0.2%
Machinery manufacturing	-2.1%	-0.1%	-0.2%
Computer and electronic product manufacturing	-1.2%	-0.3%	-0.3%
Electrical equipment and appliance manufacturing	-2.4%	-0.3%	-0.3%
Furniture and related product manufacturing	-0.4%	0.1%	0.0%
Miscellaneous manufacturing	-2.5%	-0.1%	-0.1%
Air transportation	-2.7%	0.2%	0.3%
Rail transportation	-1.4%	0.9%	1.7%
Water transportation	0.5%	0.4%	0.8%
Truck transportation	-0.4%	0.7%	0.7%
Transit and ground passenger transportation	0.0%	0.7%	0.6%
Pipeline transportation	-2.9%	0.7%	0.4%
Couriers and messengers	-2.3%	0.7%	0.9%
Warehousing and storage	0.4%	0.8%	1.5%
Publishing industries, except Internet	-0.8%	0.8%	0.7%
Motion picture and sound recording industries	-1.0%	0.5%	0.3%
Broadcasting, except Internet	-0.8%	0.4%	0.2%
Telecommunications	-2.3%	1.0%	1.2%
Securities, commodity contracts, investments	-0.1%	0.8%	0.7%

TABLE 4A-2: AVERAGE ANNUAL JOB GROWTH RATES BY INDUSTRY FOR THE FOUR-COUNTY REGION, 2016-2031 (CONT'D)

Industry	Default REMI	SCAG	Adjusted REMI
Insurance carriers and related activities	0.0%	0.6%	0.7%
Real estate	0.0%	0.6%	0.8%
Administrative and support services	0.6%	1.3%	1.3%
Waste management and remediation services	0.0%	1.6%	1.5%
Ambulatory health care services	1.1%	1.5%	1.5%
Hospitals	1.2%	0.9%	0.9%
Nursing and residential care facilities	0.7%	1.2%	1.1%
Social assistance	1.0%	1.6%	1.5%
Performing arts and spectator sports	-0.6%	0.6%	0.5%
Museums, historical sites, zoos, and parks	0.8%	0.8%	0.7%
Amusement, gambling, and recreation	0.2%	0.8%	1.3%
Accommodation	0.2%	0.7%	0.7%
Food services and drinking places	-0.1%	0.7%	0.7%
Repair and maintenance	-0.6%	1.1%	1.1%
Personal and laundry services	-0.6%	0.9%	0.9%
Membership associations and organizations	-0.3%	0.8%	0.9%
Forestry and logging; Fishing, hunting, and trapping	-0.8%	0.3%	-1.4%
Textile mills; Textile product mills	-2.8%	-0.1%	0.0%
Apparel manufacturing; Leather and allied product manufacturing	-4.1%	-0.1%	-0.1%
Motor vehicles, bodies and trailers, and parts manufacturing	-0.6%	0.2%	-0.1%
Other transportation equipment manufacturing	-1.7%	-0.4%	0.0%
Retail trade	-0.4%	0.9%	-0.6%
Scenic and sightseeing transportation; Support activities for transportation	0.1%	0.4%	0.8%
Internet publishing and broadcasting; ISPs, search portals, and data processing; Other information services	-1.6%	0.7%	0.2%
Monetary authorities - central bank; Credit intermediation and related activities; Funds, trusts, & other financial vehicles	-0.9%	0.7%	0.7%
Rental and leasing services; Lessors of nonfinancial intangible assets	0.4%	1.0%	1.1%

Updating the jobs forecast in REMI not only changes job counts, it may also change the output and the labor productivity (measured in $/job), the latter of which is a major parameter that affects a policy's job impact modeled in REMI. The labor productivity is determined according to the simplified production function below:[4]

$$Y = LP * E, \qquad (1)$$

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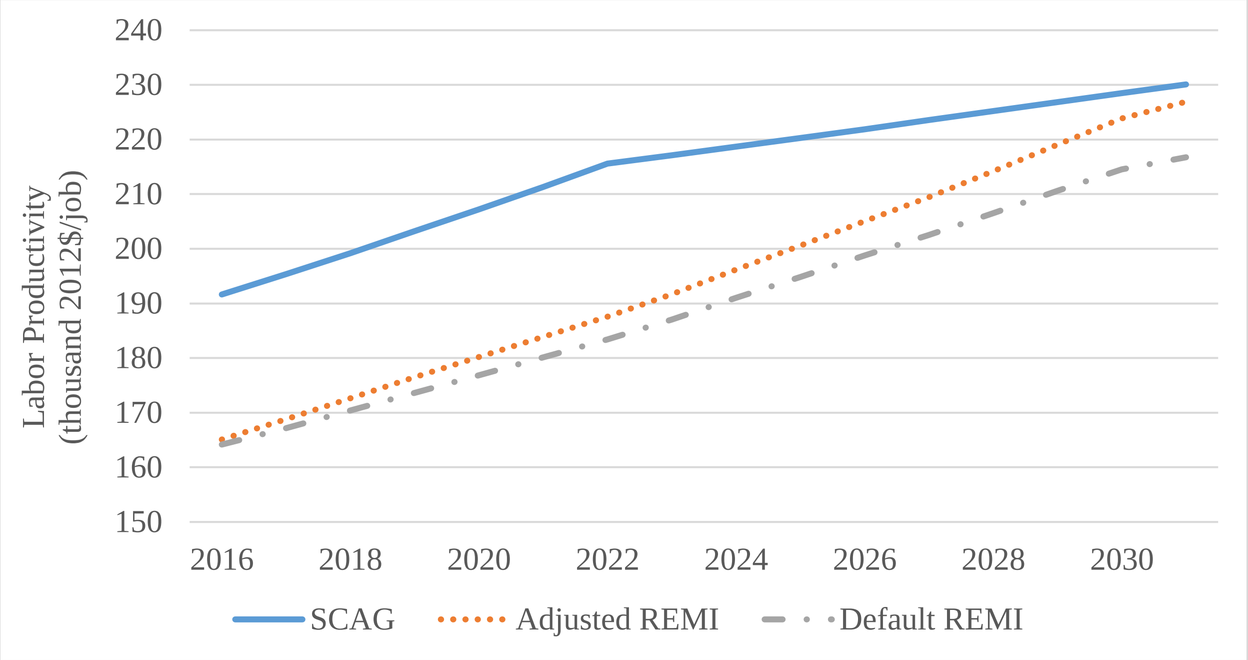
[4] This is the inverse of a simplified version of equation 2-5 from PI+ v1.7 Model Equations (REMI 2015c).

where Y is output in dollars, LP is the labor productivity, and E is the job counts. According to REMI technical staff, the Employment Update function changes E from its REMI defaults to an adjusted E' for every time period so that the period-to-period change in E' would reflect SCAG's growth rate, and an algorithm concurrently changes Y. The percent change in Y is less than the percent change in E for some industries and more for others. Therefore, the labor productivity may increase or decrease from the default values in REMI as a result of this employment update. Any difference in labor productivity as a result of this employment update is shown in Figure 4A-4. It can be seen that the difference is the largest in years further into the future. SCAQMD staff empirically tested the correlation between jobs and output changes for year 2031 and found that, on average, the ratio of the percentage change in output and percentage change in job counts was approximately one, which indicated that, on average, the labor productivity remained close to the REMI defaults and the divergence in labor productivity in later years was driven mainly by a few outliers. The by-sector percentage changes in labor productivity from default REMI to adjusted REMI in 2031 are shown in Table 4A-3.

FIGURE 4A-4: LABOR PRODUCTIVITY, 2016-2031 FOR THE FOUR-COUNTY REGION



It is important to note that, in Figure 4A-4, the labor productivity shown as the "Adjusted REMI", while on average is close in value to "Default REMI," is generally lower than the labor productivity that SCAG uses to generate forecasted output for the purpose of the 2016 AQMP baseline emission inventory. REMI does not provide a function that allows users to update both job counts and labor productivity. Even if such function exists, however, the labor productivities used by SCAG may not be directly used to replace REMI labor productivities. This is because labor productivity is calculated as output per job, and as discussed above (Equation 1), SCAG and REMI differ greatly in their employment definitions, which result in large differences in the numerator of labor productivity calculation.

TABLE 4A-3: CHANGES IN LABOR PRODUCTIVITY FROM DEFAULT REMI TO ADJUSTED REMI IN 2031 BY INDUSTRY FOR THE FOUR-COUNTY REGION

Industry	% Change	Direction
Monetary authorities – central bank; Credit intermediation and related activities; Funds, trusts, & other financial vehicles	6.3%	(+)
Amusement, gambling, and recreation	5.5%	(+)
Nonmetallic mineral product manufacturing	5.0%	(-)
Pipeline transportation	4.4%	(-)
Publishing industries, except Internet	3.6%	(-)
Mining (except oil and gas)	3.3%	(-)
Forestry and logging; Fishing, hunting, and trapping	2.3%	(-)
Beverage and tobacco product manufacturing	1.9%	(-)
Telecommunications	1.6%	(+)
Fabricated metal product manufacturing	1.4%	(-)
Food manufacturing	1.4%	(-)
Warehousing and storage	1.3%	(+)
Utilities	1.2%	(-)
Primary metal manufacturing	1.2%	(-)
Petroleum and coal products manufacturing	1.2%	(-)
Rail transportation	1.1%	(-)
Motor vehicles, bodies and trailers, and parts manufacturing	1.1%	(-)
Chemical manufacturing	1.1%	(-)
Performing arts and spectator sports	1.0%	(-)
Repair and maintenance	1.0%	(-)
Personal and laundry services	1.0%	(-)
Transit and ground passenger transportation	0.9%	(-)
Paper manufacturing	0.8%	(-)
Air transportation	0.8%	(-)
Scenic and sightseeing transportation; Support activities for transportation	0.8%	(-)
Miscellaneous manufacturing	0.8%	(-)
Motion picture and sound recording industries	0.7%	(-)
Waste management and remediation services	0.7%	(-)
Machinery manufacturing	0.6%	(-)
Furniture and related product manufacturing	0.6%	(-)
Insurance carriers and related activities	0.6%	(-)
Rental and leasing services; Lessors of nonfinancial intangible assets	0.6%	(+)
Real estate	0.6%	(+)
Textile mills; Textile product mills	0.6%	(-)
Accommodation	0.6%	(-)
Truck transportation	0.6%	(-)
Wholesale trade	0.5%	(-)
Plastics and rubber product manufacturing	0.5%	(-)
Wood product manufacturing	0.5%	(-)

TABLE 4A-3: CHANGES IN LABOR PRODUCTIVITY FROM DEFAULT REMI TO ADJUSTED REMI IN 2031 BY INDUSTRY FOR THE FOUR-COUNTY REGION (CONT'D)

Industry	% Change	Direction
Printing and related support activities	0.5%	(-)
Oil and gas extraction	0.5%	(-)
Retail trade	0.4%	(-)
Computer and electronic product manufacturing	0.4%	(-)
Electrical equipment and appliance manufacturing	0.4%	(-)
Couriers and messengers	0.4%	(-)
Social assistance	0.4%	(-)
Apparel manufacturing; Leather and allied product manufacturing	0.4%	(-)
Other transportation equipment manufacturing	0.3%	(-)
Ambulatory health care services	0.3%	(+)
Agriculture and forestry support activities	0.3%	(-)
Museums, historical sites, zoos, and parks	0.3%	(-)
Broadcasting, except Internet	0.3%	(-)
Membership associations and organizations	0.3%	(-)
Internet publishing and broadcasting; ISPs, search portals, and data processing; Other information services	0.2%	(-)
Water transportation	0.2%	(-)
Administrative and support services	0.2%	(+)
Support activities for mining	0.2%	(+)
Educational services	0.2%	(-)
Nursing and residential care facilities	0.2%	(-)
Professional, scientific, and technical services	0.1%	(+)
Food services and drinking places	0.1%	(+)
Hospitals	0.1%	(-)
Construction	0.0%	(+)
Securities, commodity contracts, investments	0.0%	(-)
Private households	0.0%	(-)
Management of companies and enterprises	0.0%	(-)

One of the important implications of the changes in the modeled labor productivity is that it affects the magnitude of job impacts that will be simulated by the REMI model. To understand this by examining direct job effects,[5] we can rewrite $Y = LP * E$ as:

$$E = EPV * Y, \qquad (2)$$

where $EPV = LP^{-1}$ is jobs per dollar of output. Totally differentiating the equation above, we obtain:

$$dE = EPV * dY. \qquad (3)$$

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[5] There are also indirect and induced effects.

Therefore, for some change in output, $dY \neq 0$, and some *EPV'>EPV,* then $|dE'| > |dE|$. In other words, a policy that directly or indirectly changes output will have an amplified jobs impact with a greater *EPV* (lower *LP*) and dampened one with a lower EPV (greater LP).

Therefore, when the REMI model with the adjusted baseline results in a lower labor productivity, job impacts will be greater than those that would be predicted by the REMI model with the default baseline. However, differentials in job impacts are minimal for most of the sectors, as labor productivity by sector is mostly very similar between the adjusted and the default REMI baselines. As an example, using the different estimates of labor productivity for the sector of apparel manufacturing and leather and allied products manufacturing in 2031, a policy that causes a $10 million decrease in output, would result in a *direct* effect of 47 predicted jobs foregone using labor productivity values in either adjusted or default REMI baselines.[6]

Population Baseline Adjustment

Data

The default population forecast embedded in the REMI model is based on the demographic assumptions used in the U.S. Census Bureau's national population projections and refined with region-specific parameters, including birth, death, and international migration rates.[7] In comparison, SCAG's sub-county population forecast is based on the projections developed for its 2016 Final RTP/SCS at the TAZ level. SCAG projections considered various data sources, including those published by the U.S. Census Bureau and the California Department of Finance, and refined with local inputs (SCAG 2016). The TAZ-level population projections by gender, race/ethnicity, and age cohort are then aggregated to the 21 sub-county regions and transmitted to the SCAQMD, specifically for the use in the REMI sub-county model which was customized for the South Coast 4-county region (REMI PI$^+$ v1.7.3). It should be noted that both the REMI and SCAG forecast methods relate population growth to job growth; higher job growth levels imply more migration into the region and vice versa.

Method

SCAG staff provided sub-county sub-population projections for 11 years between 2016 and 2031, in addition to the 2012 base year. For years that are missing from the provided forecast, linear interpolation was used to estimate population for these in-between years. The 2014-2031 data were transposed and entered into REMI using its Population Update function, concurrently with the Employment Update described above, to generate an alternative baseline scenario, or "Regional Control," that reflected SCAG's

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[6] Based on labor productivities of $0.220, and $0.221 million/job, respectively. This example is based on fixed input-output relationship, which does not take into account indirect effects. As this industry's intermediate demands change, the job effects of these changes could widen, albeit how slightly, the difference in job impact across and the adjusted and the default REMI baselines.

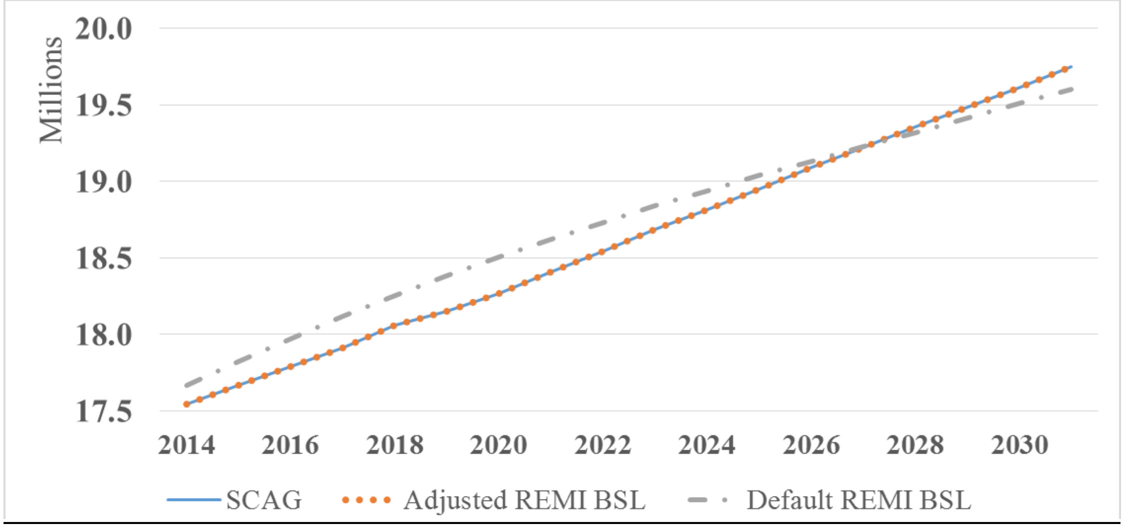
[7] REMI documentation "REMI PI$^+$ v1.7: Demographic Component of the REMI Model" (2015b) and in consultation with REMI technical staff.

projections. The 2014-2031 data were used because the Population Update function allows users to adjust population for the forecast years only, and the last historical year in REMI PI^{+} v1.7.3 is 2013.[8]

Results and Implications

It can be seen from Figure 4A-5 that the adjusted REMI baseline perfectly aligns with the projected total population using SCAG's projections for the 21 sub-county regions. An examination of the discrepancies among all sub-county, sub-population groups showed infinitesimal differences for all years.

FIGURE 4A-5: POPULATION FORECASTS, TOTAL OF 21 SUB-COUNTY REGIONS (2014-2031)



It should be noted that no adjustments of birth rates by age cohort was done prior to entering data into the Population Update. Such adjustments were recommended back in 1994 (Levy 1994) and implemented for earlier AQMPs, largely due to the lack of detailed sub-population data table as needed to populate the REMI forecast. Therefore, cohort birth rates were used to generate the needed table. This is now obviated as SCAG provides the necessary sub-population forecast data to fill the Population Update table in REMI. The birth rates in the adjusted REMI baseline are different than the REMI default rates. This is a result of the Population Update *per se* and may not reflect entirely the birth rates assumed by the SCAG demographic projections.

According to REMI technical staff, the REMI Population Update function treats the initial difference in 2014 between the adjusted and default REMI baselines as a decrease in the number of international migrants. Then, if the implied next-period population by the embedded demographic assumptions does not match up with that projected by SCAG, any remaining differences are again attributed to international migration. The process continues for all subsequent periods until 2031. Because economic behaviors do not differ by migrant status in the REMI model, this update procedure is not expected to cause any

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[8] As REMI solves its model per time period, simulation results for years 2014-2031 will not be affected by maintaining the default REMI baseline for the historical and post-2031 years. (This is in contrast to an intertemporal forward-looking model.)

changes in key parameter values that could influence simulation results, other than a different baseline population for comparison.

FINAL SOCIOECONOMIC REPORT
APPENDIX 4-B

REMI MODELING ASSUMPTIONS

MARCH 2017

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 SCAQMD 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 SCAQMD'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 were originally developed in 1996 and have been updated to reflect the 2010 Census, reflecting the politically, socially, economically, and geographically diversified structure of the Southern California economy.

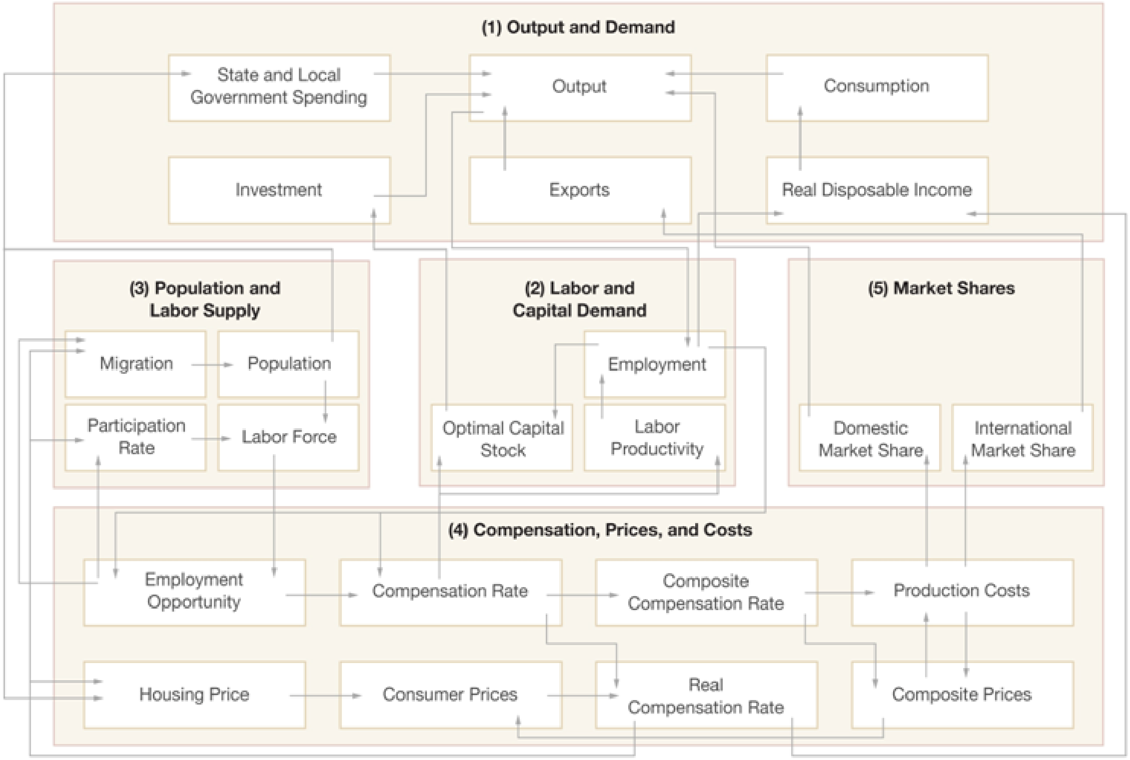
The REMI model for each sub-region is comprised of a five block structure that includes (1) output and demand, (2) labor and capital, (3) population and labor force, (4) compensation, prices and costs, and (5) market shares. These five blocks are interrelated and the linkages are shown in Figure 4B-1. 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 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 2016 AQMP Socioeconomic Assessment

The costs and benefits of the Final 2016 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 vehicles or certain household appliances, the proposed control strategies would also change or widen the range of product choices 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 Final 2016 AQMP were simulated and projected relative to the baseline forecast of the regional economy, which is absent the Final 2016 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 Final 2016 AQMP represent the cost difference between a baseline path and an alternative path as proposed by the Final 2016 AQMP to reach the attainment targets. The total incremental cost includes remaining incremental cost plus incentives. The remaining incremental costs will be incurred by the affected entities, including businesses and consumers, and it is assumed that federal or state governments will be responsible for financing the entire incentive amount. 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).

For the remaining incremental costs, 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 low-emission equipment 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 for the state budget. This is modeled using the "State Government Spending" policy variable which would result in state budget reallocation and affect provision of public services. An additional incentive funding scenario was analyzed where funds would be provided by existing funds from the federal government. For this scenario, incentives were considered as "free money" and not entered into the model.

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 was able to make reasonable assumptions about the geographical location of directly affected industries based on the review of SCAQMD 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

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[1] REMI Policy Insight Plus (PI+) South Coast Sub County Model v1.7.3 (Build 3967). For a full description of the REMI methodology, please refer to the REMI documentation available at http://www.remi.com/products/pi.

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]

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 his/her 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 his/her 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 2015):

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

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

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

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, SCAQMD 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 in Chapter 4 of this report.

TABLE 4B-1: INDUSTRIES/SECTORS INCURRING *VS.* BENEFITTING FROM COMPLIANCE COSTS/SPENDING

Control Measure	Industries Incurring Incremental Costs/Savings	Supplier Industries Benefitting from Additional/Reduced Spending
SCAQMD Stationary Source Measures		
BCM-01 (Commercial Restaurants)	Food services and drinking places	Construction
		Food services and drinking places
		Machinery manufacturing
		Wholesale trade
BCM-04 (Emission Reductions from Manure Operations)	Farm	Farm
BCM-10 (Green waste Operation)	Administrative and support services	Administrative and support services
	Retail trade	Construction
	State and Local Government	Retail trade
	Waste management and remediation services	State and Local Government
	Wholesale trade	Utilities
	Wood product manufacturing	Waste management and remediation services
		Wholesale trade
CMB-01 (Transition to zero and near-zero Technologies)	All Industries	Electrical equipment and appliance manufacturing
	Utilities	Fabricated metal product manufacturing
		Machinery manufacturing
CMB-02 (Water Heaters/Boilers)	All Industries	Construction
		Machinery manufacturing

TABLE 4B-1: INDUSTRIES/SECTORS INCURRING *VS.* BENEFITTING FROM COMPLIANCE COSTS/SPENDING (CONT'D)

Control Measure	Industries Incurring Incremental Costs/Savings	Supplier Industries Benefitting from Additional/Reduced Spending
CMB-03 (Non-Ref Flares)	Ambulatory health care services	Chemical manufacturing
	Beverage and tobacco product manufacturing	
	Food manufacturing	
	Oil and gas extraction	
	Pipeline transportation	
	Utilities	
	Waste management and remediation services	
CMB-04 (Restaurant Burners)	Food services and drinking places	Machinery manufacturing
CMB-05 (RECLAIM Refinery) CMB-05 (RECLAIM Refinery) Cont.	Petroleum and coal products manufacturing Petroleum and coal products manufacturing	Chemical manufacturing
		Construction
		Fabricated metal product manufacturing
		Machinery manufacturing
		Professional, scientific, and technical services
		Utilities
CMB-05 (RECLAIM Non-Refinery)	Chemical manufacturing	Chemical manufacturing
	Nonmetallic mineral product manufacturing	Construction
	Oil and gas extraction	Machinery manufacturing
	Paper manufacturing	Professional, scientific, and technical services
	Primary metal manufacturing	Utilities
	Scenic and sightseeing transportation; Support activities for transportation	
	Utilities	
CTS-01 (Coatings, Solvents, Adhesives, and Lubricants)	Construction	Chemical manufacturing
ECC-03 (Building Efficiency)	Consumers	Machinery manufacturing
		Utilities
FUG-01 (Leak Detections and Repairs)	Oil and gas extraction	Computer and electronic product manufacturing
	Petroleum and coal products manufacturing	Fabricated metal product manufacturing
		Support activities for mining

TABLE 4B-1: INDUSTRIES/SECTORS INCURRING *VS.* BENEFITTING FROM COMPLIANCE COSTS/SPENDING (CONT'D)

Control Measure	Industries Incurring Incremental Costs/Savings	Supplier Industries Benefitting from Additional/Reduced Spending
SCAQMD Mobile Sources		
MOB-10 (SOON Program)	Construction	Machinery manufacturing
		Wholesale trade
MOB-11 (Extended Exchange Program)	Administrative and support services	Machinery manufacturing
MOB-14 (Incentives Program)	Rail transportation	Chemical manufacturing
	Scenic and sightseeing transportation; Support activities for transportation	Machinery manufacturing
	Transit and ground passenger transportation	Motor vehicles, bodies and trailers, and parts manufacturing
	Truck transportation	Retail trade
		Wholesale trade
CARB's Measures		
ORLD-01 (Advanced Clean Cars 2)	Consumer	Motor vehicles, bodies and trailers, and parts manufacturing
		Repair and maintenance
		Utilities
ORHD-02 Low NOx Engine Standard - California Action	Truck transportation	Motor vehicles, bodies and trailers, and parts manufacturing
ORHD-02 Low NOx Engine Standard - Federal Action	Truck transportation	Motor vehicles, bodies and trailers, and parts manufacturing
ORHD-04 Advanced Clean Transit	Transit and ground passenger transportation	Chemical manufacturing
		Electrical equipment and appliance manufacturing
		Motor vehicles, bodies and trailers, and parts manufacturing
		Oil and gas extraction
		Utilities
ORHD-05 Last Mile Delivery	Couriers and messengers	Machinery manufacturing
	Truck transportation	
ORHD-09 Further Deployment: On-Road Heavy Duty	Truck transportation	Motor vehicles, bodies and trailers, and parts manufacturing

TABLE 4B-1: INDUSTRIES/SECTORS INCURRING *VS.* BENEFITTING FROM COMPLIANCE COSTS/SPENDING (CONT'D)

Control Measure	Industries Incurring Incremental Costs/Savings	Supplier Industries Benefitting from Additional/Reduced Spending
ORFIS-01 **More Stringent National Locomotive Emission Standards**	Rail transportation	Other transportation equipment manufacturing
		Repair and maintenance
		Retail trade
ORFIS-02 **Tier 4 Vessel Standard**	Water transportation	Other transportation equipment manufacturing
		Repair and maintenance
ORFIS-04 **At-Berth Regulation Amendments**	Water transportation	Other transportation equipment manufacturing
ORFIS-05 **Further Deployment: Federal and International**	Air transportation	Chemical manufacturing
	Rail transportation	Machinery manufacturing
	Water transportation	Other transportation equipment manufacturing
OFFS-01 **Zero-Emission Off-Road Forklift Regulation Phase I**	Food manufacturing	Machinery manufacturing
	Rental and leasing services; Lessors of nonfinancial intangible assets	Repair and maintenance
	Truck transportation Water Transportation	Retail trade
	Wholesale trade	Utilities
OFFS-04 **Zero-Emission Airport Ground Support Equipment**	Air transportation	Construction
	Scenic and sightseeing transportation; Support activities for transportation	Machinery manufacturing
OFFS-05 **Small Off-Road Engines**	Consumers	Machinery manufacturing
		Retail trade
		Utilities
OFFS-07 **Low-Emission Diesel**	Rail transportation	Food manufacturing
	Scenic and sightseeing transportation; Support activities for transportation	Wood product manufacturing
OFFS-08 **SCAQMD Further Deployment: Off-road Equipment**	Administrative and support services	Chemical manufacturing
	Rail transportation	Machinery manufacturing
	Truck transportation	Motor vehicles, bodies and trailers, and parts manufacturing
	Administrative and support services	Oil and gas extraction
CPP-01 **Consumer Product Program**	Consumer	Chemical manufacturing

Table 4B-2 presents the nationwide median weekly wage rates for 95 occupations obtained from the 2014 Bureau of Labor Statistics (BLS) Current Population Survey (CPS), Employment and Earnings. The wage rates are ranked in ascending order, and then divided into five groups. The range of occupational wage rates are listed in Table 4-6 of Chapter 4.

TABLE 4B-2: EARNINGS BY OCCUPATIONAL WAGE GROUP BY MEDIAN WEEKLY EARNINGS

Quintile	Occupational Title	Median Weekly Earnings
1	Media and communication equipment workers	$398
1	Nursing, psychiatric, and home health aides	$457
1	Occupational therapy and physical therapist assistants and aides	$457
1	Other healthcare support occupations	$460
1	Cooks and food preparation workers	$398
1	Food and beverage serving workers	$424
1	Other food preparation and serving related workers	$385
1	Building cleaning and pest control workers	$467
1	Grounds maintenance workers	$445
1	Entertainment attendants and related workers	$361
1	Personal appearance workers	$480
1	Other personal care and service workers	$431
1	Supervisors of farming, fishing, and forestry workers	$448
1	Agricultural workers	$418
1	Fishing and hunting workers	$448
1	Forest, conservation, and logging workers	$448
1	Other construction and related workers	$461
1	Textile, apparel, and furnishings workers	$250
1	Other transportation workers	$236
2	Life, physical, and social science technicians	$571
2	Other education, training, and library occupations	$582
2	Other protective service workers	$534
2	Supervisors of food preparation and serving workers	$529
2	Animal care and service workers	$524
2	Funeral service workers	$481
2	Baggage porters, bellhops, and concierges; Tour and travel guides	$481
2	Retail sales workers	$516
2	Information and record clerks	$603
2	Other office and administrative support workers	$611
2	Helpers, construction trades	$566
2	Extraction workers	$596
2	Assemblers and fabricators	$525

TABLE 4B-2: EARNINGS BY OCCUPATIONAL WAGE GROUP BY MEDIAN WEEKLY EARNINGS (CONT'D)

Quintile	Occupational Title	Median Weekly Earnings
2	Food processing workers	$509
2	Printing workers	$583
2	Plant and system operators	$573
2	Other production occupations	$555
2	Rail transportation workers	$619
2	Material moving workers	$486
3	Social scientists and related workers	$640
3	Religious workers	$767
3	Librarians, curators, and archivists	$685
3	Entertainers and performers, sports and related workers	$763
3	Supervisors of building and grounds cleaning, maintenance workers	$684
3	Supervisors of personal care and service workers	$687
3	Other sales and related workers	$659
3	Communications equipment operators	$638
3	Financial clerks	$624
3	Material recording, scheduling, dispatching, and distributing workers	$623
3	Secretaries and administrative assistants	$681
3	Construction trades workers	$680
3	Electrical and electronic equipment mechanics, installers, and repairers	$706
3	Vehicle and mobile equipment mechanics, installers, and repairers	$737
3	Other installation, maintenance, and repair occupations	$761
3	Metal workers and plastic workers	$645
3	Woodworkers	$623
3	Motor vehicle operators	$689
3	Water transportation workers	$620
4	Drafters, engineering technicians, and mapping technicians	$909
4	Life scientists	$960
4	Counselors and Social workers	$864
4	Miscellaneous community and social service specialists	$773
4	Legal support workers	$856
4	Preschool, primary, secondary, and special education school teachers	$935
4	Other teachers and instructors	$905
4	Art and design workers	$969
4	Health technologists and technicians	$768
4	Supervisors of protective service workers	$897

TABLE 4B-2: EARNINGS BY OCCUPATIONAL WAGE GROUP BY MEDIAN WEEKLY EARNINGS (CONT'D)

Quintile	Occupational Title	Median Weekly Earnings
4	Law enforcement workers	$899
4	Supervisors of sales workers	$776
4	Sales representatives, services	$906
4	Supervisors of office and administrative support workers	$772
4	Supervisors of installation, maintenance, and repair workers	$980
4	Supervisors of production workers	$902
4	Supervisors of transportation and material moving workers	$882
4	Military	$904
5	Top executives	$1,729
5	Advertising, marketing, promotions	$1,384
5	Operations specialties managers	$1,320
5	Other management occupations	$1,141
5	Business operations specialists	$1,074
5	Financial specialists	$1,108
5	Computer occupations	$1,367
5	Mathematical science occupations	$1,244
5	Architects, surveyors, and cartographers	$1,016
5	Engineers	$1,384
5	Physical scientists	$1,261
5	Lawyers, judges, and related workers	$1,738
5	Postsecondary teachers	$1,172
5	Media and communication workers	$995
5	Health diagnosing and treating practitioners	$1,267
5	Other healthcare practitioners and technical occupations	$1,065
5	Sales representatives, wholesale and manufacturing	$1,042
5	Supervisors of construction and extraction workers	$990
5	Air transportation workers	$1,131

FINAL SOCIOECONOMIC REPORT
APPENDIX 4-C

COMPETITIVENESS IMPACTS

MARCH 2017

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 2016 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 risks 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 welfare benefits.

Having analyzed the benefits of clean air to the region's population and workforce, this section discusses net competitiveness impacts from the perspective of business operations. The REMI model, used to estimate potential job impacts of the 2016 AQMP, also projects impacts on industry gross domestic product (GDP), cost of production, prices of locally manufactured goods, as well as exports and imports.

Impacts on Industry GDP

Industry GDP is the gross output of an industry less the value of its intermediate inputs. Table 4-8 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 2016 AQMP on industry GDP are largely negative in the beginning years of plan implementation, but then become positive towards the later years. However, the magnitude of these impacts are negligible, with a combined cost/benefit impact of less than one percent for the majority of industries.

TABLE 4C-1: IMPACTS ON INDUSTRY GDP

(Relative to Baseline)

Industry	**Incremental Costs**			**Health Benefits**			**Combined Costs and Benefits**		
	2017	**2023**	**2031**	**2017**	**2023**	**2031**	**2017**	**2023**	**2031**
Forestry, Fishing, Other	-0.07%	-0.05%	0.09%	0.01%	0.07%	0.11%	-0.06%	0.02%	0.19%
Mining, Oil and Gas Extraction	-0.25%	-0.67%	-0.99%	0.01%	0.06%	-0.08%	-0.24%	-0.60%	-1.07%
Utilities	-0.10%	-0.43%	-3.48%	0.02%	0.24%	0.41%	-0.08%	-0.19%	-3.07%
Construction	-0.42%	-0.38%	-0.20%	0.03%	0.36%	0.45%	-0.39%	-0.02%	0.24%
Manufacturing	0.12%	0.20%	0.16%	0.01%	0.08%	0.14%	0.13%	0.28%	0.29%
Wholesale Trade	-0.06%	-0.03%	0.09%	0.01%	0.11%	0.20%	-0.05%	0.08%	0.29%
Retail Trade	-0.12%	-0.08%	0.09%	0.02%	0.20%	0.37%	-0.10%	0.12%	0.46%
Transportation and Warehousing	-0.07%	0.03%	-0.04%	0.01%	0.07%	0.14%	-0.06%	0.10%	0.10%
Information	-0.08%	-0.06%	-0.01%	0.01%	0.07%	0.13%	-0.07%	0.01%	0.12%
Finance and Insurance	-0.10%	-0.06%	0.01%	0.01%	0.06%	0.12%	-0.09%	0.00%	0.13%
Real Estate, Rental, and Leasing	-0.07%	-0.06%	-0.01%	0.01%	0.18%	0.31%	-0.05%	0.12%	0.29%
Professional and Technical Services	-0.10%	-0.09%	-0.04%	0.01%	0.11%	0.19%	-0.09%	0.03%	0.15%
Management of Companies & Entr.	0.01%	0.06%	0.11%	0.01%	0.10%	0.19%	0.02%	0.16%	0.30%
Administrative and Waste Services	-0.13%	-0.02%	0.07%	0.01%	0.14%	0.26%	-0.12%	0.12%	0.33%
Educational Services	-0.09%	-0.07%	0.00%	0.02%	0.22%	0.39%	-0.07%	0.15%	0.39%
Health Care and Social Assistance	-0.11%	-0.09%	-0.01%	0.01%	0.18%	0.39%	-0.10%	0.09%	0.38%
Arts, Entertainment and Recreation	-0.06%	-0.03%	0.02%	0.01%	0.04%	0.07%	-0.05%	0.01%	0.08%
Accommodation and Food Services	-0.10%	-0.11%	-0.07%	0.02%	0.33%	0.61%	-0.08%	0.21%	0.54%
Other Services (ex. Government)	-0.14%	-0.10%	0.07%	0.01%	0.09%	0.19%	-0.13%	0.00%	0.26%

Impacts on Cost of Production

Table 4-9 shows the percent change in cost of production relative to the rest of the United States, as a result of implementing the 2016 AQMP. The impacts associated with incremental costs are mostly negative in 2017 and 2023 when most of government incentives are assumed to occur assisting consumers and industry in reducing the financial burden of acquiring equipment made with zero and near-zero emission technologies. In some cases, especially when large cost-savings from operation and maintenance are anticipated, the assumed incentive amounts could be significant enough to largely offset the incremental cost of capital equipment, thus resulting in an immediate lowering of production costs. Moreover, due to the modeling assumption that no additional revenues would 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. While these incentives are being spent by consumers and industry elsewhere in the economy, much of it is on equipment manufactured outside the region, thus much of the impact occurs outside the region.

The impacts associated with public health benefits mainly increase production costs. By attracting more economic migrants into the region via improved quality of life, the population increase 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 utility sector is projected to experience the highest increase (0.02 percent in 2023 and 0.18 percent in 2031) as a result of the 2016 AQMP, due to the many proposed stationary and mobile source control measures affecting cost and output of the sector including: Advanced Clean Cars 2, Advanced Clean Transit, CMB-01, CMB-05, and ECC-03 (for more details see Appendix 4-B). All the remaining sectors will experience a smaller magnitude of production cost impacts, whether positive or negative, on their costs of production. 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**		
	2017	**2023**	**2031**	**2017**	**2023**	**2031**	**2017**	**2023**	**2031**
Forestry, Fishing, Other	-0.01%	-0.02%	0.00%	0.00%	0.00%	-0.02%	-0.01%	-0.03%	-0.01%
Mining, Oil and Gas Extraction	-0.01%	-0.02%	0.04%	0.00%	0.19%	0.38%	-0.01%	0.17%	0.42%
Utilities	-0.01%	0.02%	0.18%	0.00%	0.11%	0.23%	-0.01%	0.13%	0.41%
Construction	-0.01%	-0.04%	0.01%	0.00%	0.01%	0.00%	-0.01%	-0.03%	0.01%
Manufacturing	-0.01%	-0.02%	0.02%	0.00%	0.01%	0.01%	-0.01%	-0.01%	0.03%
Wholesale Trade	-0.01%	-0.03%	0.00%	0.00%	0.01%	0.02%	-0.01%	-0.02%	0.02%
Retail Trade	-0.01%	-0.04%	0.00%	0.00%	0.03%	0.05%	-0.01%	-0.01%	0.05%
Transportation and Warehousing	-0.03%	0.00%	0.19%	0.00%	0.01%	0.00%	-0.03%	0.00%	0.19%
Information	-0.01%	-0.04%	-0.01%	0.00%	0.03%	0.06%	-0.01%	-0.01%	0.05%
Finance and Insurance	-0.01%	-0.05%	-0.01%	0.00%	0.04%	0.07%	-0.01%	-0.01%	0.06%
Real Estate, Rental, Leasing	-0.01%	-0.06%	-0.01%	0.00%	0.15%	0.29%	-0.01%	0.09%	0.28%
Professional and Technical Services	-0.01%	-0.04%	-0.01%	0.00%	0.00%	-0.01%	-0.01%	-0.04%	-0.02%
Management of Companies and Entr.	-0.01%	-0.04%	0.00%	0.00%	-0.01%	-0.03%	-0.01%	-0.05%	-0.04%
Administrative and Waste Services	-0.07%	-0.33%	-0.22%	0.00%	0.00%	-0.01%	-0.07%	-0.33%	-0.23%
Educational Services	-0.02%	-0.07%	-0.02%	0.00%	0.01%	0.00%	-0.02%	-0.06%	-0.03%
Health Care and Social Assistance	-0.01%	-0.05%	-0.01%	0.00%	0.00%	-0.01%	-0.02%	-0.05%	-0.02%
Arts, Entertainment and Recreation	-0.01%	-0.05%	-0.01%	0.00%	0.05%	0.09%	-0.01%	0.00%	0.08%
Accommodation and Food Services	-0.01%	-0.01%	0.08%	0.00%	0.03%	0.06%	-0.01%	0.02%	0.14%
Other Services (ex. Government)	-0.01%	-0.04%	-0.01%	0.00%	0.03%	0.04%	-0.01%	-0.02%	0.04%

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 2016 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: IMPACTS ON DELIVERED PRICES BY INDUSTRY

(Relative to Baseline)

Industry	**Incremental Costs**			**Health Benefits**			**Combined Costs and Benefits**		
	2017	**2023**	**2031**	**2017**	**2023**	**2031**	**2017**	**2023**	**2031**
Forestry, Fishing, Other	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Mining, Oil and Gas Extraction	0.00%	-0.01%	0.02%	0.00%	0.09%	0.18%	0.00%	0.08%	0.20%
Utilities	-0.01%	0.02%	0.15%	0.00%	0.09%	0.19%	-0.01%	0.11%	0.34%
Construction	-0.01%	-0.03%	0.01%	0.00%	0.01%	0.00%	-0.01%	-0.02%	0.01%
Manufacturing	-0.01%	-0.01%	0.01%	0.00%	0.01%	0.00%	-0.01%	-0.01%	0.02%
Wholesale Trade	-0.01%	-0.03%	0.00%	0.00%	0.01%	0.02%	-0.01%	-0.02%	0.01%
Retail Trade	-0.01%	-0.03%	0.00%	0.00%	0.03%	0.05%	-0.01%	-0.01%	0.05%
Transportation and Warehousing	-0.03%	-0.08%	0.00%	0.00%	0.01%	0.00%	-0.03%	-0.07%	0.00%
Information	-0.01%	-0.03%	-0.01%	0.00%	0.03%	0.06%	-0.01%	0.00%	0.05%
Finance and Insurance	-0.01%	-0.03%	-0.01%	0.00%	0.03%	0.04%	-0.01%	-0.01%	0.04%
Real Estate, Rental, and Leasing	-0.01%	-0.06%	-0.01%	0.00%	0.15%	0.29%	-0.01%	0.09%	0.28%
Professional and Technical Services	-0.01%	-0.04%	-0.01%	0.00%	0.00%	-0.01%	-0.01%	-0.04%	-0.02%
Management of Companies and Entr.	-0.01%	-0.03%	0.00%	0.00%	-0.01%	-0.03%	-0.01%	-0.04%	-0.03%
Administrative and Waste Services	-0.06%	-0.29%	-0.19%	0.00%	0.00%	-0.01%	-0.07%	-0.29%	-0.20%
Educational Services	-0.01%	-0.05%	-0.01%	0.00%	0.00%	0.00%	-0.01%	-0.04%	-0.02%
Health Care and Social Assistance	-0.01%	-0.04%	-0.01%	0.00%	0.00%	0.00%	-0.01%	-0.03%	-0.01%
Arts, Entertainment and Recreation	-0.01%	-0.04%	-0.01%	0.00%	0.04%	0.06%	-0.01%	0.00%	0.05%
Accommodation and Food Services	-0.01%	-0.01%	0.07%	0.00%	0.03%	0.05%	-0.01%	0.02%	0.12%
Other Services (ex. Government)	-0.01%	-0.04%	-0.01%	0.00%	0.03%	0.04%	-0.01%	-0.01%	0.04%

Impacts on Imports and Exports

Table 4-11 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	**2017**		**2023**		**2031**	
Exports	$80	0.01%	$134	0.02%	$19	0.00%
Imports	$2,314	0.35%	$1,893	0.30%	$4,714	0.55%

FINAL SOCIOECONOMIC REPORT
APPENDIX 6-A

ENVIRONMENTAL JUSTICE COMMUNITY SCREENING METHOD

MARCH 2017

The EJ community screening method used in this report was derived from the California Communities Environmental Health Screening Tool (CalEnviroScreen or CES), Version 2.0 (OEHHA 2014). The CES method produced an overall percentile ranking of census tracts within California, based on a formula that combined percentile rankings of numerous sociodemographic and environmental indicators.[1] For the EJ screening analysis included in this report, SCAQMD staff used the same structure of the CES formula, but applied it to census tracts within the Basin and considered alternative EJ definitions which included different sets of indicators as recommended by Industrial Economics, Inc., Levy, and Harper (2016). The general steps and mathematical formula used to produce the overall percentile ranking of census tracts under each alternative EJ definition is described below, which is followed by an illustrative example.

EJ Screening Methodology

The CES method builds upon two categories of indicators: sociodemographic (or "population characteristics") and environmental (or "pollution burden"). Chapter 6 describes the indicators included in each category under the five alternative EJ definitions used, which were also summarized in Table 6-1 of Chapter 6 and reproduced below.

Table 6A-1: Alternative Definitions for EJ Community Designation

Alternative Definition	**Sociodemographic Indicators**		**Environmental Indicators**	
	Income	Other Demographic	Air Quality	Other Environmental
1	Poverty status		PM2.5, toxic cancer risk, ozone	
2	Poverty status	Age, asthma, education, linguistic isolation, low birth weight, unemployment	PM2.5, toxic cancer risk, ozone	
2a	Poverty status	Age, asthma, education, linguistic isolation, low birth weight, unemployment, race/ethnicity	PM2.5, toxic cancer risk, ozone	
3	Poverty status	Age, asthma, education, linguistic isolation, low birth weight, unemployment	PM2.5, toxic cancer risk, ozone	Drinking water, pesticides, toxic releases, traffic, *cleanup sites, groundwater threats, hazardous waste, impaired water bodies, solid waste*
3a	Poverty status	Age, asthma, education, linguistic isolation, low birth weight, unemployment, race/ethnicity	PM2.5, toxic cancer risk, ozone	Drinking water, pesticides, toxic releases, traffic, *cleanup sites, groundwater threats, hazardous waste, impaired water bodies, solid waste*

Note: Indicators shown in *italics* were given half the weight. Other indicators were given a weight of one each.

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[1] See the final report of CES 2.0 for more information, available at http://oehha.ca.gov/media/downloads/report/ces20finalreportupdateoct2014.pdf.

Each step of the calculation is described as follows. The calculation was repeated for each of the five alternative EJ definitions examined.

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

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

Step 3): For each census tract, its average percentile under each of the two categories was scaled, or normalized, by the highest average percentile among all census tracts. The scaled number 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 into the overall EJ screening score. Every census tract within the Basin was percentile ranked again, but now based on the overall screening score. A high score would put 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 tract are ranked among the bottom 99 percent.

Step 5): Depending on the population threshold chosen, if a census tract has an overall score that is high enough to be ranked above the threshold, then it is designated as an EJ area. In this report, the population threshold was set at either top 25 percent or top 50 percent relative to the Basin's population; therefore, a census tract with an overall score ranked among the top 1st to 25th percentile is designated as an EJ area under either threshold.

The CES formula is also mathematically described below. Let the overall EJ screening score for census tract *i* be CES_i, the component score 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 census tracts within the Basin. Then the overall EJ screening score can be written as:

$$CES_i = PB_i \times PC_i,$$

where PB_i and PC_i are the ratios of the average rank of all indicators in the group to the max average rank in the Basin. Mathematically,

$$PB_i = 10 \times \frac{AvgPB_i}{\max\limits_{\mathrm{i}}\{AvgPB_i\}} \; and \; PC_i = 10 \times \frac{AvgPC_i}{\max\limits_{\mathrm{i}}\{AvgPC_i\}},$$

where

$$AvgPB_i = \frac{\sum_j^J E1rank_{i,j} + 0.5\sum_l^L E2rank_{i,l}}{J + 0.5L} \; and \; AvgPC_i = \frac{\sum_k^K Srank_{i,k}}{K},$$

with *J* denoting the set of environmental indicators that measure pollutant exposure, L is the set of environmental indicators that is recognized to contribute less to possible pollution burden than other exposure-related environmental indicators, *K* is the set of sociodemographic indicators, $E1rank_{i,j}$ is the percentile rank of exposure-related environmental indicator *j* for census tract *i*, $E2rank_{i,j}$ is the percentile rank of the half-weighted environmental indicator *j* in census tract *i*, and $Srank_{i,k}$ is the percentile rank of sociodemographic indicator *k* 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 in itself indicate whether a census tract should be designated as an EJ area or not. Therefore, a threshold needs to be chosen to determine an EJ designation for a census tract from the screening score.

EJ Screening Example

Table 6A-1 provides an illustrative example of two census tracts to demonstrate how to use the CES method to calculate the overall EJ screening score and designate EJ area. This example uses two EJ definitions: Alternative Definition 1 that is most akin to SCAQMD's current EJ definition for grant allocation purposes, which focuses on air quality indicators for pollution burden and poverty status for socioeconomic vulnerability; Alternative Definition 3a is comprised of an expansive list of indicators that largely overlaps with the indicators included in CES 2.0.

It is worth noting that the EJ designation for a census tract can be sensitive to both the definition and designation threshold chosen. As shown in the table, under Alternative Definition 1 that includes toxic cancer risk, PM2.5 and ozone concentrations, and poverty rate, Census Tract A is designated as an EJ area because it ranks among the top 50-percent most impacted census tracts. Under the expansive Alternative Definition 3a, however, the same census tract becomes a non-EJ area as it is relatively less impacted than other census tracts according to the additional indicators, whether sociodemographic or environmental. This reduces its overall screening score so much that it falls below either designation threshold. In comparison, Census Tract B is considered more impacted under Alternative Definition 3a than under Alternative Definition 1. Specifically, it ranks among the top 25-percent most impacted census tracts under the former definition, but not so under the latter. This is because Census Tract B has 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.

Table 6A-2: EJ Screening Example

		Census Tract A		Census Tract B	
		Def 1	Def 3a	Def 1	Def 3a
Step 1: Indicator Percentile					
Exposure-Related Environmental Indicators					
PM2.5		33.9	33.9	73.6	73.6
Toxic Cancer Risk		24.6	24.6	92.7	92.7
Ozone		56.9	56.9	25.3	25.3
Drinking water			46.8		70.7
Pesticide			0		0
Toxic Release			18.2		79.0
Traffic			32.5		58.6
Other Environmental Indicators (Half-					
Cleanup Sites			0		82.8
Groundwater Threats			28.9		78.2
Hazardous Waste			29.1		75.3
Impaired Water Bodies			50.4		87.1
Solid Waste			0		70.7
Sociodemographic Indicators					
Poverty		67.6	67.6	41.6	41.6
Age			13.9		59.7
Asthma			41.0		65.7
Education			55.1		55.9
Linguistic Isolation			71.6		46.9
Low Birth Weight			47.8		4.6
Unemployment			44.2		71.2
Percent Minority			38.7		57.3
Step 2: Weighted Average Percentile					
Pollution Burden (PB)		38.5	28.1	63.9	62.8
Population Characteristics (PC)		67.6	47.5	41.6	50.4
Step 3: Component Score					
Max PB		93.0	82.9	93.0	82.9
PB Component Score = (PB/Max PB) x 10		4.1	3.4	6.9	7.6
Max PC		100.0	93.7	100.0	93.7
PC Component Score = (PC/Max PC) x 10		6.8	5.1	4.2	5.4
Step 4: Overall EJ Screening Score					
EJ Score = PB Component x PC Component		27.9	17.2	28.6	40.7
EJ Percentile		55.4	30.9	56.3	80.1
Step 5: EJ Designation					
EJ Designation	50% threshold	EJ	Non-EJ	EJ	EJ
	25% threshold	Non-EJ	Non-EJ	Non-EJ	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.

FINAL SOCIOECONOMIC REPORT
APPENDIX 6-B

DATA AND DETAILED RESULTS OF THE EJ DISTRIBUTIONAL ANALYSIS

MARCH 2017

Health Risk Data

Data used to calculate the summary tables for the "Quantified Public Health Effects and Monetized Benefits in EJ and non-EJ Communities" section (Tables 6-4 to 6-6) were derived from the results presented in Chapter 3 of this report. A description of methodology that was used to estimate public health benefits can be found in Appendix 3-B. The data used in Chapter 6 are based on the projected public health benefits in attainment year 2031.

Data used for the "Evaluating Distributional Impact of the Final 2016 AQMP via Health Risk Inequality Index" section (Tables 6-7 to 6-9) 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. In contrast to Chapter 3, where the changes in pollutant concentrations between the baseline and policy scenario were used to estimate the health impact and corresponding monetized public health benefits, pollution exposure related health risk was estimated and its distribution examined 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 Final 2016 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, which applies an area-weighting approach (RTI International 2015).

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 3447 census tracts in the Basin that are examined. The mortality risk related to PM2.5 and ozone exposure at baseline has an average of 0.168 percent, with a standard deviation of 0.05 percent, implying a coefficient of variation of 0.3. Under the policy scenario, the exposure-related mortality risk has a mean of 0.145 percent and standard deviation of 0.042 percent. At baseline, the morbidity risk of asthma related emergency department visits associated with ozone exposure has a mean of 0.473 percent, with a standard deviation of 0.079 percent. Under the policy scenario, this exposure-related morbidity risk has a mean of 0.436 percent and a standard deviation of 0.074 percent. Both the mean and standard deviation, as well as the quartile statistics, are reduced for all health risk examined as a result of implementing the Final 2016 AQMP. The only statistic that is increased is the interquartile range for morbidity risk of asthma related emergency department visits associated with ozone exposure.

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 and ozone-related mortality risk	Baseline	0.168%	0.050%	0.30	0.168%	0.132%	0.193%	0.062%
	Policy	0.145%	0.042%	0.29	0.145%	0.115%	0.168%	0.053%
PM2.5-related mortality risk	Baseline	0.161%	0.050%	0.31	0.161%	0.125%	0.187%	0.062%
	Policy	0.139%	0.042%	0.30	0.140%	0.109%	0.161%	0.052%
Ozone-related mortality risk	Baseline	0.004%	0.001%	0.26	0.004%	0.003%	0.005%	0.001%
	Policy	0.004%	0.001%	0.25	0.004%	0.003%	0.004%	0.001%
Risk of ozone related Asthma ED Visits	Baseline	0.473%	0.079%	0.17	0.483%	0.423%	0.519%	0.096%
	Policy	0.436%	0.074%	0.17	0.453%	0.378%	0.482%	0.104%

As mentioned in the EJ report by Industrial Economics (2016), there is discussion in the economic literature that it may be problematic to evaluate the inequality index using something that is considered an economic "bad" as compared to an economic "good." For this reason, staff conducted a transformation on health risk using its complement, which is one minus the health risk, and can be described as the percent of the population that is not expected to experience illnesses or premature deaths. 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).

Distributional Analysis Method

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

Comprehensive results of the inequality analysis are provided. Tables 6B-2 through 6B-5 provide results based on the Atkinson and Kolm-Pollack indices (inequality aversion=0.5) for each of the alternative EJ definitions described in Chapter 6. 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. These results show the numerical values from which Table 6-9 in Chapter 6 are based.

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	5.97E-08	3.43E-09	5.95E-08	3.41E-09
	Control	4.13E-08	1.97E-09	4.12E-08	1.97E-09
	Change	-1.8E-08	-1.5E-09	-1.8E-08	-1.4E-09
	% Change	-31%	-42%	-31%	-42%
Def. 1: Top 50%	Baseline	6.01E-08	3.07E-09	5.99E-08	3.06E-09
	Control	4.15E-08	1.80E-09	4.14E-08	1.8E-09
	Change	-1.9E-08	-1.3E-09	-1.9E-08	-1.3E-09
	% Change	-31%	-41%	-31%	-41%
Def. 2: Top 25%	Baseline	5.96E-08	3.60E-09	5.94E-08	3.59E-09
	Control	4.12E-08	2.09E-09	4.11E-08	2.08E-09
	Change	-1.8E-08	-1.5E-09	-1.8E-08	-1.5E-09
	% Change	-31%	-42%	-31%	-42%
Def. 2: Top 50%	Baseline	5.89E-08	4.30E-09	5.87E-08	4.29E-09
	Control	4.07E-08	2.61E-09	4.06E-08	2.6E-09
	Change	-1.8E-08	-1.7E-09	-1.8E-08	-1.7E-09
	% Change	-31%	-39%	-31%	-39%
Def. 3: Top 25%	Baseline	6.01E-08	3.08E-09	5.99E-08	3.07E-09
	Control	4.13E-08	1.99E-09	4.12E-08	1.99E-09
	Change	-1.9E-08	-1.1E-09	-1.9E-08	-1.1E-09
	% Change	-31%	-35%	-31%	-35%
Def. 3: Top 50%	Baseline	5.90E-08	4.16E-09	5.88E-08	4.14E-09
	Control	4.06E-08	2.67E-09	4.05E-08	2.67E-09
	Change	-1.8E-08	-1.5E-09	-1.8E-08	-1.5E-09
	% Change	-31%	-36%	-31%	-36%

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	2.50E-11	1.78E-12	2.50E-11	1.81E-12
	Control	1.89E-11	1.11E-12	1.89E-11	1.1E-12
	Change	-6.1E-12	-6.8E-13	-6.1E-12	-7.1E-13
	% Change	-24%	-38%	-24%	-39%
Def. 1: Top 50%	Baseline	2.46E-11	2.24E-12	2.45E-11	2.21E-12
	Control	1.87E-11	1.38E-12	1.87E-11	1.32E-12
	Change	-5.9E-12	-8.6E-13	-5.9E-12	-8.9E-13
	% Change	-24%	-38%	-24%	-40%
Def. 2: Top 25%	Baseline	2.52E-11	1.59E-12	2.52E-11	1.53E-12
	Control	1.91E-11	8.99E-13	1.91E-11	8.88E-13
	Change	-6.1E-12	-6.9E-13	-6.1E-12	-6.4E-13
	% Change	-24%	-43%	-24%	-42%
Def. 2: Top 50%	Baseline	2.49E-11	1.95E-12	2.49E-11	1.86E-12
	Control	1.90E-11	9.68E-13	1.9E-11	1.03E-12
	Change	-6E-12	-9.8E-13	-5.9E-12	-8.3E-13
	% Change	-24%	-50%	-24%	-45%
Def. 3: Top 25%	Baseline	2.43E-11	2.48E-12	2.42E-11	2.52E-12
	Control	1.84E-11	1.55E-12	1.84E-11	1.56E-12
	Change	-5.8E-12	-9.3E-13	-5.8E-12	-9.6E-13
	% Change	-24%	-37%	-24%	-38%
Def. 3: Top 50%	Baseline	2.33E-11	3.47E-12	2.33E-11	3.43E-12
	Control	1.78E-11	2.13E-12	1.78E-11	2.16E-12
	Change	-5.5E-12	-1.3E-12	-5.5E-12	-1.3E-12
	% Change	-24%	-38%	-24%	-37%

TABLE 6B-4: INEQUALITY INDICES OF PM2.5 AND OZONE-RELATED MORTALITY RISK

		Atkinson		Kolm-Pollack	
Definition	Scenario	Within	Between	Within	Between
Def. 1 : Top 25%	Baseline	6.00E-08	3.32E-09	5.97E-08	3.31E-09
	Control	4.17E-08	1.92E-09	4.16E-08	1.92E-09
	Change	-1.8E-08	-1.4E-09	-1.8E-08	-1.4E-09
	% Change	-30%	-42%	-30%	-42%
Def. 1: Top 50%	Baseline	6.03E-08	2.96E-09	6.01E-08	2.95E-09
	Control	4.19E-08	1.75E-09	4.17E-08	1.74E-09
	Change	-1.8E-08	-1.2E-09	-1.8E-08	-1.2E-09
	% Change	-31%	-41%	-31%	-41%
Def. 2: Top 25%	Baseline	5.98E-08	3.51E-09	5.96E-08	3.5E-09
	Control	4.16E-08	2.05E-09	4.14E-08	2.04E-09
	Change	-1.8E-08	-1.5E-09	-1.8E-08	-1.5E-09
	% Change	-30%	-42%	-30%	-42%
Def. 2: Top 50%	Baseline	5.91E-08	4.19E-09	5.89E-08	4.17E-09
	Control	4.11E-08	2.56E-09	4.09E-08	2.55E-09
	Change	-1.8E-08	-1.6E-09	-1.8E-08	-1.6E-09
	% Change	-31%	-39%	-30%	-39%
Def. 3: Top 25%	Baseline	6.03E-08	2.93E-09	6.01E-08	2.92E-09
	Control	4.17E-08	1.91E-09	4.16E-08	1.9E-09
	Change	-1.9E-08	-1E-09	-1.9E-08	-1E-09
	% Change	-31%	-35%	-31%	-35%
Def. 3: Top 50%	Baseline	5.93E-08	3.95E-09	5.91E-08	3.94E-09
	Control	4.11E-08	2.56E-09	4.09E-08	2.55E-09
	Change	-1.8E-08	-1.4E-09	-1.8E-08	-1.4E-09
	% Change	-31%	-35%	-31%	-35%

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	1.45E-07	1.25E-08	1.43E-07	1.24E-08
	Control	1.25E-07	1.45E-08	1.24E-07	1.44E-08
	Change	-2E-08	2.03E-09	-2E-08	2.02E-09
	% Change	-14%	16%	-14%	16%
Def. 1: Top 50%	Baseline	1.40E-07	1.74E-08	1.38E-07	1.72E-08
	Control	1.20E-07	1.97E-08	1.19E-07	1.95E-08
	Change	-2E-08	2.28E-09	-2E-08	2.27E-09
	% Change	-14%	13%	-14%	13%
Def. 2: Top 25%	Baseline	1.42E-07	1.46E-08	1.41E-07	1.44E-08
	Control	1.23E-07	1.68E-08	1.21E-07	1.66E-08
	Change	-2E-08	2.18E-09	-2E-08	2.17E-09
	% Change	-14%	15%	-14%	15%
Def. 2: Top 50%	Baseline	1.32E-07	2.46E-08	1.31E-07	2.44E-08
	Control	1.12E-07	2.75E-08	1.11E-07	2.72E-08
	Change	-2.1E-08	2.86E-09	-2E-08	2.85E-09
	% Change	-16%	12%	-16%	12%
Def. 3: Top 25%	Baseline	1.51E-07	6.29E-09	1.49E-07	6.23E-09
	Control	1.31E-07	8.29E-09	1.3E-07	8.22E-09
	Change	-2E-08	2E-09	-1.9E-08	1.99E-09
	% Change	-13%	32%	-13%	32%
Def. 3: Top 50%	Baseline	1.48E-07	9.17E-09	1.46E-07	9.08E-09
	Control	1.28E-07	1.14E-08	1.27E-07	1.13E-08
	Change	-2E-08	2.24E-09	-2E-08	2.23E-09
	% Change	-14%	24%	-13%	25%