APPENDIX E

HEALTH BENEFITS METHODOLOGY

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Staff analyzed the cost-savings of the proposed amendments associated with five health outcomes: cardiopulmonary[1] mortality, hospitalizations for cardiovascular[2] illness, hospitalizations for respiratory[3] illness, emergency room (ER) visits for respiratory illness, and ER visits for asthma. These health outcomes were selected because

The U.S. Environmental Protection Agency (U.S. EPA) has identified these as having a *causal* or *likely causal* relationship with exposure to particulate matter (PM) 2.5 (USEPA, 2010c). U.S. EPA examined other health endpoints such as cancer, reproductive and developmental effects, but determined there was only *suggestive* evidence for a relationship between these outcomes and PM exposure, and insufficient data to include these endpoints in the national health assessment analyses routinely performed by U.S. EPA.

U.S. EPA has determined that both long-term and short-term exposure to PM2.5 plays a *causal* role in premature mortality, meaning that a substantial body of scientific evidence shows a relationship between PM2.5 exposure and increased risk of death. This relationship persists when other risk factors such as smoking rates, poverty and other factors are taken into account (USEPA, 2010b). While other mortality endpoints could be analyzed, the strongest evidence exists for cardiopulmonary mortality (CARB, 2010b). The greater scientific certainty for this effect, along with the greater specificity of the endpoint, leads to an effect estimate for cardiopulmonary deaths that is both higher and more precise than that for all-cause mortality (CARB, 2010b).

U.S. EPA has also determined a *causal* relationship between non-mortality cardiovascular effects and short and long-term exposure to PM2.5, and a *likely causal* relationship between non-mortality respiratory effects (including worsening asthma) and short and long-term PM2.5 exposure (USEPA, 2010b). These outcomes lead to hospitalizations and ER visits, and are included in this analysis.

In general, health studies have shown that populations with low socioeconomic standings are more susceptible to health problems from exposure to air pollution (Krewski, 2009; Gwynn, 2001). However, the models currently used by U.S. EPA and the California Air Resources Board (CARB) do not have the granularity to account for this impact. The location and magnitude of projected emission reductions resulting from many proposed regulations are not known with sufficient accuracy to account for socioeconomic impacts, and an attempt to do so would produce uncertainty ranges so large as to make conclusions difficult. CARB acknowledges this limitation.

Individuals who live in high risk areas near major trucking and freight corridors, for example near ports and rail yards, are exposed to higher PM concentrations from heavy-duty (HD) vehicles than the average person. These individuals are at higher risks of developing respiratory impairments as a result of HD vehicle PM emissions,

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[1] Outcomes related to the heart or lungs

[2] Outcomes related to the heart or blood vessels

[3] Respiratory illness such as chronic obstructive pulmonary disease, and respiratory infections

especially those included in the sensitive groups, such as those with low socioeconomic standing mentioned above. Although it is difficult to quantitatively determine the emission benefits in these high-risk areas, the proposed amendments are expected to provide the largest PM emission reductions in regions with the most HD truck traffic.

Table 1 shows the estimated reduction in premature mortality, hospitalizations, and emergency room visits associated with the proposed amendments. Regional emission reductions as a consequence of the proposed amendments were estimated by emission factors, and used in combination with the incidents per ton (IPT) methodology (CARB, 2010a) to estimate avoided health outcomes by air basin. Significant health benefits are expected to be obtained throughout the state, with the majority of benefits coming in the South Coast, San Joaquin Valley, and Bay Area regions.

Table 1: Cumulative Regional and Statewide Avoided Health Impacts from 2019 to 2025 Expected Due to the Proposed Amendments

	Early Mortalities Prevented	Hospitalizations Avoided	ER visits Avoided
Great Basin Valleys	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
Lake County	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
Lake Tahoe	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
Mojave Desert	2 (2 - 3)	0 (0 - 1)	1 (1 - 1)
Mountain Counties	1 (1 - 1)	0 (0 - 0)	0 (0 - 0)
North Central Coast	0 (0 - 1)	0 (0 - 0)	0 (0 - 0)
North Coast	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
Northeast Plateau	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
Sacramento Valley	6 (4 - 7)	1 (0 - 2)	1 (1 - 3)
Salton Sea	3 (2 - 3)	0 (0 - 1)	1 (1 - 1)
San Diego County	7 (5 - 8)	1 (0 - 3)	3 (2 - 4)
San Francisco Bay	12 (10 - 15)	2 (0 - 5)	5 (3 - 7)
San Joaquin Valley	19 (15 - 24)	2 (0 - 6)	8 (5 - 11)
South Central Coast	1 (1 - 2)	0 (0 - 1)	0 (0 - 1)
South Coast	82 (64 - 100)	12 (2 - 27)	35 (22 - 48)
Statewide	134 (104 - 165)	18 (2 - 46)	56 (35 - 76)

*Values in parenthesis represent the 95% confidence interval.

In accordance with U.S. EPA practice, health outcomes are monetized by multiplying incidence by a standard value derived from economic studies (USEPA, 2010a). Discounting was not used for costs in this analysis, and so was also not used for cost-savings to maintain consistent methodology.

The valuation per incident is included in Table 2. The valuation for avoided premature mortality is based on willingness to pay (USEPA, 2000). This value is a statistical construct based on the aggregated dollar amount that a large group of people would be willing to pay for a reduction in their individual risks of dying in a year. This is not an estimate of how much any single individual would be willing to pay to prevent a certain death of any particular person (USEPA, 2017), nor does it consider any specific costs associated with mortality such as hospital expenditures. While the valuation associated with reductions in premature mortality is an important benefit of the proposed amendments, the valuation used to monetize the benefit does not easily lend itself to macroeconomic modeling. The benefits associated with premature mortality are reported here, but is not included in macroeconomic modeling in Appendix D.

Unlike premature mortality valuation, the valuation for avoided hospitalizations and ER visits are based on a combination of typical costs associated with hospitalization and the willingness of surveyed individuals to pay to avoid adverse outcomes that occur when hospitalized. These include hospital charges, post-hospitalization medical care, out-of-pocket expenses, and lost earnings for both individuals and family members, lost recreation value, and lost household production (e.g., valuation of time-losses from inability to maintain the household or provide childcare) (Chestnut, 2006). Because these are most closely associated with specific cost-savings to individuals (and costs to the healthcare system), monetized benefits from avoided hospitalizations and ER visits are included in macroeconomic modeling in Appendix D.

Table 2: Valuation per Incident for Avoided Health Outcomes

Outcome	Cost-Savings per Incident ($2015)
Avoided Premature Deaths	$8,629,716
Avoided Acute Respiratory Hospitalizations	$45,221
Avoided Cardiovascular Hospitalizations	$51,844
Avoided ER Department Visits	$742

Statewide valuation of health benefits were calculated by multiplying the avoided health outcomes by the valuation per incident. The total statewide valuation due to avoided health outcomes between 2019 and 2025 is summarized in Table 3. The spatial distribution of these benefits follow the distribution of emission reductions and avoided health outcomes, therefore most cost savings to individuals will occur in the South Coast and San Joaquin Valley Air Basins.

Table 3: Statewide Valuation from Avoided Health Outcomes between 2019 and 2025 as a Result of the Proposed Amendments

Outcome	Cost-Savings (Million $)
Avoided Premature Deaths	$1,156.4
Avoided Hospitalizations	$0.9
Avoided ER Visits	$0.0

Total Cost-Savings	**$1,157.3**

To estimate the change in health outcomes from changes in emissions due to the proposed amendments, CARB uses the IPT methodology. This methodology quantifies the health benefits of primary and secondary PM2.5 reductions due to regulatory controls. Primary PM2.5 is emitted directly from the source (e.g., the black particles in diesel exhaust). Secondary PM2.5 is formed in the atmosphere as a result of chemical reactions.

This methodology is similar to the methodology developed by U.S. EPA for health benefit estimations (Fann, 2012), but uses California air basin specific relationships between emissions and air quality. The basis of the IPT methodology is the approximately linear relationship which holds between changes in emissions and estimated changes in health outcomes. Therefore, health outcomes are approximately proportional to emissions, and changes in health outcomes from the proposed amendments can be estimated by multiplying changes in emissions by a reference incidence factor, known as the IPT factor.

IPT factors were derived for a reference scenario by identifying the health incidence associated with a PM2.5 source in an air basin, and dividing by the emissions of that PM2.5 source, as in the following equation. This reference scenario is based on 2009 through 2011 average data used in the IPT health analysis, and is not the same as the regulatory business-as-usual. Separate IPT factors were developed for each health endpoint, air basin, and for primary PM2.5 and oxides of nitrogen (NOx) emissions.

$$IPT\ Factor = \frac{Reference\ Incidence\ (\#\ cases)}{Reference\ Emissions\ (tons)}$$

A change in health outcomes from the proposed amendments can then be calculated by multiplying the emission change in a given year by the IPT Factor. Since the total incidence of health outcomes is also proportional to population, the change in health outcomes are additionally scaled by the ratio of the population in a given year to the population in the reference year, which is the 2009 through 2011 average. The equation used to estimate health outcomes is:

$$Health\ Outcome_Y = [Emission\ Change_Y(tons)] * \left[IPT\ Factor\ (\frac{incidents}{ton})\right] * \left[\frac{Population_Y}{Population_R}\right]$$

where, Y is a given year for which the proposed amendments lead to a change in PM2.5 emissions, and R is the reference case. The change in health outcomes is calculated for each health endpoint, air basin, year, and for both primary PM2.5 and NOx emissions. A further description of the methodology, assumptions, and uncertainty follows.

IPT Factors

A detailed description of the methodology used to calculate premature mortality from PM2.5 has been published, and is similar to that used to determine IPT factors (CARB, 2010b). IPT factors for other health endpoints are calculated using similar methodology. Calculating IPT factors requires reference incidence rates, population data, ambient concentrations of PM2.5, and a concentration-response function (CRF) relating changes in PM2.5 exposure to changes in health incidence (CARB, 2010a). The underlying analysis was performed at the census tract level, then aggregated to air basin and statewide results.

Reference incidence rates are the number of cases of death or illness in the exposed population. Incidence rates vary according to age; for instance, an older person is more likely to die or be hospitalized because of heart disease or stroke than a child or young adult. Age-specific incidence rates were taken from the Centers for Disease Control and Prevention Wonder database (CDC, 2018). The CARB methodology divides the population into five-year age brackets up to ages 80-84, and an 85+ age bracket. Thus this analysis reflects differences in vulnerability between different age groups.

Population exposure to PM2.5 was estimated from monitored or modeled concentrations of PM2.5. Consistent with U.S. EPA practice, CARB uses the software program BenMap, which uses input exposure data and CRF to calculate estimated mortality.

Following recent U.S. EPA practice, CRF for death from heart disease and stroke are taken from a study by Krewski et al. (Krewski, 2009), for hospital admissions for heart and lung disease from a study by Bell et al. (Bell, 2008), and for asthma emergency room visits from a study by Ito et al. (Ito, 2007). Changes in cardiopulmonary mortality were not quantified when the concentrations were below 5.8 $\mu g/m^3$, because the Krewski et al study did not examine impacts below that concentration.

Population Scaling

Population was estimated by taking 2010 Census data for total population by age bracket and projecting to 2026 using total county population projections from the California Department of Finance (DOF). This accounts for overall population growth in a county but does not reflect shifts in the spatial distribution of the population such as new housing developments built on previously undeveloped land.

The original population estimation analysis was performed in 2014. Though this is not the most recent data available from DOF, the population discrepancy between the data used in this analysis and the July 2017 DOF forecast (DOF, 2017c) is less than two percent in a given year, and is randomly distributed among years (i.e., sometimes higher and sometimes lower). This uncertainty is much lower than the uncertainty for estimating either emissions changes or health outcomes, so does not meaningfully contribute to error in this analysis.

Uncertainty

This health benefit analysis relies on multiple data sources and assumptions that contain significant inherent uncertainty. The reference case used to develop IPT factors reconstructs ambient concentrations of both primary PM2.5 and secondary ammonium nitrate formed in the atmosphere from NOx emissions to estimate population exposure. These datasets were constructed from California's ambient monitoring networks, which have limited spatial and temporal coverage. Atmospheric concentrations of PM vary dramatically both spatially and temporally depending on the emission behavior of local sources, the local meteorological conditions, and topographical features. Extrapolating atmospheric concentrations between air quality monitors adds uncertainty to the underlying methodology.

CRF functions are also used to develop IPT factors, and are based on the best available scientific literature, but are difficult to measure and contain inherent uncertainty. These CRF functions do not have sufficient detail to account for all sensitive populations, specifically populations with low socioeconomic status.

Another important source of uncertainty are projected emission inventories under the baseline and proposed amendments. Projecting emission inventories relies on CARB expert judgment of likely future equipment technology changes and business behavior both in the absence of (i.e., baseline) and presence of the proposed amendments. CARB worked closely with stakeholders to identify the likely response from business both with and without the proposed amendments. Still, unforeseen events could occur that dramatically change future emissions. In addition, the spatial distribution of future emission reductions as a result of the proposed amendments contributes to high uncertainty. Health outcomes at the air basin level are presented in this analysis, but represent higher uncertainty than the statewide analysis. It is not possible to accurately constrain the error in projected emission inventories due to lack of information about future conditions.

Some of the uncertainty described above is accounted for in the health outcome calculation, as represented by the 95 percent confidence intervals. Importantly, error associated with projected emission inventories is not included in these confidence intervals. The error associated with the projected emission inventories could contribute significant additional error.