

California Air Resources Board Updated Health Endpoints Bulletin (2026)

1. Introduction

The California Air Resources Board's (CARB) mission is to promote and protect public health, welfare, and ecological resources through effective reduction of air pollutants while recognizing and considering effects on the economy. CARB is the lead agency for climate change programs and oversees all air pollution control efforts in California to attain and maintain health-based air quality standards. In carrying out this mission, CARB assesses and publishes the health benefits of its actions to reduce air pollution. CARB's health analysis quantifies a subset of morbidity and mortality health outcomes associated with PM_{2.5}.

In response to the growing body of research on health effects of air pollution, the Board directed staff through Resolution 20-13 (Health Evaluation of Air Quality and Climate Regulations and Programs) in 2020 to update and expand health analysis tools, pollutants, and health endpoints to capture a broader and more comprehensive range of benefits from reductions in air pollution.¹ Health endpoints are adverse outcomes like heart attacks and hospitalizations used to quantify public health impacts from air pollution exposure.

CARB's health analysis initially consisted of four health endpoints for PM_{2.5}: premature mortality (cardiopulmonary), hospital admissions for cardiovascular illnesses, hospital admissions for respiratory illnesses, and emergency room visits for asthma attacks. Per Resolution 20-13, CARB released a health bulletin in 2022 to 1) expand emergency room visits to cover all respiratory diseases and 2) add eight new endpoints: emergency room visits for cardiovascular illnesses, acute myocardial infarction (nonfatal), asthma onset, asthma symptoms and exacerbation, work loss days, lung cancer incidence, Alzheimer's Disease, and Parkinson's Disease.² The 2022 Bulletin noted that CARB will pursue updates and improvements, including new endpoints, to the health analysis in future bulletins.

This document is the second Health Endpoints Bulletin, covering updates to three existing endpoints and adding four new endpoints for a total of seventeen health endpoints. CARB held a public workshop on the proposed changes in October 2025.³ Staff finalized the proposed endpoints and methodology, considering comments received both during and after the workshop. This document provides the final endpoints for PM_{2.5}, the scientific basis for choosing those endpoints, information on the valuation, and next steps in expanding

¹ CARB, Health Evaluation of Air Quality and Climate Regulations and Programs: Resolution 20-13, April 2020. Retrieved March 15, 2022 from: <https://ww2.arb.ca.gov/sites/default/files/barcu/board/res/2020/res20-13.pdf>

² CARB, California Air Resources Board Updated Health Endpoints Bulletin. Sacramento, CA. <https://ww2.arb.ca.gov/resources/documents/carbs-methodology-estimating-health-effects-air-pollution>

³ CARB, Proposed Updates to Health Endpoints for Use in CARB's Health Analysis (2025). Retrieved April 8, 2026 from <https://ww2.arb.ca.gov/events/proposed-updates-health-endpoints-2025>

CARB's health analysis. The endpoints described in this Bulletin will be used in subsequent CARB health analyses for plans and regulations.

2. Background

Since the 2022 Health Endpoints Bulletin, CARB's health analysis has estimated the change in the number of cases of the following 12 mortality and morbidity health endpoints based on changes in direct PM_{2.5} emissions and a portion of secondary PM_{2.5} emissions:

- Premature mortality (cardiopulmonary)
- Hospital admissions for cardiovascular illnesses
- Hospital admissions for respiratory illnesses
- Emergency room visits for respiratory illnesses
- Emergency room visits for cardiovascular illnesses
- Asthma onset
- Lung cancer incidence
- Alzheimer's Disease
- Parkinson's Disease
- Acute myocardial infarction (nonfatal)
- Work loss days
- Asthma symptoms (albuterol use)

While these endpoints represent important health outcomes experienced by the public, they continue to reflect a small subset of the full suite of benefits to the public from reductions in air pollution. A wealth of evidence demonstrates that air pollution can cause a wide range of health effects beyond the twelve endpoints listed above. Other mortality and morbidity outcomes that impact the public and lead to societal and economic impacts include pregnancy and birth outcomes, reproductive and developmental effects, metabolic effects, and neurodevelopmental and cognitive effects. A wealth of evidence demonstrates that air pollution can cause a wide range of health effects beyond the twelve endpoints listed above. The U.S. Environmental Protection Agency (EPA)'s 2019 Integrated Science Assessment (ISA) for Particulate Matter concluded that there are several health outcomes with causal relationship with long-term PM_{2.5} exposure (**Table 1**).⁴

While U.S. EPA ended its longstanding practice of conducting health benefit assessments of air pollution reductions in 2026, the agency had already established a robust scientific foundation for evaluating the health impacts of air pollution through decades of peer-reviewed research and scientific assessments by independent reviewers. For example, U.S. EPA's ISA for Particulate Matter comprehensively evaluates the substantial body of scientific evidence linking particulate matter exposure to adverse health outcomes. The health endpoints used in CARB's analyses are grounded in this body of evidence, which remains a

⁴ U.S. EPA. (2019). *Integrated Science Assessment (ISA) for Particulate Matter (December 2019)* (EPA/600/R-19/188). Retrieved March 15, 2022 from: <https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=347534#tab-3>

critical resource providing robust scientific evaluation of existing peer reviewed literature to inform health impact assessments and evidence-based regulatory decision-making.

In past reports and guidance documents, U.S. EPA determined the causal relationship using a formal framework informed by work from federal and international groups such as the National Academies of Sciences, Engineering, and Medicine (NASEM) and the International Agency for Research on Cancer.⁵ This framework considered aspects such as number of studies, consistency of study findings, biological plausibility, and uncertainties to determine the causal relationship (e.g. causal, likely to be causal). As shown in **Table 1**, U.S. EPA’s causal framework classified endpoints in hierarchical levels, with “causal” and “likely to be causal” reflecting the most confident relationships between PM_{2.5} and attributable health impacts. “Suggestive of causal” does not necessarily mean the outcome is less associated with air pollution exposure but may reflect a lack of or limited number of studies. Out of the eight categories of health outcomes listed in **Table 1**, CARB evaluates endpoints in five categories (mortality, subsets of cardiovascular effects, respiratory effects, cancer, nervous system effects [long-term]).

Table 1. Long-term and short-term PM_{2.5} health outcomes and causality links (adapted from U.S. EPA⁶)

Causality Links	Health outcomes from PM _{2.5} exposure
Causal	Mortality* Cardiovascular Effects*
Likely to be causal	Respiratory Effects* Nervous Systems Effects (long-term only)* Cancer (long-term only)*
Suggestive of causal	Metabolic Effects Male and Female Reproduction and Fertility Effects Nervous Systems Effects (short-term only)
*CARB evaluates health endpoints in this category	

In the next Section, CARB presents updated and additional PM_{2.5}-related health endpoints that will be incorporated into the agency’s routine health analysis. The recording and presentation materials from CARB’s public workshop in October 2025 on these updates are available online.⁷ CARB’s responses to the public feedback from the workshop are provided

⁵ U.S. EPA. *Preamble to The Integrated Science Assessments (ISA)*. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/067, 2015

⁶ Ibid.

⁷ Ibid.

in this document (see “Summary of Submitted Public Comments to October 2025 Public Workshop and Responses”). In the future, CARB may consider incorporating endpoints from additional levels of causation. To support this effort, CARB and other investigators are conducting research to better capture the extent of adverse public health impacts from air pollution (see “Ongoing/Next Steps”).

3. Health Endpoints, Use of Endpoints and Supporting Studies

CARB is adding four health endpoints and updating three existing health endpoints to the PM_{2.5} health analysis methodology (**Table 2**), expanding the health analysis to 17 endpoints. For most analyses, CARB uses an “Incidents Per Ton” (IPT) methodology to calculate the health impacts per ton of pollution reduced. The IPT method, which is based on established approaches such as U.S. EPA’s Environmental Benefits Mapping and Analysis Program (BenMAP)⁸, relates changes in emissions projected in specific years to changes in health outcomes for those years. More information on the IPT method is available on CARB’s website.⁹

Table 2. List of updated and new PM_{2.5} health endpoints in CARB's health analysis methodology

Updated Endpoints	New Endpoints
Acute Myocardial Infarction, Nonfatal*	Cardiac arrest
Work loss days**	Stroke
Asthma symptoms/exacerbation***	Allergic Rhinitis (Hay fever)
	Minor Restricted Activity Days
*CARB previously calculated this endpoint but is updating the effect estimate to use a more recent study. **CARB previously calculated this endpoint but is updating the effect estimate to use a California-specific study. ***CARB previously calculated this endpoint in children (age 17 years and under) but is updating to separately add asthma exacerbation in adults (age 18 years and over) with the effect estimate from a California-specific study.	

To calculate changes in health outcomes, CARB uses a concentration-response (CR) function. A CR function calculates a change in the health outcome in the population based on the

⁸ U.S. EPA. (2019). Environmental Benefits Mapping and Analysis Program - Community Edition (BenMAP-CE). Retrieved March 15, 2022 from <https://www.epa.gov/benmap>

⁹ CARB’s Methodology for Estimating the Health Effects of Air Pollution. Retrieved March 18, 2022 from: <https://ww2.arb.ca.gov/resources/documents/carbs-methodology-estimating-health-effects-air-pollution>

change in the pollutant concentration to which that population is exposed. CARB uses inputs to the CR function that are specific to each endpoint. These inputs are the baseline incidence rate and the effect estimate. The baseline incidence rate is the number of events of illness or death, or the number of people experiencing that event, in the population. Baseline incidence rates can be acquired through health databases from state or federal agencies or through databases built into BenMAP.¹⁰ The effect estimate for an endpoint is the incremental change in health effect per unit change in pollution (1 $\mu\text{g}/\text{m}^3$) and is derived from epidemiological studies. The effect estimates are applicable to all types of $\text{PM}_{2.5}$ as evidence suggests similar effect estimates for components of $\text{PM}_{2.5}$ as with total mass concentration.¹¹

Table 3 lists the studies and the corresponding effect estimates from U.S. EPA's ISA or from CARB-funded California-specific epidemiological studies to quantify the 17 endpoints. All 17 of these endpoints were determined by U.S. EPA's ISA to have a "causal" or "likely causal" relationship with particulate matter (also see the 2022 Supplement to the 2019 ISA).¹² The set of criteria used to establish these causal relationships in the ISA is summarized in **Table 4**. Each criterion had its own list of preferred study attributes, and the U.S. EPA considered these criteria collectively when evaluating studies. For instance, a study location in the US or Canada and a study size with a large population were preferred. U.S. EPA provided more details about these criteria in the aforementioned 2021 TSD.¹³ Thus, these health endpoints are based on a body of peer-reviewed health research. Each of these endpoints are described in more detail later in this section.

Some endpoints are grouped in **Table 3** because they utilize the same study (cardiovascular and respiratory hospital admissions; and hospitalizations for Alzheimer's and Parkinson's diseases). Most of the listed endpoints rely on studies using hospital data of coded diagnoses, and multiple diseases are categorized under the cardiovascular and respiratory endpoints. CARB has noted the codes from the International Classification of Diseases, Ninth Revision (ICD-9) for each endpoint, with their specific definitions provided in **Table 5**, for reference.¹⁴ Each endpoint listed below is noted as either being *Updated* or *New* for CARB's health analysis methodology (**Table 2**). The endpoints will use the new or updated effect estimates in the studies noted for that endpoint.

¹⁰ See U.S. EPA. (2019) BenMAP-CE.

¹¹ See U.S. EPA. (2019) *ISA for Particulate Matter*.

¹² U.S. EPA. (2021). *Supplement to the 2019 Integrated Science Assessment for Particulate Matter*.

¹³ See U.S. EPA. (2021) *TSD*.

¹⁴ Centers for Disease Control and Prevention (CDC): National Center for Health Statistics. International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM). Retrieved March 15, 2022 from: <https://www.cdc.gov/nchs/icd/icd9cm.htm>

Table 3. List of health endpoints and summary of studies (adapted from U.S. EPA⁴). The full reference for each study is provided in the sections describing each endpoint.

	Endpoint(s)	Study	Age Range	Location	Effect Estimate
Cardiovascular	Cardiovascular hospital admissions	Bell et al. (2015)	Seniors (65-99)	US	0.00065
	Cardiovascular ED visits	Ostro et al. (2016)	All ages (0-99)	US (CA)	0.00061
	Acute myocardial infarction, nonfatal*	Wei et al. (2019)	Adults (18-99)	US	0.0011
	Stroke	Kloog et al. (2012)	Older adults (65-99)	US (New England)	0.00343
	Cardiac arrest	3 studies: • Ensor et al. (2013) • Rosenthal et al. (2008) • Silverman et al. (2010)	All ages (0-99)	US	3 studies: • 0.00638 • 0.00198 • 0.00392
Respiratory	Respiratory hospital admissions	Bell et al. (2015)	Seniors (65-99)	US	0.00025
	Respiratory ED visits	Krall et al. (2017)	All ages (0-99)	US	4 locations: • 0.00055 • 0.00097 • 0.00083 • 0.00135
	Asthma onset	Tetreault et al. (2016)	Children (0-13)	Canada	0.04367
	Asthma symptoms	Rabinovitch et al. (2006)	Children (6-17)	US	0.002
	Asthma exacerbation**	Su et al. (2024)	Adults (18-64)	US	0.008752
	Work loss days*	Meng et al. (2023)	Adults (18-64)	US	0.0193

	Allergic rhinitis (Hay fever)	Parker et al. (2009)	Children (3-17)	US	0.0254
	Minor restricted activity days	Ostro and Rothschild, 1989	Adults (18-64)	US	0.00741
Cancer	Lung cancer incidence	Gharibvand et al. (2017)	Adults (30-99)	US and Canada	0.03784
Nervous System Effects	Alzheimer's disease	Kioumourtzoglou et al. (2016)	Seniors (65-99)	US	0.13976
	Parkinson's disease	Kioumourtzoglou et al. (2016)	Seniors (65-99)	US	0.07696

ED = emergency department

*CARB previously calculated this endpoint but is updating the effect estimate to use a more recent study.

**CARB previously calculated this endpoint but is updating to separately consider asthma exacerbation in children (age 6 to 17 years) and exacerbation in adults (age over 18 years).

Table 4. Summary of U.S. EPA's criteria for selecting studies and risk estimates (adapted from U.S. EPA⁴)

Criterion	Description of Preferred Attributes
Study Period	Longer period of time and more recent studies
Exposure Estimate	Exposures estimated using a combination of approaches (e.g., modeling, monitoring, etc.). Long-term/chronic exposure studies over short-term.
Study Type	For long-term epidemiological studies, cohort studies over case-control studies, and both are preferred over cross-sectional or ecological studies.
Population Attributes	Study populations that are representative of the greater affected population (diverse race/ethnicities, both sexes, broader age groups).
Study Location	US or Canada
Health Endpoints	Broad health endpoints over more specific endpoints.
Study Size	Relatively large sample sizes
Pollutant Concentrations	Evaluate air pollutant exposures that are close to or below current conditions.
Hazard/Risk Estimate	Use of multiple well-established statistical models
Lag Period	Strongest multi-day/distributed lag periods that are more biological plausible

3.1. Cardiac Arrest – New

Cardiac arrest refers to a sudden and unexpected halt of heartbeat and has a high fatality rate (ICD-9 code 427.5). Among multiple available studies for cardiac arrest, U.S. EPA identified three¹⁵ that met rigorous selection criteria in its 2022 Supplement to the 2019 ISA. All three studies strongly support the link between short-term PM_{2.5} exposure and out of hospital cardiac arrest (OHCA) not classified as dead on arrival (i.e., not overlapping with cardiovascular mortality)¹⁶. The results from these studies will be used together, or pooled, in CARB's analysis. The method for pooling is described in U.S. EPA's BenMAP manual.¹⁷ It was found that each 1 µg/m³ increase in PM_{2.5} is associated with a 0.46% increase in OHCA.

3.2. Stroke – New

Stroke is defined as the blockage or bursting of blood vessels to or on the surface of the brain. In California, stroke was the fourth leading cause of death in 2021, accounting for approximately 37 deaths per 100,000 residents. Older adults in particular are at high risk, and evidence indicates that stroke-related hospitalizations increase with both short-term and long-term exposure to PM_{2.5}. To quantify this endpoint, CARB will rely on Kloog et al.'s study examining the relationship between PM_{2.5} exposure and stroke risk.¹⁸ The study analyzed hospital records of adults aged 65 and older across multiple U.S. states, linking daily predicted PM_{2.5} concentrations to stroke outcomes. The findings indicate that long-term PM_{2.5} exposure has a stronger effect on stroke risk than short-term exposure. Specifically, each 1 µg/m³ increase in PM_{2.5} concentration is associated with a 0.3% increase in stroke risk.

3.3. Acute Myocardial Infarction (AMI), Nonfatal – Updated

An Acute Myocardial Infarction (AMI) is also called a heart attack; this endpoint refers to hospitalizations from heart attacks (ICD-9 code 410) and does not include deaths resulting from heart attacks. The 2019 ISA included three studies that strengthened evidence of short-term exposure to PM_{2.5} and AMI-related ED and hospital admission risk. The 2022 Supplement to the 2019 ISA identified a more recent study by Wei et al. that met selection

¹⁵ From "Technical Support Document (TSD) for the 2022 PM NAAQS Reconsideration Proposal RIA, Estimating PM_{2.5}- and Ozone-Attributed Health Benefits", by Environmental Protection Agency, 2023.

¹⁶ Ensor, KB, Raun, LH and Persse, D (2013). A case-crossover analysis of out-of-hospital cardiac arrest and air pollution. *Circulation* 127(11): 1192-1199

Rosenthal, FS, Carney, JP and Olinger, ML (2008). Out-of-hospital cardiac arrest and airborne fine particulate matter: a case-crossover analysis of emergency medical services data in Indianapolis, Indiana. *Environ Health Perspect* 116(5): 631-636

Silverman, RA, Ito, K, Freese, J, Kaufman, BJ, De Claro, D, Braun, J and Prezant, DJ (2010). Association of ambient fine particles with out-of-hospital cardiac arrests in New York City. *Am J Epidemiol* 172(8): 917-923.

¹⁷ U.S. EPA. (2022). Environmental Benefits Mapping and Analysis Program - Community Edition: User's Manual. Retrieved March 22, 2022 from https://www.epa.gov/sites/default/files/2015-04/documents/benmap-ce_user_manual_march_2015.pdf?VersionId=7BSmKllr0O6KccspW4pA.nMsu4EeLlrt

¹⁸ Kloog I, Coull BA, Zanobetti A, Koutrakis P, Schwartz JD. Acute and chronic effects of particles on hospital admissions in New-England. *PLoS One*. 2012;7(4):e34664. doi: 10.1371/journal.pone.0034664

criteria in **Table 4**. The selected study is U.S.-based and analyzed over 95 million in-patient hospital claims from adults (18-99 years old).¹⁹ This study evaluated relationships between zip-code level daily predictions of PM_{2.5} exposure and hospital admissions for 214 disease groups, including cardiovascular health outcomes such as AML-related hospitalizations. Wei et al. found that more than 600,000 annual hospitalizations are due to heart attacks in the U.S. After CARB's quantification, it was found that per 1 µg/m³ increase in PM_{2.5}, there is a 0.11% increase in risk of AML-related hospitalization.

3.4. Minor Restricted Activity Days – New

Minor restricted activity days (MRAD) refer to days when adults reduce their usual daily activities due to health issues but are not completely incapacitated. Outcomes such as missing work entirely or being confined to bed are considered more severe and fall outside this definition. This endpoint captures impacts on both health and quality of life. To quantify this endpoint, CARB is using the Ostro and Rothschild, 1989 study examining the relationship between PM_{2.5} exposure and minor restrictions in activity, work loss, and bed disability due to respiratory symptoms.²⁰ The study is a U.S.-based national analysis using data from six Annual Health Interview Surveys (1976-1981), which controlled for differences in exposures across cities. The study found that PM_{2.5} exposure is associated with increases in these outcomes in adults. Specifically, each 1 µg/m³ increase in PM_{2.5} concentration is associated with a 0.7% increase in the risk of MRAD.

3.5. Allergic Rhinitis – New

Allergic rhinitis, also known as hay fever, is a group of respiratory allergy symptoms prevalent across socioeconomic and urban-rural statuses. To quantify this endpoint, CARB will utilize the Parker et al., 2008 study as selected by the U.S. EPA. Parker et al. analyzed over 70,000 children (aged 3-17 years) in the U.S. using National Health Interview Survey data from 1999 to 2005.²¹ The study examined the associations between long-term exposure to PM_{2.5} and allergic rhinitis. The study found a significant link between chronic PM_{2.5} exposure and allergic rhinitis in children, with a 1 µg/m³ increase in PM_{2.5} associated with a 2.9% increase in the risk of allergic rhinitis.

¹⁹ Wei Y, Wang Y, Di Q, Choirat C, Wang Y, Koutrakis P, Zanobetti A, Dominici F, and Schwartz JD. Short term exposure to fine particulate matter and hospital admission risks and costs in the Medicare population: time stratified, case crossover study. *BMJ*. 2019;367:16258. doi: 10.1136/bmj.16258

²⁰ Ostro BD, Rothschild S. Air pollution and acute respiratory morbidity: an observational study of multiple pollutants. *Environ Res*. 1989 Dec;50(2):238-47. doi: 10.1016/s0013-9351(89)80004-0

²¹ Parker JD, Akinbami LJ, Woodruff TJ. Air pollution and childhood respiratory allergies in the United States. *Environ Health Perspect*. 2009 Jan;117(1):140-7. doi: 10.1289/ehp.11497

3.6. Asthma Symptoms/Exacerbation – New

The asthma symptoms health endpoint can include symptoms such as chest pain, shortness of breath, coughing, or wheezing which can result in prescription medication use, doctor's office visit, hospitalization, hospital-based outpatient visits and emergency room care, imposing a substantial economic burden. The Rabinovitch et al. study²² used in the U.S. EPA's BenMAP for the asthma symptoms endpoint focuses on children and is somewhat outdated, with a limited sample size, and less precise exposure assessment and statistical analyses. To address these limitations, CARB is supplementing this endpoint with a CARB-funded, California-specific study based on adult populations.²³ This study used a unique dataset collected by digital sensors monitoring medication inhaler use for 3,386 patients across California from January 1, 2012 to December 31, 2019, with precise exposure assessments and advanced statistical methods to quantify the impact of air pollution on asthma. The results provided a robust indication of increased asthma medication use associated with PM_{2.5} exposure among adult Californians. A 1 µg/m³ increase in PM_{2.5} was associated with a 0.88% increase in medication use.

The estimated effect of PM_{2.5} on asthma medication use in the CARB study is higher than in the EPA study (Odds = 0.88% vs. 0.2%), indicating an almost fourfold increase. This disparity is likely due to Su et al.'s use of more recent California-specific data, advanced exposure assessments, and sophisticated statistical methods. CARB will incorporate health impact estimates for adult asthma symptoms using effect estimates from Su et al.

3.7. Work loss days – Updated

Some acute health impacts from PM_{2.5} exposure, such as coughs and headaches, may not be severe enough to require hospitalization or emergency care but can still lead to missed days of work. BenMAP relies on work-loss estimates from a 1987 study by Ostro.^{24,25} However, that study used limited exposure data derived from airport visibility records rather than direct air pollutant measurements, due to technological constraints of the time. Additionally, the health data were based on national survey responses from 1976, which may not accurately reflect present-day health status of Californians. Because work loss due to illness poses a significant economic burden, it is important to update estimates of short-term PM_{2.5} exposure effects on this endpoint.

²² Rabinovitch N, Strand M, Gelfand EW. Particulate levels are associated with early asthma worsening in children with persistent disease. *American journal of respiratory and critical care medicine*. 2006 May 15;173(10):1098-105.

²³ Su JG, Vuong V, Shahriary E, Aslebagh S, Yakutis E, Sage E, Haile R, Balmes J, Barrett M. Health effects of air pollution on respiratory symptoms: A longitudinal study using digital health sensors. *Environment International*. 2024 Jul 1;189:108810.

²⁴ US EPA. 2024. Estimating PM_{2.5}- and Ozone-Attributable Health Benefits: 2024 Update. Washington, DC: US Environmental Protection Agency.

²⁵ Ostro BD. 1987. Air pollution and morbidity revisited: A specification test. *Journal of Environmental Economics and Management* 14(1):87-98.

CARB will adopt an updated and more robust estimate from Meng et al. (2023), which uses recent, large-scale survey data, advanced exposure models, and improved statistical methods.²⁶ The study linked statewide representative data from the 2015-2018 California Health Interview Survey (CHIS; n = 44,544 adults) to PM_{2.5} exposure estimates based on respondents' residential addresses. Meng et al. modeled daily PM_{2.5} concentrations and evaluated the association between two-week average PM_{2.5} exposure and work loss using appropriate statistical models and extensive sensitivity analyses.

Meng et al. reported that work-loss risk increased by 2.0% (Beta = 0.0193, standard error = 0.0143) for every 1 µg/m³ increase in PM_{2.5}. This effect estimate is approximately four times larger than that reported by Ostro (Beta = 0.0046), assuming that the odds ratio approximates the risk ratio because work-loss events are relatively uncommon. To reconcile the effect estimate from Meng et al.'s study (i.e., probability of experiencing any work-loss event) with Ostro's estimate (i.e., number of work-loss days), Meng et al. provided two additional parameters: (1) the incidence of having any work-loss event based on 2015-2018 CHIS data, and (2) the average number of days per event derived from pooled California data from the 2001-2016 Medical Expenditure Panel Survey (MEPS).²⁷ Both CHIS and MEPS are population-based, representative datasets, providing California-specific and updated estimates.

For health impact analysis, CARB will apply the updated effect estimates from Meng et al.'s study. Compared with Ostro's study used in BenMAP, Meng et al. relied on more recent, California-specific health data; more refined exposure assessment methods (continuous spatial PM_{2.5} surfaces at 3 km-resolution vs. airport visibility data); and more rigorous statistical techniques, including adjustment for complex survey weights and multiple sensitivity analyses.

²⁶ Meng YY, Yu Y, Al-Hamdan MZ, Marlier ME, Wilkins JL, Garcia-Gonzales D, Chen X, Jerrett M. 2023. Short-Term total and wildfire fine particulate matter exposure and work loss in California. *Environment International*. 178:108045.

²⁷ Cawley J, Biener A, Meyerhoefer C, Ding Y, Zvenyach T, Smolarz BG, Ramasamy A. 2021. Job absenteeism costs of obesity in the United States: national and state-level estimates. *Journal of occupational and environmental medicine*. 63(7):565-73.

Table 5. Selected relevant codes from the International Classification of Diseases, Ninth Revision (ICD-9) (adapted from CDC¹⁴)

ICD-9 Code	Disease
331.0	Alzheimer's disease
332	Parkinson's disease
390	Rheumatic fever without mention of heart involvement
410	Acute myocardial infarction
411	Other acute and subacute forms of ischemic heart disease
412	Old myocardial infarction
413	Angina pectoris
414	Other forms of chronic ischemic heart disease
426	Conduction disorders
427	Cardiac dysrhythmias
428	Heart failure
429	Ill-defined descriptions and complications of heart disease
430-438	Cerebrovascular disease
440	Atherosclerosis
441	Aortic aneurysm and dissection
442	Other aneurysm
443	Other peripheral vascular disease
444	Arterial embolism and thrombosis
445	Atheroembolism
446	Polyarteritis nodosa and allied conditions

Table 5 (continued).

ICD-9 Code	Disease
447	Other disorders of arteries and arterioles
448	Disease of capillaries
460-466	Acute respiratory infections
477	Allergic rhinitis
480	Viral pneumonia
481	Pneumococcal pneumonia
482	Other bacterial pneumonia
483	Pneumonia due to other specified organism
484	Pneumonia in infectious diseases classified elsewhere
485	Bronchopneumonia, organism, unspecified
486	Pneumonia, organism unspecified
487	Influenza
490	Bronchitis, not specified as acute or chronic
491	Chronic bronchitis
492	Emphysema
493	Asthma
496	Chronic airway obstruction, not elsewhere classified
786.07	Wheezing

4. Valuation

As part of updating the health endpoints, CARB will also update the corresponding valuations in regulatory impact assessments. Valuation refers to placing a monetary value on an estimated health incident. Improvements in air quality will lower the risk of developing adverse health effects, resulting in fewer cases of the adverse health effects. Monetizing the benefits of reduced air pollution involves estimating society's willingness to pay (WTP) to avoid these adverse outcomes or estimating the observed Cost of Illness (COI) of the health endpoint.²⁸ CARB's process for valuing endpoints is largely based on U.S. EPA's Technical Support Documents for estimating PM_{2.5}- and ozone-attributable health benefits (2024)²⁹, but considers California demographic and economic data.

The statewide valuations of health benefits for specific endpoints associated with a proposed regulation or scenario are calculated by multiplying the value per incident by the statewide total number of avoided incidents. The value of the health benefits may be compared with other costs and benefits of a proposed regulation or scenario to better understand a regulation or plan's total impacts.

The savings for avoided hospitalizations and emergency room visits are based on a combination of typical costs associated with hospitalization and the WTP of surveyed individuals to avoid adverse outcomes that occur when hospitalized. These costs include hospital charges, post-hospitalization medical care, out-of-pocket expenses, and lost earnings of 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).^{30,31} The valuation for hospitalizations draws on published estimates of California illness costs while the valuation for emergency department visits draws on national estimates.

CARB's methodology will use the same valuation studies that are included in BenMAP. Staff will use IPT methodology to estimate the number of cases of each endpoint, then apply these valuation studies to calculate the total valuation for the proposed scenario in a regulation, rule, or program. CARB will use California specific data on inflation, wages, income, and demographics, where applicable.

²⁸ COI includes the direct medical costs and lost earnings associated with illness. COI may understate the true economic value of reductions in risk of health effects, as it may not include other factors such as avoided pain and suffering. WTP estimates may include these other factors but may be less readily available.

²⁹ See U.S. EPA. (2021) *TSD*.

³⁰ Chestnut, Lauraine G., et al. "The economic value of preventing respiratory and cardiovascular hospitalizations." *Contemporary Economic Policy* 24.1 (2006):127-143. doi: 10.1093/cep/byj007

³¹ Smith, David H., et al. "A national estimate of the economic costs of asthma." *American journal of respiratory and critical care medicine* 156.3 (1997): 787-793. doi: 10.1164/ajrccm.156.3.9611072 <https://www.atsjournals.org/doi/full/>

5. At-Risk Populations

A growing body of literature shows that some populations are more susceptible to air pollutants and are at higher risk of air pollution-related illnesses. Understanding health and exposure disparities is critical to reducing air pollution exposure and health risks among low-income communities and communities of color. These communities are often heavily burdened by higher levels of pollution from traffic and other industrial sources.^{32,33} They also often simultaneously face other stressors such as poor nutrition, economic insecurity, and sub-optimal living conditions that add to vulnerability to air pollution impacts.^{34,35}

U.S. EPA's 2019 ISA for particulate matter and the 2022 Supplement discuss factors contributing to increased risk of PM_{2.5}-related health effects including life stage, race/ethnicity, and socioeconomic status. For example, nonwhite groups, in particular the black population, are at higher risk for air pollution-related health impacts based on exposure and health studies analyzing different race/ethnic groups. There is also strong evidence that children are at increased risk of respiratory illnesses from long-term PM_{2.5} exposure even after accounting for physiological factors that increase their effective dose. Based on this evidence, CARB may implement additional quantitative methods for evaluating health impacts by demographic characteristics such as race/ethnicity, income, and age.

Research institutions and public health organizations have been emphasizing the need for disclosing disparities and working towards closing the socio-economic gaps in exposure. In a 2024 report, NASEM established the need for analysis of disparities in exposure and provided a comprehensive framework and geospatial tools for developing screening tools for environmental justice.³⁶ The Health Effects Institute noted "a need to enhance policy-relevant research efforts to better address and reduce disproportionate exposures and effects in marginalized communities" in its critical review on assessing adverse health effects of long-term exposure to low levels of ambient air pollution.³⁷ The American Lung Association's "State of the Air" report cites extensive research supporting the higher exposure in communities with people of color and highlights the increased vulnerability and risk from air

³² Apte, Joshua. "A Method to Prioritize Sources for Reducing High PM_{2.5} Exposures in Environmental Justice Communities in California." (CARB Contract Number 17RD006). Retrieved March 15, 2022 from: https://ww3.arb.ca.gov/research/single-project.php?row_id=67021

³³ Tessum CW, Paolella DA, Chambliss SE, Apte JS, Hill JD, Marshall JD. PM_{2.5} polluters disproportionately and systemically affect people of color in the United States. *Sci Adv*. 2021 Apr 28;7(18):eabf4491. doi: 10.1126/sciadv.abf4491

³⁴ OEHHA. CalEnviroScreen. California Office of Environmental Health Hazard Assessment. Retrieved March 15, 2022 from: <https://oehha.ca.gov/calenviroscreen/about-calenviroscreen>

³⁵ Braveman P, Gottlieb L. The Social Determinants of Health: It's Time to Consider the Causes of the Causes. *Public Health Reports*. 2014;129(1_suppl2):19-31. doi:10.1177/003335491412915206

³⁶ National Academies of Sciences, Engineering, and Medicine. 2024. Constructing Valid Geospatial Tools for Environmental Justice. Washington, DC: The National Academies Press.

³⁷ Boogard H, Crouse DL, Tanner E, Mantus E, van Erp AM, Vedal S, and Samet J. Assessing Adverse Health Effects of Long-Term Exposure to Low Levels of Ambient Air Pollution: The HEI Experience and What's Next? *Environ Sci Technol*. 2024;58: 12767-12783. doi: 10.1021/acs.est.3c09745

pollution in sub-populations without access to healthcare, elderly and children, and people with existing respiratory and cardiovascular conditions.³⁸

Moving forward, CARB may use epidemiological studies demonstrating health outcomes in specific sub-populations to provide disaggregated health outcome information that better reflects vulnerabilities in sub-populations. CARB is evaluating methods to incorporate localized data on at-risk populations, and staff are considering methods to incorporate population vulnerability from existing scientific evidence and tools that demonstrate health, exposure, and relative risk disparities at various spatial scales including census tract.

6. Summary of Submitted Public Comments to October 2025 Public Workshop and Responses

CARB held a public workshop titled “Updating Health Endpoints for Use in CARB’s Health Analysis (2025)” in October 2025, followed by a public comment period. The comments received offered valuable perspectives and constructive recommendations for strengthening the health analysis.

Commenters expressed strong support for CARB’s expansion of health benefit evaluations under Resolution 20-13, specifically endorsing the inclusion of new endpoints in future policy analyses. To improve the process, Commenters suggested adopting a structured evaluation framework similar to U.S. EPA’s ISAs to assess emerging endpoints like metabolic health and birth outcomes. Furthermore, Commenters requested clarification on the exclusion of ozone-related health outcomes in this endpoints process, raised questions about the strength of the evidence for some endpoints, potential double counting, and uncertainties in CR functions at low concentrations, and urged greater transparency in economic valuation and the treatment of vulnerable populations.

CARB appreciates the support and feedback from all Commenters and will continue updating its health analysis methodology using the latest scientific evidence, including California-specific research on emerging health endpoints.^{39,40} CARB identifies health endpoints consistent with the rigorous scientific review and causality framework previously established by U.S. EPA.⁴¹ Detailed description of the economic valuation of the updated health endpoints will be provided in regulatory documents for public review and public comment. While ozone-related impacts were not part of the October 2025 Public Workshop, CARB is exploring methods and studies for future inclusion. To ensure technical rigor, CARB

³⁸ American Lung Association. (2026, April 22). State of the Air. Retrieved June 24, 2026, from <https://www.lung.org/research/sota>

³⁹ Meng YY, Yu Y, Al-Hamdan MZ, Marlier ME, Wilkins JL, Garcia-Gonzales D, Chen X, Jerrett M. Short-Term total and wildfire fine particulate matter exposure and work loss in California. *Environment International*. 2023 Aug 1;178:108045.

⁴⁰ Su JG, Vuong V, Shahriary E, Aslebagh S, Yakutis E, Sage E, Haile R, Balmes J, Barrett M. Health effects of air pollution on respiratory symptoms: A longitudinal study using digital health sensors. *Environment International*. 2024 Jul 1;189:108810.

⁴¹ U.S. EPA. Estimating PM2.5- and Ozone-Attributable Health Benefits: 2024 Update, U.S Environmental Protection Agency, Office of Air and Radiation, Research Triangle Park, North Carolina June 2024.

aligns its morbidity endpoints with established, peer reviewed methodologies to minimize double counting. CARB maintains that its study evaluations prioritize the overall strength of study design, exposure assessment, and analytical rigor rather than statistical significance alone. Finally, CARB recognizes the importance of accounting for vulnerable populations and communities disproportionately impacted by air pollution and is continuing to refine methods to better capture localized impacts on these communities.

7. Ongoing/Next Steps

This Bulletin covers a routine update, in part using effect estimates for work loss days and asthma exacerbation in adults from CARB-funded studies, to make the health impact analysis of CARB's plans and regulations more comprehensive. CARB is continuing to develop California-specific effect estimates for emerging health endpoints. CARB has ongoing, completed, or upcoming research contracts investigating neurological, natal, metabolic, and ozone-related respiratory outcomes. Some contracts assess outcomes by demographic characteristics such as race and ethnicity, income, age, housing, and healthcare access depending on data availability. Further information on the completed and ongoing contracts is available on the CARB website.⁴² Staff are also evaluating possible methods for more local-scale analysis and incorporating qualitative methods to address community factors affecting health.

Additionally, CARB will continue to evaluate approaches to provide both quantitative and qualitative information on health outcomes in low-income communities and communities of color. As part of that process, CARB contracted several health consultants from academia and with backgrounds in epidemiology, environmental health, environmental justice, and exposure assessment. The consultants provided individual recommendations to CARB staff. They also presented the recommendations at a public meeting in April 2026 (meeting recording and presentation materials are available online).⁴³ In the coming months, staff will evaluate the recommendations for feasibility, relevance, and impact. CARB's health analysis methodology will be not amended or updated unless such changes are presented in a public workshop followed by a public comment period.

Per CARB's longstanding focus on providing reliable evidence to effectively and sustainably address challenges in air quality and climate change in California, staff will be pursuing additional updates and improvements, including consideration of additional causation categories for the endpoints and endpoints for additional pollutants, in future bulletins by relying on the best available science.

⁴² CARB. Research Division Contracts. Retrieved July 9, 2026 from <https://ww2.arb.ca.gov/our-work/programs/research-planning/research-division-contracts>

⁴³ CARB. Public Meeting: Health Analysis Consultants' Findings on Environmental Justice in Health Impact Assessments. Retrieved July 9, 2026 from <https://ww2.arb.ca.gov/events/public-meeting-health-analysis-consultants-findings-environmental-justice-health-impact>