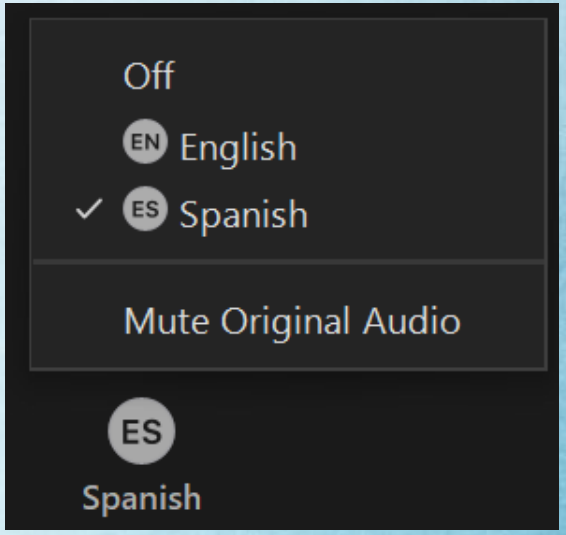
CALIFORNIA
AIR RESOURCES BOARD

Public Workshop: Updating Health Endpoints for Use in CARB's Health Analysis (2025)

October 31, 2025

Spanish Interpretation on Zoom

- Spanish interpretation is being provided
- Interpretation feature requires downloading the Zoom application to your desktop
  - English: select Off or English
  - Spanish: select Spanish, then Mute Original Audio

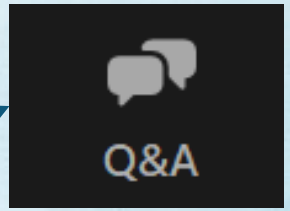


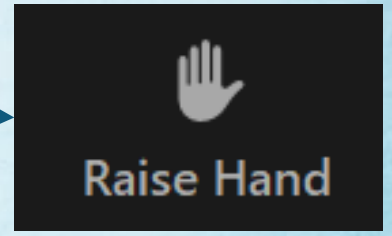
- Se ofrecerá interpretación al español.
- Para acceder a la función de interpretación, se debe descargar la aplicación de Zoom a su escritorio.
  - English: select Off or English.
  - Español: seleccionen “Español” y luego, “Mute Original Audio” (Silenciar audio original).

CARB

How to Ask a Question

- Meeting is being recorded
- We will respond to questions at the end of the workshop
  - Submit your questions at any time in the Q&A
  - To provide verbal comment or question, you may raise your hand to be added to the speaking queue





Welcome

Opening remarks

Bonnie Holmes-Gen

Chief of the Health & Exposure Assessment Branch

Facilitator

Pradeep Prathibha, PhD

Manager of the Health & Ecosystem Analysis Section

Main presenters

Arash Mohegh, PhD

Erika Ramsey, MS

Joshua Montefalcon, MPH

Hnin Hnin Aung, PhD

Feng-Chiao Su, PhD

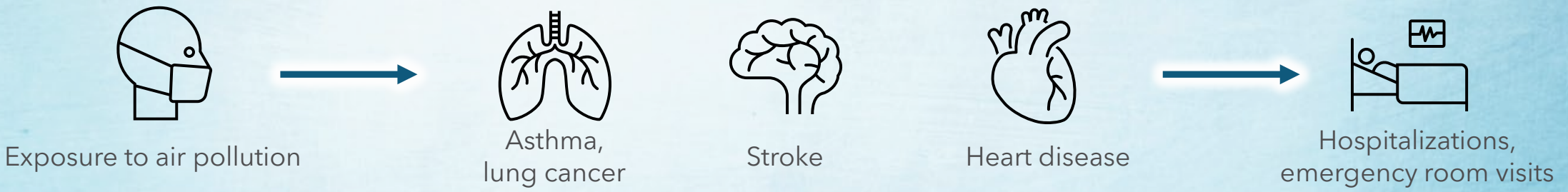
Nargis Jareen, MBBS, MPH

Workshop Outline

1. What are health endpoints?
2. Why update the health endpoints?
3. How do we select and evaluate the health endpoints?
4. New and updated health endpoints
5. Next steps
6. Questions and feedback

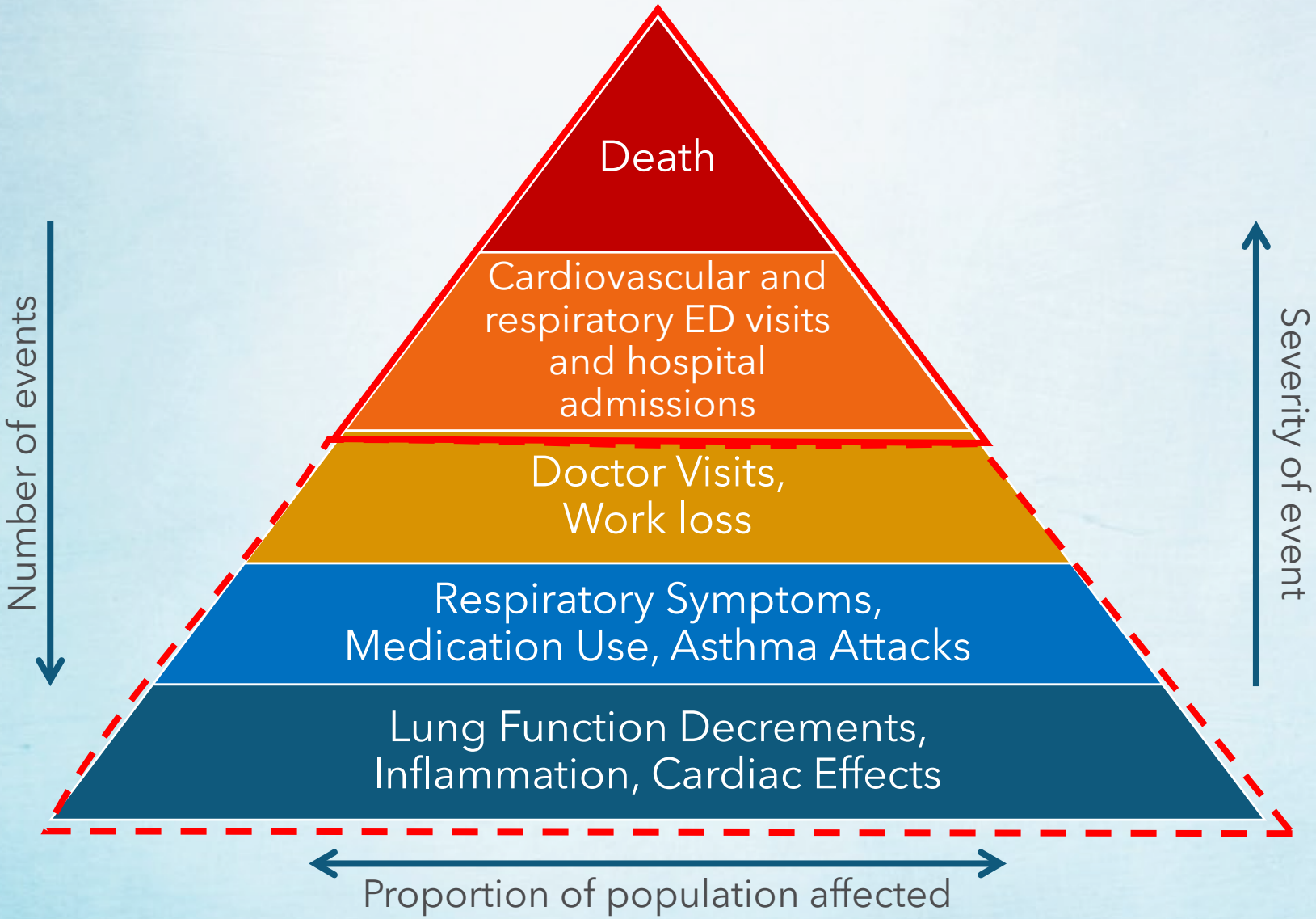
1. What Are Health Endpoints?

- An **adverse health outcome** used to evaluate quantitative or qualitative health impacts
- Used to evaluate effects from criteria pollutants or air toxics
- Our workshop today focuses on health endpoints related to **ambient $PM_{2.5}$**



$PM_{2.5}$: fine inhalable particles with diameters generally 2.5 micrometers and small

Air Pollution Health Effects



Current outcomes:
Higher severity, lower prevalence

Other important, more prevalent outcomes:
- Birth outcomes
- Metabolic effects
- Neurological effects
- Reproductive effects

Adapted from https://www.epa.gov/benmap/how-benmap-ce-estimates-health-and-economic-effects-air-pollution

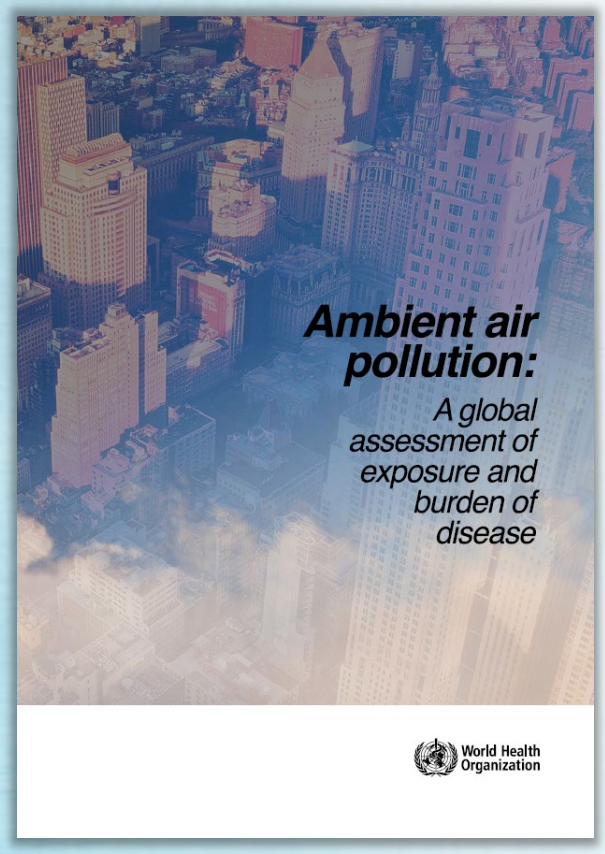
Background on CARB's Health Analysis

- Health analysis informs the benefits of CARB regulations, plans, and programs
- Current approach includes a subset of $PM_{2.5}$ health impacts

Previous Endpoints (in use till 2023)	New Endpoints (added in 2023)	What next?
Cardiopulmonary mortality	Cardiovascular Emergency Room Visits	GOAL: A more complete evaluation of the health benefits of air quality and climate actions
Cardiovascular Hospital Admissions	Acute Myocardial Infarction, Nonfatal	
Respiratory Hospital Admissions	Respiratory Emergency Room Visits	
Asthma Emergency Room Visits	Asthma Onset	
	Asthma Symptoms / Exacerbation	
	Lung Cancer Incidence	
	Work Loss Days	
	Alzheimer's Disease	
	Parkinson's Disease	

WHO Report Demonstrates High Air Pollution Health Risk

World Health Organization (WHO)



"Air pollution represents **the biggest environmental risk to health**." (2016)

"The burden of disease attributable to air pollution is now estimated to be on a par with other major global health risks such as unhealthy diet and tobacco smoking, and **air pollution is now recognized as the single biggest environmental threat to human health**." (2021)

Ambient $PM_{2.5}$ Ranks High in Global Burden of Disease (GBD)

DEATHS

2nd largest risk factor for deaths

In 2023, 7.9 million deaths linked to $PM_{2.5}$

- 96% of total deaths due to air pollution
- Largest environmental & occupational risk

Global Risk Factors for Death

All ages	Under 5 yrs
1. High blood pressure	1. Malnutrition
2. Air pollution	**2. Air pollution**
3. Tobacco	3. Water, sanitation, and hygiene
4. Diet	4. High or low temperature
5. High fasting plasma glucose	5. Tobacco

State of Global Air 2025
Global Burden of Disease project

QUALITY OF LIFE: DALY

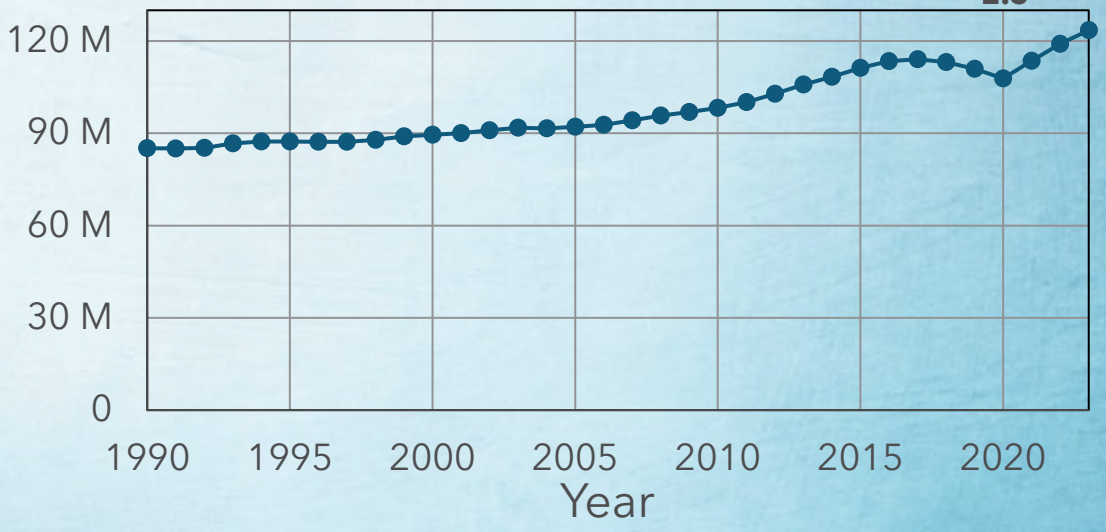
DALY: Disability-adjusted life years
1 DALY = 1 lost year of healthy life

Leading overall risk for DALYs

In 2023, 124 million DALYs due to $PM_{2.5}$

- 8% of total DALYs attributed to air pollution

Number of DALYs Attributable to $PM_{2.5}$



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Growing Body of Evidence of $PM_{2.5}$ Health Outcomes

Integrated Science Assessments (ISAs)

- Released by U.S. EPA in 2019

'"accurately reflect the **latest** scientific knowledge useful in indicating the **kind and extent** of identifiable **effects on public health and welfare** which may be expected from the presence of **pollutant(s) in the ambient air**" as described in…**the Clean Air Act**.'

- Cites 1,870 new scientific studies

"A **large body of scientific evidence spanning many decades** clearly demonstrates there are health effects attributed to both short- and long-term PM exposure..."

Quotes from 2019 Particulate Matter ISA

Determination of health outcomes from long-term exposure to $PM_{2.5}$

Causal	• Mortality • Cardiovascular effects
Likely to be causal	• Respiratory effects • Nervous system effects • Cancer
Suggestive of causal	• Metabolic effects • Male and female reproduction and fertility effects • Pregnancy and birth outcomes

Vulnerability to $PM_{2.5}$-related health effects varies by population characteristics

Factors contributing to increased risk of $PM_{2.5}$-related health effects include:

- Life stage
  Children, older adults
- Pre-existing diseases
  Cardiovascular, metabolic, or respiratory diseases
- Race/ethnicity
- Socioeconomic status, individual and community-level
  Income, education, occupation, etc.

New Research Finds Health Risks at Low $PM_{2.5}$ Concentrations

The Health Effects Institute's comprehensive research initiative

- **Large populations** (7-69 mil) with
- **Long-term exposures** (16-32 years) to
- **Low ambient $PM_{2.5}$** (8-15 µg/m^3)

All three studies found positive associations between mortality and exposure to $PM_{2.5}$ below previous U.S. National Ambient Air Quality Standard of 12 µg/m^3

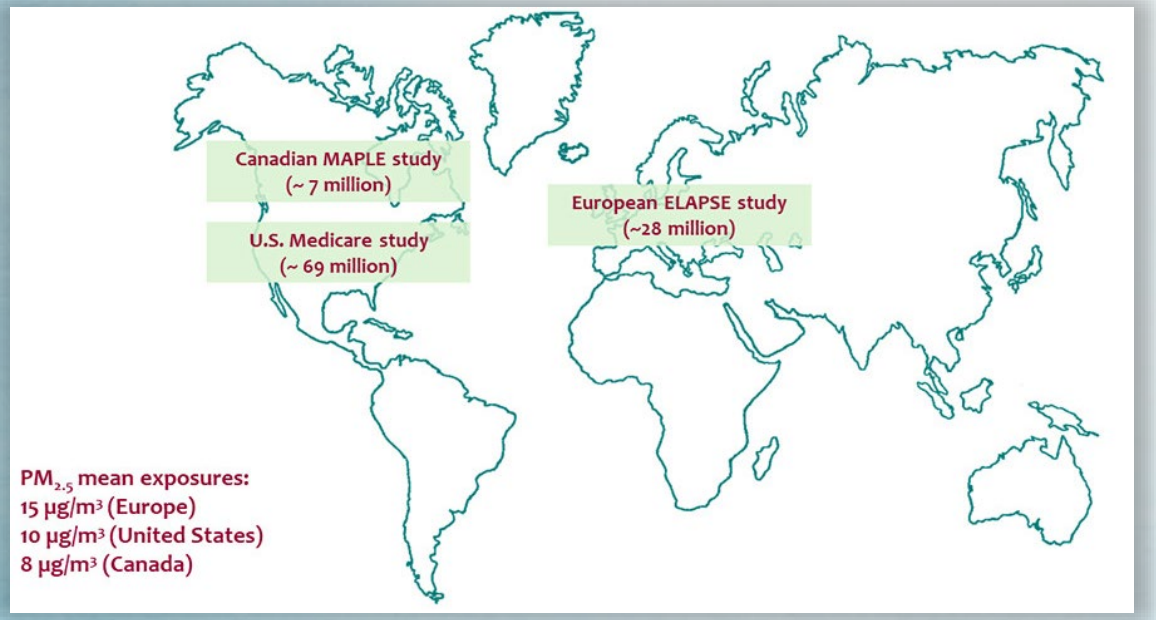

Figure adapted from Boogaard et al. (2024)

Additional endpoints associated with $PM_{2.5}$:

- Lung cancer
- Stroke
- Coronary heart disease
- Asthma
- Chronic obstructive pulmonary disease

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Board Resolution 20-13

April 23, 2020

Health Evaluation of Air Quality and Climate Regulations and Programs

Goal: a more comprehensive evaluation of the health benefits of CA's air quality & climate actions

NOW, THEREFORE, BE IT RESOLVED that the Board directs staff to pursue the following actions, with input from the public and stakeholders as appropriate:

1. Develop new quantitative and qualitative approaches to evaluate the health benefits of CARB's air quality and climate regulatory actions and programs;

2. Explore and develop new methods for evaluating health impacts in disadvantaged communities that account for increased vulnerability and exposure to sources of pollution that impact communities;

3. Update and expand the methodologies to analyze the health benefits from reducing emissions of ozone and secondary particle pollution and develop methodologies for additional pollutants;

4. Evaluate and propose new approaches to evaluate and communicate the public health benefits of reducing greenhouse gases and improving community sustainability, resiliency, and quality of life;

5. Investigate approaches to expanding health analysis to include a range of additional health outcomes linked to pollution exposure.

New and Updated Health Endpoints

Estimating Health Impacts from Air Pollution

Health effects from air pollution (or health benefits from reductions in air pollution) are estimated using a concentration-response (CR) function

$$\text{Change in health outcome} = \text{Population} \times \text{Baseline incidence rate} \times \left(1 - e^{-\beta \times \text{change in pollutant concentration}}\right)$$

Estimating Health Impacts from Air Pollution

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$$\text{Change in health outcome} = \text{Population} \times \text{Baseline incidence rate} \times (1 - e^{-\beta \times \text{change in pollutant concentration}})$$

Factor	Example (for mortality)
Population (of certain age group in geographic area of interest)	**25 million** (30-99 year olds in the state of CA)
Baseline incidence rate of the health endpoint of interest	**0.005** (5 deaths per 1000 people occur per year)
β (effect estimate) relates the health impact to a unit of pollution Derived from epidemiological studies	**0.0058** (derived from a hazard ratio of 1.06 for the association between $PM_{2.5}$ and all-cause mortality per 10 μg/m³ increase of $PM_{2.5}$)
Change in pollutant concentration	**1 μg/m³** (increase in $PM_{2.5}$)

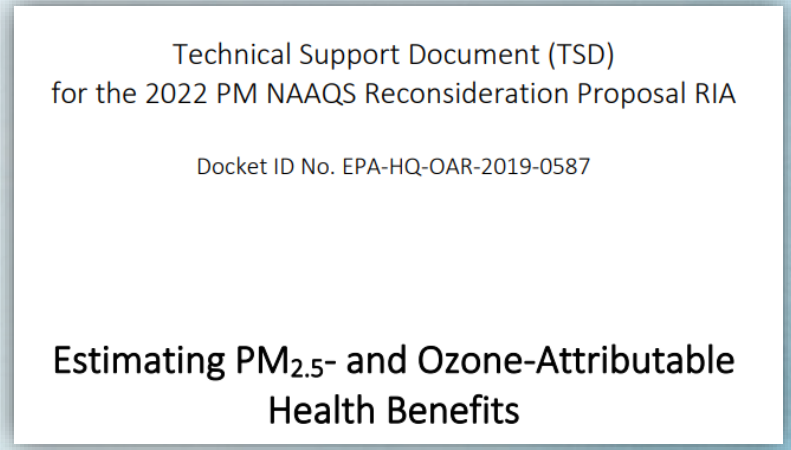
$$720 = 0.005 \times 25 \text{ million} \times (1 - e^{-0.0058 \times 1})$$

CARB → **720 more deaths due to increase in $PM_{2.5}$ by 1 μg/m³ in California**

CARB Plans To Quantify New $PM_{2.5}$ Health Endpoints

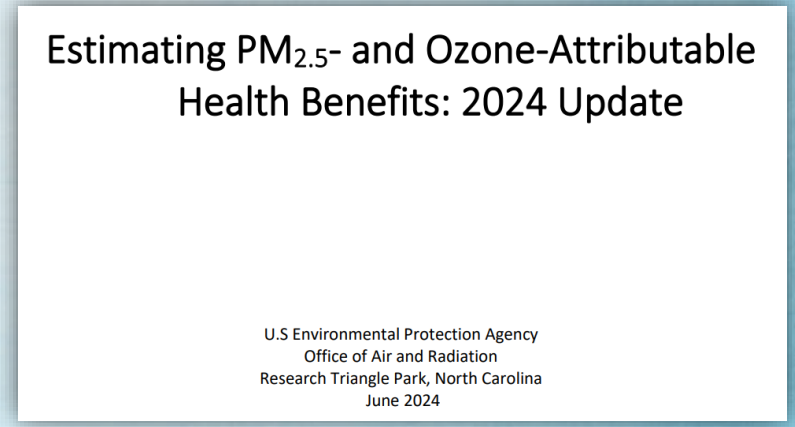
- Based on health research
- Analysis in US EPA's updated Technical Support Document (TSD)
- Underlying data is publicly available in US EPA's BenMAP software (https://www.epa.gov/benmap)

RIA: risk impact analyses


Technical Support Document (TSD)
for the 2022 PM NAAQS Reconsideration Proposal RIA

Docket ID No. EPA-HQ-OAR-2019-0587

Estimating $PM_{2.5}$- and Ozone-Attributable Health Benefits


Estimating $PM_{2.5}$- and Ozone-Attributable Health Benefits: 2024 Update

U.S Environmental Protection Agency
Office of Air and Radiation
Research Triangle Park, North Carolina
June 2024

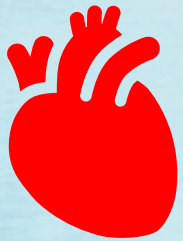
Criteria for Selecting Studies and Risk Estimates

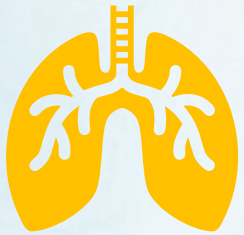
Criteria	Description
Study Period	Longer period of time and more recent studies are preferred.
Exposure Estimate	Preferred that exposures are estimated using combination of approaches (e.g., modeling, monitoring, etc.). Long-term/chronic exposure studies are preferred over short-term.
Study Type	For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

(Adapted from Tables 1 and 2 from US EPA's TSD)

Expanded $PM_{2.5}$ Health Endpoints

Previous Endpoints (in use till 2023)	New Endpoints (added in 2023)	What next?
Cardiopulmonary mortality	Cardiovascular Emergency Room Visits	Acute Myocardial Infarction, Nonfatal
Cardiovascular Hospital Admissions	Acute Myocardial Infarction, Nonfatal	Lost Work-Days
Respiratory Hospital Admissions	Respiratory Emergency Room Visits	Asthma Symptoms/Exacerbation
Asthma Emergency Room Visits	Asthma Onset	Cardiac Arrest
	Asthma Symptoms/Exacerbation	Stroke
	Lung Cancer Incidence	Allergic Rhinitis (Hay Fever)
	Work Loss Days	Minor Restricted Activity Days
	Alzheimer's Disease	
	Parkinson's Disease	





Total 17 endpoints

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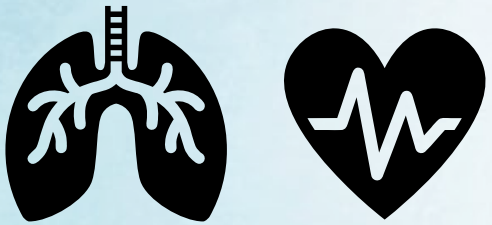
Valuation of Health Endpoints

Public Health Benefits

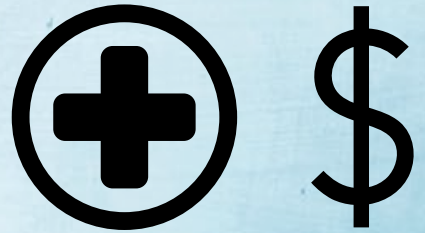


Quantified reductions in negative health outcomes because of a regulation, plan, or project

Standard Models and Datasets

- Valuation performed using standardized methods and data
- Pooled data from various studies

Valuation of Health Benefits



- Reduced medical costs
- Fewer lost wages
- Willingness to pay to reduce risk of mortality (value of statistical life)

Health endpoints

Definition

Significance

Why is this endpoint important?

Study: Association of exposure and endpoint

Scientific evidence for association between
$PM_{2.5}$ and health endpoint

Journal, Year

Novelty

How is the new scientific evidence distinct?

Study: Health endpoint and economic valuation

Scientific evidence for association between
health endpoint and economic valuation

Journal, Year

Acute Myocardial Infarction (Heart attack)

Hospitalization due to a non-fatal heart attack

Significance

- More than 600,000 hospitalizations due to heart attacks
- Captures health outcomes from short-term $PM_{2.5}$ exposure on cardiovascular health outcomes

Novelty

- U.S.-based study
- Analyzed over 95 million Medicare in-patient hospital claims from 2000-2012.
- Used zip code-level daily predictions of $PM_{2.5}$
- 1 μg/m³ increase in $PM_{2.5}$ associated with a 0.11% increase in AMI-related hospitalization risk.

Daily $PM_{2.5}$ exposure is associated with increased hospital admissions

Short term exposure to fine particulate matter and hospital admission risks and costs in the Medicare population: time stratified, case crossover study

Yaguang Wei [1], Yan Wang [1 2], Qian Di [3], Christine Choirat [4], Yun Wang [2], Petros Koutrakis [1], Antonella Zanobetti [1], Francesca Dominici [5], Joel D Schwartz [1]

BMJ, 2019

Economic Valuation

Cost estimation of cardiovascular disease events in the US

Amy K O'Sullivan [1], Jaime Rubin, Joshua Nyambose, Andreas Kuznik, David J Cohen, David Thompson

Pharmacoeconomics, 2011

Cardiac Arrest

Sudden and unexpected halt of heartbeat

Significance

- Endpoint with high rate (~90%) of fatality
- Bolsters link between $PM_{2.5}$ and emergency room visits for Out-of-Hospital Cardiac Arrest
- Captures effect of short-term $PM_{2.5}$ exposure on cardiovascular health outcomes

Novelty

- U.S.-based studies
- Strongest associations are seen consistently in shorter lag times (0-2 days) rather than longer lags.
- 1 μg/m³ increase in $PM_{2.5}$ is associated 0.46% increase in OHCA risk

$PM_{2.5}$ exposure is associated with increased risk of cardiac arrest

A Case-Crossover Analysis of Out-of-Hospital Cardiac Arrest and Air Pollution

Katherine B. Ensor, PhD; Loren H. Raun, PhD; D...

Circulation, 2013

Out-of-Hospital Cardiac Arrest and Airborne Fine Particulate Matter: A Case–Crossover Analysis of Emergency Medical Services Data in Indianapolis, Indiana

Authors: Frank. S. Rosenthal, John P. Carney, and M...

Environ Health Perspectives, 2008

Association of ambient fine particles with out-of-hospital cardiac arrests in New York City

Robert A Silverman [1], Kazuhiko Ito, John Free... Prezant

Am J Epidemiology, 2010

Economic Valuation

Cost estimation of cardiovascular disease events in the US

Amy K O'Sullivan [1], Jaime Rubin, Joshua Nyambose, Andreas Kuznik, David J Cohen, David Thompson

Pharmacoeconomics, 2011

Stroke

Blockage or bursting of blood vessels to or on the surface of the brain

Significance

- 37 deaths per 100,000 Californians (2020-2022)
- 4th leading cause of death in CA (2021)
- Higher risk in older adults
- Risk for stroke-related hospitalizations increases for both short- and long-term $PM_{2.5}$ exposure

Novelty

- U.S.-based study
- Used hospital records of adults aged 65 and older across six New England states.
- Used daily predicted $PM_{2.5}$ concentration levels
- 1 µg/m³ increase in $PM_{2.5}$ associated with 0.3% increase in stroke risk

Long-term $PM_{2.5}$ exposure has stronger effect on stroke risk than short term exposure

Acute and Chronic Effects of Particles on Hospital Admissions in New-England

Itai Kloog [1,*], Brent A Coull [2], Antonella Zanobetti [1], Petros Koutrakis [1], Joel D Schwartz [1]

PloS ONE, 2012

Economic Valuation

Real-world costs of ischemic stroke by discharge status

F Mu [1], D Hurley [2], K A Betts [1], A J Messali [1], M Paschoalin [3], C Kelley [1], E Q Wu [1]

Current medical research and opinion, 2017

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Minor Restricted Activity Days

Days with reductions, but not absenteeism, in adults' daily activities

Significance

- Captures effects on health and quality of life
- Measure of economic impacts of ambient air pollution

Novelty

- U.S.-based, national study
- Based on six annual Health Interview Surveys (1976-1981)
- Controls for differences in exposures across cities
- 1 μg/m³ increase in $PM_{2.5}$ associated with 0.7% increase in minor restricted activity days risk

$PM_{2.5}$ exposure is associated with 1) minor restrictions in activity and 2) work loss and bed disability due to respiratory symptoms

Air pollution and acute respiratory morbidity: an observational study of multiple pollutants

B D Ostro [1], S Rothschild

J of Environ Research, 1989

Economic Valuation

FROM: Robert E. Unsworth and James E. Neumann. Industrial Economics, Incorporated

SUBJECT: Review of Existing Value of Morbidity Avoidance Estimates: Draft Valuation Document

Method developed for EPA for estimate Willingness to Pay (WTP), or demand for healthcare to avoid marginal decline in health

Memorandum to Jim Democker, US EPA/OPAR, 1993

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Allergic Rhinitis (Hay fever)

A group of respiratory allergy symptoms affecting the nose

Significance

- Strong association between chronic $PM_{2.5}$ exposure and reporting of allergic rhinitis
- Associations persisted across socioeconomic status and urban-rural status

Novelty

- U.S.-based, national study
- Analyzed data from ~70,000 children (1999-2005 National Health Interview Survey data)
- Extensive sensitivity analyses on multi-pollutant exposures
- 1 µg/m³ increase in $PM_{2.5}$ is associated with a 2.9% increase in allergic rhinitis risk.

Chronic $PM_{2.5}$ exposure is associated with childhood respiratory allergies

Air Pollution and Childhood Respiratory Allergies in the United States

Jennifer D. Parker,[1] Lara J. Akinbami,[1] and Tracey J. Woodruff[2]

Environ Health Perspectives, 2009

Economic Valuation

Allergic rhinitis : trends in use and expenditures, 2000 and 2005

Author(s): Soni, Anita

United States Agency for Healthcare Research and Quality

Medical Expenditure Panel Survey, 2010

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Work Loss Days

Work loss events due to illness

Significance

- Captures health outcomes of short-term exposure that cause sick leave but not hospitalization
- Contributes to losses in productivity and economic growth

Novelty

- **California-specific** study using recent, representative population health data
- Incorporates advanced $PM_{2.5}$ exposure assessments
- Applies sophisticated statistical methods
- 1 µg/m³ increase in $PM_{2.5}$ associated with 2% increase in work loss day risk.

$PM_{2.5}$ exposure among Californians is associated with increased risk of work loss

Short-Term total and wildfire fine particulate matter exposure and work loss in California

Ying-Ying Meng [a], Yu Yu [a b], Mohammad Z. Al-Hamdan [c d], Miriam E. Marlier [b], Joseph L. Wilkins [e f], Diane Garcia-Gonzales [b], Xiao Chen [a], Michael Jerrett [b]

Environ International, 2023

Economic Valuation

Health and economic cost estimates of short-term total and wildfire PM2.5 exposure on work loss: using the consecutive California Health Interview Survey (CHIS) data 2015–2018

Ying-Ying Meng [1,✉], Yu Yu [1], Diane Garcia-Gonzales [2], Mohammad Z Al-Hamdan [3,4], Miriam E Marlier [2], Joseph L Wilkins [5,6], Ninez Ponce [1,7], Michael Jerrett [2]

BMJ Public Health, 2024

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Adult Asthma Symptoms

Shortness of breath, coughing, or wheezing

Significance

- Captures medical cost of asthma (prescriptions, hospitalization, outpatient visits, and emergency room care)

Novelty

- **California-specific** study with 2012-2019 data
- Relies on digital sensors to capture:
  - Participant-specific health outcomes
  - Year-round activity and exposure to pollution
- 1 µg/m³ increase in $PM_{2.5}$ associated with a 0.9% increase in medication use.

$PM_{2.5}$ exposure among Californians is associated with increased asthma medication use

Health effects of air pollution on respiratory symptoms: A longitudinal study using digital health sensors

Jason G. Su [a], Vy Vuong [b], Ehsan Shahriary [a], Shadi Aslebagh [a], Emma Yakutis [a], Emma Sage [a], Rebecca Hatle [a], John Balmes [a], Meredith Barrett [a]

Environ International, 2024

Economic Valuation

Ann Am Thorac Soc. 2018 Mar;15(3):348-356. doi: 10.1513/AnnalsATS.201703-259OC.

The Economic Burden of Asthma in the United States, 2008–2013

Tursynbek Nurmagambetov [1], Robin Kuwahara [1], Paul Garbe [1]

Ann Am Thorac Soc, 2018

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Summary of Studies

$$\text{Change in health outcome} = \text{Baseline incidence rate} \times \text{Population} \times (1 - e^{-\beta \times \text{change in pollutant concentration}})$$

Endpoint	Study	Effect Estimate	Age Range	Location
Acute Myocardial Infarction, nonfatal	Wei et al., 2019	0.0011	Adults 65-99	US
Cardiac arrest	Ensor et al., 2013	0.0064	All ages 0-99	US
	Rosenthal et al., 2008	0.0019		
	Silverman et al., 2010	0.0039		
Stroke	Kloog et a., 2012	0.0034	Adults 65-99	New England
Allergic Rhinitis (Hay fever)	Parker et al., 2009	0.0254	Children 3-17	US
Minor Restricted Activity Days	Ostro and Rothschild, 1989	0.0074	Adults 18-64	US
Work Loss Days	Meng et al., 2023	0.0193	Adults 18-64	CA
Adult Asthma Symptoms	Su et al., 2024	0.0089	All ages 4-90	CA

Estimated Outcomes for Californians Due to $PM_{2.5}$ Exposure

$$\text{Change in health outcome} = \text{Baseline incidence rate} \times \text{Population} \times \left(1 - e^{-\beta \times \text{change in pollutant concentration}}\right)$$

Endpoint	Age Range	Annual number
Acute Myocardial Infarction, nonfatal	Adults 18-99	366 Hospitalizations
Cardiac arrest	All ages 0-99	181 Hospitalizations
Stroke	Adults 65-99	739 Hospitalizations
Allergic Rhinitis (Hay fever)	Children 3-17	215.3 K Cases
Minor Restricted Activity Days	Adults 18-64	10.4 M Days
Work Loss Days	Adults 18-64	7 M Days
Adult Asthma Symptoms	All ages 4-90	12.9 M Cases

(Estimated using 2023 CARB PM2.5 satellite driven surface data in US EPA's BenMAP software version 1.5.8; *numbers above are draft values*)

Next Steps

Near-Term Next Steps

- Oct 31-Nov 21: CARB will take **public comment** on these additional health endpoints.
- Early 2026: CARB will release **Updated Health Endpoints Bulletin**, with the following information:
  - Description of the supporting research
  - Effect estimate (CR function) to calculate the endpoints
  - General responses to questions raised during the workshop and in the online public comments
  - Valuation methodology
  - Approximate timeline for incorporating the endpoints in regulatory analysis

Ongoing and Longer-Term Work

EXPANDING CARB ANALYSES

Health consultants

- Review available community-focused health analysis methods
- Recommend approaches to expand CARB's health impact analyses

Health Equity analysis

- Develop methods to quantify differences in health outcomes for subpopulations

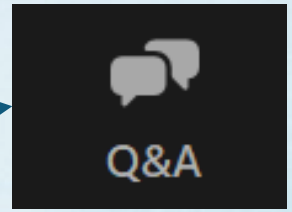
CARB-FUNDED STUDIES OF CALIFORNIA POPULATIONS

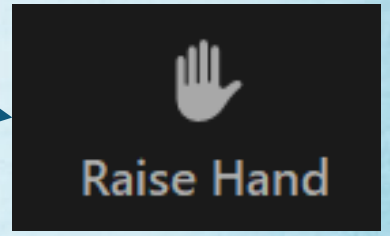
- **Metabolic Health** and criteria pollutants
  Diabetes incidence, medication use, ED visits, hospitalizations, death
- **Birth Outcomes** and criteria pollutants
  Pre-term birth, low birth weight, Autism Spectrum Disorder
- **Neurodegeneration** and criteria pollutants
  Parkinson and Alzheimer's Diseases, cognitive decline
- **Neurodevelopment** and criteria pollutants
  Student standardized test performance
- **Life Expectancy** and $PM_{2.5}$
  Change in life expectancy over time
- **Respiratory Symptoms** and train, port emissions
  Use of medication puff and ED visits in Southern California

Questions and Feedback

You can either:

- Type your question in the Q&A
- Raise your hand to be added to the speaking queue
  - Click **Raise Hand**
  - If using a phone, **Dial *9**





Thank you for attending!

To provide public comments:

- Online by November 21, 2025: https://ww2.arb.ca.gov/public-comments/proposed-updates-health-endpoints-use-carbs-health-analysis-2025

We will compile comments and address them in the upcoming Bulletin.