CalSPEC
California State Policy Evidence Consortium

Near-Roadway Indoor Air Pollution

A Legislative Policy Briefing

Thursday, March 7, 2024

2:00-3:30pm

Agenda

2:00 – 2:05pm	**Legislative Staff Introduction**	**Eric Walters** Senate EQ Committee
2:05 – 2:15pm	**About CalSPEC**	**Richard Kravitz, MD, MSPH** **Dominique Ritley, MPH** CalSPEC Co-directors
2:15 – 2:25pm 2:25 – 2:35pm	**Composition and Prevalence of Near-Roadway Indoor Air Pollutants** *Questions*	**Suzanne Paulson, PhD** **Viraj Sawant, PhD candidate** UCLA
2:35 – 2:45pm 2:45 – 2:55pm	**Health Effects of Near-Roadway Air Pollutants** *Questions*	**Nicholas Chartres, PhD** **Tracey Woodruff, PhD** UCSF
2:55 – 3:10pm 3:10 – 3:20pm	**Mitigation Strategies** *Questions*	**Ling Jin, PhD** **Madeline Sit, MPH candidate** LBNL
3:20 – 3:30pm	**Additional Questions/Discussion**	**All**

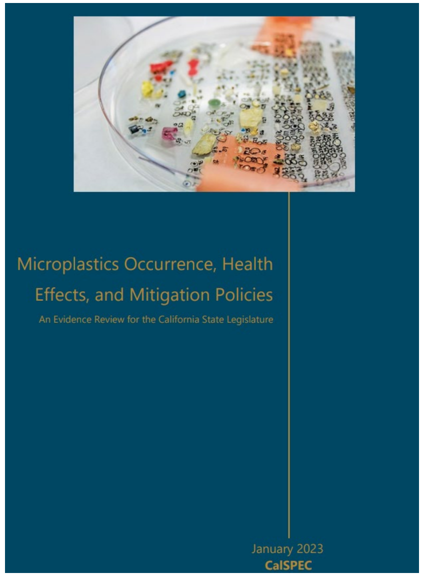
Aims

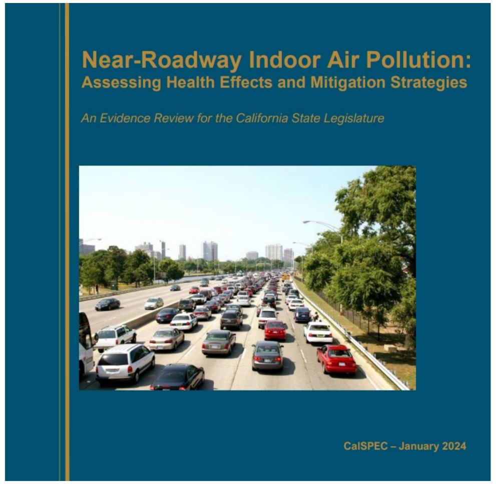
- Enlist California's premier public research university in supporting public policy

- Synthesize evidence that informs state legislative deliberations

Initial Guideposts

Funding for two report cycles





Project requirements

- **Select important problem**, driven by legislative committee needs
- Focus on **evidence synthesis**, not opinion or primary empirical research
- Provide **balanced, unbiased, non-partisan, reproducible summary** of available evidence

CalSPEC Structure

Consortium Advisory Council

Administrative/Editorial Core

Campus Partner 1	Campus Partner 2	Campus Partner 3

Cycle #1	Microplastics	UC Davis	UCSF	UC Berkeley
Cycle #2	Near-Roadway Indoor Air Pollution	UCLA	UCSF	LBNL

Composition And Prevalence of Near-Roadway Indoor Air Pollutants

Dr. Suzanne Paulson – Professor, Atmospheric and Oceanic Sciences, University of California, Los Angeles

Viraj Sawant, MS – Doctoral Candidate, Institute of Environment and Sustainability, University of California, Los Angeles

Key Questions

- What are the traffic-related air pollutants that are elevated near roadways and what are their spatial distributions?
- How do pollutants enter indoor environments and what are the factors affecting the entry process?
- What is the evidence on indoor prevalence of traffic related air pollutants and how does contribution from outdoors compare with that from indoor sources?

Key Definitions

Near-roadway Air Pollution (NRAP)

Air pollution "within a few hundred meters – about 500-600 feet downwind from the vicinity of heavily traveled roadways or along corridors with significant trucking traffic or rail activities. This distance will vary by location and time of day or year, prevailing meteorology, topology, near land use, traffic patterns, as well as the individual pollutant". (EPA, 2014)

Heavily-trafficked Roadways

- Urban traffic >100,000 vehicles/day
- Rural traffic >50,000 vehicles/day

(CA Public Resources Code, Section 21151.8)

Methods

Literature review for following broad topics:

- Roadway pollutants
- Spatial variability of pollutants around roadways
- Indoor-outdoor ratio
- Infiltration of air pollutants into indoor spaces

Key Insight 1: Roadway pollutants come from tailpipes, brakes, tires, and road wear

Source	Pollutants
Gasoline Tailpipe Emissions	Ultrafine particles (UFP/$PM_{0.1}$) Nitrogen oxides (NO and NO_2) Volatile organic compounds (VOCs) Carbon Monoxide (CO) Carbon Dioxide (CO_2) Sulfur Dioxide (SO_2) Ammonia (NH_3)
Diesel Tailpipe Emissions	Nitrogen Oxides (NO_x) Ultrafine Particles (UFP) Elemental Carbon (EC)
Brake and Tire Wear	Particulate matter (PM) – mostly in the PM_{10} size range; some $PM_{2.5}$)
Road Dust	Particulate matter (PM) – mostly in the PM_{10} size range; some $PM_{2.5}$)
Evaporative Emissions (including fuel leaks)	Volatile organic compounds (VOCs)

Particulate Matter:

Ultrafine particles (UFP/ $PM_{0.1}$): particles smaller than 0.1 microns in diameter

$P.M_{2.5}$: particles smaller than 2.5 microns in diameter

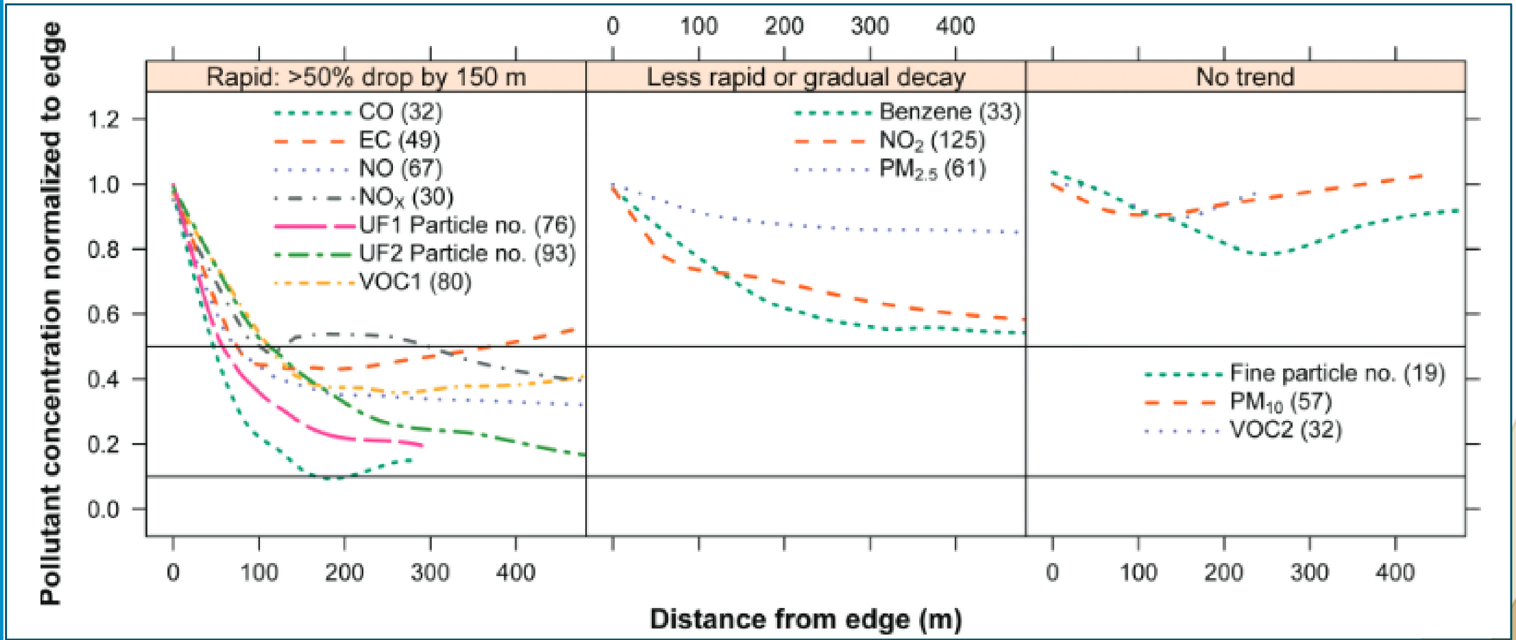
$P.M_{10}$: particles smaller than 10 microns in diameter

Volatile Organic Compounds: gas phase compounds consisting of carbon and hydrogen (may include other elements)

- Vary widely in toxicity, odors, and other characteristics
- Includes air toxics such as benzene

Key Insight 2: Several harmful pollutants are highly elevated near roadways

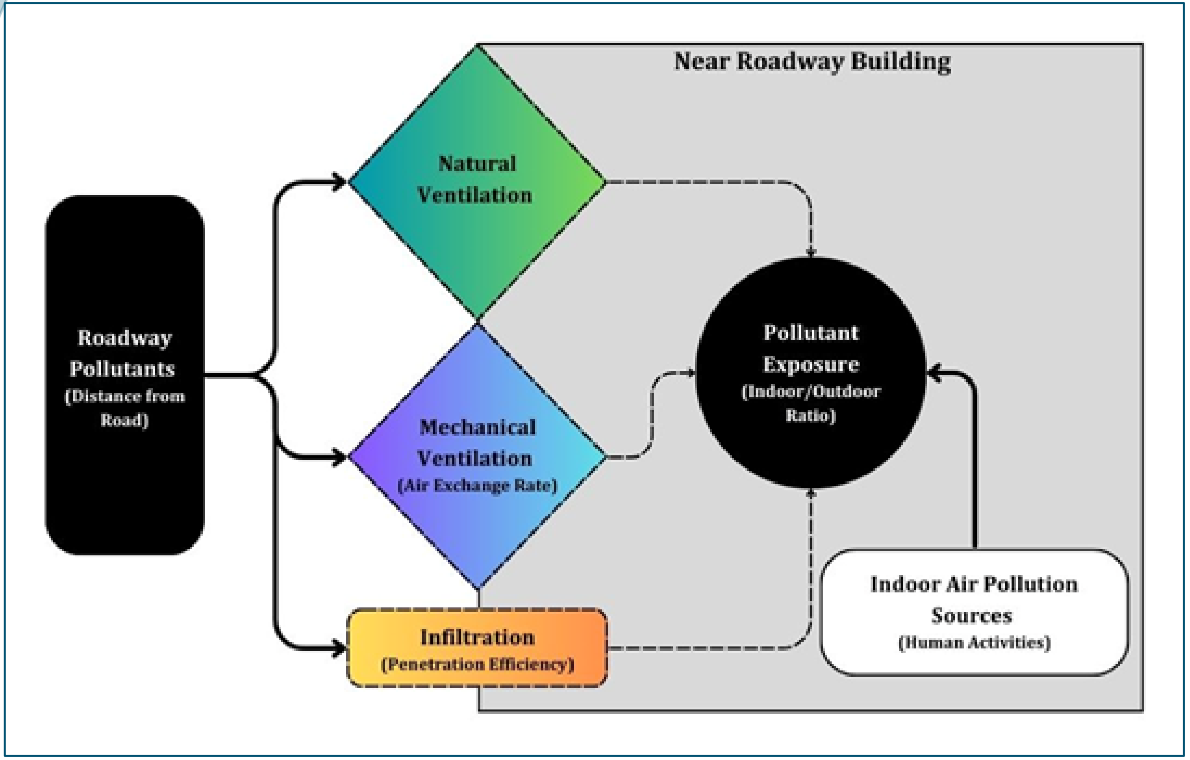
- Pollutants that are highly elevated near roadways (compared with urban air farther away):
  - Nitrogen oxides (NO and NO_2)
  - Ultrafine Particles (UFPs)
  - Elemental Carbon (EC)
  - Carbon Monoxide (CO)
- Pollutants that are also elevated:
  - Brake and tire wear particles
  - $PM_{2.5}$ particles are slightly elevated
- NO_2, $PM_{2.5}$ and CO are regulated as NAAQS or CAAQS but these pollutant levels do not commonly exceed their respective standards



500 ft ≅ 150 m

- Pollutant concentrations tend to drop off during daytime (see figure)
- Studies in California show that at night and during early morning rush hour, impact distances can be much farther (≥1000 m)

Key Insight 3: Pollutants enter indoor environments through multiple pathways



Three pathways through which outdoor air pollution enters indoor environments:

1. *Natural Ventilation:* Open windows, doors
2. *Mechanical Ventilation:* Ventilation systems
3. *Infiltration:* Gaps/cracks in building envelope

Metrics used to analyze pathways:

1. *Air Change Rate:* Rate at which air in an indoor environment is rotated outside
   - a volume equal to the indoor space is usually exchanged at least once/hour
2. *Indoor/Outdoor Ratio:* Ratio of the indoor concentration of a pollutant to the outdoor concentration
3. *Penetration Efficiency:* Ability of a pollutant to penetrate through the building envelope

Key Insight 4: Contribution of outdoor sources to indoor air pollution is significant

- Challenging to estimate the proportion of indoor pollution that originates outdoors
  - Dependent on many factors such as pollutant, structure type/age, occupant behavior, indoor sources
- Outdoor sources are responsible for *approximately 30-90%* of the pollutant concentration indoors

Examples of research findings demonstrating variation:

- Review of studies about schools and offices found average I/O ratio for NO_2 to be 0.9.
- A Denver study reported an NO_2 I/O ratio to be 2.3 in homes with gas stoves and 1.0 in homes without gas stoves (Gas stoves - major indoor source of NO_2).
- A study at three retirement homes in Los Angeles Basin reported I/O ratio of 0.8 for EC (a TRAP tracer) with high indoor/outdoor correlation (0.83) supporting significant contribution of outdoor sources to indoor air pollution.

Conclusions

- Major pollutants commonly elevated near-roadways:
  - Ultrafine particles (UFPs)
  - nitrogen oxides (NO and NO_2)
  - Carbon monoxide (CO)
  - Volatile Organic Compounds (VOCs)
  - Brake, tire, and road wear particles
- Pollutant concentrations indoors are modestly lower (~10% - 40%) than outdoor concentrations (absent indoor pollutant sources)
- Outdoor pollution is responsible for around 30% – 90% of most indoor pollutant concentrations (varies due to many factors)
- Even when indoor sources are present, outdoor sources still make a significant contribution to indoor pollutant concentrations

Future Outlook

- **Despite increasing vehicle miles traveled, tailpipe emissions have fallen dramatically over the past decades due to regulations**
  - Tailpipe emissions are expected to continue to decline due to clean vehicle regulations, but the transition will take years
- **Brake, tire, and road wear particles have been increasing recently; emissions increase as vehicle weight increases**
  - Electric vehicles are heavier than older vehicles. Some research suggests regenerative braking may mitigate brake wear emissions, but less effective at mitigating tire wear particles
  - There is little regulation of this type of emissions; technical solutions are in their early stages
- **Urban neighborhoods with lower socioeconomic position often have higher exposures to roadway pollutants**

Questions?

Health Effects of Near Roadway Air Pollutants

Emily Lasher, MSPH Candidate[1]

Olivia Stoddard, MPH Candidate[1]

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Nicholas Chartres, PhD[2]

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Key Questions

What are the human health effects of exposure to near roadway air pollution (NRAP)?

To what extent are specific groups of Californians at increased risk for negative health effects of NRAP?

Objectives

1. ***Identify, assess the quality, and summarize the data of systematic reviews*** evaluating the human health effects of NRAP.

2. Provide a ***conclusive summary statement*** about the human health effects of NRAP.

3. Address the extent to which ***specific groups of Californians*** (identified by age, race/ethnicity, socioeconomic status, or health history) ***are at increased risk*** for negative health effects of NRAP.

Methods

- Conducted a ***rapid overview of reviews*** using well-established methods

- ***Developed and published a protocol*** with the following steps:
  - search strategy,
  - inclusion/exclusion criteria,
  - method for evaluating systematic review quality and,
  - overall strength of evidence

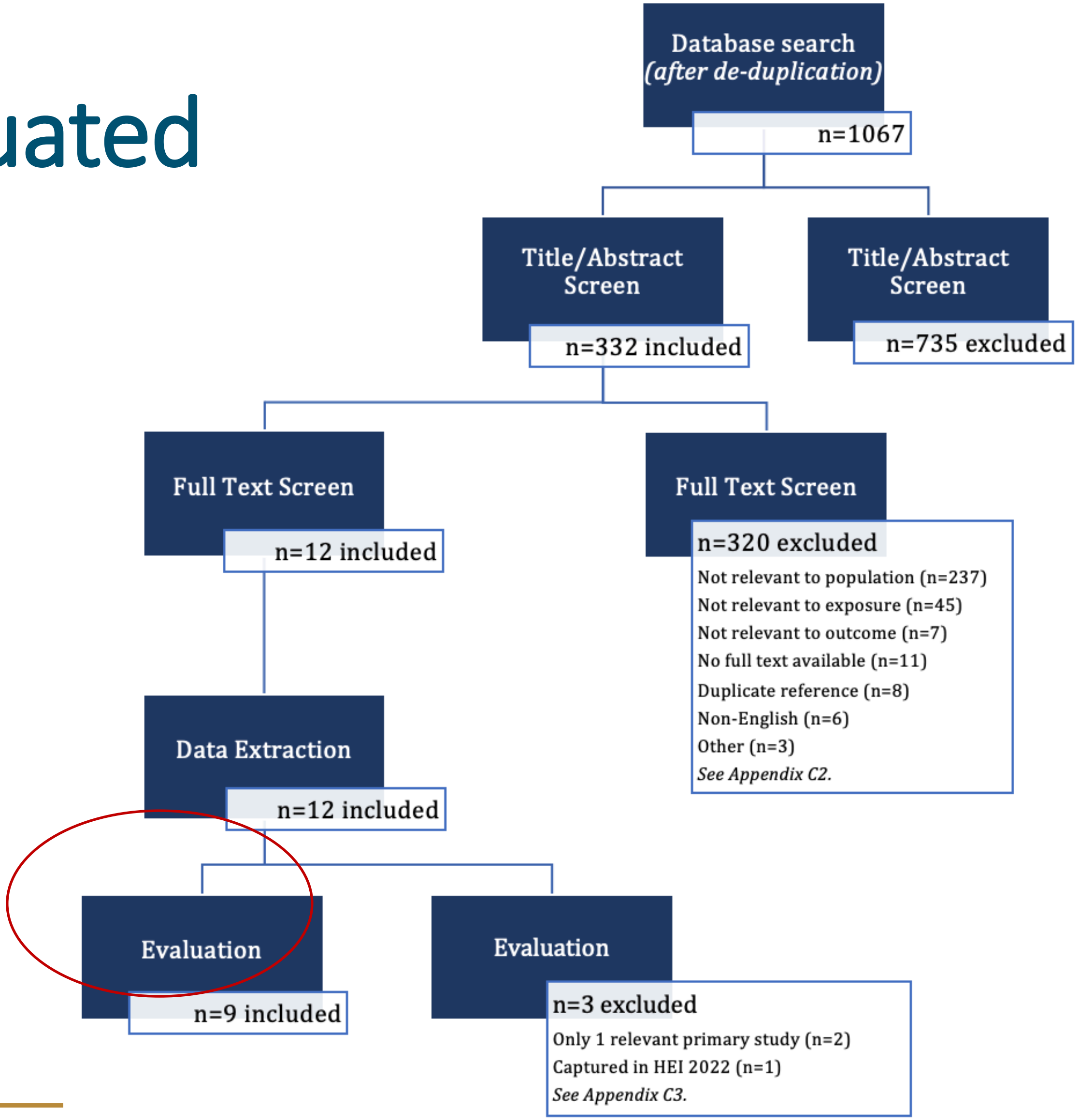
Methods

- Exposures
  - ***Focused on reviews evaluating***
    - *proxy measures of NRAP* (distance to roadway/traffic density)
    - And/or single pollutants ***nitrogen dioxide (NO_2) and elemental carbon (EC)*** near roadways (indicators of NRAP)

- Health Effects
  - ***Focused on mortality*** and health effects related to ***respiratory, cardiovascular, reproductive, nervous, endocrine systems, and cancer.***

Systematic Reviews Evaluated

- ***Nine systematic reviews*** were selected for a rigorous evaluation of quality
  - ***Three systematic review*** met all CalSPEC evaluation criteria for reporting results
- Published between 2016 – 2023



Exposures and Health Effects Prioritized for Evaluation

Body System	Health Effect	Exposure
Cardiovascular	Hypertensive disorders of pregnancy	Traffic measures, NO_2
	Ischemic heart disease (IHD)	NO_2, EC
	Incidence of coronary events	NO_2
	Stroke	NO_2, EC
Respiratory	Prevalence of asthma ever in children	NO_2, EC
	Incidence of COPD	NO_2
Reproductive	Term low birth weight	NO_2, EC
	Term birth weight	NO_2, EC
	Small for gestational age	NO_2, EC
	Preterm birth	NO_2, EC
Endocrine	Diabetes	NO_2, EC
Mortality	All-cause mortality	NO_2, EC
	Cause-specific mortality – circulatory	NO_2, EC
	Cause-specific mortality – respiratory	NO_2, EC
	Cause-specific mortality – lung cancer	NO_2, EC
	Cause-specific mortality – IHD	NO_2, EC
	Cause-specific mortality – stroke	NO_2
	Cause-specific mortality – COPD	NO_2

Findings from Systematic Reviews

The body of evidence meeting CalSPEC's methodological quality criteria found:

Established Evidence that NRAP exposure increases the risk of:	*Likely Evidence* that NRAP exposure increases the risk of:	*Suggestive Evidence* that NRAP exposure increases the risk of:
• prevalence of ever having asthma in children • diabetes • all-cause mortality • lung cancer mortality • heart disease mortality	• hypertensive disorders of pregnancy • heart disease and incidence of coronary events • term low birth weight • circulatory mortality • respiratory mortality • stroke mortality • chronic obstructive pulmonary disease mortality	• stroke • decreased term birth weight • preterm birth

Disproportionate Health Impacts of NRAP

CalSPEC evaluated associations between population characteristics and NRAP exposure:

- Traffic exposure data for census tracts in California from **CalEnviroScreen 4.0**
- Demographic variables: age, race/ethnicity, linguistic isolation, and sex
- Socioeconomic variables: poverty, health insurance status, and educational attainment

We found census tracts with a greater proportion of:

- **people of color** (Black, 18% Latino, 2% and AAPI, 19%)
- those experiencing **linguistic isolation** (42%), and
- those that are **uninsured** (75%)

are *more* likely to live in areas with higher traffic pollution

Conclusions

Significant Evidence that NRAP increases the risk of multiple health conditions/outcomes across broad swath of biological systems:

- Cardiovascular
- Endocrine
- Reproductive
- Respiratory
- Mortality

Large body of low quality evidence bolsters conclusion that traffic density and proximity to busy roads increases risk of multiple adverse health outcomes

- Cardiovascular (incidence of heart disease, stroke)
- Respiratory (asthma in adults)
- Reproductive (decreased term birth weight)
- Endocrine (type 2 diabetes)
- Mortality (circulatory, respiratory, heart disease, stroke)

NRAP is also an environmental justice issue

- People of color, those experiencing linguistic isolation, and those uninsured are most likely to experience higher traffic pollution in California.

Policy Implications

The available evidence supports **action to mitigate and/or prevent exposures from NRAP** based on *Established Evidence, Likely Evidence,* and *Suggestive Evidence* due to

- widespread, disproportionate exposure
- environmental justice concerns
- likelihood of underestimating health effects

Questions?

Chapter 3: Mitigation Strategies

Dr. Ling Jin, Research Scientist - Lawrence Berkeley National Laboratory
Madeline Sit, MPH candidate - University of California, Berkeley

Key Questions

- To what extent have specific mitigation strategies been effective in reducing near-roadway indoor air pollution?

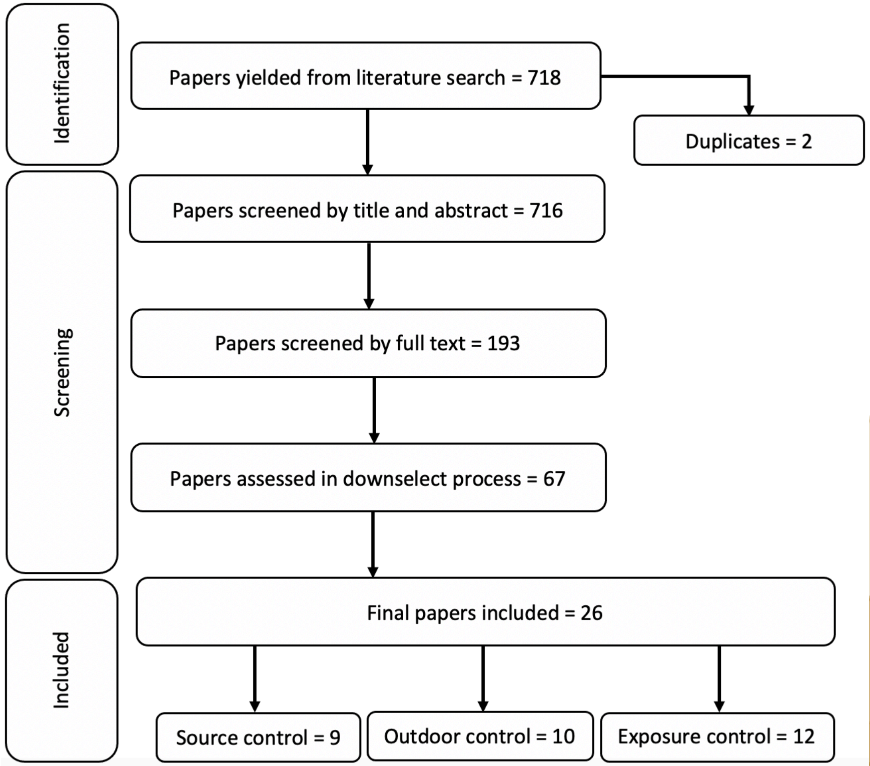
- What is the relative cost (or when available, cost-effectiveness) of these strategies?

Methods: Literature Search around Three Categories of Control Strategies

Source control: reduce the amount of primary and precursor emissions related to on-road traffic (e.g., strategies to reduce vehicle miles travelled, improve fuel efficiency, travel and traffic controls.)

Outdoor control: reduce near-roadway outdoor concentrations of TRAP arriving at the receptor buildings. (e.g. barriers and sinks, built environment design.)

Indoor Control: reduce indoor exposure and health impacts. (e.g. building envelope control and indoor removal by air tightening and upgrading heating and air conditioning filters)



Study selection diagram

Evaluation Methods

To assess the weight of evidence, we considered: quality of body of evidence, direction of effect estimates, confidence in effect estimates.

Weight of Evidence Level	Definition and Criteria
Sufficient	At least 3 primary studies suggest an effect based on observed via diverse settings and/or methods; mostly absent of known confounding factors or biases (>50% of the primary studies).
Moderate	At least 3 primary studies suggest an effect, but downgraded due to reasons such as: (1) *lack of diversity of the methods* or experimental approaches used to estimate the effects (e.g., effects were based entirely on model simulations rather than field measurements); (2) *potential confounding effects* and biases in >50% of the studies; or (3) *limited generalizability* related to the study time period or location/population.
Insufficient	There is a paucity of evidence of effect due to a lack of studies (<3 primary studies referenced across all the included review articles) or inconsistent or weak effects (e.g., substantial directional inconsistency and/or non-statistically significant outcomes).

Source Control Finding 1: Vehicle Technology Advances

Sufficient
Moderate
Insufficient

Strategies	Effects of Strategy on Reducing:	
Intervention Assessed	**On-Road Emissions**	**Near-Road Concentrations**
Emerging vehicle technology advances and adoption	From <20% to >50% reduction in gaseous pollutants. Inconclusive for PM pollutants.	Inconclusive
Long-term policies to improve fuel and emission standards	Reduction up to 99% measured long-term.	Reduces near-roadway concentrations

CalSPEC found sufficient evidence that long-term interventions, such as tightened fuel/emission standards, were effective in reducing on-road vehicular emissions.

Source Control Finding 2: Travel and Traffic Management

Sufficient
Moderate
Insufficient

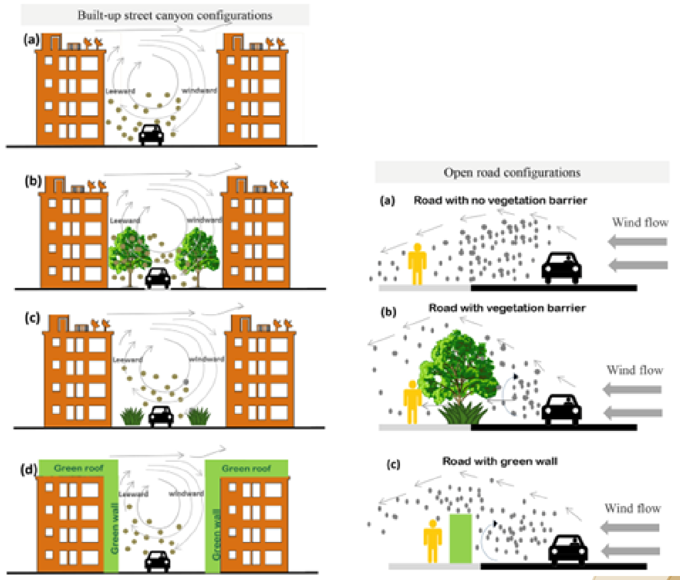
Strategies		Effects of Strategy on Reducing:	
Subcategory	Intervention Assessed	On-Road Emissions	Near-Road Concentrations
Operating restrictions and pricing	Road congestion pricing	<50%	<25%
	Low emission zones	<50%	<25%
	Vehicle operation restrictions	Varies from <20% to >50%	Inconclusive
Speed management	Lower speed limits	<27%	Inconclusive
Traffic flow control	Intersection control device	<50%	N/A
	Traffic signal timing	<50%	N/A
Eco-driving/eco-routing	Eco-driving/eco-routing	<20%	N/A

CalSPEC found moderate evidence that the above interventions were effective in reducing on-road emissions. Lower speed limits and eco-driving are the top-ranking strategies in terms of their cost effectiveness for emission controls, largely because they do not require costly investment in infrastructure or significant technology improvements.

Outdoor Control Finding 1: Obstacles and Sinks

Sufficient
Moderate
Insufficient

Strategies		Effects of Strategy on Reducing Ambient Concentrations
Subcategory	**Intervention Assessed**	
Green infrastructure	Vegetation barriers	**Trees**: *worsen* NRAP in street canyons; >50% reduction near open street. **Hedges**: reduction by 24-61% in street canyons and by 15-60% near open streets.
	Green walls/roofs	**Green walls:** reduction up to 95%, 50%, and 46% in ultra-fine particles, PM10, and NO2. **Green roofs**: reduction by 2-52%.
Non-vegetation obstacles	Roadside barriers	Reduction <50%
	Parked cars	Reduction by 15–49%
	Artificial sinks	Reduction by 40-50%



Abhijith et al. 2017

CalSPEC found sufficient evidence that roadside barriers were effective in improving local air quality near roadways. Trees and hedges have low installation and operation costs, while fully grown green walls are more expensive. Maintenance costs are considered moderate following routine gardening practices. Parked cars are low cost.

Outdoor Control Finding 2: Built Environment Design

Sufficient
Moderate
Insufficient

Strategies		Effects of Strategy on Reducing Ambient Concentrations
Subcategory	**Recommended Design**	
Street canyon configuration	Canyon orientation – streets parallel to wind directions	Increase ventilation and reduce pollutant levels.
	Lower aspect ratio (AR), preferably with height-to-width less than 0.65.	
Building architecture	Roof shape – pitched roofs rather than flat roofs in canyons with AR < 1	Increase ventilation and reduce pollutant levels.
	Building height – variable building heights preferred	Reduction by 40-45%.
	Building setback – half open space outside on the side of the building is recommended	Reduction by 6-13%.
	Building permeability – lift-up design with void decks underneath first floor	Reduction by 34-50%.
Land use buffers	Separation distance from roadways – 500m away	Reduce concentration from roadway edge level to background level.

CalSPEC found moderate evidence that proper design of the above interventions might reduce ambient pollutant levels near roadways.

Indoor Control Findings

Sufficient
Moderate
Insufficient

Strategies	Effects of Strategy on Reducing:	
	Exposure/Concentrations	Health Risks
Retrofits	Inconclusive	Decreasing
Ventilation schedule and rates	34-43%	N/A
Filtration	Air purifiers: 22.6-92% Air purifiers with HEPA: 30-90% HVAC systems with high efficiency filters: 30-99%	Mixed
Phytoremediation	28-93%	Low

CalSPEC found sufficient evidence that indoor air filtration is highly effective at removing pollutant concentrations, but mixed evidence of its effectiveness on intermediate health outcomes. There is moderate evidence that phytoremediation can reduce indoor air pollution.

Concluding Statement

On-Road Source Control Strategies	Near-Roadway (Ambient) Air Pollution Control Strategies	Indoor NRAP Control Strategies
Sufficient Evidence of Effectiveness • Advancement in vehicle technologies (especially those that comply with tightened fuel and emission standards)	**Sufficient Evidence of Effectiveness** • Obstacles and sinks, especially roadside barriers (e.g., soundwalls) that block or inhibit pollution movement	**Sufficient Evidence of Effectiveness** • Indoor removal through filtration
Moderate Evidence of Effectiveness • Clean vehicle policies • Traffic management (road congestion pricing, vehicle operation restrictions, low emission zones, lower speed limits, intersection controls with roundabouts and signal timing, and eco-driving)	**Moderate Evidence of Effectiveness** • Green infrastructure (tree/hedge barriers, vegetation walls/roofs) • Non-vegetation obstacles (parked cars and artificial sink devices) • Optimized design of built environment including street canyons, building architecture, and land use planning	**Moderate Evidence of Effectiveness** • Retrofits • Phytoremediation

To improve cost-efficiency, priority deployment of these interventions should target subpopulations most at risk as identified by the health effects findings.

However, these populations will likely require considerable support to access maintain these interventions (e.g., portable filters at household level).

Policy Implications

- Mitigation in the context of infill policies
  - Incentivizing clean vehicles; improving traffic management through intersection design and traffic restrictions in and around these communities.
  - Appropriate built environment design for infill housing would preserve enough ground-level open space for urban ventilation and reduced NRAP accumulation.
- Prioritize mitigation considering environmental justice
  - Pilot projects across California based on local needs and constraints such as population density and vulnerability to NRAP health effects, built environment, local weather patterns, and traffic volume.
- Target influential sources for mitigation
  - Diesel trucks are the primary source of black carbon and NOx, which drive adverse health outcomes; thus, exploring policies to restrict diesel truck traffic and/or incentivize electrification of truck fleets would likely improve indoor air quality among structures near high-trafficked roads, and may have a positive impact on reducing disparities among vulnerable populations.

Policy Implications

- Consider near-term mitigation strategies
  - Short-term intervention with portable air cleaners for indoor filtration, which do not require additional costly construction and can be deployed quickly among priority communities.
  - Financial support
- Long-term monitoring and program evaluation
  - Consider increasing NRAP permanent outdoor and rotating indoor monitoring in densely populated areas for neighborhoods 100–500 feet (or more) from high-traffic roads to improve baseline data and measure effectiveness of mitigation strategies that may be implemented locally or statewide.
  - Monitor federal activities for future funding opportunities for mitigation pilot projects, research evaluations, and strategy implementation and deployment to fill the data and research gaps.

Questions?

Read CalSPEC's Full Report on Near-Roadway Indoor Air Pollution:

https://uccs.ucdavis.edu/2023-research-topic-near-roadway-indoor-air-pollution

Contact the CalSPEC team: CalSPEC@ucdavis.edu