Photo: Robert Collins, Unsplash

Healthy Air for Healthy Kids

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Northwest PEHSU
Pediatric Environmental Health Specialty Units

Scope of this Presentation

POLICY STATEMENT Organizational Principles to Guide and Define the Child Health Care System and/or Improve the Health of all Children

American Academy of Pediatrics

DEDICATED TO THE HEALTH OF ALL CHILDREN®

Ambient Air Pollution: Health Hazards to Children

Heather L. Brumberg, MD, MPH, FAAP,[a] Catherine J. Karr, MD, PhD, FAAP,[b] COUNCIL ON ENVIRONMENTAL HEALTH

- ✓ U.S./high income country focused
- ✓ Anthropogenic pollutants that originate outdoors
- ✓ Some local data and data from my research program

Sources, Types & Disparities

Complex Mixture of Gases & Particles

Local, regional & long range transport

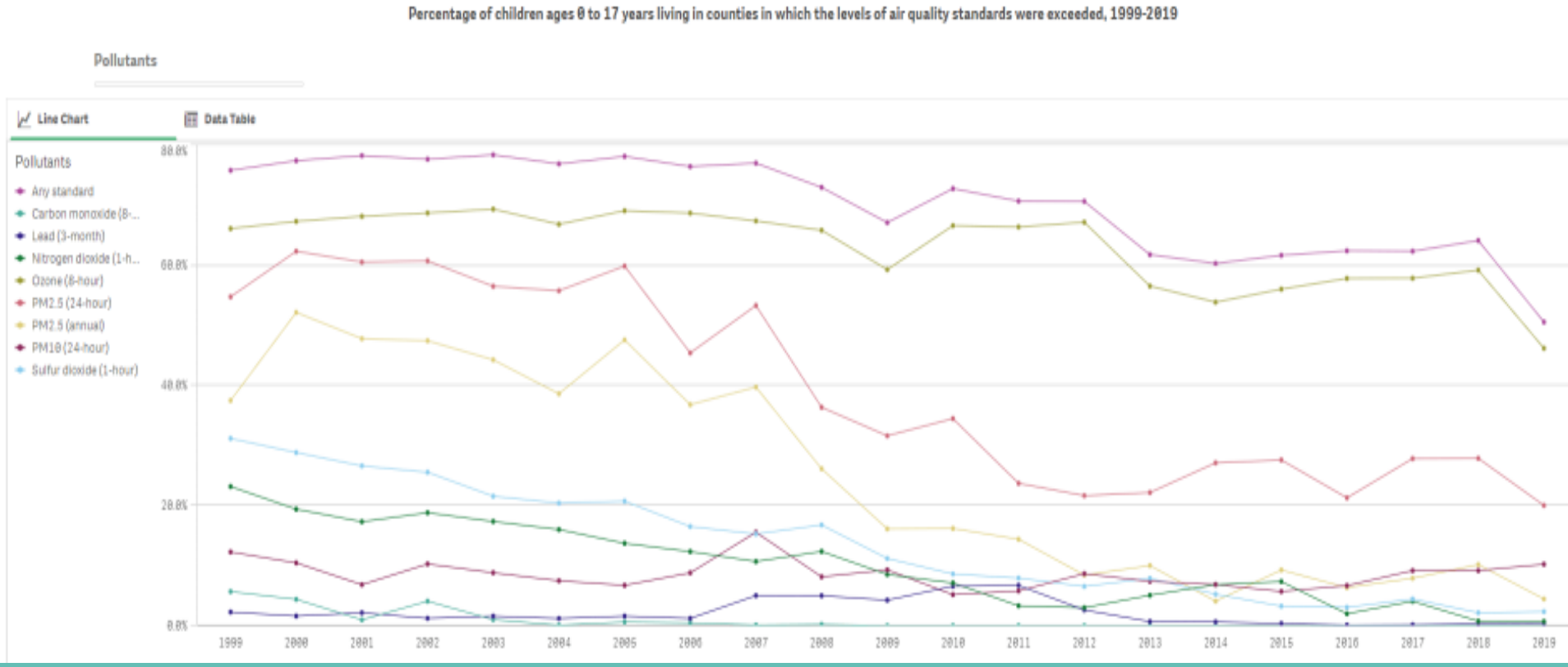
Image sources: Traffic emissions - https://commons.wikimedia.org/wiki/File:Emission-control.jpg
https://commons.wikimedia.org/wiki/File:Berlin-_An_electricity_power_plant_smokestack_in_-_3982.jpg
https://woodsmokepollution.org/wood-stoves.html, wildfire smoke photo: Mike Segal, Seattle Times

US EPA Criteria Air Pollutants

- **Ozone (O_3)**
- **Nitrogen oxides (NO_x)**
- Sulfur oxides (SO_x)
- Carbon monoxide (CO)
- Lead (Pb)
- **Particulate Matter (PM)**
  - **PM_{10}**
  - **$PM_{2.5}$**

- Most common air pollutants
- Public Health Concern
- Regulated as individual pollutant concentrations

How are we doing?



From 1999 to 2019, % of kids living in counties with measured pollutant concentrations above one or more national ambient air quality standards decreased from 76% to 51%.

U.S. EPA. America's Children and the Environment, Updated 2022

Race, Ethnicity, SES and Exposure to Air Pollutants

EPA Data on race/ethnicity and criteria air pollutants 2000-2019

- Compared to non-Hispanic white children:

  Asian American or Pacific Islander, Black non-Hispanic, and Hispanic children were more likely to reside in counties unable to meet the air quality standards for PM2.5, ozone.

Review of SES and air pollution among studies around the world (2015)

- “Overall, most North American studies have shown that areas where low socioeconomic status (SES) communities dwell experience higher concentrations of criteria air pollutants.”

Text source: America's Children and the Environment, Third Edition. U.S. Environmental Protection Agency, Washington, D.C., Updated 2019. Hajat A, Hsia C, O'Neill MS. Socioeconomic Disparities and Air Pollution Exposure: a Global Review.
Curr Environ Health Rep. 2015;2(4):440-450. doi:10.1007/s40572-015-0069-5

Ozone, Particulate Matter (PM), and Traffic Related Air Pollution (TRAP)

Tropospheric Ozone O_3 (aka smog)

Highly reactive form of oxygen

interferes with lung epithelium proteins/lipids → cell injury response → inflammation

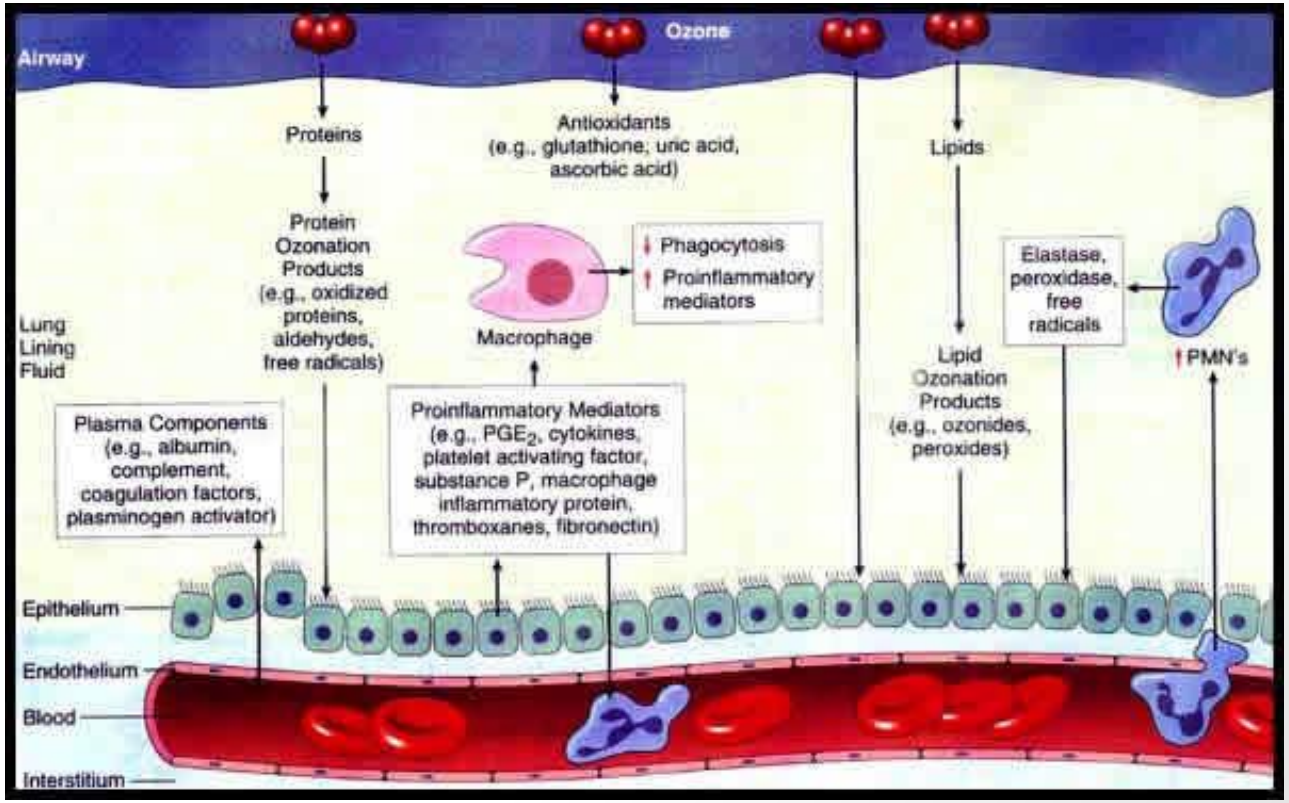


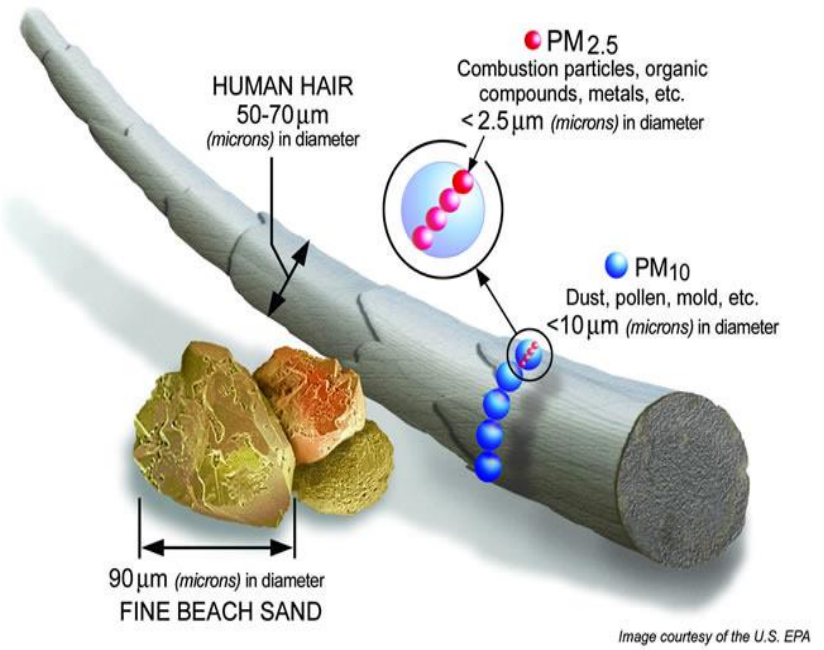
Image Source: https://www3.epa.gov/apti/ozonehealth/population.html

Particulate Matter (PM10, PM2.5, PM0.1)

- Mixture of solid particles and liquid droplets
- **Coarse particles –** Inhalable, < 10 µm
- **Fine particles-** Diameter < 2.5 µm
- **Ultrafine particles –** Diameter < 0.1 µm

  Size influences surface area/deposition/toxicity

- **Primary particles:** emitted directly from source
- **Secondary particles:** formed by atmospheric chemical rxns
- Complex chemistry – toxicological implications
  - heavy metals, nitrate, sulfate, ammonium
  - Polycyclic Aromatic Hydrocarbons (PAHs)
  - Mutagens, carcinogens, neurotoxicants, endocrine disruptors



TRAP – Traffic Derived Air Pollutants

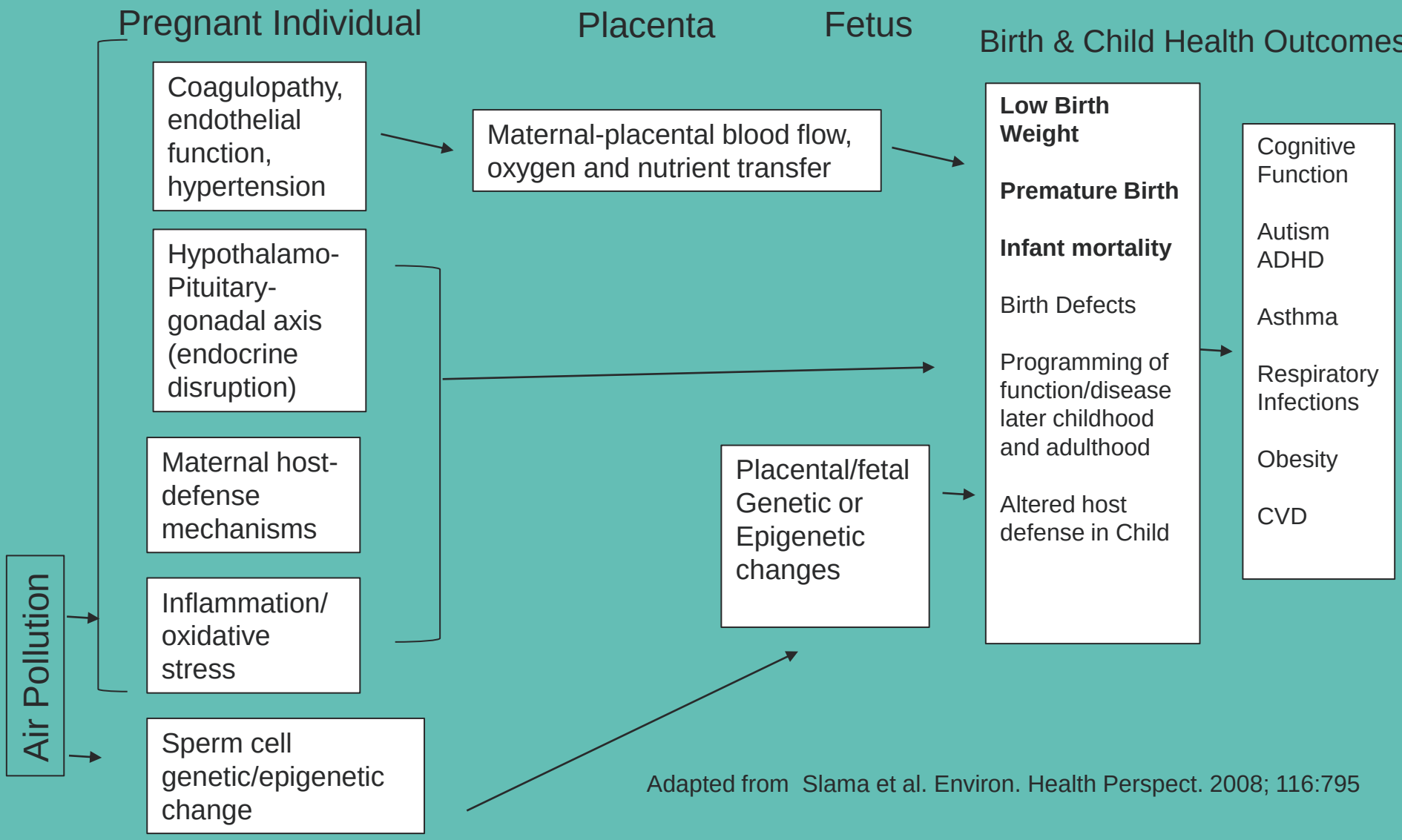
- Nitrogen dioxide (NO_2)
- Particulate matter (PM)
- Black carbon (BC)
- Ultrafine particles (UFP)
- Carbon monoxide (CO)
- Benzene, other volatile organic compounds (VOCs)
- Polycyclic aromatic hydrocarbons (PAHs).

Exposure & Developmental Toxicity Considerations
“Kids are not small adults”

Higher “dose”

- Child’s large lung surface area per kg, higher respiratory rate
- Child - Time spent outdoors
- Child - Time spent in physical exertion/increased respiratory rate

Prenatal Development



Adapted from Slama et al. Environ. Health Perspect. 2008; 116:795

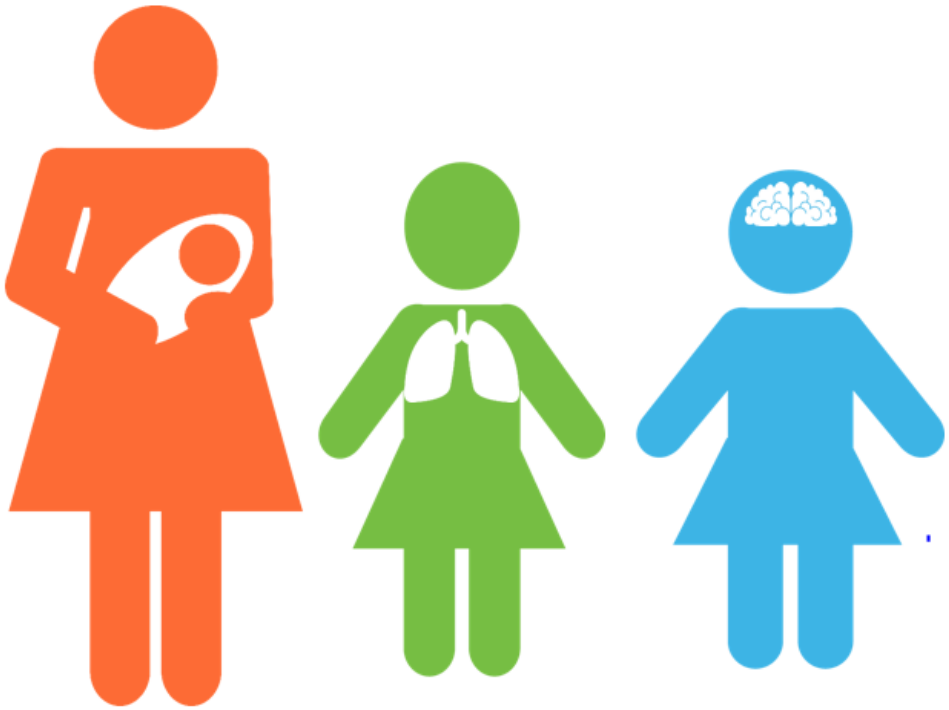
Postnatal Development

- At birth, the lung is a relatively immature organ
- During the first years of life, alveoli (air sacs) in the lung form at a high rate to increase in number similar to that of an adult
- **Between birth and young adulthood, the lung volume increases by as much as 23-fold**
- Brain development includes ***cascading and overlapping*** events from **prenatal period to adolescence**.

(neuronal proliferation→apoptosis →neurotransmitter maturation →glial proliferation →axon and dendrite sprouting →synapse formation →myelination →synapse pruning)

Health Effects in Children

Evidence of Early Life Exposures on Child Health Outcomes



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Obesity

Blood pressure

Cancer

Adult Health Outcomes

Birth outcomes Airway Health Neurodevelopment

Adverse Birth Outcomes

Fetal growth – Term Low Birth Weight, Small for Gestational Age

Premature Birth

Birth Defects – congenital heart malformations, orofacial defects

AAP Policy Statement 2021

K Ravindra et al. Exposure to air pollutants and risk of congenital anomalies: A systematic review and Meta-analysis, Science of The Total Environment, 2021: 765

Low Birth Weight & Preterm Birth

Large number of studies, several reviews, some pooled and meta-analyses

	CO	NO_2	O_3	PM10	PM2.5	SO_2
Pollutant increment	1 ppm	20 ppb	20 ppb	20 ug/m^3	10 ug/m^3	5 ppb
Change in birthweight (g) (95% CI)	-11.4 (-29.7, 6.9)	-28.1 (-44.8, -11.5)	-10.0 (-32.4, 12.4)	-16.8 (-20.2, -13.3)	-23.4 (-45.5, -1.4)	7.3 (-7.7, 22.3)
Odds ratio for low birth weight (95% CI)	1.07 (1.02, 1.12)	1.05 (1.00, 1.09)	1.01 (0.82,1.25)	1.10 (1.05, 1.15)	1.05 (0.99, 1.12)	1.03 (1.02, 1.05)
Odds ration for preterm birth (95% CI)	1.04 (1.02-1.06)	1.06 (0.96-1.18)	0.97 (0.86-1.10)	1.06 (1.03-1.11)	1.05 (0.98-1.13)	-

Source: Summary of pooled effect estimates from DM Stieb et al. Ambient air pollution, birth weight and preterm birth: A systematic review and meta-analysis, Environmental Research 2012:117;100-111.

Airway Health

- Respiratory Symptoms
- Respiratory Infections – URI, LRI
- Exacerbation of asthma, CF
- Enhancement of Allergic Sensitization
- Post neonatal respiratory mortality
- Reduced lung function growth
- Development of asthma

AAP Policy Statement 2021

PM2.5 increases bronchiolitis risk in infancy

- Study in SoCal Air Basin
- Hospital discharge and birth record data linked
- Cases (hospitalized bronchiolitis)
- Match to 10 age- and gestational-age-matched controls

- Assessed infant exposure to PM2.5, NO_2, CO, O_3
  - month prior to hospitalization (subchronic)
  - mean lifetime exposure (chronic)
  - PM2.5 per 10-μg/m^3 increase (chronic & subchronic)
    - adjusted odds ratio = 1.09 (95% confidence interval: 1.04, 1.14)

Karr, C et al. Am J Epi. 2006

Traffic in LA Basin increases asthma risk

Research | Children's Health

Childhood Incident Asthma and Traffic-Related Air Pollution at Home and School

Rob McConnell,[1] Talat Islam,[1] Ketan Shankardass,[2] Michael Jerrett,[3] Fred Lurmann,[4] Frank Gilliland,[1] Jim Gauderman,[1] Ed Avol,[1] Nino Künzli,[5] Ling Yao,[6] John Peters,[1] and Kiros Berhane[1]

[1]University of Southern California, Los Angeles, California, USA; [2]St. Michael's Hospital, Toronto, Ontario, Canada; [3]University of California, Berkeley, California, USA; [4]Sonoma Technology, Inc, Petaluma, California, USA; [5]Swiss Tropical and Public Health Institute, Basel and University of Basel, Switzerland; [6]United Health Group, City of Hope Hospital Medical Center, Los Angeles, California, USA

McConnell 2010:

- Prospective study in SoCal from 13 communities and 45 schools: 2,497 children followed for 3 years → 120 developed asthma
- Ambient measures of regional ozone, NO_2 & PM
- Local traffic-related pollutants modeled by roadway proximity, local traffic density, vehicle emission rates, and meteorological variables
- **School and home exposures associated with new-onset asthma; effects of each comparable**

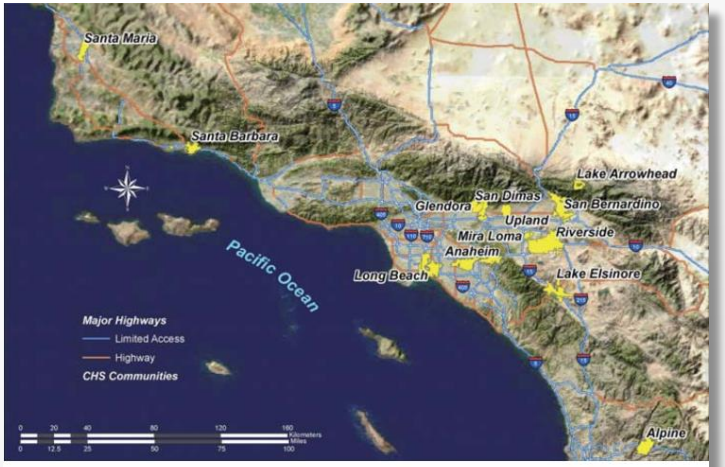
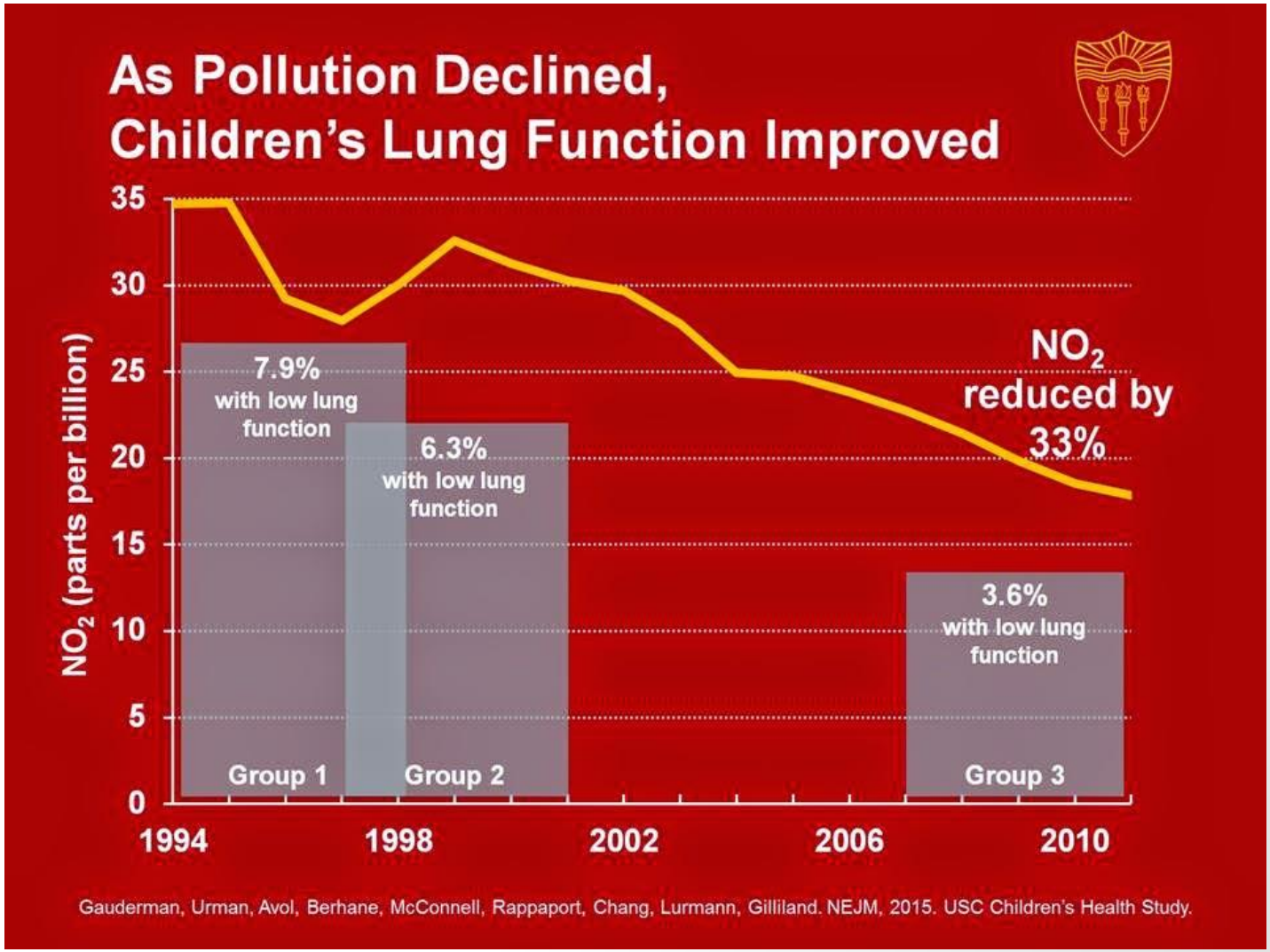


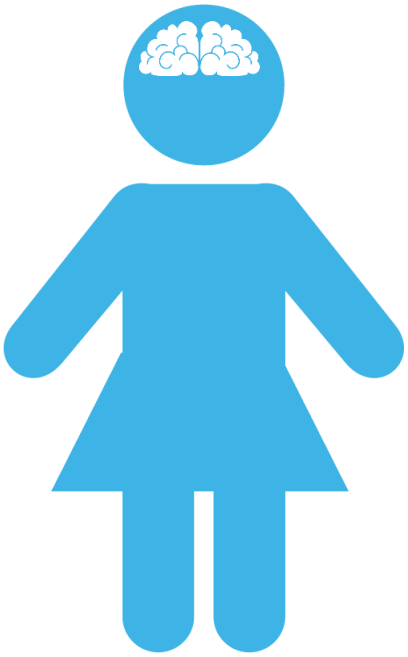
Figure 1. Location of study communities.

Sources: 1. McConnell, Rob, et al. "Childhood incident asthma and traffic-related air pollution at home and school." *Environmental health perspectives* (2010): 1021-1026.
2. McConnell, Rob, et al. "Traffic, susceptibility, and childhood asthma." *Environmental health perspectives* (2006): 766-772.

Improved Air Quality, Improves Child Lung Function in LA basin

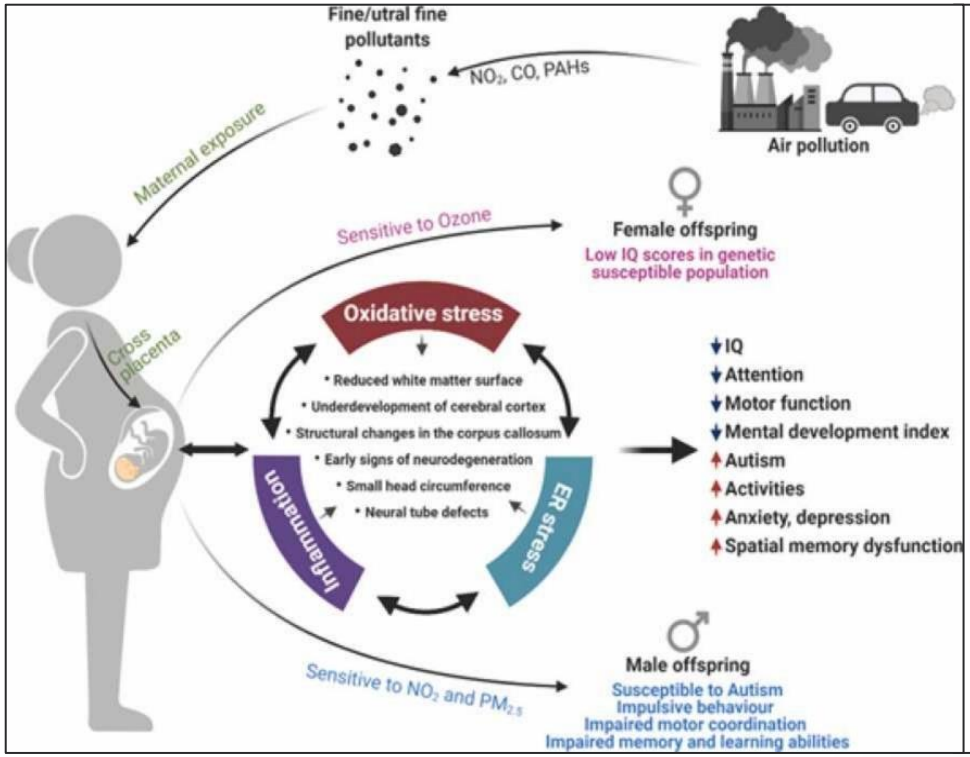


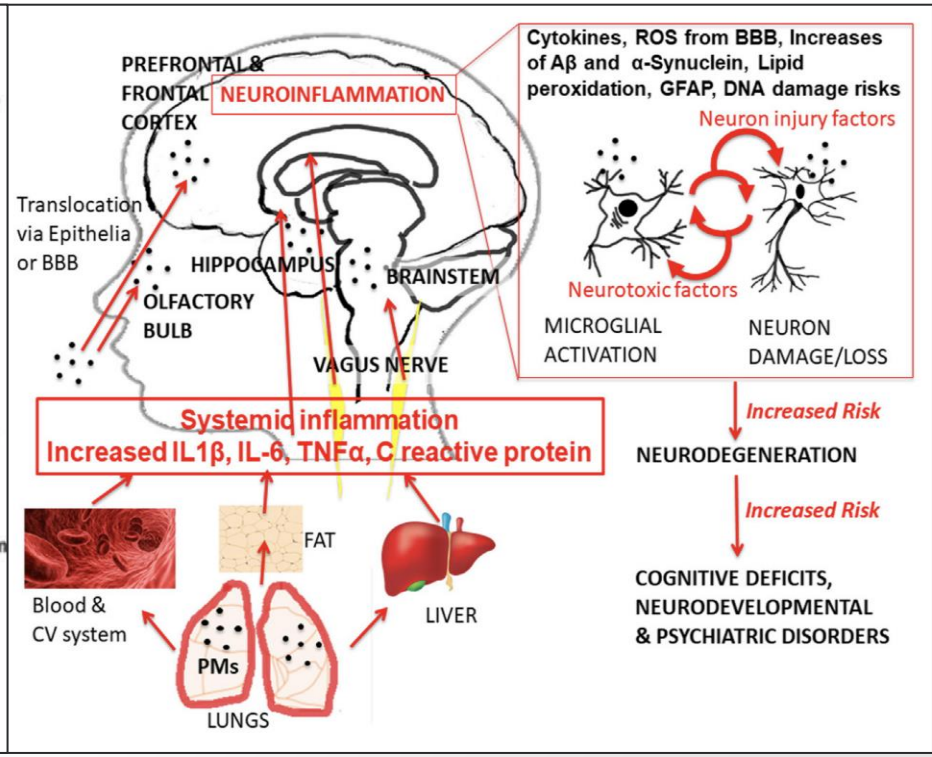
Neurodevelopment



- Cognitive function deficits
- Externalizing Behavior - Hyperactivity and reduced attention, ADHD
- Autism

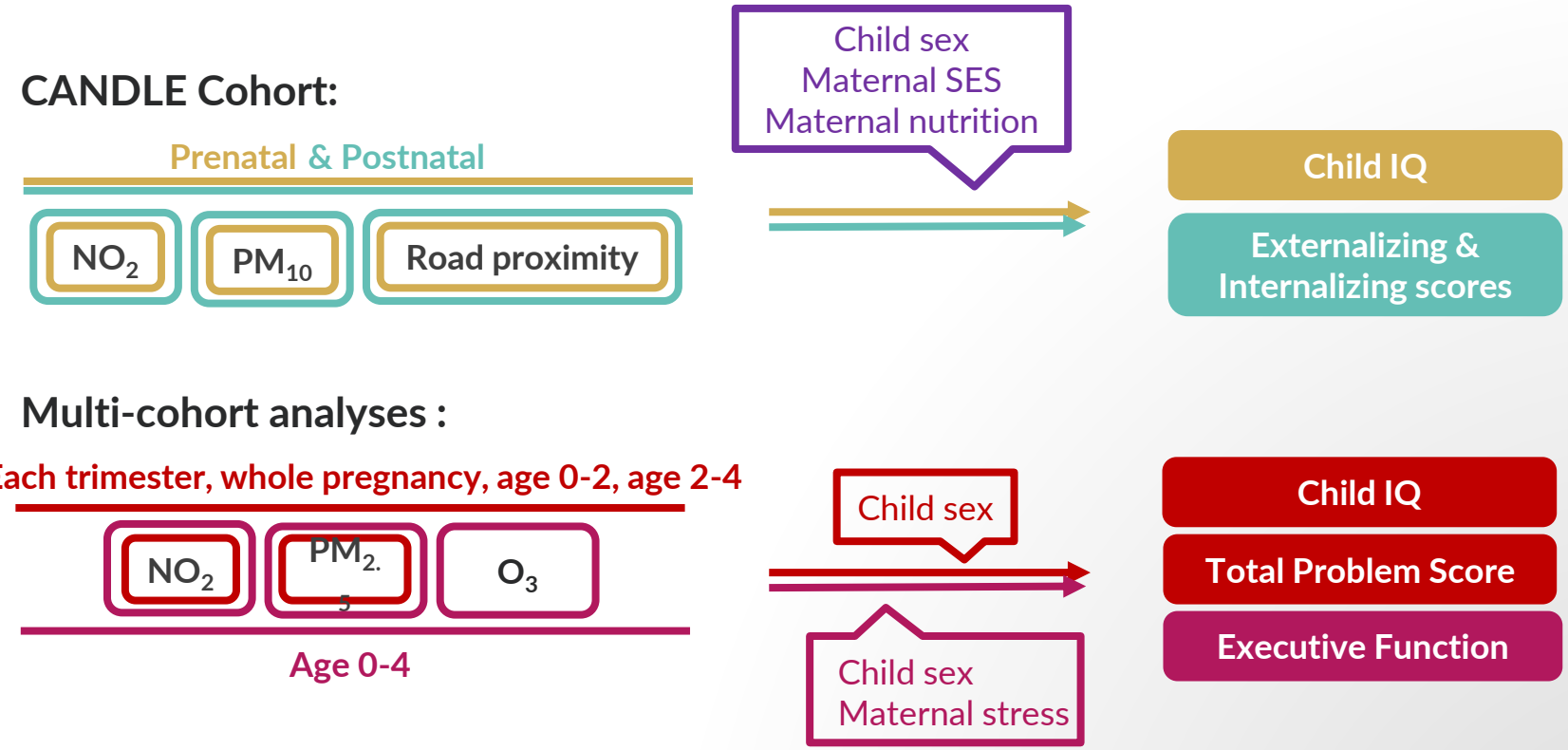
Mechanisms of neurotoxicity





Yi et al. (2022), D'Angiulli (2018)

Neurodevelopment – Karr lab



Neurodevelopment Key Finding– Karr lab

Main findings:

- Pre- and postnatal NO_2 exposures were associated with more behavioral problems and poorer cognitive function, including lower cognitive flexibility

- Postnatal $PM_{2.5}$ exposures were associated with more behavioral problems and poorer cognitive function;

- The largest effect sizes detected -- postnatal $PM_{2.5}$ with IQ and behavioral problems -- are comparable to a 10- micrograms/dl increase in blood lead.

Vulnerabilities (Enhanced risk):

mothers with low folate intake during pregnancy

participants with socioeconomic adversity

Black participants

ASD and Air Pollution – Recent Review and Meta-Analysis Findings

- 28 studies, representing 758,997 children
- Each increase of 5 μg/m^3 in PM2.5 was associated with an increased risk of ASD
- Effects for all exposure timing - preconception, prenatal, first two years
- Evidence levels were poor for other pollutants (PM10, NOx, O_3, metals, solvents, styrene, PAHs, pesticides)

F Dutheil et al. Autism spectrum disorder and air pollution: A systematic review and meta-analysis, Environmental Pollution 2021;278

Exposure and Harm Reduction

Intervention & Prevention Strategies

Individual Level

- Reduce exposure through resources and education
  - Air Quality Index (airnow.gov) – educate on potential protective behaviors
  - Portable HEPA cleaners/optimal HVAC filters

Population Level

- Advocate for programs and policies to protect kids
  - Updated NAAQS to reflect new evidence/vulnerability of subgroups
  - Focus research and program efforts to promote environmental justice
  - Move to carbon free transportation/energy
  - Homes/school/day care siting policies
  - School bus retrofit, no idling policies

AQI- airnow.gov (also an app!)

Air Quality Index	Who Needs to be Concerned?	What Should I Do?
Good 0-50	It's a great day to be active outside.	
Moderate 51-100	Some people who may be unusually sensitive to particle pollution.	**Unusually sensitive people:** *Consider reducing* prolonged or heavy exertion. Watch for symptoms such as coughing or shortness of breath. These are signs to take it easier. **Everyone else:** It's a good day to be active outside.
Unhealthy for Sensitive Groups 101-150	Sensitive groups include **people with heart or lung disease, older adults, children and teenagers.**	**Sensitive groups:** *Reduce* prolonged or heavy exertion. It's OK to be active outside, but take more breaks and do less intense activities. Watch for symptoms such as coughing or shortness of breath. **People with asthma** should follow their asthma action plans and keep quick relief medicine handy. **If you have heart disease:** Symptoms such as palpitations, shortness of breath, or unusual fatigue may indicate a serious problem. If you have any of these, contact your heath care provider.
Unhealthy 151 to 200	**Everyone**	**Sensitive groups:** *Avoid* prolonged or heavy exertion. Move activities indoors or reschedule to a time when the air quality is better. **Everyone else:** *Reduce* prolonged or heavy exertion. Take more breaks during all outdoor activities.
Very Unhealthy 201-300	**Everyone**	**Sensitive groups:** *Avoid all* physical activity outdoors. Move activities indoors or reschedule to a time when air quality is better. **Everyone else:** *Avoid* prolonged or heavy exertion. Consider moving activities indoors or rescheduling to a time when air quality is better.
Hazardous 301-500	**Everyone**	**Everyone**: *Avoid all* physical activity outdoors. **Sensitive groups:** Remain indoors and keep activity levels low. Follow tips for keeping particle levels low indoors.

Source: US EPA https://www.epa.gov/pmcourse/patient-exposure-and-air-quality-index/

Indoor Air Filtration

HVAC system – Use a MERV 13 or higher for highest efficiency filtration of fine particles

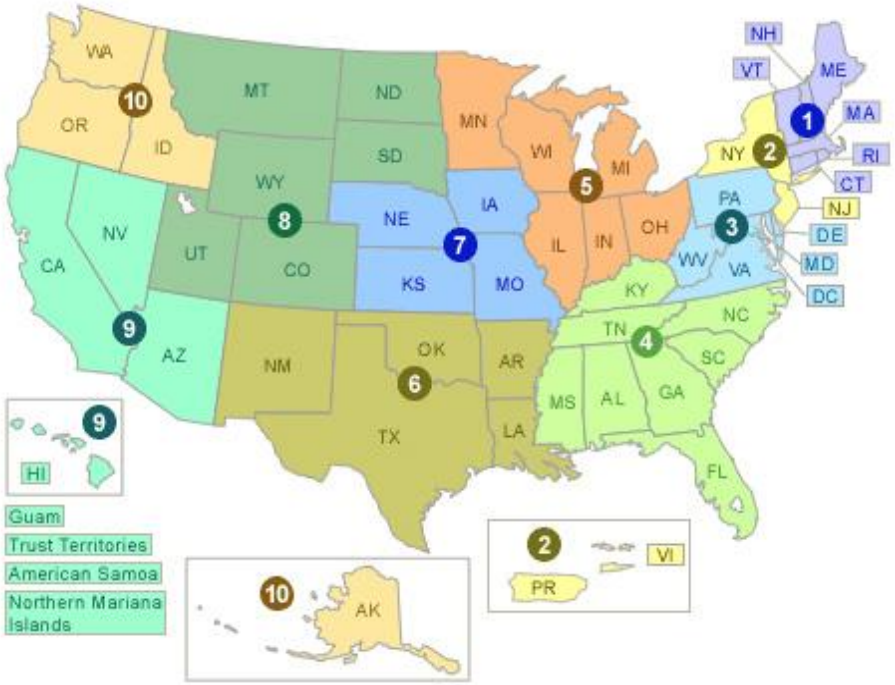
Portable HEPA Air Cleaners or DIY Box Fan plus Filter versions are effective

CA Air Resources Board: https://ww2.arb.ca.gov/resources/fact-sheets/air-cleaning-devices-home

Air Pollution and Child Health: Take Aways

- Children's vulnerability to air pollution exposure and toxicity is well-established
- Current evidence is sufficient to support actions to reduce exposures among pregnant women and children.
- Recognized disparities should drive our research and policy

Pediatric Environmental Health Specialty Units (PEHSU)



CDC/EPA sponsored network of pediatric EH specialists based at academic medical centers

Provide free consultation, referral, outreach and education

- Public Health Depts
- Clinicians, healthcare professionals
- Public health and medical trainees
- Communities
- Families

National PEHSU

NW PEHSU (Karr Director) – AK, WA, ID, OR

Western States PEHSU – include CA

Thank you

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Extra slides

National Ambient Air Quality Standards (NAAQS)

TABLE 1 Six EPA Criteria Pollutants With National Ambient Air Quality Standards

Pollutants	Standard
CO	9 ppm over 8 h, 35 ppm over 1 h
Lead	0.15 $\mu g/m^3$ over 3 mo
NO_2	100 ppb over 1 h; 53 ppb annual average
PM, including $PM_{2.5}$ and PM_{10}	$PM_{2.5}$: 35 $\mu g/m^3$ over 24 h; 12 $\mu g/m^3$ annual average PM_{10}: 150 $\mu g/m^3$ over 24 h
SO_2	75 ppb over 1 h
Ozone	0.070 ppm over 8 h

Permissible levels of the 6 criteria air pollutants (primary standards based on public health protection). These enforceable standards are reevaluated periodically by the EPA. Standards noted are based on information from the EPA National Ambient Air Quality Standards Table. (Available at: https://www.epa.gov/criteria-air-pollutants/naaqs-table. Accessed February 4, 2019.)

Primary standards **are set to protect health**, including protecting the health of at-risk populations including children.

Source: Ambient Air Pollution: Health Hazards to Children
Heather L. Brumberg, Catherine J. Karr
Pediatrics Jun 2021, 147 (6) e2021051484; **DOI:** 10.1542/peds.2021-051484

ADHD and Air Pollution

- Mixed evidence to date (more studies report increased risk than report no association)
- Evidence for PM, Black Carbon, Elemental Carbon effects > PAH
- Current studies provide limited evidence to support the idea that exposure to air pollution may be linked to increased risk of ADHD

AAP Policy Statement 2021.
M Aghaei et al. Association between ambient gaseous and particulate air pollutants and attention deficit hyperactivity disorder (ADHD) in children; a systematic review, Environmental Research 2019; 173:135-156.

Pediatric Cancer

- Air pollution components include known and suspected human carcinogens
- Evidence review – Leukemia risk

  Traffic related air pollution

    particularly benzene emissions from traffic (AML associations strongest, some evidence NO2, only at highest exposure levels)
- Large study in Denmark – NHL risk
  - NO_2, PM2.5, BC

Tommaso Filippini, Julia E. Heck, Carlotta Malagoli, Cinzia Del Giovane & Marco Vinceti (2015) A Review and Meta-Analysis of Outdoor Air Pollution and Risk of Childhood Leukemia, Journal of Environmental Science and Health, Part C, 33:1, 36-66, DOI: 10.1080/10590501.2015.1002999

UA Hividtfeldt et al. Air pollution exposure at the residence and risk of childhood cancers in Denmark: A nationwide register-based case-control study. Eclinical Medicine 2020;28. 100569

Obesity

- Multi-factorial and complex relationship to air pollution
  - Direct effects – EDC toxicological properties
  - Indirect effects – avoidance of physical activity in high traffic area
- Current epidemiological evidence is mixed
- Heterogeneity of study design, air pollution exposure assessment, outcome definition, and study populations

AAP Policy Statement

An, R., Ji, M., Yan, H. *et al.* Impact of ambient air pollution on obesity: a systematic review. *Int J Obes* 2018;**42:** 1112–1126

Prenatal Exposure & Child Blood Pressure

Associations of Pre- and Postnatal Air Pollution Exposures with Child Blood Pressure and Modification by Maternal Nutrition: A Prospective Study in the CANDLE Cohort

Yu Ni,[1] Adam A. Szpiro,[2] Michael T. Young,[3] Christine T. Loftus,[3] Nicole R. Bush,[4,5] Kaja Z. LeWinn,[4] Sheela Sathyanarayana,[3,6,7] Daniel A. Enquobahrie,[1,8] Robert L. Davis,[9,10] Mario Kratz,[1,11] Annette L. Fitzpatrick,[1,12,13] Jennifer T. Sonney,[14] Frances A. Tylavsky,[15] and Catherine J. Karr[1,3,6]

PM2.5	N	SBP (%ile) Beta (95% CI)	DBP (%ile) Beta (95% CI)	HBP (IRR 95% CI)
1st	756	2.11 (-7.18, 11.40)	3.87 (-2.88, 10.63)	0.90 (0.50, 1.59)
2nd	756	**14.61 (4.62, 24.60)**	**8.65 (1.38, 15.92)**	0.97 (0.52, 1.82)
3rd	753	-1.55 (-9.15, 6.05)	4.28 (-1.48, 10.05)	1.11 (0.72, 1.71)
Pregnancy	756	8.83 (-2.45, 20.11)	**11.58 (2.94, 20.22)**	1.50 (0.71, 3.14)

2nd trimester effects stronger for children of mothers with lowest quartile folate concentrations in pregnancy

No effects observed for NO2, postnatal PM2.5 or proximity to roadway

Environ. Health Perspect 2021;129