



Characteristics of Brake-Wear Particles and Chemical Speciation Profiles and Potential Health Effects of the Particles in California

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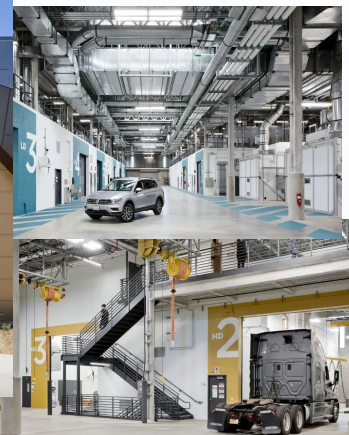
CARB leads California's fight against air pollution and climate change, protects public health, and promotes clean, energy-efficient fuels and technology.



Sacramento Headquarters

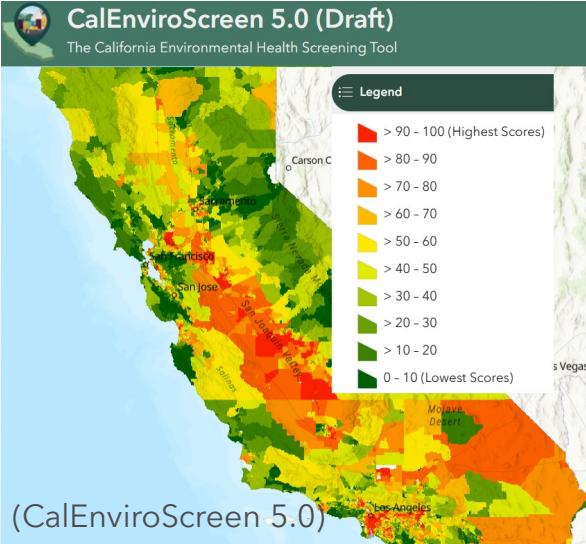


Riverside Headquarters

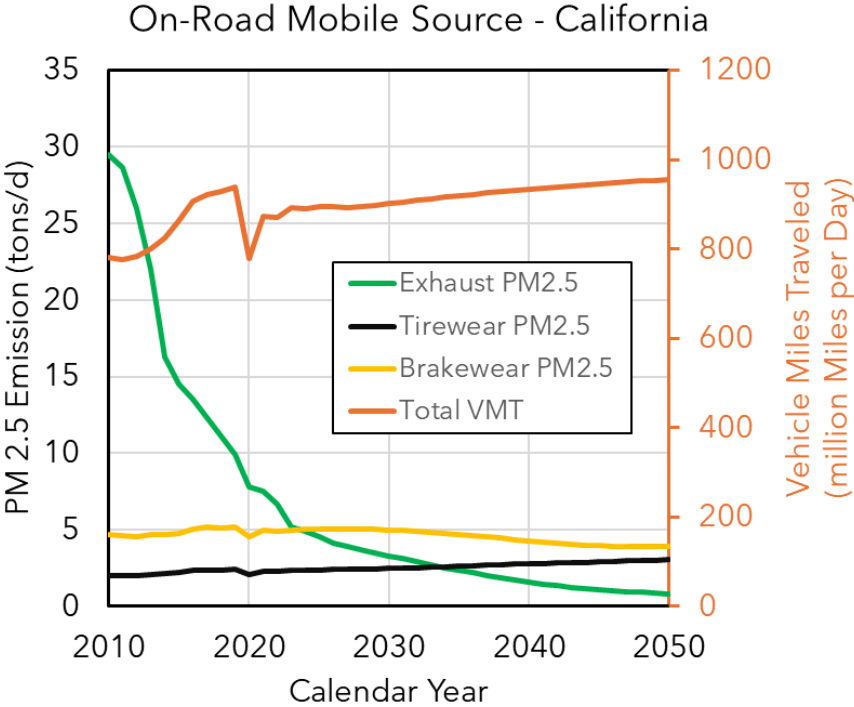
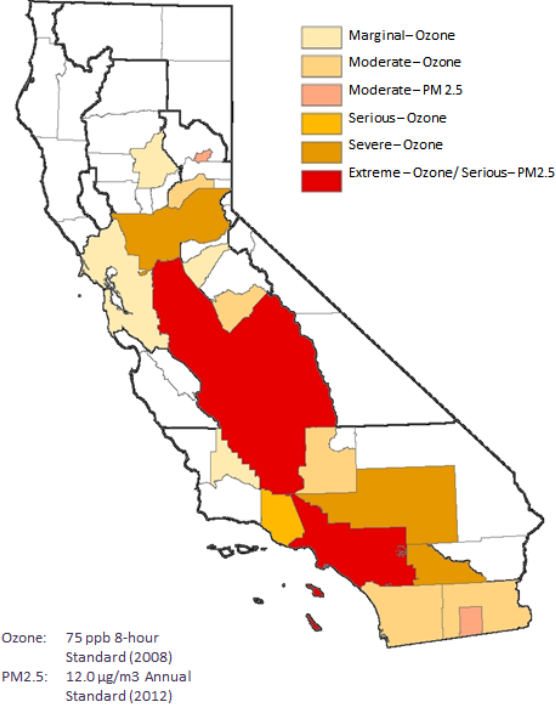


California needs to improve air quality regionally and locally

Disadvantaged Communities



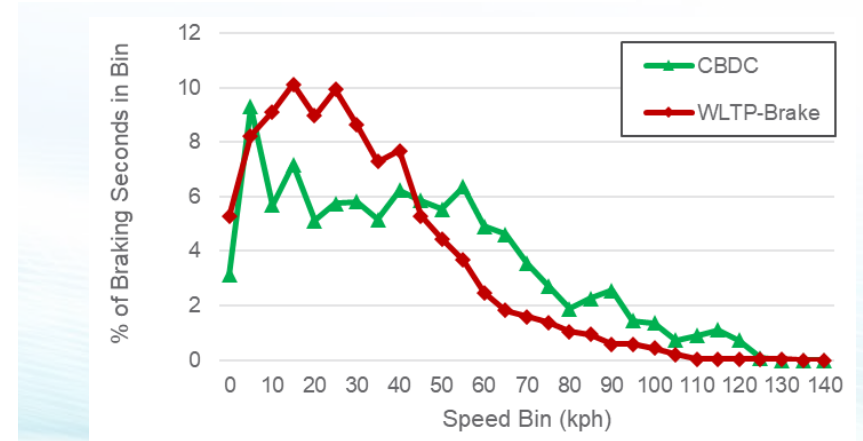
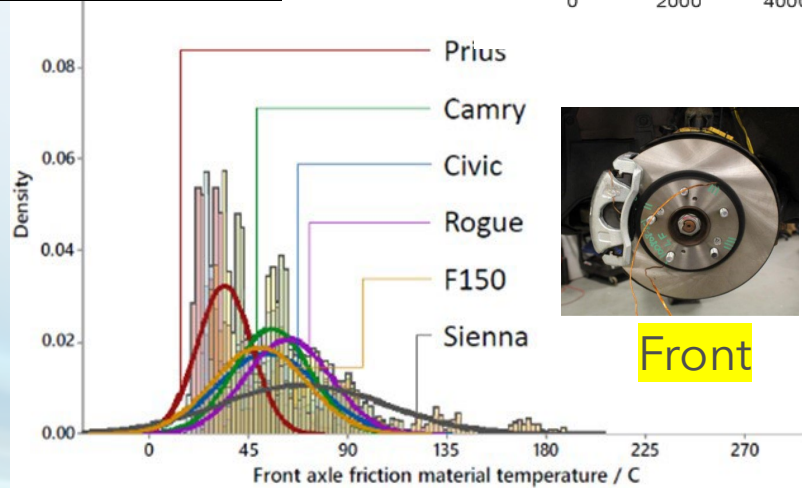
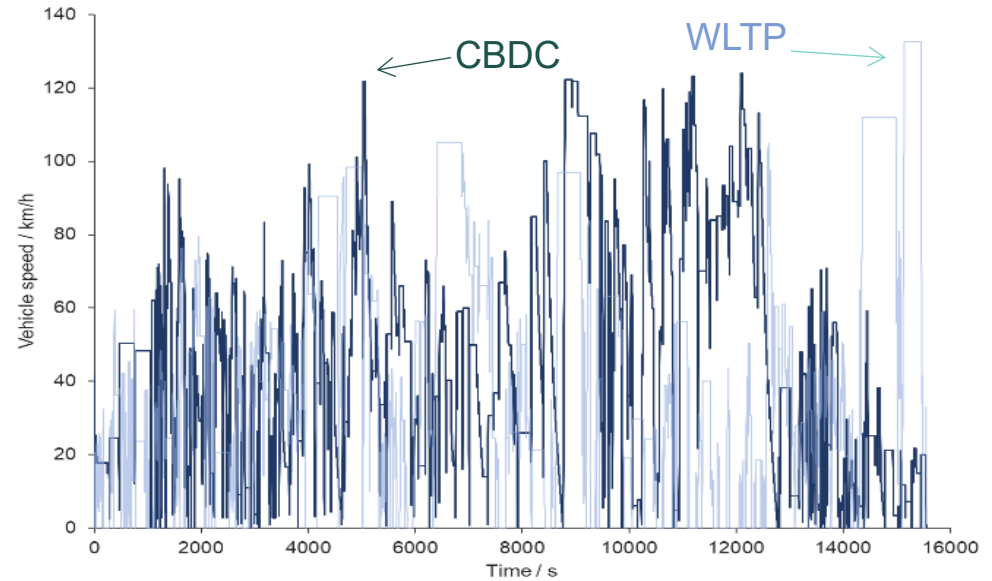
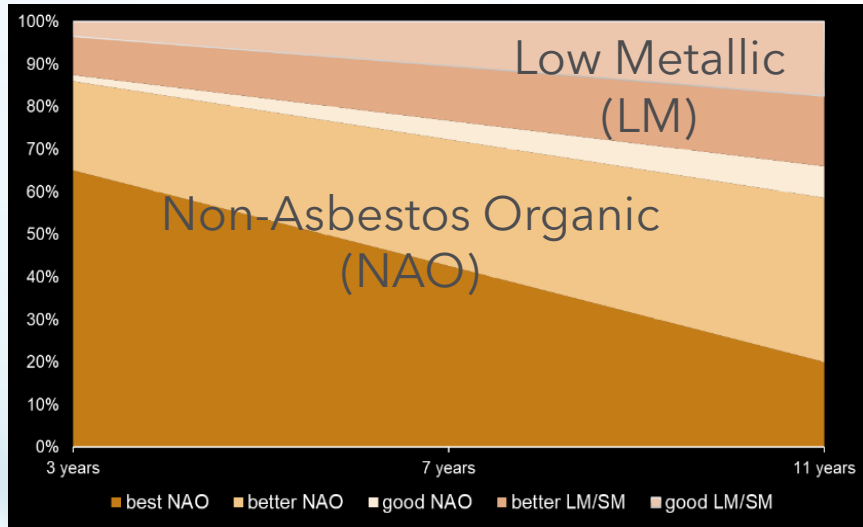
Nonattainment Areas in California Ozone and PM2.5



Understanding brake-wear emissions is critical for air quality planning at the regional and local levels:

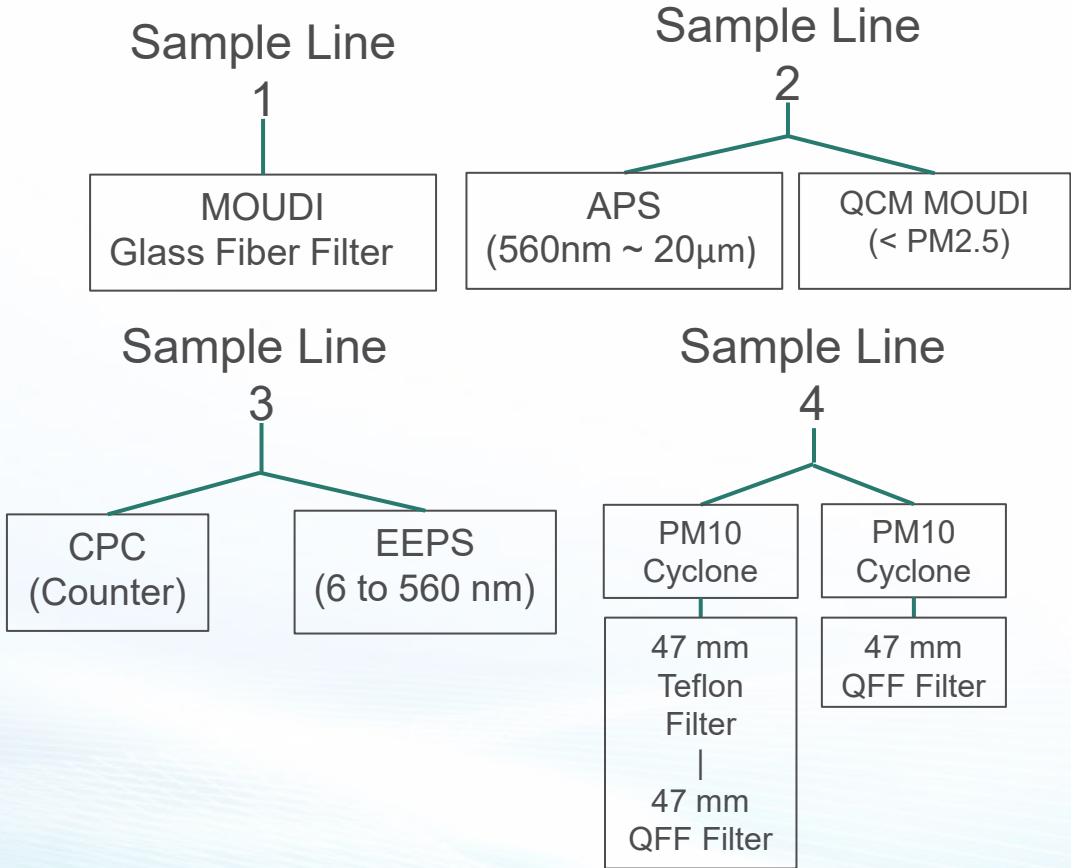
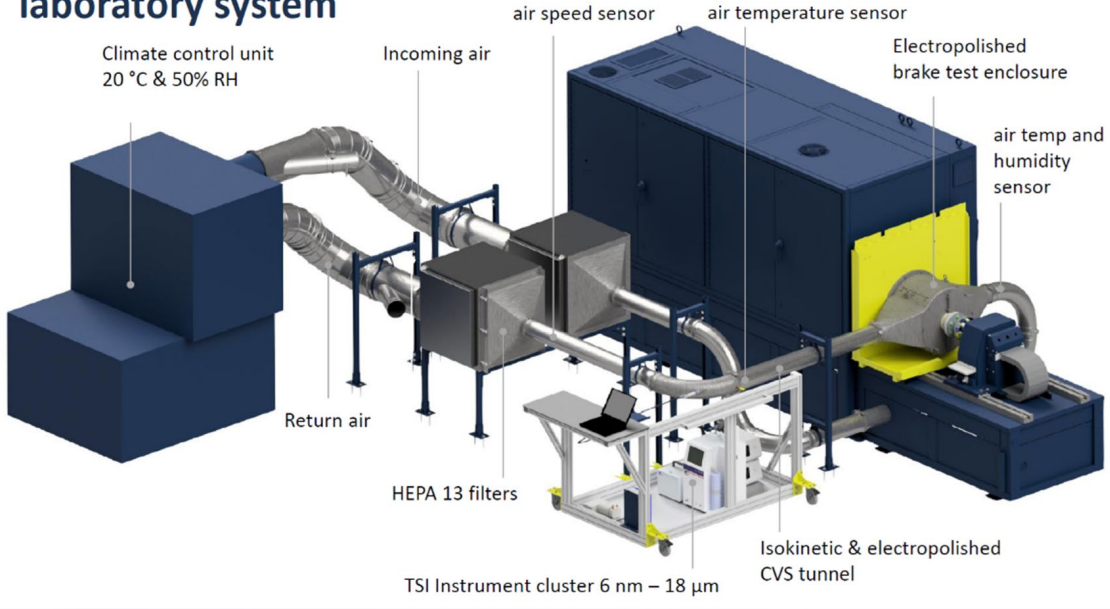
- Particle size distributions,
- Particle mass by vehicle technologies
- Chemical speciation, and
- Potential health effects.

California Brake-Dynamometer Cycle (CBDC) was developed to characterize brake-wear particles



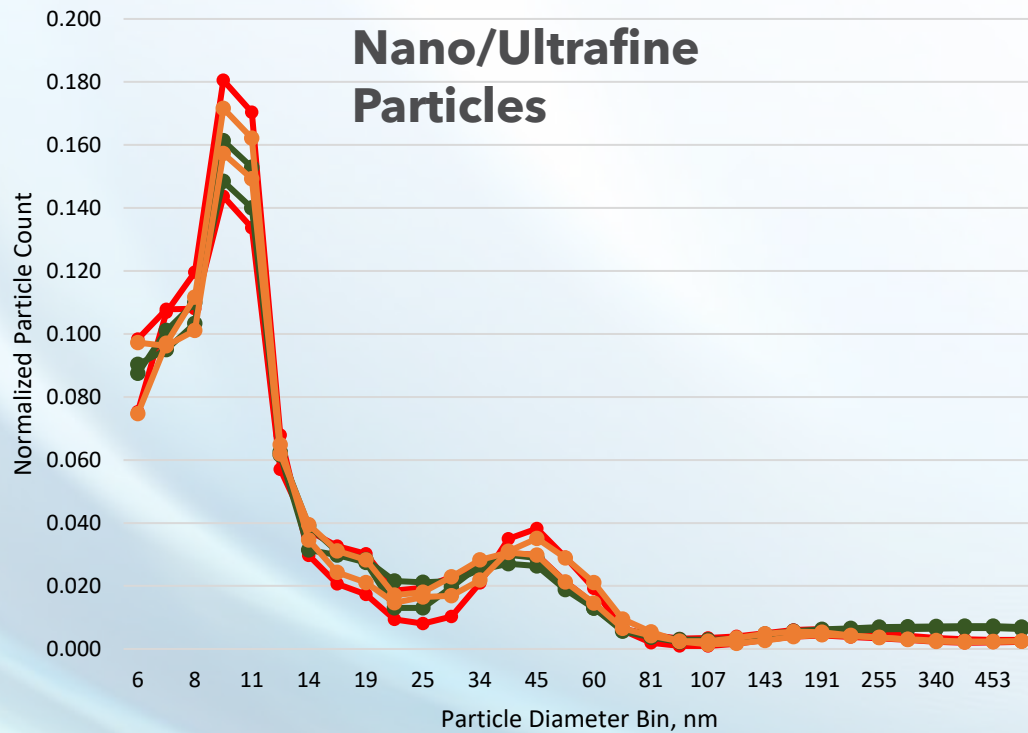
Brake-Dynamometer Experimental Setup

laboratory system

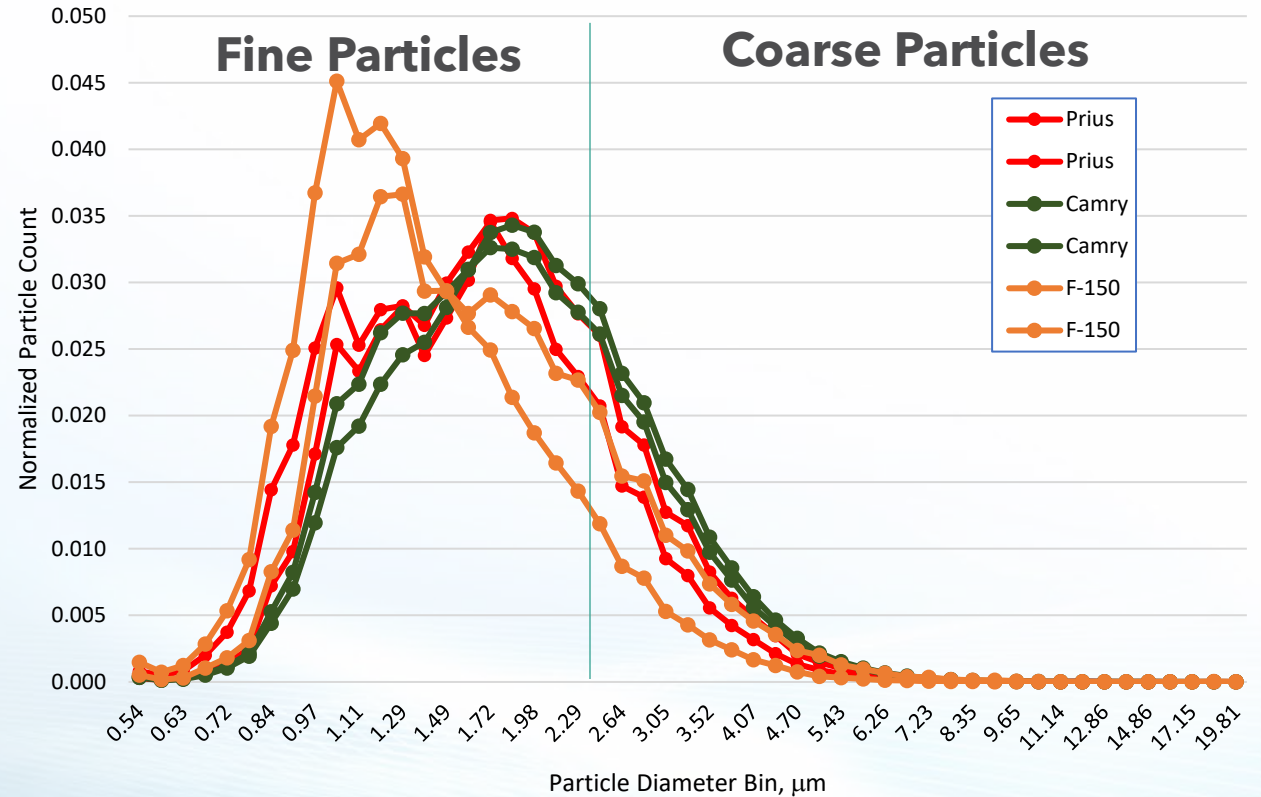


Particle Size Distributions for NAO Brake Pads

Engine Exhaust Particle Sizer (EEPS)



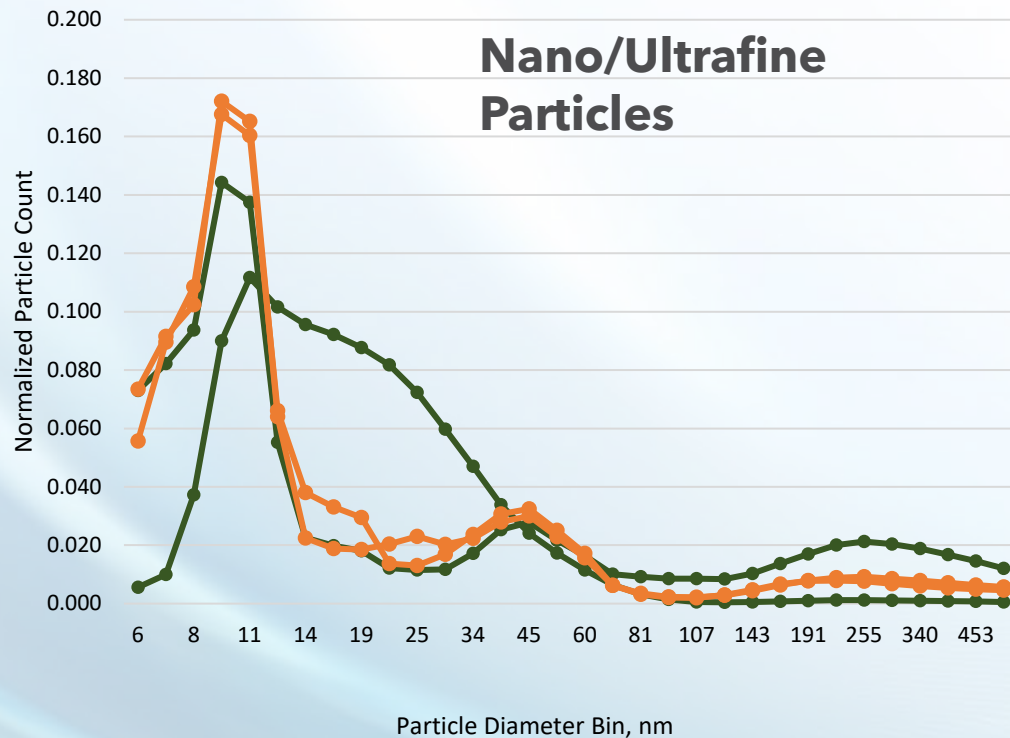
Aerodynamic Particle Sizer (APS)



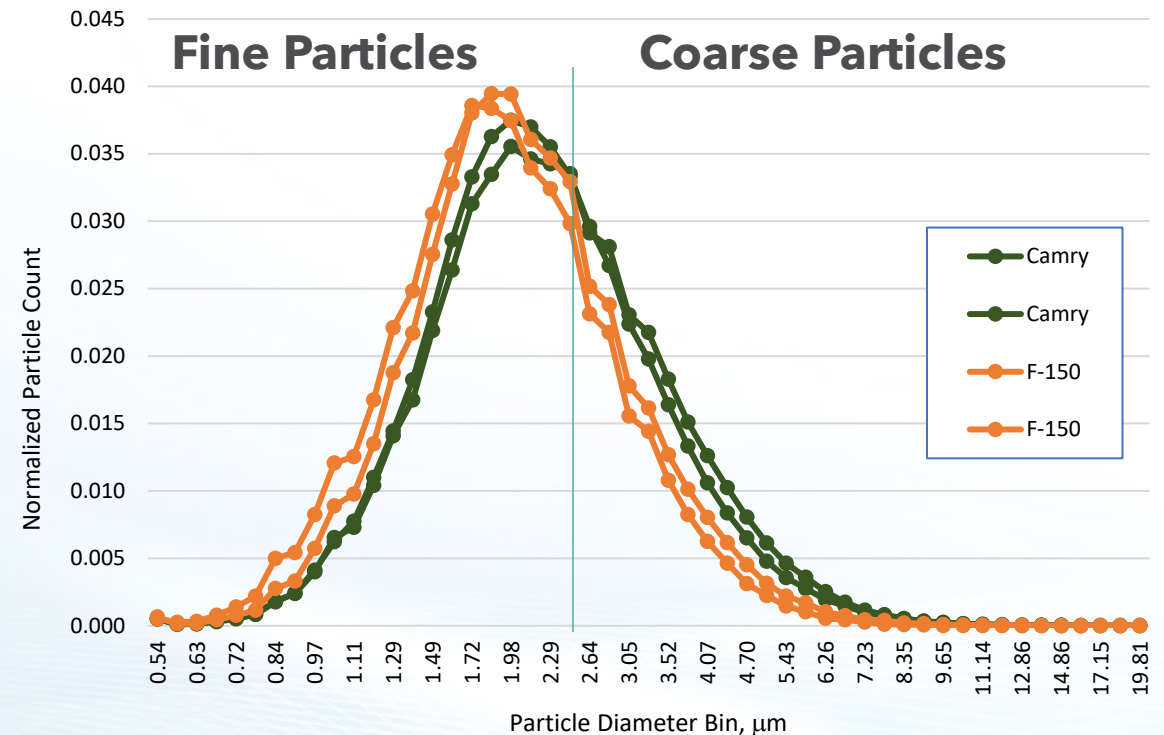
Bimodal distributions with peaks around 1 and 2 μm were observed for NAO brake pad particles.

Particle Size Distributions for LM Brake Pads

Engine Exhaust Particle Sizer (EEPS)



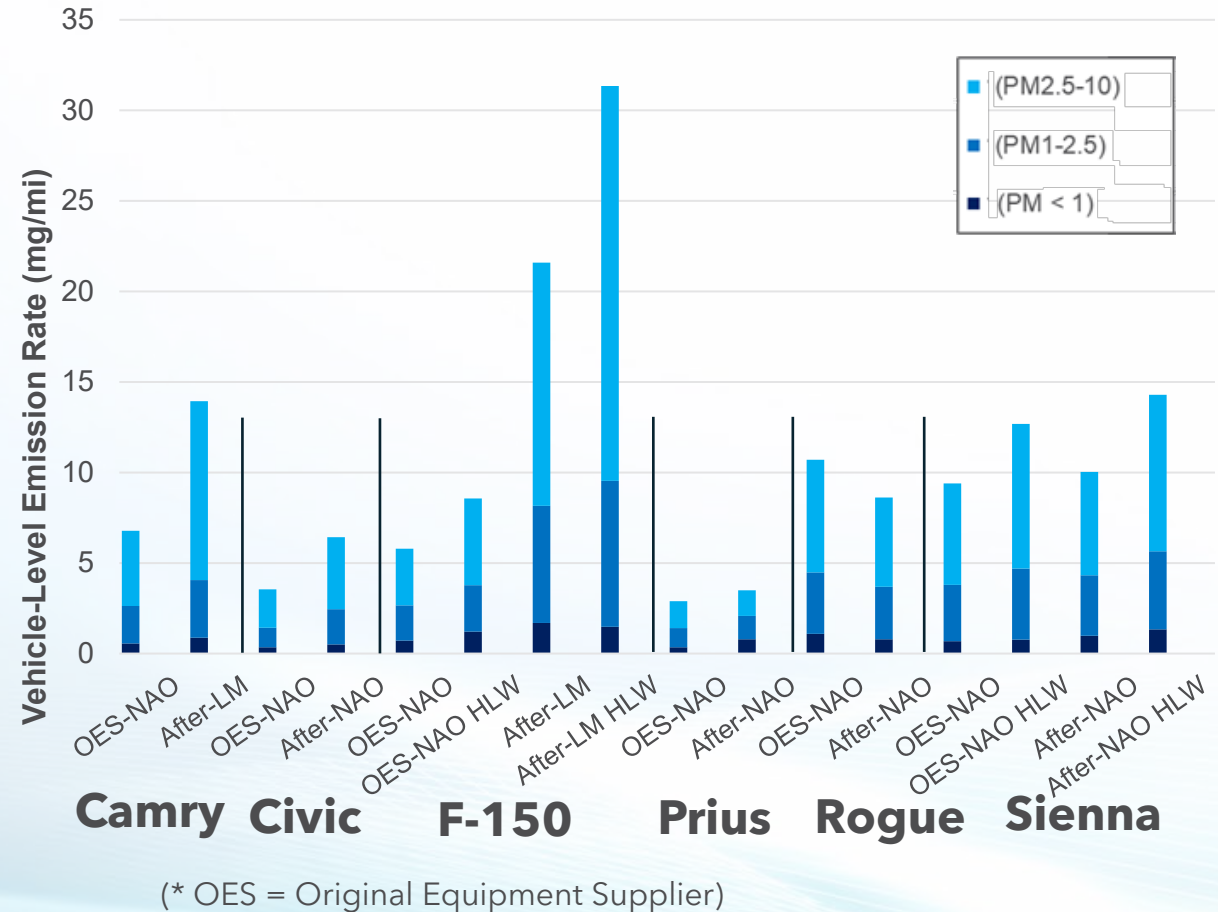
Aerodynamic Particle Sizer (APS)



No apparent peaks around 1 μm were observed for LM brake pad particles.

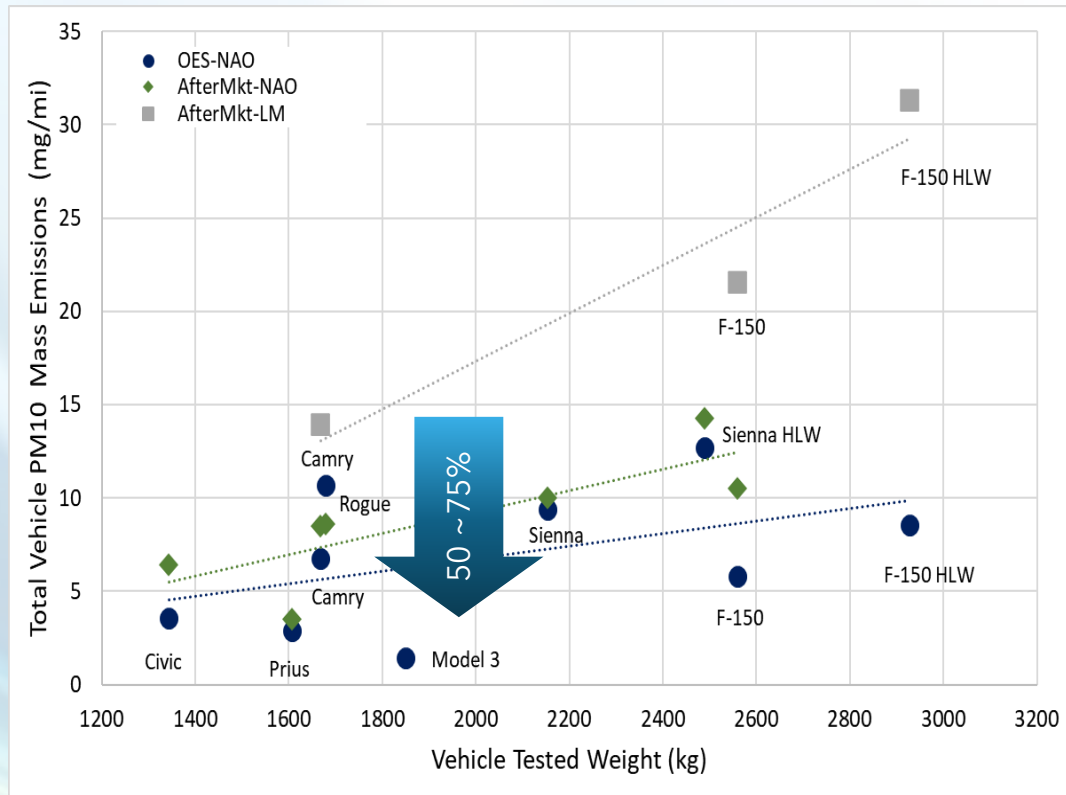
Particle Mass Distributions by Size

Understanding particle mass by vehicle technology and their chemical composition will help inform health effect assessment and air quality planning.



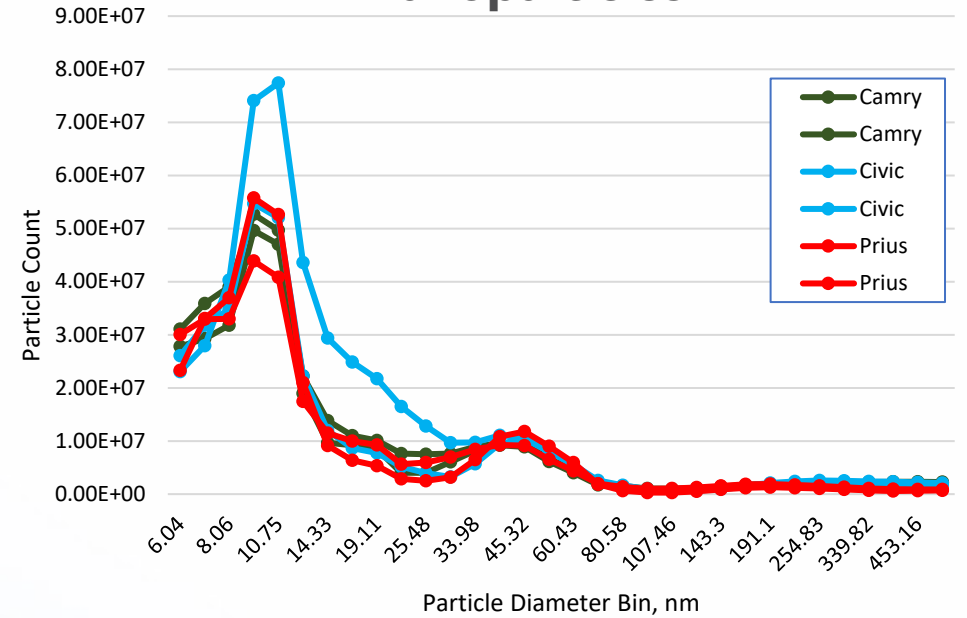
Opportunities to Reduce Brake-Wear Particles with Clean Transportation Technologies

Total PM10

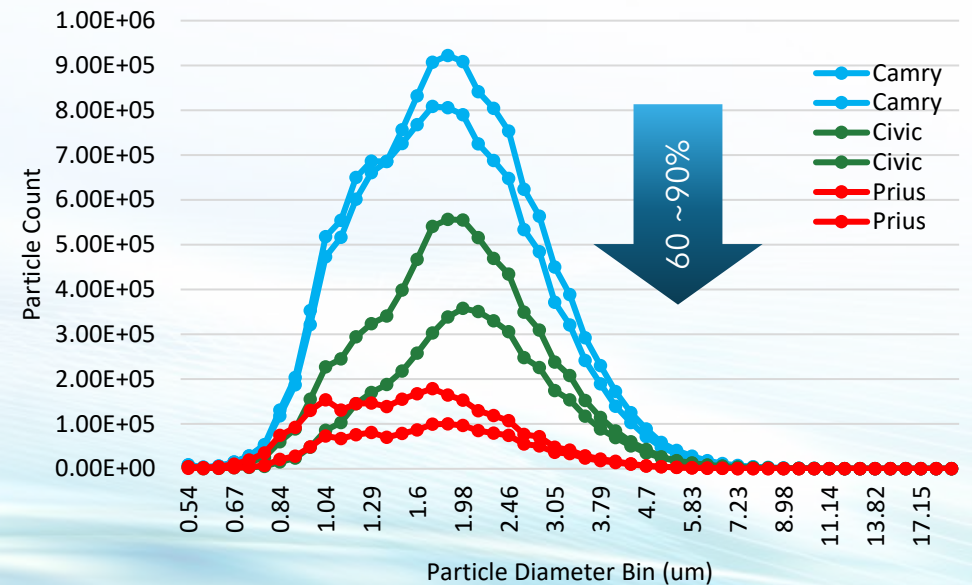


(ERG, Final Report: Brake & Tire Wear Emissions, 2021)

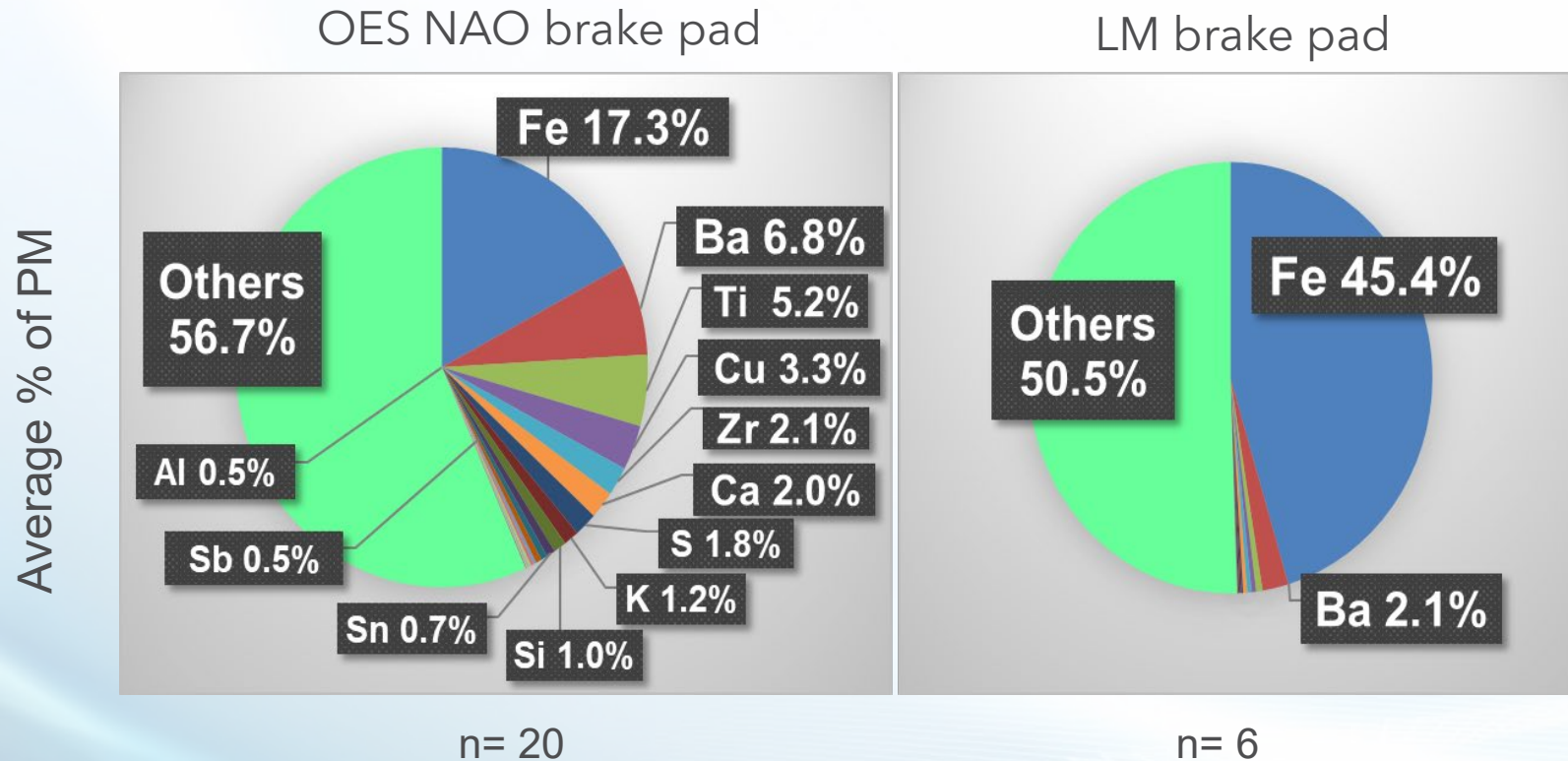
Nanoparticles



Fine/Coarse Particles



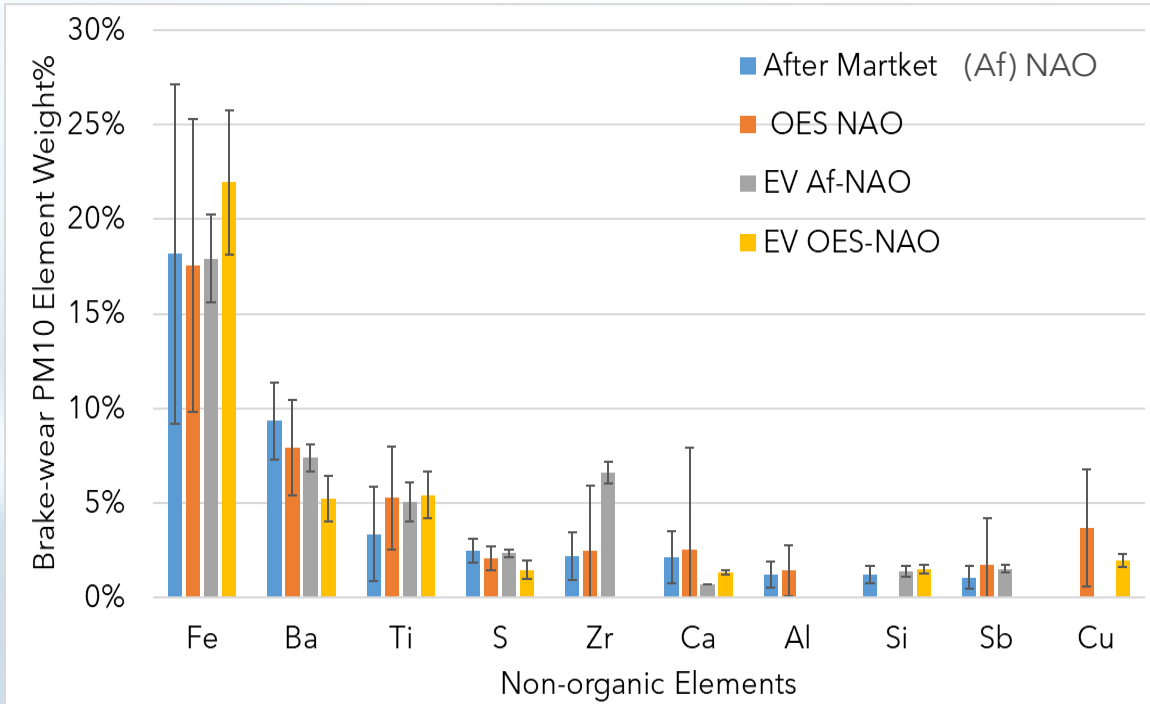
Chemical Speciation for PM10 Samples - XRF Metal Analysis



(Detailed information is available from Report: [PM Speciation Profiles for Light-Duty Vehicle Brake Wear, 2024](#))

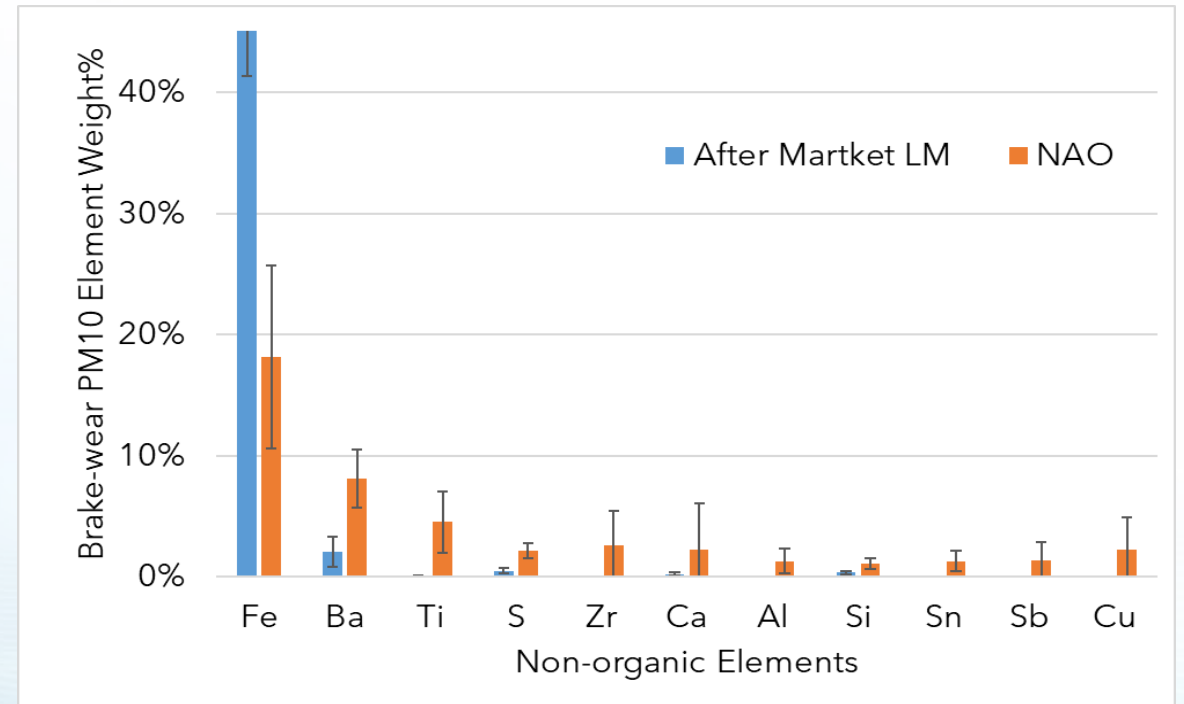
Metal Speciation Profiles

NAO Brake Pads



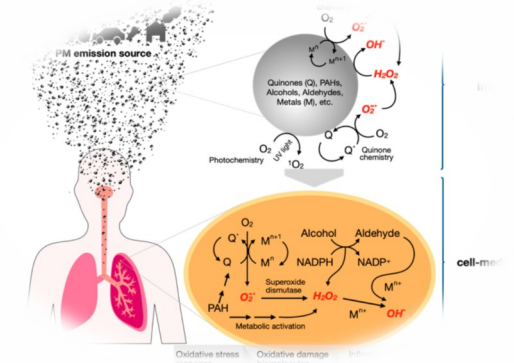
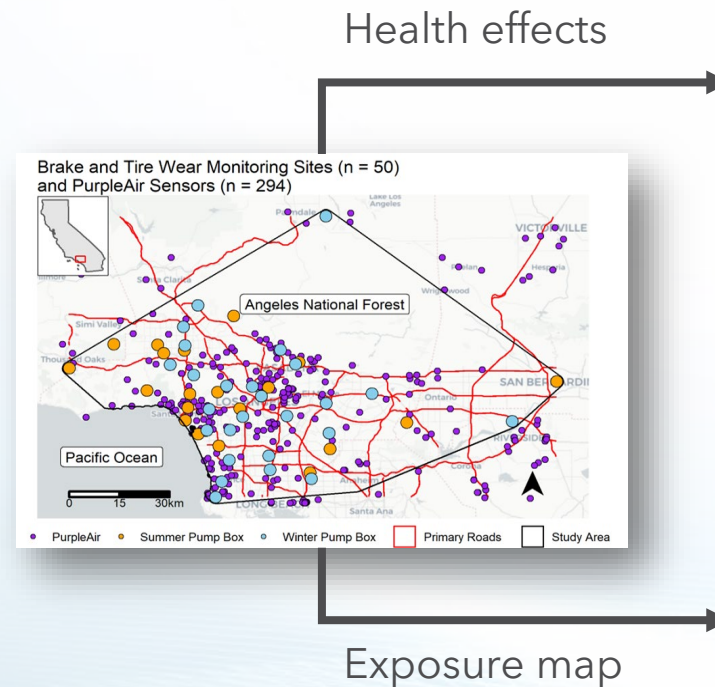
Chemical profiles between gasoline and EV brake particles are very similar to each other.

LM vs. NAO Brake Pads

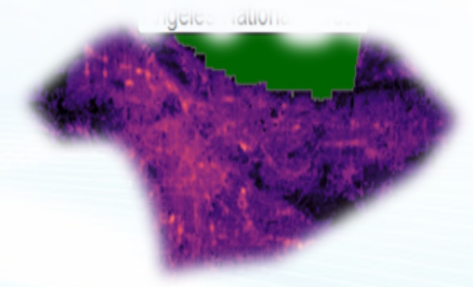


Health Effect Study in Los Angeles Area

- Understand potential health effects of brake and tire wear PM using ambient PM samples
 - Characterize spatial variations in PM_{2.5} metal concentrations
 - Integrate exposure model into health studies

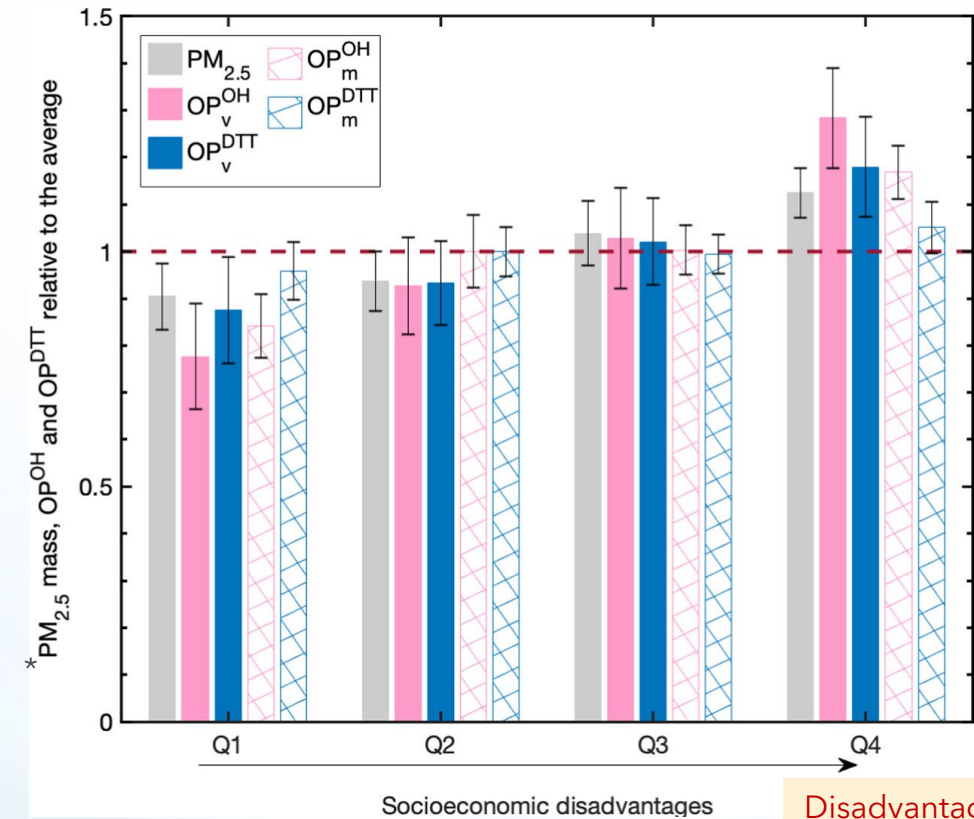
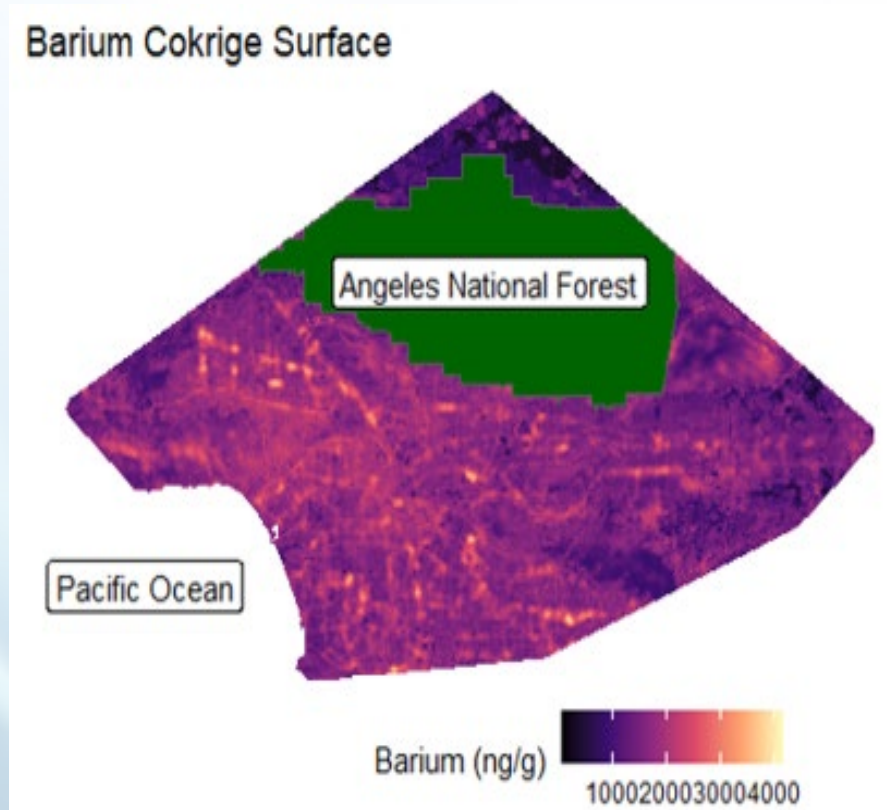


Molina et al. (2020)



(UCLA, Final Report: Effects of Brake and Tire Wear on PM Composition, Reactive Oxygen Species, Placental Development and Birth Outcomes in Los Angeles, 2022)

Brake-Wear PM Exposure and Oxidative Potentials



* PM_{2.5} samples include brake and tire-wear particles

Near-road and disadvantaged communities can be exposed to greater brake-wear emissions and adverse health effects.

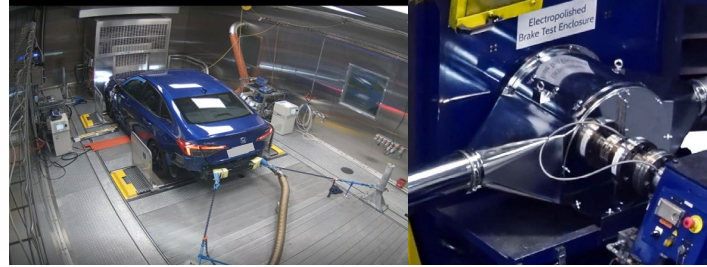
Summary

- Brake-wear is a dominant source of total direct PM_{2.5} emissions and may need to be further reduced where possible.
- Brake-wear particles can be associated with adverse health effects at local and regional levels.
- California's clean transportation programs may help reduce brake-wear particles substantially, especially at the community levels, where many disadvantaged communities are located.
- A comprehensive understanding of the effects of brake-wear particles requires further research in consideration of:
 1. Characterizing brake-wear particles, mass, and chemical profiles
 2. Assessing air quality impacts of the particles locally and regionally
 3. Quantifying community exposure levels and associated health risks
 4. Leveraging clean transportation technologies in reducing brake-wear particles

Current Research Efforts



Brake-Wear and Tire-Wear
On-road measurements for heavy- and light-duty vehicles



Zero-Emission Vehicle Brake-Wear Emissions Reduction
Laboratory testing comparing emissions from gasoline and electric vehicles



Exposure/Health Study
Exposure and health effects of NEE in San Joaquin Valley



Wheel-Wear and Rail-Wear
Laboratory rail- and wheel-wear emissions measurement

Off-Road Brake-Wear
Laboratory dynamometer emissions measurement



Acknowledgement

- Brake Emissions Research
 - Eastern Research Group: Alan Stanard, John Koupal, Sandeep Kishan
 - LINK Engineering: Carlos Agudelo
- Health Effects of Brake and Tire-Wear Emissions Research
 - University of California, Los Angeles: Michael Jerrett, Susanne Paulson, Yifang Zhu



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Appendix: HDV Brake-Dynamometer Test Process and Results

HDV: fleet representative chassis-dyno cycles were identified for track testing

Usage pattern	Vocation Cycle	Cycle Distance (miles)	Brake Power Density (unitless)	Average Speed (mph)
Long haul	Long haul - out of state	21.1	0.66	48.6
Long haul	Long haul - in state	18.5	1.21	41.3
Pick-up & delivery	Airport shuttle	7.5	2.60	15.0
Pick-up & delivery	Refuse	5.2	4.32	11.1
Pick-up & delivery	Food distribution	17.8	0.88	36.1
Pick-up & delivery	Beverage distribution	5.6	2.85	14.2
Pick-up & delivery	Local moving	15.3	1.28	32.6
Pick-up & delivery	Urban buses	7.1	3.82	14.9
Pick-up & delivery	Express buses	14.5	1.50	30.2
Service	Utility - repair	11.3	2.19	22.7
Service	Public - freeway work	10.9	2.06	24.5
Service	Public - sweeping	8.5	1.49	18.2
Service	Public - municipal work	13.6	1.87	28.6
Service	Public - towing	16.8	1.59	36.8
Short haul	Drayage - Northern CA	4.3	3.33	11.9
Short haul	Drayage - Southern CA	9.4	1.94	19.3
Short haul	Agriculture - Southern	18.3	0.85	44.8
Short haul	Construction	15.4	1.44	32.3
Short haul	Cement mixers	11.6	1.89	28.1

$$Brake\ Power\ Density_{cycle} = \frac{\sum_{t=1}^{duration} [(Speed_{t-1}^2 - Speed_t^2) \div (Deceleration\ Rate)]}{Cycle\ Distance}$$

Vehicle/Configuration	Load	Vocation Cycles					
		Drayage Northern California	Beverage Distribution	Long Haul In-State	Towing	Refuse	Urban Bus
Class 8 All-Disc Tractor + Drum Trailer	Full Load (80,000 lbs)	•	•	•			
	Unloaded (37,500 lbs)	•					
Class 8 All-Drum Tractor + Drum Trailer	Full Load	•	•				
	Unloaded	•	•				
MD Hydraulic disc	26,000 lbs		•		•		
Refuse truck simulation: Class 8 All-Disc Tractor + Actuators representing refuse + Unbraked 28' Control Trailer	Full Load (over tractor king pin)					•	
Bus Coach	37,500 lbs						•



Class 8 truck used for drum, air disc, refuse track tests

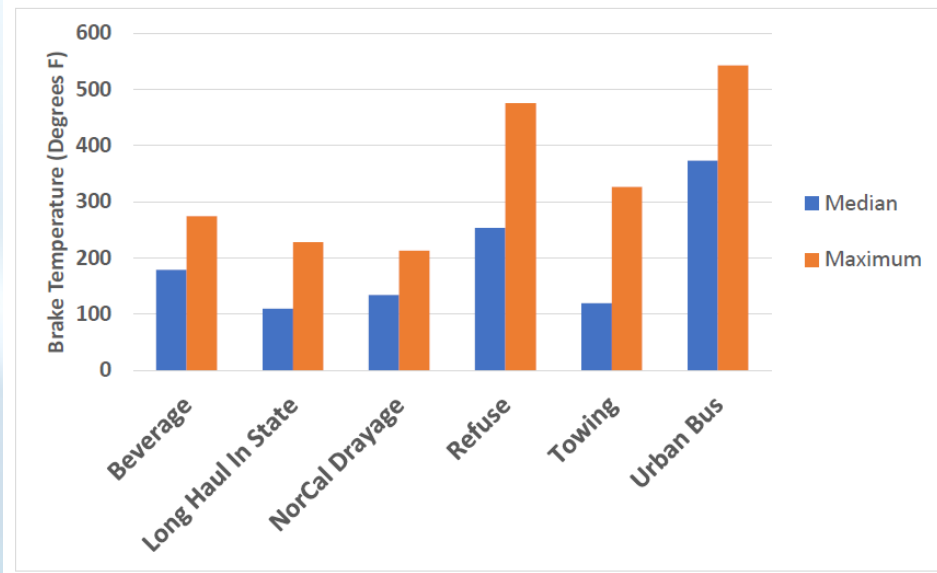


Class 6 truck used for hydraulic disc track tests



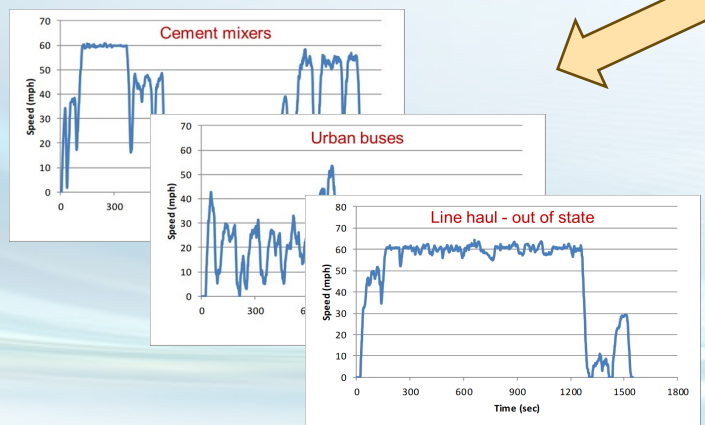
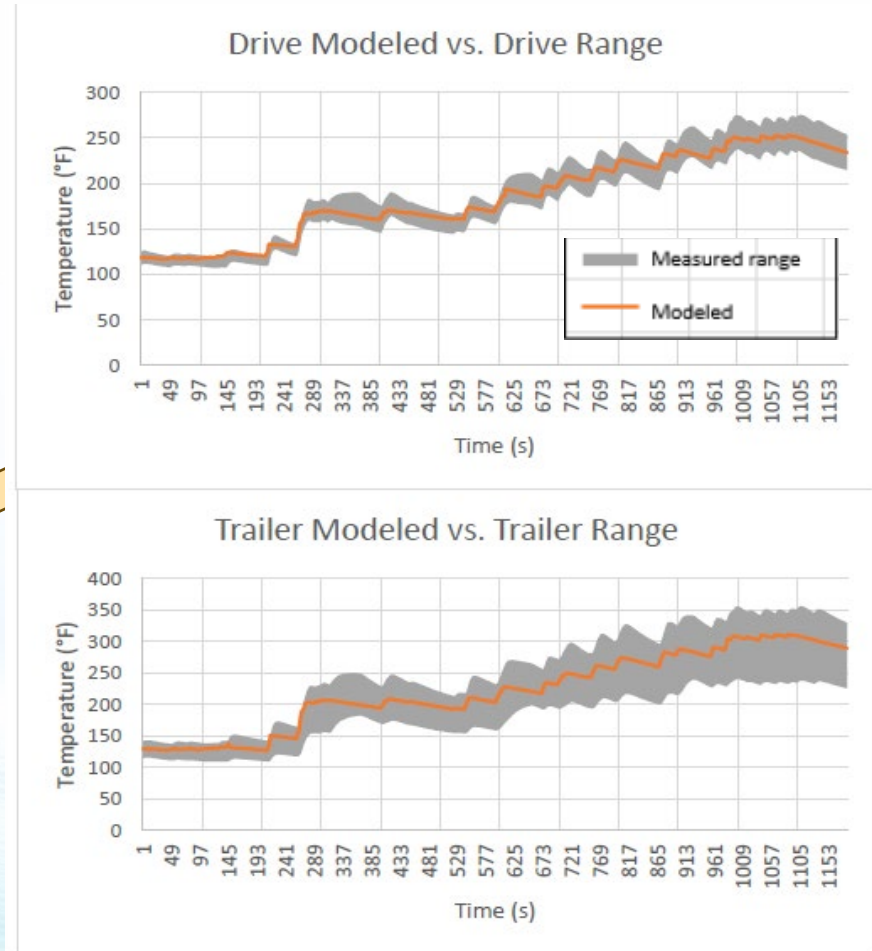
Bus coach used for urban bus air disc track tests

HDV: temperature profiles were developed and applied for brake-dyno testing

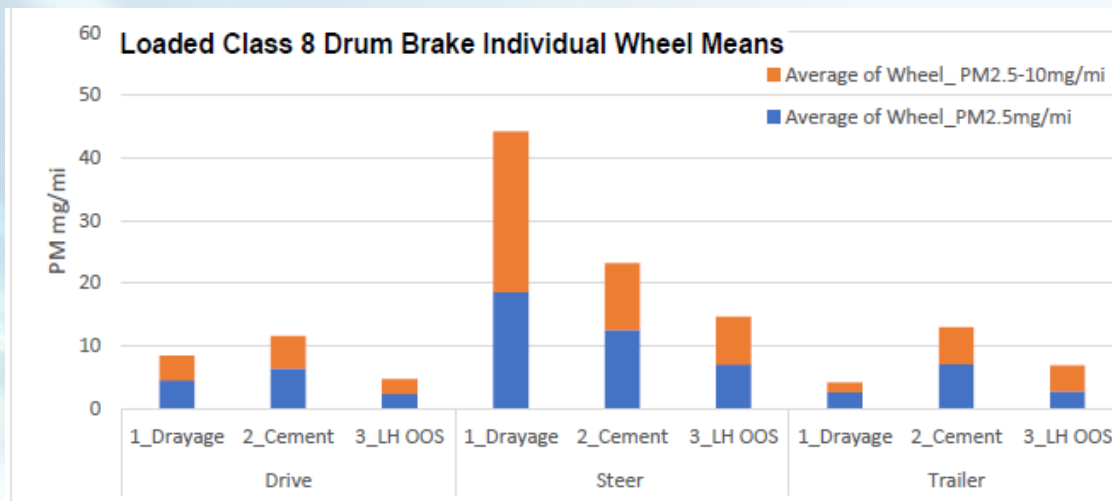
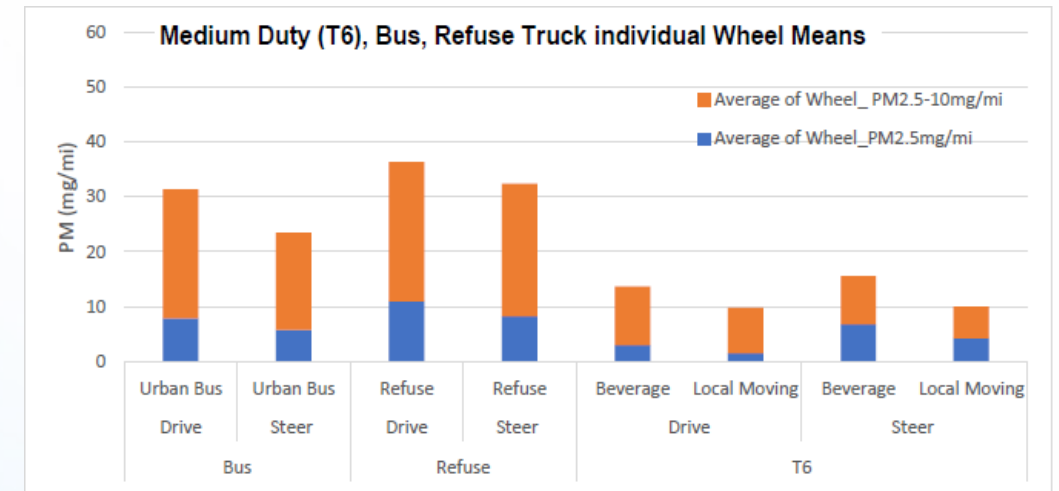
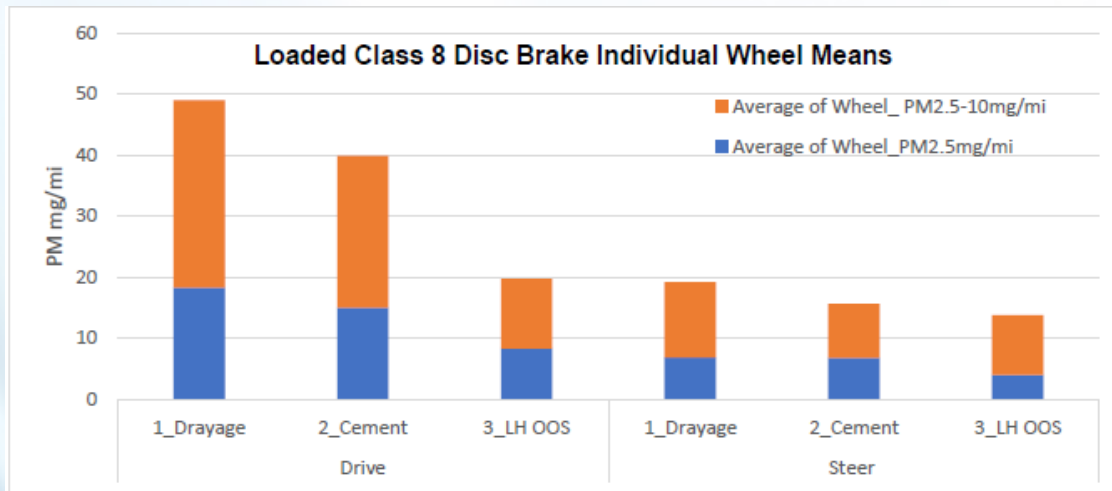


Brake Temperature Model

$$T = T_i e^{-t/\tau} + \left(\frac{HP_B}{h(v)} + T_a \right) (1 - e^{-t/\tau})$$

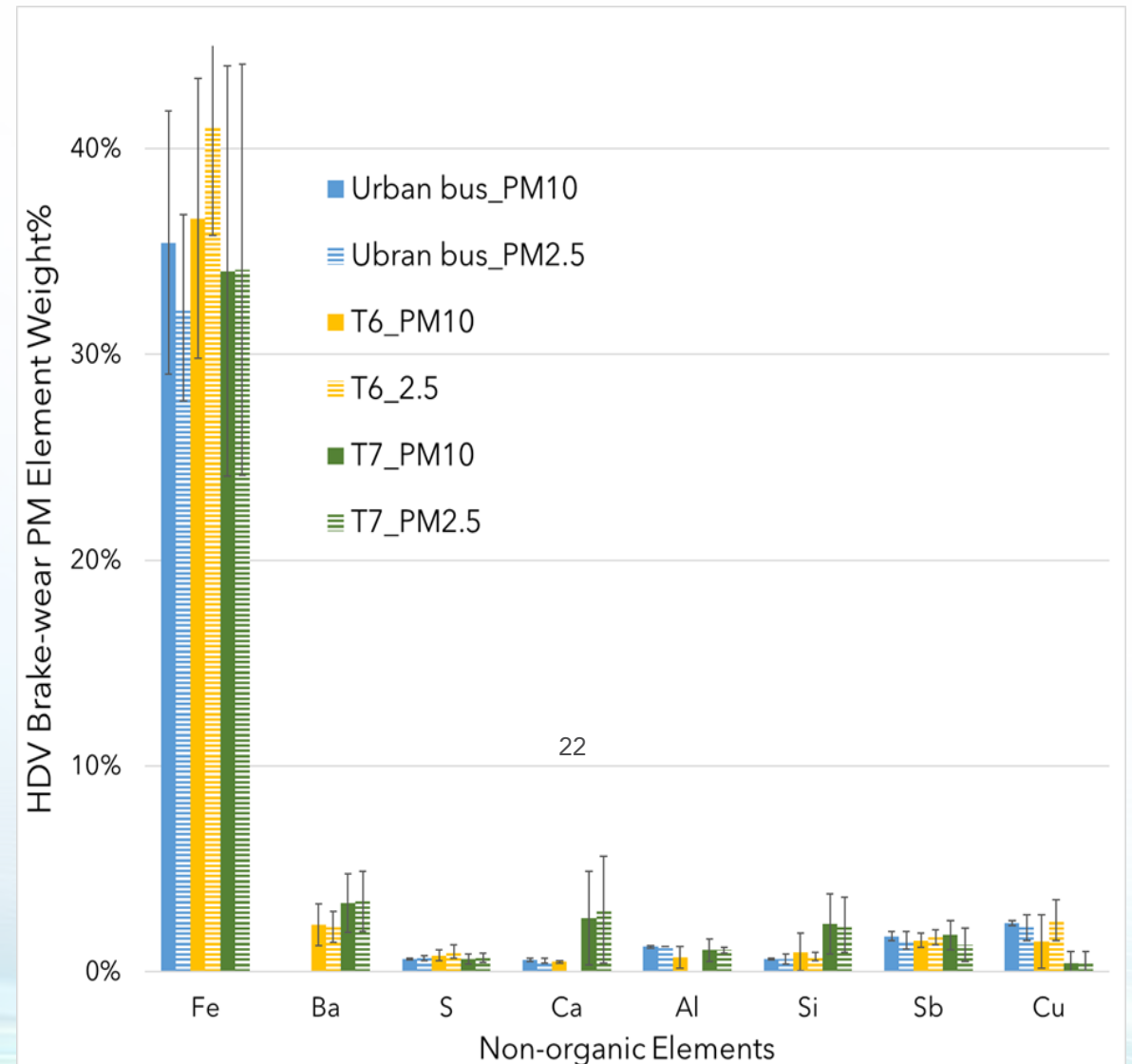
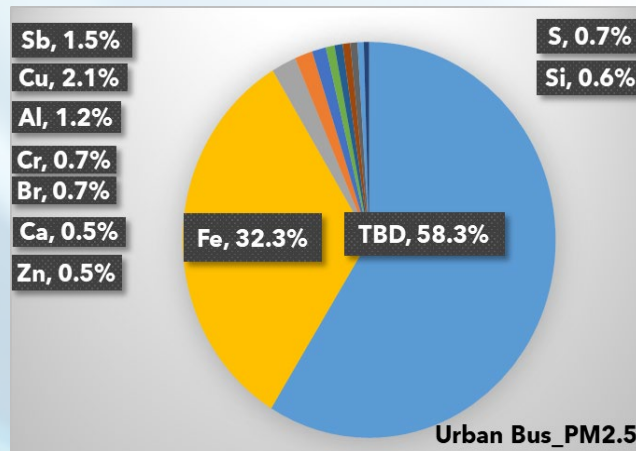
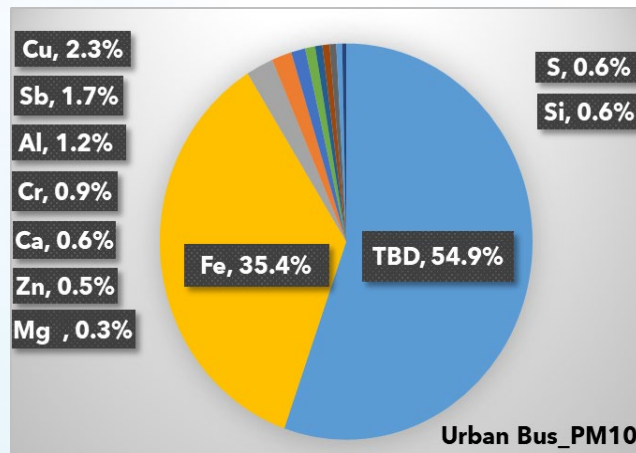


HDV: brake-wear PM emission rates of individual wheels for loaded trucks



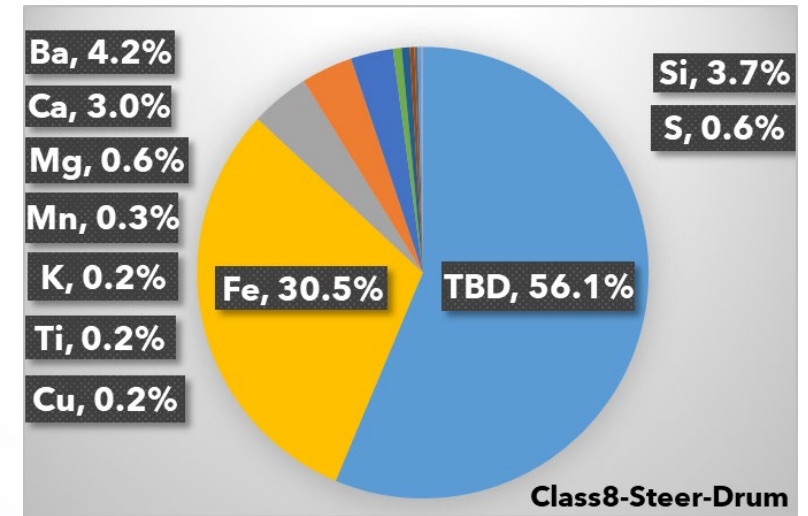
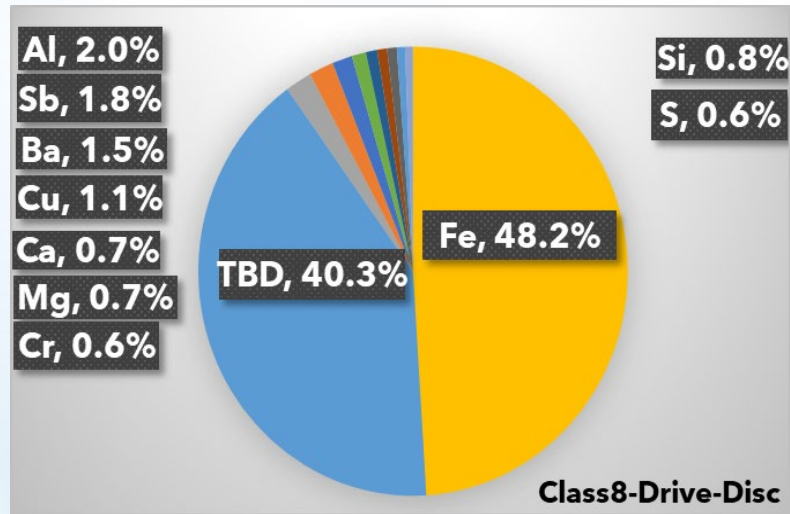
(Details are available from [Caltrans' research report](#), 2021)

HDV Brake-wear Composition Profile: PM10 vs. PM2.5

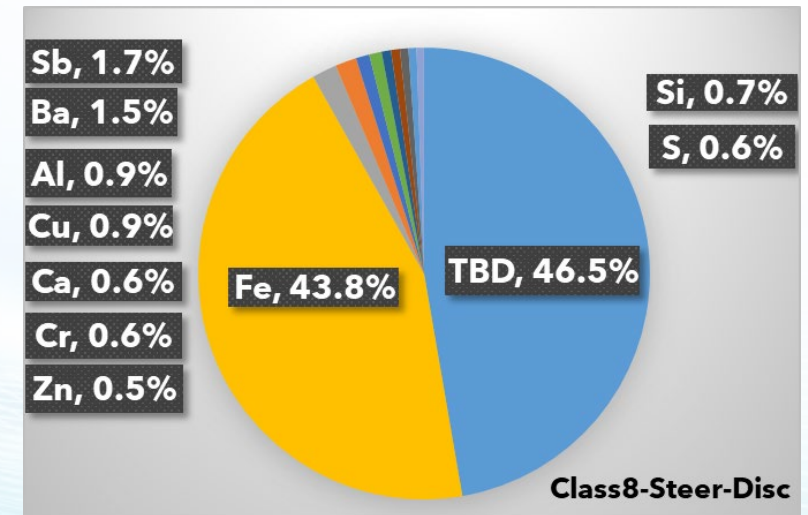
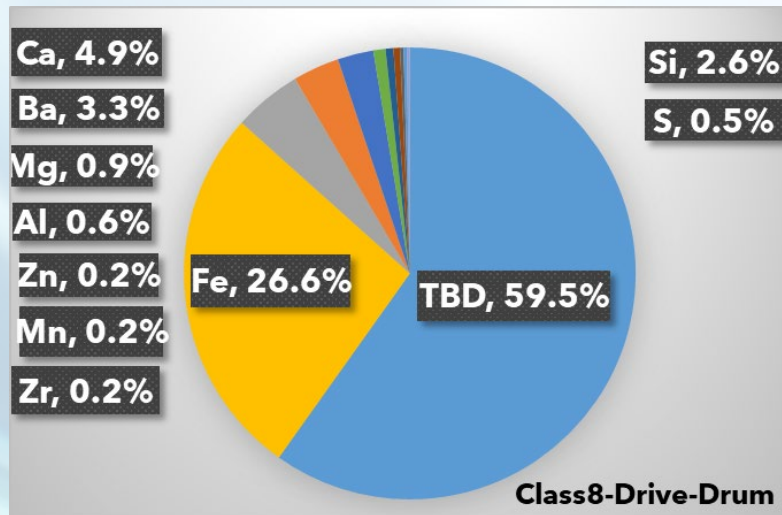


PM size is **NOT** impacting
BW composition profile

HDV BW Composition Profile: Disc vs. Drum



Drive: Drive axle
Steer: Steer axle
Drum: Drum brake
Disc: Disc brake



HDV braking technology is impacting BW composition profile