Addressing In-Use Non-Exhaust Emissions from Heavy-Duty and Light-Duty Vehicles: Development of a New Research Laboratory at CE-CERT

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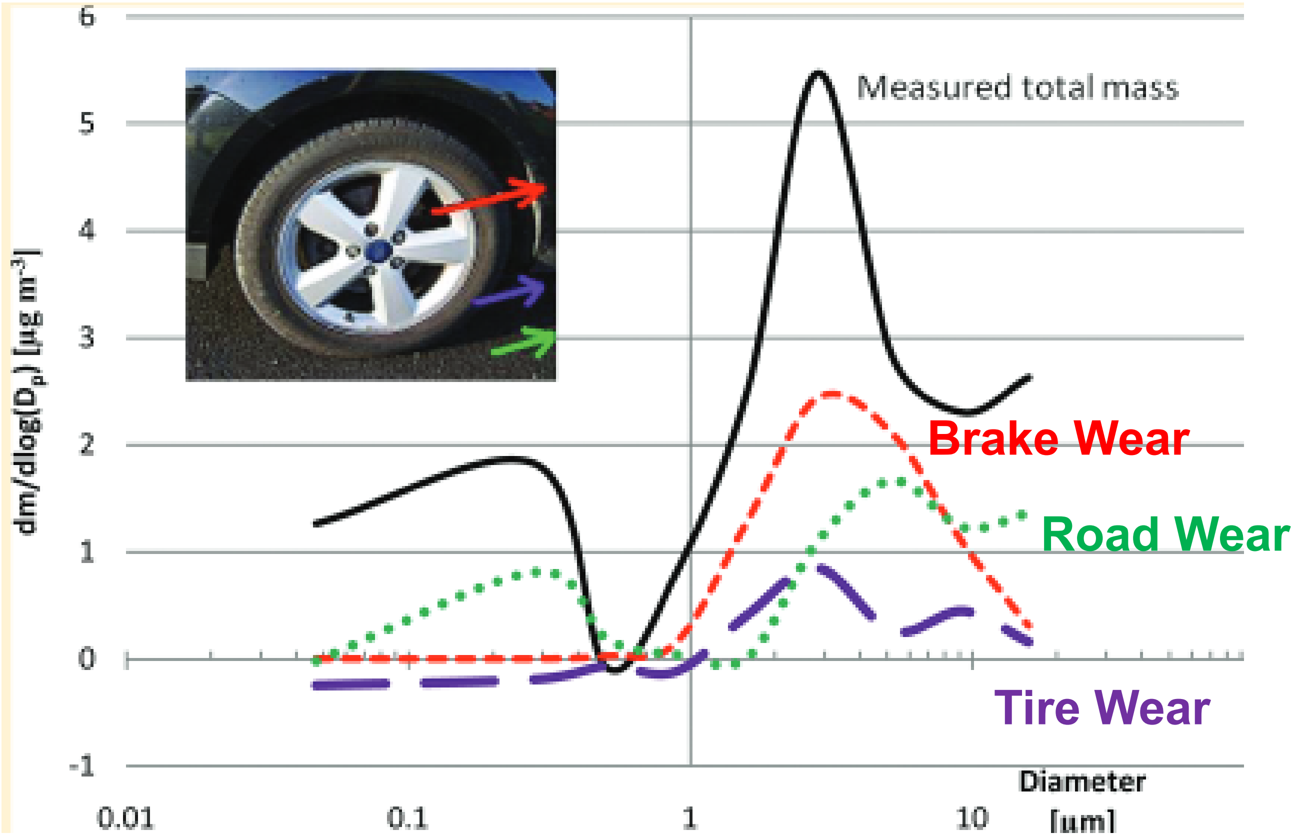
UCR's Motivation to Expand Research in Non-Exhaust Emissions

- Dramatic reductions in exhaust PM emissions from mobile sources, with increasing non-exhaust share of total PM emissions
- Transportation landscape is changing
  - More electric vehicles on the road
  - Regenerative braking
  - Driving habits
- Considerable uncertainty remains regarding the amount and nature of non-exhaust PM emissions during real-world operation
  - What are the factors affecting these emissions?

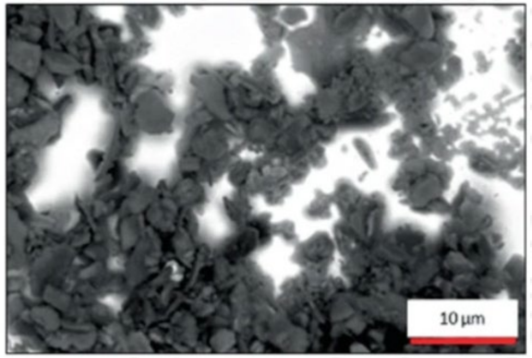
What are Non-Exhaust Emissions?



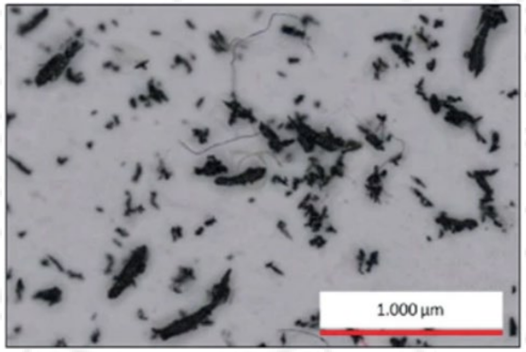
Harrison et al., EST 2012

- Primary/directly emitted particles
- Mechanical abrasion
  - From brake pads and discs
  - From eroded tires
- Road wear and road dust resuspension: particles eroded from road surfaces and suspended in the air by vehicle traffic

Brake wear: complex/inhomogeneous forms



Tire wear: circular/dendritic particles



Tire Wear

Tire Tread Constituents

- Natural rubber and
- Synthetic polymers (butadiene rubber, styrene-butadiene rubber, halogenated polyisobutylene rubber)
- Steel
- Fillers (carbon black and silica)
- Softeners (oil and resin)
- Vulcanization agents (sulfur and zinc oxide)
- Antioxidants and antiozonants

Composition of Tire Wear PM

- Rubber and microplastics
- Metals and elements
- Polycyclic aromatic hydrocarbons (PAHs)
- 6PPD-quinone (6PPD-Q; 2-anilino-5-[(4-methylpentan-2-yl)amino]cyclohexa-2,5-diene-1,4-dione)
- Semivolatiles: PAHs, IVOCs, etc.

Brake Wear

Brake Linings Composition

- Binders (phenol-formaldehyde resins)
- Reinforcing fibres (copper, steel, brass potassium titanate, glass, organic material, and Kevlar)
- Fillers (barium and antimony sulphate, magnesium and chromium oxides, silicates, ground slag, stone and metal powders)
- Frictional additives or lubricants (graphite, ground rubber, metallic particles, carbon black, etc.)
- Abrasives (aluminum oxide, iron oxides, silicon oxides, and zircon)

Composition of Brake Wear PM

- Metals and elements
- Metal oxides
- Black carbon
- Polycyclic aromatic hydrocarbons (PAHs) and other intermediate volatility organic compounds (IVOCs)
- Other organic compounds (acids, ethers, sterols, etc.)

Road Surface (and Dust Resuspension)

Road Surface PM Composition

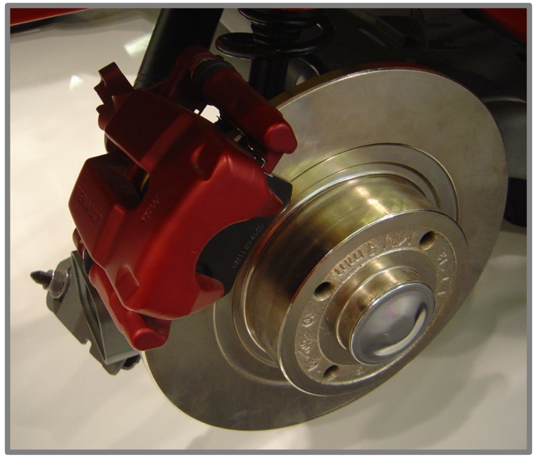
- Concrete (mixture of mineral aggregate, sand, and cement)
- Asphalt tarmac (mixture of mineral aggregates and bituminous binder)

Road Surface PM Emissions

- Crustal material of small mineral fragments, such as Si, CA, K, Fe, and Al (originated from the aggregate)
- High molecular weight aliphatic and aromatic hydrocarbons, polymers, epoxy resins, and metal complexes (originated from the bituminous binder)
- Platinum group elements (wear of catalysts)

Factors Affecting Non-Exhaust Emissions

Brake Wear



- Brake materials
- Number & type of brakes
- Driving conditions
- Brake pad temperatures
- Vehicle load

Tire Wear

- Tire materials
- Driving behavior
- Road condition (and age)
- Pavement type (concrete vs. asphalt)

Road Dust Resuspension

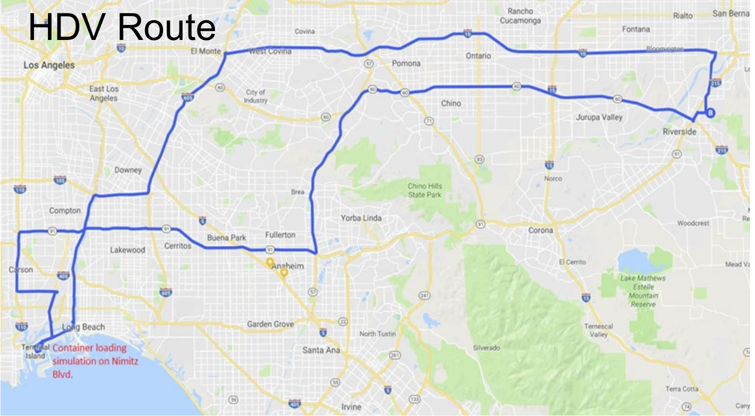
- Urban vs. rural area
- Season (temperature & precipitation)
- Wind speed
- Proximity to crustal materials
- Driving speed
- Vehicle weight

Experimental Approach

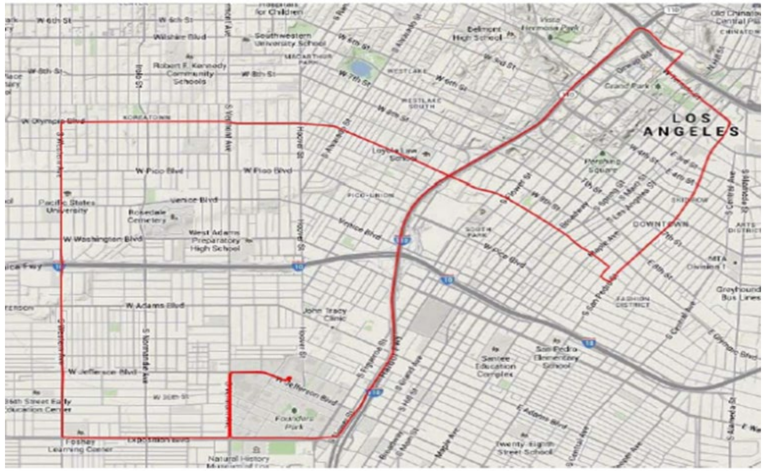
CARB funded project (3 years); Project team: UCR, ERG, Ricardo, Link Engineering

- Task 1: Literature review
- Task 2:
  - Survey brake and tire market share and identify fleet
  - Characterize California road data and identity
  - Design on-road sampling method/pilot tests
- Task 3: Test plan based on findings from Task 2
- Task 4: On-road testing

Test Routes and Vehicles



LDV Route



- Typical goods movements and port drayage routes
- Route selection will also be based on pavement material (concrete vs. asphalt)
  - Use of Caltrans PaveM database and visual inspection
- Test vehicles: Likely one Class 8 truck and one LDV (PHEV or BEV) or more
  - Three different set of tires will be used for the LDV over different routes

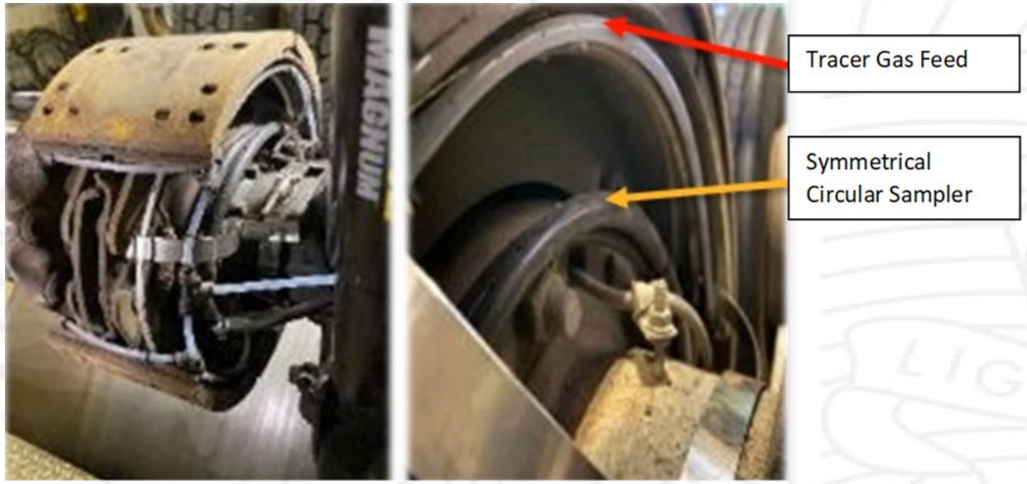
On-Road Brake Wear Sampling System

LDV Sampling System

- Design developed by Ricardo:
  - Full enclosure will be fabricated around the brake rotor and caliper
  - CVS technique
  - Optimized airflow rate to minimize PM losses and also to cool the brakes
    - Positive pressure pump upstream of the enclosure to be supplemented by a negative pressure pump downstream the CVS

HDV Sampling System

- Design developed by CARB:
  - Injection of a tracer gas into the drum area to quantify the mass of CO_2 recovered
  - Sampling through a symmetrical circular sampler



On-Road Tire Wear Sampling System

- Design developed by Ricardo with modifications
- Inlet probe mounted behind the tire/road interface
  - Moves with the tire, both in suspension travel and steering
- Challenges with system design (must maintain isokinetic flow at sampling point for accurate PM measurement):
  - CVS-based (constant flow into the sampling tunnel)
  - System to vary sample flowrate proportionally with vehicle speed

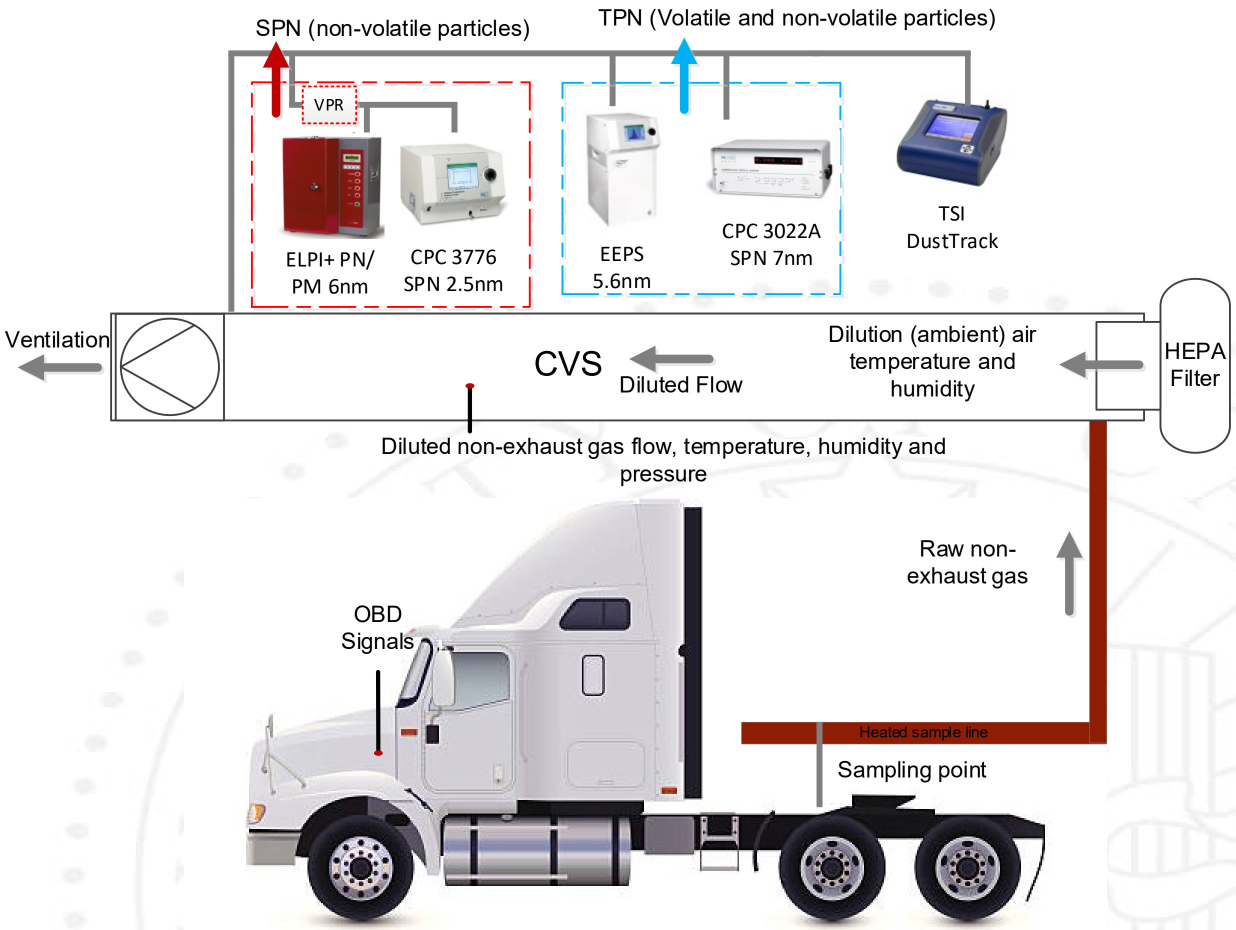
Prevent of cross-contamination:
Use of brake enclosure sampling system's inlet pump to draw sample out of the enclosure to prevent mixing of brake PM into the tire PM sample

Design Considerations

- Ability to measure brake- and tire-wear emissions separately
- Ability to concurrently sample for background/ambient PM including road dust
- Minimization of the contamination of brake PM into the tire PM sampling and vice versa
- Minimization of the effect of the measurement system on the operational characteristics of the vehicle
- High collection efficiency/minimal particle losses
- Ability to utilize the system across a range of vehicle types
- Ability to measure both front and rear tires/brakes

Sampling Protocol

- Real-time PM2.5 and PM10
- Collection of PM1, PM2.5, and PM10 filter samples
- Particle number and particle size distributions
- Total (volatile and nonvolatile) and solid particle number
- OBD data (engine load, engine speed, vehicle speed, etc.) and GPS data



Additional dilution may be needed for the real-time instruments

Real-Time Measurements

Measurement	Rate	Instrument
Particle number concentration (size range 5.6-560 nm, 32 channels)	1 s	Engine Exhaust Particle Sizer (EEPS, Model 3090, TSI, Inc.)
Particle number concentration (size range 6nm-20 µm)	1 s	Dekati ELPI+
Particle Number Concentrations	1 s	Ultrafine Condensation Particle Counter (CPC 3776, TSI, Inc.)
Mass Measurements ($PM_{2.5}$ and PM_{10})	1-5 s	TSI DustTrak Aerosol Monitor
Particle number concentration (size range 0.5-20 µm, 52 channels)	1 s	Aerodynamic Particle Sizer (APS, Model 3321, TSI, Inc.) - ***Optional based on availability***
Meteorological Measurements (Temperature, Pressure, etc.)	1 s	To be determined
OBD data collection	1 s	Silverscan Tool (or similar)
Longitude and latitude	1 s	Global positioning system (Crescent R100, Hemisphere GPS)

Chemical Speciation

- Elemental carbon and organic carbon (NIOSH method 5040)
- Metals and elements according to EPA IO-3.3 method
- 6PPD-quinone & IPPD-quinone (Liquid Chromatography)
- PM-PAHs and vapor-phase PAHs (GC-MS)
- Reactive oxygen species (ROS) and dithiothreitol (DTT) assays

Future Non-Exhaust Emissions Projects

- Phase 1 – Characterization of Tire-Wear and Brake-Wear PM Emissions Under On-Road Driving Conditions
  - Funding secured by CARB
  - Project team: ERG, Ricardo, and Link Engineering
- Phase 2 – More In-Use Non-Exhaust Emissions Characterization
  - Expand vehicle technologies to include EVs, FCVs, PHEVS/HEVs
  - Health effects (and animal) studies with epithelial cells exposure
- Phase 3 – Harmonization of non-exhaust emission sampling methodology
  - Particle losses investigation
  - Lab-to-lab reproducibility and repeatability
- Phase 4 – Expanding OSAR to Non-Exhaust Emissions
  - Monitor vehicle activity + weight, tire pressure, and meteorology sensors
  - PM/PN sensors

Thank you!