CALIFORNIA
AIR RESOURCES BOARD

Brake-wear PM Research for California Emission Inventory

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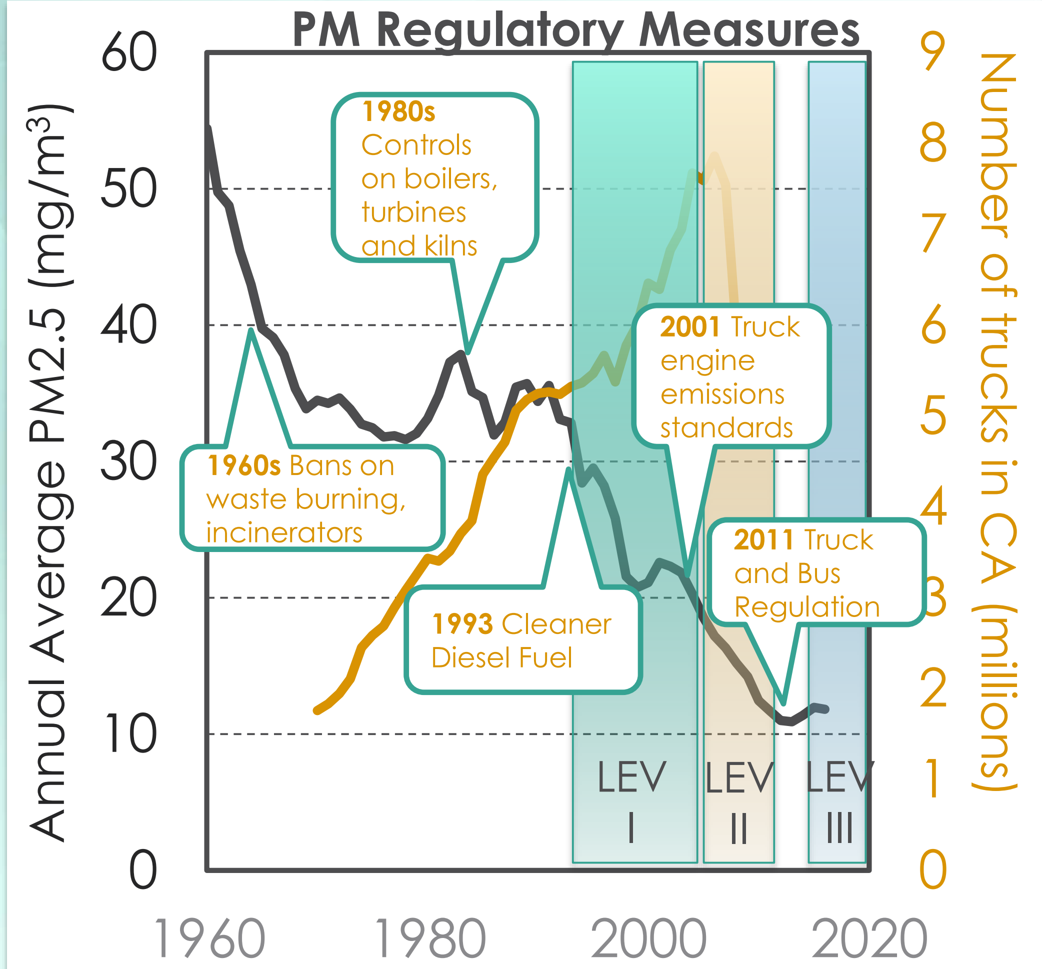
CalTrans: Simon Bisrat, Yoojoong Choi, Mauricio Serrano
U.S. EPA

CARB Goals

- Protect the public from the harmful effects of air pollution
  - Regulatory measures
  - Enforcement
  - Setting standards
  - Monitoring
  - State Implementation Plan (SIP)



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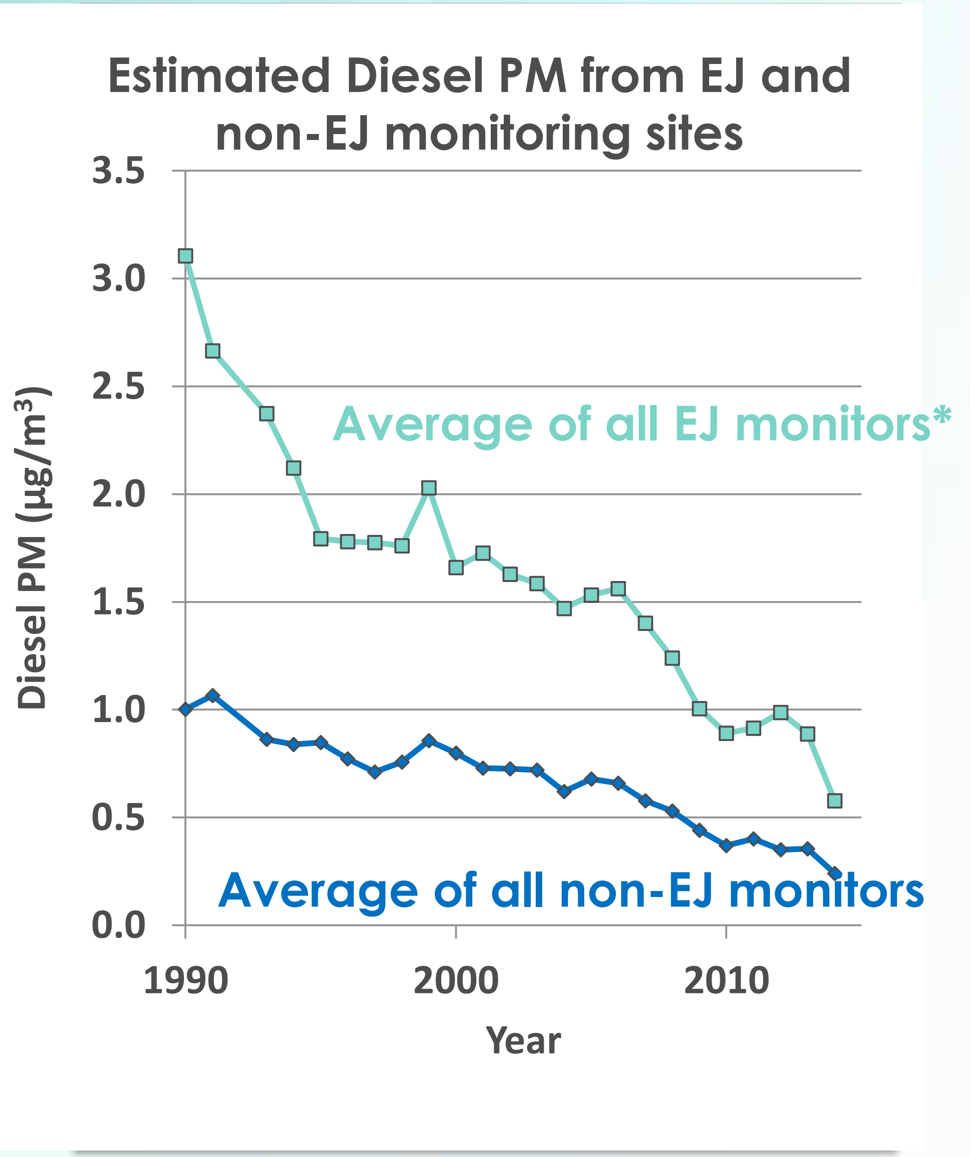
CARB Goals

- Reduce exposure in communities most impacted by air pollution
- Reduce air quality disparity between communities



* EJ monitors are located in areas disproportionally impacted by environmental factors and have lower socioeconomic status

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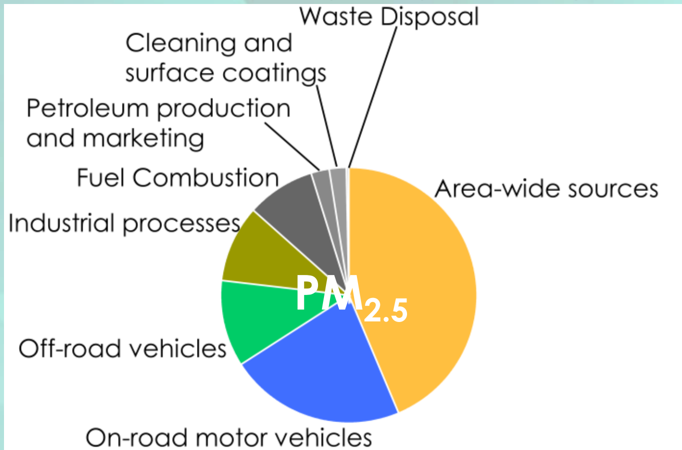
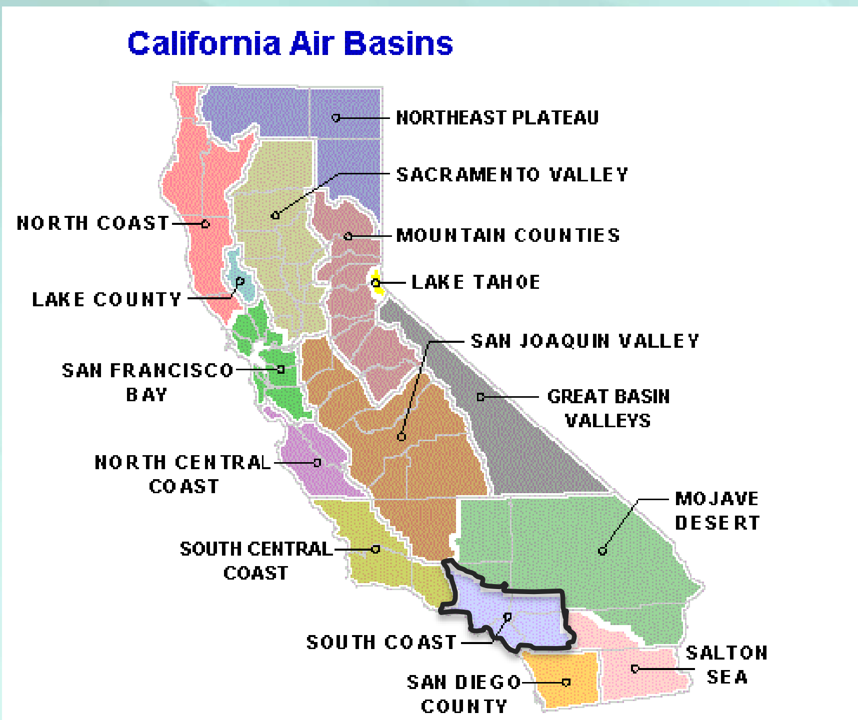
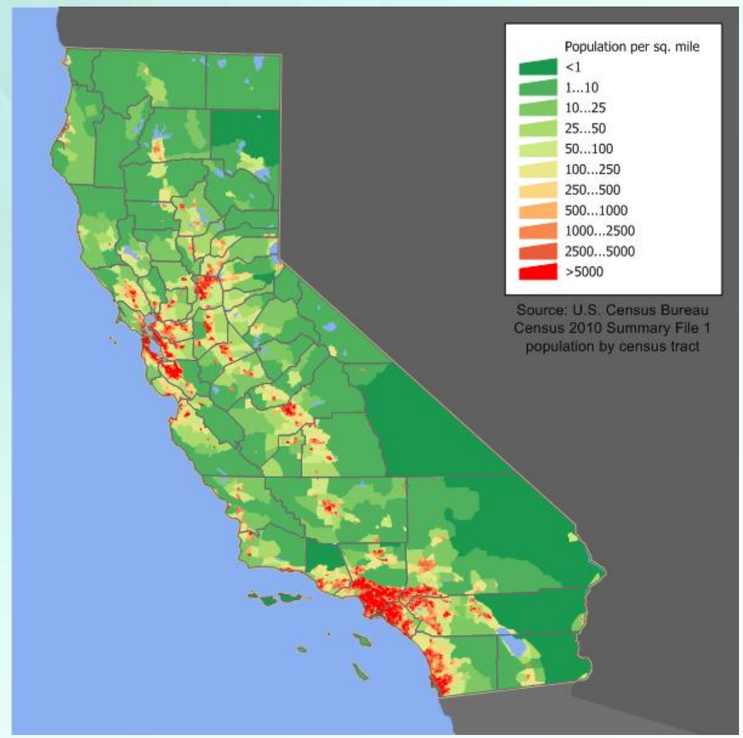
Sources of PM2.5 in South Coast Air Basin (2012)







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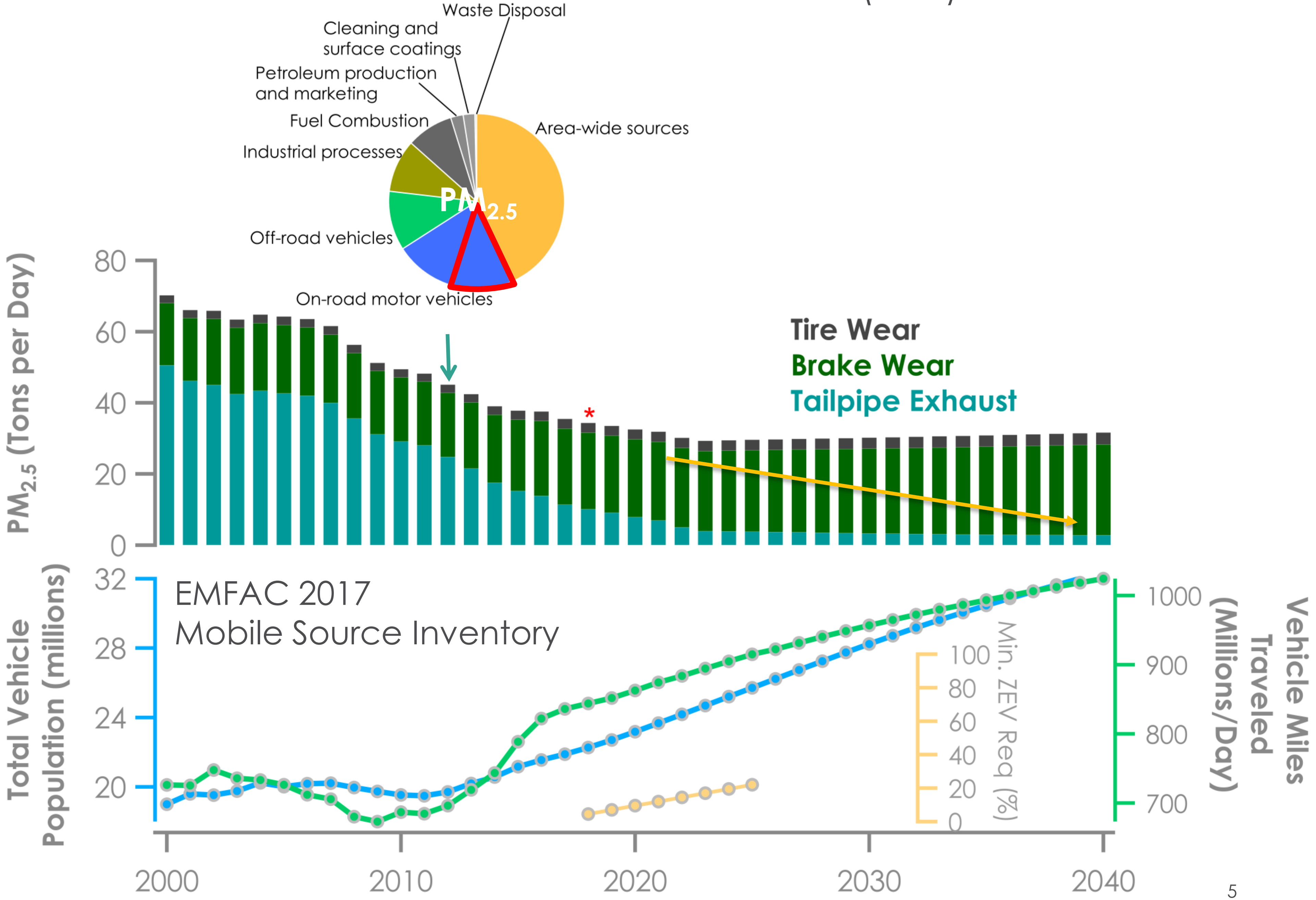
Sources of PM2.5 in South Coast Air Basin (2012)



Inventory Basics: Brake Wear

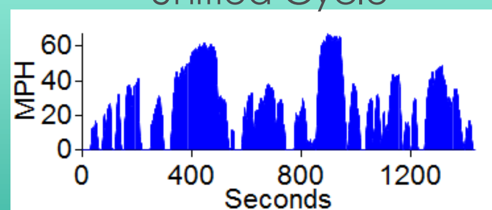
Cycle Averaged PM EF

PM emitted per braking event from laboratory measurements

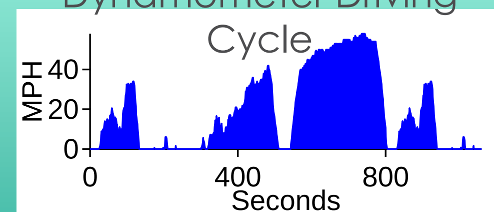
X Airborne Factor

# of braking events per mile

Unified Cycle



Heavy Duty Urban Dynamometer Driving Cycle



# of brakes per vehicle

Miles driven per day

VMT

Vehicle Population

Emissions in Tons/Day

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Source Data

- EMFAC 2007 and earlier: 1983 data
- EMFAC 2011 and later: 2000/2003 data
- NOTE! data source studies not designed specifically to meet EMFAC needs (cycle based)

Reference	Garg, et al. 2000	Sanders, et al. 2002 & 2003
Number of individual brake pads	7 (Top GM models, >80% of marketshare)	3 (LM-mid size, SM-truck, NOA-full size)
Number of individual tests	21 (varied brake id's and temperatures)	11 (3-4 UDP tests for 3 types of pads: LM, SM, NAO)
Cycles/Total Brake Events	BSL-035 (100, 200, 300, 400 °C) 50→0 km/hr, 0.3 g	UDP (24 brake events, 0.6-1.6 m/s^2)
Method	Enclosed brake dyno	Enclosed brake dyno

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Source Data Adaptation

- Data was extrapolated to cover all technology groups and standard drive cycles

Vehicle Type	Braking Cycle	Braking Frequency (Apps/mile)
Passenger Cars and SUVs	UC	4
Medium-HD Trucks	ARB-MHD	5
Heavy-HD Trucks	ARB-HD	1.2
Urban Transit Buses	OCTA	8.2
School Buses	MHD-LS Transient	14

- Wheel load dependence extrapolated from available data (linear fits)

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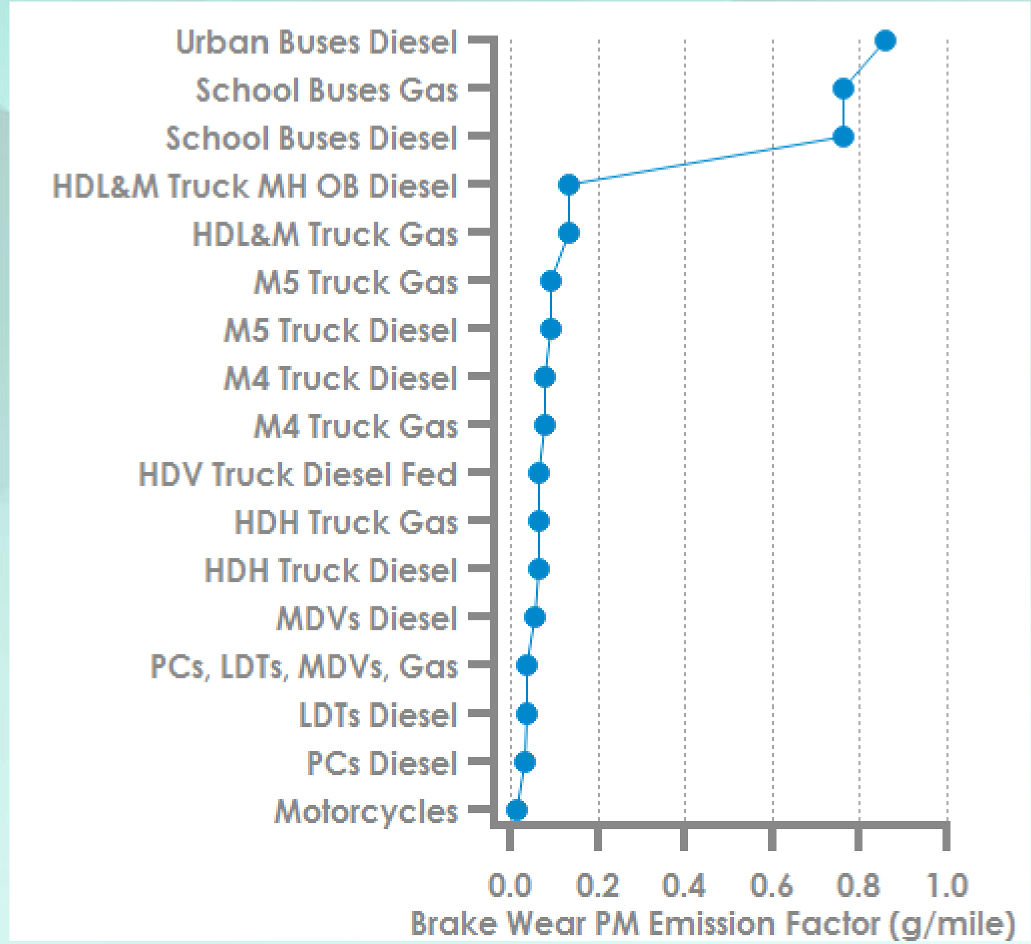
Brake Wear PM Emission Factor Summary



- HDVs have high EFs
  - More brakes, different cycle
- Buses have high EFs
  - Many stops in typical cycle
- **Not speed dependent**

EMFAC 2017 Documentation

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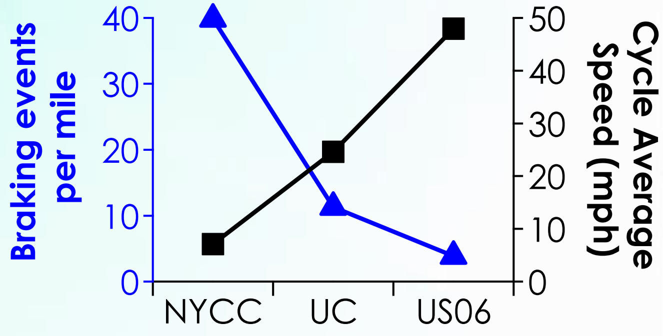
Priorities for new emission factor development

- Use CA relevant vehicles and brake components
- LDVs, MDVs, HDVs
- Identify speed dependent braking cycle reflecting CA behavior
- Identify cycles for LDVs, MDVs and HDVs
- Use methods being adopted by JRC (Enclosed brake dynamometer)
- Maintain realistic temperatures
- Develop method to simulate regenerative braking



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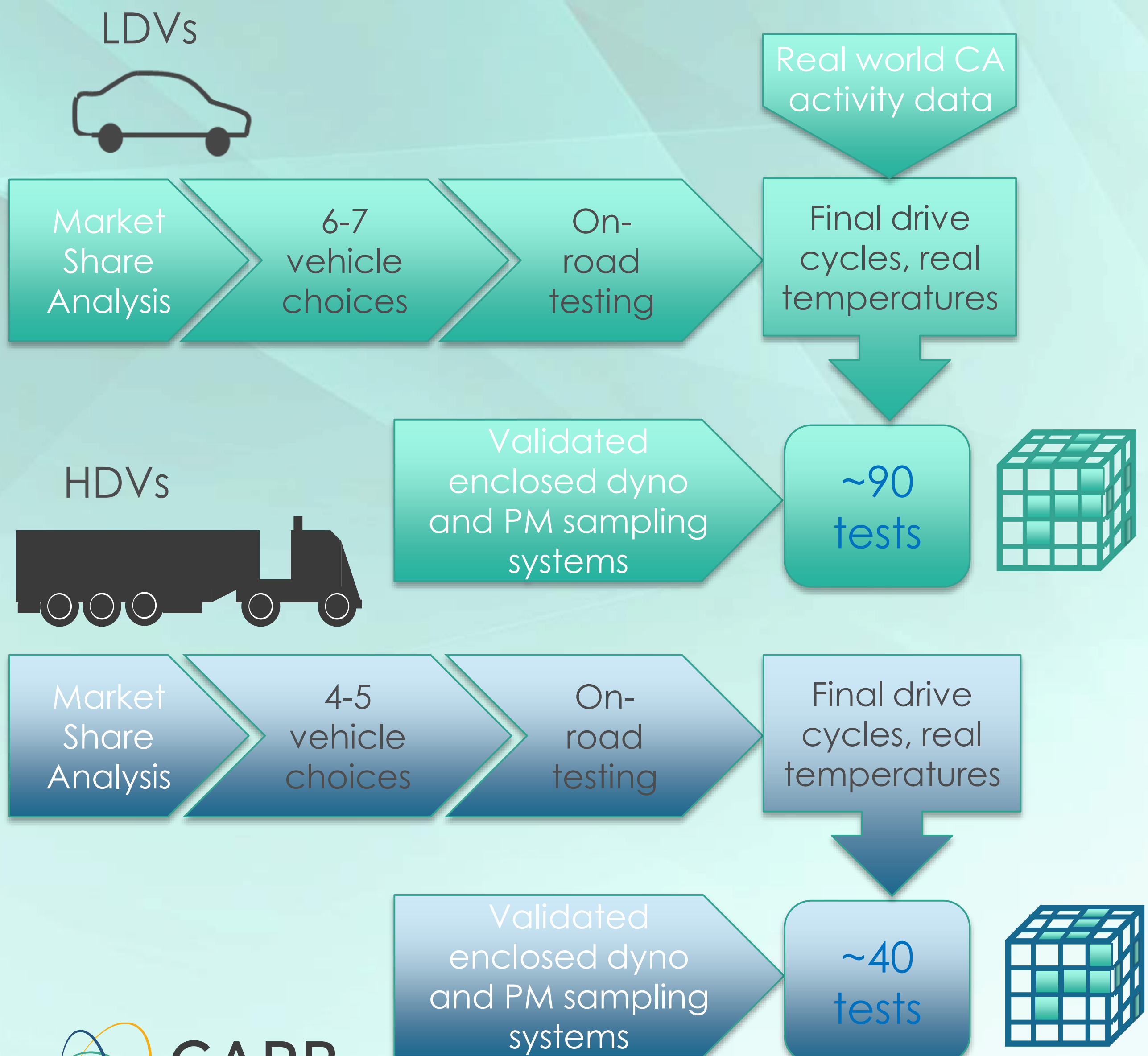
Proposed Work



<u>Vehicle N</u>:
Front brake pads
Rear brake pads/drums
Popular aftermarket pads
Loaded/unloaded
Replicates

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New project will capture larger market, materials and conditions

	Previous Source Data	Current Project
Vehicles represented	6 (LDA) 4 (LDT)	3 (LDA) 2 (LDT) 2-3 (LDA-regen capable) 4 (HDV)
Number of individual brake pads	10 (LDV)	24 (LDV) 12 (HDV, tractor and trailer)
Number of tests	32	130
Cycles/Total Brake Events	UDP, BSL-035/~285	TBD/1000's to 10,000's
Test Conditions	Discretized temperatures, brake force	Continuous distribution, focused on realistic conditions
Method	Enclosed brake dyno	Commonly accepted enclosed brake dyno (TF2)

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Results will include…

- Updated emission factors
  - Cycle based - Speed dependent
  - Regenerative braking effects
  - Effects of load, vehicle type, pad type
- On different time scales, explore various effects on mass, PN, PM size:

Cycle Averaged	Micro-trip Averaged	Individual Brake Events
Vehicle configuration Pad material Repeatability	Speed Driving behavior Repeatability	Braking power Temperature Repeatability

- Chemical composition

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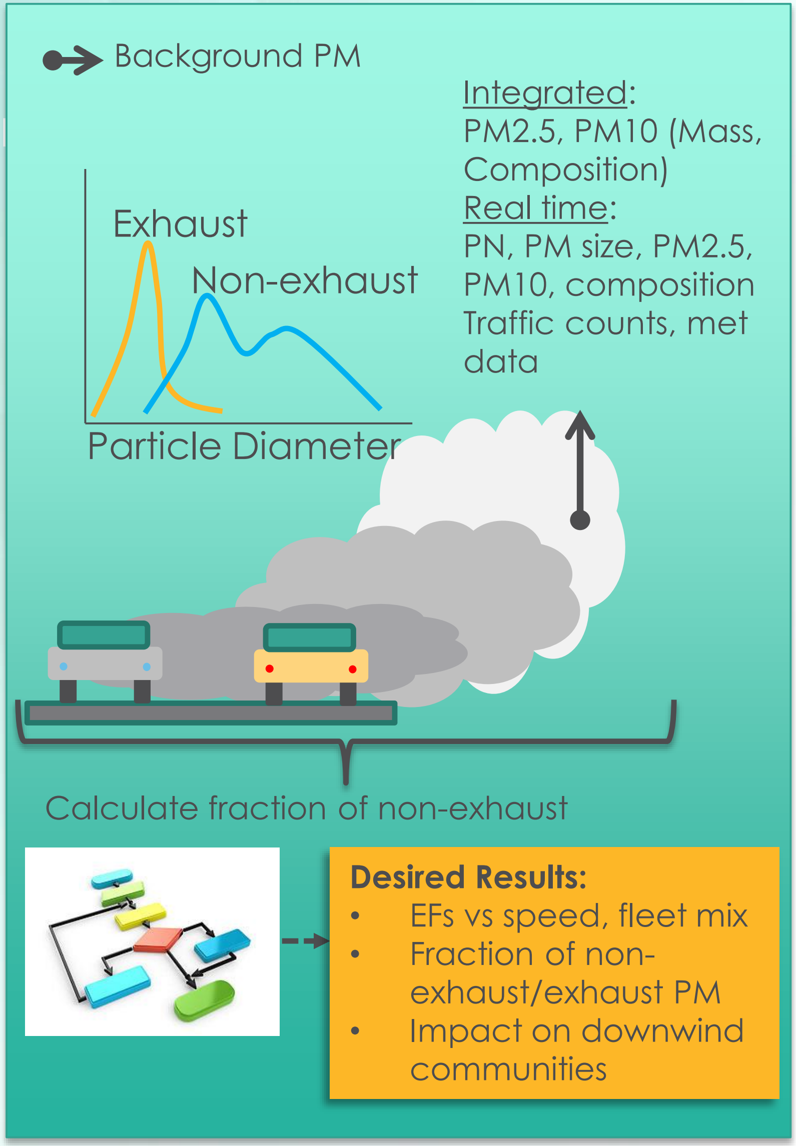
Comprehensive Research Approaches for Brake PM in California

- Bottom up approach
  - External contract with ERG/LINK
  - Many advantages
  - Some disadvantages
- Second bottom up approach
  - In-house project
  - Full chassis dyno tests
- Top down approach
  - External contract with UC Riverside
  - Roadside measurements
- Health effects
  - External contract with UCLA
  - Epidemiology study (LA)



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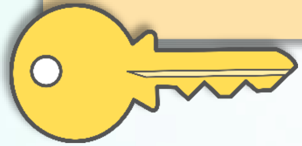
Closing remarks

Updated Inventory

- Inform programs and policies for AQ improvement
- Transportation planning, conformity
- Provide much needed information for health related projects
- Assess scope of BWPM issues



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Appendix: Research Approaches

Bottom Up Approach: External Research Contracts with ERG/LINK

- Driving behavior
  - Representative CA
  - EU: Novel World Harmonized Light Vehicle Test Program (WLTP) Brake Cycle
  - Temperature range
- Modern materials and vehicles
  - Market-share Research
  - Brake pads and rotors
    - Aftermarket parts
  - CA fleet relevant vehicles
    - Range of vehicle weights
- Regenerative braking
- Collect brake wear PM in brake dyno
  - Simulate all of the above parameters

Desired Results:

- Updated EFs: PM mass per cycle, effects of vehicle weight, cycle speed
- PM mass, PM size, PN per braking event, material, weight, etc.
- Chemical composition

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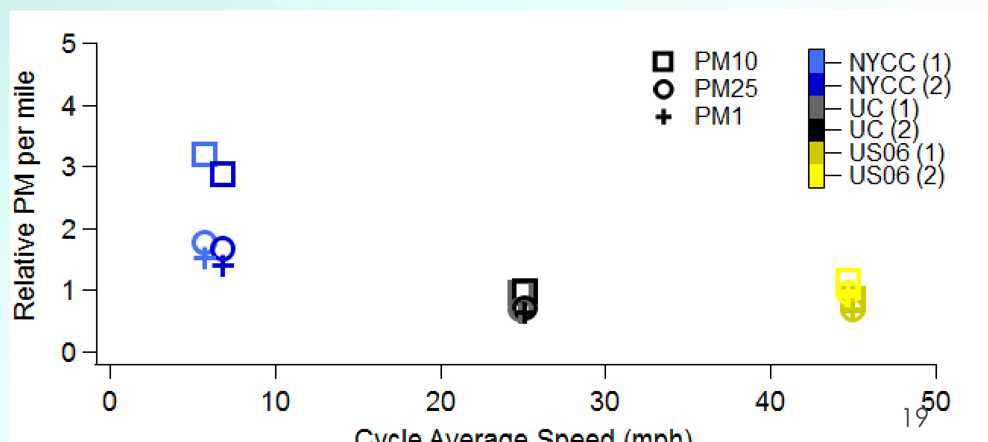
Bottom Up Approach: In-House

- Use sealed running loss-SHED
- Recruit representative vehicles
- Determine appropriate dilution factors and particle loss rates
- Derive EFs per cycle

Desired Results:
- Cross-check with enclosed dyno results
- PM mass, PM size, PN per braking event, material, weight, etc.
- Chemical composition



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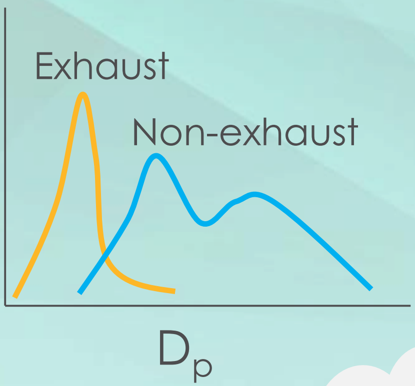
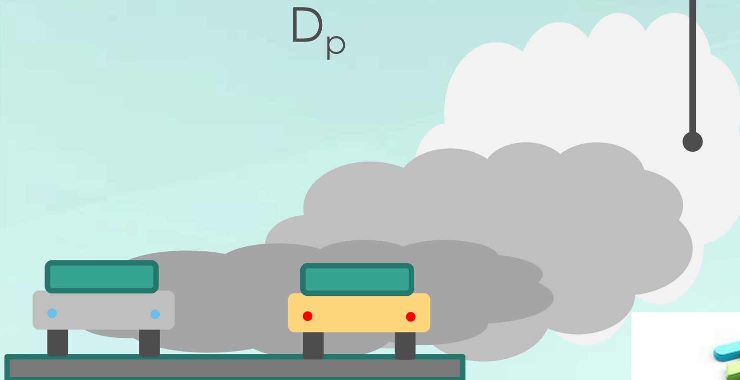
Top Down Approach: Roadside Measurement + Dispersion Model

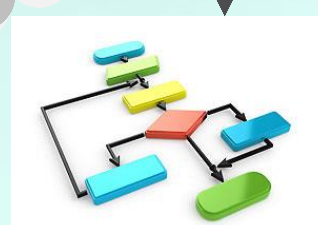




Background PM

<u>Integrated</u>:
PM2.5, PM10 (Mass, Composition)
<u>Real time</u>:
PN, PM size, PM2.5, PM10, composition
Traffic counts, met data

Calculate fraction of non-exhaust



- Use laboratory derived source profiles
- Location with varying speeds and fleet mixes
- Derive EFs
- Input into dispersion model

Desired Results:
- EFs vs speed, fleet mix
- Fraction of non-exhaust/exhaust PM
- Impact on downwind communities