Contributions of Tire Wear and Brake Wear to Particulate Matter Emissions Inventories for On-Road Mobile Sources

Song Bai, Yuan Du, and Stephen Reid
Sonoma Technology, Inc., Petaluma, CA

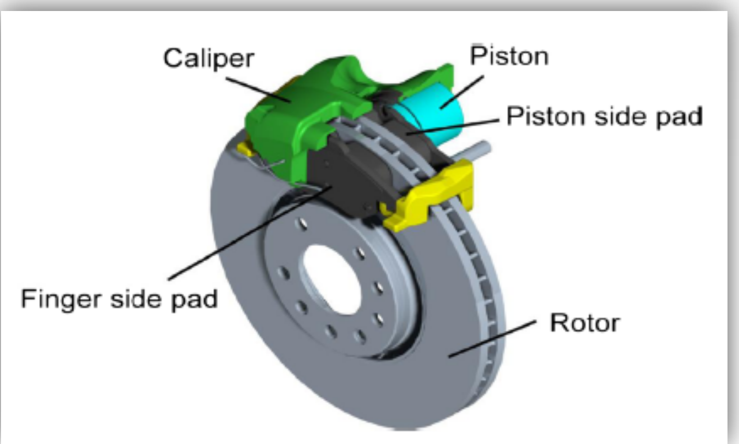
Presented at the
2015 International Emission Inventory Conference
San Diego, CA

April 16, 2015

Sonoma Technology, Inc.

Outline

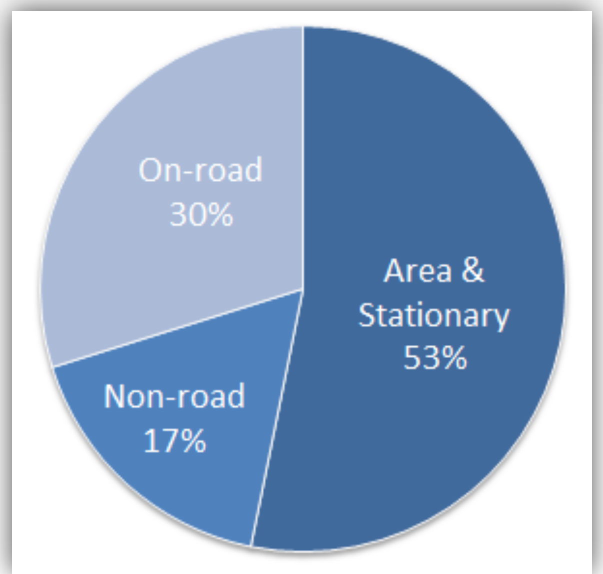
- Introduction
  - Background
  - Objectives
- Modeling Data and Methods
  - Emissions research
  - Tools: MOVES and EMFAC
- Results Comparison
  - Project level (a case study)
- Discussion



Disc brake system (Wahlström 2009)

Background (1)

- On-road mobile sources are a major contributor to particulate matter (PM) emissions in urban areas:
  - Exhaust
  - Brake wear
  - Tire wear
  - Dust suspension/resuspension

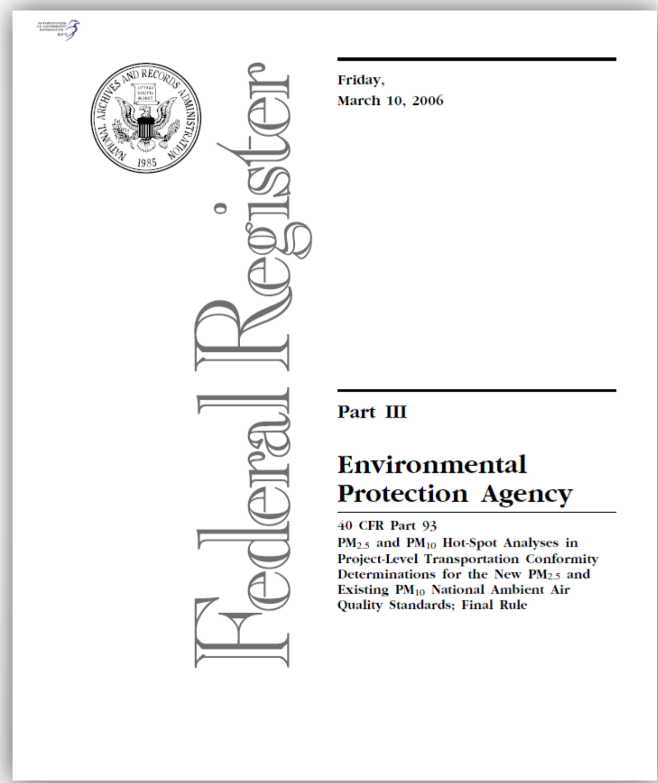


Annual average daily PM_{10} emissions of San Francisco, CA (ARB, 2012)

- Exhaust emissions have been more thoroughly evaluated and regulated than emissions from the remaining processes

Background (2)

- Emissions forecasts indicate that the contribution of various processes to total on-road PM emissions will change over time
- This trend has implications for transportation planners
  - Conformity assessments
  - Project-level “hot-spot” analyses



Federal Register

Friday,
March 10, 2006

Part III

Environmental Protection Agency

40 CFR Part 93
$PM_{2.5}$ and PM_{10} Hot-Spot Analyses in Project-Level Transportation Conformity Determinations for the New $PM_{2.5}$ and Existing PM_{10} National Ambient Air Quality Standards; Final Rule

Objectives

- Review current methods for modeling brake wear and tire wear (BWTW) emissions
- Assess the contribution of BWTW emissions to total on-road PM inventories
  - Regional scale
  - Project level
  - Changes over time
- Discuss the potential implications of BWTW emissions modeling for the transportation planning community

Emissions Research (1)

Typical data sources

- Brake wear
  - Dynamometer test results
  - Roadside measurements
  - Wind tunnel tests
- Tire wear
  - Tread depth measurements
  - Tire weight loss measurements

Emissions Research (2)

Key factors impacting BWTW emissions

Factors	Brake Wear	Tire Wear
Vehicle characteristics	Vehicle weight (heavier vehicles with larger brake pads have higher brake wear)	Vehicle weight, suspension, steering geometry, tire material, and design
Roadway condition and environment	Traffic conditions (stop-and-go traffic increases brake use and wear)	Road surface roughness, highway geometry, moisture conditions
Airborne PM to total wear fraction	Grigoratos and Martini: 50% EPA: 60%	Prior study: wide range EPA: 8%
PM_{10} to $PM_{2.5}$ ratio	Prior studies: wide range EPA: 8	Prior studies: wide range EPA: 6.667

Emissions Research (3)

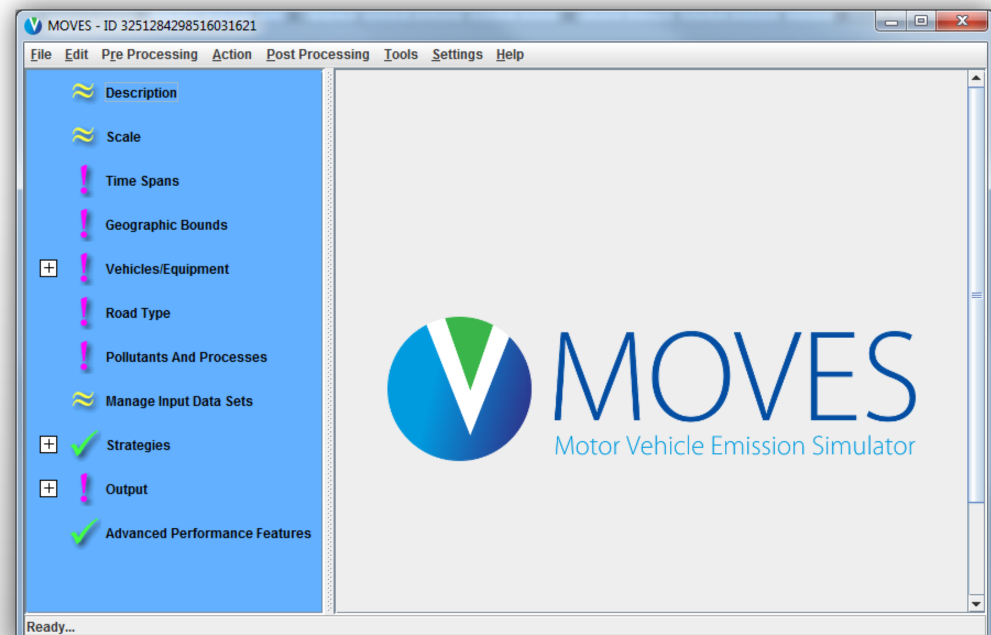
Research issues

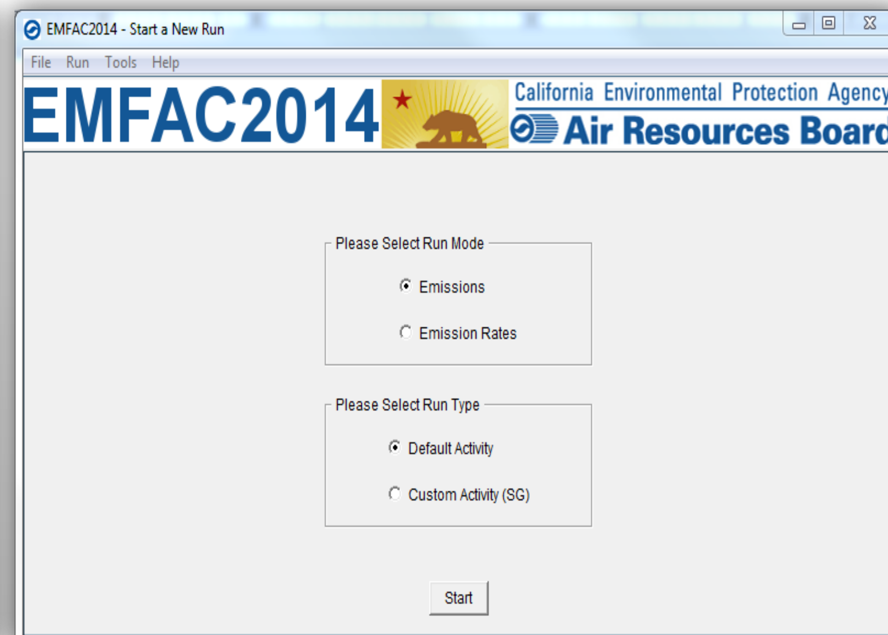
- Limited number of published studies on BWTW
- Most testing data focus on light-duty vehicles
- Studies show disagreement regarding key factors (e.g., $PM_{10}/PM_{2.5}$ ratios)
- Published emissions data are not directly applicable for emissions modeling

Modeling Tools

EPA-approved models to support SIP development and transportation conformity assessments

- EPA's MOVES2014
- CARB's EMFAC2014 (California only)



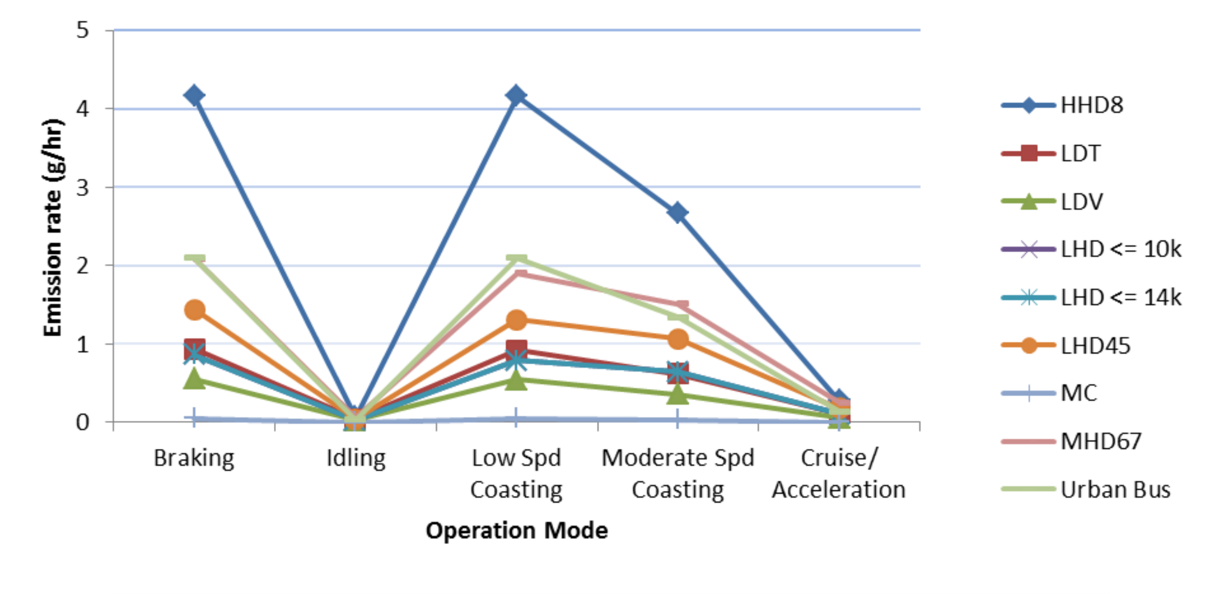


MOVES Method (1)

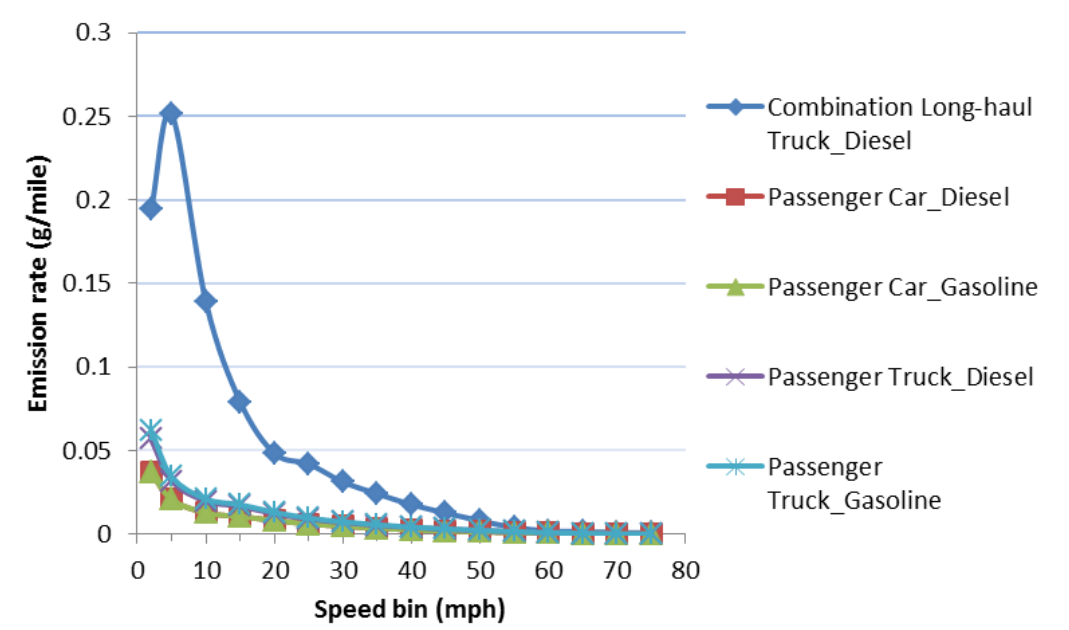
Brake Wear

- Specifies $PM_{2.5}$ emission rates by operation mode for light-duty vehicles (LDV)
- Extrapolates/interpolates LDV emission rates to other vehicle types based on weight
- Uses a $PM_{10}/PM_{2.5}$ ratio of 8 to derive PM_{10} emissions

MOVES Method (2)



Top: MOVES-based $PM_{2.5}$ emission rates for brake wear by operating mode



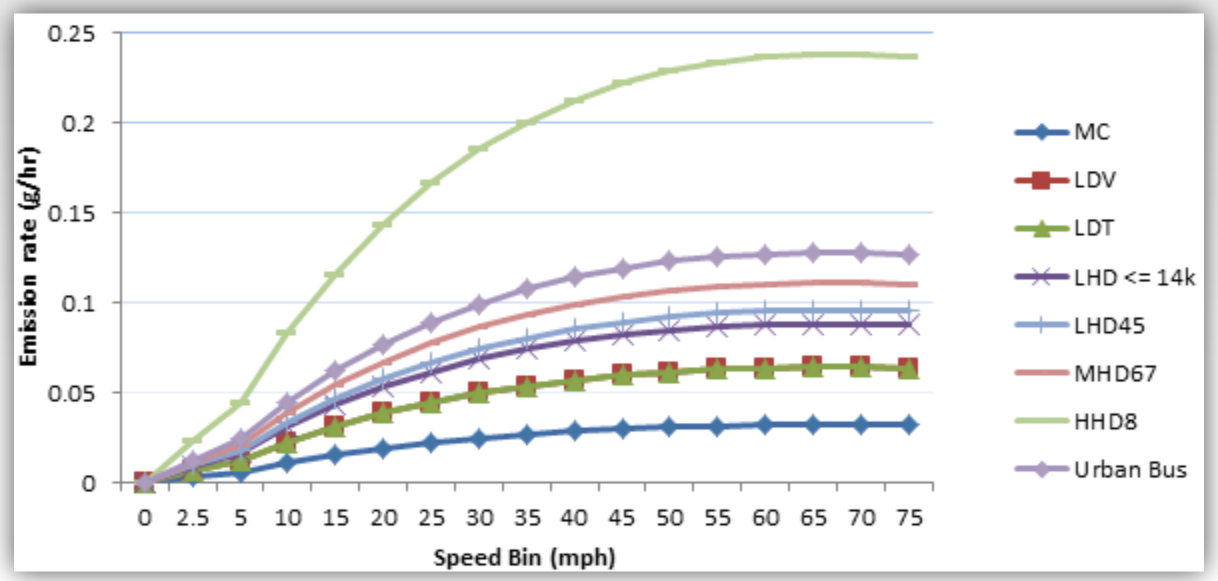
Bottom: MOVES-based $PM_{2.5}$ emission rates for brake wear by average speed bin

MOVES Method (3)

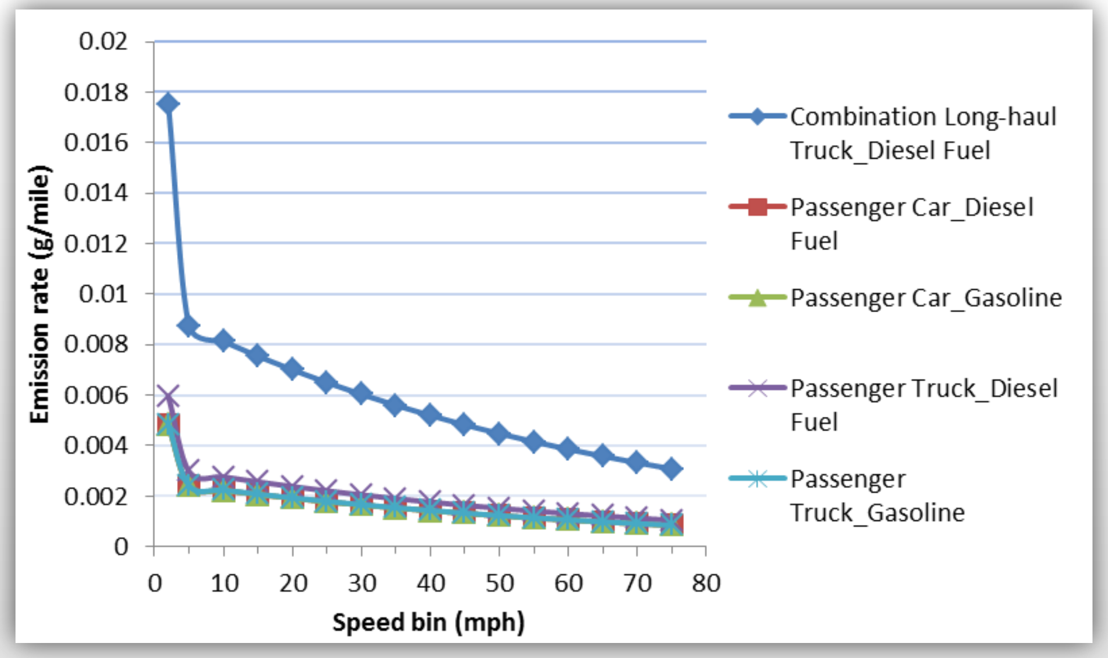
Tire Wear

- Specifies per-mile $PM_{2.5}$ emission rates by speed bin for LDV
- For other vehicle types, treats tire wear as a function of the number of tires only
- Assigns an airborne fraction of total tire wear (8% for PM_{10} and 1.2% for $PM_{2.5}$)
- Converts per-mile emission rates to per-hour emission rates using the average speed of each modeled speed bin

MOVES Method (4)



Top: MOVES-based per-hour $PM_{2.5}$ emission rates for tire wear by operation mode



Bottom: MOVES-based per-mile $PM_{2.5}$ emission rates for tire wear by speed bin

EMFAC Method (1)

Brake wear

- Generates PM_{30} emission rates and applies factors to represent the PM_{10} (98%) and $PM_{2.5}$ (42%) fractions
- Models dust emission rates per brake application (assumes different braking attributes by vehicle type)

$$ER = \left(\sum_i n_i \times ER_i\right) \times F \times N$$

Where,

ER: per-mile PM brake wear emission rates (g/mile)

i: type of brake application (e.g., rear wheel brake with semi-metallic brake pad materials

n: number of brakes for the same type of brake application

ER_i: dust emission rates per brake application (g/application)

F: fraction of dust that becomes airborne

N: number of brake applications per mile of travel

EMFAC Method (2)

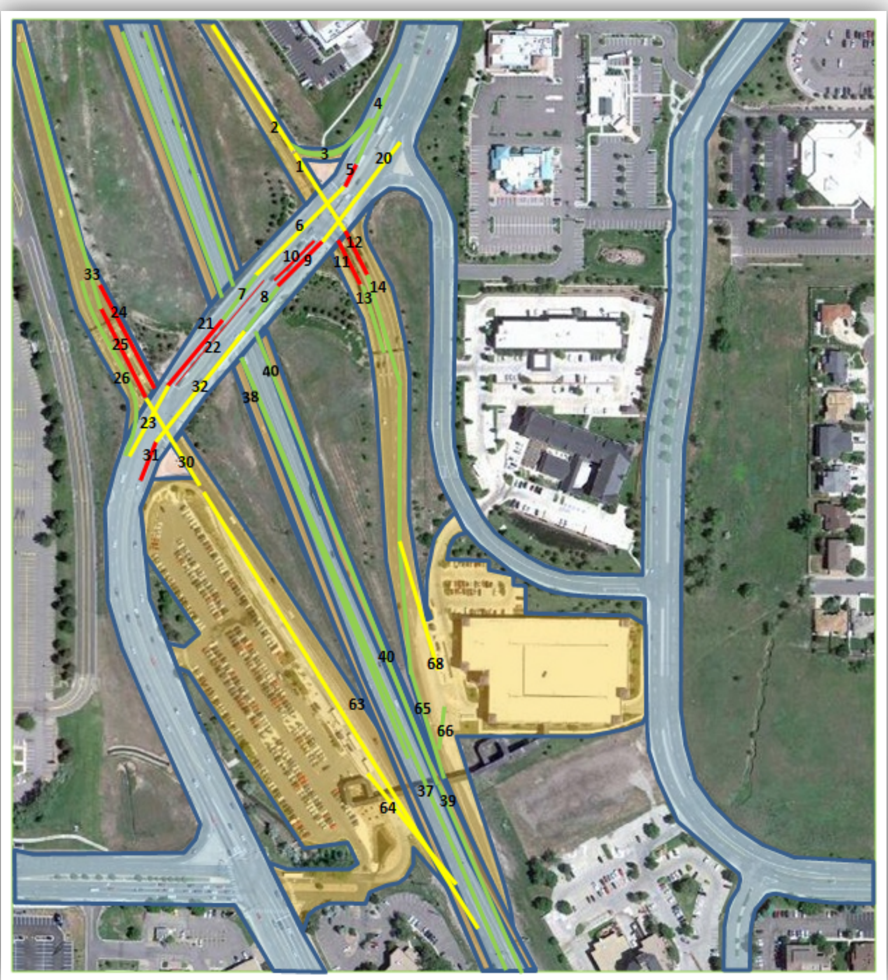
Tire wear

- Generates PM_{30} emission rates and applies factors to represent the PM_{10} (100%) and $PM_{2.5}$ (25%) fractions
- Models dust emissions as a constant per-wheel airborne PM emission rate of 0.002 g/mi/wheel
- Assumes an average number of wheels for various vehicle types

Project-Level Emissions

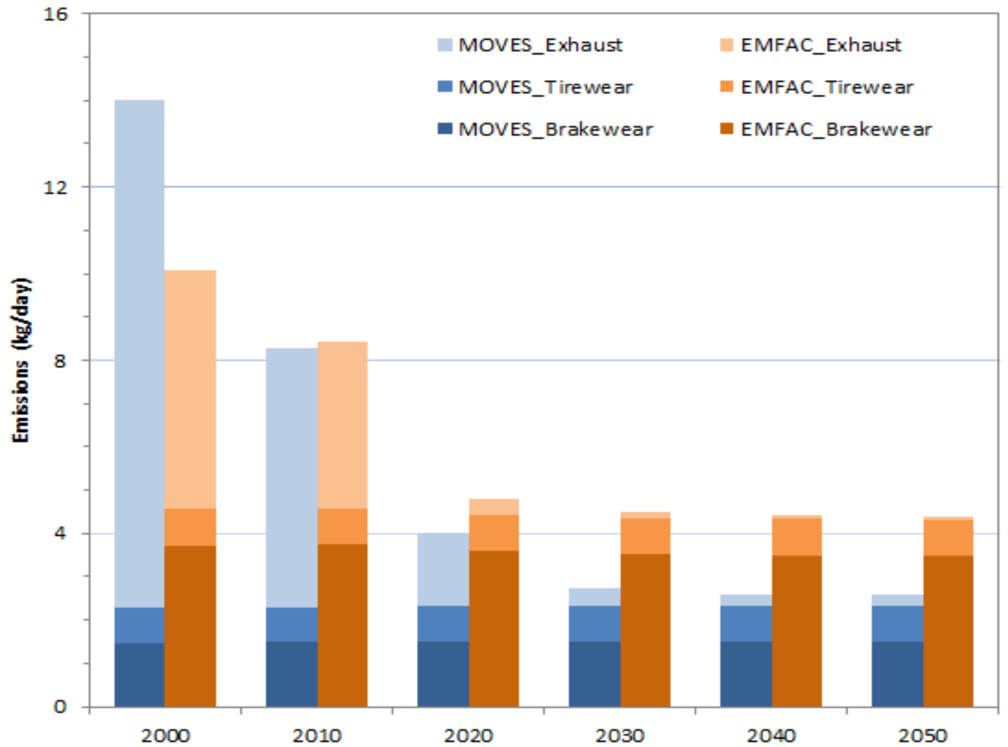
Case study Developed by EPA for a 2011 PM hot-spot training class

- Involves the addition of high-occupancy vehicle (HOV) lanes to a freeway
- Located in an urbanized part of Fresno, CA
- Traffic volumes = 125,000 annual average daily traffic (AADT), 8% trucks



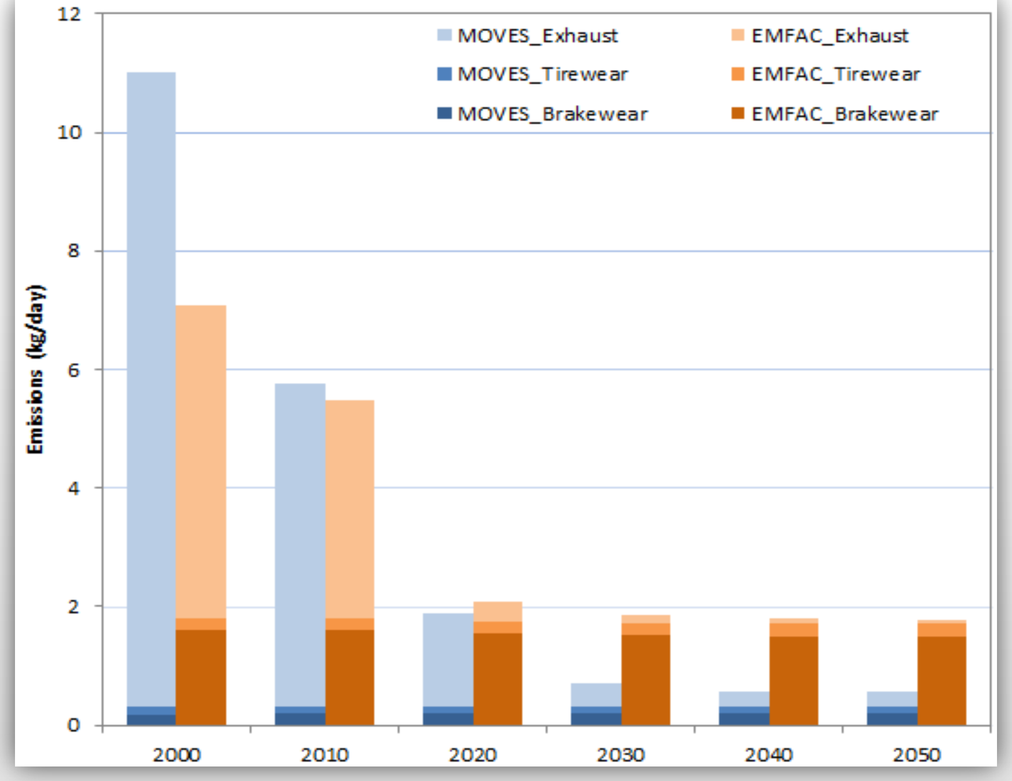
Project-Level PM_{10} Emissions

- Exhaust emissions decrease sharply, especially from 2010 to 2020
- BWTW emissions are nearly constant over time
- BWTW account for an increasing portion of total emissions (MOVES: 16% in 2000 and 89% in 2050)
- EMFAC BW ~2.5x higher than MOVES



Project-Level $PM_{2.5}$ Emissions

- Pattern similar to statewide PM_{10} emissions
- EMFAC emissions virtually all BWTW after 2020
- BWTW account for an increasing portion of total emissions (MOVES: 3% in 2000 and 55% in 2050)
- EMFAC BW 8x higher than MOVES (different $PM_{10}/PM_{2.5}$ ratios)



Discussion

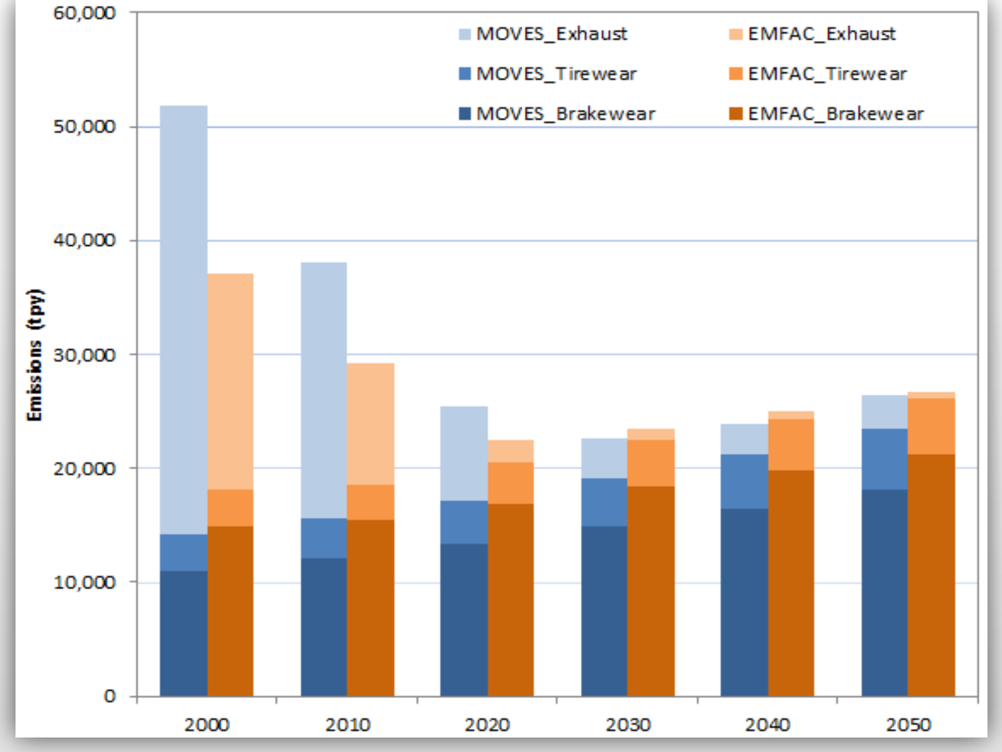
- The most uncertain components of on-road PM emissions inventories are growing in importance
  - BWTW emissions have not been researched as extensively as exhaust emissions
  - MOVES and EMFAC employ a range of assumptions to estimate emission rates and BW results differ substantially
  - The contribution of BWTW to on-road emissions is growing over time as exhaust emissions decrease
- This trend presents challenges for the transportation planning community (e.g., identifying mitigation strategies for processes that are not impacted by fleet turnover)

Contact

Song Bai
sbai@sonomatech.com
707.665.9900

CA Statewide PM_{10} Emissions

- Exhaust emissions decrease sharply, especially from 2010 to 2020
- BWTW emissions increase due to growing vehicle activity, fleet changes
- BWTW account for an increasing portion of total emissions (MOVES: 27% in 2000 and 89% in 2050)
- EMFAC BW 17% to 35% higher than MOVES



CA Statewide $PM_{2.5}$ Emissions

- Similar pattern to PM_{10} – exhaust emissions decrease sharply, as TWBW emissions increase somewhat
- BWTW account for an increasing portion of total emissions (MOVES: 5% in 2000 and 53% in 2050)
- EMFAC BW four times higher than MOVES (different $PM_{10}/PM_{2.5}$ ratios)