

Update to UNECE PMP #54 | 09 Jan 2024  
**Brake Emissions from Heavy Truck Vocations Based on  
STATE OF CALIFORNIA REPORT # CA21-3232**



Caltrans®



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# **New Research On Brake Wear Particulate Matter Emissions From Several Heavy Truck Vocations In California**

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California Dept. of Transportation (CalTrans)

32<sup>nd</sup> CRC Real World Emissions Workshop  
March 13-16, 2022



Original presentation (slides 1...24)



...the rest of  
the team

**ERG** – Alan Stanard, Timothy DeFries

**EPA** – Chad Bailey, Bob Gianelli

**LINK** – Quinn O’Hare, Jerry Lawruk, Mark Hunt,  
Brian Nycek, Josh Bautell, Trent Fagrell, Aaron Voisard

**CARB** – Sonya Collier, Seungju Yoon, Jeff Long,  
Sara Forestieri, Qi Yao, Inna Dzhema, Oliver Chang

**Brake suppliers** – Federal-Mogul, ArvinMeritor, Bendix



topics

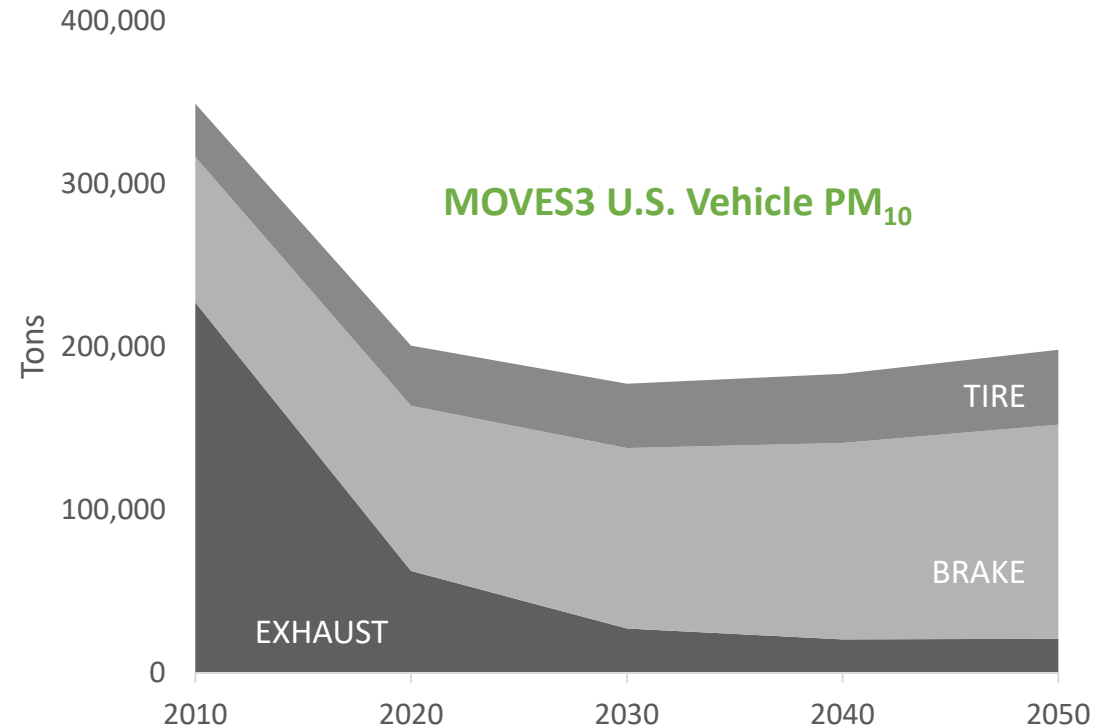
Background

Temperature regimes

High-level results

EU Aerosolfd

# Background

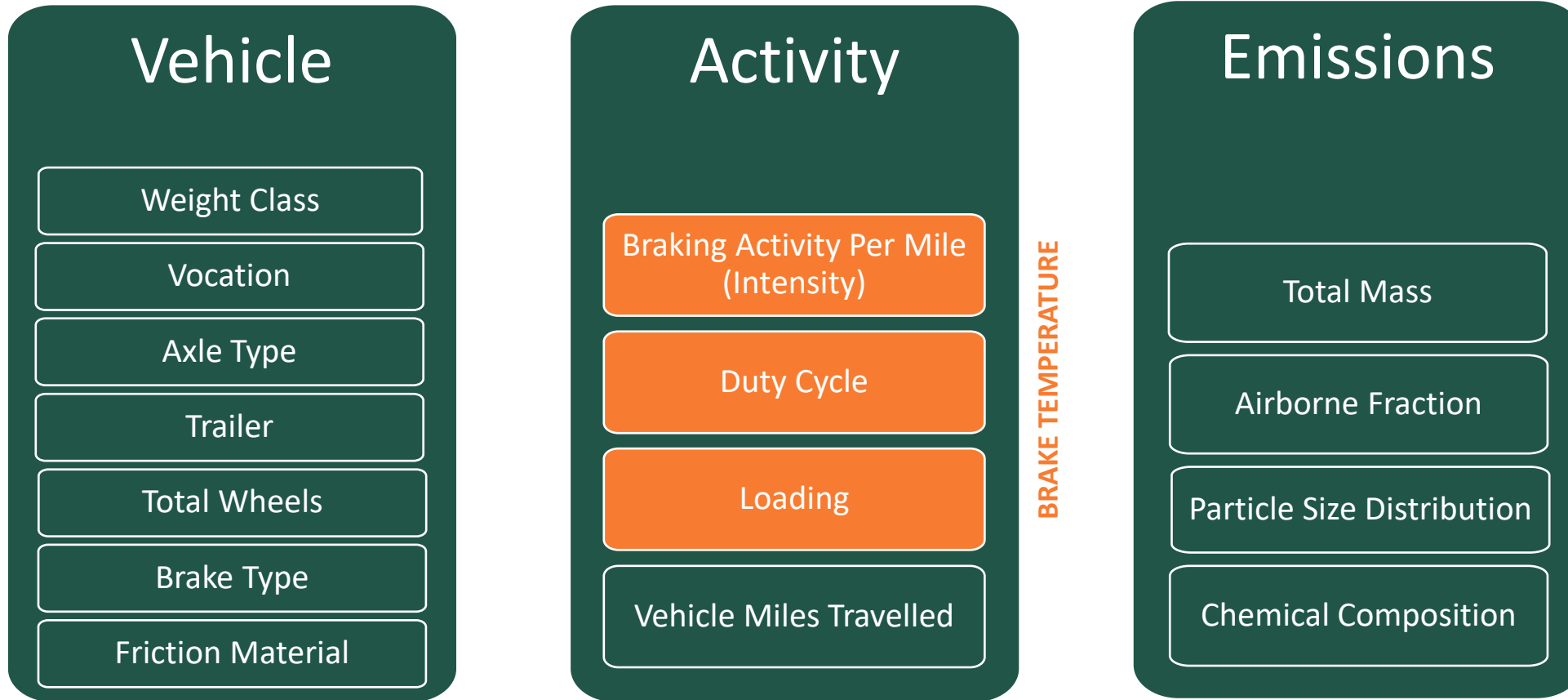


ERG/LINK studies to update EMFAC2021 brake emissions:

- **CARB:** Light-Duty Brake Study Project 17RD016
- **Caltrans:** Heavy-Duty + EV Brake Study (today's talk)
- <https://ww2.arb.ca.gov/resources/documents/brake-tire-wear-emissions>

# Factors to Account for in Emissions Inventories for HD Truck Brakes

Three-step assessment



# Project Phases

## Work Packages

### Brake Temperature Evaluation

- Track testing
- Brake temperature modeling

### Test Matrix Development

- HD brake market survey
- Mass balance analysis

### Emissions Testing

- Dynamometer build-out
- Dyno temperature adjustment
- Emissions tests (filter & real time sampling)

### EMFAC Update

- Determine significant effects
- Aggregate & roll up PM filter results
- Determine speed corrections





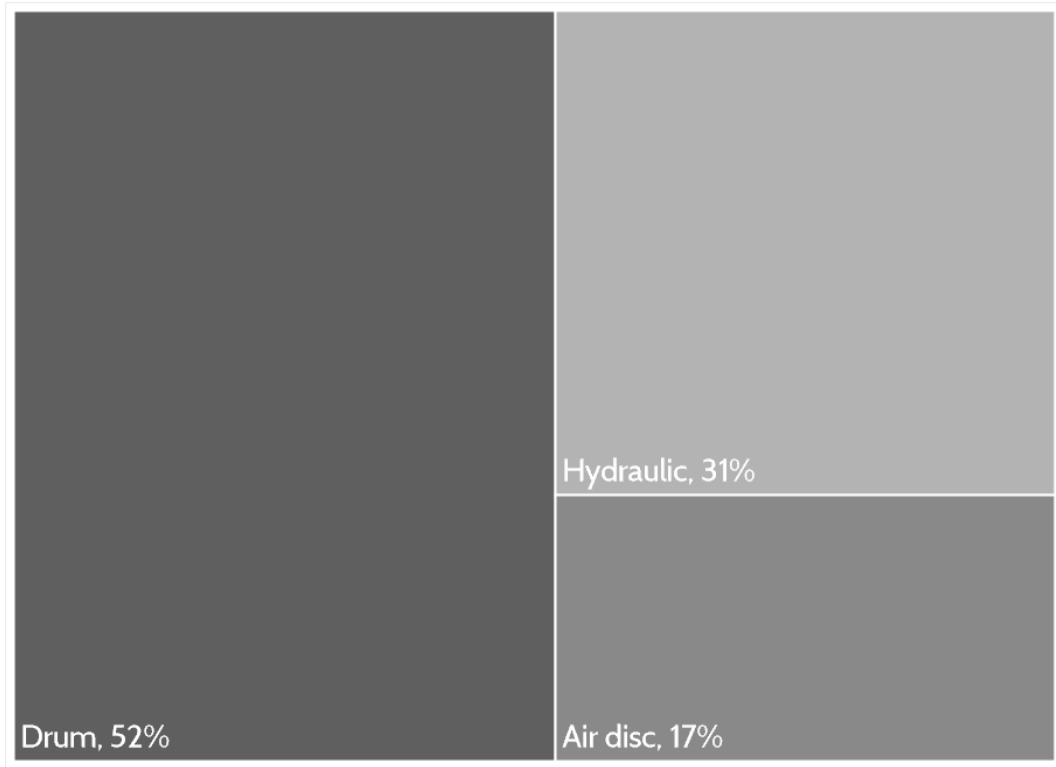
Heavy Truck vocation in California was a crucial aspect of the project



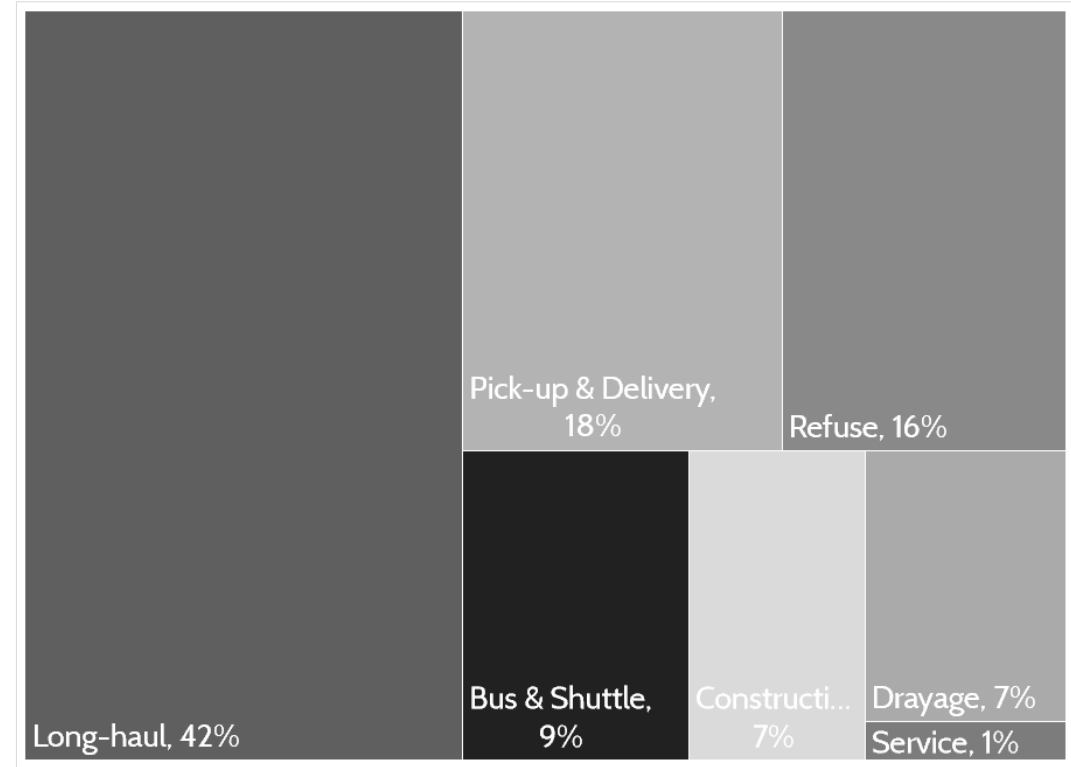


# Input for Brake Wear Balance Estimates

Using business intelligence



by braking system



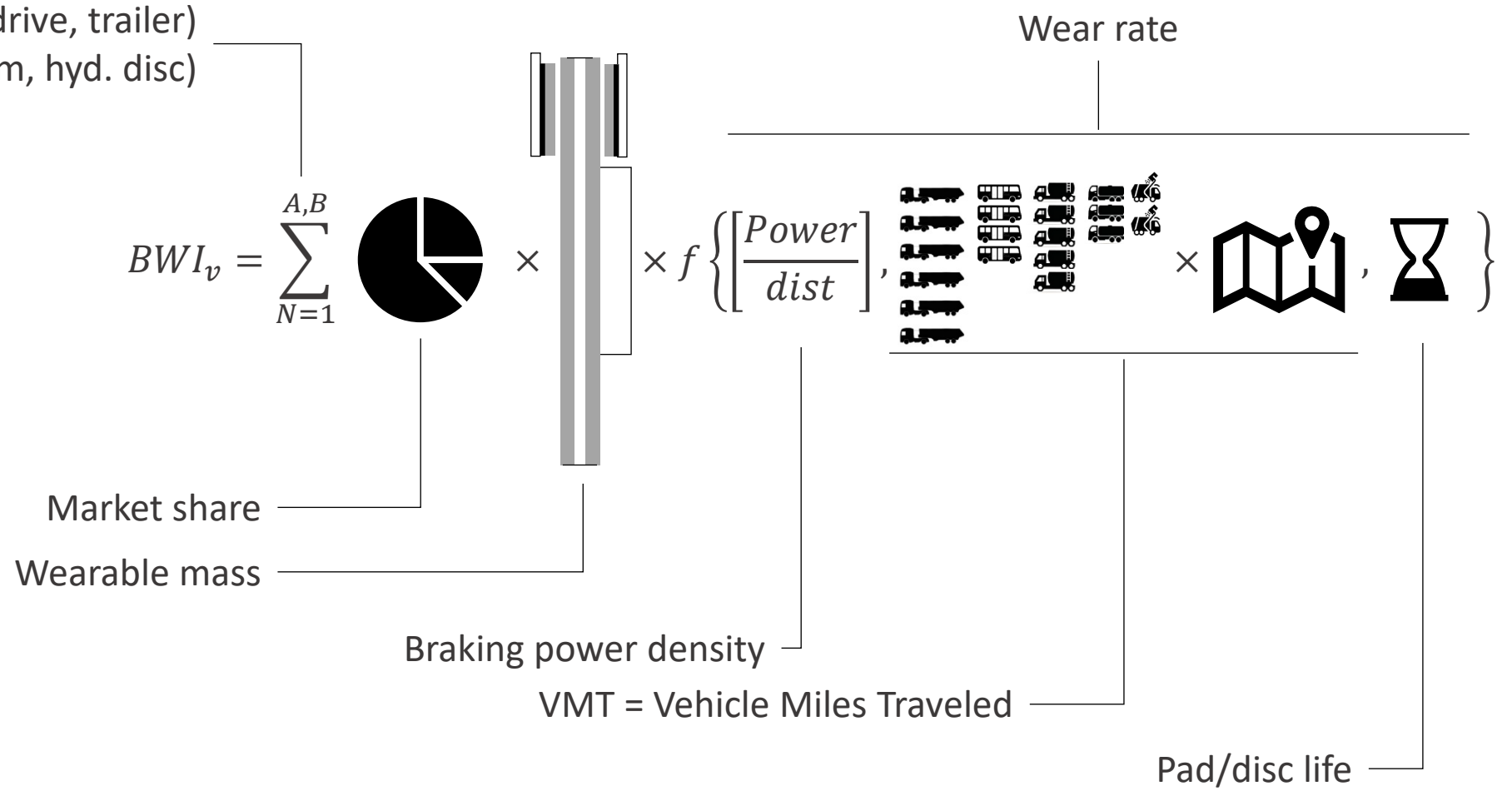
by vehicle vocation

# Brake Wear Mass Balance Analysis per EMFAC2011 Vehicle Category

BRAKE WEAR INDEX (BWI) as surrogate of activity and intensity

**A** = axle type (steer, drive, trailer)

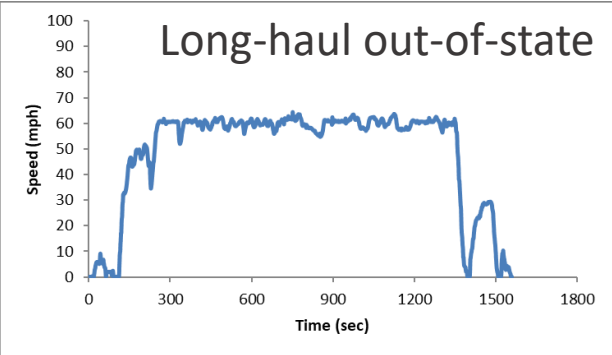
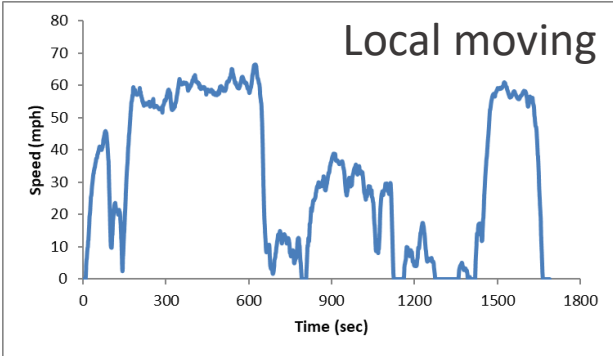
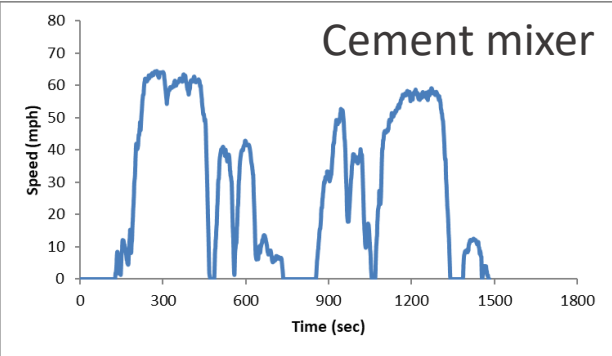
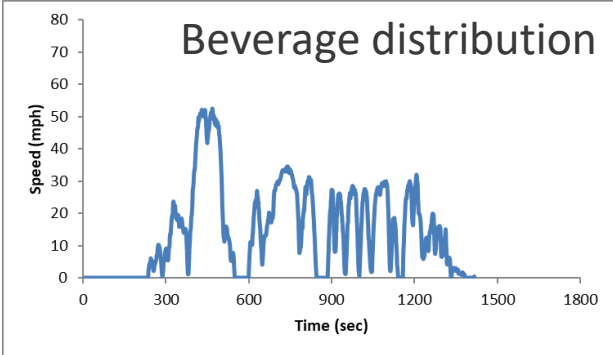
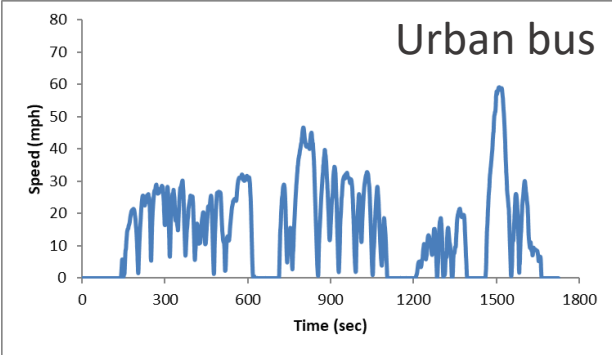
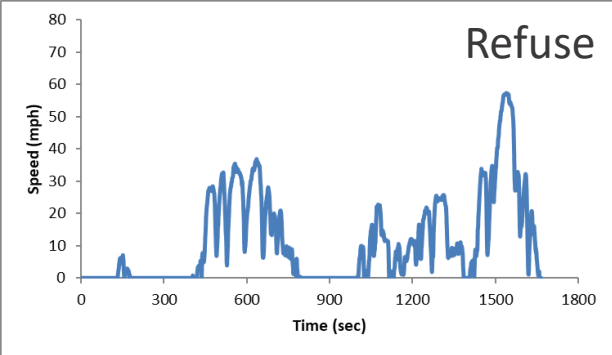
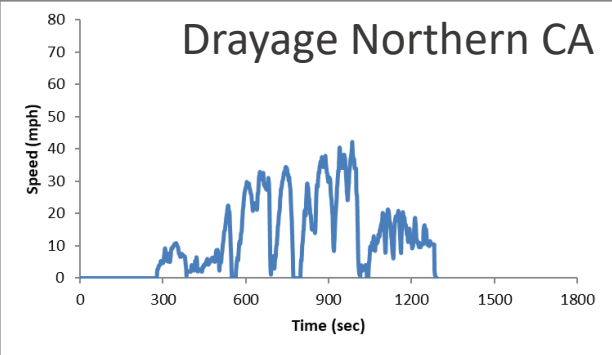
**B** = brake type (ADB, drum, hyd. disc)





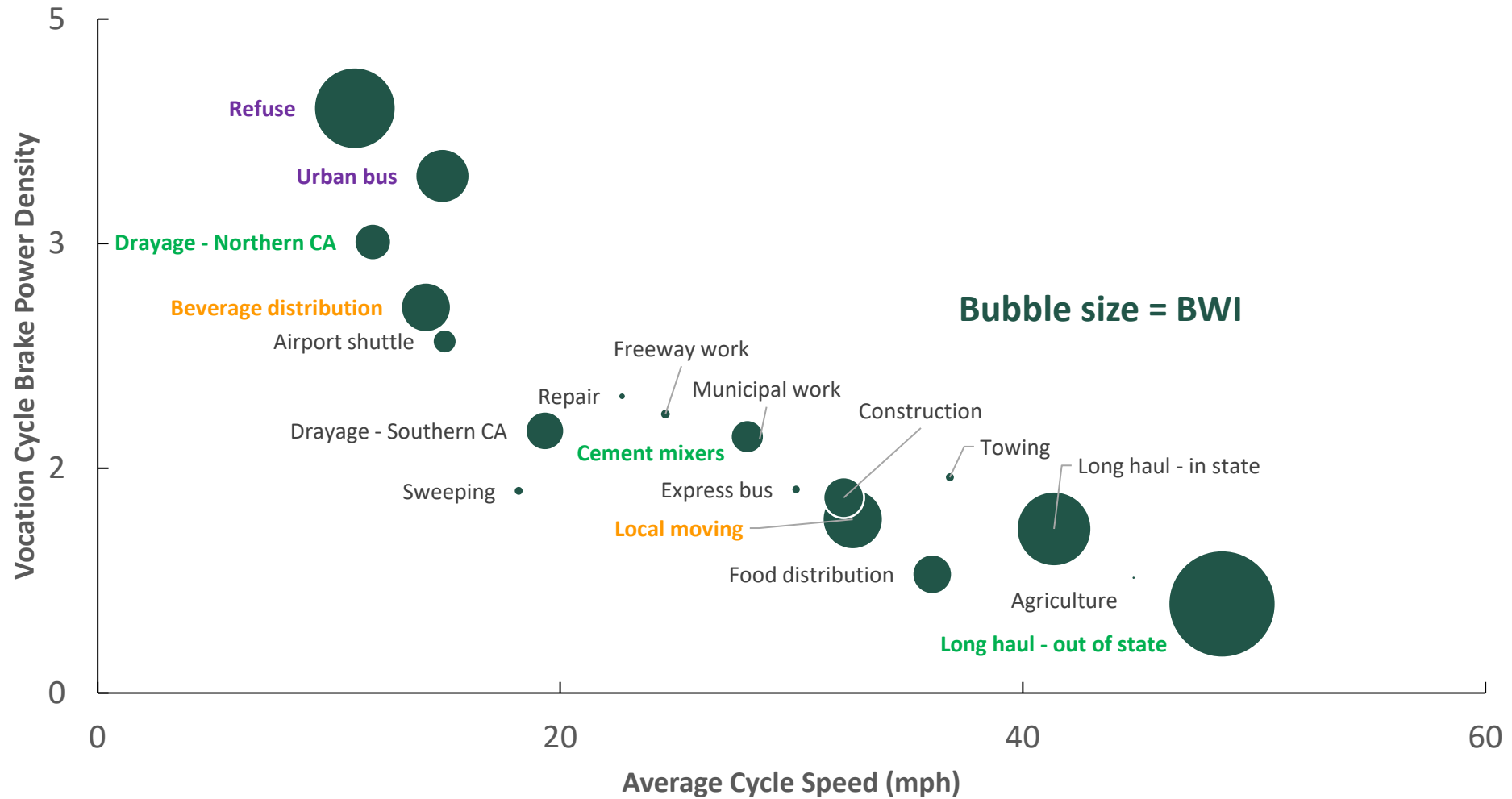
# Drive Cycles

Using 2021 field study from University of California – Riverside (UC-CERT)








# Brake Wear Index by Vocation

Relative to the average cycle speed





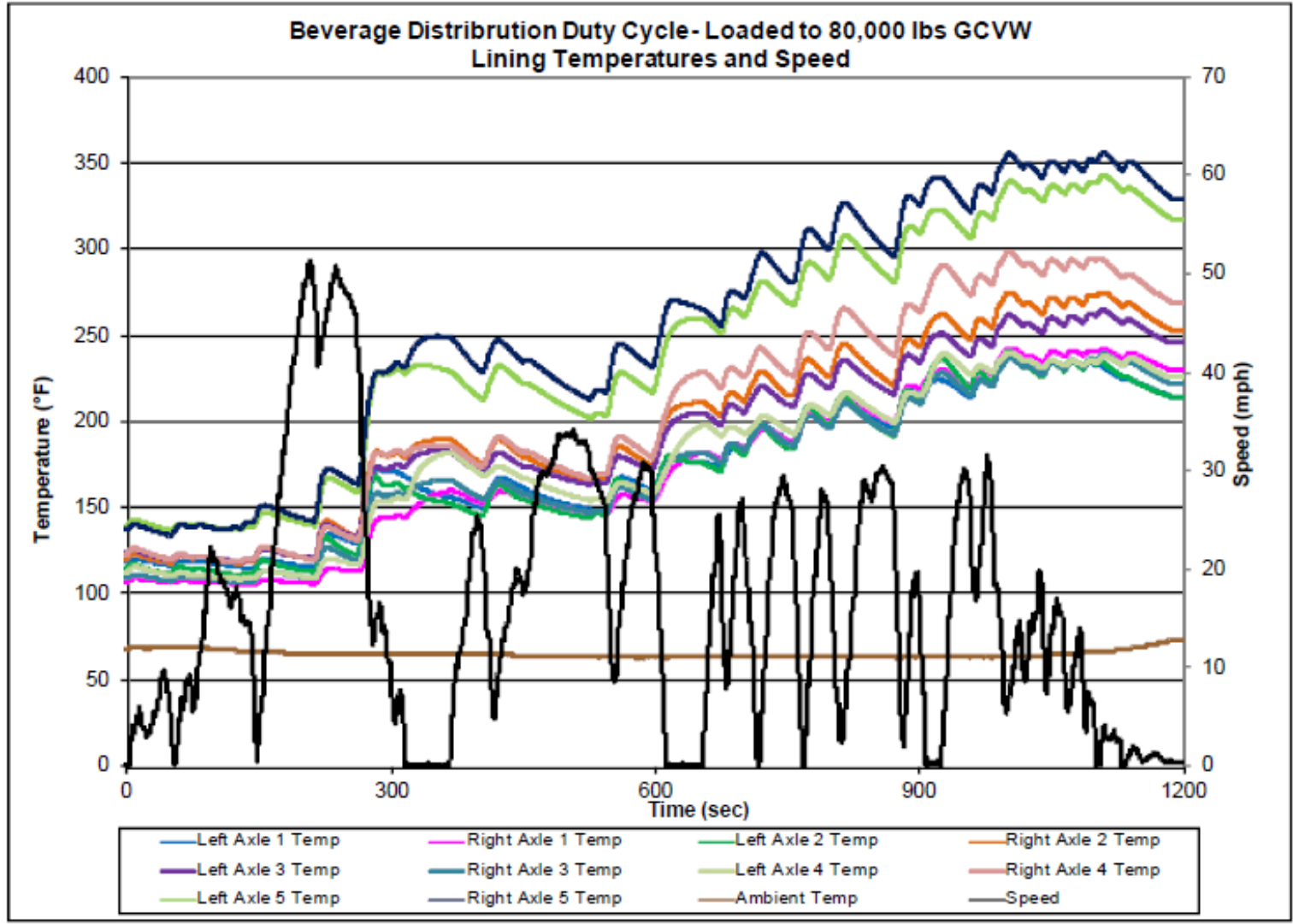
# Brake Temperature Evaluation

Vehicle	Load	Vocation					
		Dryage	Beverage delivery	Long haul	Towing	Refuse	Urban bus
Class 8 ADB 	Full	●	●	●			
	Unloaded	●					
Class 8 drum 	Full	●	●				
	Unloaded	●	●				
Class 6 hydraulic 	26k lbs		●		●		
Refuse 	Full					●	
Bus 	37.5k lbs						●



# Example Brake Temp Results

e.g. Test track measurement on Class 8 drum brake on beverage delivery cycle



Thermocouples in primary brake shoes of all wheels per FMVSS 121





# Brake Temperature Modeling

Updated UMTRI model with track data

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

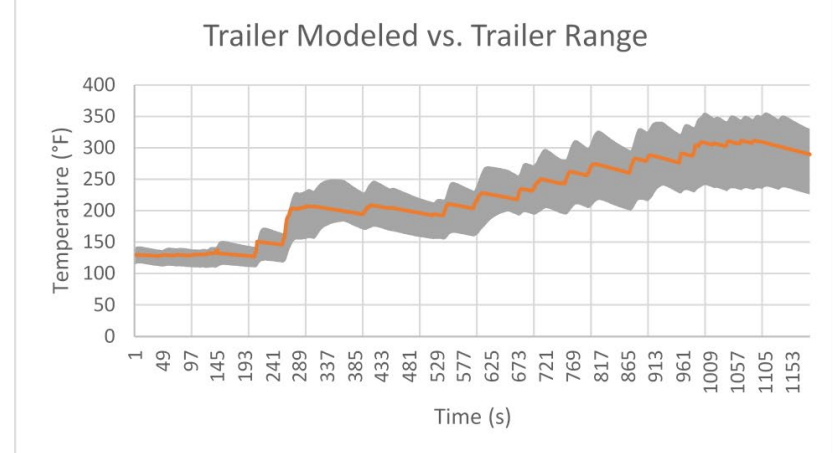
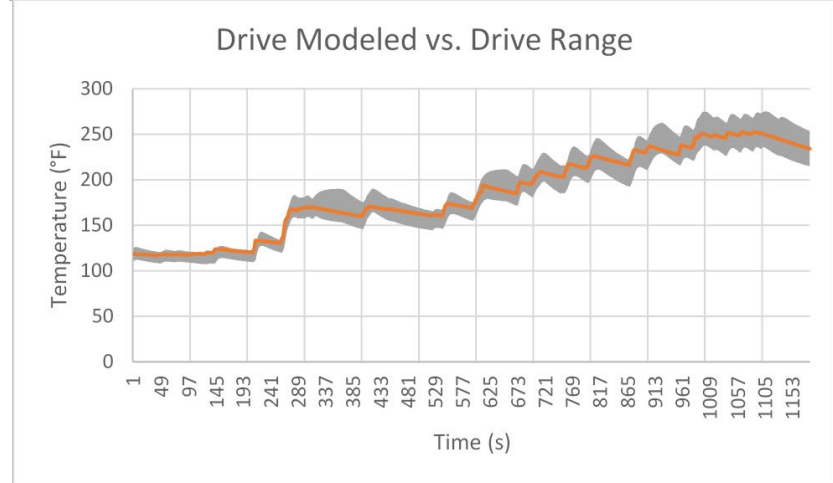
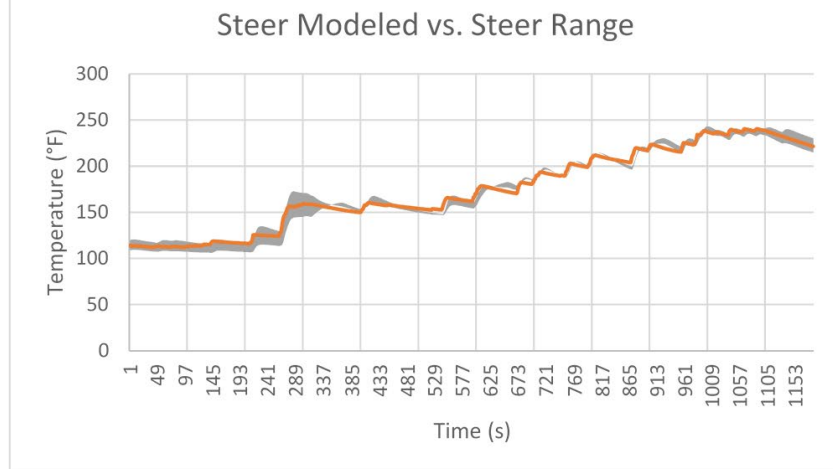
Labels for the equation components:

- Temperature
- Initial temperature
- Time
- Heating/cooling constant
- Braking horsepower
- Cooling coefficient 2
- Ambient temperature

Adaptations:

- Braking events v. coast downs
- Estimation of braking power

Target temperatures for emissions tests



# Emissions Test Matrix

Combining vehicles, brake types, cycles, loading, and repeatability tests

Vehicle	Brake/axle	Cycle 1	Cycle 2	Cycle 3	Load	Repeat	EMFAC class
Class 8	drum steer	Drayage N*	Cement	LH OOS**	1		T7
	drum drive	Drayage N	Cement	LH OOS	2	Yes	
	ADB steer	Drayage N	Cement	LH OOS	2	Yes	
	ADB drive	Drayage N	Cement	LH OOS	1		
Refuse	ADB steer	Refuse			2		Refuse
	ADB drive	Refuse			1		
Urban bus	ADB steer	Urban bus			1		Bus
	ADB drive	Urban bus			1		
Service	Hyd. Disc steer	Beverage	Delivery		1		T6
	Hyd. Disc drive	Beverage	Delivery		1	yes	

\*Northern CA Drayage \*\* Long-Haul Out-of-State

# Multipurpose Heavy Truck Dynamometer

Example



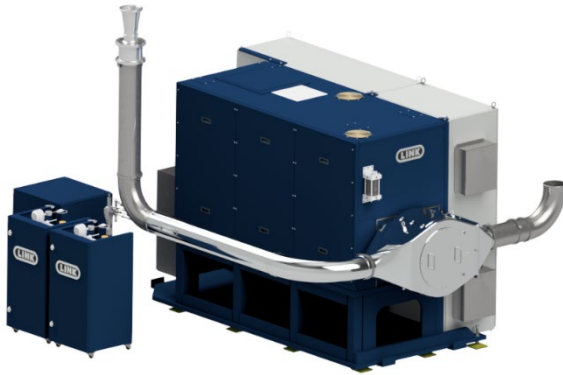
overview of dyno setup (showing emissions upgrade)



brake emissions enclosure

# Brake Dynamometers Types

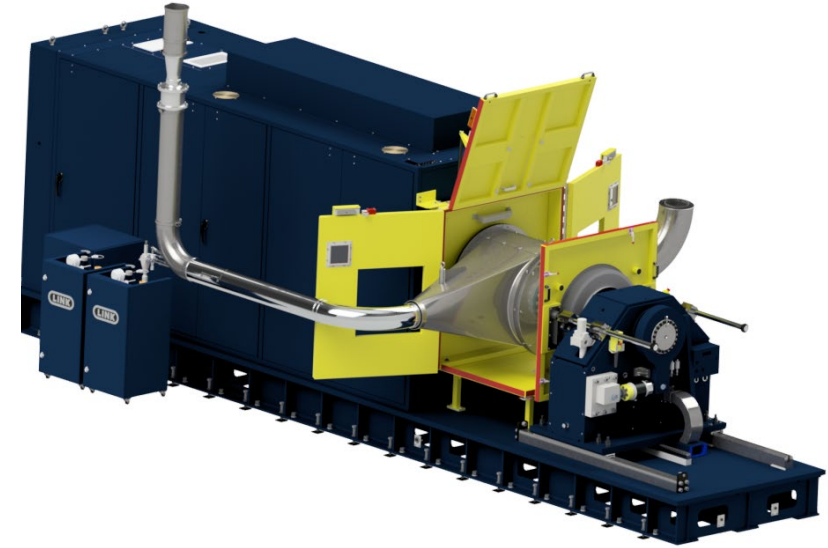
Current GTR 24 provides the basis to cover the entire vehicle range



GTR 24 dyno  
*Light Vehicles*



GTR 24-compliant upgrade  
*Light Vehicles*

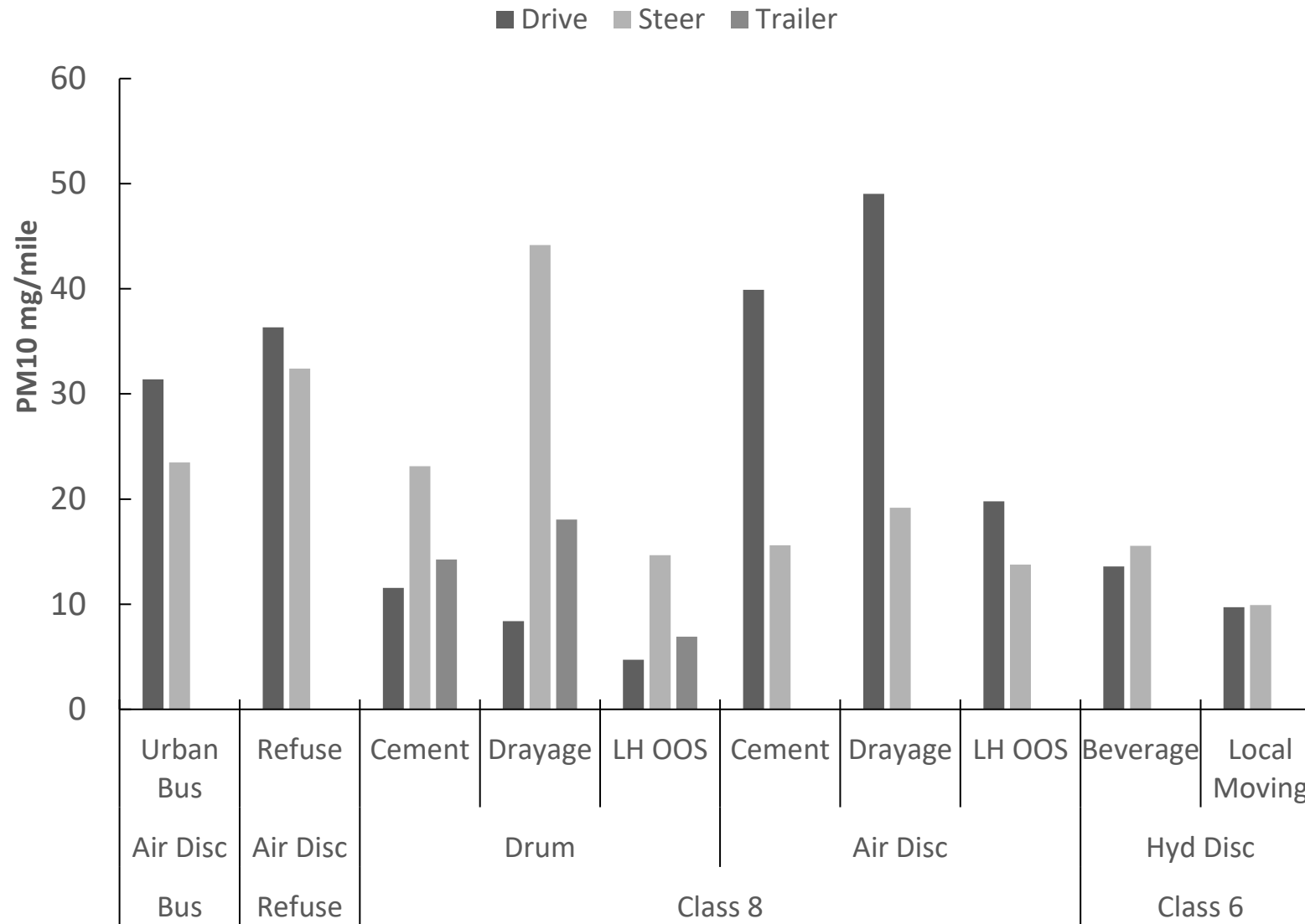


GTR 24-based upgrade  
*Commercial Vehicles*



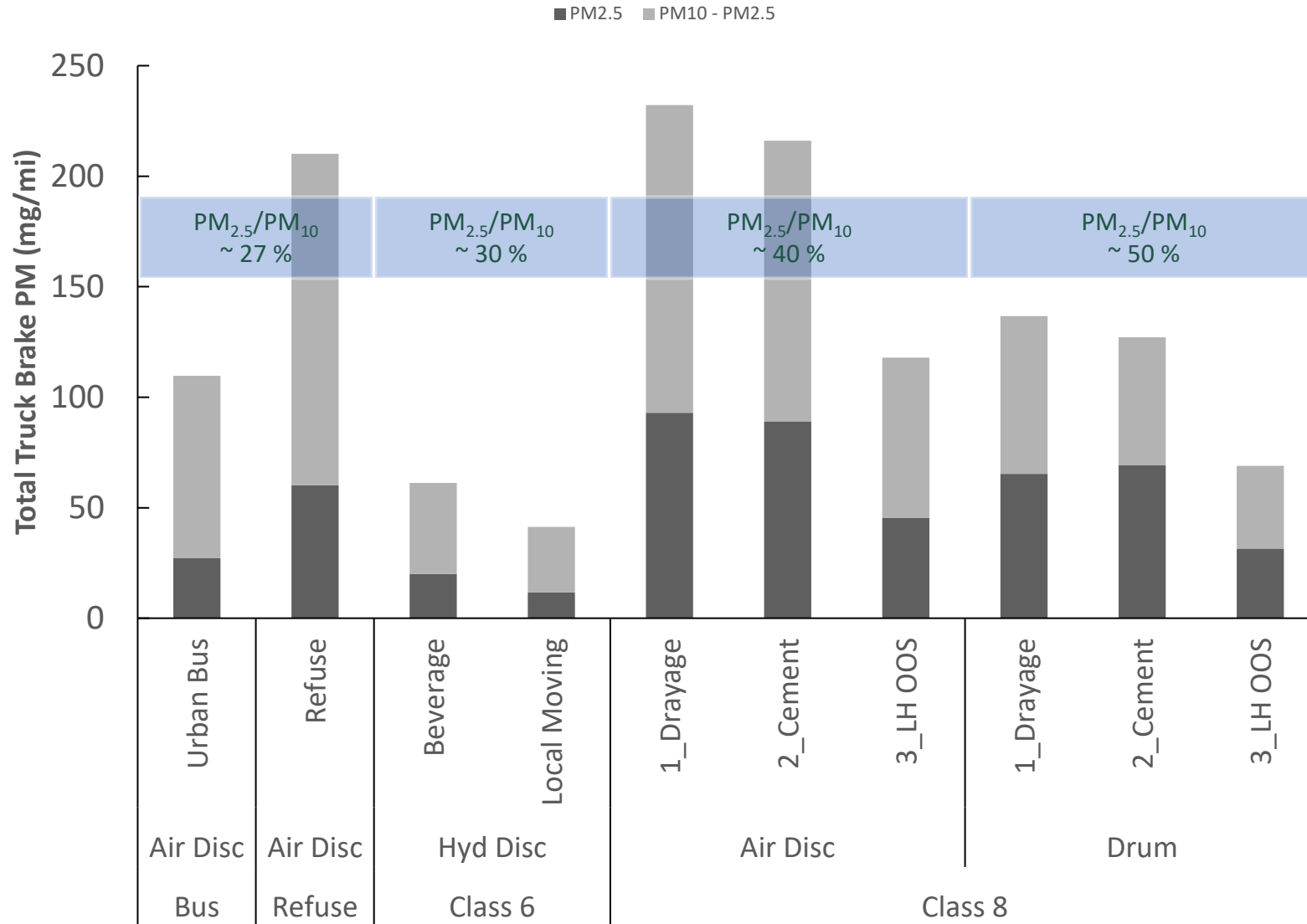
# PM10 Filter Results – Individual Wheel

Significant effects from cycle, axle position, and type of brake



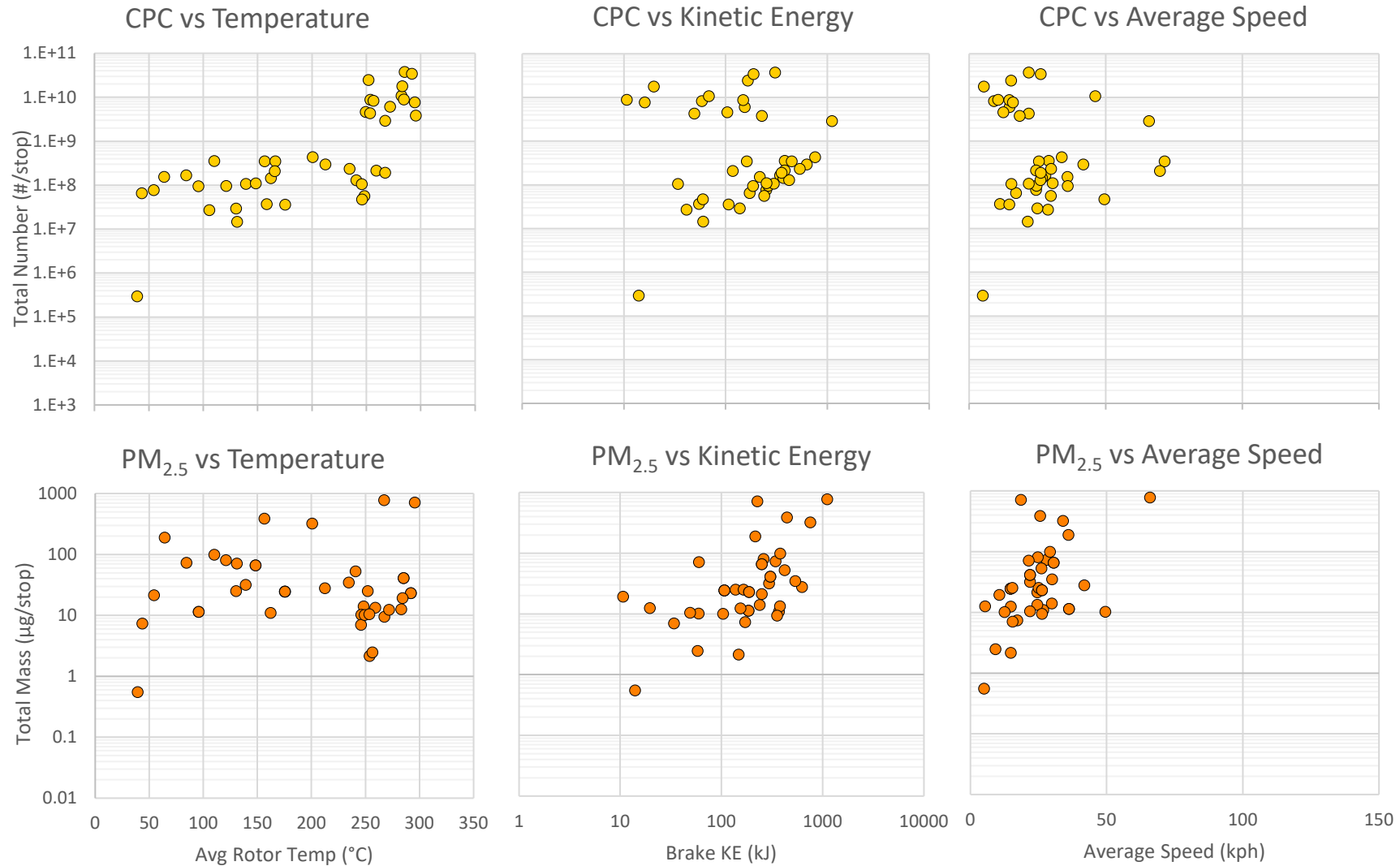
# Total Truck PM<sub>10</sub>

The PM<sub>2.5</sub>/PM<sub>10</sub> fraction exhibited differences across brake types



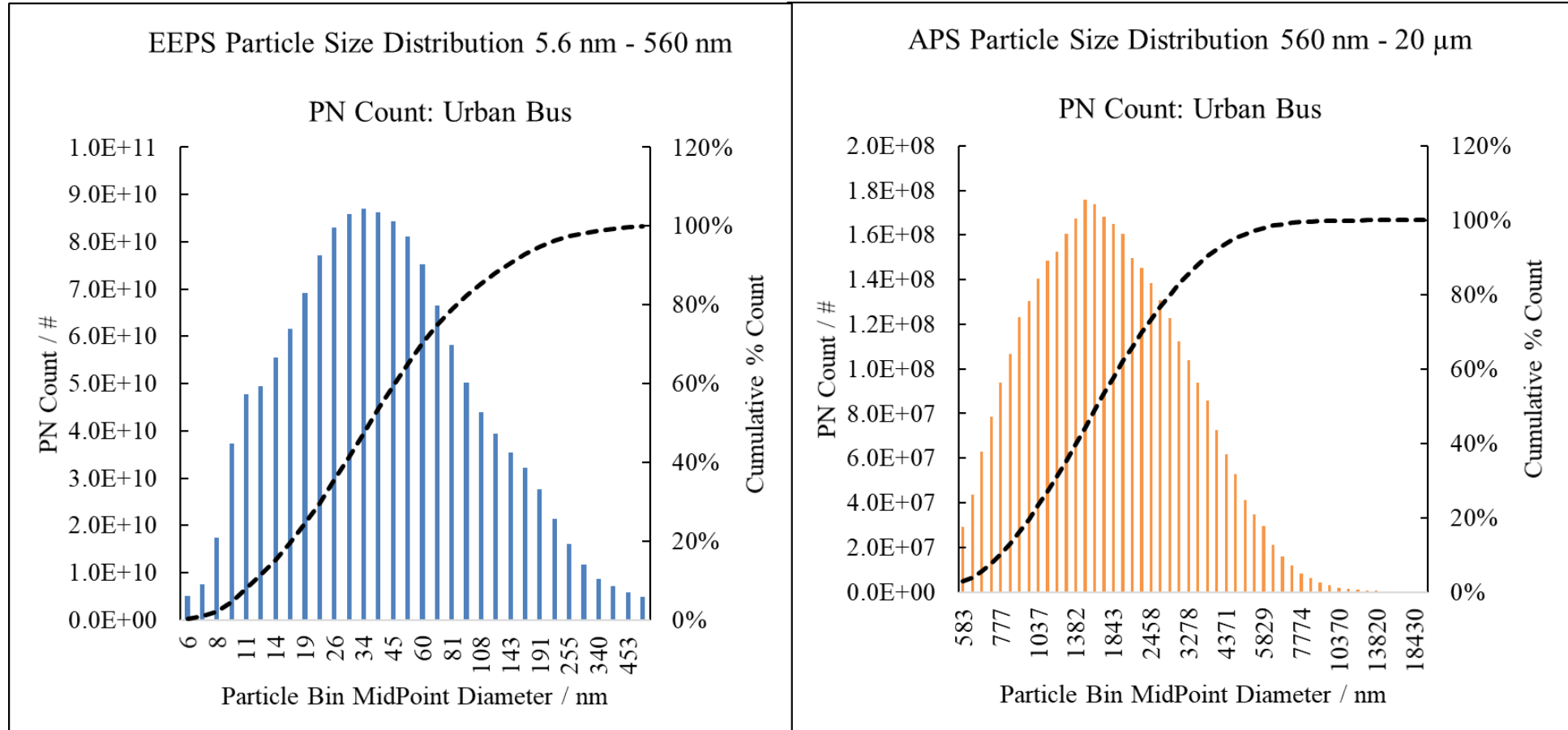
# Example Real-Time Results

e.g., TPN23 & PM<sub>2.5</sub> vs. temperature, brake energy, speed (Urban Bus)



# Real-Time Results for Particle Size Distribution

e.g., Urban Bus





# Caltrans Project's Advancements to Update EMFAC2021

As continuation of CARB program on LDV

CALTRAS, CARB, EPA Steering team (project management and scientific)

## Updates:

Proving ground data

Brake temp. model

Current formulations

Current cycles

## Test setup:

Lab based

Aligned with PMP/IWG

Using driving cycles

Realtime mass, PN and size distribution (6 nm...20  $\mu\text{m}$ )

## PM<sub>10</sub>, PM<sub>2.5</sub> & TPN23:

Hydraulic disc, air disc, and drum brakes

Loaded and unloaded configurations

OEM and aftermarket friction materials

**...one more thing**



**Fast Track to  
Cleaner Urban Air**

# Partnership

Reduce fleet PM > 90% with a cost < 10% of fleet value







Valladolid

Ancona

Ljubljana



# Route Mapping

## Minimal intrusion, brake activity and temperature, actual route mapping

D2.1 – Defintion of a Driving Cycle



the measurement devices. Additionally wear mass measurements of the brake pads were performed in Valladolid.



Figure 1: Solaris Bus from AUVASA's Bus Line C1 and Line 3 in Valladolid



Figure 2: LINK VMAX Data Acquisition System

D2.1 – Defintion of a Driving Cycle

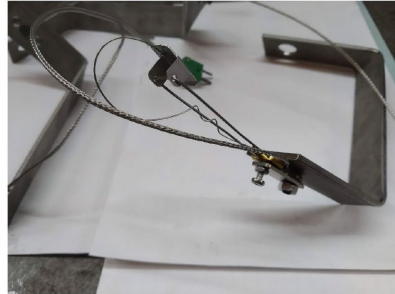


Figure 5: Sliding Thermocouple for temperature measurement at the brake disc's surface



Figure 6: Thermocouple installed at the brake

D2.1 – Defintion of a Driving Cycle



Figure 3: Control Screen for LINK VMAX

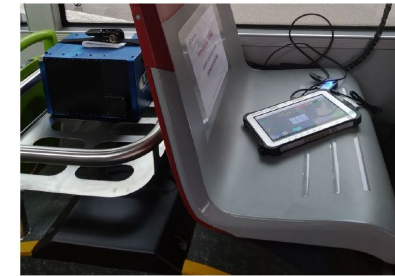
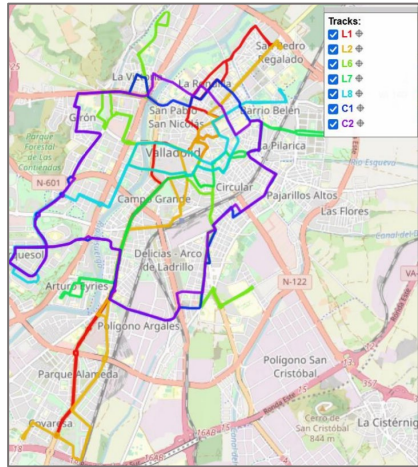


Figure 4: LINK VMAX fixed in longitudinal direction to the bus (left) and Control Screen (right)

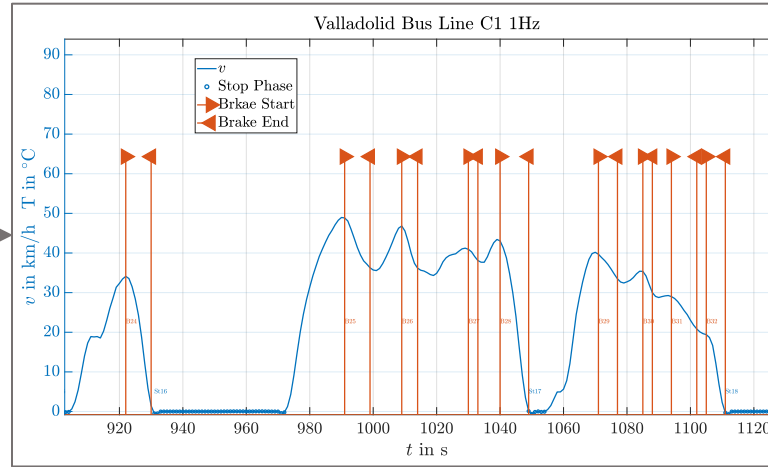


# Drive Cycle Design

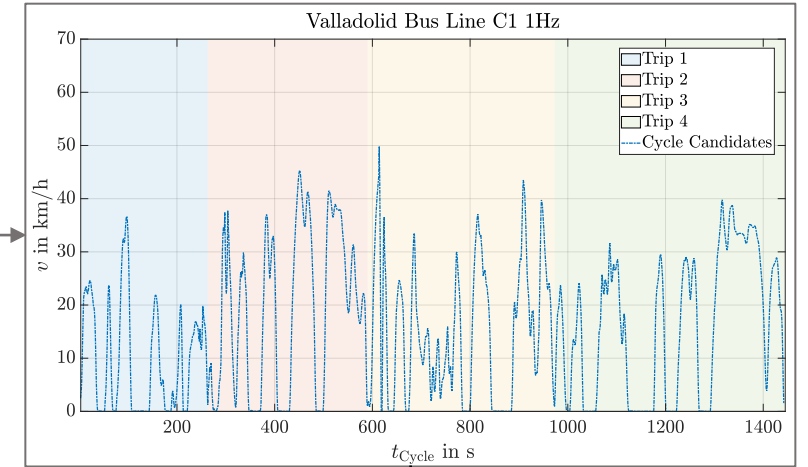
Following WLTC-WLTP method



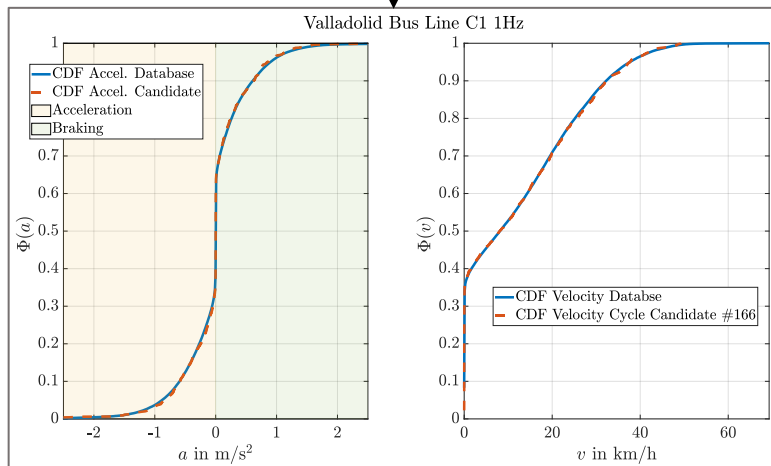
route selection



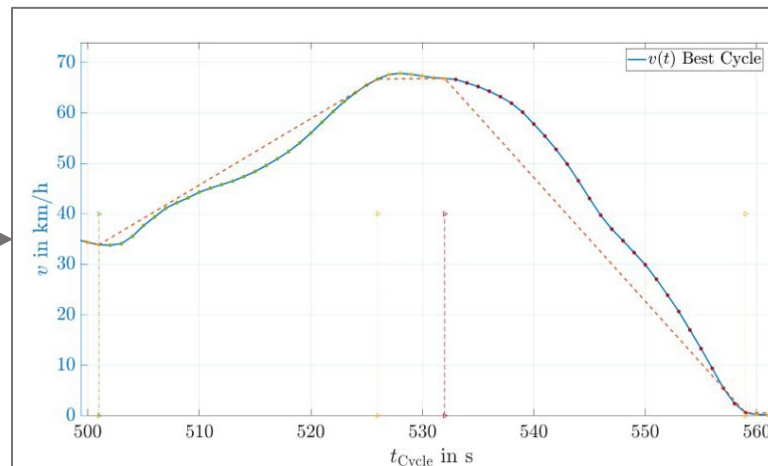
short trips



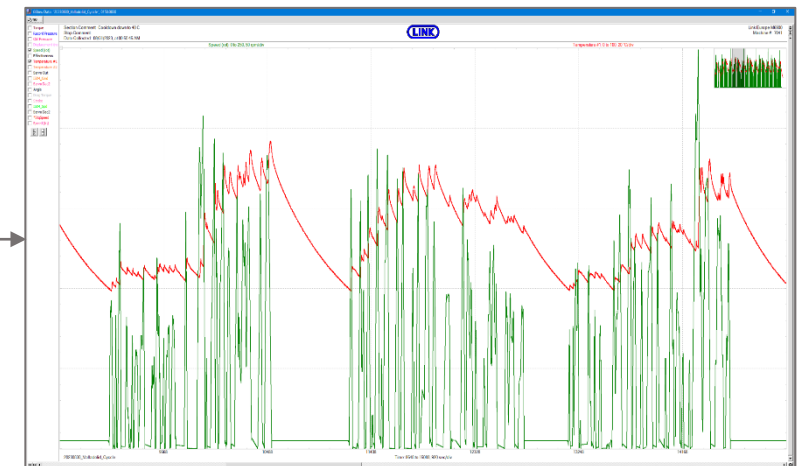
cycle consolidation



cycle validation



engineered brake events



dynamometer validation

# GTR XX for heavy trucks

Some topics to consider within TF5

1. Analysis and evaluation of existing driving cycles, databases, and factors (e.g., vehicle dynamics, topography, type of foundation brake, engine retarders, electrification)



2. Development of realistic driving cycle(s) considering vehicle factors and vocation(s) by brake type
3. Adapt all applicable items from GTR 24





Thank you



Simon Bisrat

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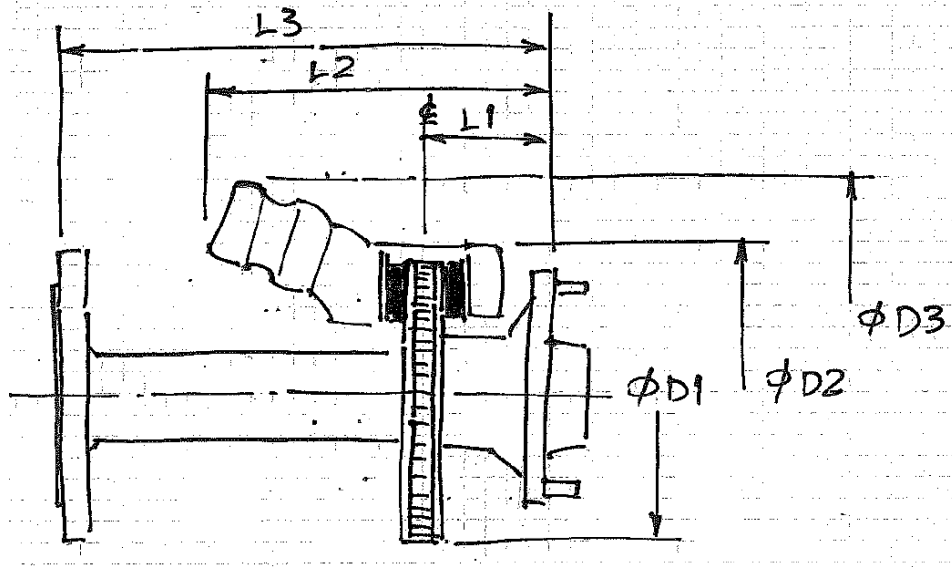
“An impressive array of instruments and procedures exist to measure PM and associated pollutants in great detail. But until atmospheric chemists know what should be measured, they are faced with an impossible task, as everything cannot be measured in ultimate detail.”<sup>1</sup>

<sup>1</sup> Robert Phalen, *The Particulate Air Pollution Controversy – A Case Study and Lessons Learned*, 2002



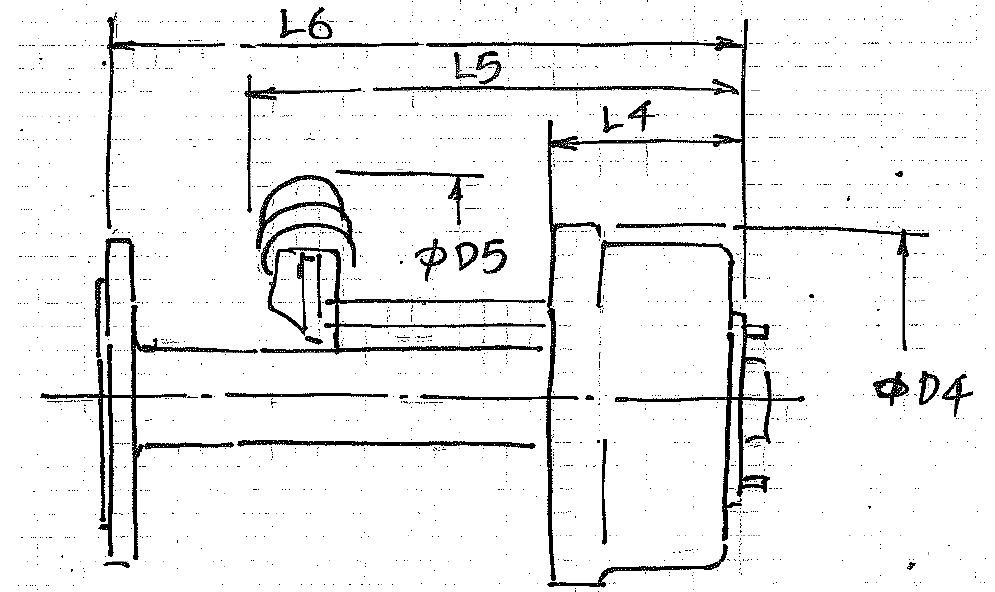
# Envelope dimensions for brake assemblies

The embodiment of the actuation system has a significant effect on overall size



Air-disc brakes

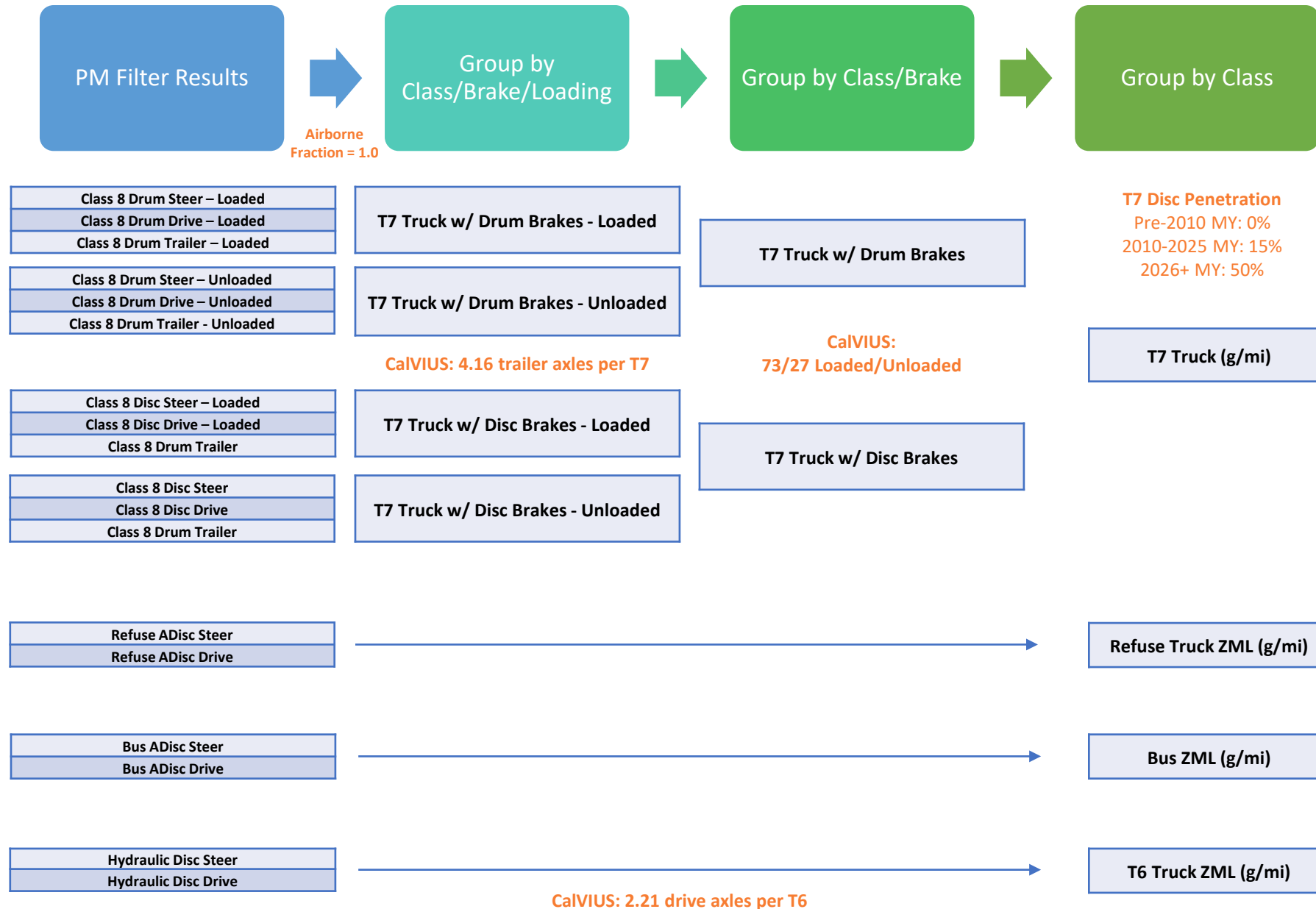
L2 [450...650 mm], D2 [450...600 mm]



Air-drum brakes

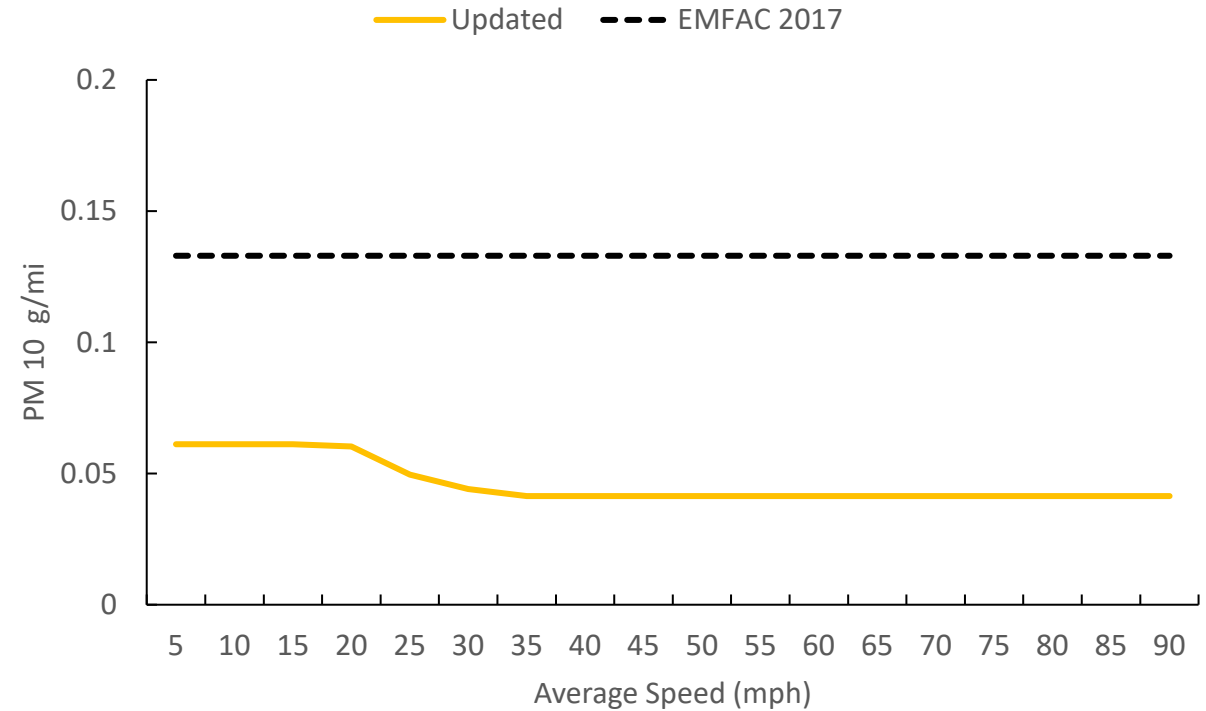
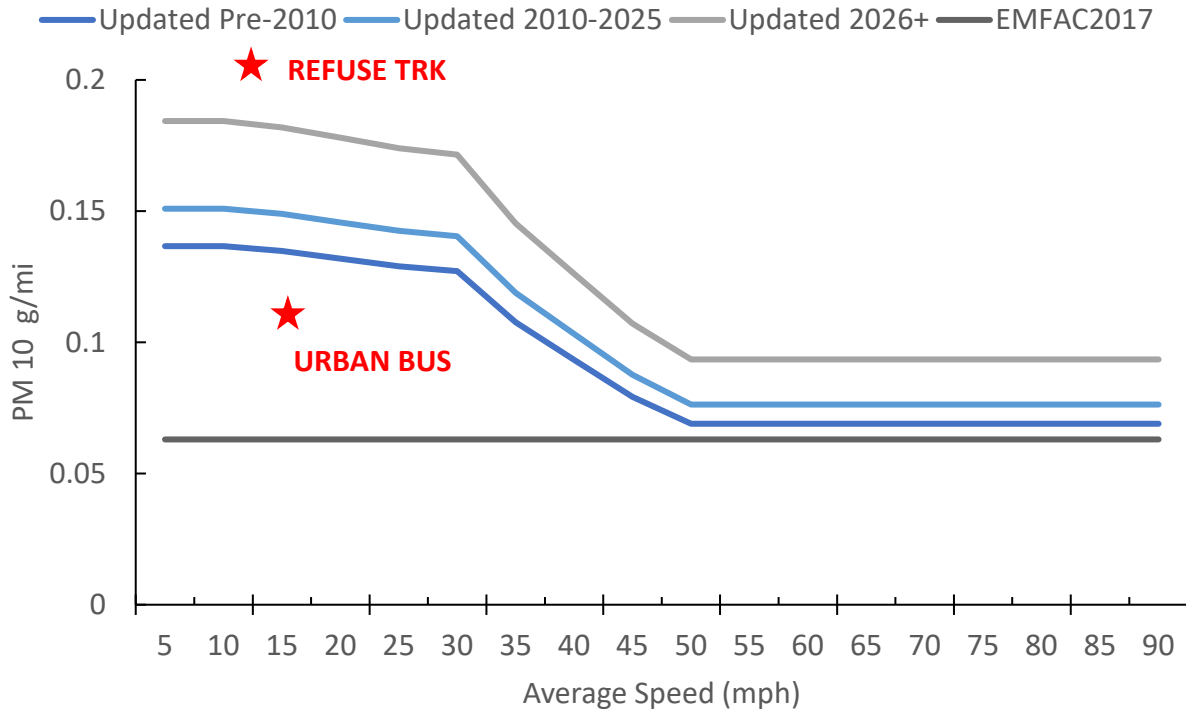
L5 [550...850 mm], D4 [380...520 mm]

# EMFAC rates





# Updated EMFAC2021 with HD Brake PM<sub>10</sub> Rates



## Class 8 HD (T7)

- Rates based on projection of turnover (Drum to ADB)
- Reduced stopping rules expected to hasten this turnover
- Market survey estimates only 15% Disc currently
- Assumed 50% by 2026.

## Medium HD (T6)

- Rates assume 100% hyd. disc, based on market survey
- EMFAC2017 assumed mix of disc and drum

