A COMPREHESIVE EVALUATION OF NEW LOW NOx 1065 COMPLIANT PEMS

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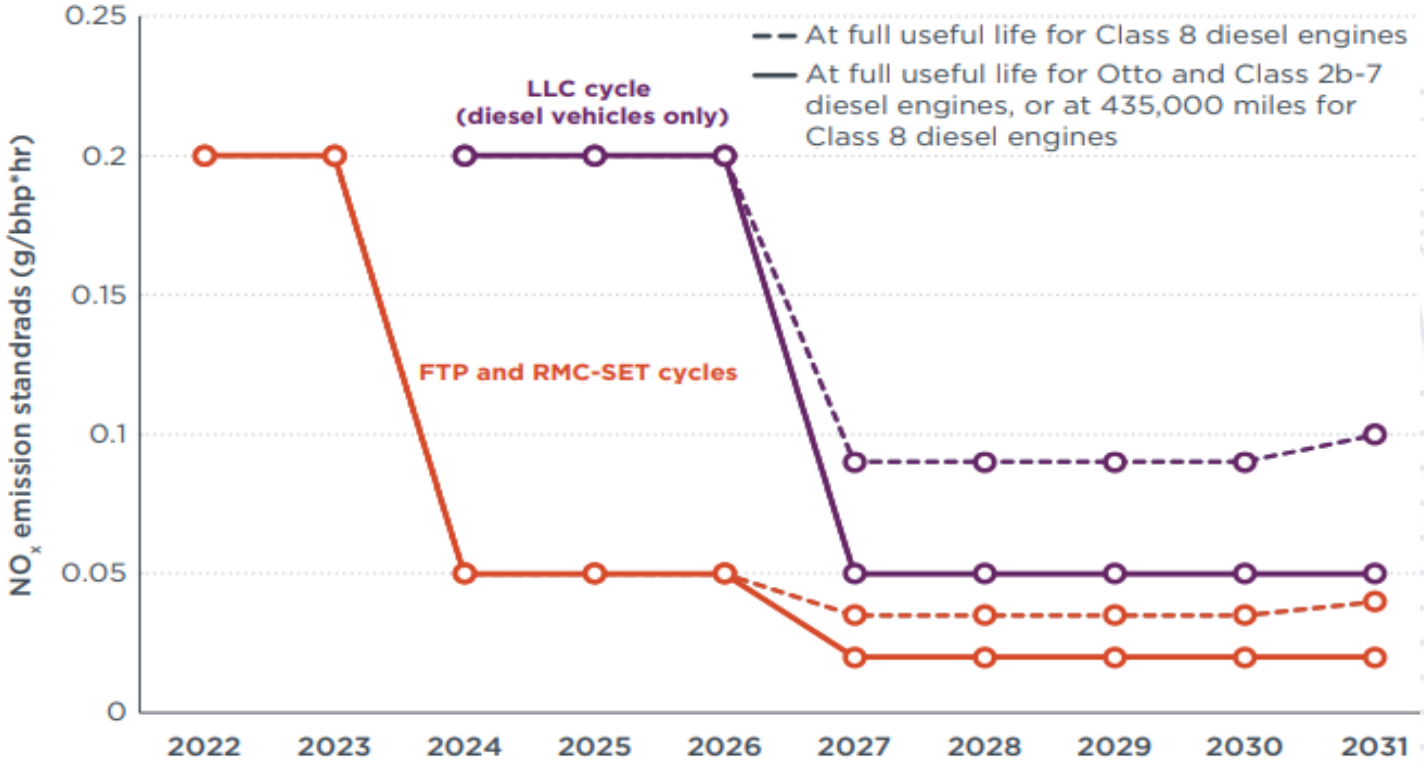
NO_x Emissions: Further Reductions



- CARB and EPA are reducing NOx further from 0.2
- **How do PEMS work at this lower emission level**
- Evaluate with EPA in-use 3BIN MAW
  - **Bin 1:** 7.5 g/hr
  - **Bin 2:** 0.075 g/bhphr
  - **Bin 3:** 0.030 g/bhphr

Ref: ICCT policy update: Heavy-Duty Omnibus Regulation Dec 2021(CARB)

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Project Overview

- Determination of new Low NO_x PEMS Measurement Allowance
- The goal of this project is to validate a Monte Carlo model of error surfaces using an on-road reference laboratory.
- Similar project was performed in 2007 (gaseous PEMS) and 2009 (PM PEMS) using UCR's Mobile Emissions Laboratory (MEL). 0.45 g/hp-hr delta
- UCR's Mobile Emissions Laboratory (MEL) was upgraded to perform this validation
  - New Horiba MEXA ONE raw and dilute emissions bench
  - Enhanced measurements include
    - Dilute ultra-low NO_x bench
    - Raw and dilute ovens for hot NO_x measurements
    - NO_x and NO measurements for both raw and dilute
    - Quantum cascade laser (QCL) for raw N_2O and NH_3 measurements

PEMS Selected

- **Utilized all 1065 approved gas PEMS manufactures (Horiba, AVL, and Sensors)**
  - Each was specifically upgraded for Low NOx measurements
  - Improved thermal management for lower zero drift and better signal processing

Horiba

AVL

Sensors

Routes Used for the Validation

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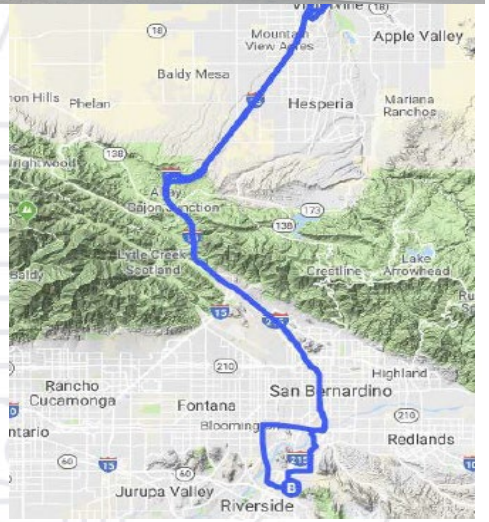
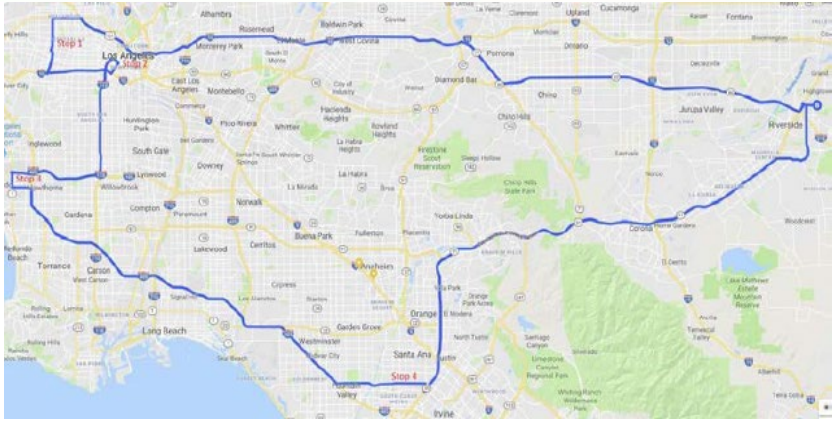
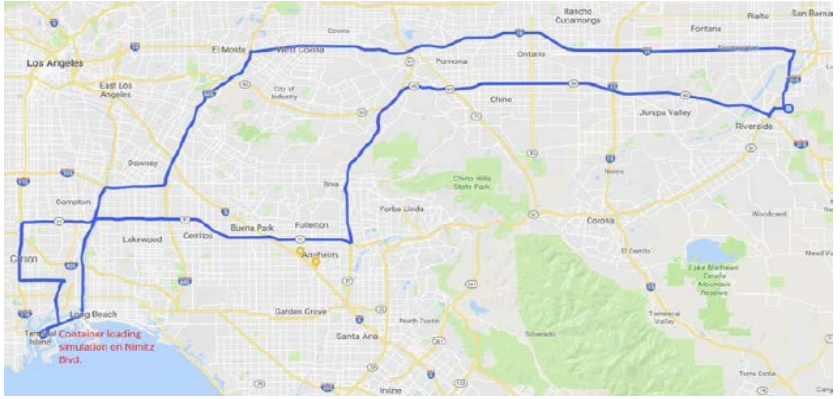
(b) The Highway Goods Movement route



(c) The goods movement with elevation change



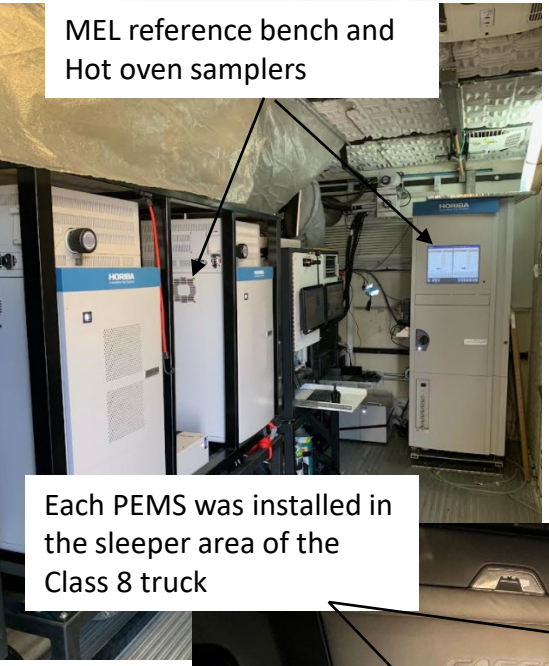
(a) The Grocery Distribution route



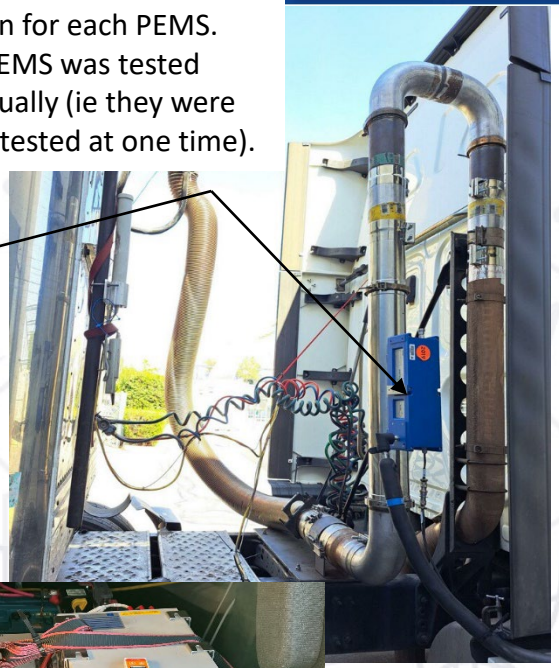
(d) The port-drayage route

PEMS Installation

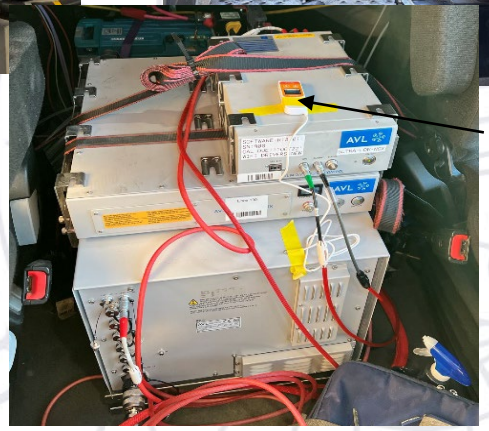
MEL reference bench and Hot oven samplers



Exhaust flow meter location for each PEMS. Each PEMS was tested individually (ie they were not all tested at one time).



Each PEMS was installed in the sleeper area of the Class 8 truck



Temperature Sensor
To record the boundary layer temperature between the surface of the PEMS and the cabin temperature.

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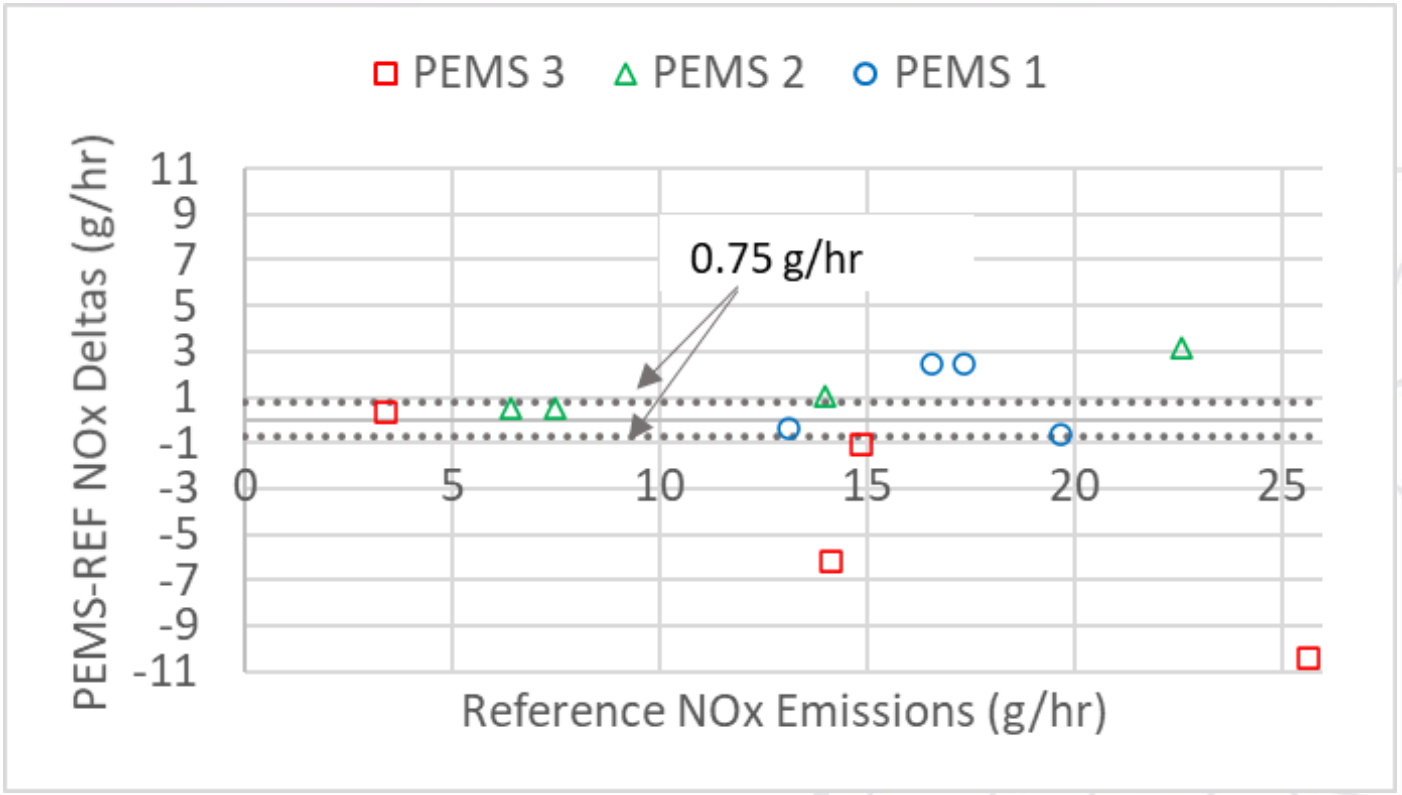
Test Vehicle Specifications

Company	Detroit diesel corporation
Engine family	KDDXH14.8EAD
Engine model	DD15
Model year	**Apr 2019**
Displacement (liters)	14.8
Fuel type	Diesel
Features	Direct Injection, Turbocharger
Aftertreatment	Change air cooler (CAC) Exhaust gas recirculation (EGR) Oxidizing catalyst (OC) Periodic trap oxidizer **(PTOX)** Selective catalytic reduction, urea (**SCR-U**) Ammonia oxidation catalyst (AMOX)
Advertised horsepower at 1650 rpm	505
Fuel rate at adv. horsepower (mm3/stroke)	291.0
Certified NOx (FTP)	**0.12**

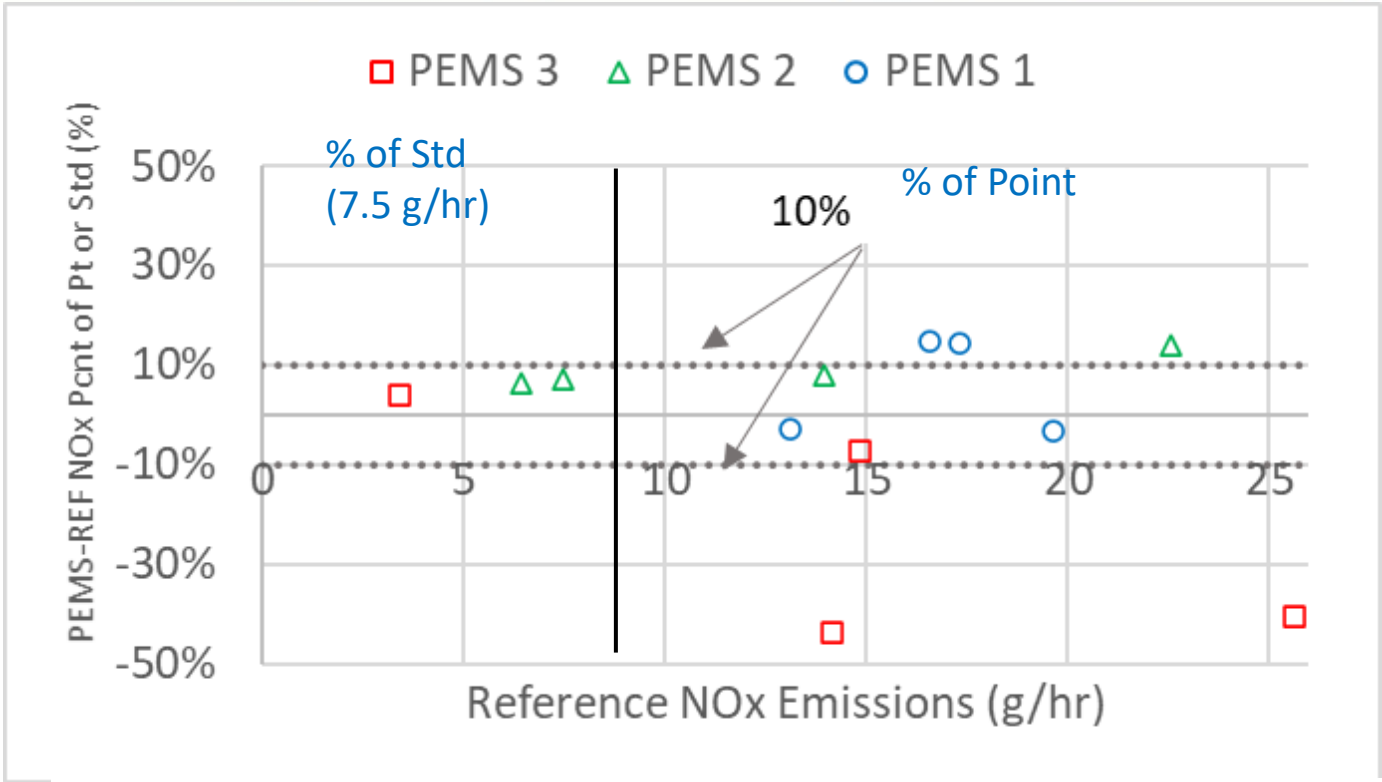
BIN1: Deltas



Emission Rate was less than 25 g/hr

- The NO_x emission deltas varied for all three PEMS from + 3 to -10 g/hr.
- NO_x emissions below 7.5 g/hr (BIN 1 limit) deltas were less than 0.75 g/hr.

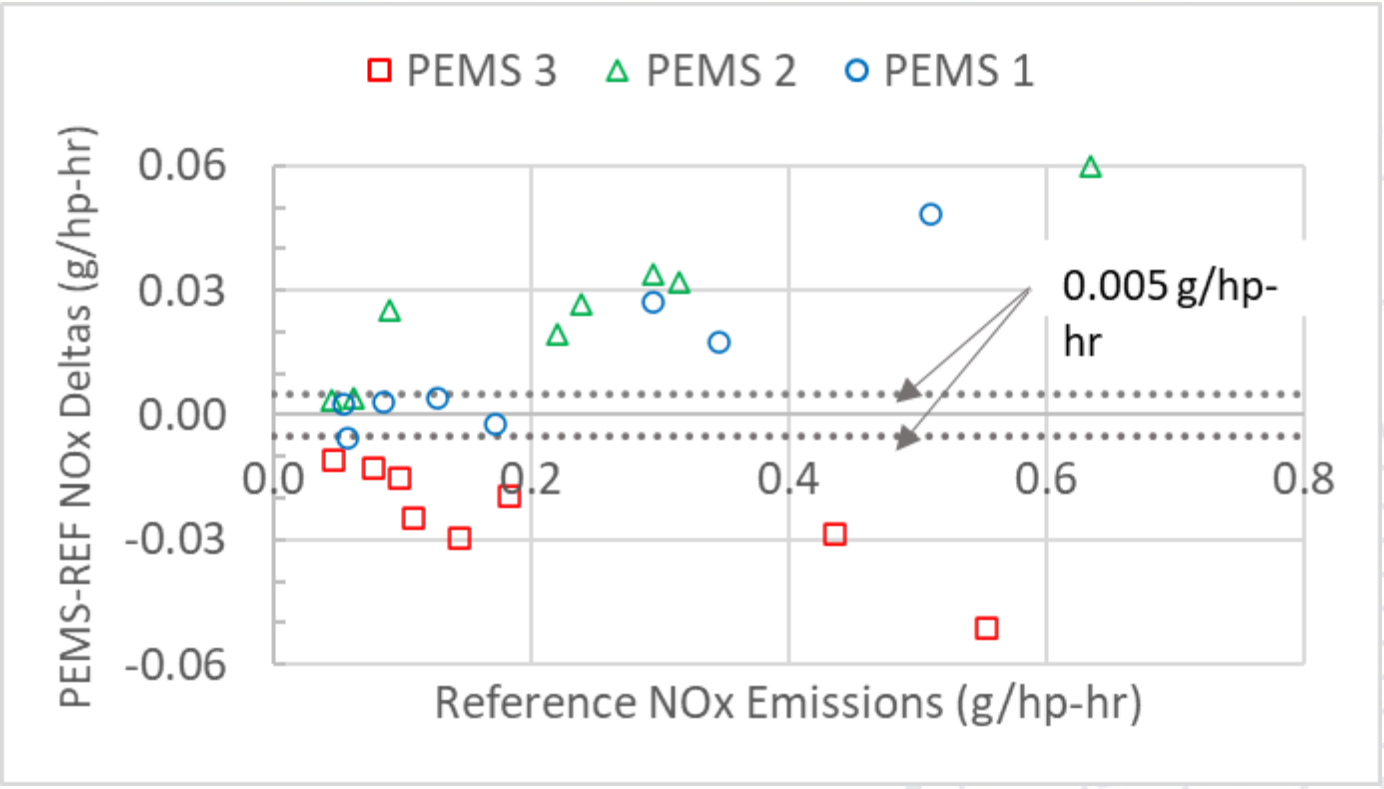
BIN1: Rel Error



Emission Rate was less than 25 g/hr

- The relative error was below 10% at < 7.5g/hr for all PEMS
- The relative error was close to 10% above 7.5 h/hr for PEMS 1 and 2, but PEMS 3 was around 40%. Errors for PEMS3 were in the idle exhaust flow

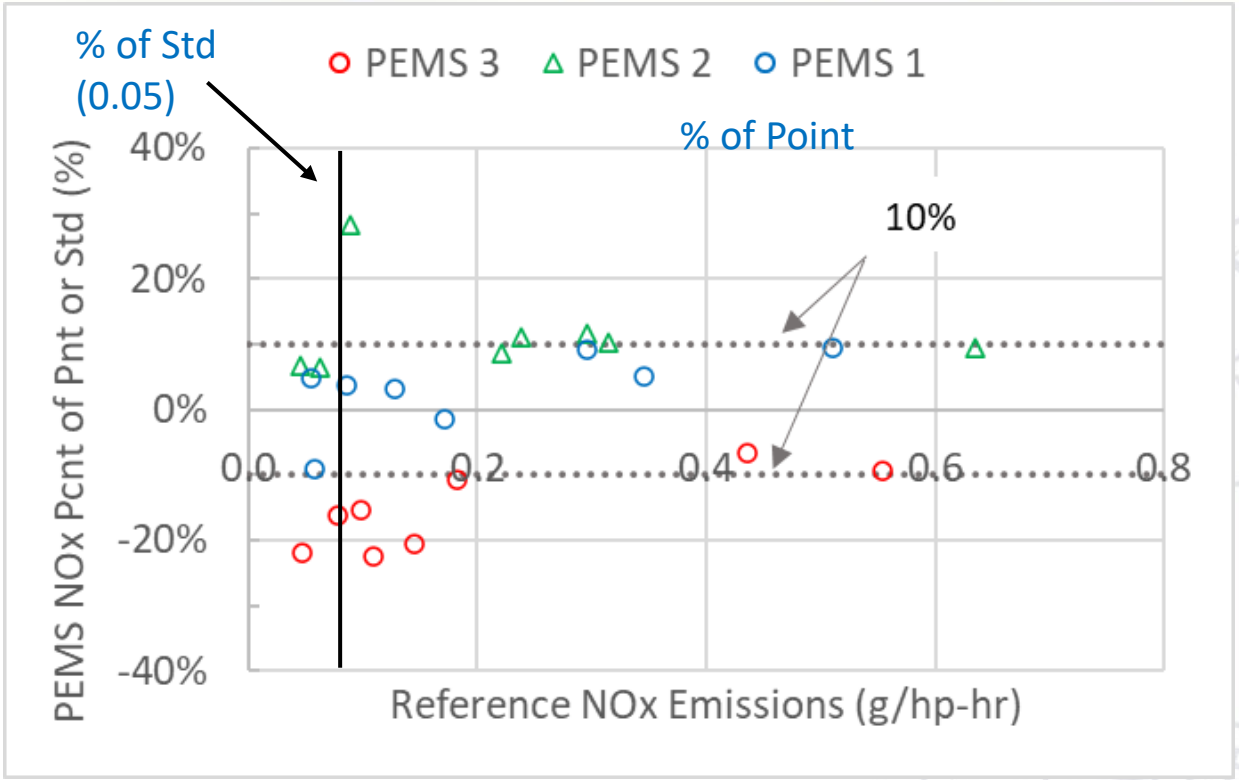
BIN2, 3: Deltas



Emission Rate was less than 0.8 and mostly below 0.4 g/hp-hr

- PEMS deltas ranged 0.06 to -0.05 g/hp-hr for emissions up to 0.8 g/hp-hr
- NO_x emissions PEMS 3 showed a consistent low bias.

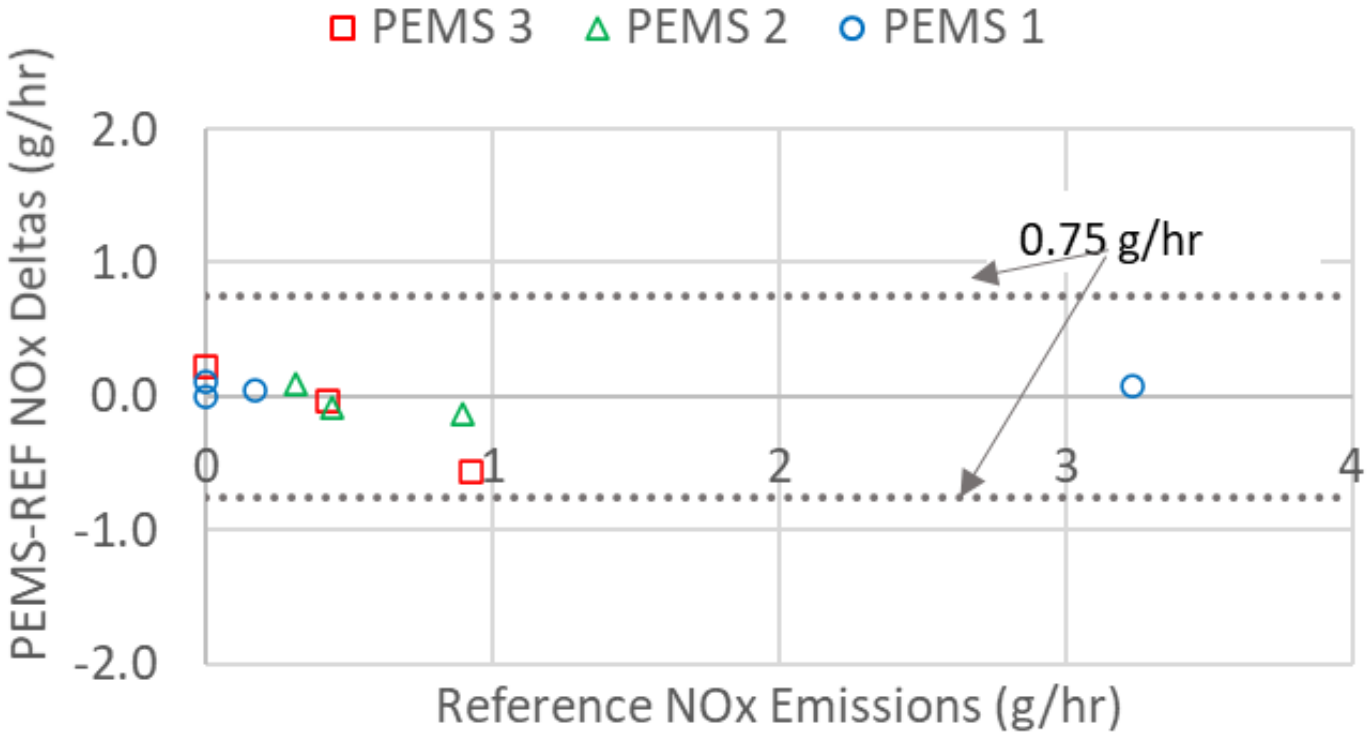
BIN2, 3: Rel Error



Emission Rate was less than 0.8 and mostly below 0.4 g/hp-hr

- The emissions below the 0.05 g/bhp-hr reference were less than 10% for PEMS 1 and 2. PEMS 1 and 2 were mostly lower than 10% above 0.05 g/bhp-hr
- PEMS 3 showed a low bias above and below 0.05 g/bhp-hr reference

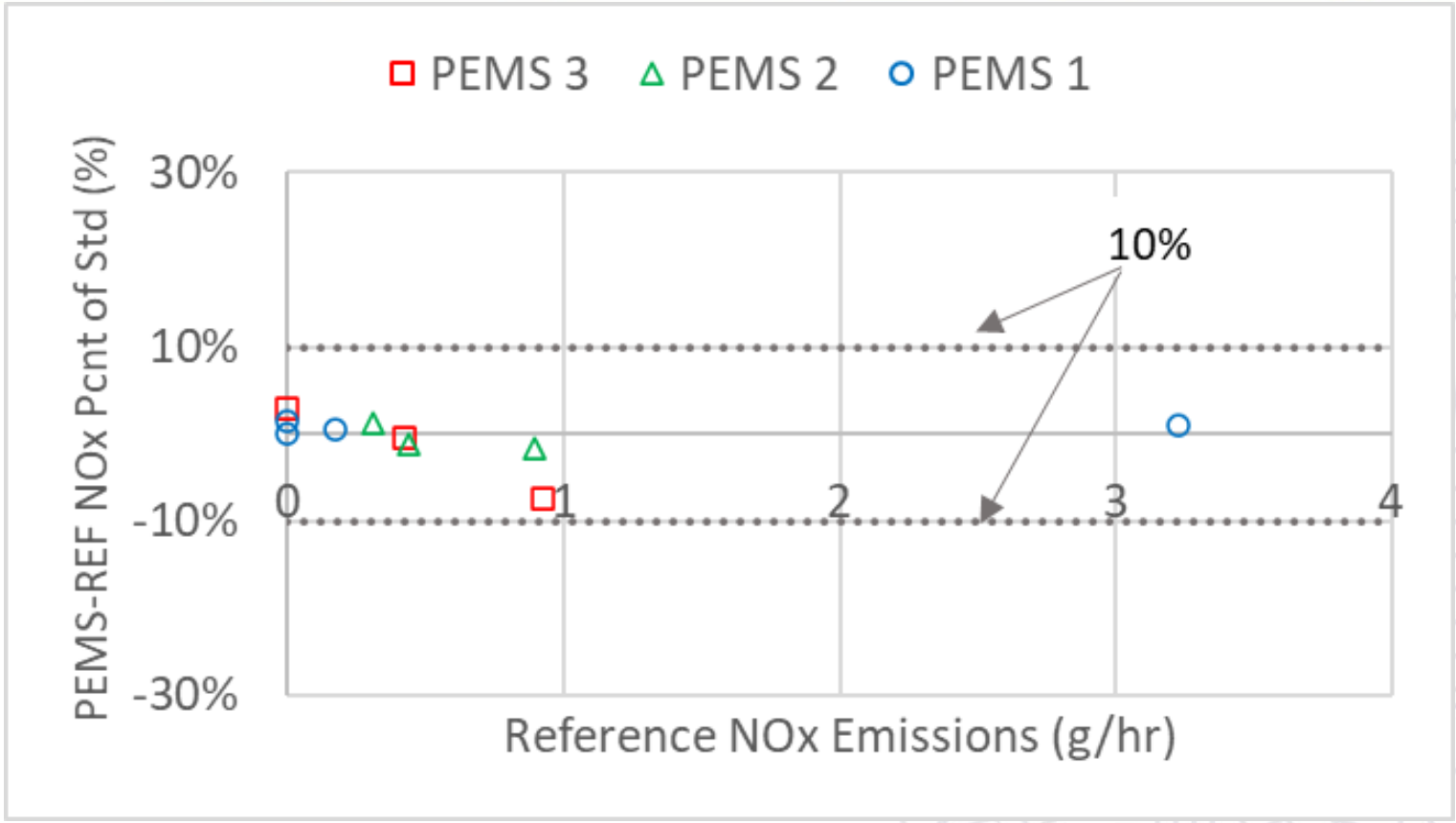
Low NOx Data: BIN 1 Deltas



Emission Rate was less than 4 and mostly below 1 g/hr

- All PEMS showed results within 0.75 g/hr for emissions less than 4 g/hr

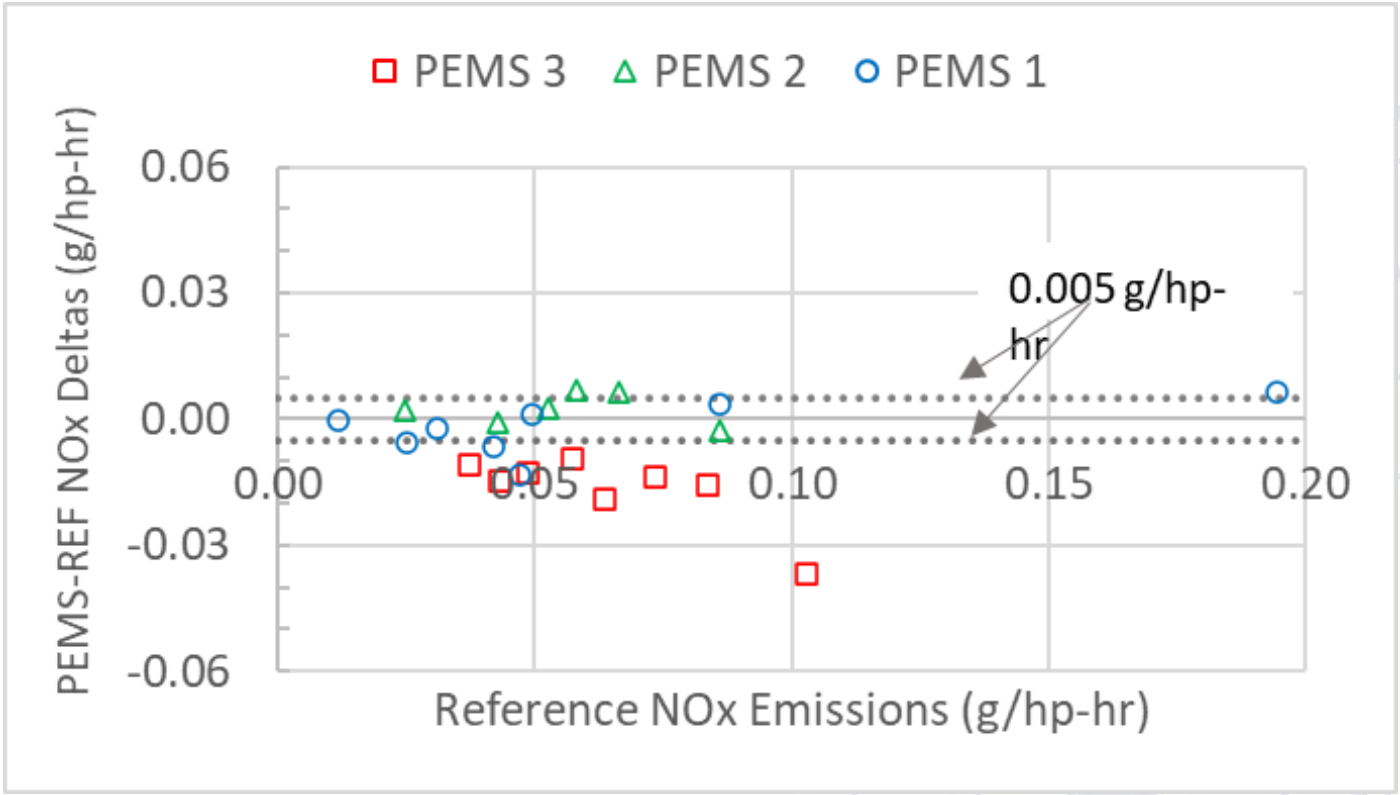
Low NOx Data: BIN 1 Rel Err



Emission Rate was less than 4 and mostly below 1 g/hr

➢ **All PEMS showed results 10% for emissions less than 4 g/hr**

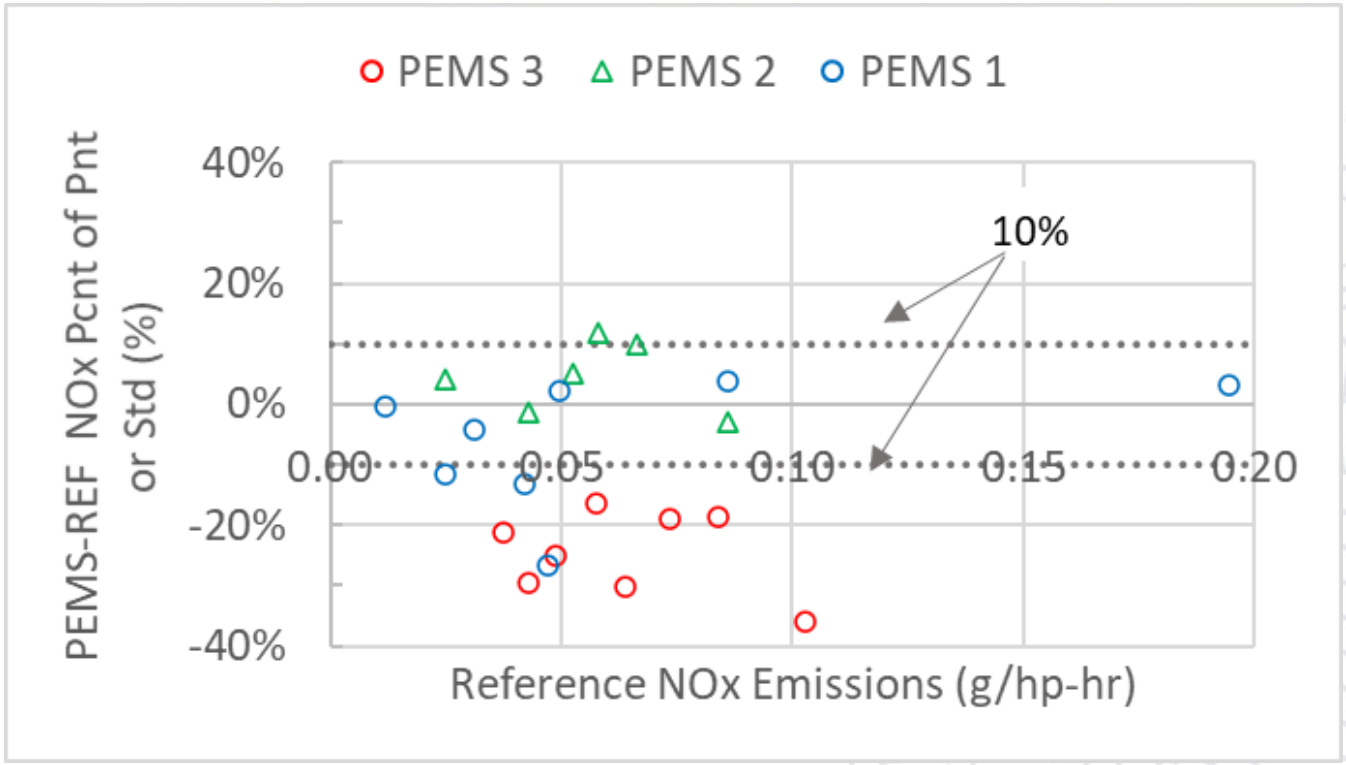
Low NOx: BIN2,3 Deltas



Emission Rate was less than 0.2 and mostly below 0.1 g/hp-hr

- PEMS 1 and 2 deltas were mostly withing or at 0.005 g/hp-hr
- PEMS 3 showed some deltas as high as 0.04 g/hp-hr

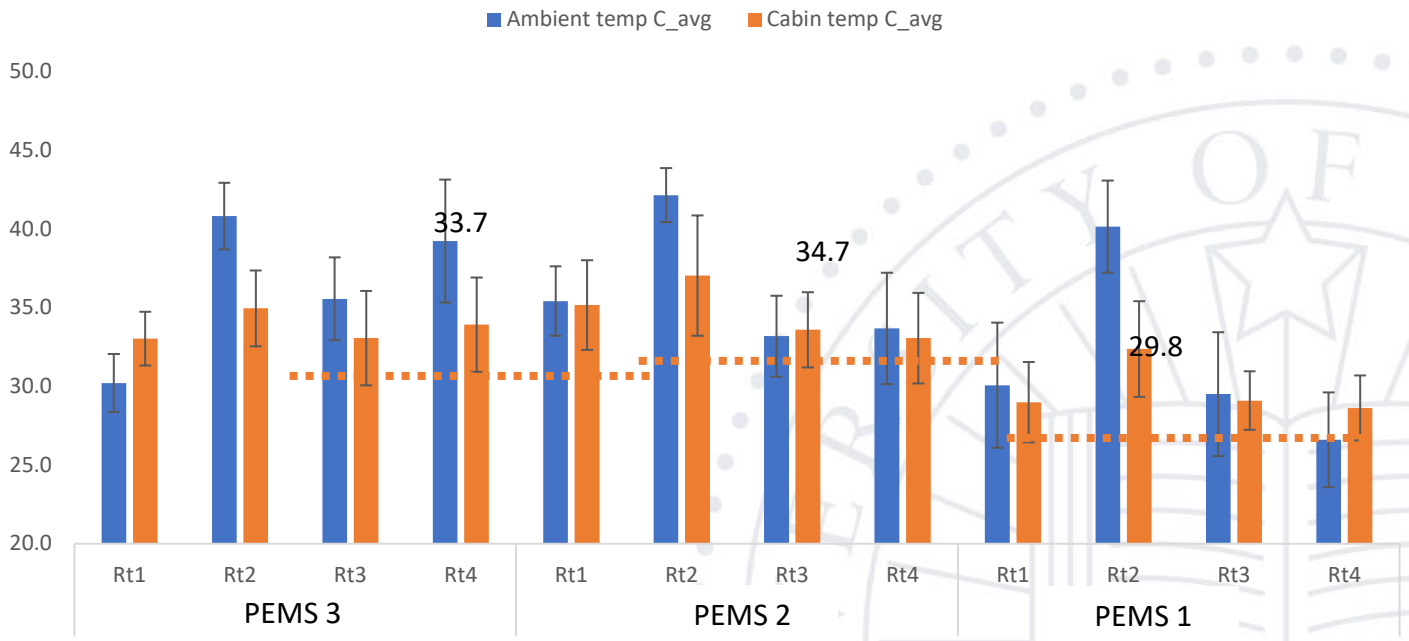
One Day Is Not Enough



Emission Rate was less than 0.2 and mostly below 0.1 g/hp-hr

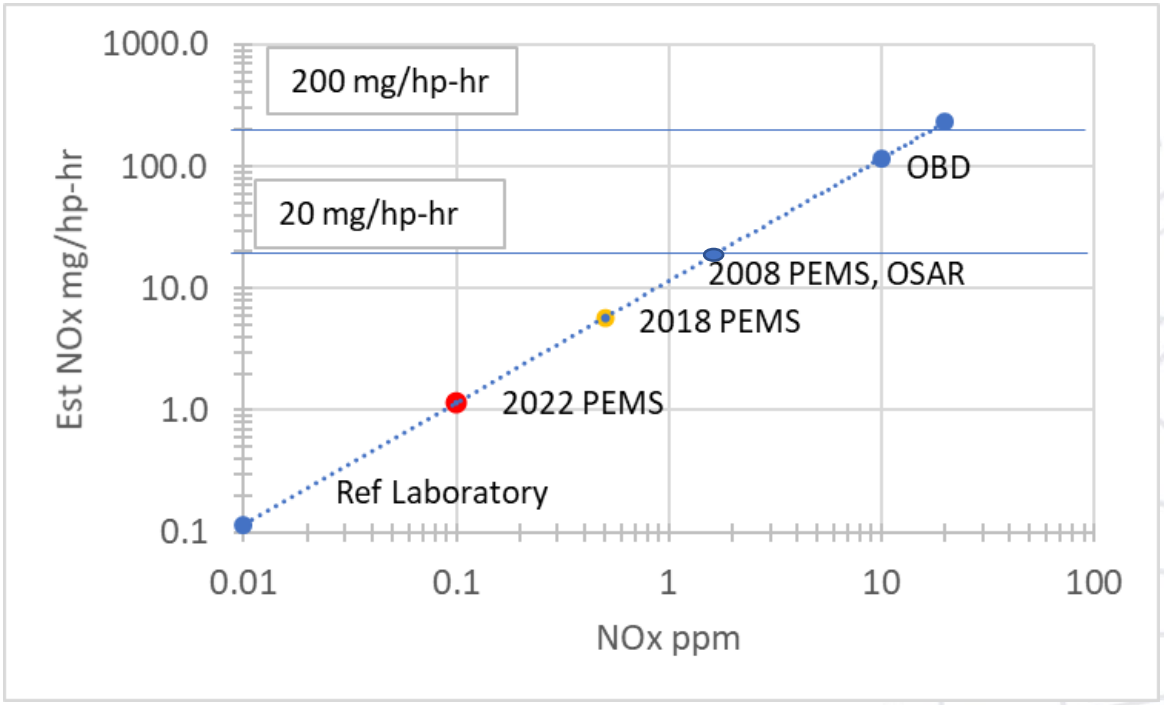
- **PEMS 2 was the only PEMS that was within 10% for most emission rates below 0.2**
- **PEMS 3 showed a relative error ranging from -15% to -35%**

Summary of Cabin and Ambient Temperatures



➢**PEMS 1 was subjected to a slightly lower cabin temperature (5 deg C lower) compared to PEMS 2 and 3**

Summary of Drift Conditions



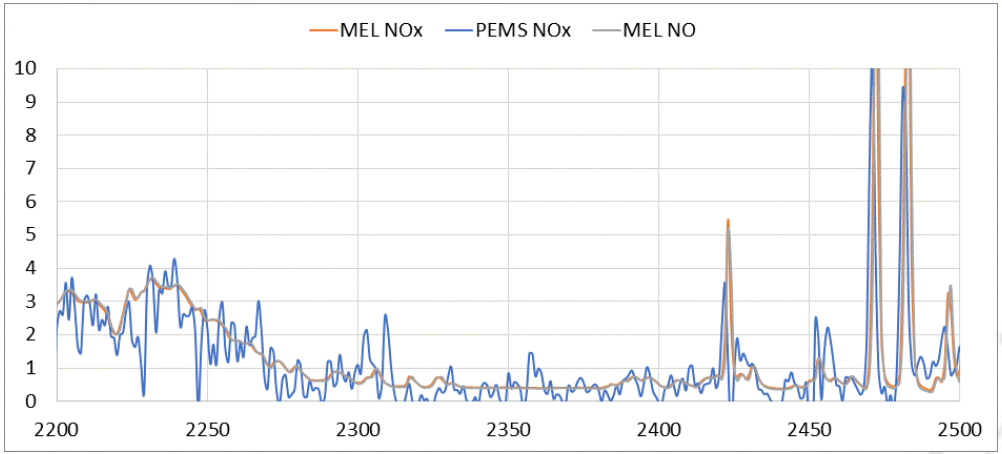
Drift Statistics

	PEMS 3	PEMS 2	PEMS 1
max	1.589	0.180	0.978
min	-2.428	-0.265	-0.983
stdev	1.464	0.171	0.704
delta	4.016	0.445	1.960
mean	-0.092	-0.071	0.035

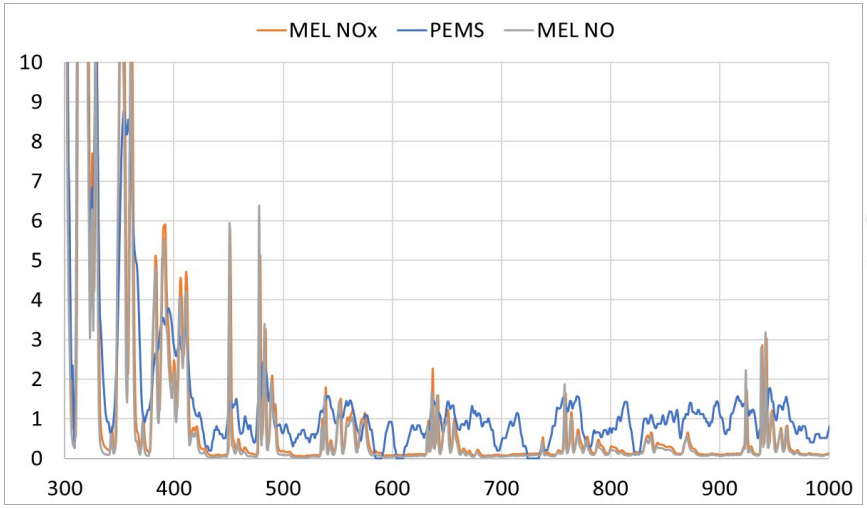
- PEMS 1 showed the lowest overall average drift (0.035)
- PEMS 2 showed the most consistent low drift with a max/min of 0.18 and -0.26 ppm
- PEMS3 had the highest drift

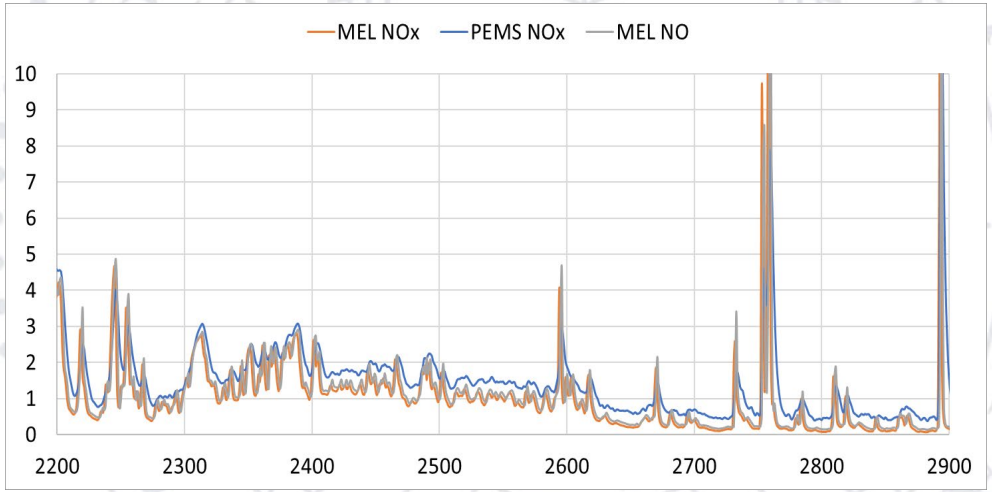
➢Low NOx PEMS are expected to show significant improvements over previous PEMS if drift is around 0.2 ppm

PEMS vs MEL raw < 10 ppm varies



- Two PEMS showed a poor < 10 ppm comparison to the reference
- One PEMS agreed well





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Summary

- Low NO_x PEMS were compared to a mobile reference laboratory over varying routes and environmental conditions
- Two PEMS performed around 10% above and below the 2027 standard (up to 0.8 g/hp-hr).
- One PEMS had performed 20-40% above and below the 2027 standard. Errors seemed to result from an exhaust flow measurement bias.
- The two PEMS BIN2 and 3 deltas were within 0.005 g/hp-hr below the 2027 standard and one was around 0.015 g/hp-hr
- It appears these new low NO_x PEMS can be utilized to quantify emissions at and below the 2027 standard.

Acknowledgement

We acknowledge funding from the Engine Manufacturers Association (EMA)

We thank the in-kind access to the PEMS equipment, their calibration prior to testing, and in-kind on the group testing support from Cummins (AVL PEMS), Horiba. and Sensors

We thank the technical discussions and contributions from the California Air Resources Board, South West Research Institute, South Coast Air Quality Management District, Environmental Protection Agency, SGS, EMA, and the various industry partners of the Emissions Measurement Testing Committee (EMTC)


BACKUP SLIDES
https://www.alamy.com/

EPA 3 BIN Analysis Information

UCR performed EPA 3BIN analysis in the following way:

(1) Determine the mean mass percent of CO_2 of a window, $\bar{w}_{CO2win}$, using the following equation:

$$\bar{w}_{CO2win} = \frac{\bar{\dot{m}}_{CO2win}}{\dot{m}_{CO2max}}$$

Where:

$\bar{\dot{m}}_{CO2win}$ = mean mass rate of CO_2 over the valid window (300 seconds average moving window).

$\dot{m}_{CO2max} = e_{CO2FTPFCL} \cdot P_{max}$

$e_{CO2FTPFCL}$ = the engine's FTP FCL CO_2 emission value.

P_{max} = the engine family's maximum power determined according to the torque mapping test procedure defined in 40 CFR 1065.510.

Bin	Mean mass percent of CO_2
Idle	$\bar{w}_{CO2win} \leq 6\ \%$
Low load	$6\ \% < \bar{w}_{CO2win} \leq 20\ \%$
Medium/high load	$\bar{w}_{CO2win} > 20\ \%$

EPA 3 BIN Analysis Information

Parameters we used for EPA 3 BIN analysis:

- eCO2 FTP FCL (the engine's FTP FCL CO2 emission value) = 514 g/hp·hr
- Pmax = 505 hp from engine label
- CARB 2031 Standard (435k mile)
  - Bin 1: 7.5 g/hr
  - Bin 2: 0.075 g/bhphr
  - Bin 3: 0.030 g/bhphr

	EPA CERTIFICATE OF CONFORMITY	
	KDDXH14.8EAD-003	
In g/bhp-hr	CO_2	
	FTP	SET
STD	~~555~~	460
FCL	514	454
FEL	~~529~~	468
CERT	504	440

Source: EXECUTIVE ORDER A-290-0169-1