



# **IN-USE PEMS CORRELATIONS WITH UCR'S MEL (MOBILE EMISSION LABORATORY)**

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## Background and Motivation

- The dispute on the Not-To-Exceed (NTE) standard
- Heavy-Duty In-Use NTE testing (HDUIT)  
=> In use, on-road test run by manufacturer
- PEMS (Portable Emissions Measurement Systems) for criteria pollutants
- CE-CERT/UCR was selected to the project which provides accuracy of PEMS measurement under in-use condition and basis to the development of Measurement Allowance program for both and gaseous and PM measurement.

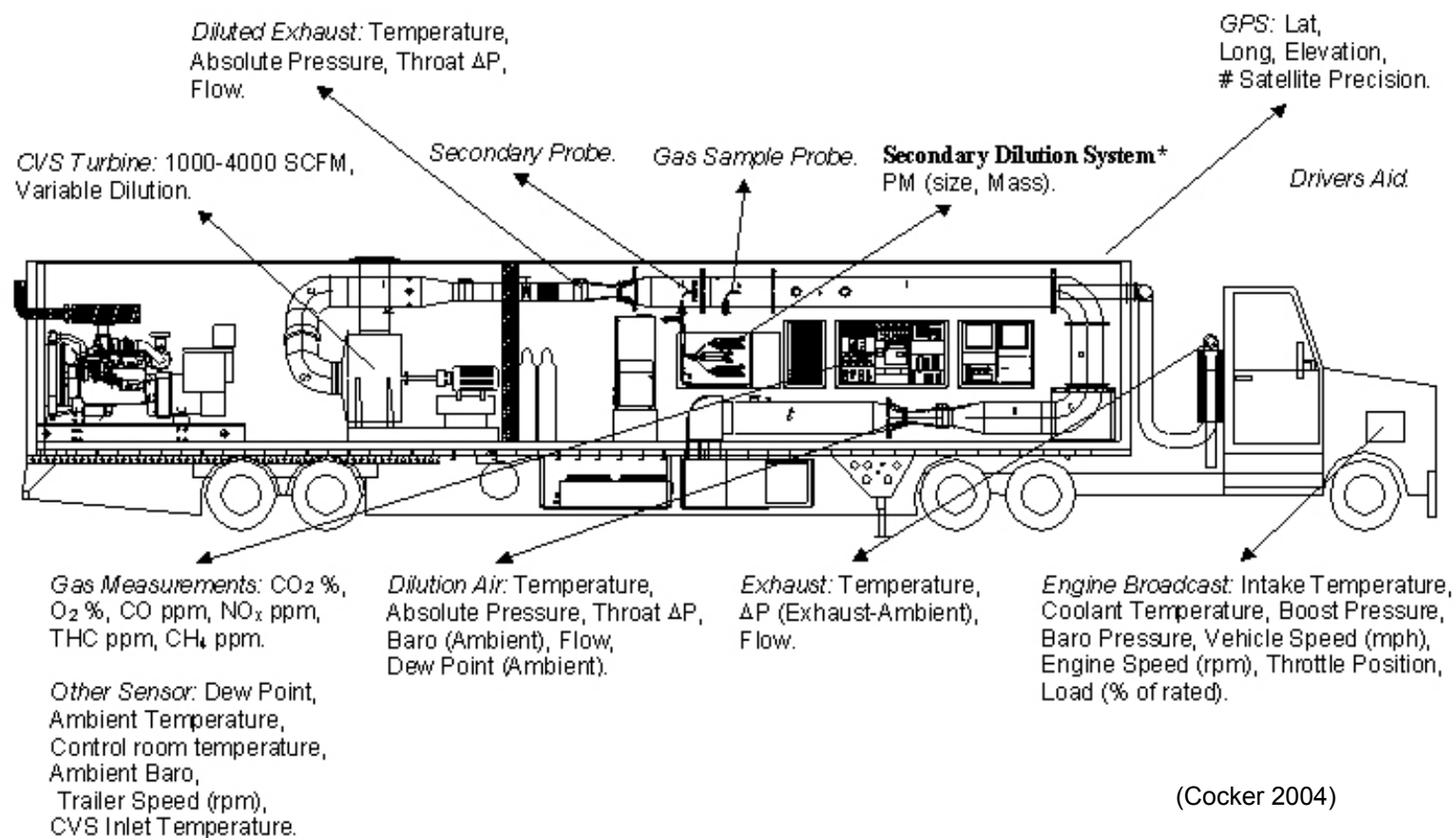


## Outline

- UCR's In-Use PEMS Evaluation Platform and It's Development
- Gaseous PEMS Lessons Learned
- PM PEMS Lessons Learned
- Conclusion



# PEMS Comparisons Were Made a CFR Reference Mobile Emissions Laboratory (MEL)



(Cocker 2004)





# MEL Accuracy Was Verified and Accepted by Industry and Regulators



- MEL passed a complete system audit
- Less than 2% instrument drift for MEL during in-use audits
  - 0 – 8,000 ft elevation
  - Wide Temp and RH
  - Shock, Vibration
- Correlation With SwRI Laboratory
  - NO<sub>x</sub> and CO<sub>2</sub> 2% accuracy 1% COV
  - PM 5% accuracy 2% COV



- Other correlations were also performed at CARB and the National Renewable Emissions Laboratory (NREL)



# The Routes Were Designed to Cover a Range of Temperature, Humidity and Elevation



**Test 1\*, 2a\*\*, and 2b\*\* Caterpillar**

Route	Temperature (F)	Humidity (RH %)	Elevation (Ft)
1	45 - 90	5 - 40%	1000 to 5500
3	65 - 85	30 - 80%	0 to 2000

\* only part of route one was used

\*\*extended range to 5500 feet

**Test 3a and 3b Cummins and Volvo**

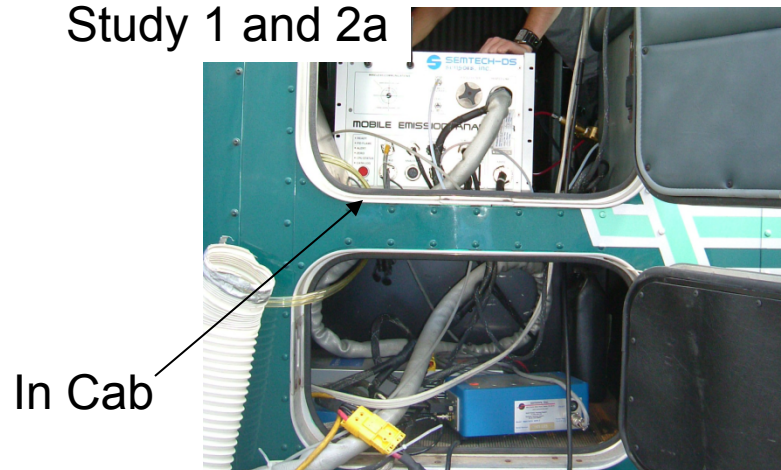
Route	Temperature (F)	Humidity (RH %)	Elevation (Ft)
1	50 - 80	10 - 30%	1000 to 4500
2	50 - 80	10 - 30%	0 to 3000
3	50 - 75	20 - 40%	0 to 2000
4	50 - 75	20 - 30%	1000 to 2000



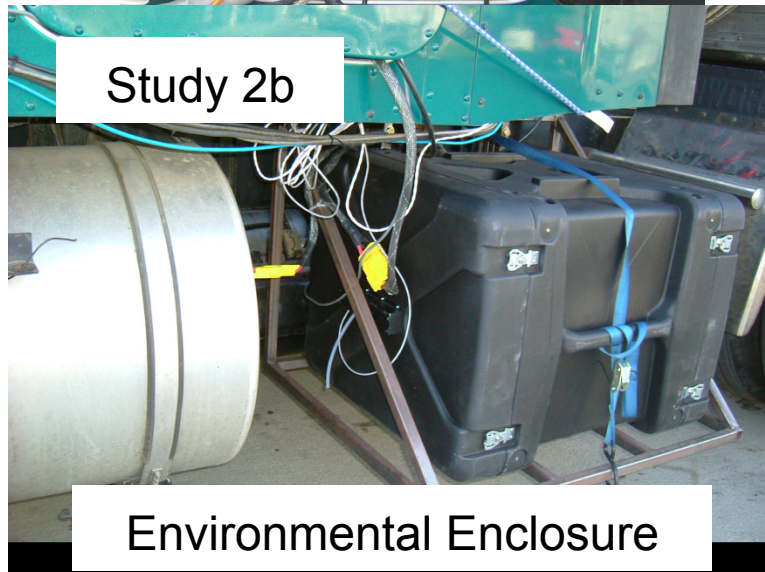


## Several PEMS Mounting Options Were Investigated

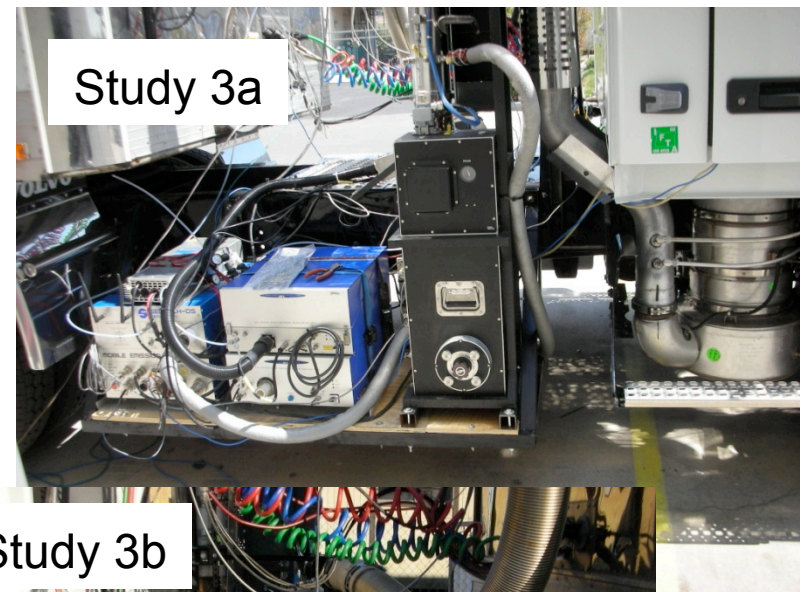
Study 1 and 2a



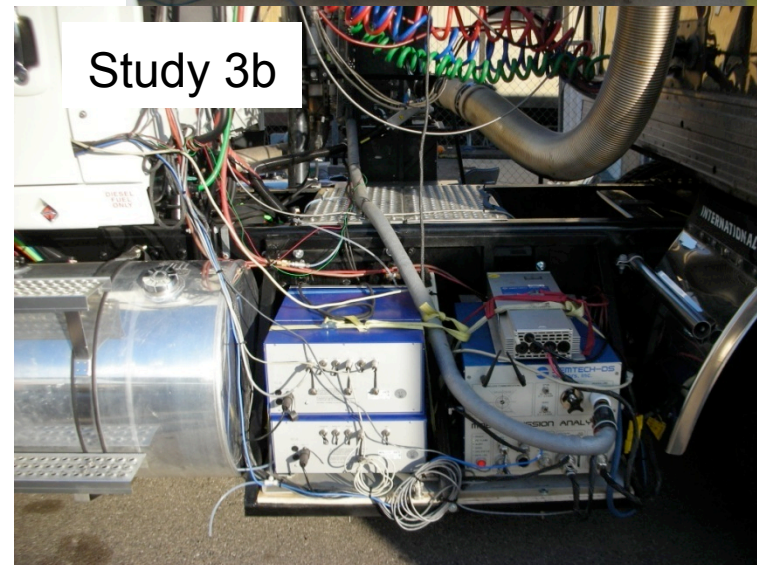
Study 2b



Study 3a



Study 3b





## In-Use Gaseous PEMS Test Matrix

Test Setup	Test Days	PEMS2 Year	PEMS2 Location	Engine	Aftertreatment	NO <sub>x</sub> Level g/hp-h	Notes	Effort # NTE Points
Test 1	1	ID#1 2003	In Cab	2000 <sup>i</sup> Caterpillar C15	none	3.0 - 3.5 (1%NO <sub>2</sub> )	OEM	12
Test 2a	3	ID#2 2005	In Cab	2000 <sup>i</sup> Caterpillar C15	DOC    passive DPF	2.5 - 4.5 (30%NO <sub>2</sub> )	OEM	129
Test 2b	3	ID#2 2005	Enclosure On Frame	2005 Caterpillar C15	DOC    passive DPF	2.5 - 4.5 (30%NO <sub>2</sub> )	OEM	139
Test 3a	4	ID#3 2007	On Frame	2007 Cummins ISX 450	OEM DPF	0.7 - 6 (40%NO <sub>2</sub> )	Regen ECM Mods	175
Test 3b	4	ID#4 2007	On Frame	2007 Volvo D13	OEM DPF	0.7 - 6 (40%NO <sub>2</sub> )	Regen/ECM Mods Bypass	153

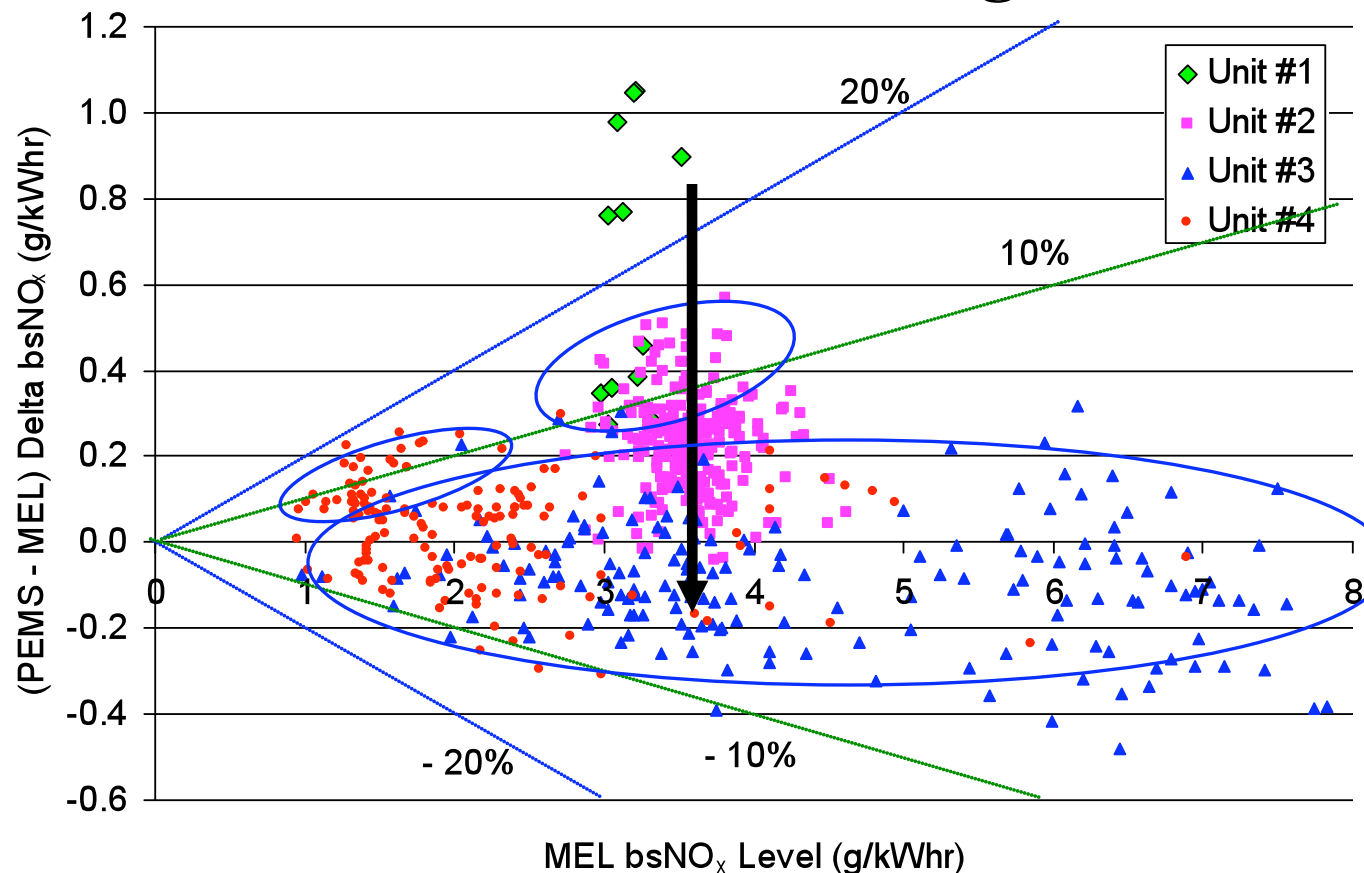
### Acronyms

- PEMS                      Portable Emission Measurement System, Semtech DS
- OEM                      Original Equipment Manufacture
- DPF                      Diesel Particulate Filter
- DOC                      Diesel Oxidation Catalyst
- Regen                    Forced regenerations with OEM tools
- ECM Mods              Recalibrated ECM to change NO<sub>x</sub> emissions levels
- Bypass                   Added tubing to bypass the OEM after treatment system





## NO<sub>x</sub> Measurements Appear to Have Improved at Around the 3.5 g/kW-h level



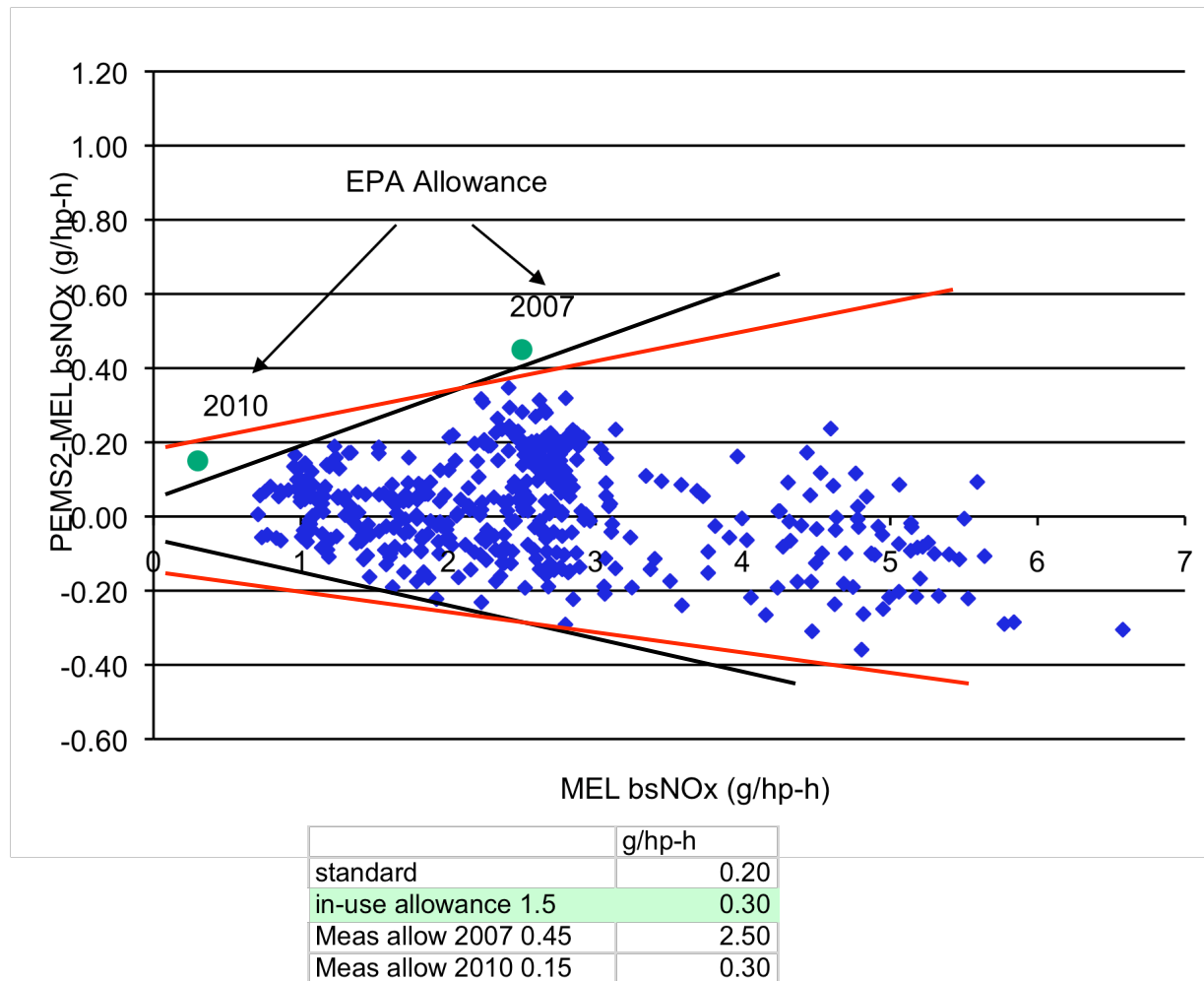
1) bsNO<sub>x</sub> dropped for Unit #3 to < 10% for all points

2) Unit #3 and #4 spread due to ECM mods

3) Unit #4 shows at low level the bsNO<sub>x</sub> deltas exceed 10%



# Combined PEMS Deltas vs NO<sub>x</sub> Uncertainty for 2010



**1) Will PEMS be able to quantify 2010 NO<sub>x</sub> certification standards?**

It depends!  
We need data at low NO<sub>x</sub> condition.

**2) What if one uses MEL Instead of PEMS?**

Yes, it will be better. The trade-off needs to be thought.



## In-Use PM PEMS Test Matrix

Test Count	Test Days	Raw Sampled Instruments		CVS Diluted Instruments		Engine	Nominal PM g/hp-h	Notes	Total Filters
Test 1	4	PEMS1	PEMS3a	PEMS4	PEMS5	2000 Caterpillar C15	0.05	OEM	70
Test 2	6	PEMS2a	PEMS3a	PEMS4	PEMS5	2000 Caterpillar C15	0.05	OEM	96
Test 3	4	PEMS2b	PEMS3b	PEMS4	PEMS5	2007 DPF Cummins ISX 450	<0.01	Regen ECM Mods	28
Test 4	4	PEMS2c	PEMS3c	PEMS4	PEMS5	2007 DPF Volvo D13	<0.01	Regen/ECM Mods Bypass	39

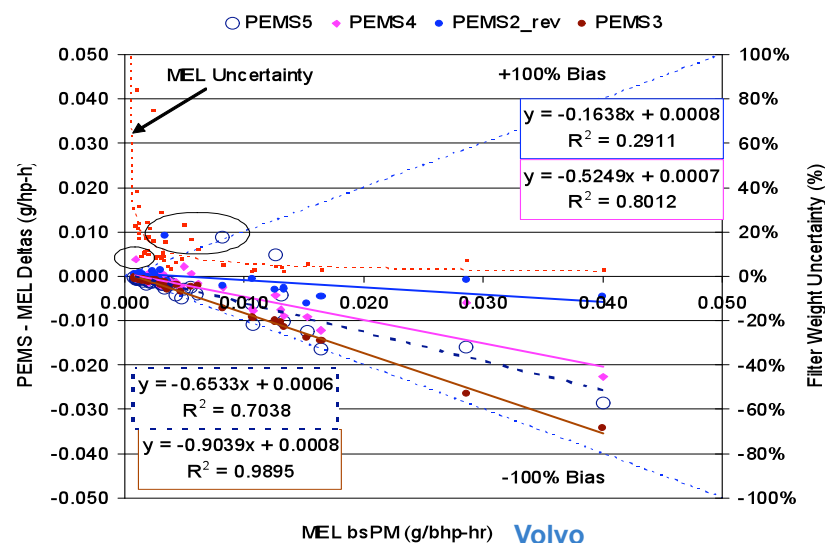
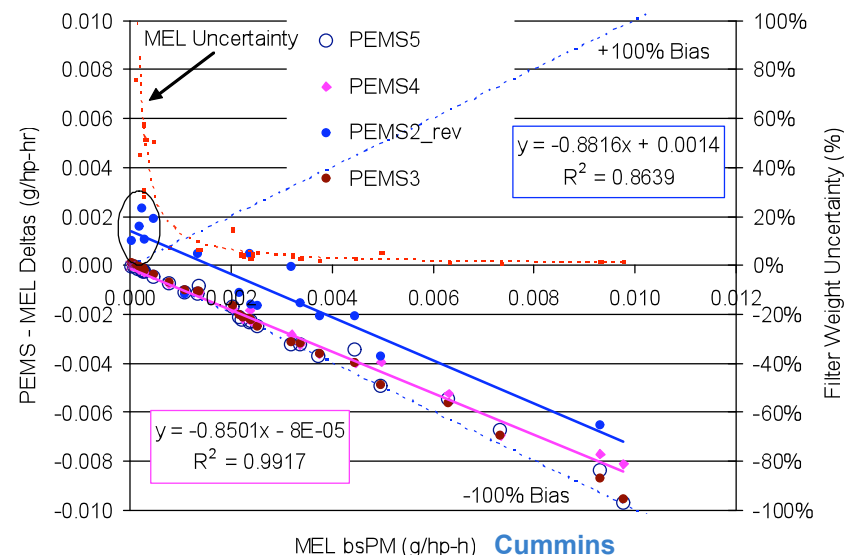
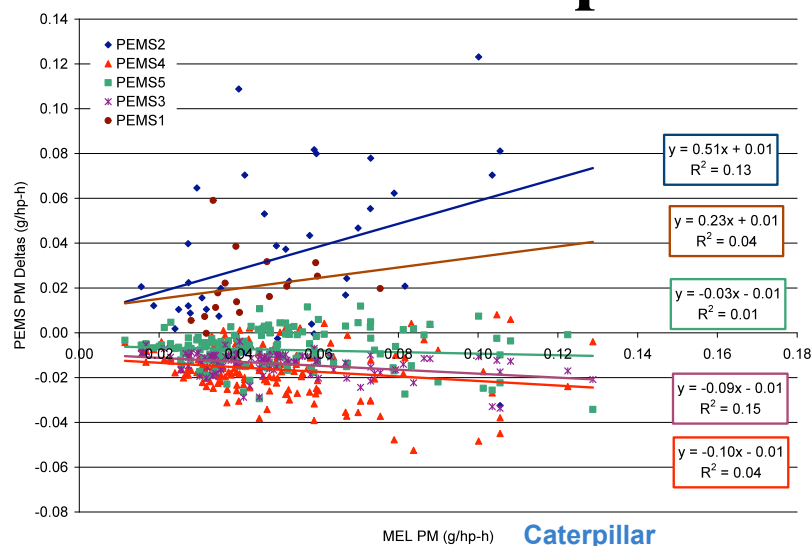
### Acronyms

- OEM                      Original Equipment Manufacture
- DPF                      Wall flow diesel particulate filter
- Regen                    Forced regenerations with OEM tools
- ECM Mods              Recalibrated ECM to change emissions levels
- Bypass                   Added tubing to bypass the OEM after treatment system





# PM PEMS Measurements Vary by Level, Composition, and Particle Size



PEMS	Caterpillar		Volvo		Cummins	
	Slope	R <sup>2</sup>	Slope	R <sup>2</sup>	Slope	R <sup>2</sup>
1	1.23	0.55				
2	1.50	0.50	0.84	0.90	0.12	0.10
3	0.91	0.95	0.10	0.50	0.04	0.40
4	0.90	0.77	0.50	0.80	0.15	0.80
5	0.97	0.88	0.35	0.40	0.07	0.40

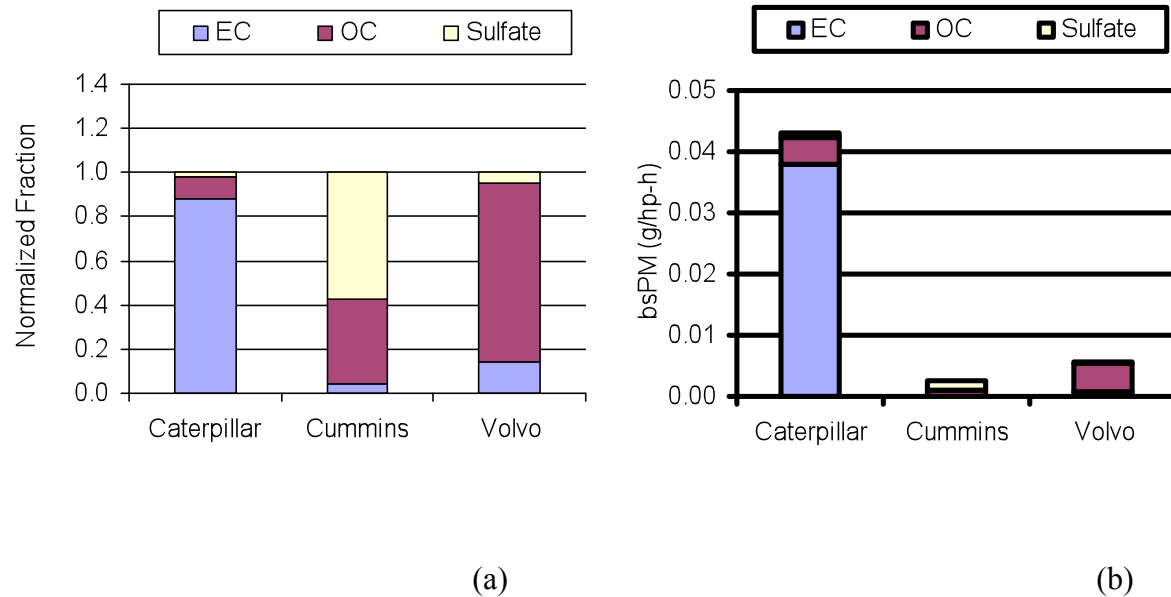
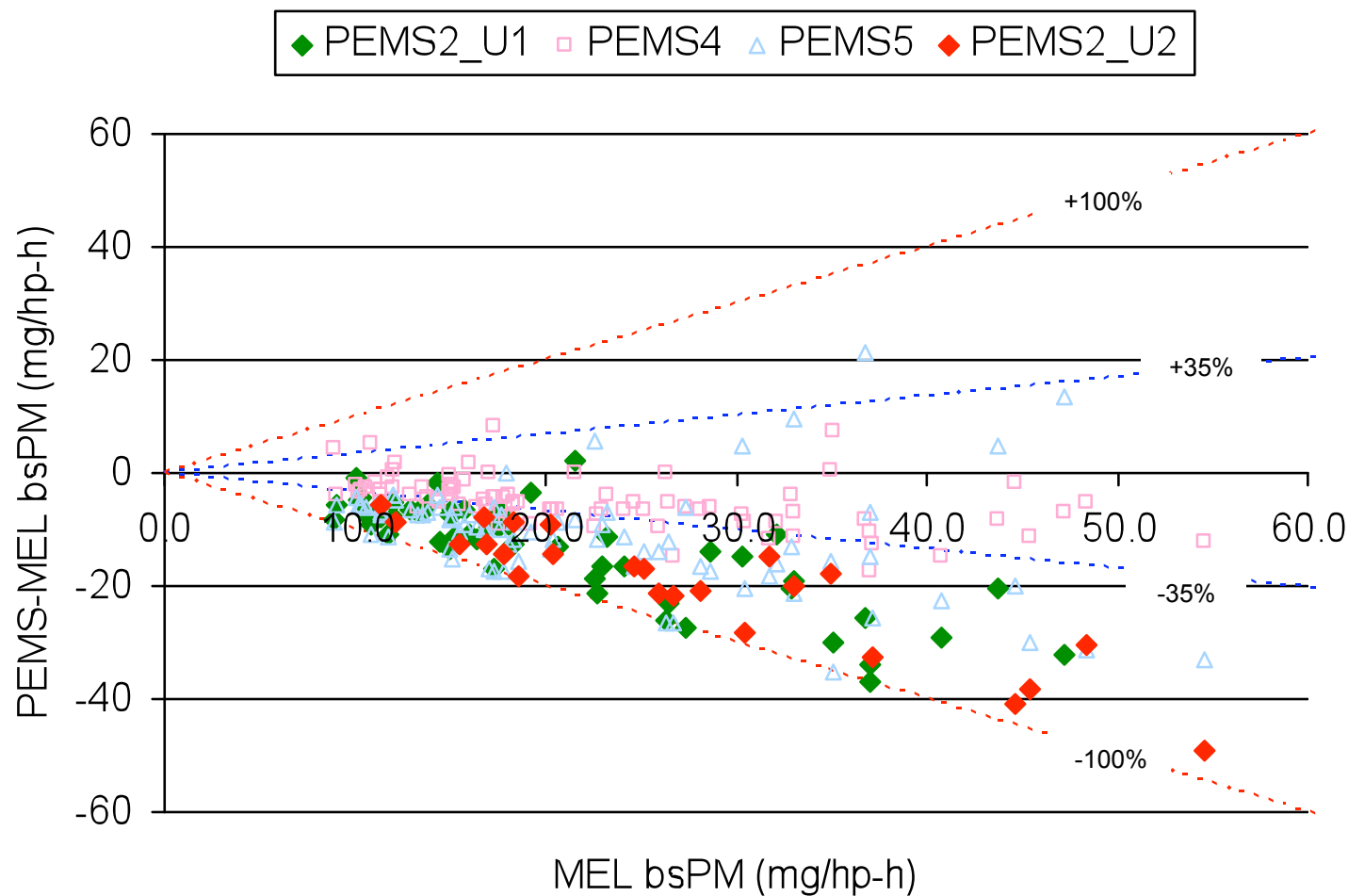


Figure 4-24 Normalized PM fractions (a) and bsPM fractions (b) for all test engines



# Measurement Allowance PM PEMS Significant Negative Bias







## Conclusions

- An in-use verification method was developed for gaseous and PM PEMS
- In-use gaseous PEMS for 2010 on-highway NO<sub>x</sub> certification standards is questionable. We need data at the low NO<sub>x</sub> level to be more conclusive.
- There are significant differences between gravimetric MEL PM mass vs PM PEMS measurement for DPF out PM emission.
- Inferred gravimetric PM PEMS are reliable for in-use engine out emission measurements.



## Acknowledgements

- **Funding Sources**
  - **CARB**
  - **EPA**
  - **EMA**





# Thanks!





## **CE-CERT PEMS reference list**

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