Characterizing Aggregate Baseline NOx Performance of Today's HD SCR Technology

Using Real-World PEMS and OBD Data

CECERT 2018 PEMS Workshop

March 22nd, 2018

50 Years

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Bringing Clean Power to the World

Presentation Outline

- Analysis of aggregate real world data
  - Establish today's "baseline" level of performance
- Initial data interpretation
- Recommendations and next steps

Analysis of Real World Data

- Purpose
  - Characterize NOx from today's HD SCR technology
    - Seeking a real world technology "baseline"
  - Aggregate NOx is what our environment "sees"
    - Sum all NOx mass emitted, e.g., in grams; then normalize to total work or distance
  - The effectiveness of a Low NOx program should be assessed vs. this baseline
    - Note this is not an assessment of today's *mix* of vehicles; this is not a NOx *inventory*

- Two datasets were investigated
  - Used all data, including starts and extended idle
    - Data from a small number of vehicles with missing distance data were excluded
  - Manufacturer-run Heavy-Duty In-Use Tests for NTE compliance
    - "HDIUT", 122 vehicles
  - CARB-sponsored CECERT vehicle activity data collection via OBD*
    - "CECERT", 67 vehicles

*"Collection of Activity Data from On-Road Heavy-Duty Diesel Vehicles, FINAL REPORT" (ARB Agreement No. 13-301), May 2017

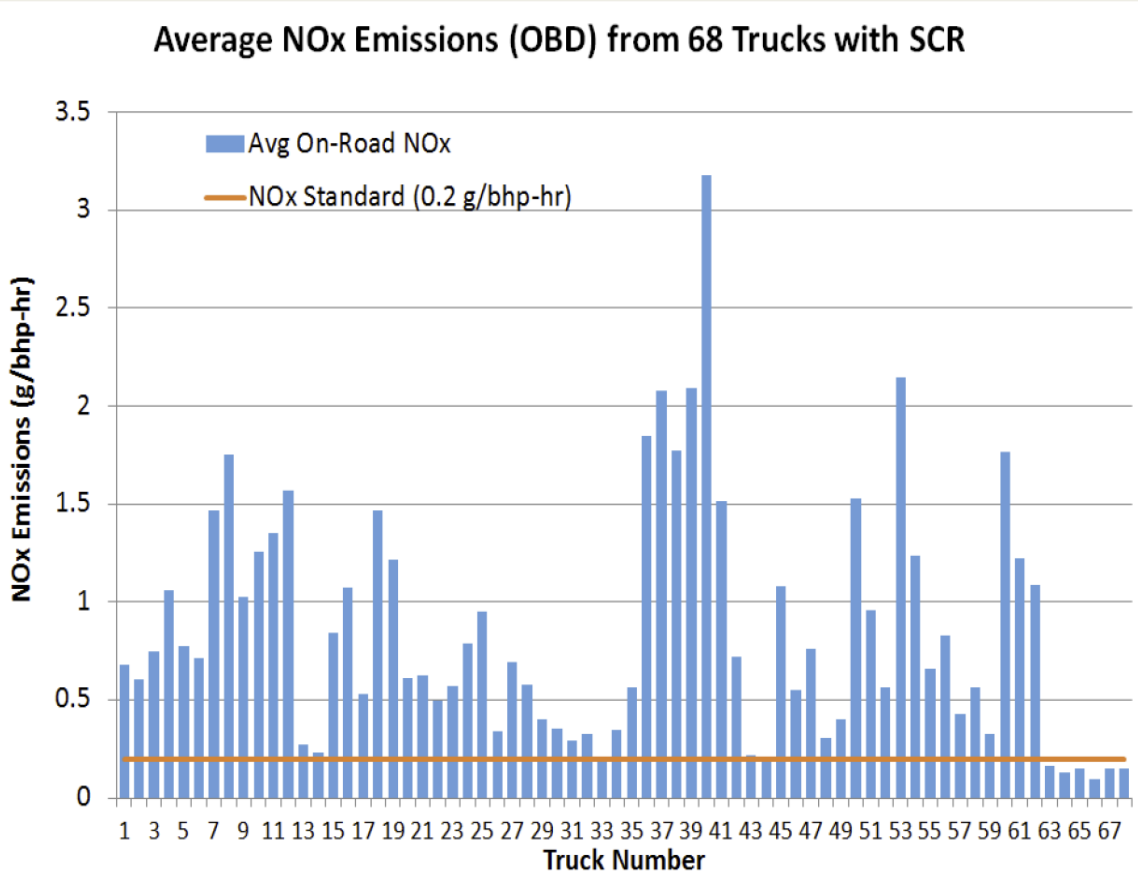
A Number of Metrics Were Investigated

- The real-world fleet is very diverse
  - Investigated the data from more than one perspective
- The metrics
  - Binned vehicles by their dataset average brake-specific NOx
  - Binned vehicles by type and VMT-weighted their NOx
  - Brake-specific, g/hp-hr
  - Distance-specific, g/mi
  - Weighted rates, ~g/mi, ~g/hr
- Combined datasets

A First Look at CECERT's SCR Vehicle Data
CARB OBD Workshop: Nov 2, 2017

Real-World NOx from Trucks A Big Concern

- Project: logged OBD data from 68 trucks
- 1+ month activity each
- 2010 – 2015 MYs
- 4 engine makes, many truck types



- Aggregate Brake-specific NOx, by vehicle
  - OBD NOx sensor
    - Shut-off <~190C Exh T
    - Potential *low* bias
  - OBD Exh. Flow
    - OBD fuel + air
  - OBD torque x speed
- Sample designed to capture light-load, low activity vehicles
  - Potential *high* bias from more frequent low SCR η

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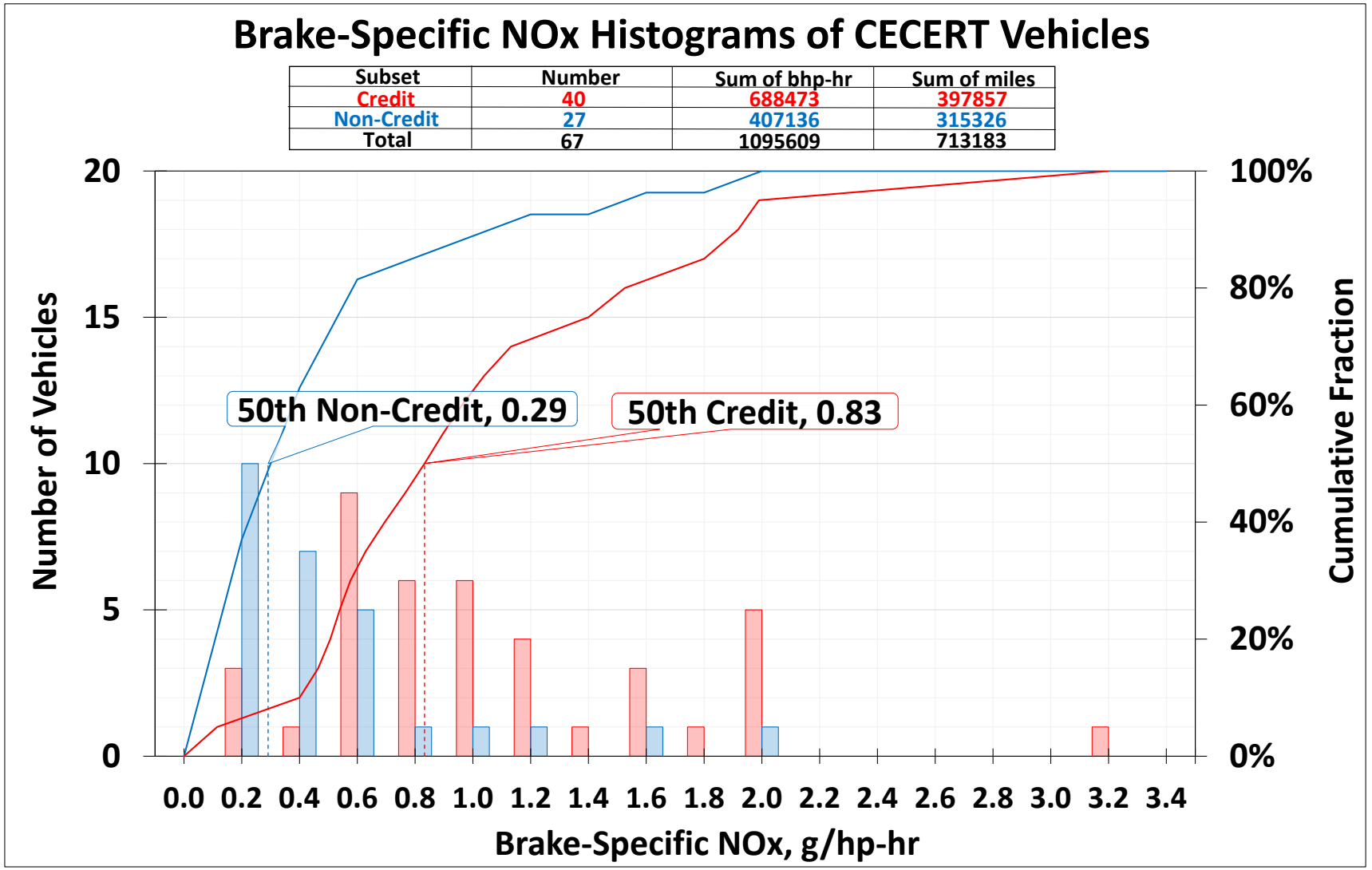
Histogram of Same Exact CECERT Data Points With Distinct Technology Levels Separated



- "**Credit**" means engine family was certified using banked emissions credits
- "**Non-Credit**" means engine family was certified to 0.20 g/hp-hr (0.30 NTE) without using banked credits

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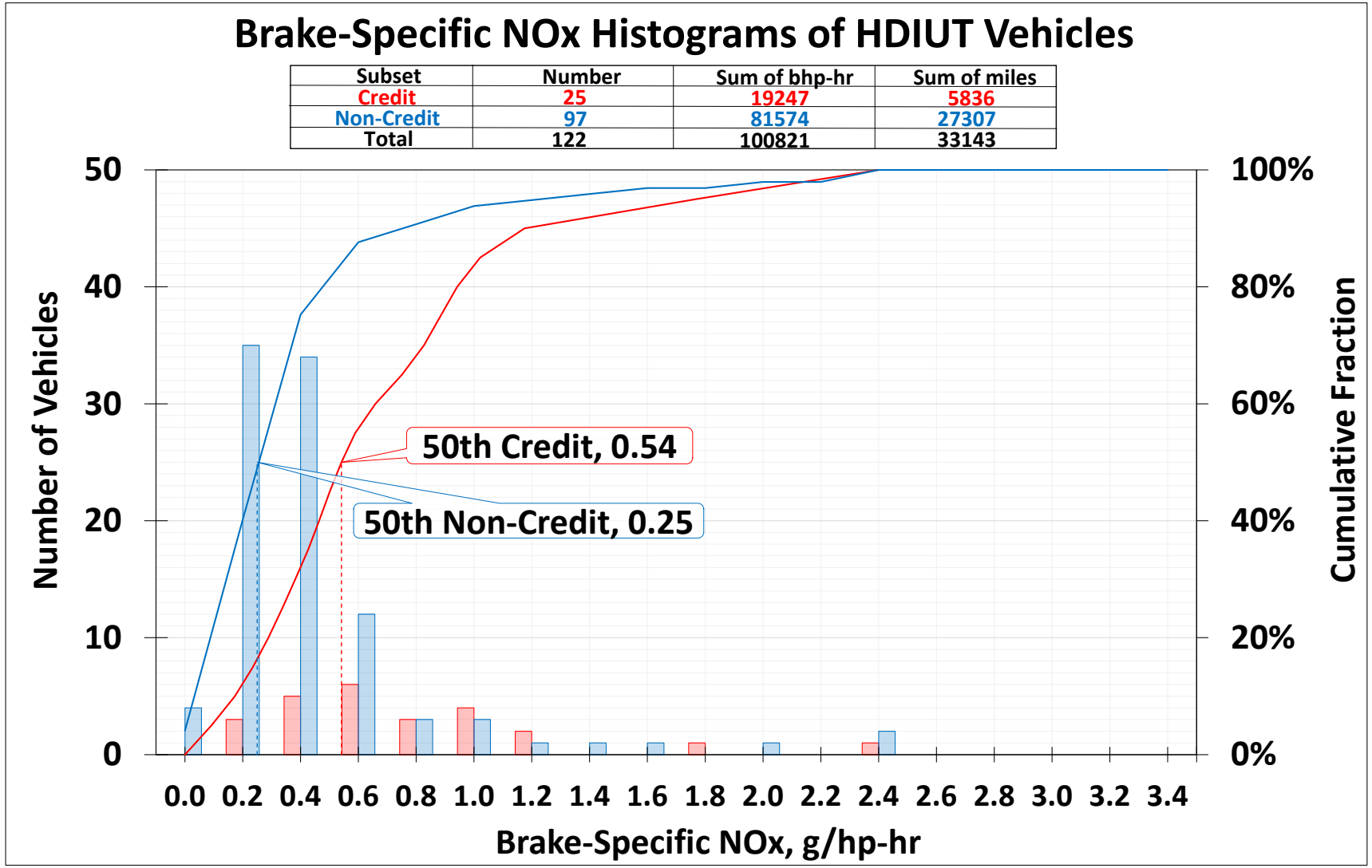
Same Analysis Using HDIUT Data



- PEMS data
  - Includes NOx <190C Exh Temp
- More vehicles
- Less VMT
- Will not include datasets that did not meet EPA HDIUT test requirements

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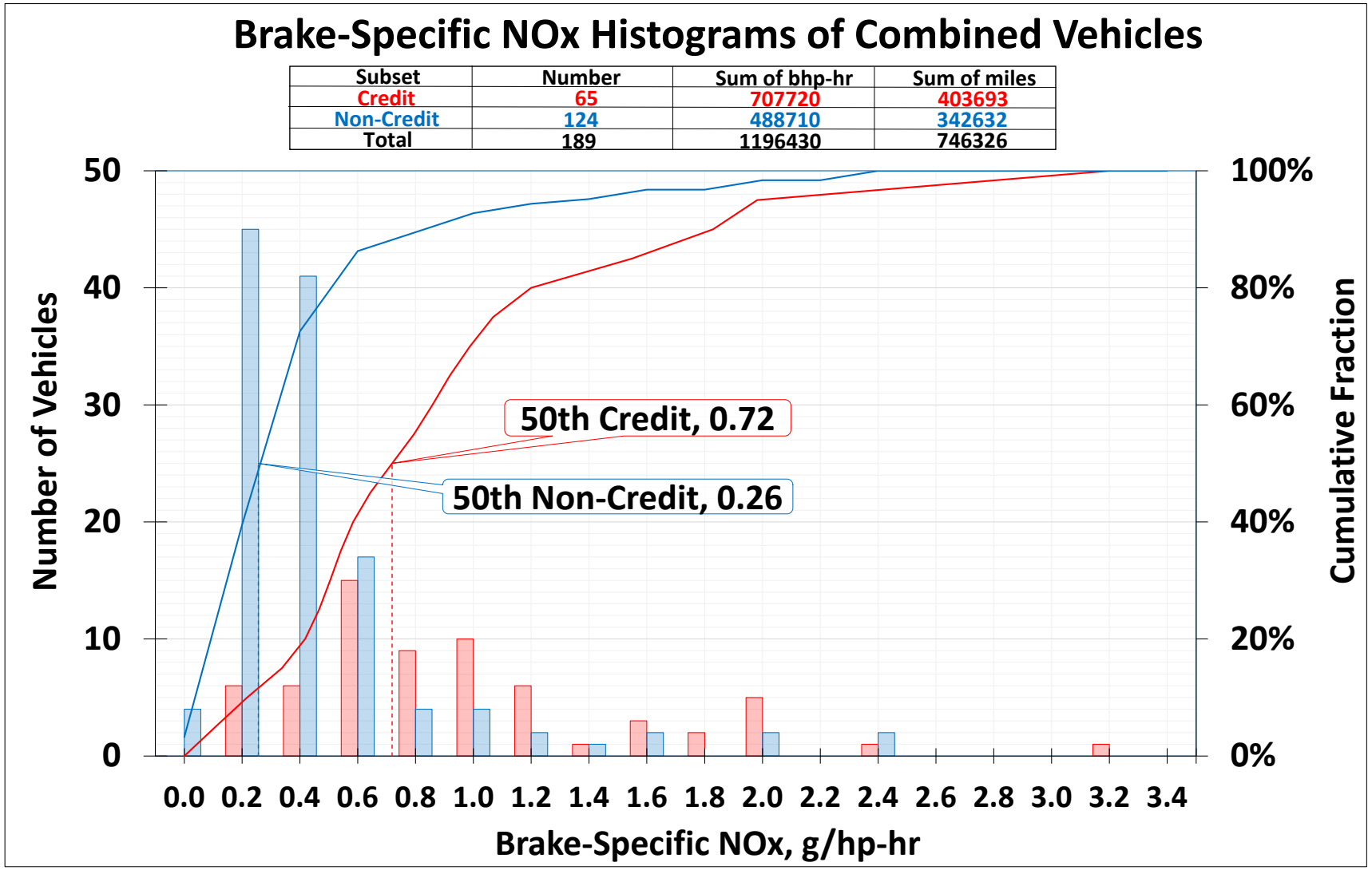
Combined Dataset
Is there currently a larger real-world SCR dataset?



- HDIUT data has dominant influence by vehicle number
  - CECERT data will have dominant influence by summing all NOx
- Engines certified to lower standards tend to have lower in-use emissions
- Distributions are skewed
  - Are these "tails" significant?

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Sum of all NOx Divided by Sum of all Work "Unweighted Σ-over-Σ"

- Aggregate all data
- Sum of all NOx is what *these* vehicles emitted into the environment
- Sum of all work is a measure of *these* vehicles total activity
- CECERT data would have a dominant influence in a combined dataset, due to its 1-month datasets vs. HDIUT's 1-day datasets

Unweighted Σ-over-Σ Brake-specific NOx, g/hp-hr			
	CECERT	HDIUT	Combined
Credit	1.02	0.70	1.01
Non-Credit	0.33	0.37	0.34

VMT-Weighting

Vehicle Group	Relative VMT, %
Long Haul	67%
Pick-up and Delivery	20%
Short Haul	13%
Service-Oriented	1%

- An attempt to correct sample bias of under-sampling high activity vehicles or over-sampling low activity vehicles
- Analytical process
  - Assigned vehicles to one of four major vehicle groups
    - Based on CECERT report that aggregated EMFAC vehicle categories and VMT*
  - Repeated Σ-over-Σ process
    - Weighted sums in numerator and denominator
    - CECERT data still would be dominant in a combined dataset
    - Calculated a VMT-weighted average

*"Collection of Activity Data from On-Road Heavy-Duty Diesel Vehicles, FINAL REPORT" (ARB Agreement No. 13-301), May 2017

VMT-Weighted Results

- CECERT Σ-over-Σ results decreased upon VMT-weighting
  - VMT weighting might be revealing CECERT sample's high bias
    - Correcting over-sampling of light-load, lower SCR η, low activity vehicles
  - VMT weighting might be revealing CECERT data's measurement low bias
    - NOx sensor shutoff <190C causing a low bias: 0.23 versus HDIUT's 0.37 g/hp-hr

Σ-over-Σ VMT-Weighted Brake-specific NOx, g/hp-hr			
	CECERT	HDIUT	Combined
Credit	0.70	0.74	0.70
Non-Credit	0.23	0.37	0.29

Repeated from Slide 9: Σ-over-Σ Unweighted Brake-specific NOx, g/hp-hr			
	CECERT	HDIUT	Combined
Credit	1.02	0.70	1.01
Non-Credit	0.33	0.37	0.34

Distance-Specific NOx Emissions, g/mi

- Similar bias correction trends as brake-specific
- Larger differences between CECERT and HDIUT warrant further investigation

VMT-Weighted Distance-specific NOx, g/mi			
	CECERT	HDIUT	Combined
Credit	1.26	2.42	1.30
Non-Credit	0.33	1.11	0.49

Unweighted Distance-specific NOx, g/mi			
	CECERT	HDIUT	Combined
Credit	1.76	2.30	1.77
Non-Credit	0.42	1.12	0.48

Relative VMT-Weighted NOx Rate

- Relative *VMT*-Weighted NOx Rate in g/*mi** takes into account both the Σ-over-Σ emissions rates and vehicle groups' VMT
- Example: Non-Credit Combined Dataset, VMT-Weighted
  - NOx sensor shutoff low bias could mean Short Haul could be even more significant

Vehicle Group, Number of Vehicles	Relative VMT, %	Average NOx Rate, g/mi	Relative VMT-Weighted NOx Rate*
Long-Haul, n=57	67%	0.41	56%
Pick-up and Delivery, n=36	20%	0.47	20%
Short Haul, n=17	13%	0.92	24%
Service-Oriented, n=14	1%	0.42	0.7%

*Equivalent to Relative *Time*-Weighted NOx Rate in g/*hr*

Initial Data Interpretation

- Sample size might be sufficient for initial data interpretation
  - 189 vehicles, ~3/4 million VMT, sample of vehicles populated all four vehicle groups
  - 1.2 million hp-hr = ~50,000 FTPs; ~2 years of test cell time, running 24 hr/day, 7 day/wk

- VMT-Weighted Σ-over-Σ versus distributions' 50th percentiles

Non-Credit, g/hp-hr			
Dataset	50th Percentile of #	Σ-over-Σ, Un-Wtd	Σ-over-Σ, VMT-Wtd
HDIUT	0.25	0.37	0.37
CECERT	0.29	0.33	0.23

- Non-Credit engines represent today's baseline—that is what is being produced today
  - In MY2017 and MY2018, 93% of all engine families certified at 0.20 g/hp-hr, 2 families at 0.30
  - Important to separate Non-Credit from Credit
  - Initial estimate of aggregate baseline NOx of today's HD SCR technology: 0.37 g/hp-hr

*Based on ~30 engine families certified per year by EPA as of March 12, 2018:
https://www.epa.gov/compliance-and-fuel-economy-data/annual-certification-data-vehicles-engines-and-equipment

Recommendations and Next Steps

- Fill data gaps
  - Use Micro-PEMS: NOx sensors that are on during all operation
  - Sample fleet according to VMT
  - EMA is funding this work now; scheduled for completion Summer 2018
- Examine second-by-second data more closely, but carefully
  - Identify where real-world *aggregate* emissions can be impacted
  - Avoid becoming distracted by high brake- or distance-specific emissions that do not impact the aggregate; beware of asymptotes
- Critically evaluate EMFAC and MOVES versus real-world datasets
  - Decision-making should be informed by models that reflect real-world aggregate emissions

EMA Micro-PEMS Sampling Plan

Table 1.10: Final proposed vehicle test matrix as a function of primary EMFAC vehicle class, vocation, activity and engine model year.

Type	EMFAC Class	Vocation	Activity	<=2016	>2016	Total
1a	T7 NNOOS, NOOS, CAIRP		Long haul	15	10	25
1b	T7 tractor		Long haul	5	3	8
2a	T7 POLA	Southern Ports	Short haul	5	4	9
2b		Northern Ports	Short haul	5	2	7
3a	T7 single construction	Construction	Short haul	2	2	4
3b		Cement mixer	Short haul	2	1	3
4	T7 tractor construction		Short haul	2	1	3
5	T6 instate construction small		Pick-up	3	2	5
6a	T6 instate small	Food/Beverage Distribution	Pick-up	5	5	10
6b	T6 instate heavy	Moving	Pick-up	5	3	8
7a	T7 Single	Goods distribution	Short haul	2	2	4
7b		Moving	Short haul	2	2	4
8a	T7 Public	Towing	Service	2	2	4
8b		Freeway work	Service	2	1	3
8c		Municipal work	Service	2	1	3
Total				**59**	**41**	**100**

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Thank You.

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Figure 2-2 From CECERT Report*

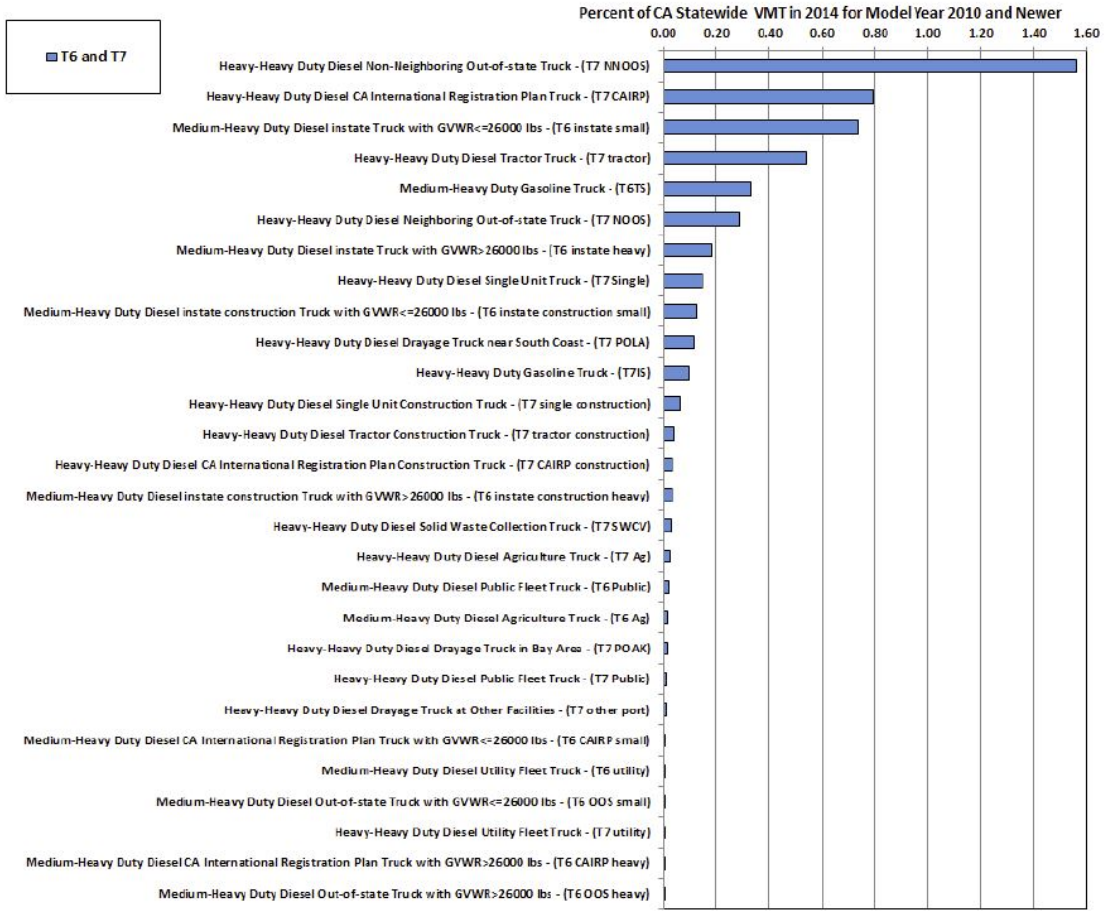

Figure 2-2. Percent of statewide vehicle miles traveled per day in 2014 for model years 2010+

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Figure 2-4 From CECERT Report*

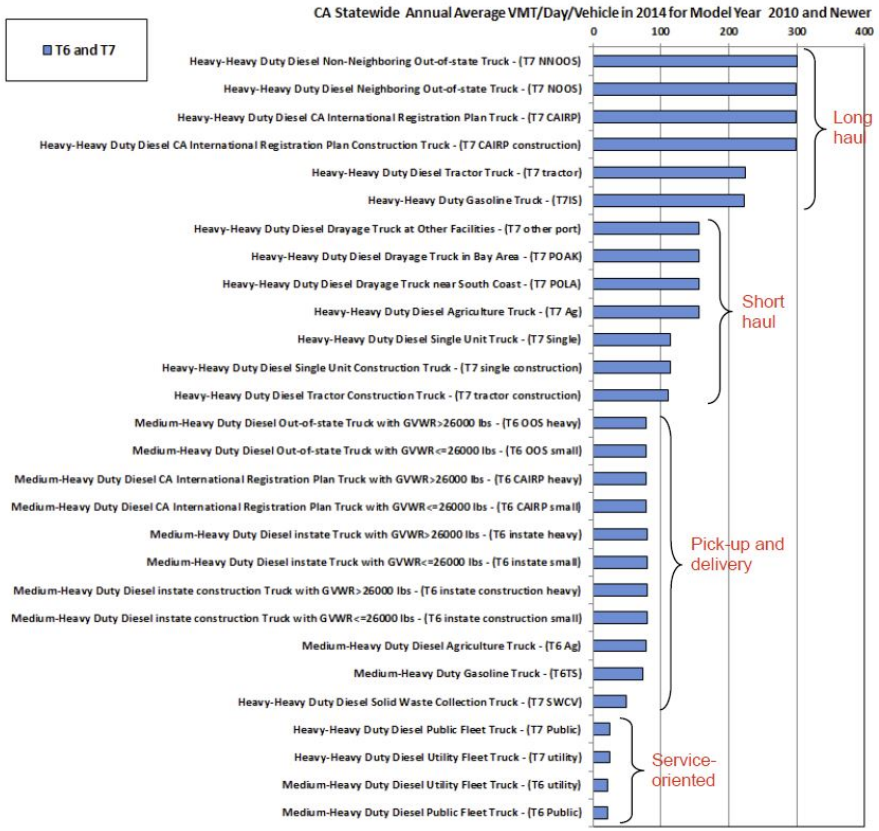

Figure 2-4. Annual average vehicle miles traveled per day per vehicle in 2014 for model years 2010+

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