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Comparison of NOX Emissions from In-Use 2010 Technology Heavy-Duty Engines to Their Certification Standards

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California Air Resources Board

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Heavy-Duty Engine Certification Standards and In-Use Vehicle Emissions

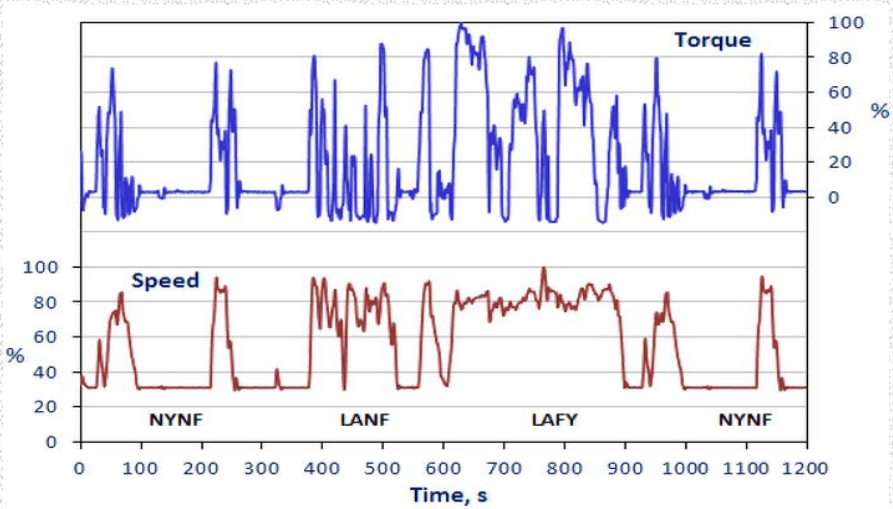
- Certification standards and in-use vehicle emissions are used for developing air quality plans, emission reduction programs, and emission models in California
- Heavy-duty engines need to be certified to emission standards using the engine-dynamometer testing procedures
  - Measure emissions from an engine, not integrated with vehicle chassis

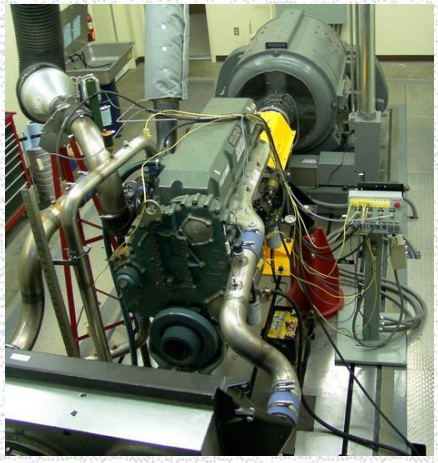
Heavy-Duty Engine Certification Standards and In-Use Vehicle Emissions (Cont.)

- In-use vehicle emissions are measured through chassis-dynamometer testing
  - Measure emissions from a vehicle fully integrated with an engine
- If the test cycles used for the engine-dynamometer are comparable to the cycles for the chassis-dynamometer, so should be the emissions
  - Reductions of in-use NOX from 2010 diesel trucks should achieve the same reductions expected based on certification standards

Heavy-Duty Engine Certification Procedure, Cycle, and Emissions

- Measure brake-specific emissions (g/bhp-hr) on an engine-dynamometer with FTP cycle





CE-CERT Heavy-Duty Engine-Dynamometer set-up

- Emissions include cold and hot start emissions

$$^{g}/_{bhp-hr} = {}^{1}/_{7}\, Cold\ Start + {}^{6}/_{7}\, Hot\ Start$$

California Environmental Protection Agency
AIR RESOURCES BOARD

CUMMINS INC.

EXECUTIVE ORDER A-021-0521-2
New On-Road Heavy-Duty Engines
Page 1 of 2 Pages

Pursuant to the authority vested in the Air Resources Board by Health and Safety Code Division 26, Part 5, Chapter 2; and pursuant to the authority vested in the undersigned by Health and Safety Code Sections 39515 and 39516 and Executive Order G-02-003;

IT IS ORDERED AND RESOLVED: The engine and emission control systems produced by the manufacturer are certified as described below for use in on-road motor vehicles with a manufacturer's GVWR over 14,000 pounds. Production engines shall be in all material respects the same as those for which certification is granted.

MODEL YEAR	ENGINE FAMILY	ENGINE SIZES (L)	FUEL TYPE [1]	STANDARDS & TEST PROCEDURE	INTENDED SERVICE CLASS [2]	ECS & SPECIAL FEATURES [3]	DIAGNOSTIC [6]
2010	ACEXH0912XAP	14.9	Diesel	Diesel	HHDD	DDI, TC, CAC, ECM, EGR, OC, SCR-U, PTOX	OBD (P)

PRIMARY ENGINE'S IDLE EMISSIONS CONTROL [5]	ADDITIONAL IDLE EMISSIONS CONTROL [5]
30g	N/A

ENGINE (L)	ENGINE MODELS / CODES (rated power, in hp)
14.9	See attachment for engine models and ratings

* =not applicable; **GVWR**=gross vehicle weight rating; **13 CCR xyz**=Title 13, California Code of Regulations, Section xyz; **40 CFR 86.abc**=Title 40, Code of Federal Regulations, Section 86.abc; L=liter; **hp**=horsepower; **kw**=kilowatt; **hr**=hour;

1 **CNG/LNG**=compressed/liquefied natural gas; **LPG**=liquefied petroleum gas; **E85**=85% ethanol fuel; **MF**=multi fuel a.k.a. **BF**=bi fuel; **DF**=dual fuel; **FF**=flexible fuel;

2 **L/M/H HDD**=light/medium/heavy heavy-duty diesel; **UB**=urban bus; **HDO**=heavy duty Otto;

3 **ECS**=emission control system; **TWC/OC**=three-way/oxidizing catalyst; **NAC**=NOx adsorption catalyst; **SCR-U / SCR-N**=selective catalytic reduction – ures / – ammonia; **WU (prefix)** =warm-up catalyst; **DPF**=diesel particulate filter; **PTOX**=periodic trap oxidizer; **HO2S/O2S**=heated/oxygen sensor; **HAFS/AFS**=heated/air-fuel-ratio sensor (a.k.a., universal or linear oxygen sensor); **TBI**=throttle body fuel injection; **SFI/MFI**=sequential/multi port fuel injection; **DGI**=direct gasoline injection; **GCARB**=gaseous carburetor; **IDI/DDI**=indirect/direct diesel injection; **TC/SC**=turbo/super charger; **CAC**=charge air cooler; **EGR / EGR-C**=exhaust gas recirculation / cooled EGR; **PAIR/AIR**=pulsed/secondary air injection; **SPL**=smoke puff limiter; **ECM/PCM**=engine/powertrain control module; **EM**=engine modification; **2 (prefix)**=parallel; **(2) (suffix)**=in series;

5 **ESS**=engine shutdown system (per 13 CCR 1956.8(a)(6)(A)(1); **30g**=30 g/hr NOx (per 13 CCR 1956.8(a)(6)(C); **APS** =internal combustion auxiliary power system; **ALT**=alternative method (per 13 CCR 1956.8(a)(6)(D); **Exempt**=exempted per 13 CCR 1956.8(a)(6)(B) or for CNG/LNG fuel systems; **N/A**=not applicable (e.g., Otto engines and vehicles);

6 **EMD**=engine manufacturer diagnostic system (13 CCR 1971); **OBD**=on-board diagnostic system (13 CCR 1971.1);

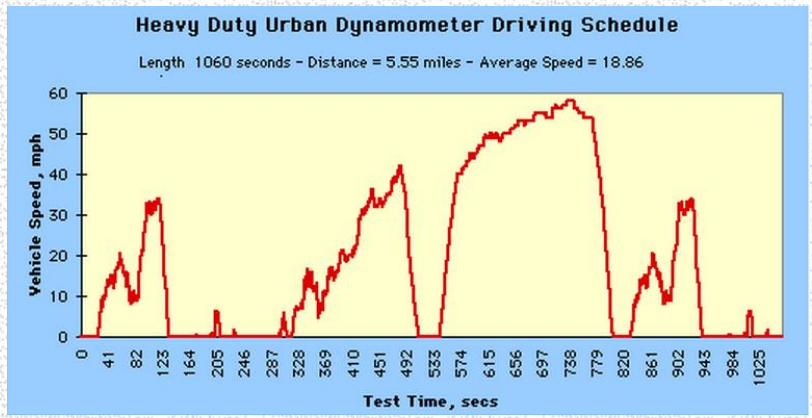
Following are: 1) the FTP exhaust emission standards, or family emission limit(s) as applicable, under 13 CCR 1956.8; 2) the EURO and NTE limits under the applicable California exhaust emission standards and test procedures for heavy-duty diesel engines and vehicles (Test Procedures); and 3) the corresponding certification levels, for this engine family. "Diesel" CO, EURO and NTE certification compliance may have been demonstrated by the manufacturer as provided under the applicable Test Procedures in lieu of testing. (For flexible- and dual-fueled engines, the CERT values in brackets [ ] are those when tested on conventional test fuel. For multi-fueled engines, the STD and CERT values for default operation permitted in 13 CCR 1956.8 are in parentheses.).

in g/bhp-hr	NMHC		NOx		NMHC+NOx		CO		PM		HCHO	
	FTP	EURO	FTP	EURO	FTP	EURO	FTP	EURO	FTP	EURO	FTP	EURO
STD	0.14	0.14	*	*	*	*	15.5	15.5	0.01	0.01	*	*
FEL	*	*	0.35	0.35	*	*	*	*	*	*	*	*
CERT	0.001	0.000	0.25	0.19	*	*	1.4	0.0	0.002	0.000	*	*
NTE	0.21		0.52		*		19.4		0.02		*	

g/bhp-hr=grams per brake horsepower-hour; FTP=Federal Test Procedure; **EURO**=Euro III European Steady-State Cycle, including **RMCSET**=ram mode cycle supplemental emissions

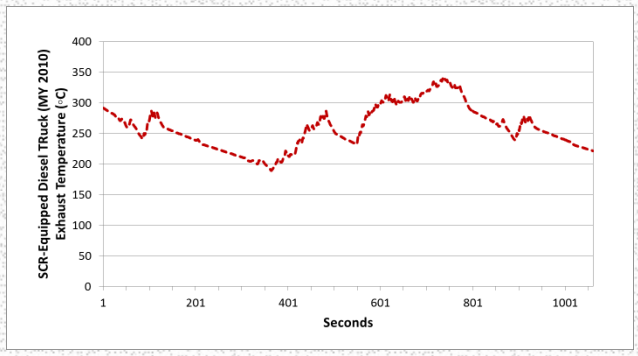
In-Use Heavy-Duty Vehicle Tests, Cycles, and Emissions

- Measure distance-specific emissions (g/mi) on a chassis-dynamometer with UDDS cycle



- Measured emissions do not include cold start emissions, hot running emissions only

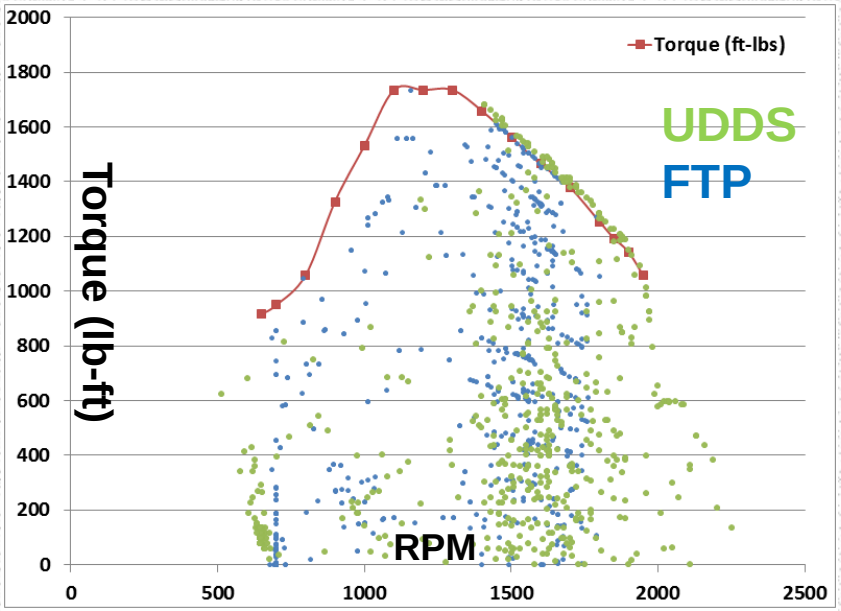
ARB Heavy-Duty Chassis-Dynamometer set-up



ARB, 2010 SCR-equipped HDDV (2012)

FTP and UDDS Cycles

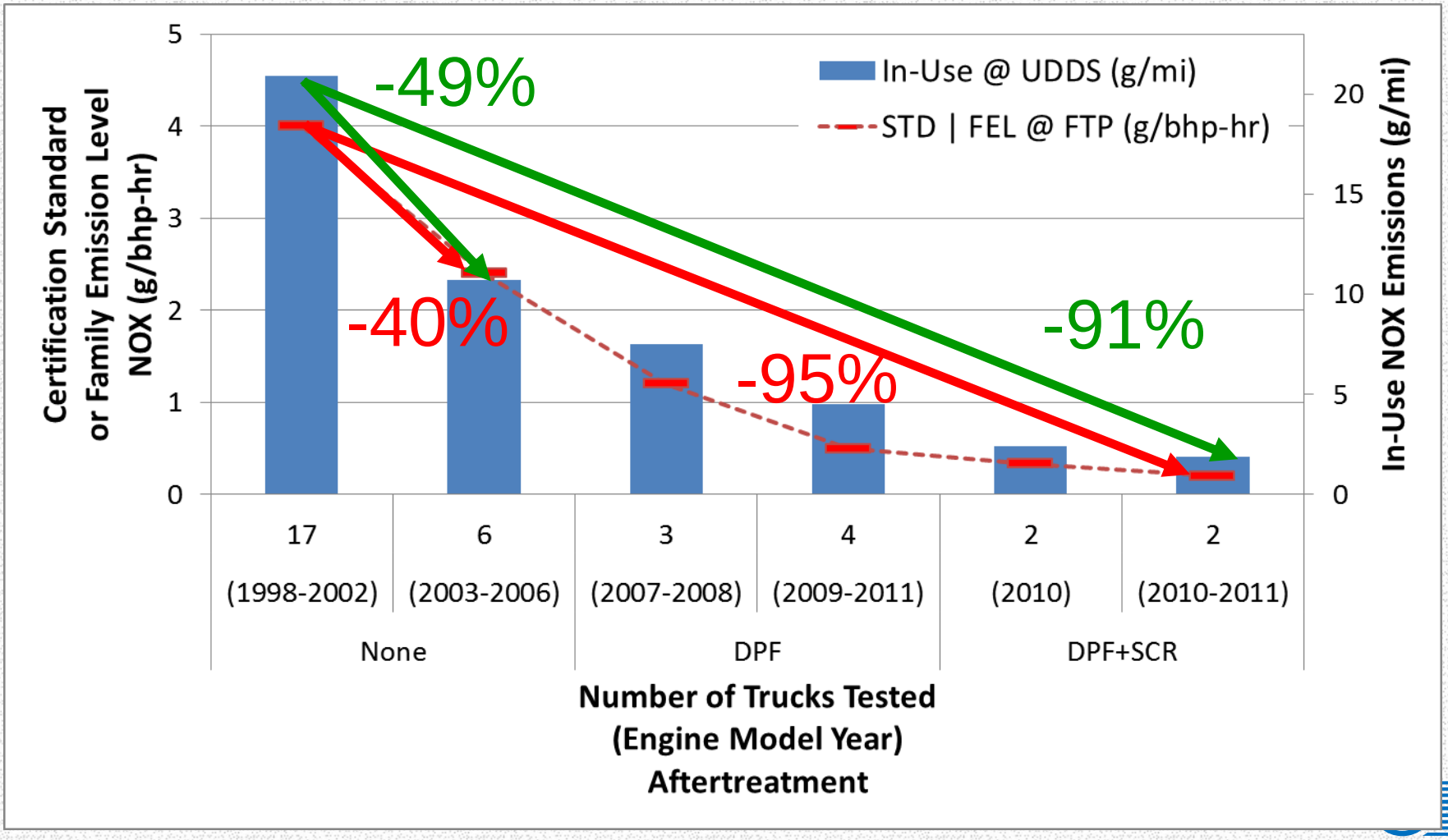
- Based on in-use truck and bus operations collected at LA and NYC in 1974 (CAPE-21 database)
- Measured torque at RPM over FTP and UDDS cycles with engine- and chassis-dynamometers, respectively (*WVU provided*)
  - 2008 Cummins engine
  - 14.9L engine size
  - LNG/ULSD duel fuel



In-Use and Certification Emissions Data

- In-use data:
  - MY 1998-2002: CRC E55/59 Project
  - MY 2003-2006: CRC E55/59 Project & ARB Studies
  - My 2007-2011: AQMD & ARB Studies
  - Chassis-Dynamometer Test cycle: UDDS
  - Test weights: 56,000 or 69,000 lbs
- Certification data:
  - ARB executive orders for Volvo, Cummins, Caterpillar, and Navistar engines
  - Engine-Dynamometer Test Cycle: FTP

Reductions of In-Use and Certification NOX Emissions



Conversion Factors for Distance-Specific NOX to Brake-Specific NOX

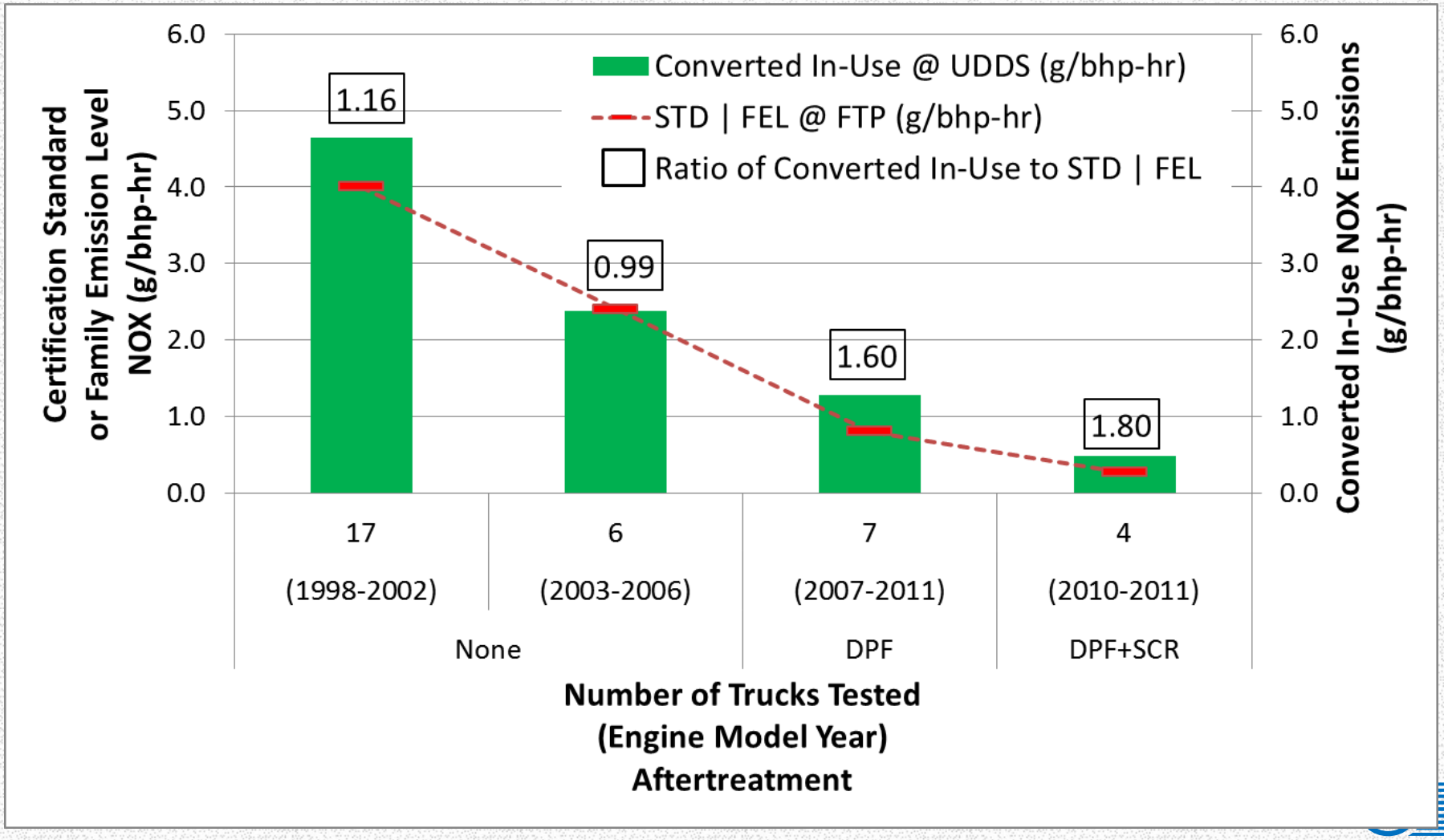
- Chassis-dynamometer emissions to ECU engine power over the UDDS cycle

$$CF\left(\frac{bhp-hr}{mi}\right) = \frac{NOX\ (\frac{g}{mi})}{NOX\ (\frac{g}{bhp-hr})}$$

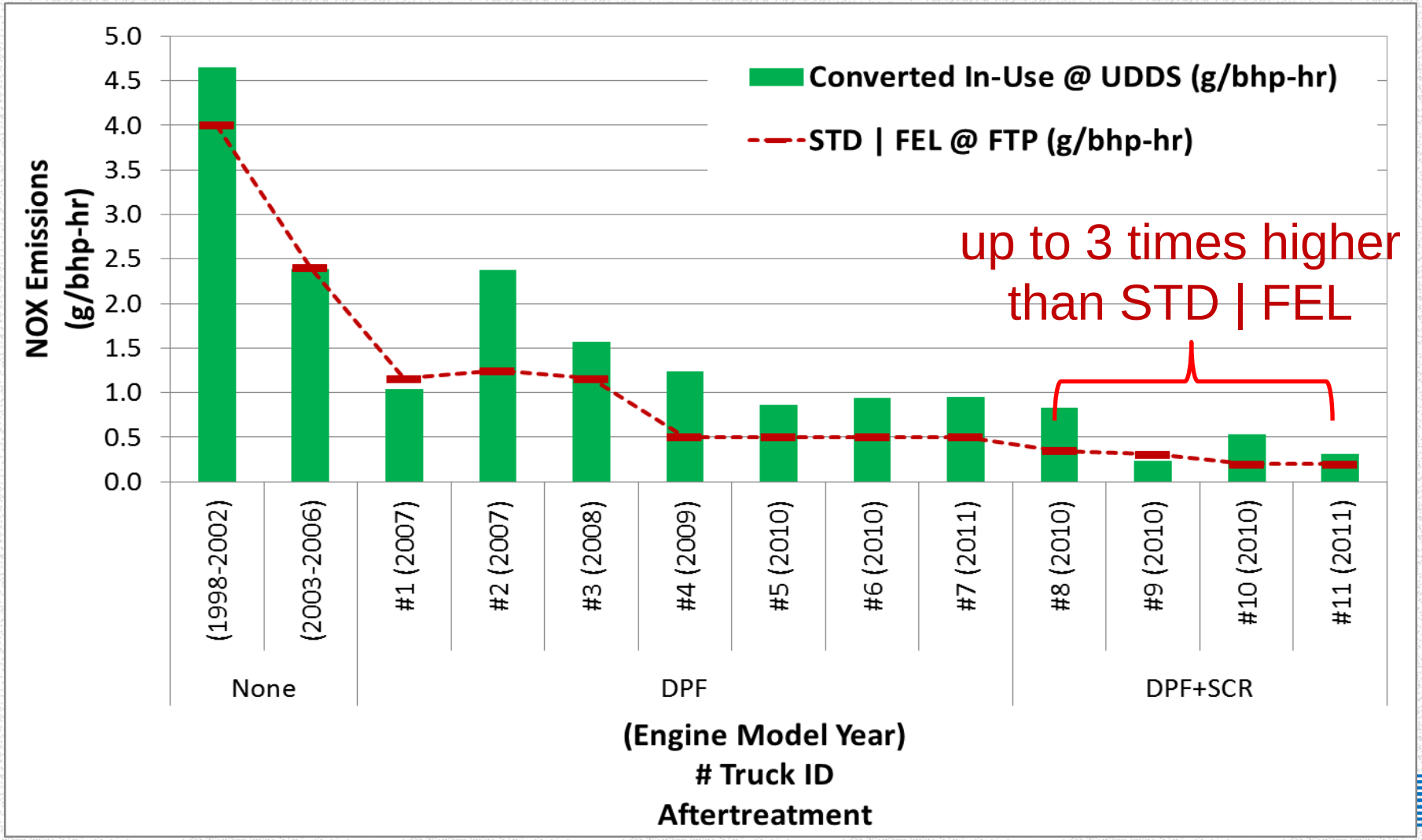
  - 4.5 (1/7cold start +6/7hot start) for Class 8 trucks: AQMD Study (2013)
  - 4.0 (hot running) for Class 8 trucks: ARB Test (2012)

- Conversion factor of ***4.5*** is used for this analysis

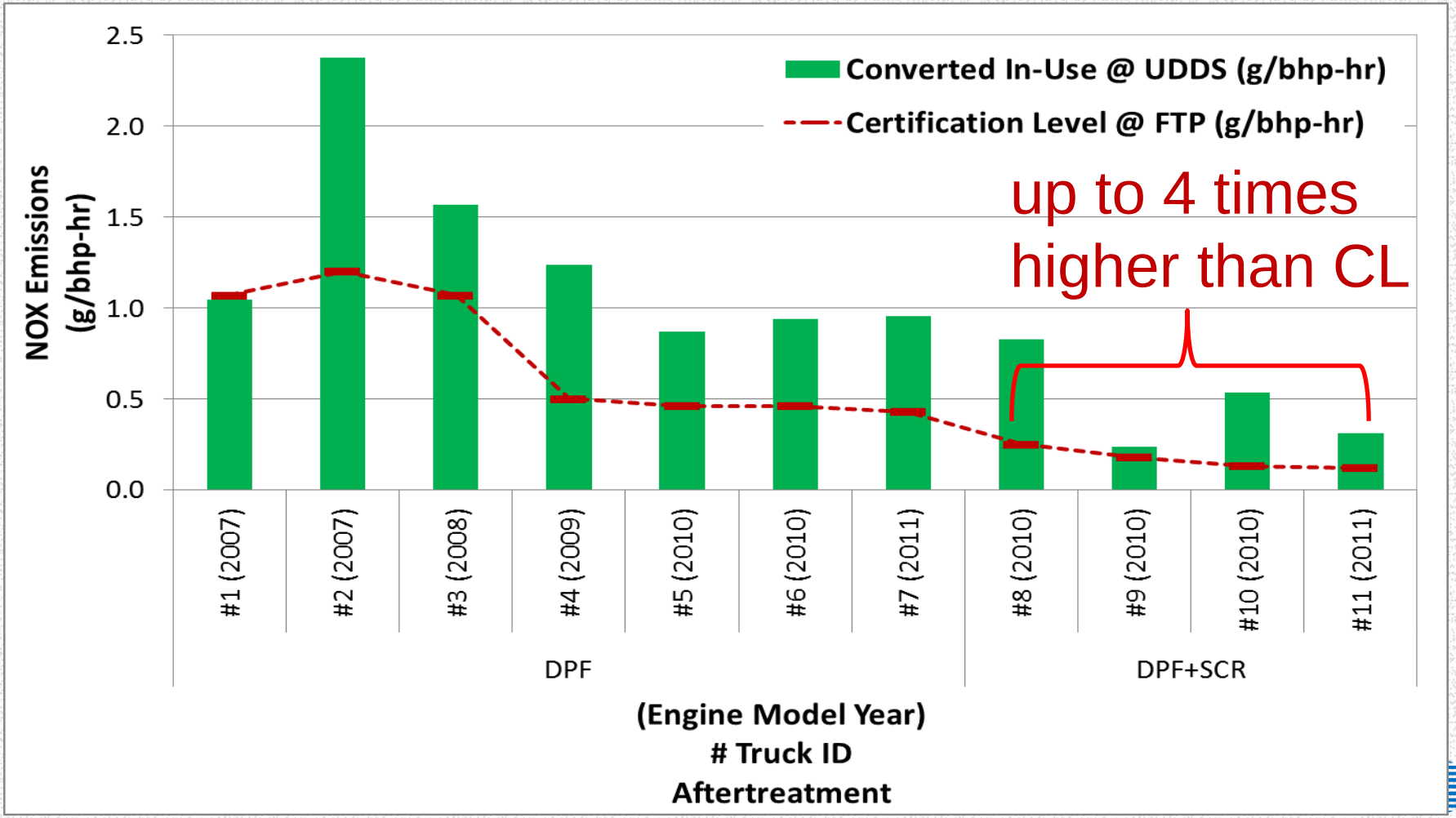
Comparison of In-Use to STD | FEL NOX by Engine + Aftertreatment Technology



Comparison of In-Use to STD | FEL NOX by Truck



Comparison of In-Use to Certification Level NOX (Actual Engine Emissions)



Findings and Implications

- Reductions of in-use NOX from 2010 diesel trucks were less than the reductions expected based on certification standard NOX
- In-use NOX emissions from 2010 diesel trucks were higher than the certification standard and the certification level NOX
  - Up to 3 times higher than the STD | FEL
  - Up to 4 times higher than the Certification Level
- Air quality attainment goals may be delayed due to less NOX reduction than expected

Next Step

- A research plan is in development to better understand the intrinsic differences between in-use NOX emissions from 2010 or newer HDDVs and the emissions obtained from the same engines during certification
  - Characterize the same engines over the FTP and UDDS cycles
  - Evaluate the differences between engine- and chassis-dynamometer testing procedures
  - Evaluate the effectiveness of current HDDE certification procedure for controlling in-use NOx emissions from HDDVs