CALIFORNIA
AIR RESOURCES BOARD

Heavy-Duty Low NOx Program

Low Load Cycle

Public Workshop
Diamond Bar, CA
September 26, 2019

MSCD/ECCD

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Outline

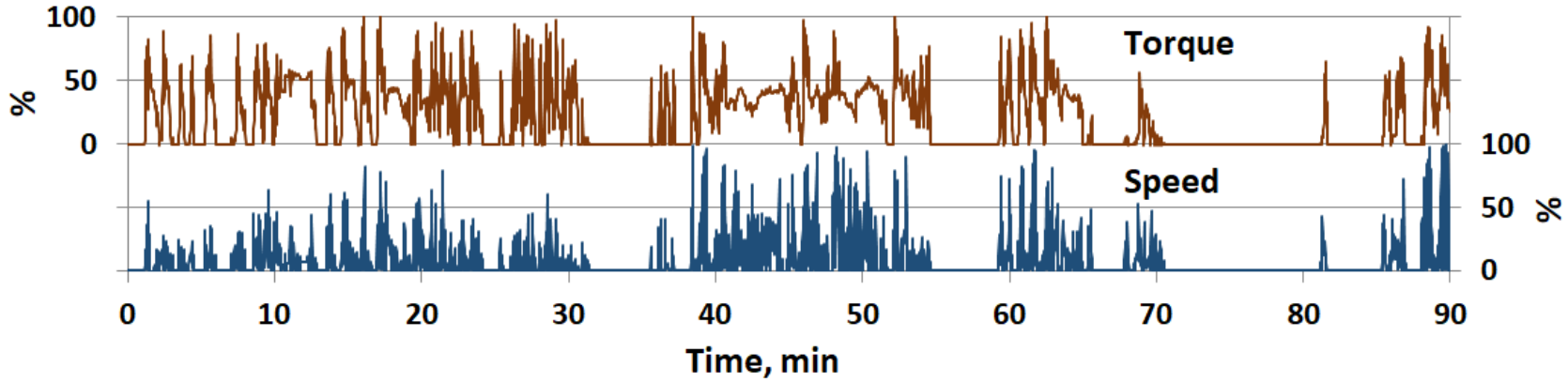
- Background
- Developments Since Previous Workshop
- Testing/Modeling Results
- Conclusions

Background

- LLC proposed as a supplemental certification cycle to address deficiency of certification cycles in validating emission control at low loads
- LLC developed from real-world activity data to represent urban tractor and vocational vehicle operations characterized by low loads
- Three candidate cycles (#7, #8, #10) were previously presented, ranging in duration from 70 to 90 min

Developments Since Previous Workshop

- LLC candidate #7 downselected as the final cycle
  - Duration: ~90 minutes
  - Includes highest percentage of non-idle operation among 3 candidates



- Option to add auxiliary load (3.5, 2.5 and 1.5 kW for HHD, MHD and LHD) to idle points
  - More realistic, and allows for more effective function of technologies such as cylinder deactivation (CDA) during idle

Performance of Current (2017/2018) Production Engines Over LLC

	Engine A	Engine B
Engine-out NOx [g/bhp-hr]	4.2	3.2
Tailpipe NOx [g/bhp-hr]	1.5	0.8
NOx Conversion	64%	74%
CO2 [g/bhp-hr]	613	710

- Drastic differences in NOx and CO_2 emission rates

Performance of Upgraded Volvo MD13TC Engine Over LLC

	Baseline	Improved Calibrations and Advanced AT		
		No Miniburner *	Miniburner, no relight **	Miniburner, with relight **
Engine-out NOx [g/bhp-hr]	3.4	3.1	2.8	3.0
Tailpipe NOx [g/bhp-hr]	0.34	0.27	0.12	0.075
NOx Conversion	90%	91%	96%	98%
CO2 [g/bhp-hr]	607	598	603	607

- Significant improvement using advanced AT system and improved engine calibrations, even without leveraging mini-burner
- Optimized thermal management achieved 0.075 g/bhp-hr NOx while remaining CO2 neutral

* FTP/RMC calibration only

** Improved engine calibration for lower NOx at lower AT temperatures (did not impact FTP/RMC NOx levels) + low NOx idle mode

Performance of Upgraded Cummins X15 Engine Over LLC

	Baseline	Config 2B	Config 1A
Engine-out NOx [g/bhp-hr]	4.0	3.4	2.9
Tailpipe NOx [g/bhp-hr]	1.4	0.053	0.036
NOx Conversion	65%	98.5%	98.7%
CO2 [g/bhp-hr]	624	609	633

- Possible to achieve significant NOx reductions with lower CO2 emissions using CDA, improved engine calibrations and advanced AT

Emissions Modeling Over LLC

- Modeling performed by MECA
  - System configuration based on 2019 engines in production today
  - Full useful life aged catalysts
  - Industry-average SCR system volume
  - Single urea doser with maximum ammonia-to-NOx ratio of 1.3
- Low temperature ammonia delivery using heated dosing can achieve emissions below 0.2 g/bhp-hr

Model Run on LLC	DPF PGM Loading	SCR Prestorage with Ammonia	Urea Dosing Temperature (°C)	Tailpipe NOx (g/bhp-hr)
Baseline	X	20%	170	0.40
Scenario 1	2X	20%	170	0.38
Scenario 2	2X	50%	170	0.23
Scenario 3	2X	50%	150	0.18

SCR: selective-reduction catalyst; DPF: diesel particulate filter, PGM: platinum-group metals
Source: http://www.meca.org/resources/MECA_MY_2024_HD_Low_NOx_Report_061019.pdf

Conclusions

- Significant NOx emissions reductions can be achieved using advanced engine hardware, improved engine calibrations and advanced aftertreatment system
- Modeling results support a 0.2 g/bhp-hr standard over the LLC for 2024 MY vehicles with improved engine calibrations and market ready technology options

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