Low Load Certification Cycle

Public Workshop to Discuss Potential Changes to the Heavy-Duty Engine and Vehicle Emission Standards, Test Procedures, Warranty, and Other Related Heavy-Duty Programs

November 3, 2016

Diamond Bar, California

California Environmental Protection Agency

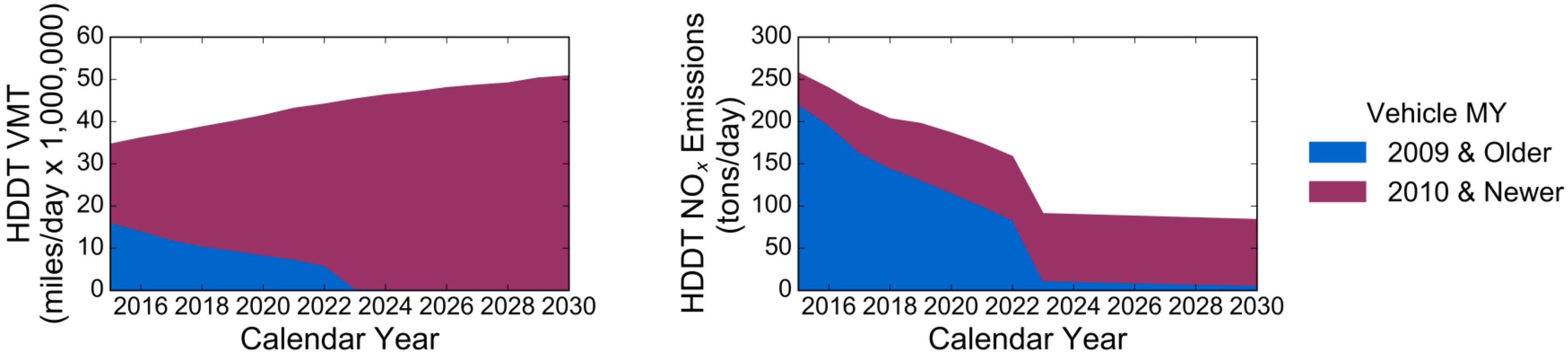
Air Resources Board

Outline

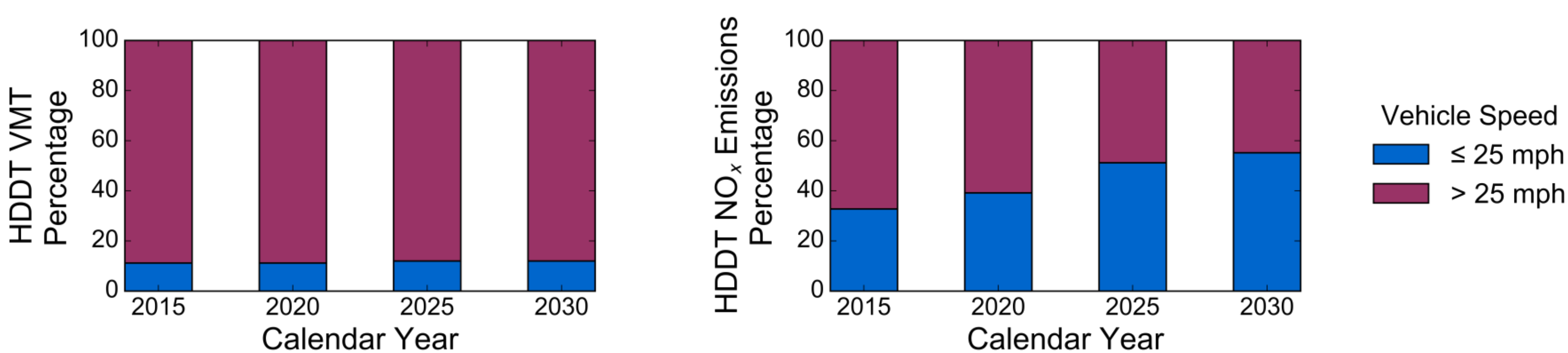
- Need for a Low Load Cycle (LLC)
  - Heavy-duty Diesel Truck (HDDT) NO_x Emissions at Low Speeds
  - Shortcomings of Current Certification Cycles
- Engine Cycle Development Approach
  - Background on HD-FTP Development
- Strategy for Developing LLC
- Opportunity to Join Workgroup

Low Load NO_x Emissions from 2010+ MY HDDTs

- VMT and NO_x emissions from 2009 and older HDDTs to decrease substantially by 2023



- NO_x emissions from low-speed operation to become increasingly significant, due to SCR inefficiency at low loads



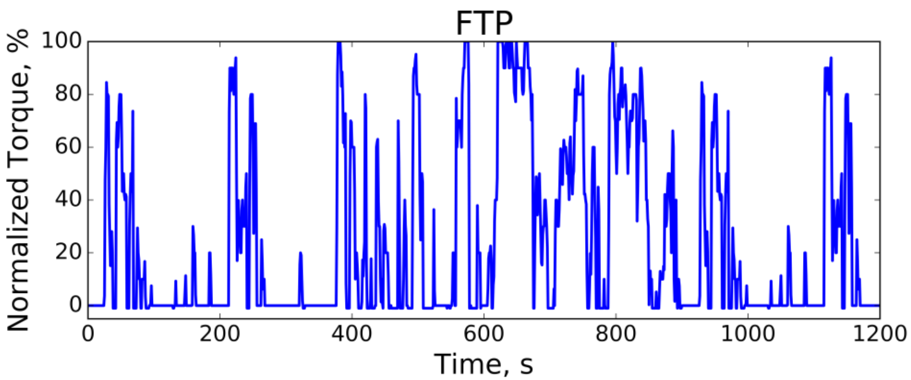
Low Load NO_x Emissions from 2010+ MY HDDTs

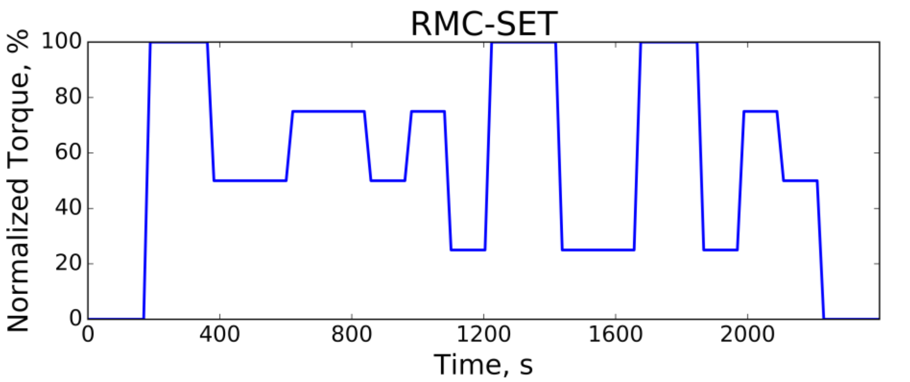
- In-use chassis dynamometer and PEMS on-road testing data* show much higher NO_x emissions from 2010+ MY HDDTs, compared to certification levels

Activity		Average Speed, mph	Emissions, g/bhp-hr	Certification Level, g/bhp-hr
Cycle	Drayage- Near Dock	6.8	1.80	0.12
	Drayage- Local	9.3	1.18	0.12
	Drayage- Regional	24	0.36	0.12
	UDDS	19	0.34-0.88	0.11-0.12
On-Road	Urban	26	0.32-0.97	0.11-0.13
	Rural	40	0.17-0.41	0.11-0.13

* S. Yoon, J.F. Collins, C. Misra, J.D. Herner, M.W. Carter, T.P. Sax, "High In-Use NO_x Emissions from Heavy-Duty Trucks Equipped with SCR Systems and Their Impact on Air Quality Planning in California", to be presented at 2017 Transportation Research Board Meeting.

Shortcomings of Current Certification Cycles: HD-FTP and RMC/SET

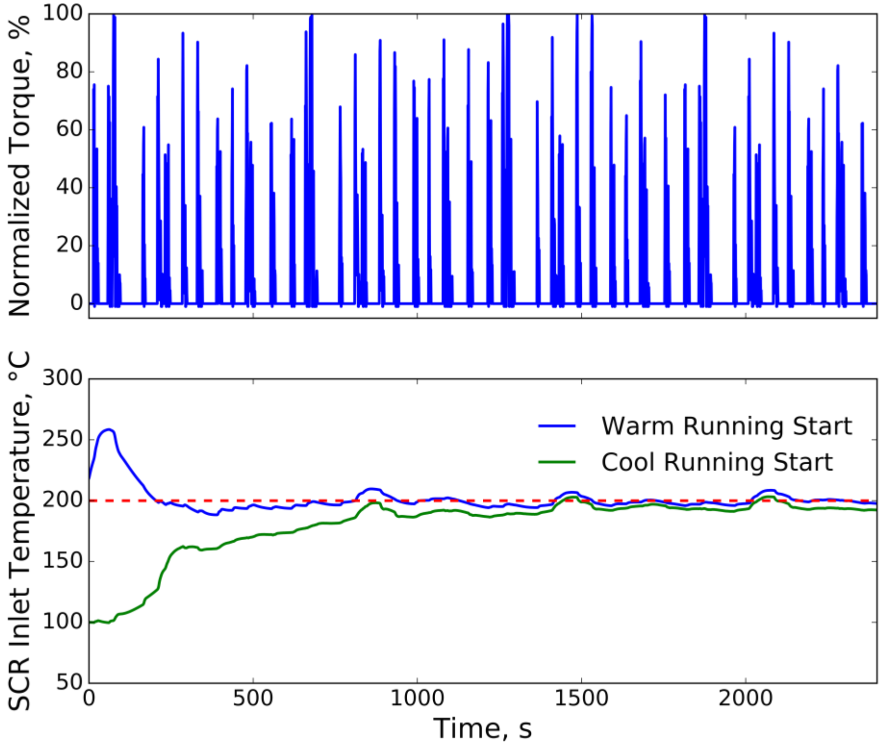




- HD-FTP and RMC/SET cycles do not account for sustained low load operations
- HD-FTP is not of sufficient length to verify active thermal management of SCR systems
- HD-FTP was developed in 1970's:
  - Real-world vehicle and engine activities nowadays might be markedly different
  - Methods used then to estimate engine load factors were not of high accuracy

Shortcomings of Current Certification Cycles

- Vocational cycles typically exhibit significantly lower exhaust temperatures
- Example: New York Bus Cycle* (NYBC)



SCR inlet temperature consistently under 200°C, even under warm start

NO_x Emission:

0.55 g/bhp-hr (warm running start)

2.35 g/bhp-hr (cool running start)

* https://www.arb.ca.gov/research/veh-emissions/low-nox/low-nox.htm

New Low-Load Engine Cycle

- Objective is to develop a new HD engine test cycle that:
  - Represents real-world urban tractor and vocational vehicle operations, characterized by low engine loads
  - Is of sufficient length such that continuous active thermal management is required
  - Has an emission standard that balances the need for NO_x emission reductions and GHG emission impacts

Engine Test Cycle Development–General Approach

- Typical steps of development process:
  1. Collection of real-world activity data
  2. Construction of candidate cycles using appropriately selected methodology
  3. Evaluation and selection of final cycle, based on its level of representativeness using statistical target parameters such as average speed, acceleration and deceleration, stops per unit distance, kinetic energy, maximum speed, kinetic intensity, etc.

Engine Test Cycle Construction Methodologies

- An engine cycle can be constructed from:

1. In-use engine activity data directly, either
   - Point-by-point, through random sampling that relies on a stochastic model to account for probability of successive transitions, or
   - Linking divided activity segments ("microtrip" data, defined as stop-to-stop travel), that are selected at random
2. Chassis dynamometer testing:

   Chassis cycle is first constructed from in-use vehicle speed data, then translated to corresponding engine cycle through chassis dynamometer testing of representative vehicles

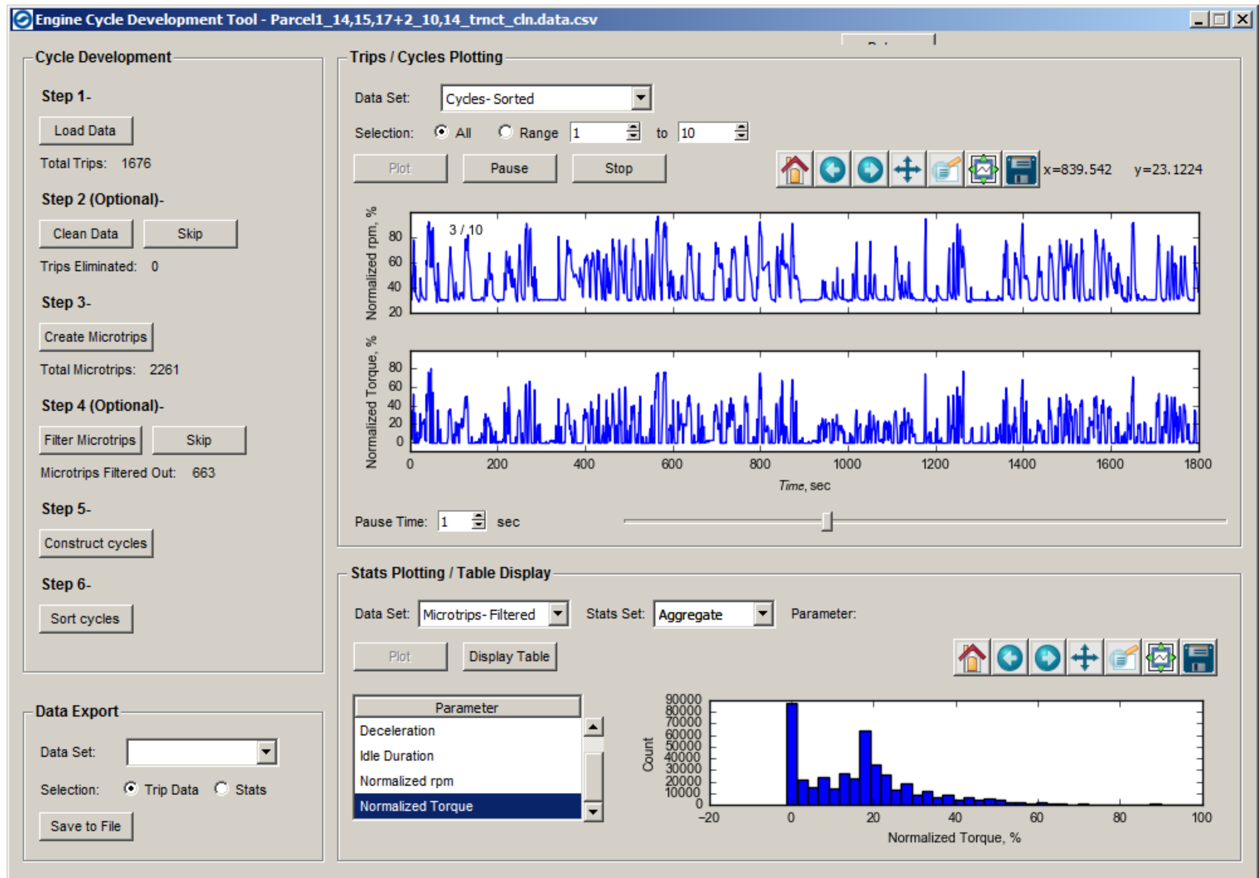
Development of HD-FTP

- Developed, along with HD-UDDS, in late 70's from in-use data for 44 trucks and 4 buses in NY, and 44 trucks and 3 buses in LA
- Consists of four 5 minutes segments corresponding to NY non-freeway, LA non-freeway, LA freeway, and NY non-freeway operations
- Engine load factor estimated based on manifold vacuum for gasoline engines, rack position or rail pressure for diesel engines
- Cycle constructed by randomly sampling individual engine speed/load points, using Markov Chain model to describe likelihood of successive transitions

Engine Cycle Development Tool

Tool developed by ARB staff with following capabilities:

- Statistical analysis and filtering of large amounts of activity data
- Development of custom representative engine cycles directly from in-use engine activity data, with approach similar to that used in FTP development



Low Load Cycle Development Plan

- ARB staff will work with SwRI/NREL to develop the low load cycle
- Activity data from following projects will be utilized:
  - Collection of Activity Data from On-Road Heavy-Duty Diesel Vehicles (UCR, completed 2016)
  - Data Collection, Testing, and Analysis of Hybrid Electric Trucks and Buses Operating in California Fleets (NREL, completed 2015)
  - Additional activity data collection projects sponsored by SCAQMD, EPA, etc

Opportunity

- ARB requests vocational activity data from the HDV industry to supplement existing data for the low load cycle development
- HD CERTIFICATION STANDARDS AND TEST PROCEDURES WORKGROUP
  - Discuss policy and procedure
  - Share data on vocational engine/vehicle activity and methodology of developing test cycles

Rulemaking Schedule/Contact

- Board Hearing: 2019
- More workshops through 2019
- Contact:
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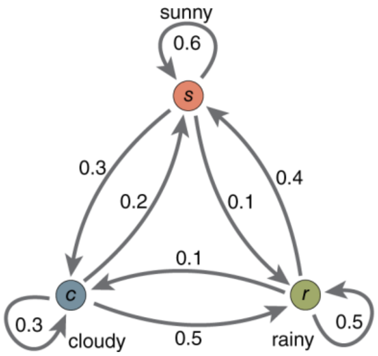
  - lee.wang@arb.ca.gov
  - (626) 450-6145

BACKUP SLIDES

Markov Chains

- Markov Chain is a mathematical system that represents transition probabilities between states
- Example: weather states



- For engine data, the state at each point is defined by 4 parameters – speed, load, and changes in speed and load to next point