



Heavy-Duty Start Emission Rates

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Background & Objectives

Background: MOVES includes start emissions for heavy-duty vehicles. The emission rate varies by the amount of soak time preceding the start.

Objectives: Focus on MY 2010 and newer heavy-duty diesel and gasoline vehicles

1. Update the cold start emissions (>720 minute soak time)
2. Update start emissions for starts with soak times ranging between 3 minutes and >720 minutes (MOVES OpModes 101-108)



COLD START EMISSIONS UPDATE



MOVES2014 Background HD Diesel

- HD cold start emissions are modeled in MOVES as grams of emission per start for HC, CO, NO_x, and PM
- The cold start rates in MOVES2014 are based on the following data:
 - LHDD: 21 MY 1988-2000 LHD diesel vehicles on the Federal Test Procedure (FTP)
 - MHDD/HHDD: One MY 2007 MHDD and PEMS testing of 24 idling trucks.
 - Mixed results for NO_x, led to determination of zero NO_x emissions for cold starts. The HC and CO emissions are a result of the single MHDD engine tested.
 - The PM emissions for MY 2007 and later were projected based on a 90 percent reduction to account for the 2007 HD PM standards and application of diesel particulate filters.
- No differentiation by MY, except for PM for post-2007.



MOVES2014 Background

HD Gasoline

- The LHD rates in MOVES2014 are based on a number of pickup trucks tested over the FTP to determine cold start emission rates (see table below)
 - Projected HC and NOx values for 2005-07 and 2008-17 MY groups based on ratio of standards.
 - Incorporated Tier 3 standards for CO, HC, and NOx
- LHD45, MHD, and HHD Gasoline HC, CO, and NOx rates were projected based on ratio of HD engine standards to HD vehicle standards

Model-year Group	Age Group (Years)					Total
	0-3	4-5	6-7	8-9	10-14	
1960-1989				19	22	41
1990			1	29		30
1991-1997	73	59	32	4		168
1998-2004	8					8
Total	81	59	33	52	22	247



New Data

- Analyzed MY 2015-2017 HD engine data from EPA's Compliance Division
 - We began collecting separate cold and hot results starting with 2015 MY
- Removed data under the following conditions:
 - Duplicate entries of engines
 - One HD gasoline family had the same emission levels for hot and cold for all emissions. Concluded this was a data entry error into VERIFY.
- The number of unique engines analyzed for each category is shown below -

Category	Number of Engines	Manufacturers
HD Gas	3	Ford, GM, Powertrain Integration
LHDD	5	Ford, FPT, Hino, Isuzu
MHDD	6	Ford, Hino, Cummins, Detroit Diesel
HHDD	11	Cummins, Hino, PACCAR, Volvo, Detroit Diesel



Calculations of Cold Start Emissions

- For each engine, the cold start emissions are determined by the difference between the emissions from a FTP with a cold start and a FTP with a warm start .
- Because the FTP measurements are in grams per horsepower-hour, a FTP cycle work conversion is required.

Grams per start

= [Cold FTP Emission Results (g/hp-hr)

*– Hot FTP Emission Results (g/hp-hr)] * FTP Cycle Work (hp-hr)*



FTP Cycle Work Determination

- Background: The amount of work (hp-hr) performed over the engine FTP cycle is unique to each engine and is not supplied with the certification data. Therefore, we needed to determine a surrogate that is included in the certification data.
- To determine the FTP cycle work, we gathered test results that included cycle work and the engine's rated power data

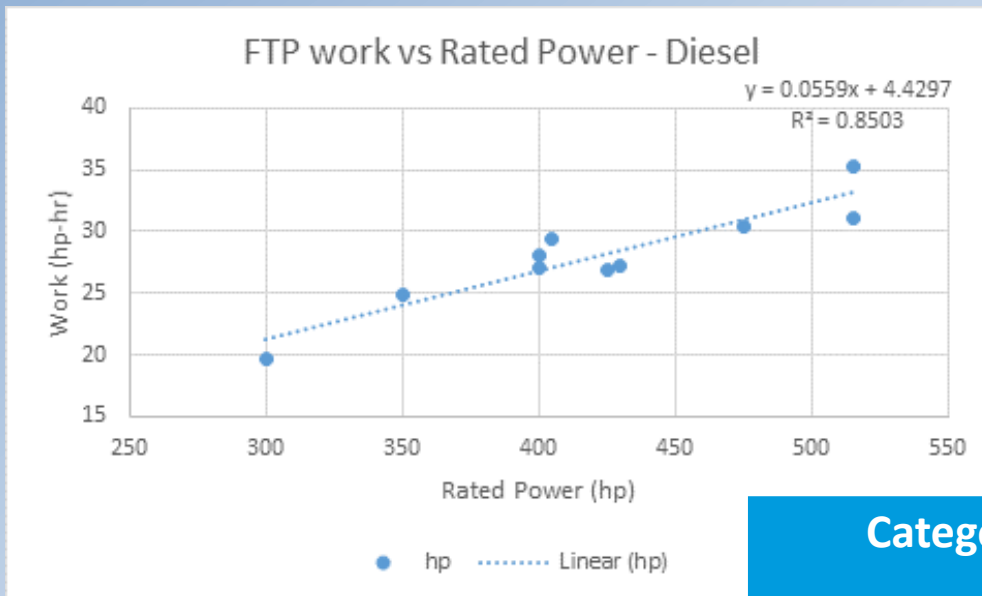
Engine	MY	Lab	Rated power [hp]	FTP cycle work [hp-hr]
Cummins ISB	2010	NVFEL	300	19.67
Volvo D13	2012		405	29.38
Volvo D13	2012		515	35.36
Cummins ISX	2012		400	28.01
DDC S60	2004		515	31.06
Caterpillar 3406E	1996	WVU	475	30.37
DDC S60	1994		430	27.26
Mack E7-400	1995		400	27
Cummins M11-350E+	1997		350	24.94
Volvo VE D12B	1998		425	26.9



HD Diesel Engine FTP Cycle Work Determination

Evaluated FTP cycle work in relation to the Rated Power

$$\text{FTP Cycle Work (hp-hr)} = 0.0559 * \text{Rated Power (hp)} + 4.4297$$



Category	HD Engine FTP Cycle Work Using Equation (hp-hr)
LHDD	13-23
MHDD	17-26
HHDD	18-38



HD Gasoline Engine FTP Cycle Work Determination

- The HD Gasoline FTP cycle is different than the HD Diesel FTP cycle
- Only one set of gasoline engine data included cycle work, so we are using this value to represent all three HD gasoline engines

Engine	MY	Lab	Rated power [hp]	FTP cycle work [hp-hr]
Ford V10 Gas	2010+	SwRI	286	19.32

Category	HD Engine FTP Cycle Work (hp-hr)
HD Gasoline	19.3



Cold Start Results HHDD

Grams/Start	HC (NMHC+CH4)	CO	NOX	PM
MOVES2014	0.0	16.0	0.0	0.011
New Analysis - Mean	0.08	6.6	8.4	0.013
New Analysis – StdDev	0.1	5.6	1.7	0.029

Regulatory Class 48 for MY 2010 and newer.
No differentiation by Age.



Cold Start Results MHDD

Grams/Start	HC (NMHC+CH4)	CO	NOX	PM
MOVES2014	0.0	16.0	0.0	0.011
New Analysis - Mean	0.20	2.5	6.4	0.008
New Analysis – StdDev	0.2	2.7	1.8	0.017

Regulatory Class 46 and 47 for MY 2010 and newer.
No differentiation by Age.



Cold Start Results LHDD

Grams/Start	HC (NMHC+CH4)	CO	NOX	PM
MOVES2014	<i>0.13</i>	<i>1.38</i>	<i>1.68</i>	<i>0.01099</i>
New Analysis - Mean	0.005	2.47	6.77	0.00
New Analysis – StdDev	0.11	2.61	2.24	0.01

Regulatory Class 40, 41, 42 for MY 2010 and newer.
No differentiation by Age.



Cold Start Results HD Gasoline

Grams/Start	HC (NMHC+CH4)	CO	NOX	PM
MOVES2014	1.4	260	0.21	0.012
New Analysis - Mean	5.57	31.5	1.88	0.084
New Analysis – StdDev	0.6	6.36	1.04	0.049

Regulatory Class LHD45 for MY 2010 and newer
0-3 Year Age results



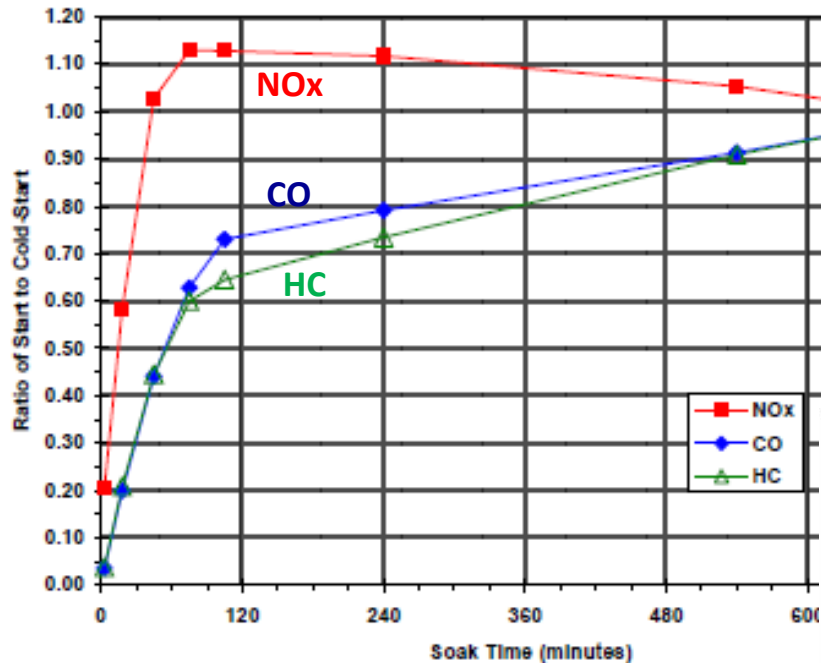
SOAK TIME IMPACT ON START EMISSIONS UPDATE



Background

HD soak time impacts in MOVES2014 based on LD soak period effects

Figure 2-36. Soak Fractions Applied to Cold-Start Emissions (opModeID = 108) to Estimate Emissions for shorter Soak Periods (operating modes 101-107). This Figure is reproduced the Light-duty emissions Report⁸



OpmodelID Code	Operating Mode Description
101	Soak Time < 6 minutes
102	6 minutes ≤ Soak Time < 30 minutes
103	30 minutes ≤ Soak Time < 60 minutes
104	60 minutes ≤ Soak Time < 90 minutes
105	90 minutes ≤ Soak Time < 120 minutes
106	120 minutes ≤ Soak Time < 360 minutes
107	360 minutes ≤ Soak Time < 720 minutes
108	720 minutes ≤ Soak Time

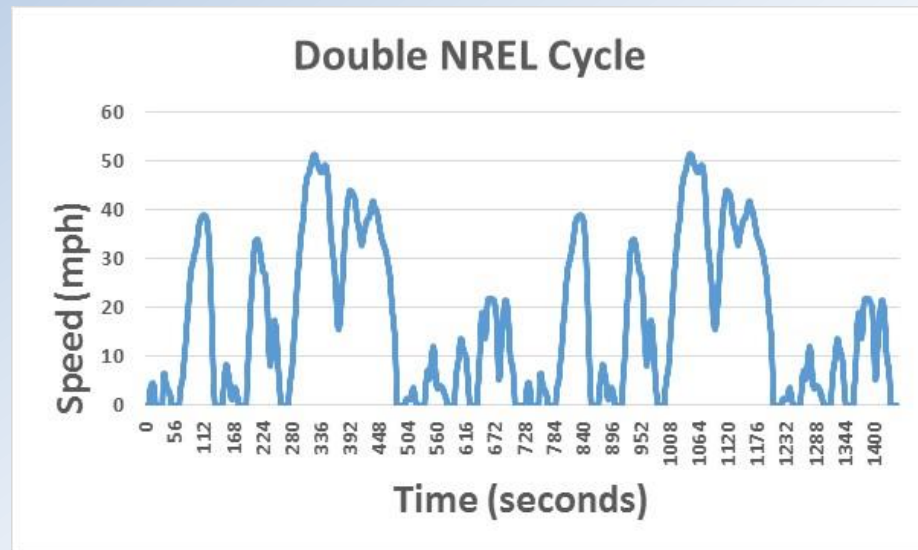
New HD Soak Curve Testing

- Conducted two sets of new testing
 - Chassis Tests on 2015 MY Class 8 Diesel Day Cab
 - PEMS On-road Tests on MD Gasoline Truck and MD Diesel Truck



HD Chassis Testing

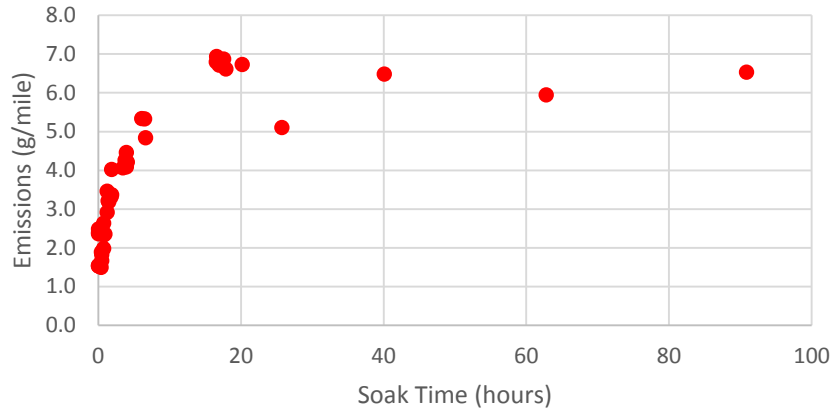
- Vehicle: 2015 MY day cab tractor
- Engine: 2015 MY diesel engine
- Odometer: 10,000 miles
- Cycle: NREL Transient Cycle (2x)
- Measurements:
 - Gaseous using bag and raw modal: THC, NMHC, CO, NO_x
 - PM filters with triplicate weights
- Dyno inertia: 60,000 lb



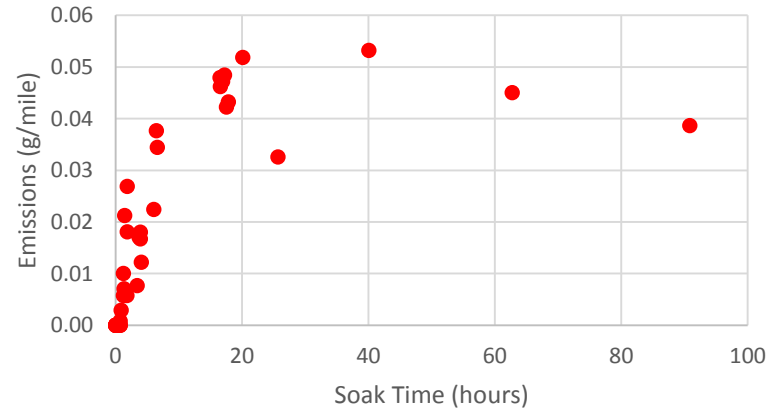
Chassis Test Results

Emissions vs. Soak Time

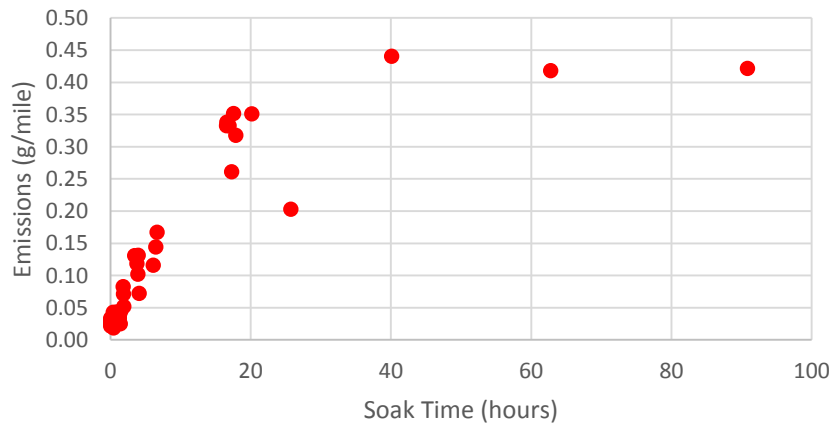
NOx



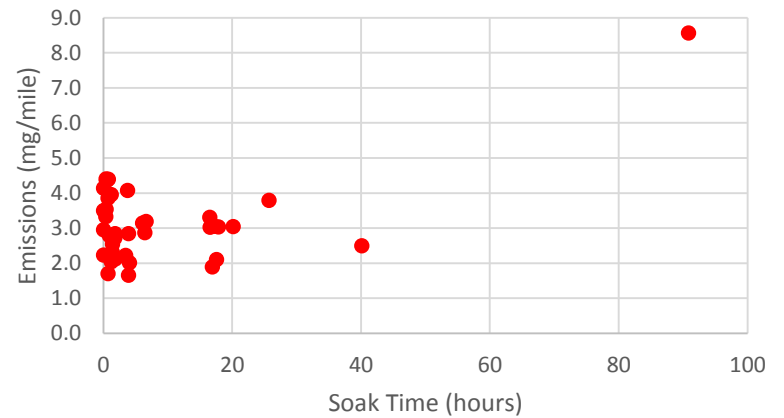
HC



CO



PM



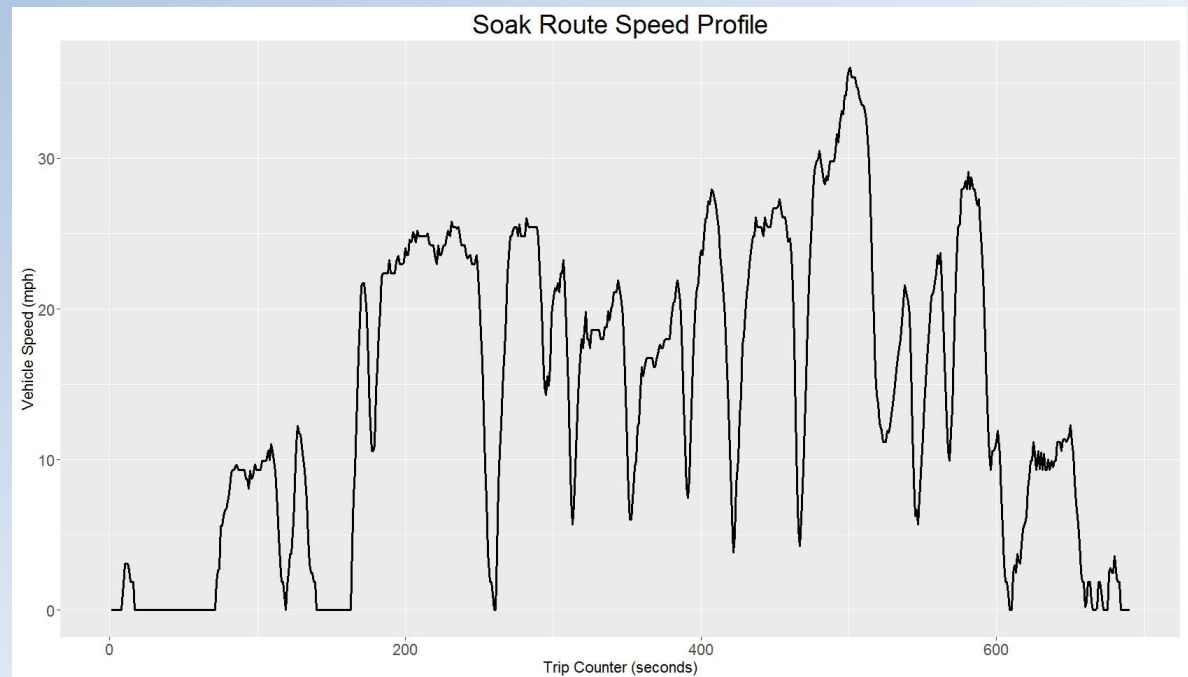
PEMS Testing

- Vehicles
 - 2012 MY box truck with gasoline engine
 - 2016 MY work van with diesel engine
- Test Cycle and Conditions
 - Vehicles soaked and started inside the laboratory for controlled temperature
 - Ambient temperatures $> 50^{\circ}$ F
 - 10 seconds of idle followed by soak route (see next slide)
- Replicates
 - 2-5 replicates for each soak period for each vehicle

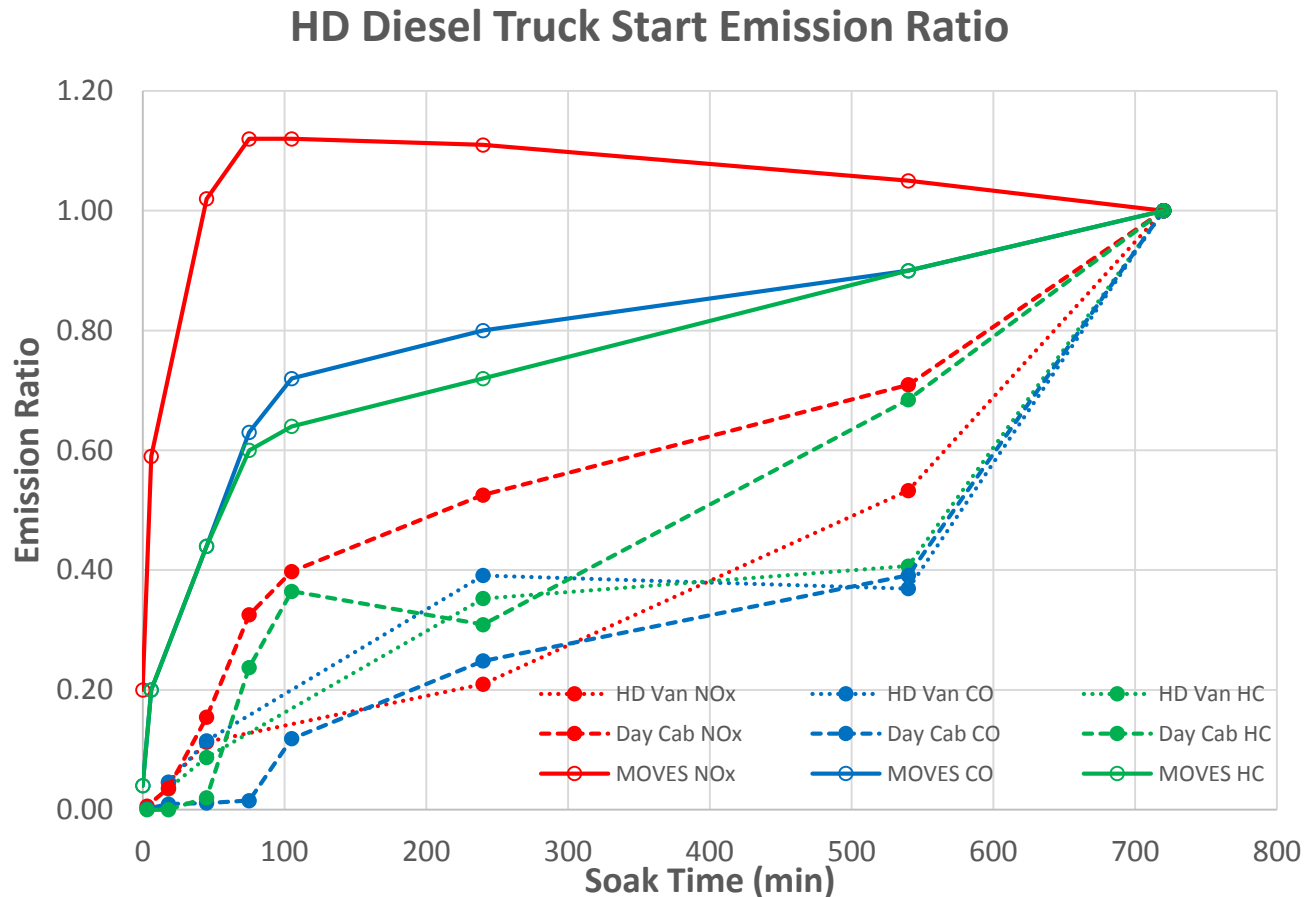


PEMS Test Route

- Same route used for the LD soak work
- 2.7 miles
- 700 seconds
- City driving around our laboratory



HD Diesel Soak Curve

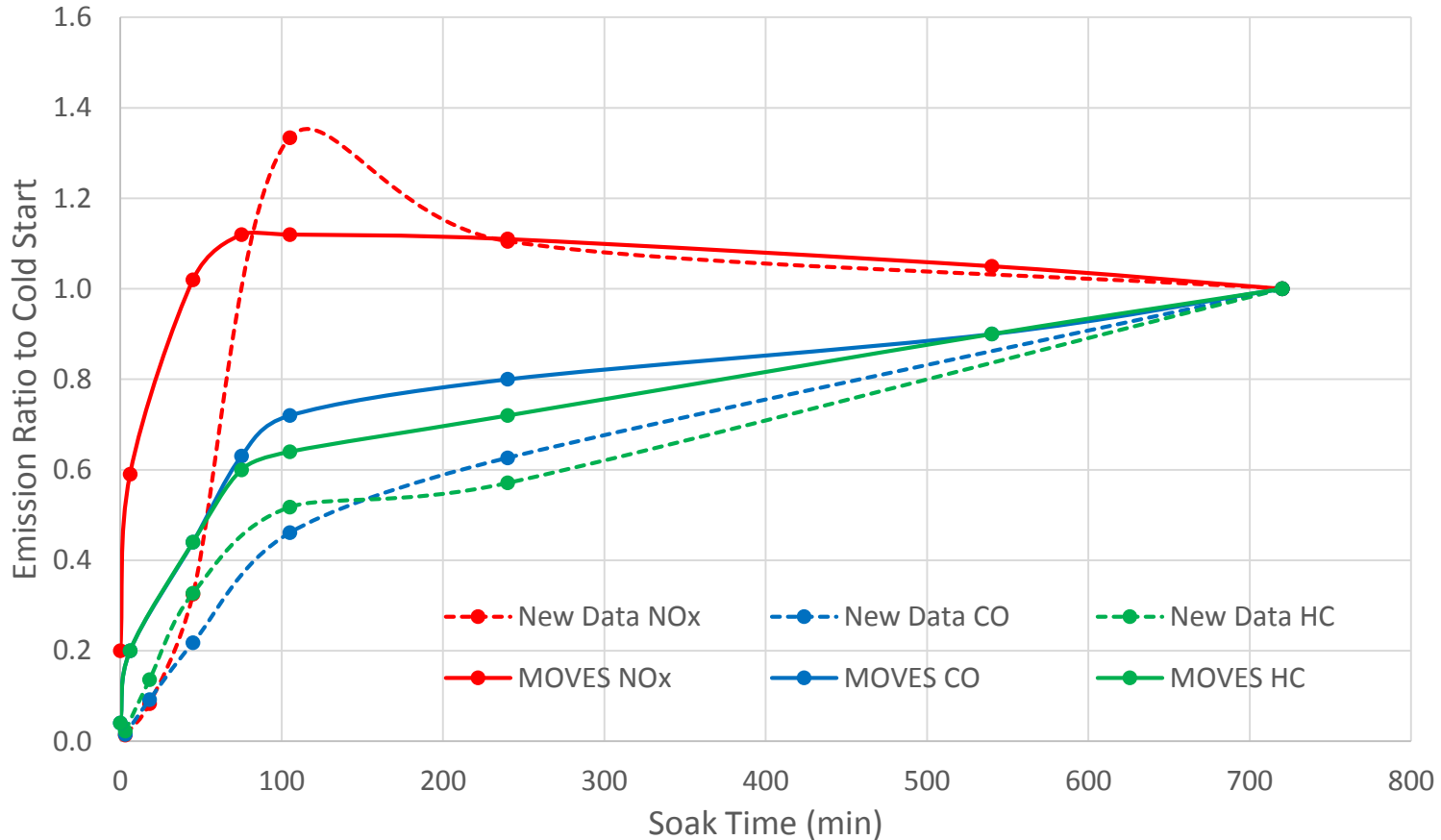


The HD diesel trucks show different trends than the ratios currently in MOVES2014, so propose to revise ratios in MOVES based on the average of the two vehicles



HD Gasoline Soak Curve

HD Gasoline Truck Start Emission Ratio



The MD gasoline truck shows similar trends as the soak ratios currently in MOVES, so propose to continue to use the existing ratios in MOVES



Summary

- Propose to update the following start emission rates:
 - MY 2010 and newer Heavy-Duty Diesel based on new 12-hour soak emission rate and new soak curve
 - MY 2010 and newer Heavy-Duty Gasoline based on new cold start 12-hour soak emission rate and using the current light-duty gasoline soak curve

