Emission Rate Development

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FACA Modeling Workgroup Meeting
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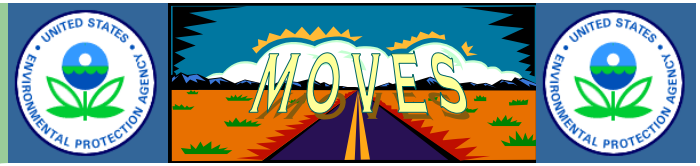
Outline

- **MOVES2004 Emission Rate Sources**
- **Running Total Energy Rates**
  - Modal Binning Approach
  - Source Bin Approach
  - Binning Process
  - Hole Filling Options
- **Rates for Other Processes and Pollutants**
  - CH_4 & N_2O
  - Starts
  - Extended Idle
  - Well-To-Pump



Emission Rate Characterization Depends on Pollutant/Process

- **Each pollutant/process is unique in terms of:**
  - Activity characteristics that need to be accounted for
    - Operating Mode definitions
  - Vehicle characteristics that need to be accounted for
    - Source Bins definitions
  - Available data → appropriate level of aggregation
- **MOVES is designed with flexibility to define each pollutant/process uniquely**
  - Although for simplicity it is desirable to have common definitions where possible, esp. across pollutant

MOVES2004
Emission Rate Sources

Pollutant/Process	Running	Start	Extended Idle	Well-To-Pump	Manufacture/ Disposal
Total Energy	MSOD Second-By-Second Data	MSOD Bag Data	EPA Testing	GREET (version produced for EPA by Argonne National Lab)	
Petroleum Energy	Calculated from Total Energy				
Fossil Energy					
Atmospheric CO_2					
CH_4	MSOD Bag Data		Not Estimated		
N_2O	MSOD Bag Data				
CO_2 Equivalent	Calculated from CO_2, CH_4, N_2O				

Emission Rate Characterization

- **Running**
  - Energy: modal emission rates (KJ/SHO by bin)
  - CH_4 & N_2O: aggregate emission rates (KJ/SHO)
- **Start**
  - Incremental energy/emissions per start
- **Extended Idle**
  - Per hour of extended idle (energy only)
- **Well-To-Pump**
  - Well-to-pump energy/emissions per KJ consumed on-road
- **Manufacture/Disposal**
  - Energy/emissions per vehicle mass
  - Broken into manufacture, non-fuel consumables, disposal

Modal Emission & Activity Approach

- **Applies only to running energy consumption for MOVES 2004**
  - Plan to use for HC, CO, PM, NOx, Toxics for later versions
- **Basis of MOBILE models is average speed**
  - Aggregate approach “averages out”
  - Appropriate for larger modeling domains
  - Does not separate out differences in acceleration
- **Transportation community has pushed for approach which accounts for speed & acceleration**
  - Intersection modeling, Hot-spot analysis, TRANSIMS
- **NRC recommended a modeling approach applicable to multiple analysis scales but internally consistent**

MOVES "Binning" Approach

- **Group activity and emissions into "Bins"**
  - Vehicle Specific Power (VSP) & Speed
    - VSP accounts for speed, acceleration, grade, road load
- **Any driving pattern can be modeled based on distribution of time spent in bins**
  - Adds major flexibility compared to MOBILE
- **Provides common emission rates for all scales**

Binning Approach - Background

- **Initially looked at binning by VSP only**
  - On-Board Shootout (on web)
  - NC State analysis of modal approaches (on web)
- **Concluded that VSP alone not sufficient**
  - Would produce bias at low and hi speeds
  - Draft MOVES GHG Emission Analysis Plan proposed binning by VSP and average speed
- **Have since conducted further assessment to find improved binning approach**
  - "Engine Specific Power": Nam CRC 2003 Presentation
  - Revised binning assessment conducted Summer 2003 - results presented for first time today

Goals Of Binning Assessment

- **Improve prediction over VSP-only approach**
- **Define bins in such as way as to:**
  - Use readily-available activity parameters
    - Binning by RPM or engine friction fails this test
  - Allow bin definition based on what the vehicle is doing in that moment
    - Binning by average speed fails this test
- **Define common set of bins for all vehicles and pollutants**
- **Allow bins to be filled across a broad range of vehicles (source bins) using available data**

Binning Assessment

- **Chose instantaneous speed as second binning variable**
  - Also looked at RPM, acceleration
- **Used HTBR to show important VSP and speed breakpoints**
- **Assessed 5 different combinations of VSP & speed**
- **Decided on bin structure that performed well and could be filled from IM240 data**
  - majority of light-duty data for MOVES2004 will be from NYIPA program

“Bin Option 5” (17 bins)

Braking (B in 0)			
Idle (B in 1)			
VSP \Speed	0-25 mph	25-50	>50
< 0 kw/tonne	B in 11	B in 21	
0 to 3	B in 12	B in 22	
3 to 6	B in 13	B in 23	
6 to 9	B in 14	B in 24	
9 to 12	B in 15	B in 25	
12 and greater	B in 16	B in 26	B in 36
6 to 12			B in 35
< 6			B in 33

Binning Proof-Of-Concept

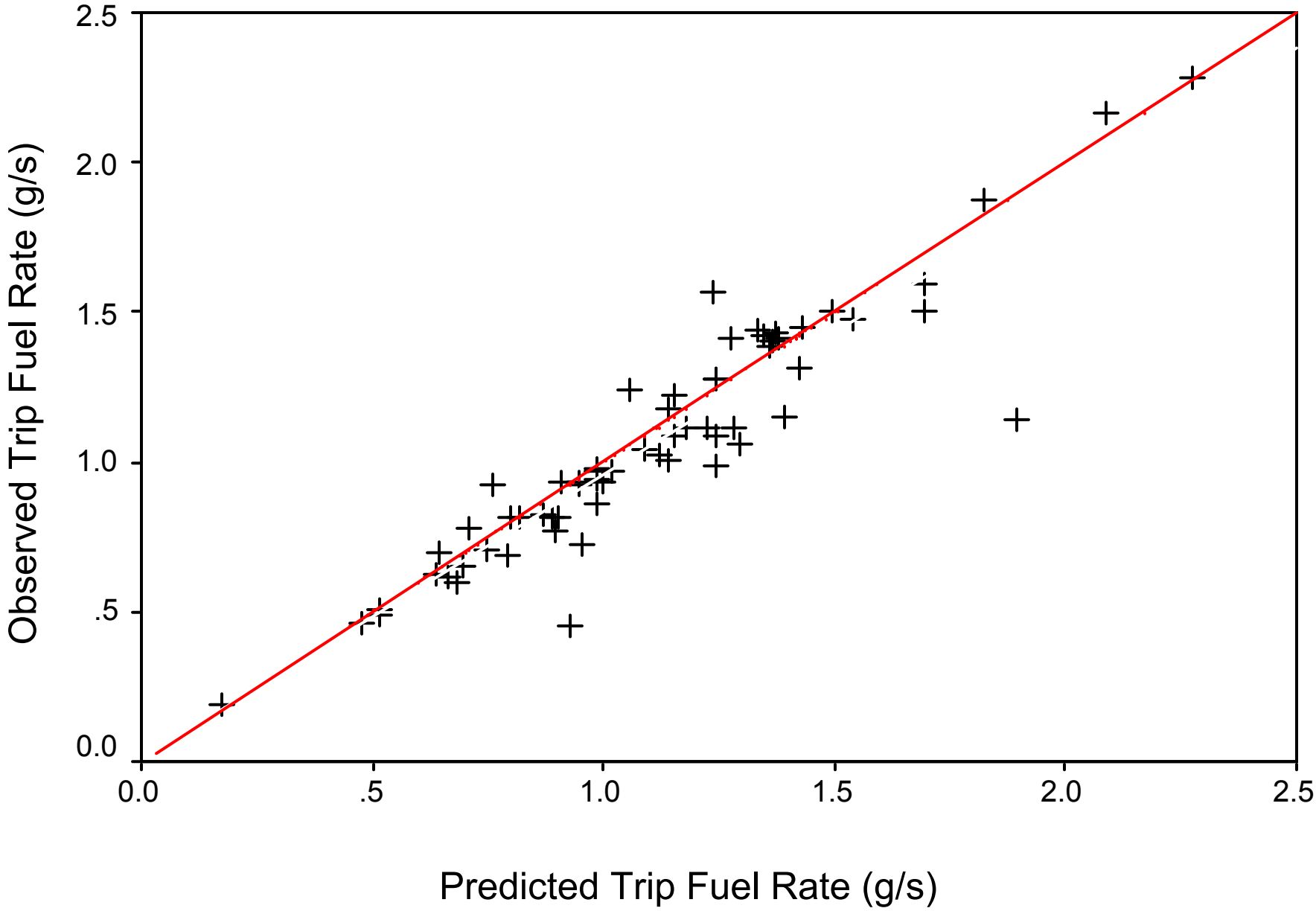
- **Analysis sample**
  - Light-duty
    - ARB UCC Dataset (26 veh, ~150 trips)
    - EPA On-Board Shootout (15 veh, ~ 70 trips)
  - Heavy-duty
    - CE-CERT HD Trailer Data (11 veh, ~ 60 trips)
    - EPA On-Board Shootout (15 buses, ~ 15 trips)
- **Random sample of trips removed**
- **Binned g/s emission rates developed from remaining trips**
- **Emissions of removed trips independently predicted based on distribution of time in bins**

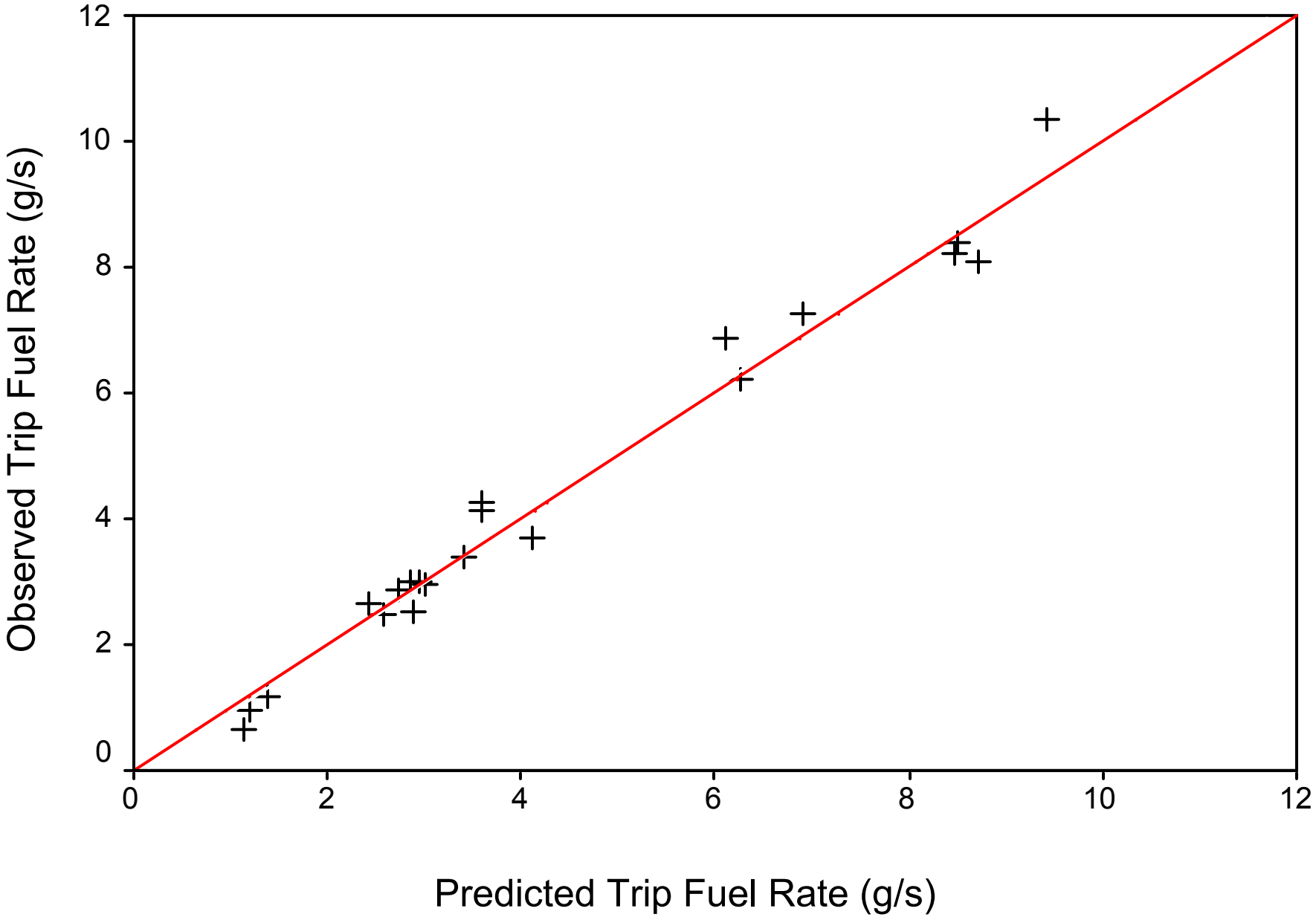
Validation Results: Bin Option 5 and VSP-Only Approaches

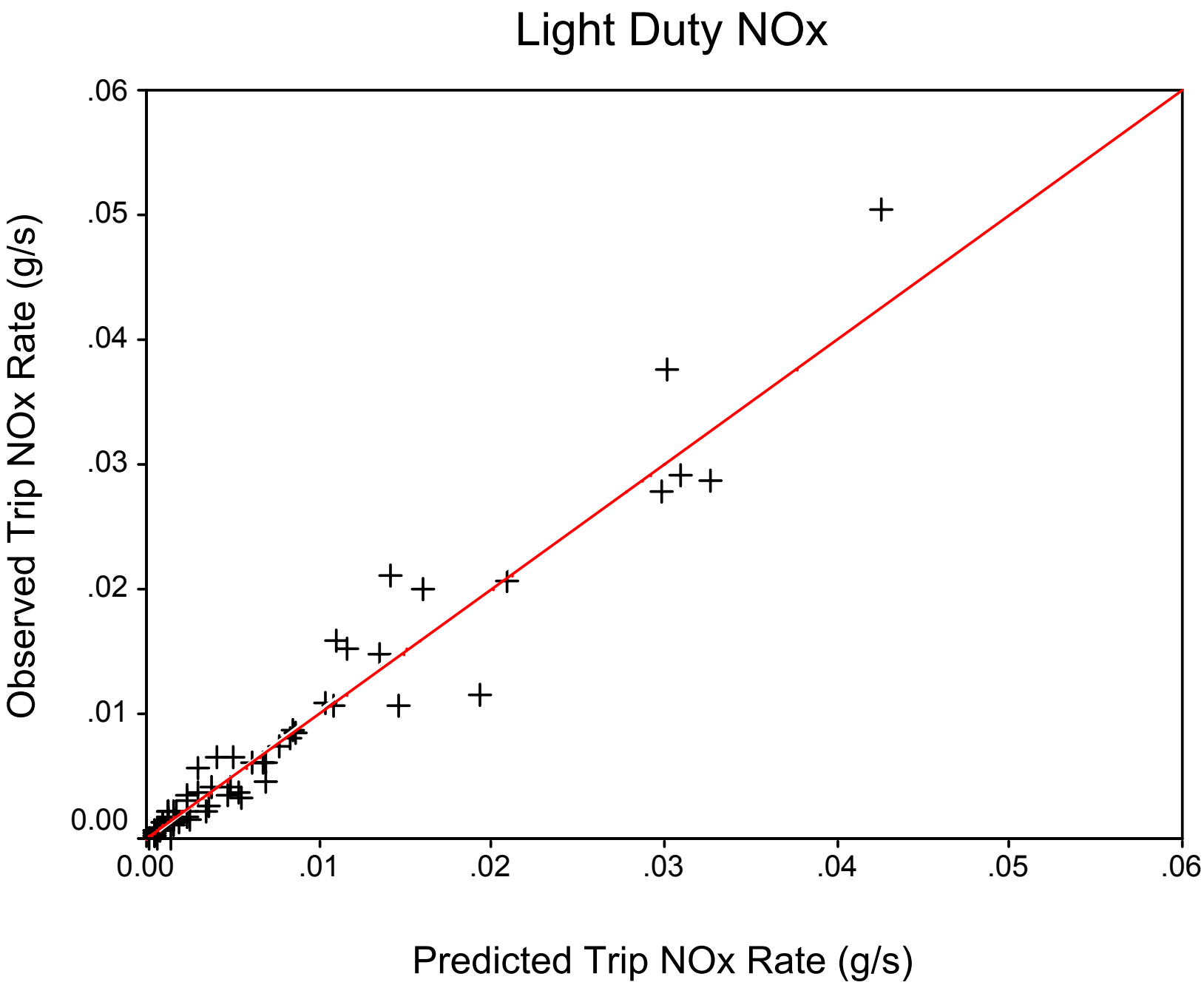
Percent Difference From Observed Average Trip Fuel/Emission Rates

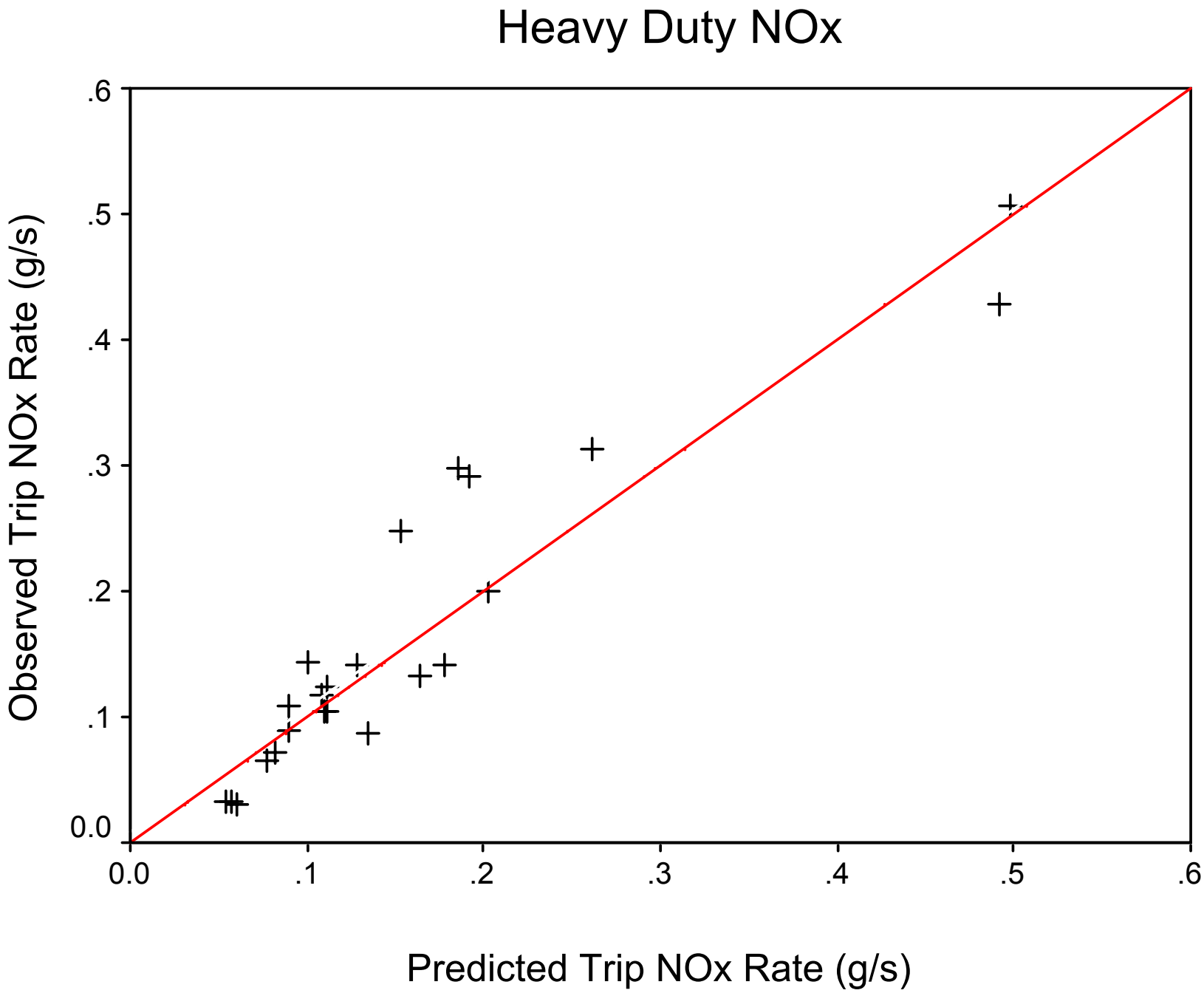
All Trips								
	Light-Duty				Heavy-Duty			
	Fuel	HC	CO	NOx	Fuel	HC	CO	NOx
VSP	9%	1%	6%	5%	1%	15%	13%	-3%
BO5	4%	1%	3%	-3%	-1%	10%	14%	-4%
Trips w/Average Speed < 30								
	Light-Duty				Heavy-Duty			
	Fuel	HC	CO	NOx	Fuel	HC	CO	NOx
VSP	22%	14%	8%	14%	10%	36%	25%	19%
BO5	8%	6%	4%	-7%	0%	23%	21%	7%
Trips w/Average Speed > 30								
	Light-Duty				Heavy-Duty			
	Fuel	HC	CO	NOx	Fuel	HC	CO	NOx
VSP	-1%	-6%	6%	1%	-6%	-15%	-4%	-16%
BO5	1%	-2%	3%	-1%	-2%	-9%	3%	-11%

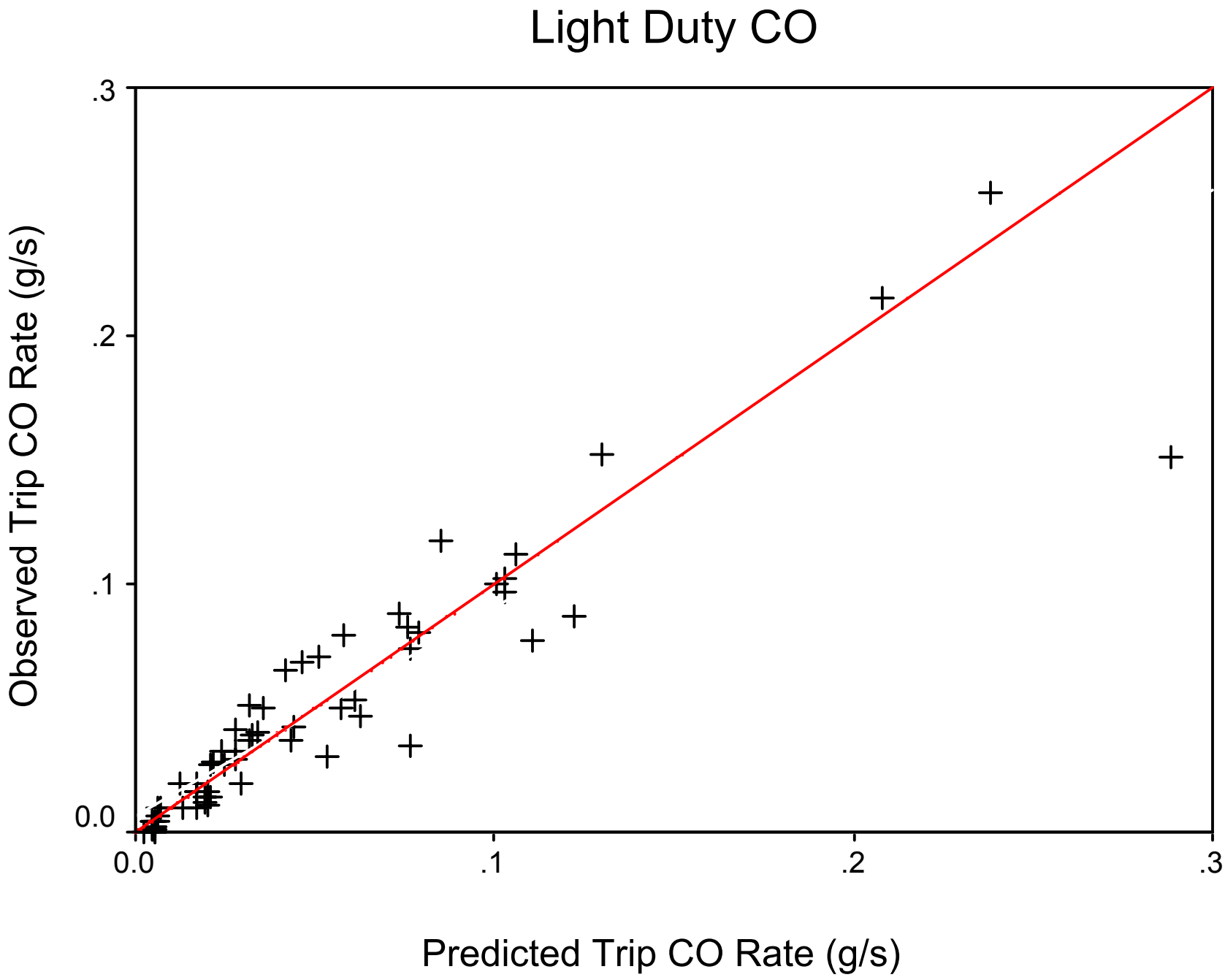
Per-Trip Results for BO5 In Following Slides

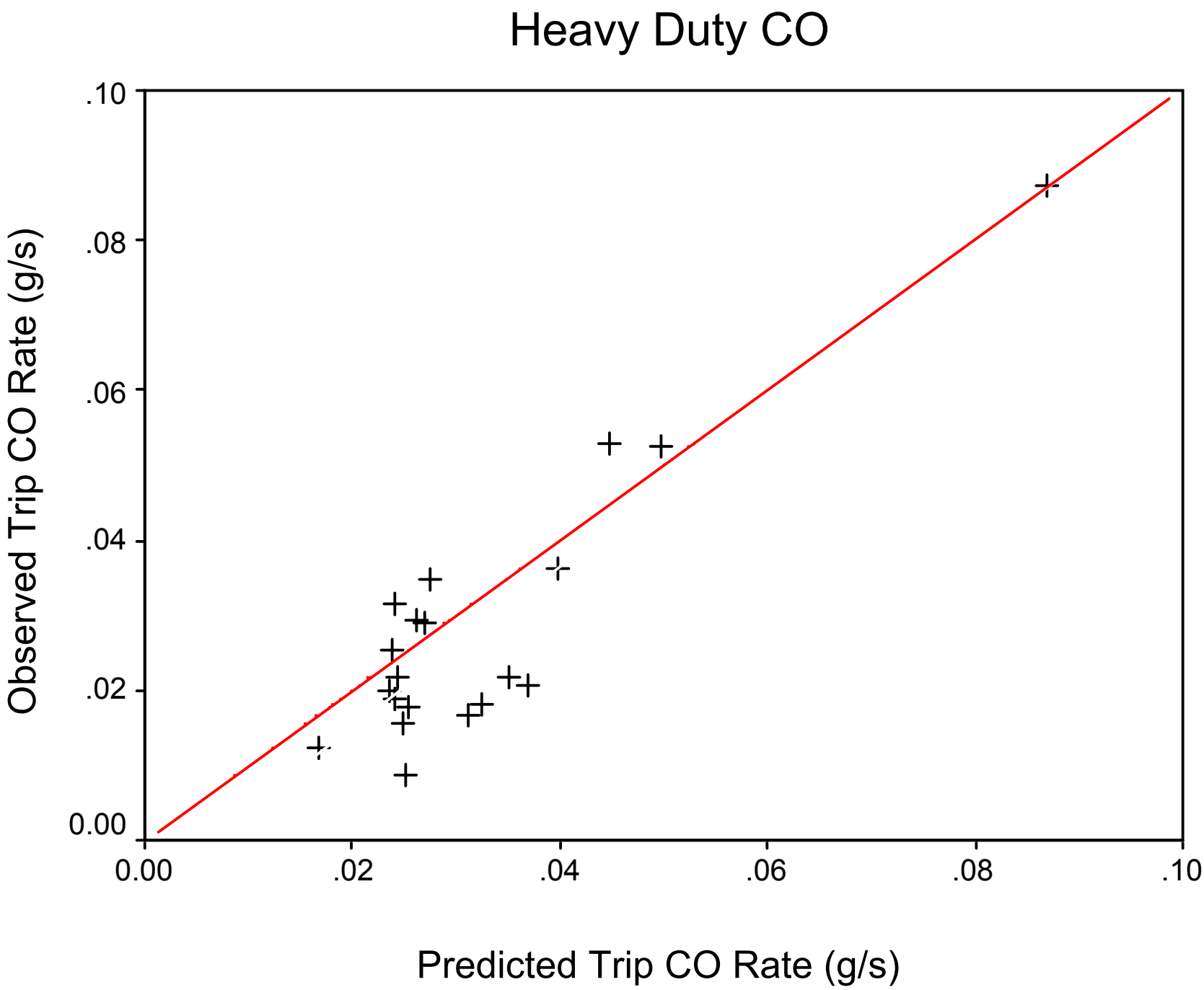

Observed Trip Fuel Rate (g/s)
2.5
2.0
1.5
1.0
.5
0.0
0.0
.5
1.0
1.5
2.0
2.5
Predicted Trip Fuel Rate (g/s)

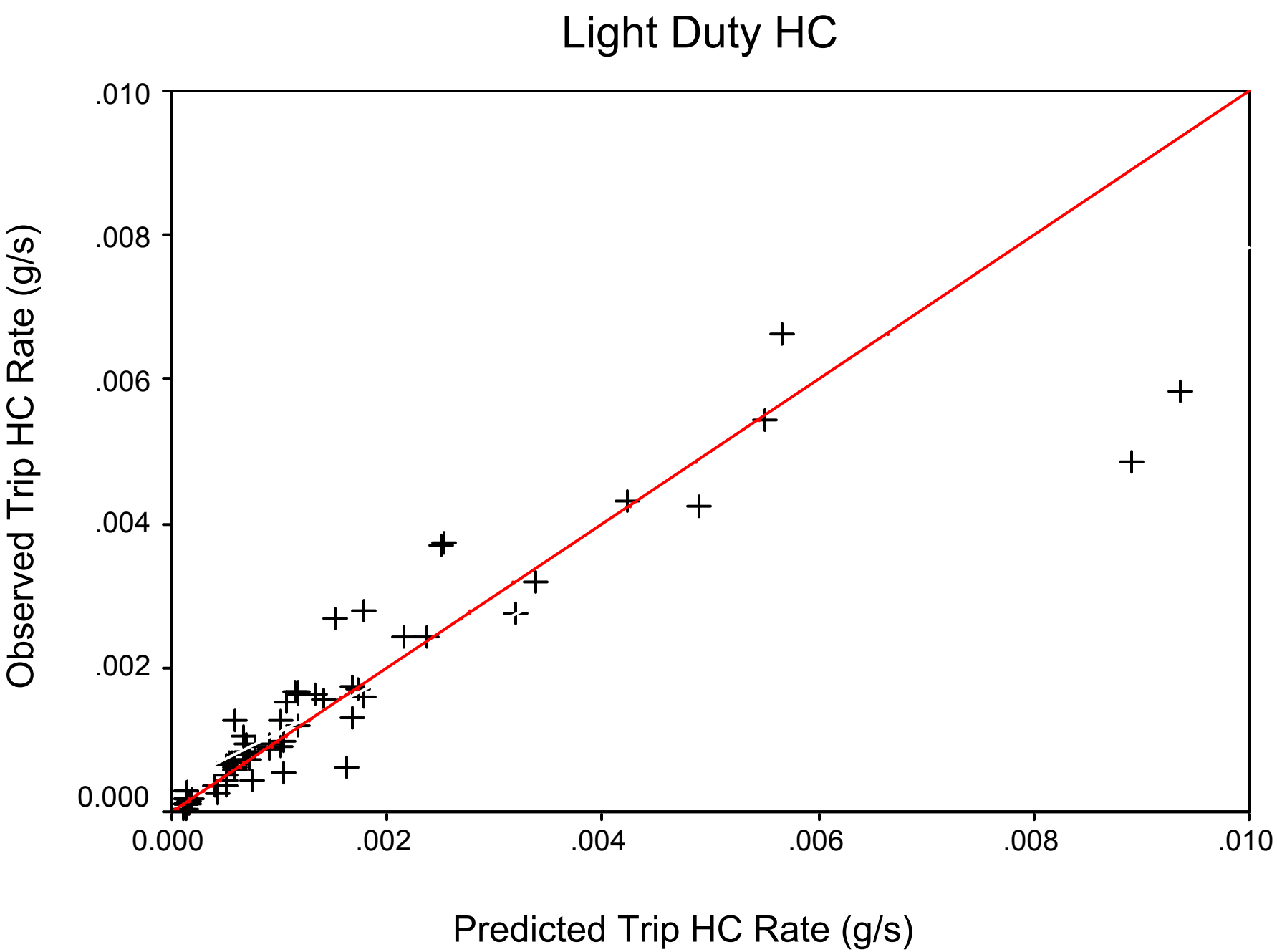

Observed Trip Fuel Rate (g/s)
Predicted Trip Fuel Rate (g/s)
0
2
4
6
8
10
12

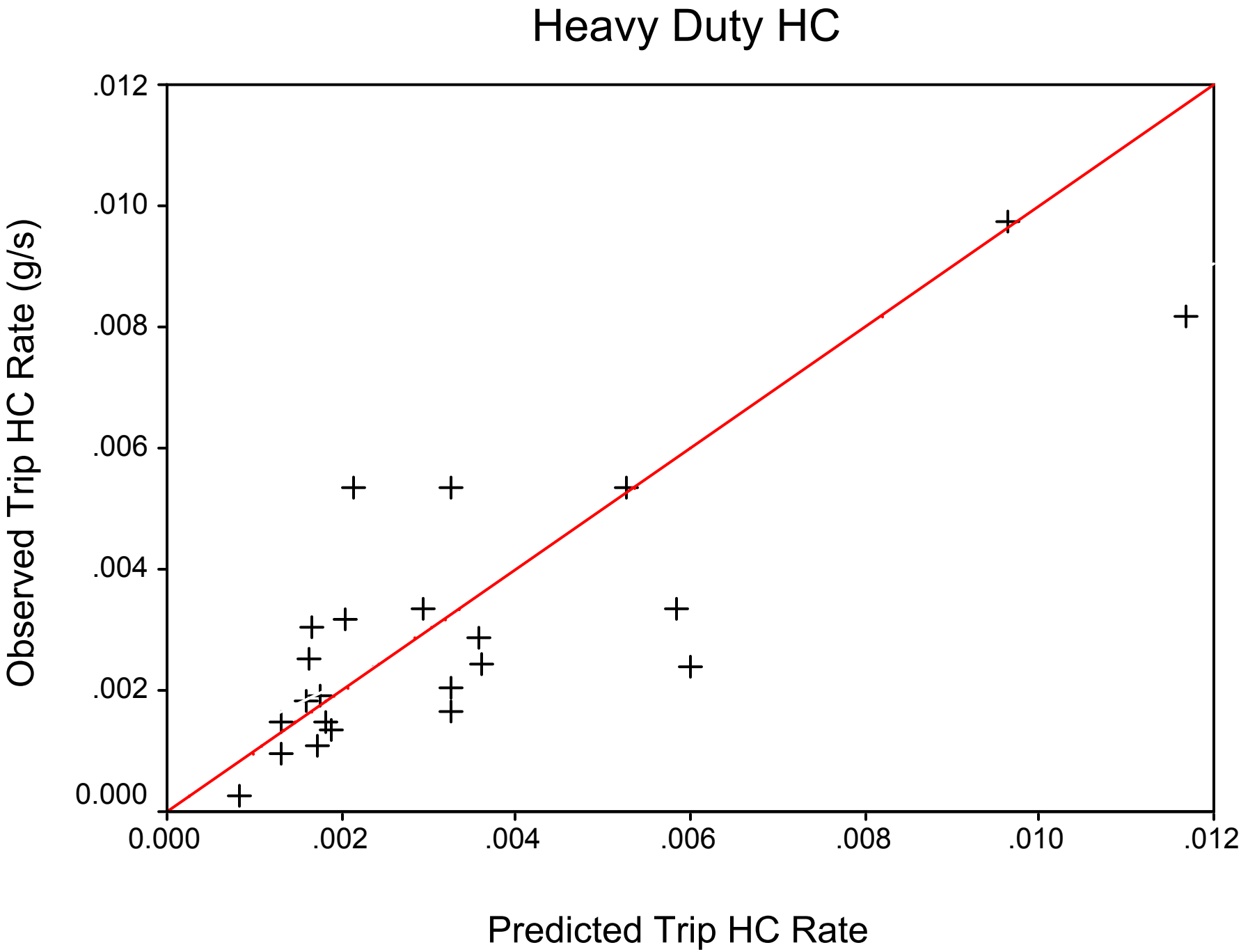

Light Duty NOx
Observed Trip NOx Rate (g/s)
Predicted Trip NOx Rate (g/s)
.06
.05
.04
.03
.02
.01
0.00
0.00
.01
.02
.03
.04
.05
.06

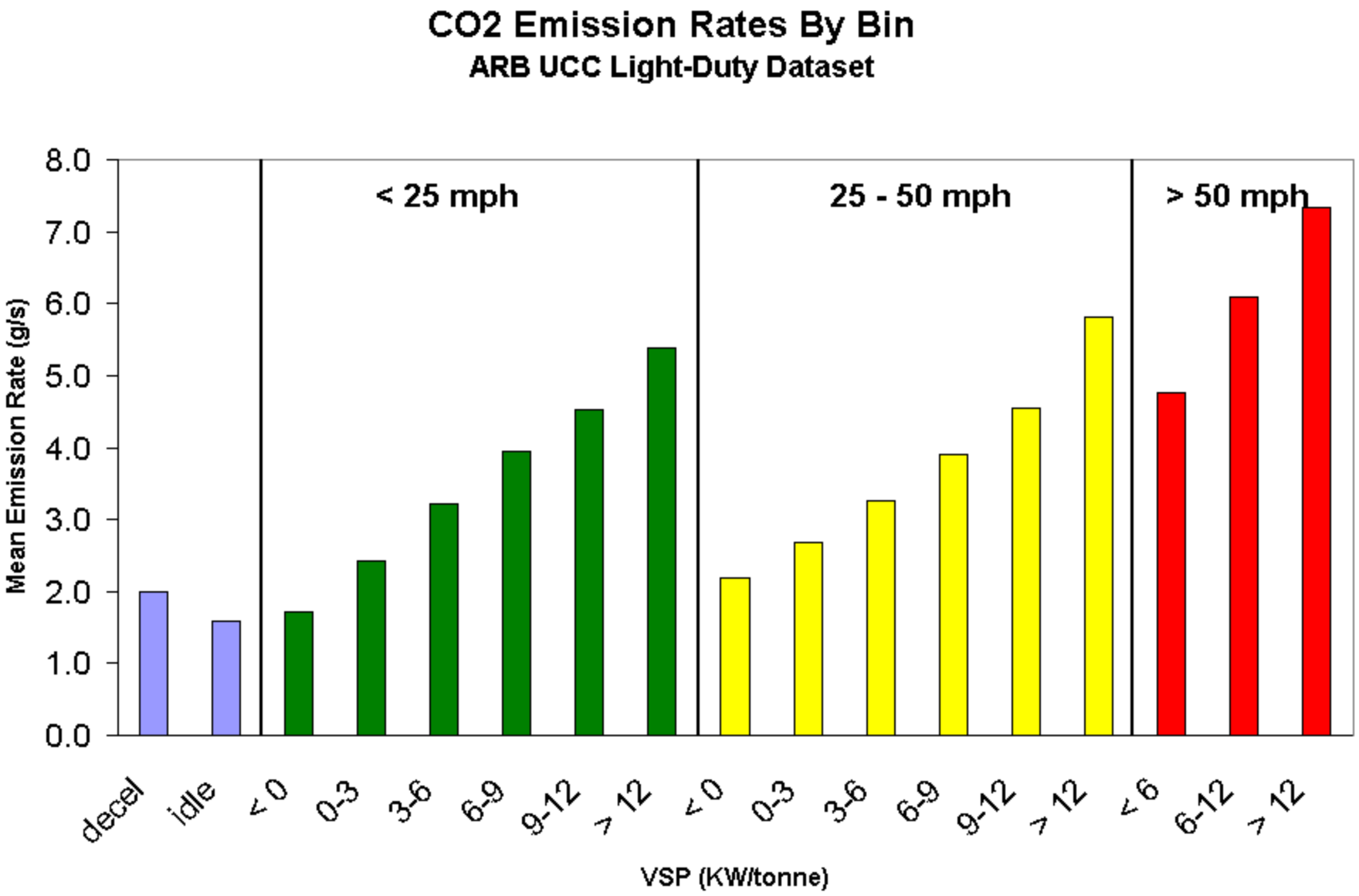

Heavy Duty NOx
Observed Trip NOx Rate (g/s)
Predicted Trip NOx Rate (g/s)
0.0
.1
.2
.3
.4
.5
.6


Light Duty CO
Observed Trip CO Rate (g/s)
Predicted Trip CO Rate (g/s)
.3
.2
.1
0.0
0.0
.1
.2
.3

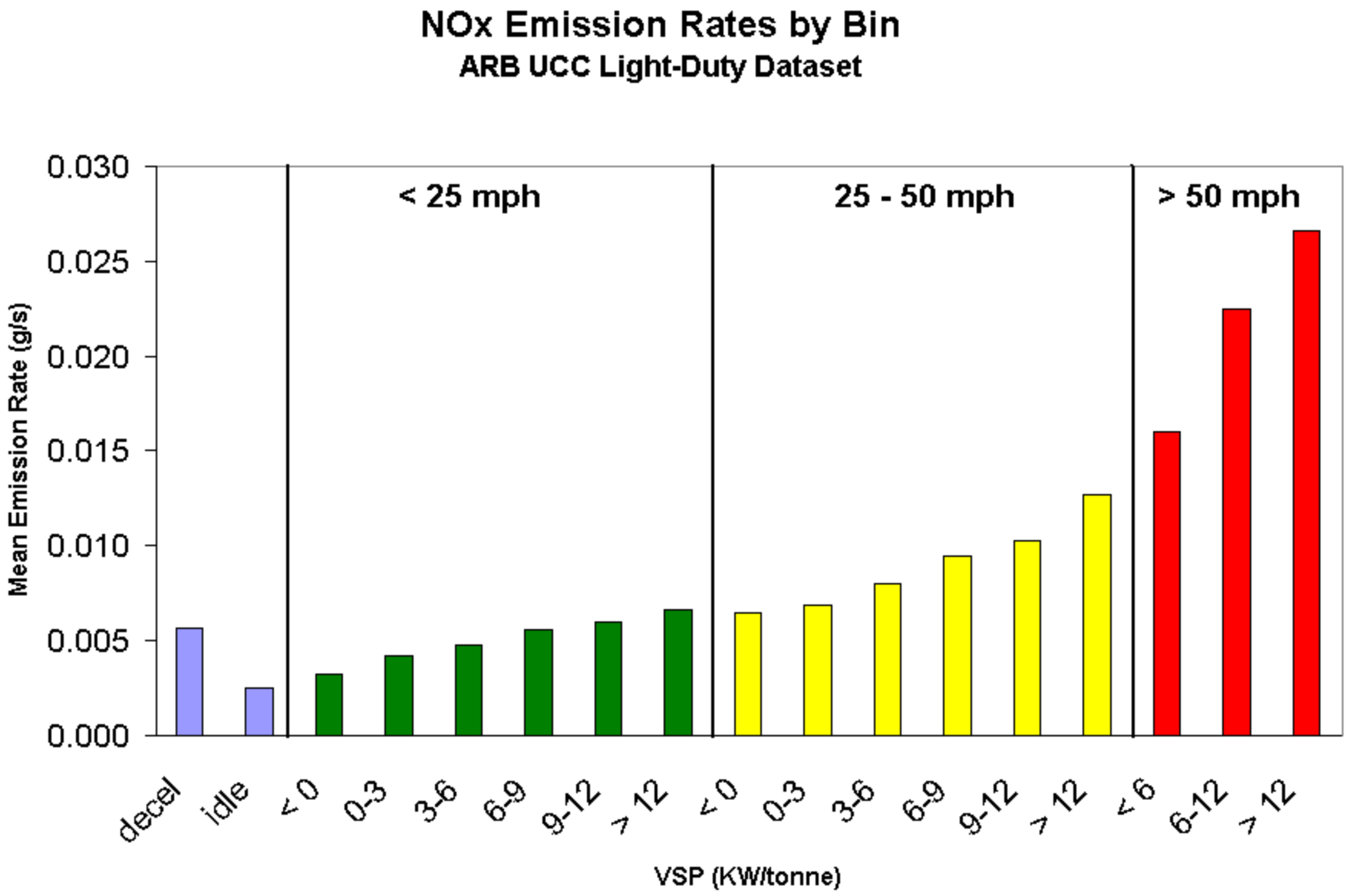

Heavy Duty CO
Observed Trip CO Rate (g/s)
Predicted Trip CO Rate (g/s)
.10
.08
.06
.04
.02
0.00
0.00
.02
.04
.06
.08
.10


Light Duty HC
Observed Trip HC Rate (g/s)
.010
.008
.006
.004
.002
0.000
0.000
.002
.004
.006
.008
.010
Predicted Trip HC Rate (g/s)


Heavy Duty HC
Observed Trip HC Rate (g/s)
Predicted Trip HC Rate
.012
.010
.008
.006
.004
.002
0.000
0.000
.002
.004
.006
.008
.010
.012



Note: The rates shown here were developed for example purposes only. Rates developed for MOVES will be further divided by source bins, I.e. categories defined vehicle weight, engine size and fuel type



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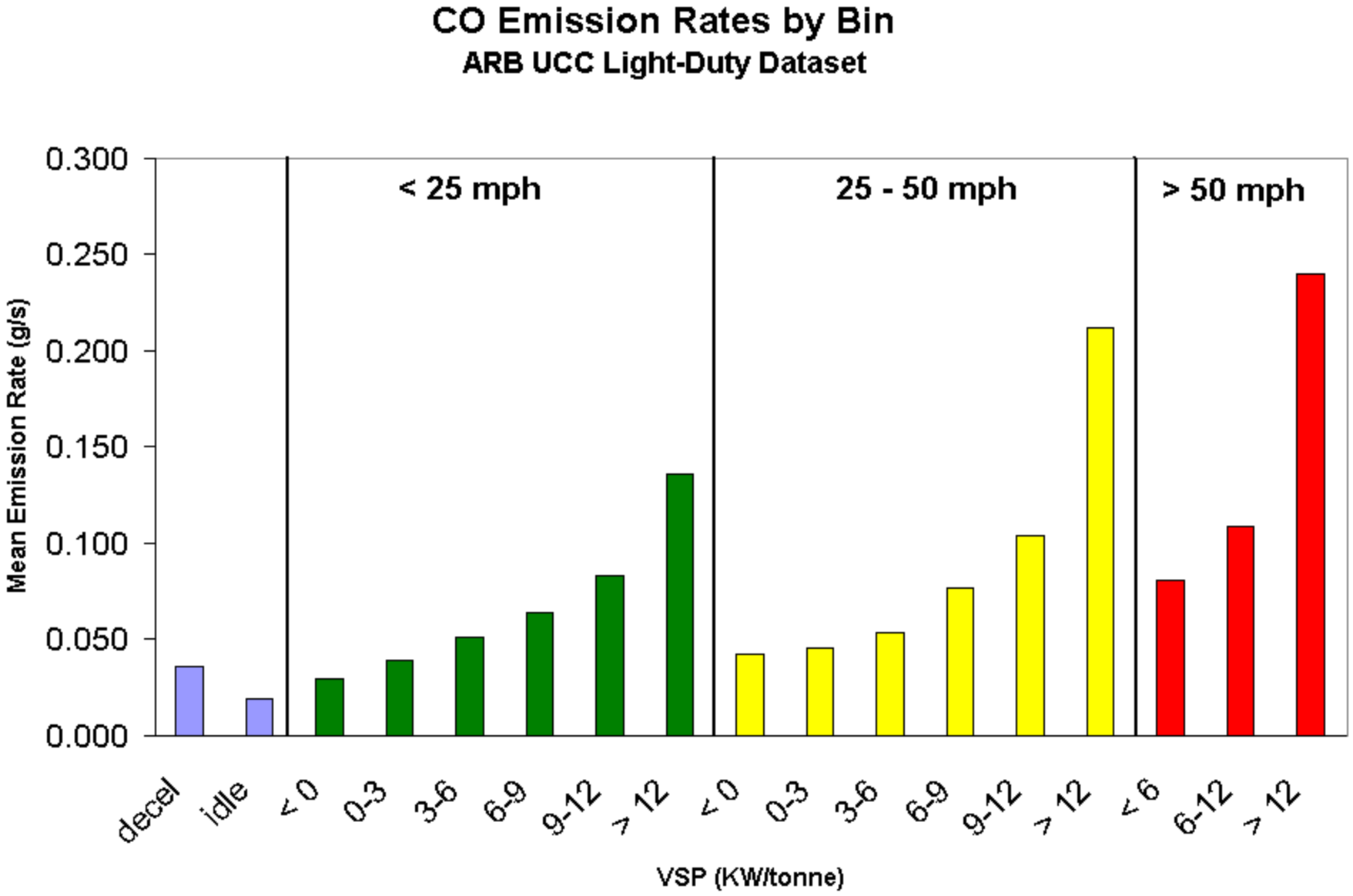

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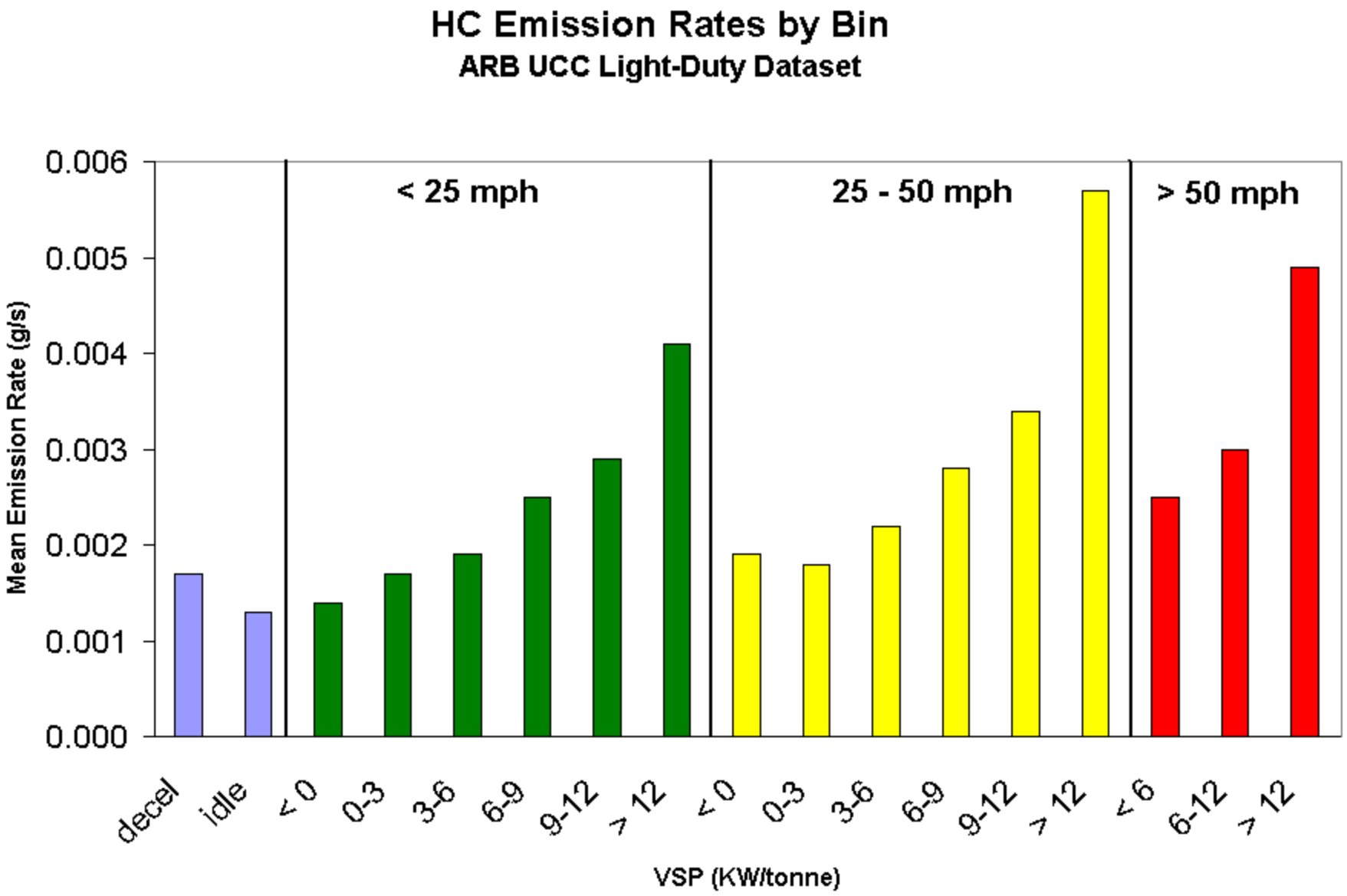

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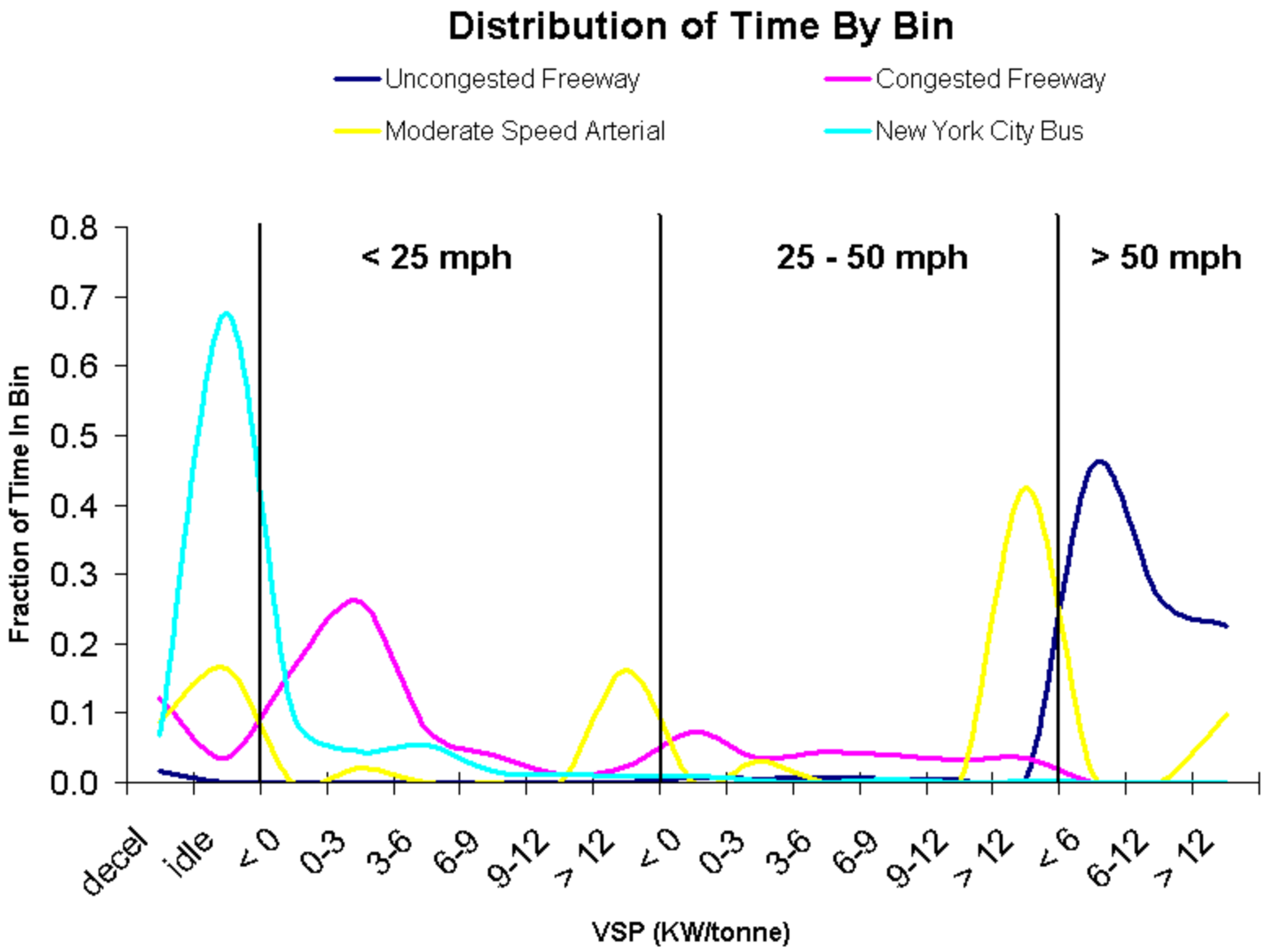
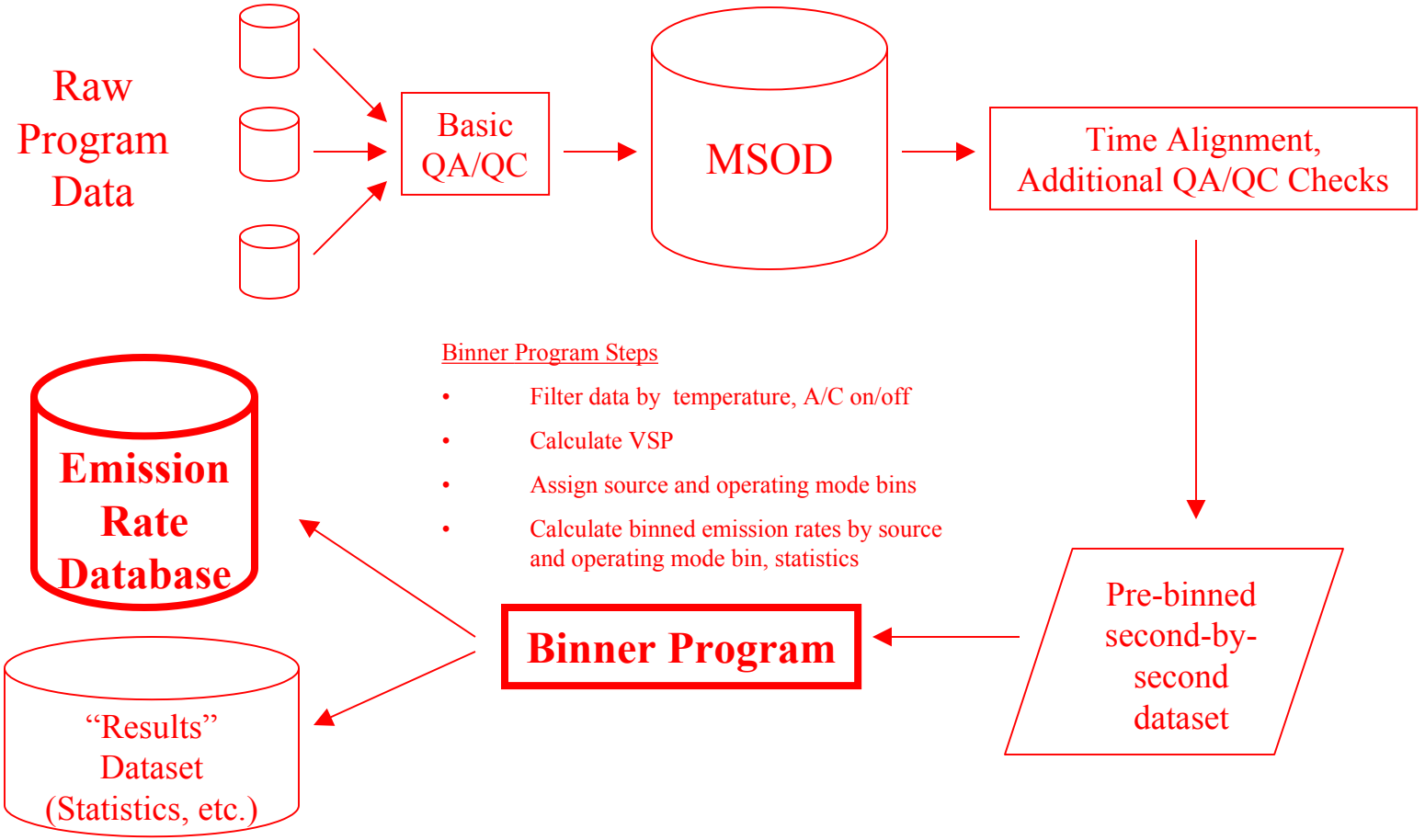

Distribution of Time By Bin
Uncongested Freeway
Congested Freeway
Moderate Speed Arterial
New York City Bus
< 25 mph
25 - 50 mph
> 50 mph
Fraction of Time In Bin
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
decel
idle
< 0
0-3
3-6
6-9
9-12
> 12
< 0
0-3
3-6
6-9
9-12
> 12
< 6
6-12
> 12
VSP (KW/tonne)

Binning Process (Running Total Energy)



Binner Results (as of Nov 24th)

- **Number of total energy source bins making up the 1999 Calendar Year fleet = 605**
- **Number of source bins with data from MSOD = 151**
- **Percent of 1999 fleet covered, by source use type:**

Passenger car: 98%	Motorhome: 58%
Passenger truck: 93%	Combination Short-haul: 36%
Light commercial truck: 87%	Combination Long-haul: 24%
Single Unit Short-haul: 65%	Urban bus: 99%
Single Unit Long-haul: 65%	School bus: 84%
Refuse Truck: 86%	Interstate bus: 100%
	Motorcycles: 0%

Filling Holes

- **Emission rates needed for bins which are not covered by MSOD**
- **Number of source bin "holes" needed to cover 98% of fleet: 131**
- **Hole-filling approaches investigated:**
  - Interpolation with surrounding bins
  - Derive binned rates from bag data
  - Calibrate PERE to bag data, generate binned data

CH_4 and N_2O

- **FTP bag data from MSOD**
  - Includes new data from ARB and CE-CERT
- **Aggregate rates (i.e. not binned)**
  - Running: gram/hour of operation
  - Start: gram/start
- **Methodology:**
  - Analysis performed by ICF
  - Source bins defined according to emission technology categories in EPA's "Inventory of U.S. Greenhouse Gas Emission and Sinks"

Starts

- **FTP bag data from MSOD**
- **Proposed methodology:**
  - Total energy (KJ/start) = Bag 1 – Bag 3
  - CH_4 & N_2O (gram/start) = Composite FTP – Bag 2
- **Temperature adjustments based on MSOD bag data (Total energy only)**

Extended Idle

- **EPA testing**
- **Paired tests on 5 HHD trucks**
  - 600 rpm and 1200 rpm (typical curb & extended)
  - AC on and off
- **Increase in fuel consumption between low and high speed idle = 220%**
- **Proposed Methodology:**
  - Multiply running idle rates by 2.22 for source bins making up Combination Long-Haul trucks

Well-To-Pump

- **GREET**
  - Total, Fossil, Petroleum Energy
    - Upstream energy consumption per on-road energy consumption
  - CH_4 and N_2O
    - Upstream emissions per on-road energy consumption
  - Emission rates by
    - Calendar year (1990 through 2020)
    - Fuel pathway option
      - CG, RFG, E10, Diesel, Biodiesel, FT Diesel, Ethanol, Methanol, CNG, LPG, Gaseous Hydrogen, Liquid Hydrogen, Electricity

Summary

- Emission rates under development for all pollutants/processes in MOVES2004
- Modal binning approach has been developed for running total energy and as prelude for other pollutants; validation looks good
- Binning program “Data Crank” will enable easy updates of emission rates with new data
- Existing data covers large portion of fleet; currently investigating options for filling holes
- Methods proposed for start, CH_4, N_2O, extended idle and well-to-pump rates