A Physical Emissions Rate Estimator for MOVES

Edward Nam

Ford Research & Advanced Engineering

13th CRC On-Road Vehicle Emissions Worlshop

April 8, 2003

Acknowledgments

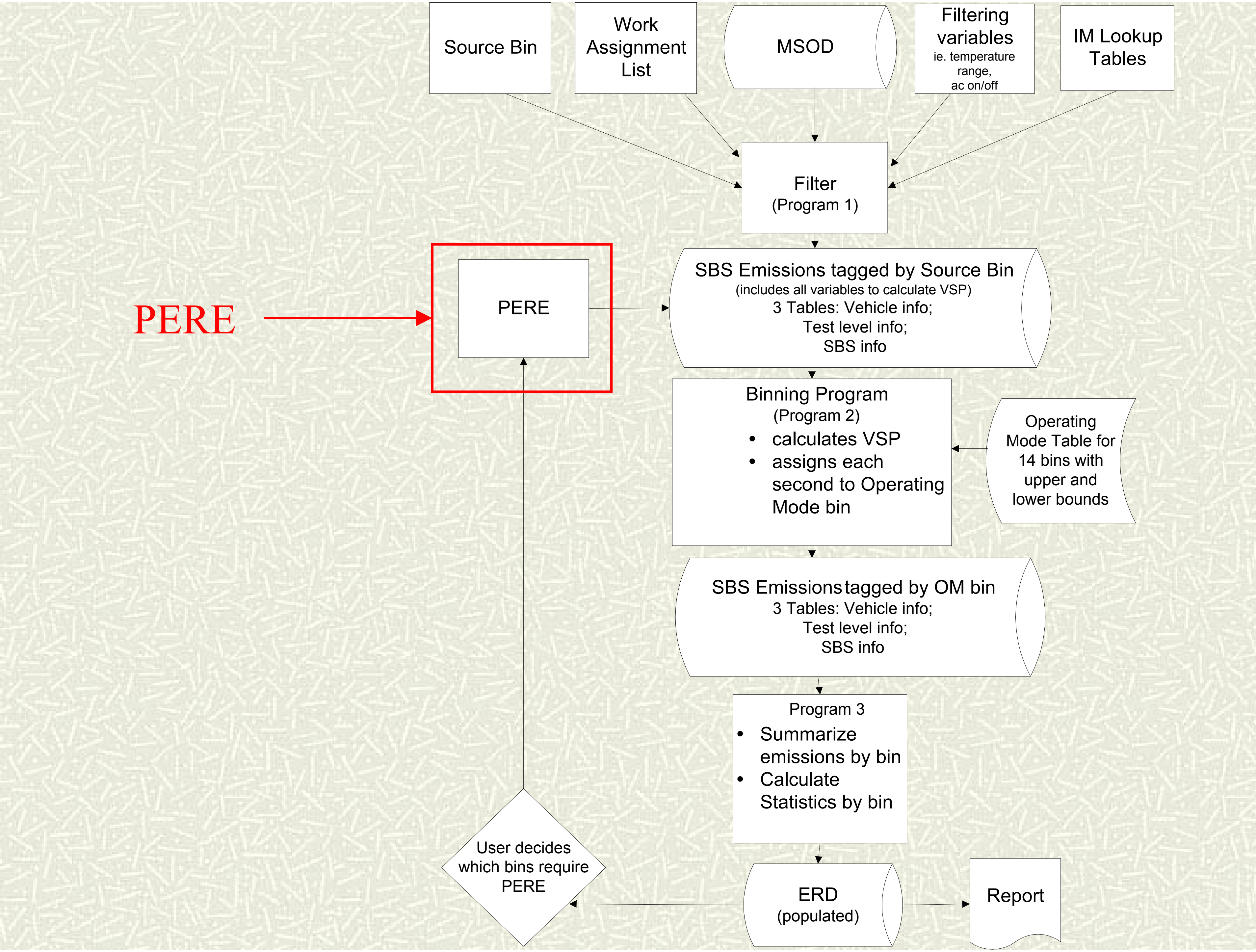
- Ford: David Chock
- EPA: Bob Giannelli, John Koupal, Connie Hart, David Brzezinski, Chad Bailey

Outline

- MOVES design
- Physical Emissions Rate Estimator (PERE)
- VSP and Fuel Rate
- Fuel Rate validation
- Fuel rate limitations
- Engine out model and validation
- Catalyst Pass Fraction model and validation
- CPF limitations

The Next Generation EPA Emissions Model (MOVES)

- Should be data driven (Dyno, on road, IM, RSD, etc)
- Emissions rates based on road load (VSP, or power) instead of average speed
- But what about where data is lacking?

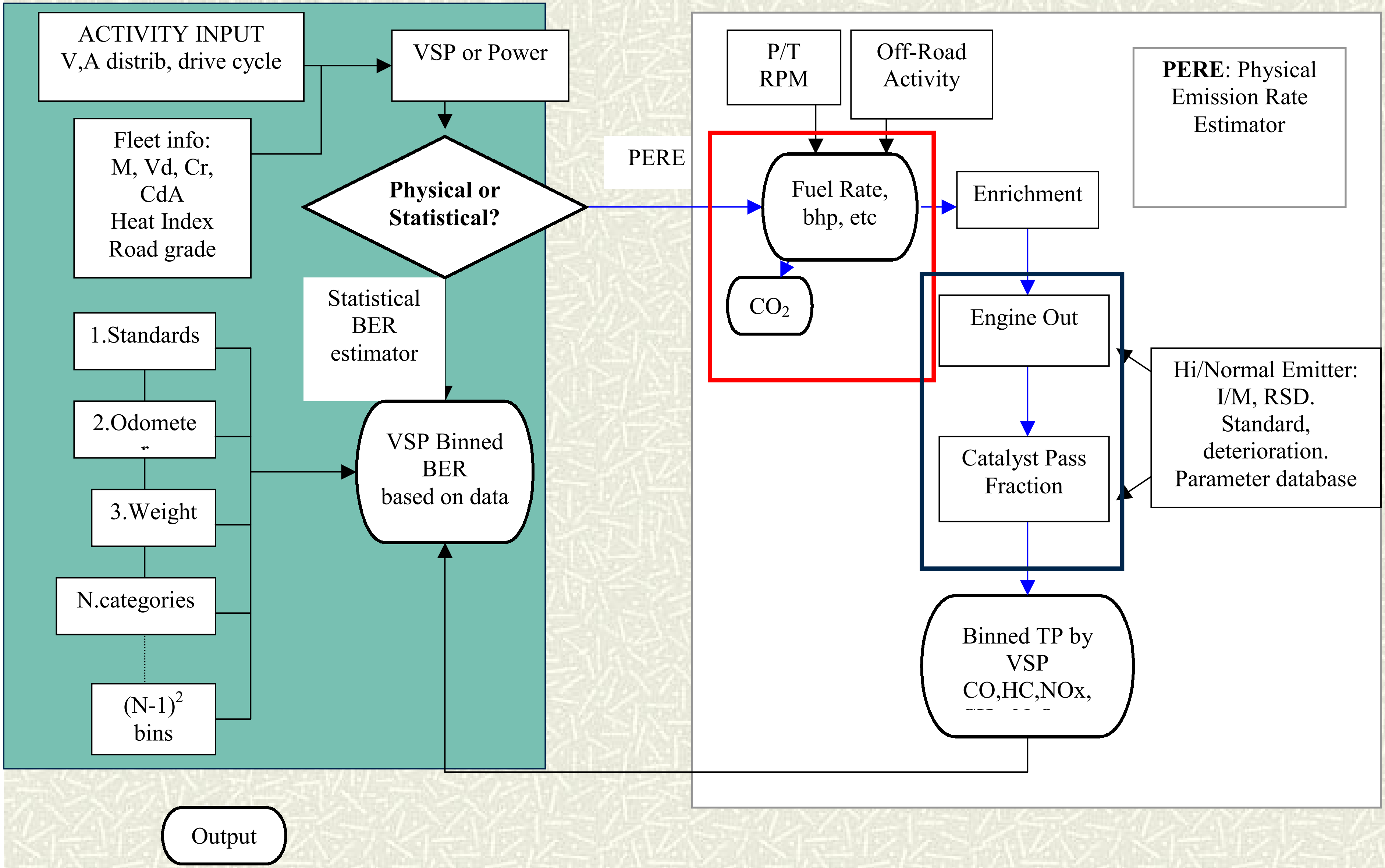

Source Bin
Work Assignment List
MSOD
Filtering variables
ie. temperature range, ac on/off
IM Lookup Tables
Filter
(Program 1)
PERE
PERE
SBS Emissions tagged by Source Bin
(includes all variables to calculate VSP)
3 Tables: Vehicle info;
Test level info;
SBS info
Binning Program
(Program 2)
• calculates VSP
• assigns each second to Operating Mode bin
Operating Mode Table for 14 bins with upper and lower bounds
SBS Emissions tagged by OM bin
3 Tables: Vehicle info;
Test level info;
SBS info
Program 3
• Summarize emissions by bin
• Calculate Statistics by bin
User decides which bins require PERE
ERD
(populated)
Report

Physical Emission Rate Estimator

- Based on Basic Physical Principles
  - Based on Comprehensive Modal Emissions Model: CMEM (UC Riverside, CE-CERT)
- Parameterized and Statistically binned
- Calibrated to known data
- Fill sparsely populated bins
  - Reducing data needs and possibly cost
  - Helps extrapolate and interpolate data points
  - Deterioration
  - New technologies
  - Off-Road vehicles
  - Fuel Types, etc
- Allows a method to check quality of data

PERE Process

- Understand a small controlled sample set in great detail
- Develop a physical model (compatible with MOVES) that describes the data
- Generalize to other (limited) data sets and modify model as needed
- “Living Model”


ACTIVITY INPUT
V,A distrib, drive cycle
VSP or Power
Fleet info:
M, Vd, Cr,
CdA
Heat Index
Road grade
Physical or Statistical?
PERE
Statistical BER estimator
1.Standards
2.Odomete r
3.Weight
N.categories
(N-1)2 bins
VSP Binned BER based on data
P/T RPM
Off-Road Activity
PERE: Physical Emission Rate Estimator
Fuel Rate, bhp, etc
Enrichment
CO2
Engine Out
Catalyst Pass Fraction
Hi/Normal Emitter:
I/M, RSD.
Standard,
deterioration.
Parameter database
Binned TP by VSP
CO,HC,NOx,
Output

Vehicle Specific Power

- Based on Road Load power demand

- ***$VSP = v *(a*(1+\varepsilon) + g*grade + g*C_R) + 0.5?*C_D*A*v^3/m$***

  - *v*: is vehicle speed (assuming no headwind) in m/s
  - *a*: is vehicle acceleration in m/s^2
  - ε: is mass factor accounting for the rotational masses
  - *g*: is acceleration due to gravity
  - *grade*: is road grade
  - C_R: is rolling resistance (~0.01)
  - *?*: is air density (1.2)
  - $C_D A$: is aerodynamic drag coefficient and Area (0.7)
  - *m*: is vehicle mass in metric tonnes.

Fuel Rate (consumption)

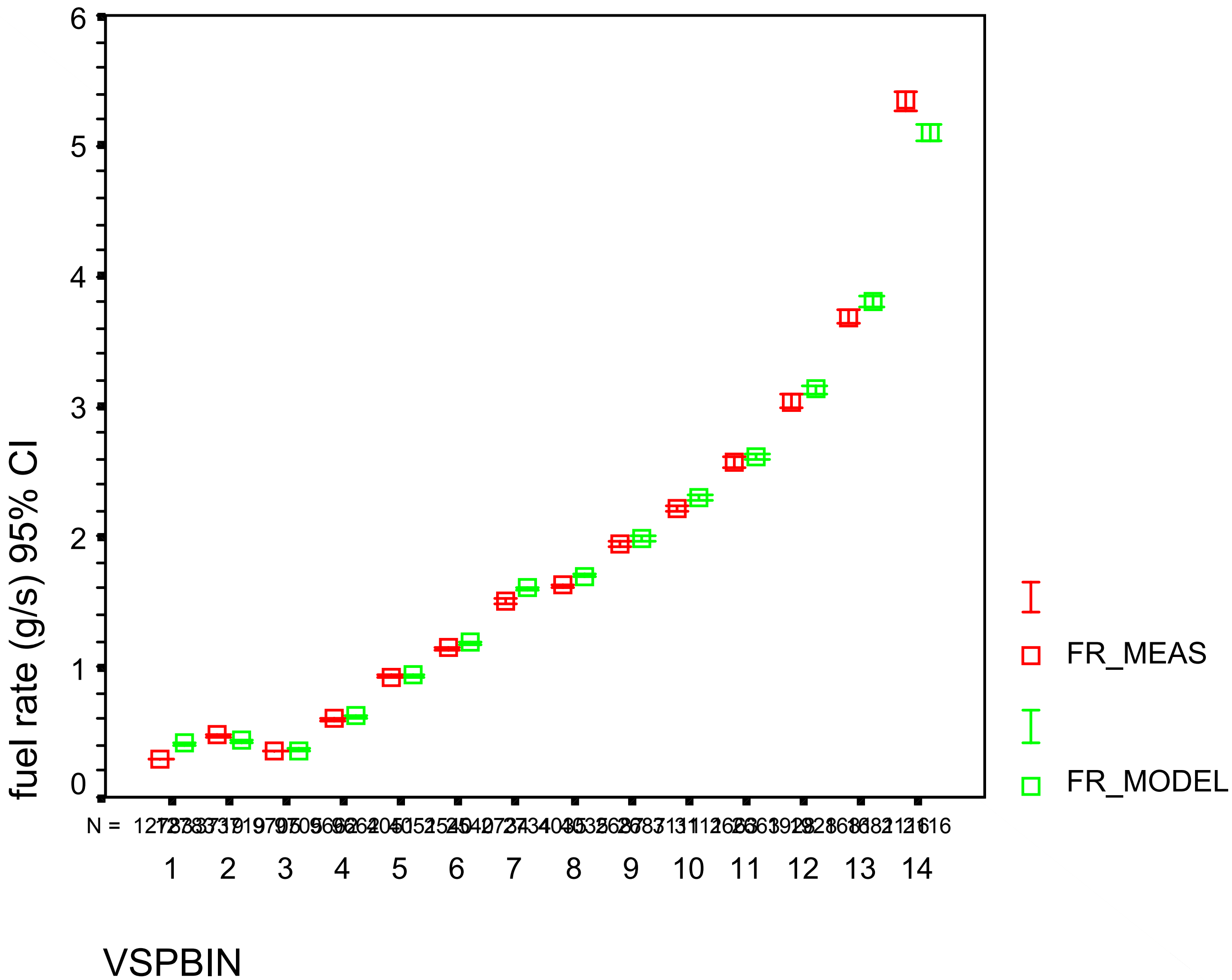
- $FR = f * [K(N)*N(v)*V_d + (VSP*m + P_{acc}(T,N))/?] / LHV$

  - *f* : is the fuel air equivalence ratio (mostly =1)
  - *K(N)*: is the power independent portion of engine friction, dependent on engine speed.
  - *N(v)*: is the engine speed
  - V_d: is the engine displacement volume
  - *?*: is a measure of the engine indicated efficiency (~0.38)
  - *Pacc(T,N)*: is the power draw of accessories such as air conditioning. (Without AC ~ 1kW)
  - *LHV*: is the factor lower heating value of the fuel (~44kJ/g)

Proof of Concept

- For 40 'Normally Emitting' Tier 1 vehicles
- Sec by Sec Engine Out and Tailpipe Measured at UC Riverside
- Calibrated to the hot portions of the FTP & the US06 cycles
- Validated to their MEC01 driving cycle
- Cold Start can be modeled separately later

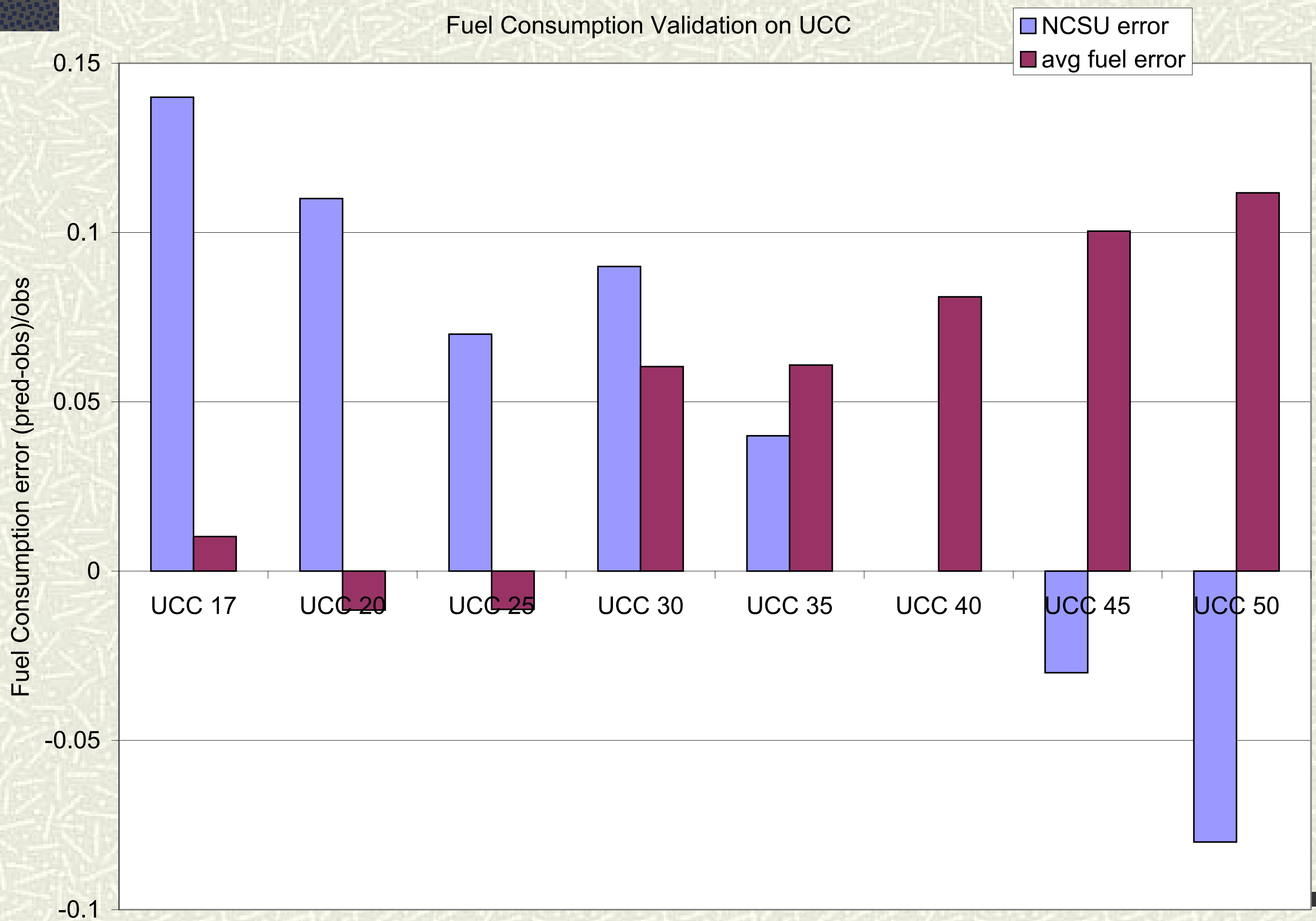
Fuel Rate Validated to MEC01



UCC validation

- Model applied to different vehicle set
- Using 8 different driving cycles (avg speed)

California Speed Cycle Validation



Fuel Rate Limitations

- Validated for MEC cycle
- Speed effects show up on UCC speed cycles
- Systematic errors at higher speeds
- Subject of next study

Is this framework good for criteria pollutants?

- Engine Out
- Catalyst Pass Fractions

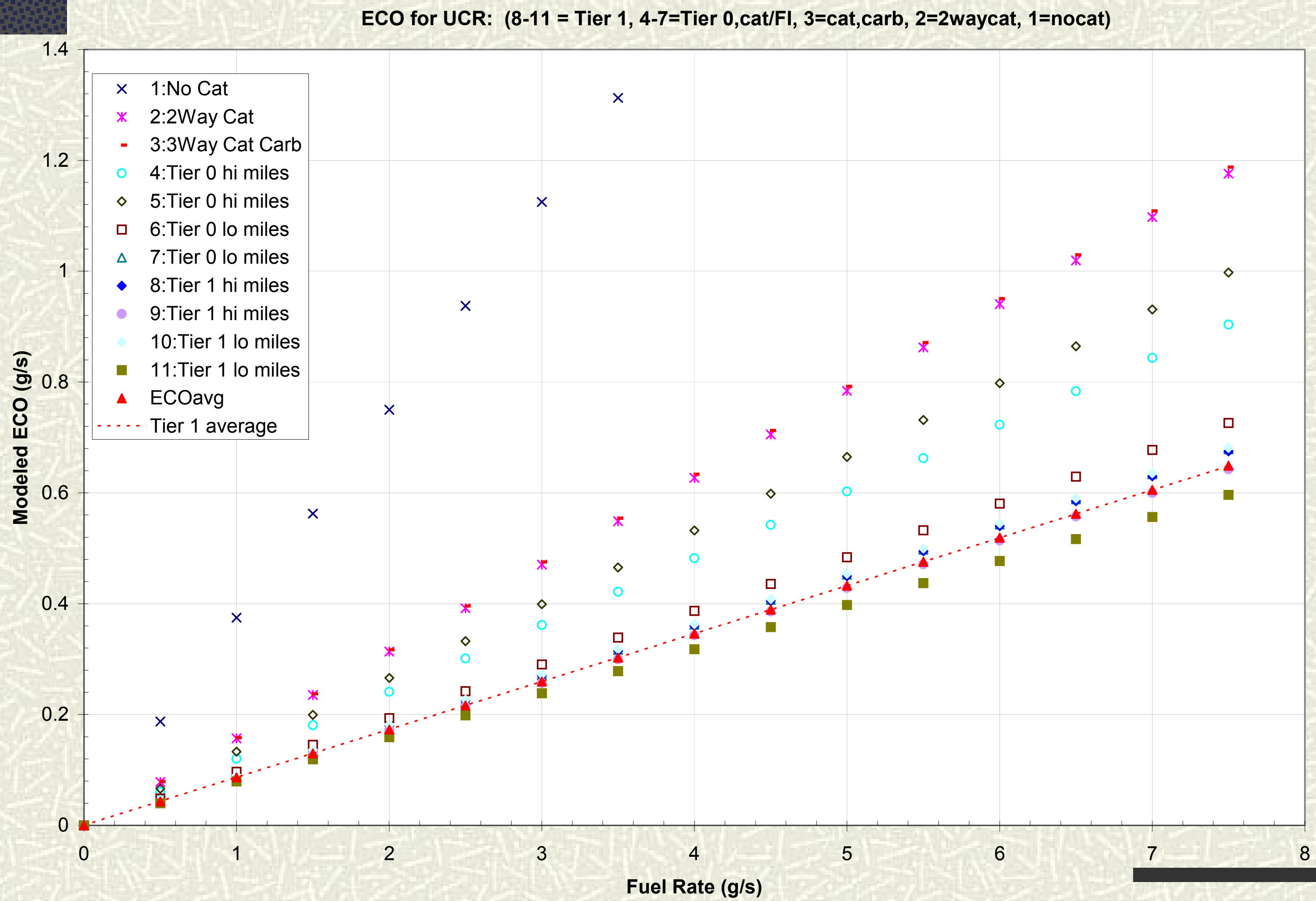
Why model Engine Out (pre-cat)?

- It is easier to model than tailpipe (less scatter)
- To first order, tailpipe emissions follows engine
- Helps give insight into variability of TP data
- Can isolate effects to engine or aftertreatment
- Can physically develop a separate module for catalyst (and new aftertreatment) technologies
- This is the practical limit for most hi emitters
- For vehicles without aftertreatment: EO = TP

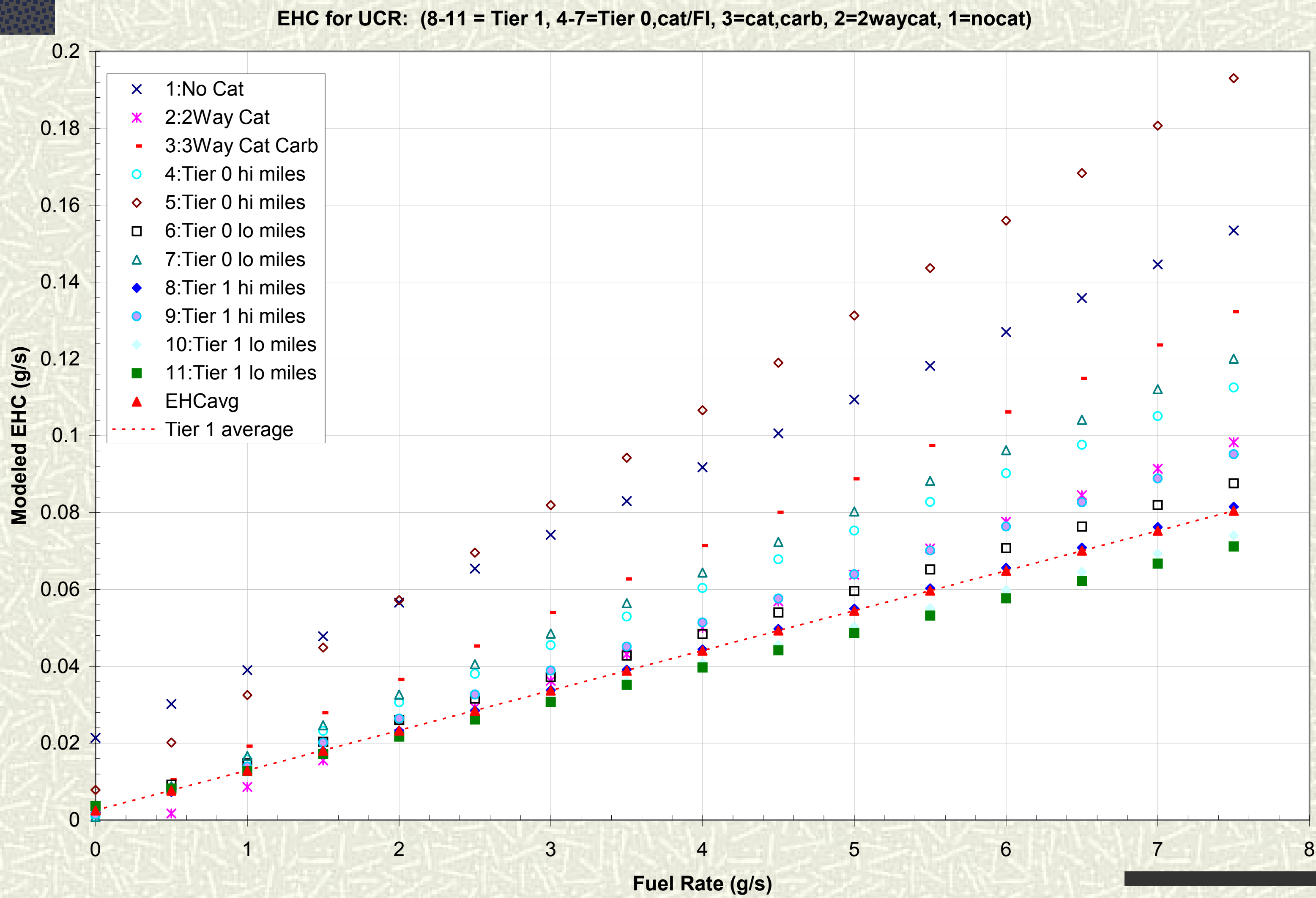
But…

- Engine out data is scarce and hard to collect
- So given a limited EO database, we need to show that EO emissions are stable
- Engine out emissions are relatively steady (on average) within emissions standards

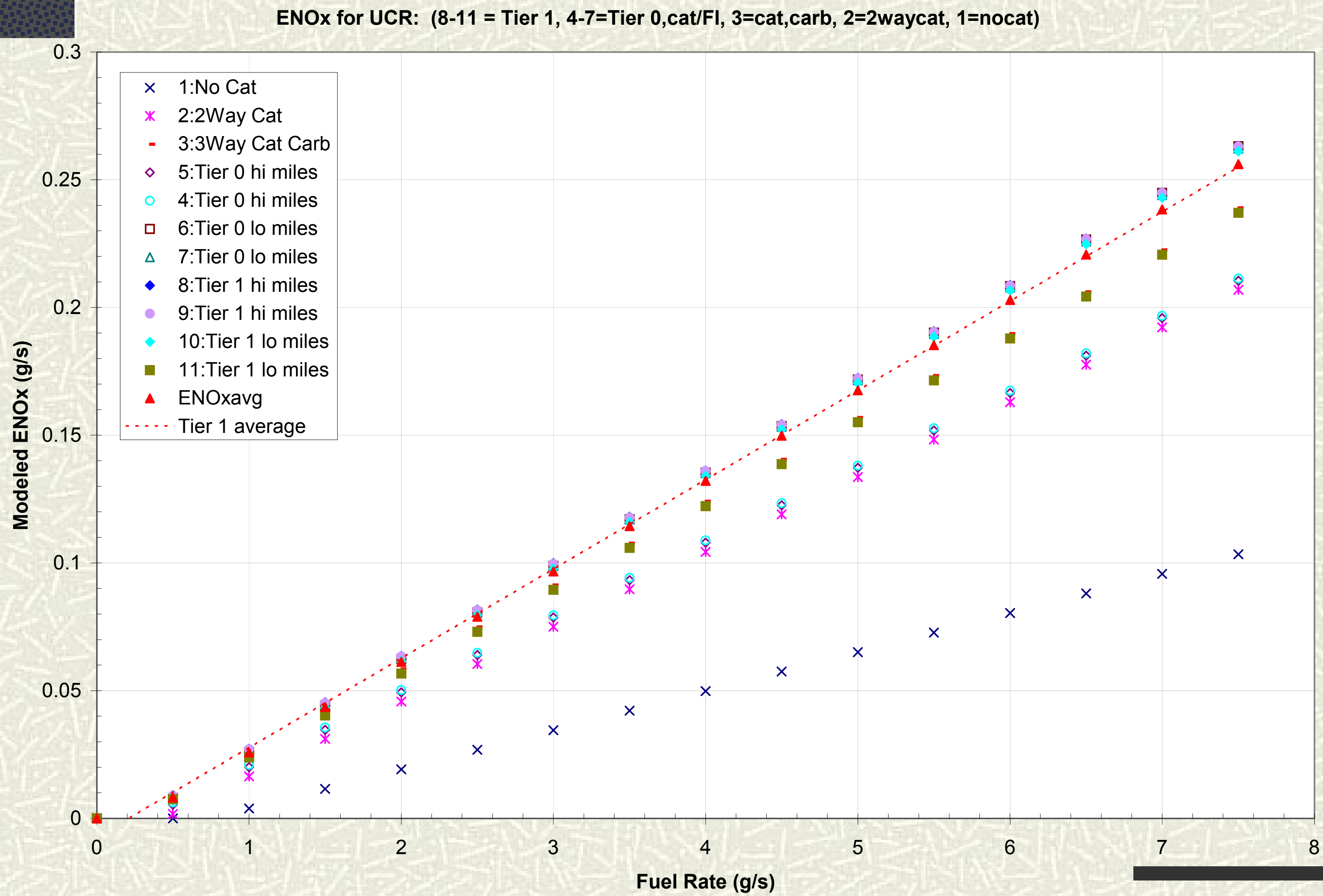
Engine Out CO from CMEM



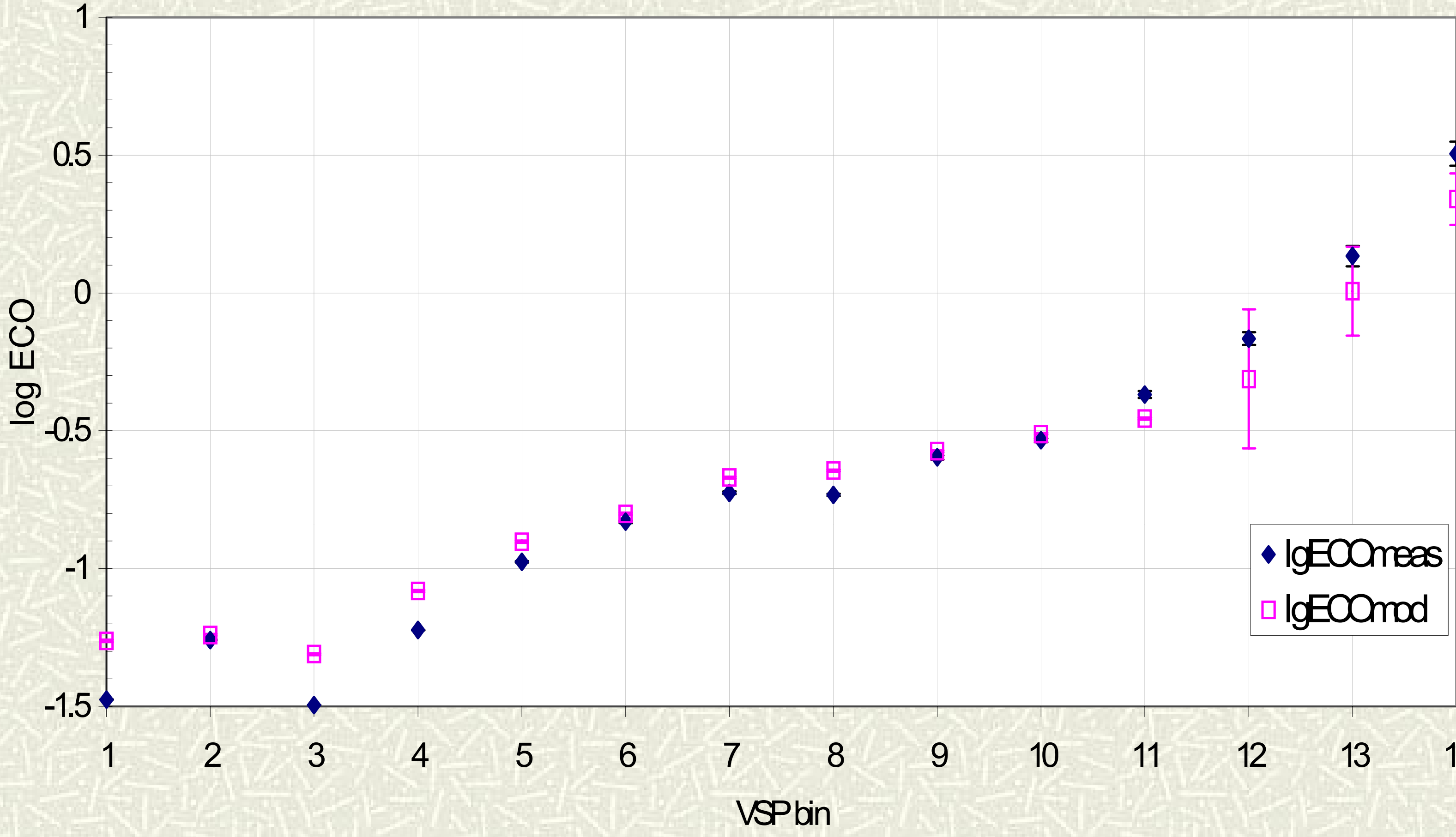
Engine Out HC in CMEM



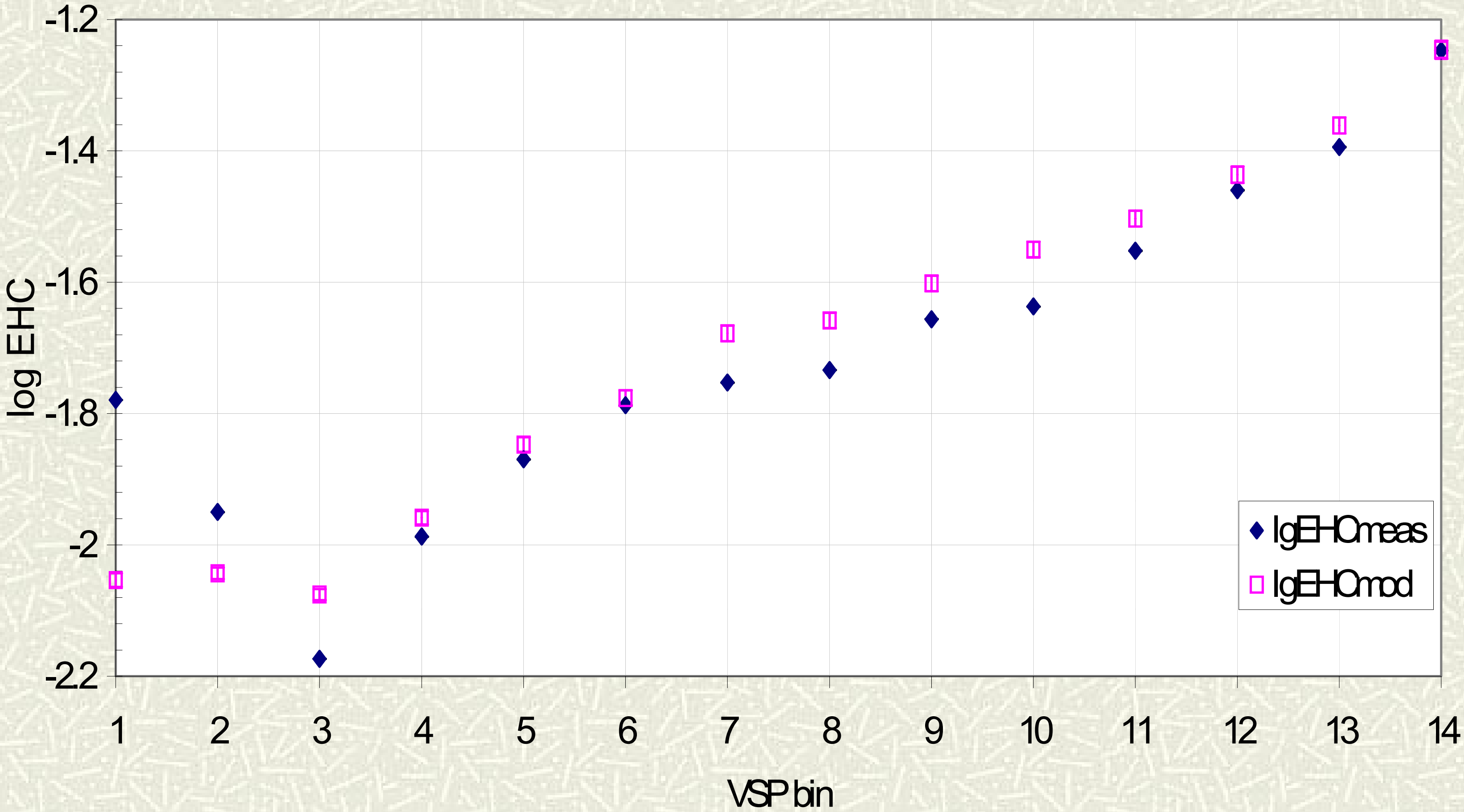
Engine Out NOx in CMEM



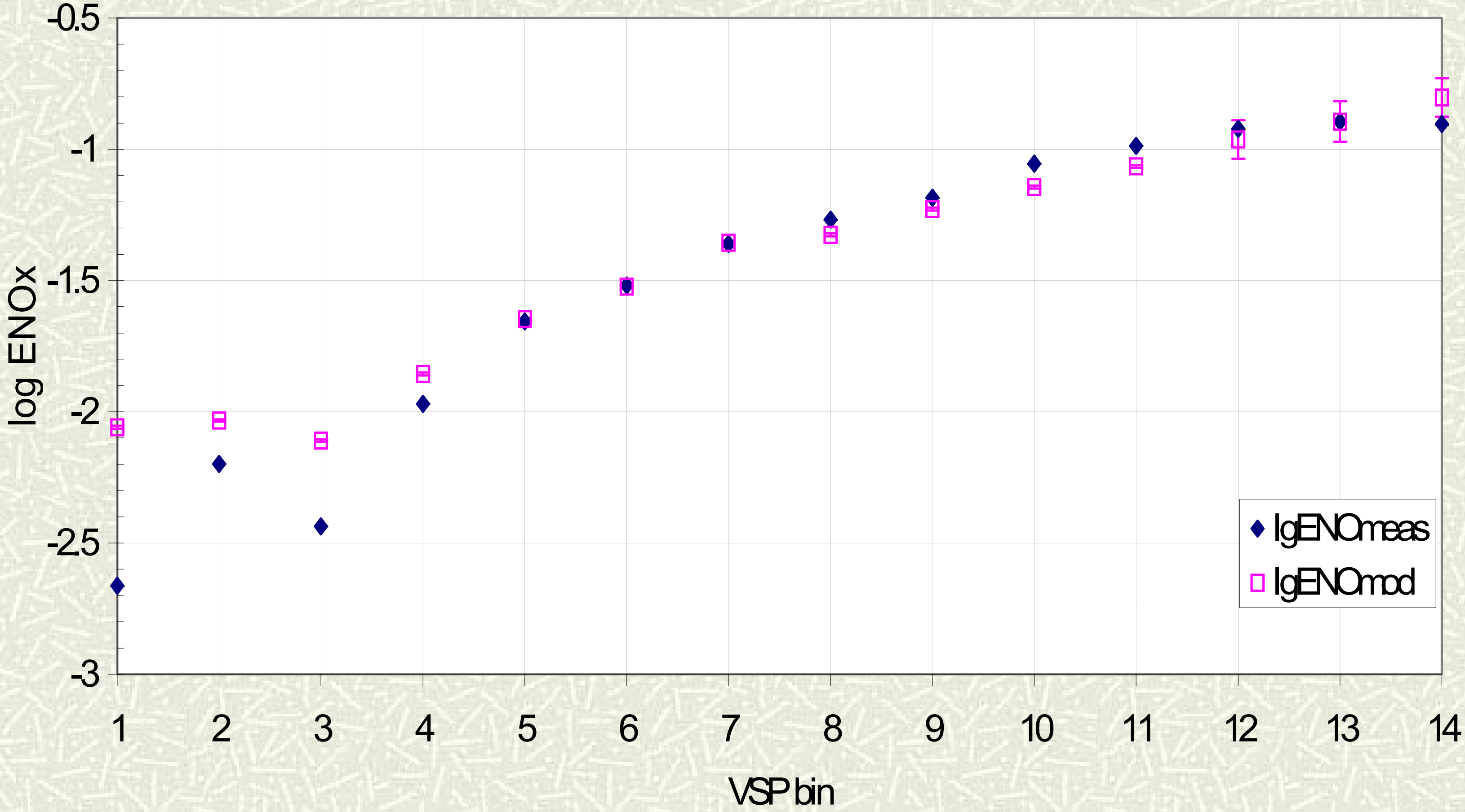
Engine Out CO Validation



Engine Out HC Validation



Engine Out NOx Validation



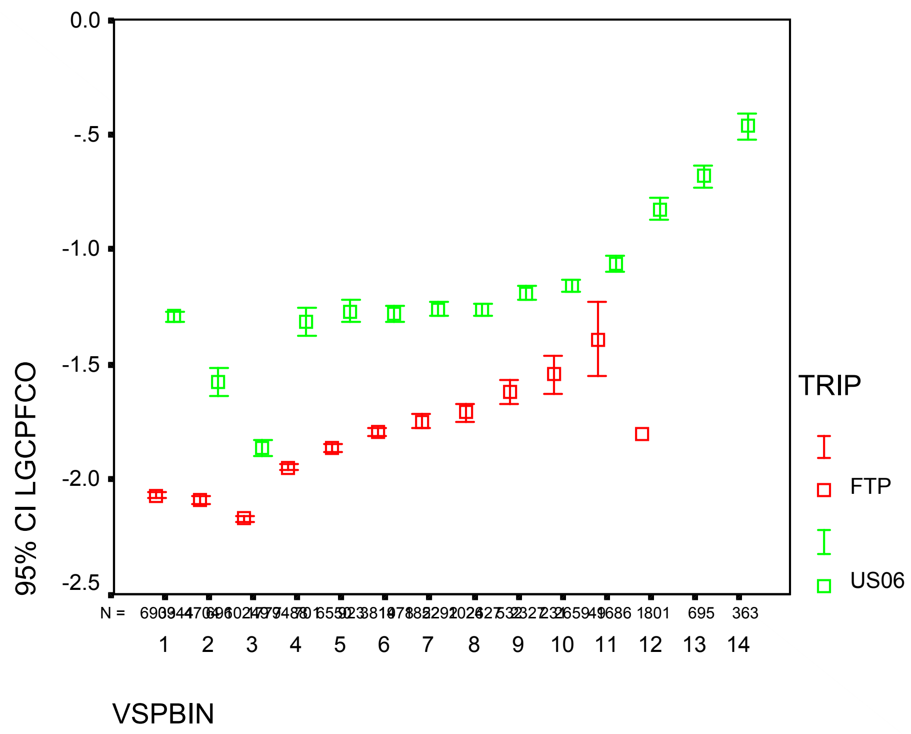
Catalyst Pass Fractions

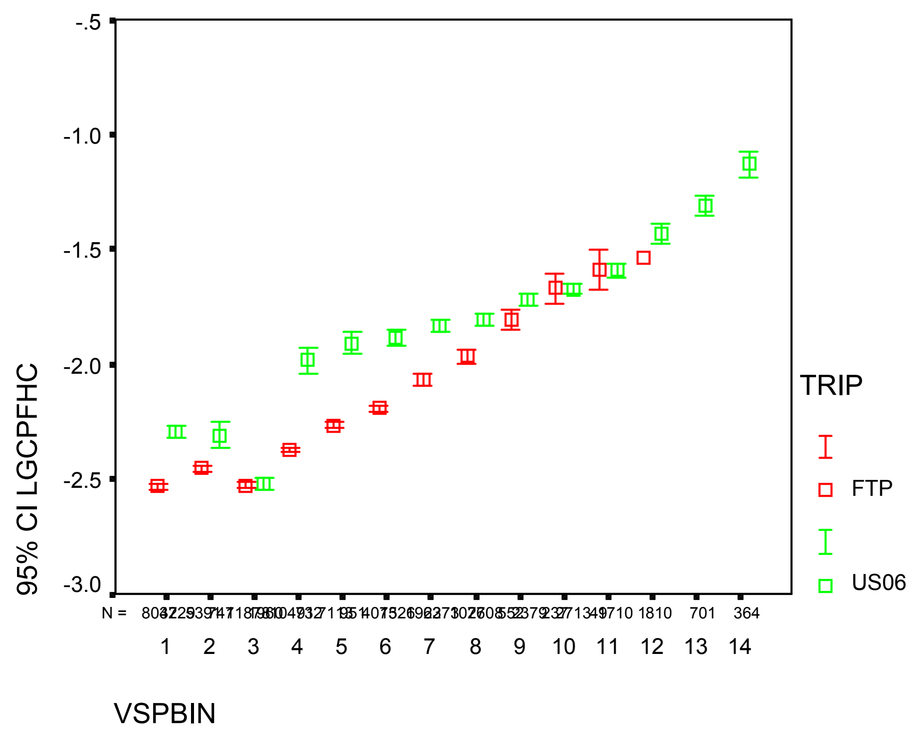
- To First Order, Tailpipe Emissions follows EO (for a given vehicle)
- All else is second order (though it may be significant)

  - TP = CPF * EO
  - Catalyst Eff (Γ)= 100%*(1-CPF)

- Due to their extreme data scatter, CPF is very difficult to model accurately.
- We will average in VSP bins to see trends

CPF Trends for CO & HC

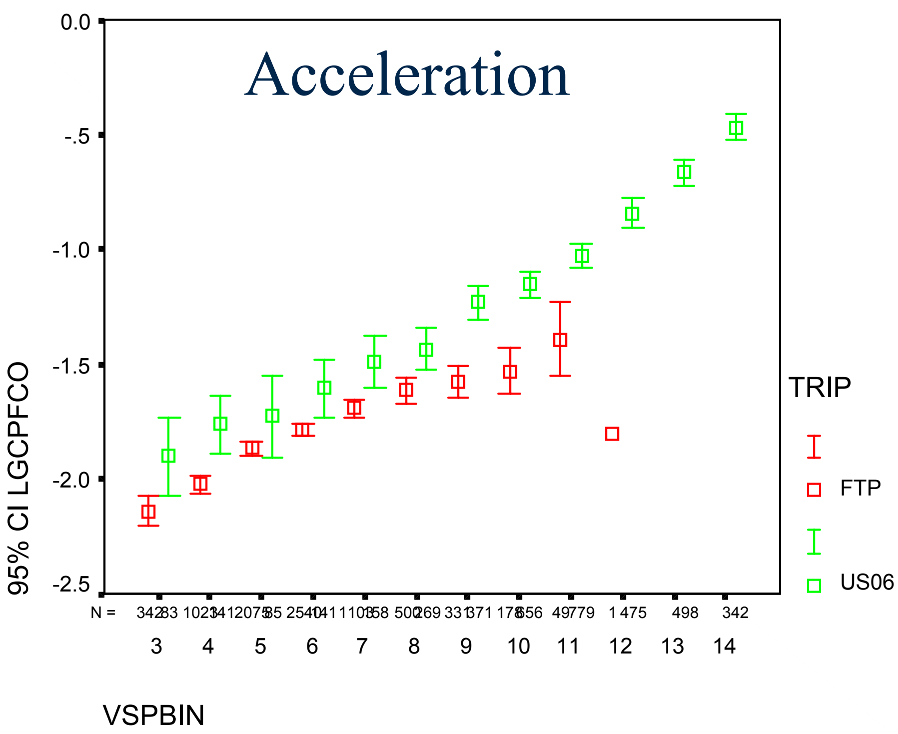


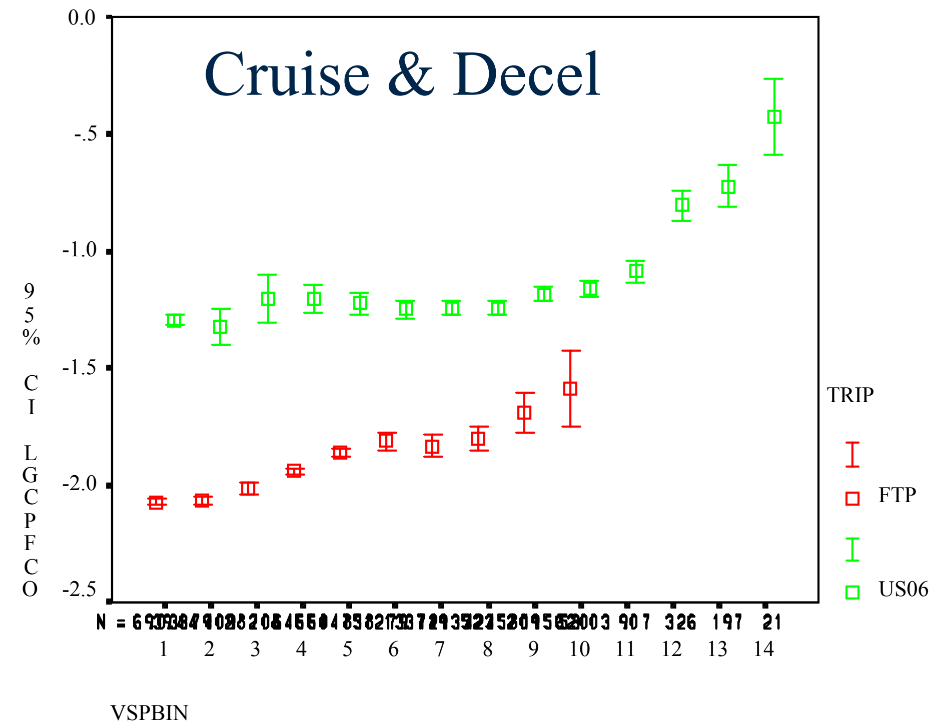


What's going on?

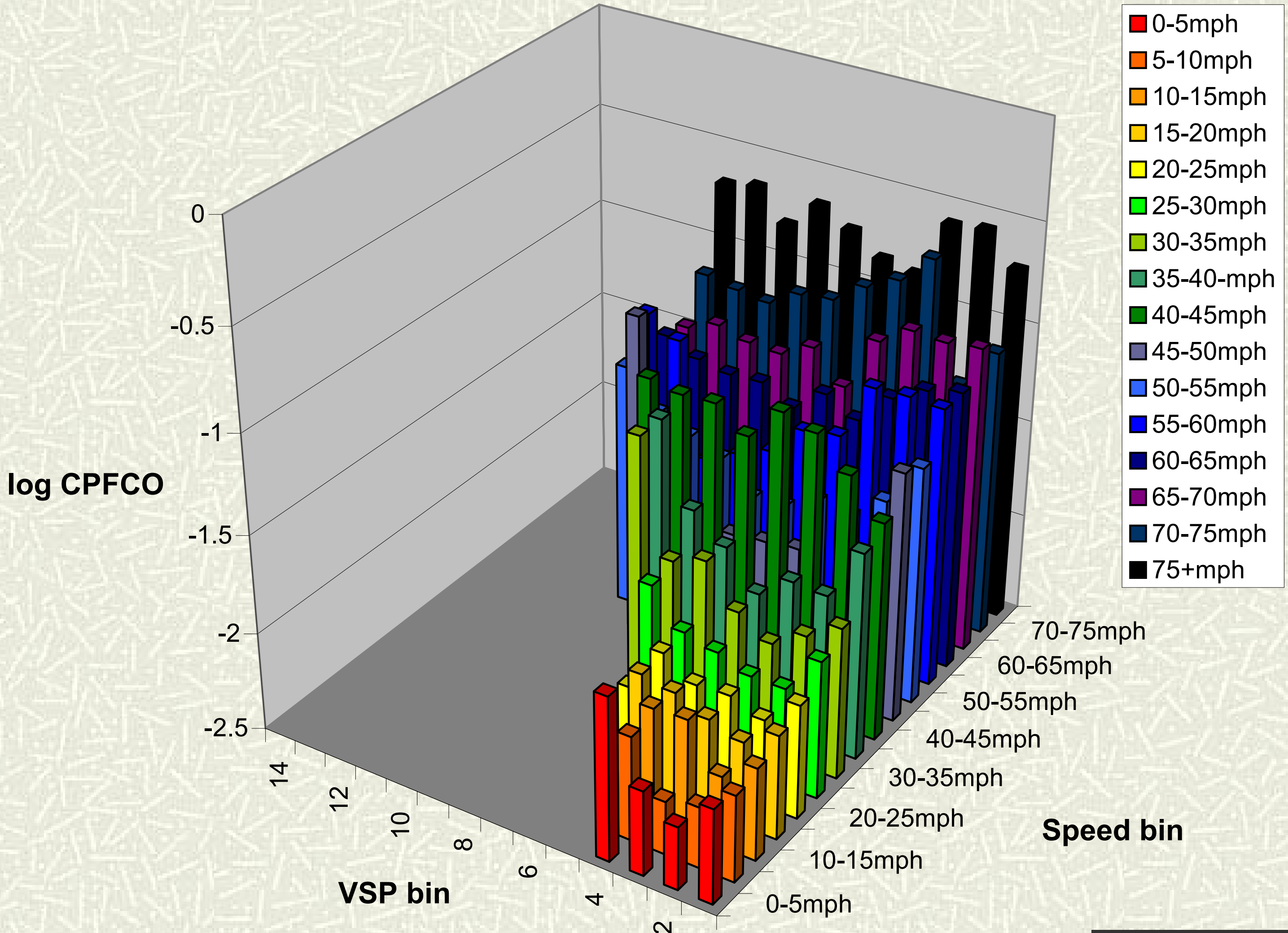
- Emission should be dependent on VSP only!
- This effect is minimal in Engine Out
- Frey et al, noticed a speed effect in UCC cycles, I/M, and RSD data
- High speed cruise & decels in US06 is disturbing the VSP trend

Split out Cruise from Accels

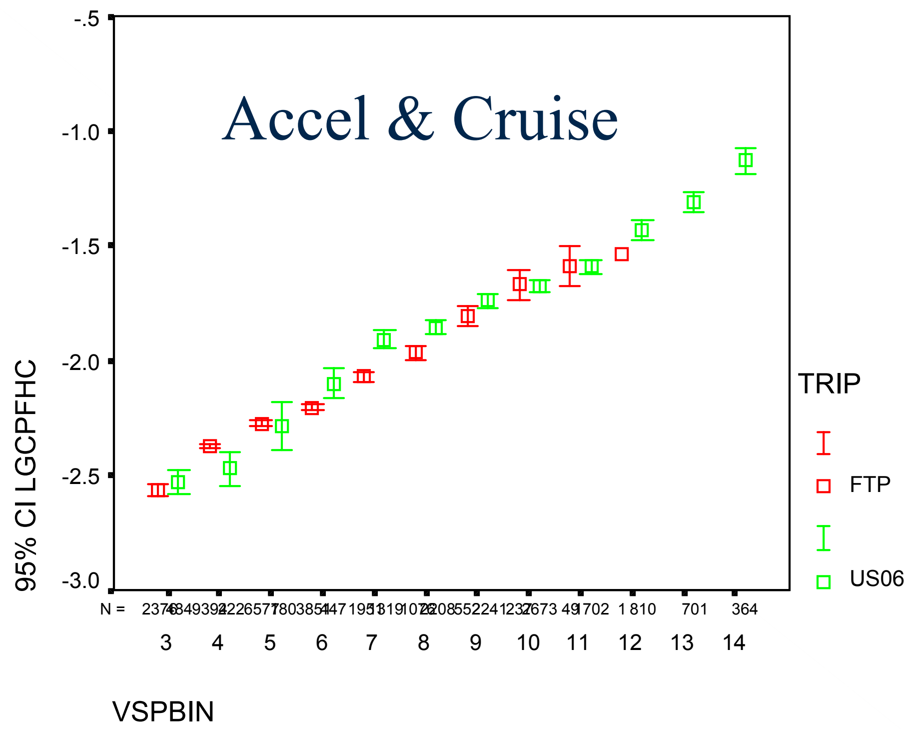


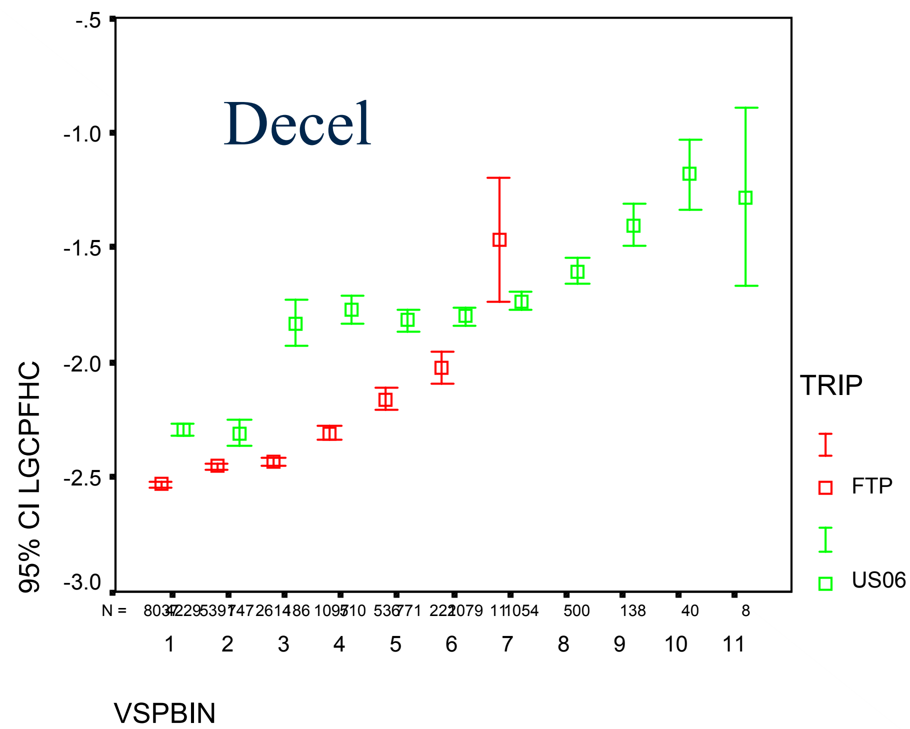


Cruise and Deceleration "Modes"

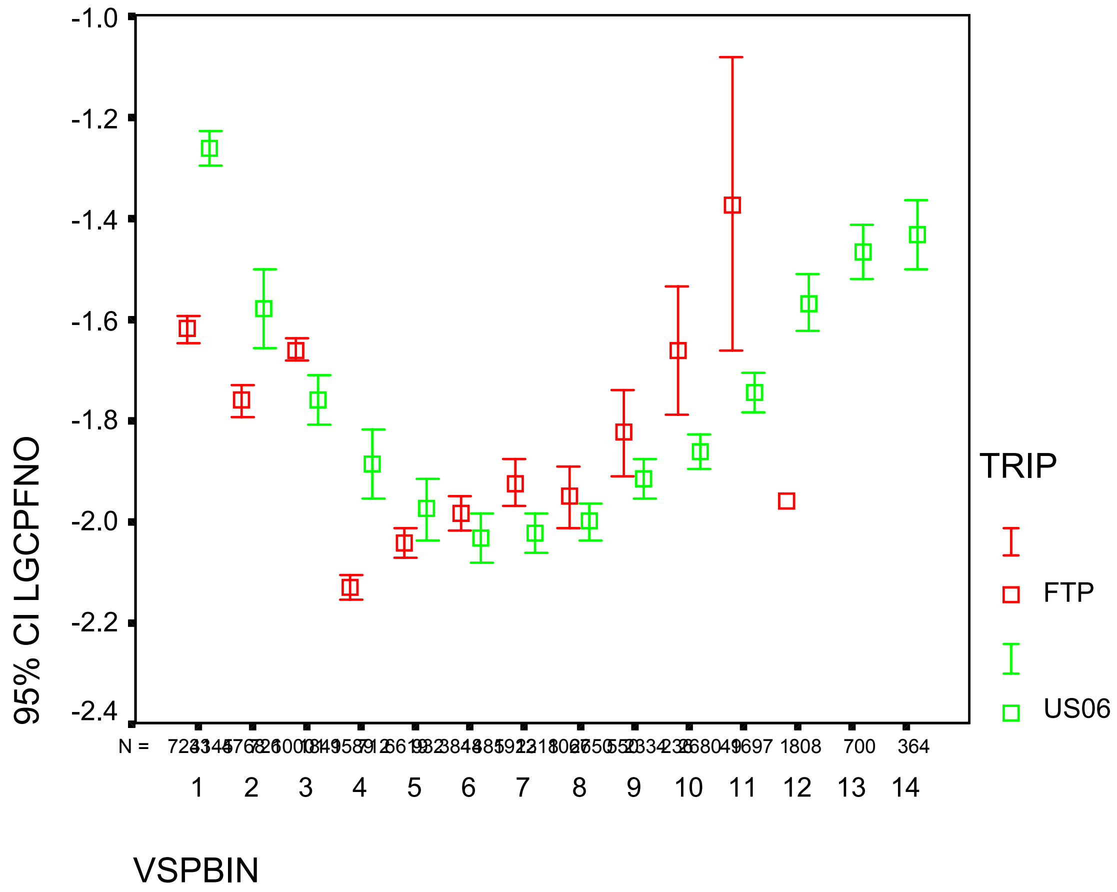


CPF HC in Accel/Cruise and Decel Modes

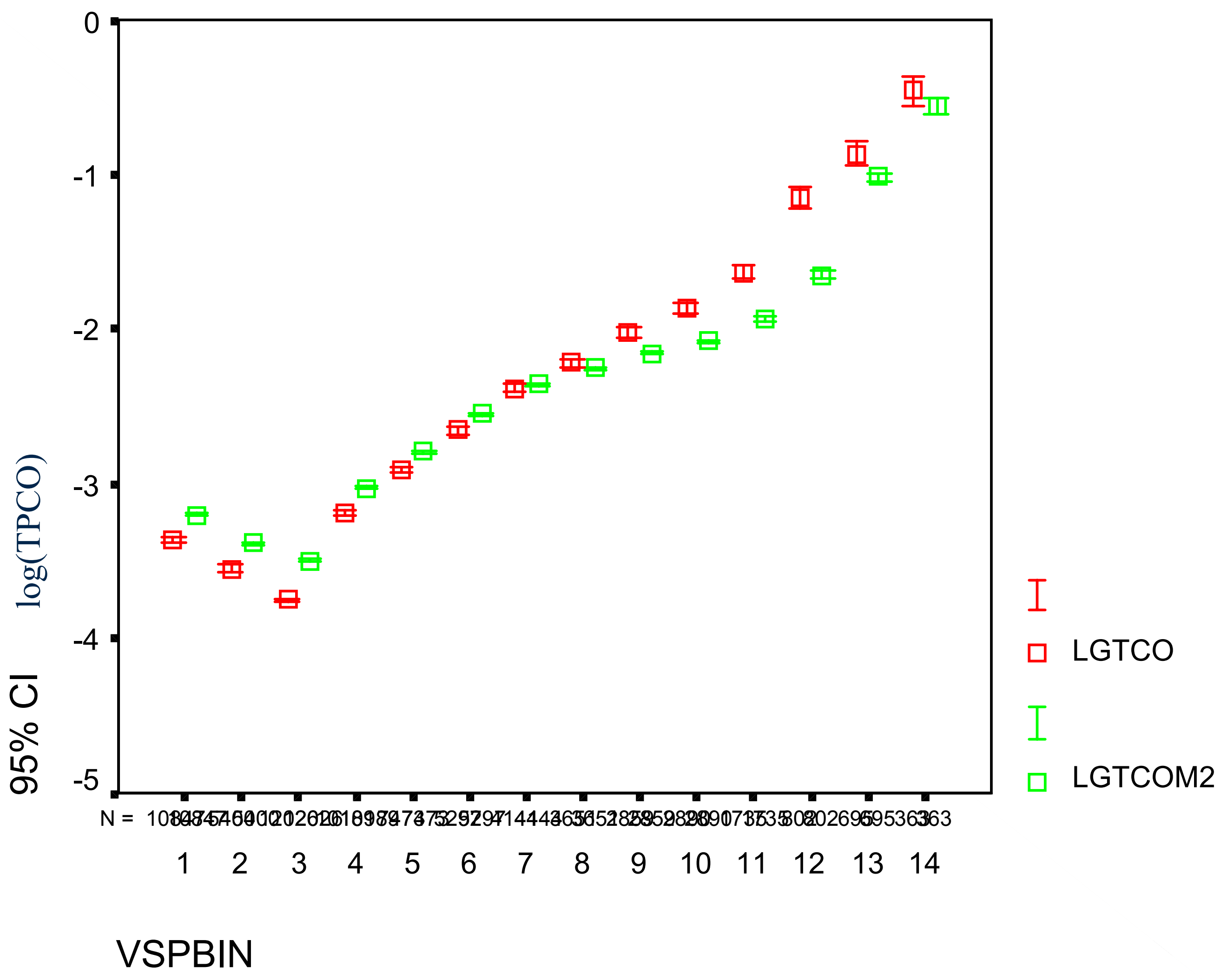




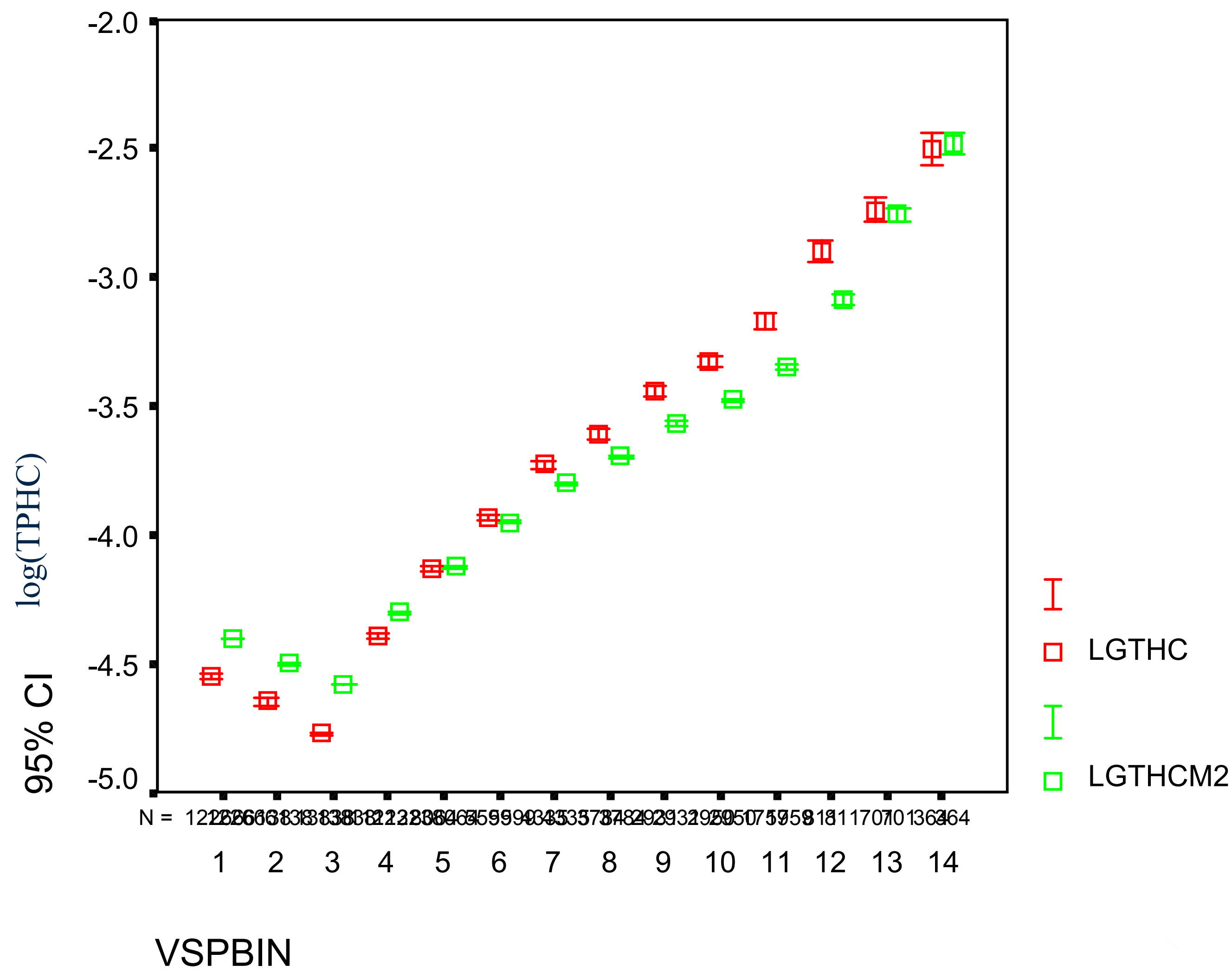
CPF NOx Trends



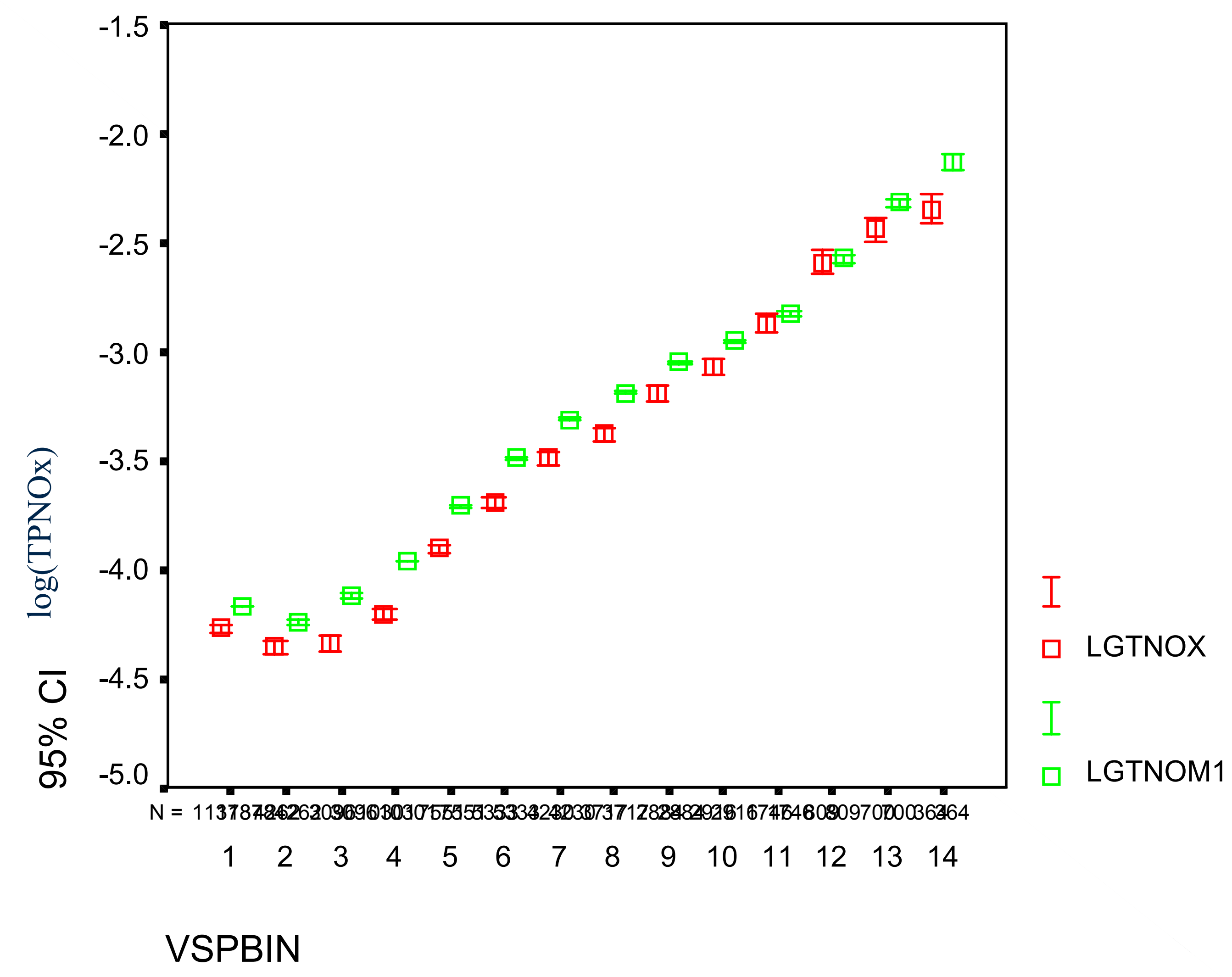
Validation to TP CO



Validation to TP HC



Validation to TP NOx



Conclusions

- Physical Model is designed to supplement MOVES data driven model
- Proof of concept conducted on warmed up Tier 1 (non SFTP certified) properly functioning cars
- Fuel Rate Model – speed error seen
- Uniformity of Tier 1 Engine Out Emissions
- Validated EO model
  - Enrichment thresholds must be revisited for CO
- Catalyst Model – speed error seen for CO
- Need to revisit later for vehicles meeting current (SFTP) & future standards and advanced technologies
- More work to be done…