Development of an International version of the MOVES model

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MOVES International Approach

- Overall goal is to create a generalized process for modifying MOVES for International application.
- Initial project creates a *framework* for MOVES expansion
  - Identify preliminary steps
  - Applies steps to Java codebase and MySQL structure
  - Intended to be used in limited analysis conditions for light duty vehicles
  - Identify potential future improvements
- Initial research into MOVES International development documented in a white paper by Koupal et al.
  - http://www.epa.gov/oms/models/moves/MOVES2010a/paper137-tap2010.pdf

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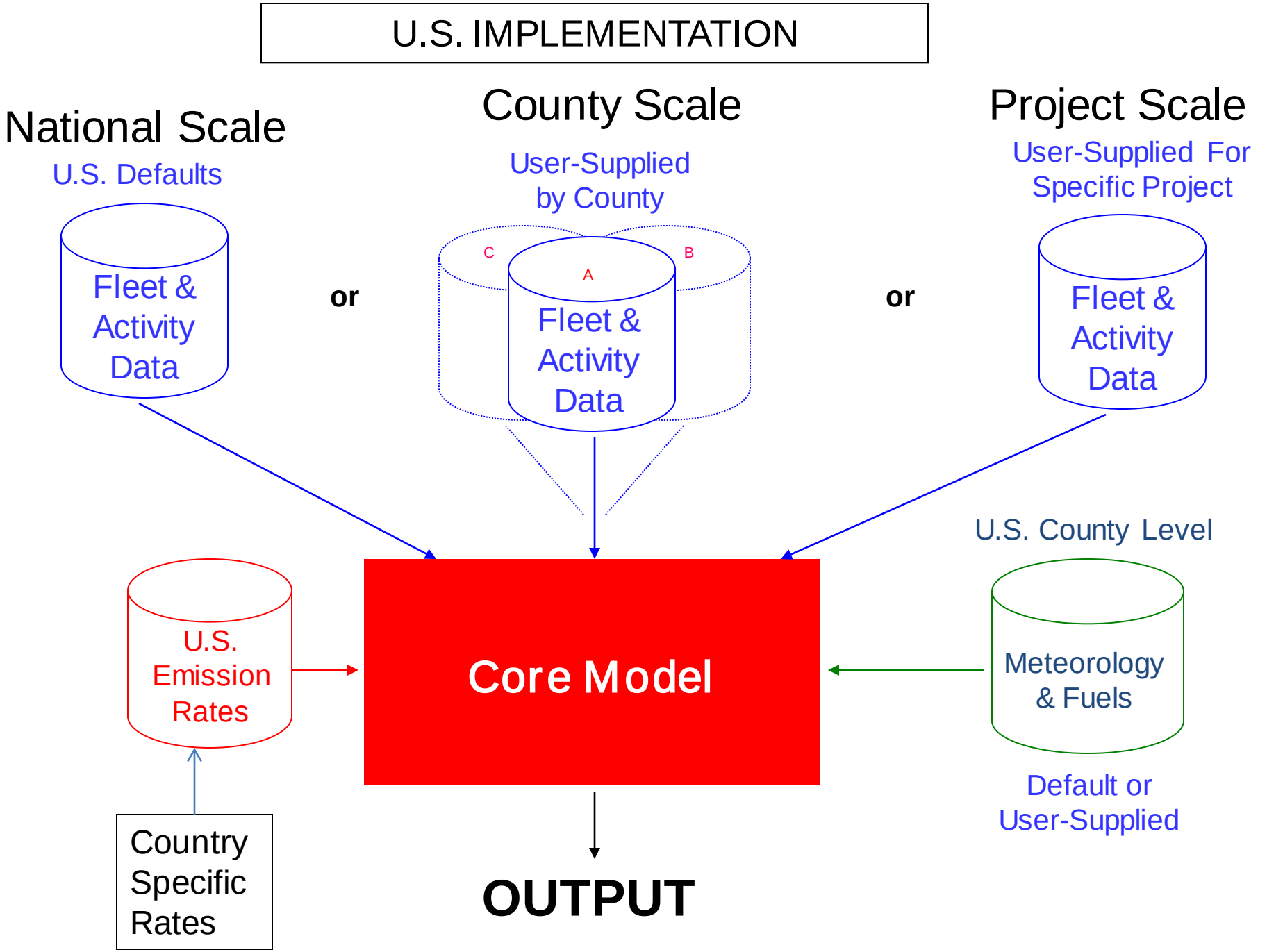
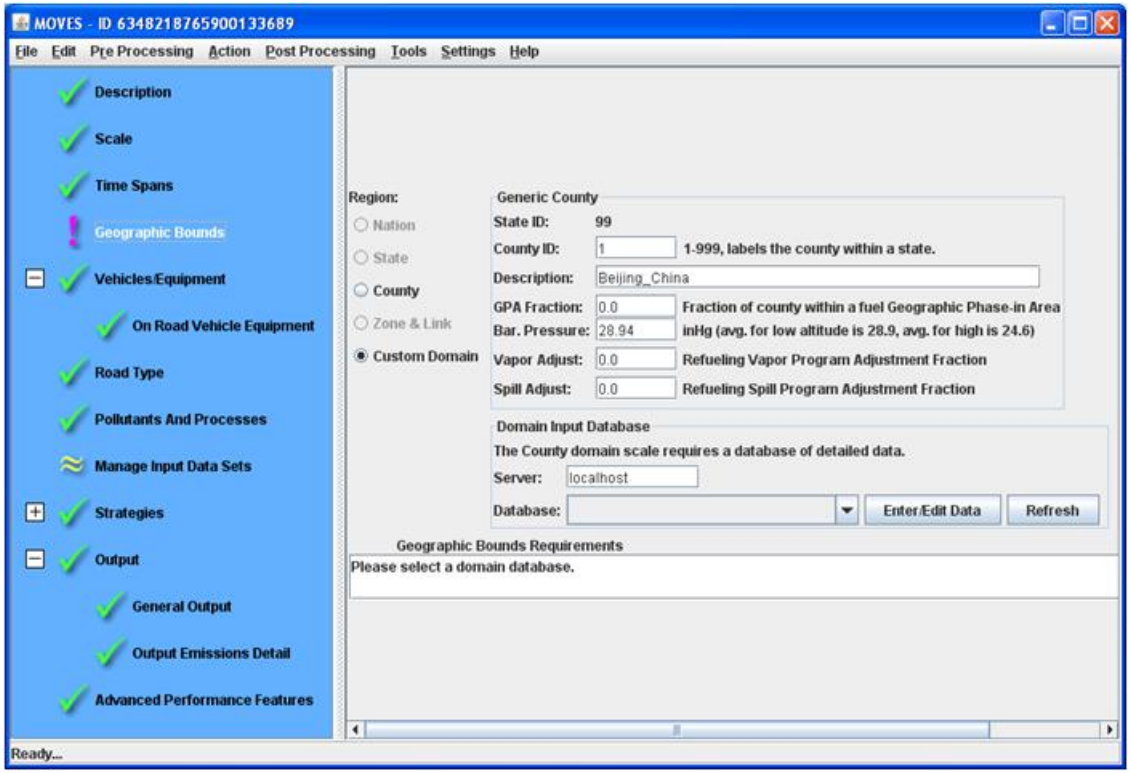
Recommend a "Tiered" approach to customization

- EPA's Tiered Approach – required because full customization of the model would require intensive data collection and analysis
  - Tier 1: Use MOVES "Custom Domain" for input of some local data
    - Activity, fleet, fuel data and other parameters
    - Would still use US-centric emission rates and drive cycles
  - Tier 2: Implementation of International Emissions Standards
    - Develop alternate emission rate tables
    - Take into account fleet penetration and implementation dates
    - Would still use US-centric drive cycles, vehicle classes, road types, etc.
  - Tier 3: Complete Data Customization
    - Allow for customized vehicle classes, road types, drive cycles
    - Requires most effort in both development and data analysis


U.S. IMPLEMENTATION
National Scale
U.S. Defaults
Fleet & Activity Data
or
County Scale
User-Supplied by County
C
B
A
Fleet & Activity Data
or
Project Scale
User-Supplied For Specific Project
Fleet & Activity Data
U.S. County Level
U.S. Emission Rates
Core Model
Meteorology & Fuels
Default or User-Supplied
Country Specific Rates
OUTPUT

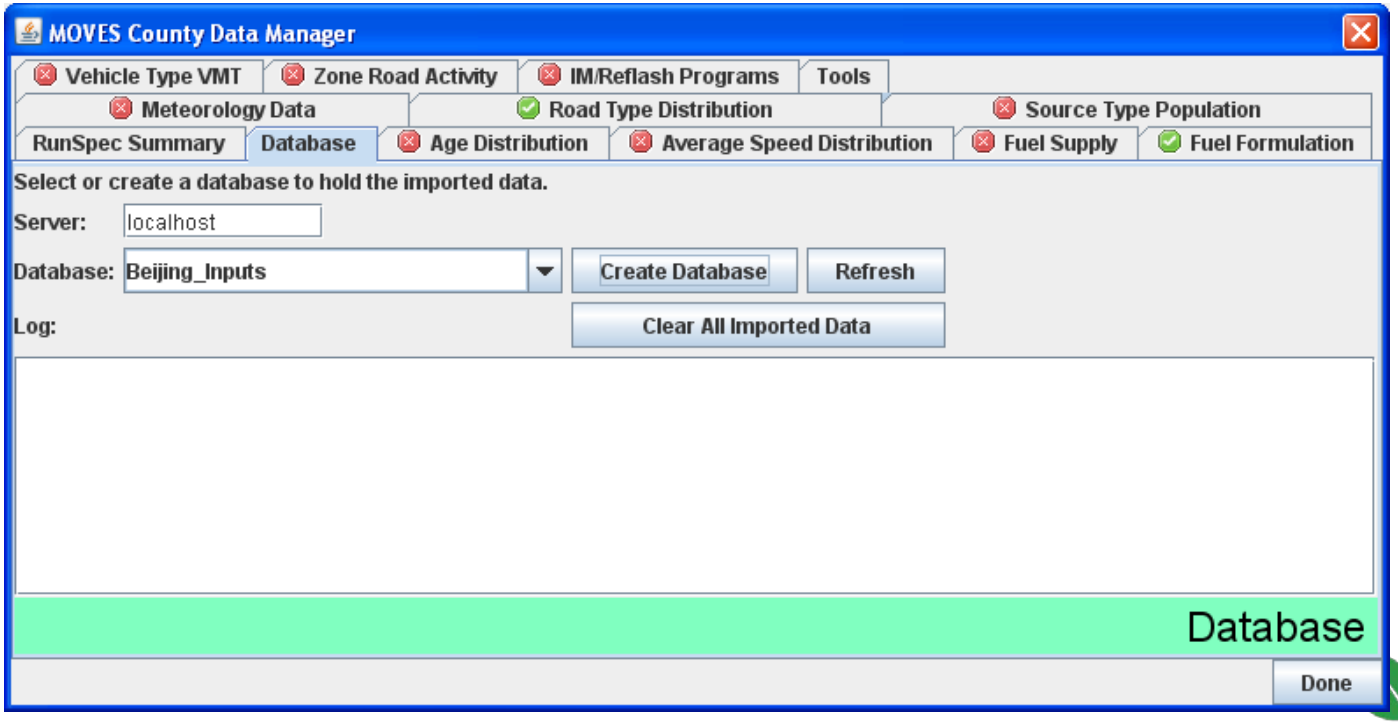
MOVES designed to be adapted for international use

- "Custom domain" option allows international users to define and customize their region



MOVES County Data Manager can be used to easily set up custom database of "1st Tier" data

– Accepts inputs for custom fleet, fuel and activity in MS Excel format, converts to MySQL data used by the model



Initial MOVES Coding Changes

- Allow for use of the MOVES Custom Domain option in input of localized data
- Code updates proposed:
  - Allow for the fleet to be certified to any US or Euro standard
  - Fuel Effects Generator (Java) must be generalized
  - Sulfur Model (SQL) must be generalized
  - Importer will account for metric and English units
  - InputDataManager to be restricted during import of int'l data
- MySQL Table Updates: *numerous,* see below

Initial MOVES Coding Changes

Partial List of MySQL Tables Requiring Update

Table	Model Year	Model Year Group	Source Bin	Age	Rates	Ratios or Coeffs
atBaseEmissions						X
atRatioGas2						X
atRatioNonGas		X				X
baseFuel		X				
crankcaseEmissionRatio		X				X
cumTVVCoeffs		X				X
dioxinEmissionRate		X			X	
emissionRate			X		X	
emissionRateByAge			X	X	X	
fuelModelWtFactor		X		X		X
fuelModelYearGroup		X				X

Emission Rate Converter

- ERG has developed a software tool to create a suite of emission rate tables for input to MOVES
  - The tool serves as a "front-end" to generate inputs to the MOVES model that are appropriate for international locations
- Tool will allow user to enter standards and phase-ins by vehicle class and model year
- If no new data are available, tool will map existing MOVES rates to desired standards

Current MOVES Uses ratios for estimating Emissions

- Tier 1 Emissions levels used to benchmark emissions levels
- Tier 2 (bin 2-bin 10) and LEV emissions levels are developed based on ratios to Tier 1 levels
- This structure allows for the use of international vehicle emissions standards in MOVES

Emission Standard Ratios: Relating Various EURO Standards to U.S. Tier 1

- ERG used PEMS data to develop FTP (US) and NEDC (EURO) cycle emissions estimates for light-duty vehicles available from:
  - US : Kansas City Study (500 vehicles)
  - Europe – EC Joint Research Center (JRC), Milan (~10 vehicles)
  - Hong Kong – Environmental Protection Division (EPD) (~ 25 vehicles)

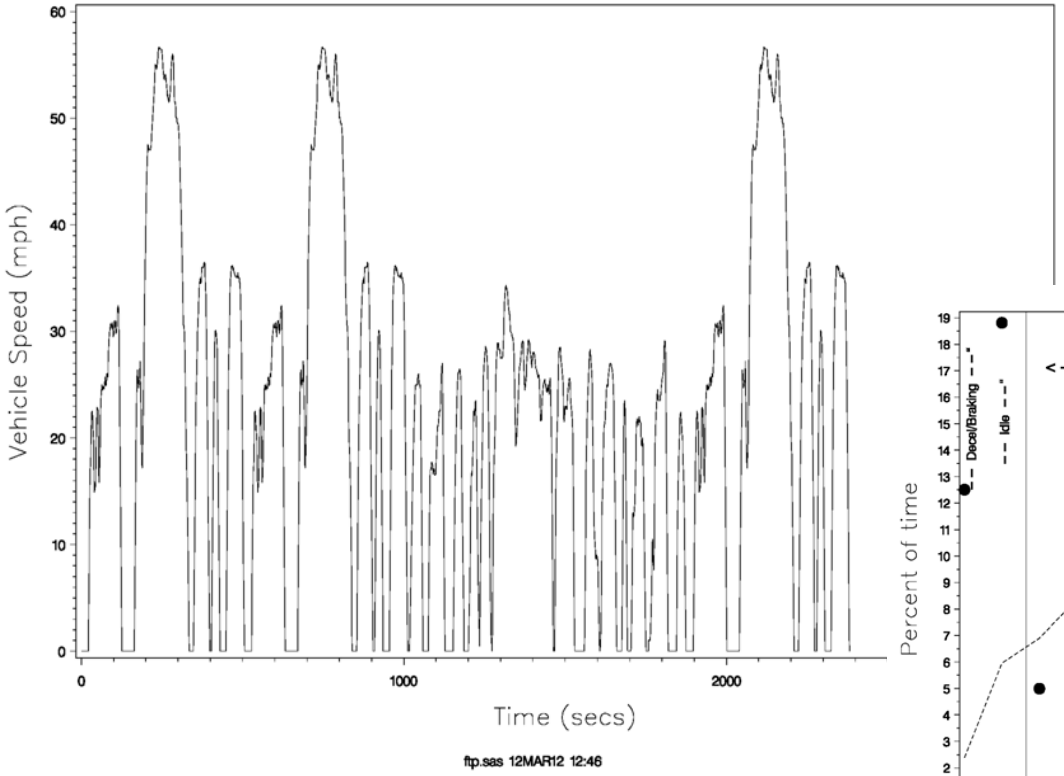
- For this data, instantaneous VSP was calculated on a sec-by-sec basis

$$VSP_{v,t} = \frac{Av_t + Bv_t^2 + Cv_t^3 + mv_t a_t + mgv_{vertical}}{m}$$

- HC, CO, and NOx emissions were then binned by VSP/speed, and average emissions calculated. These averages were applied to the FTP and NEDC VSP bin distributions for cycle-equivalent estimates
- In the future, emissions data from PEMS or dynamometers could directly be used in the development of emissions rates

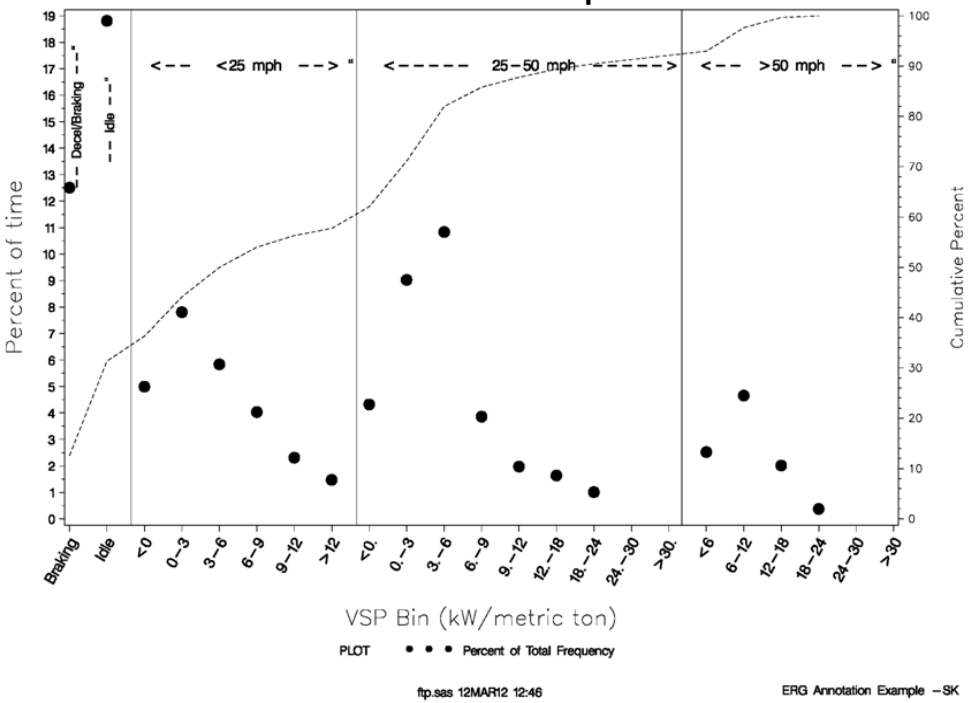
U.S. Light Duty Test Cycle – FTP-75

Speed Trace



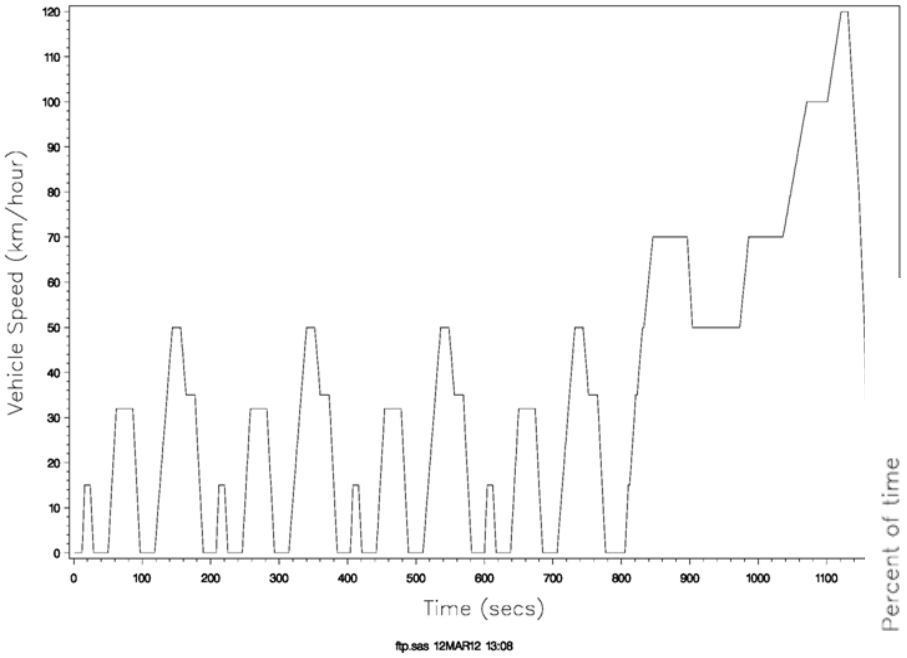
Maximum Speed: 57 mph
Avg. Speed: 21 mph

Percent of Time Spent in Each VSP Bin for a typical vehicle, with cumulative percent



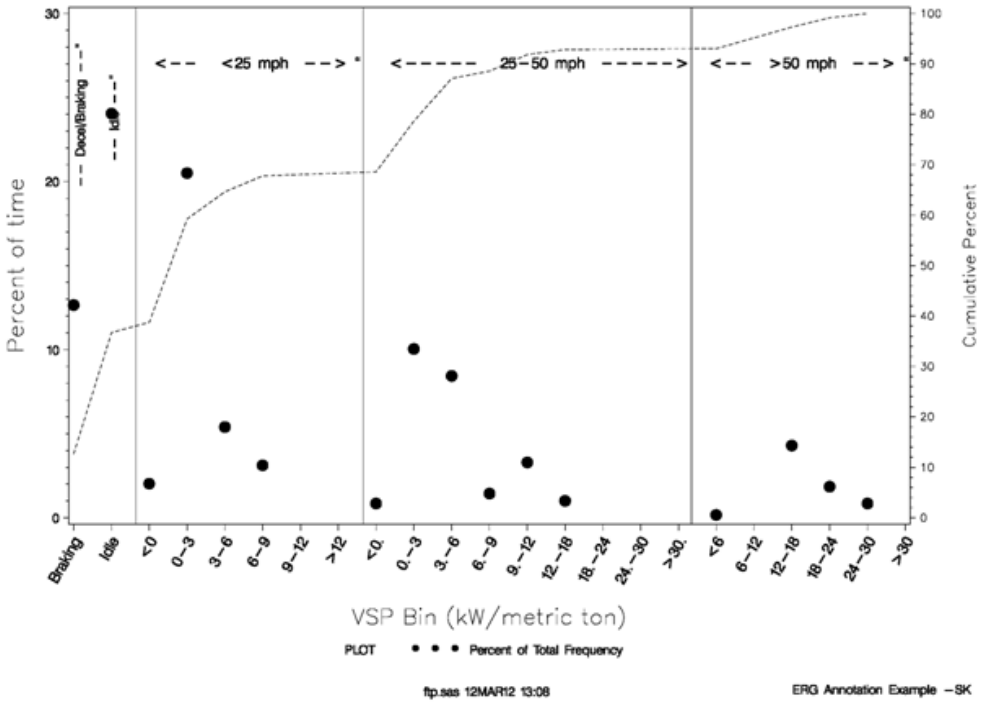
European Light Duty Test Cycle – New European Drive Cycle (NEDC)

Speed Trace



Maximum Speed: 75 mph
Avg. Speed: 21 mph

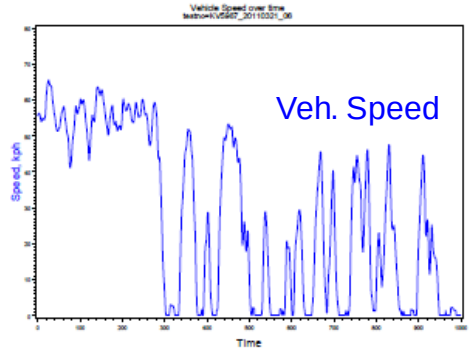
Percent of Time Spent in Each VSP Bin for a typical vehicle, with cumulative percent



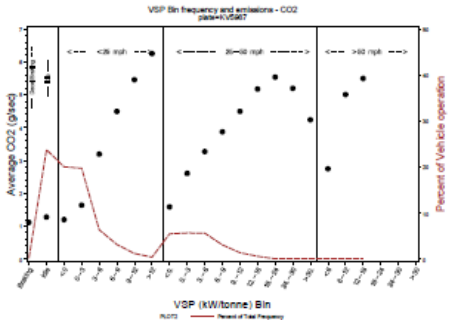
Analysis of Emissions Data by VSP

Method for Estimating FTP-Equivalent Emissions

Calculate VSP from vehicle speed, acceleration, mass, and road grade for each observation



Classify data observations into 23 bins depending on VSP and vehicle speed



Find average emission level in each VSP bin

Find distribution of time spent in each VSP bin for a similar size/weight vehicle over the FTP cycle

Multiply calculated average emissions by the FTP/NEDC VSP bin time distribution and sum for all bins

FTP/NEDC Equivalent Emission Level

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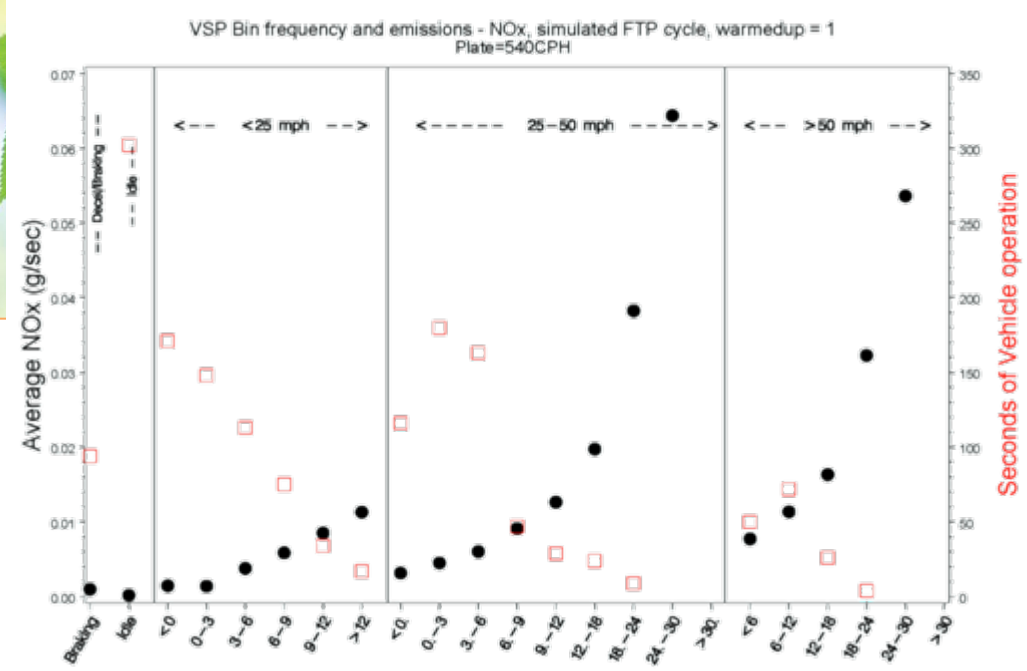
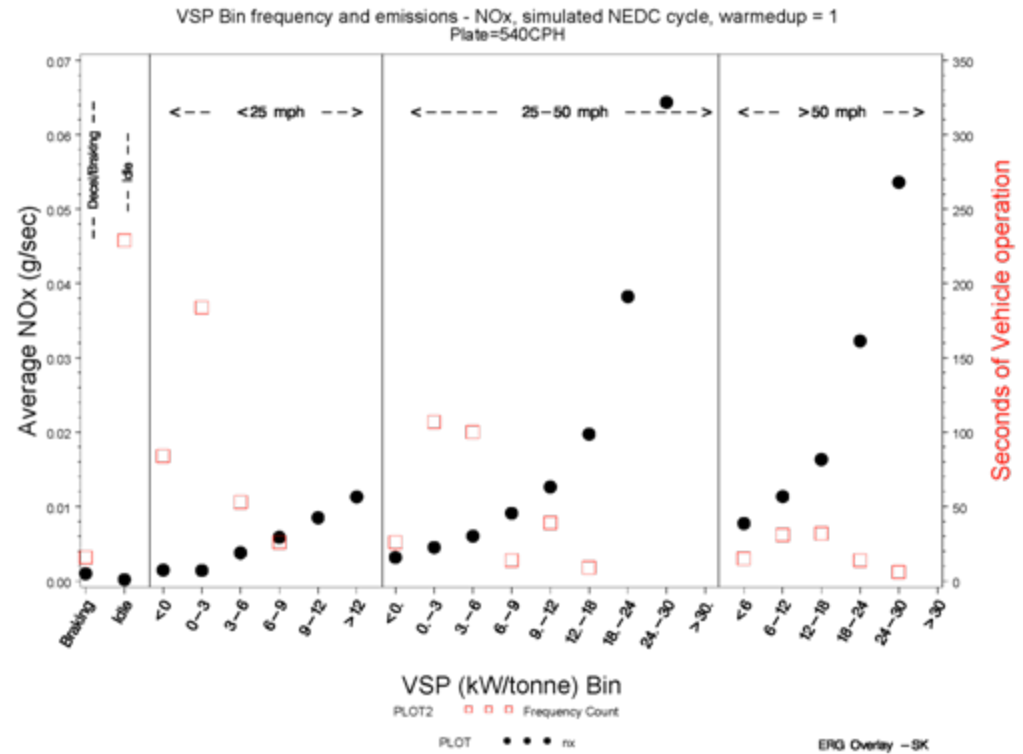


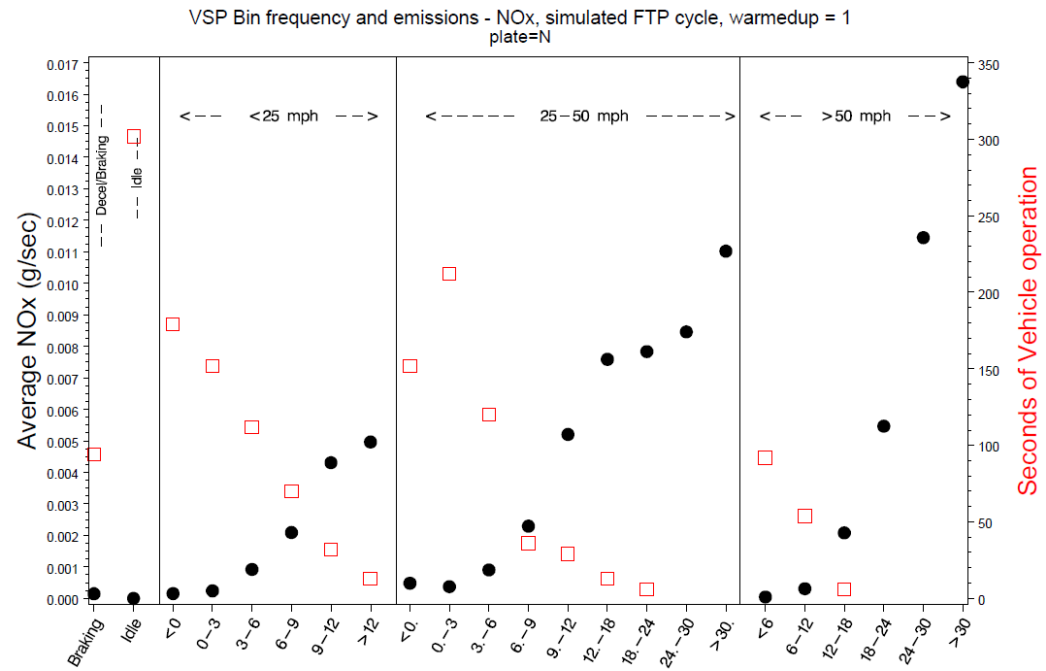


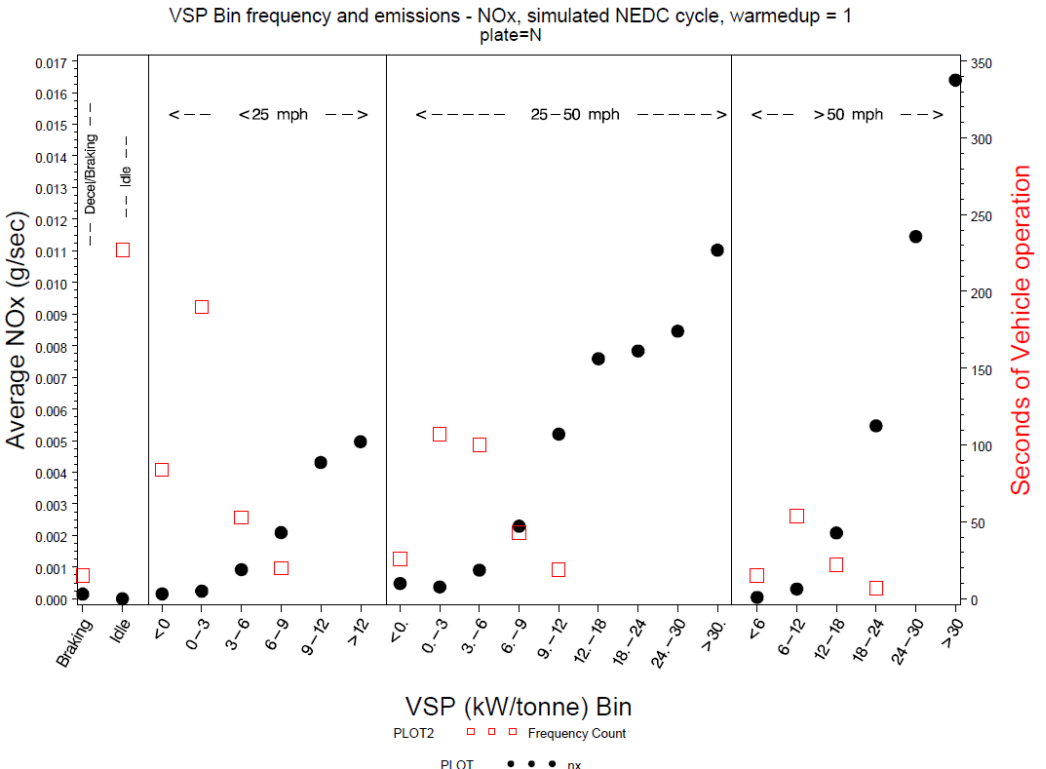
Kansas City

cycle-equivalent emissions levels

FTP : 0.878 g/mi

NEDC : 0.979 g/mi



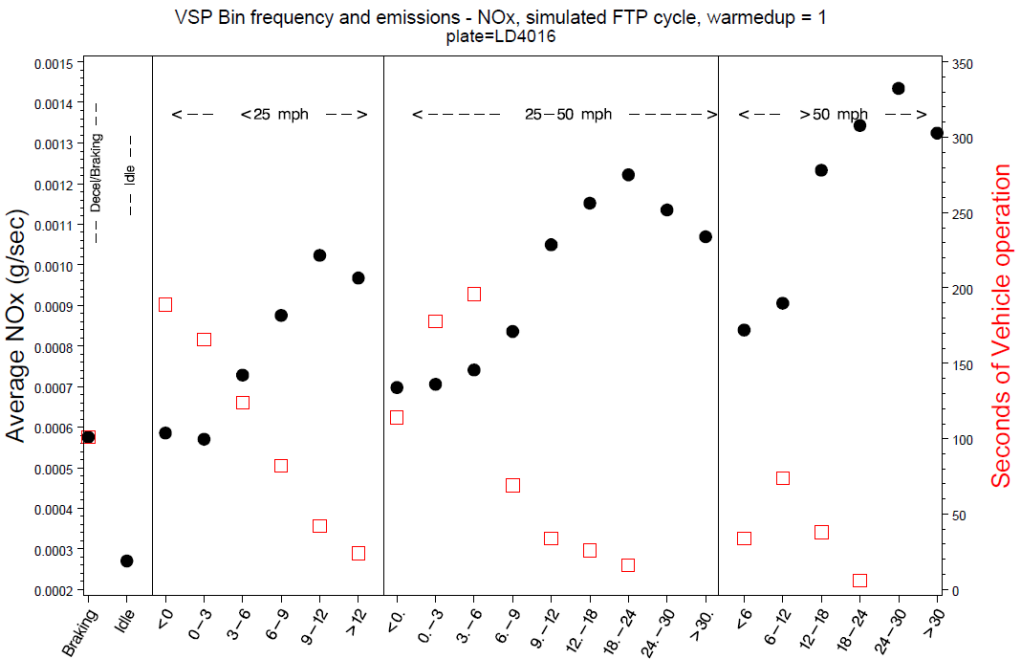


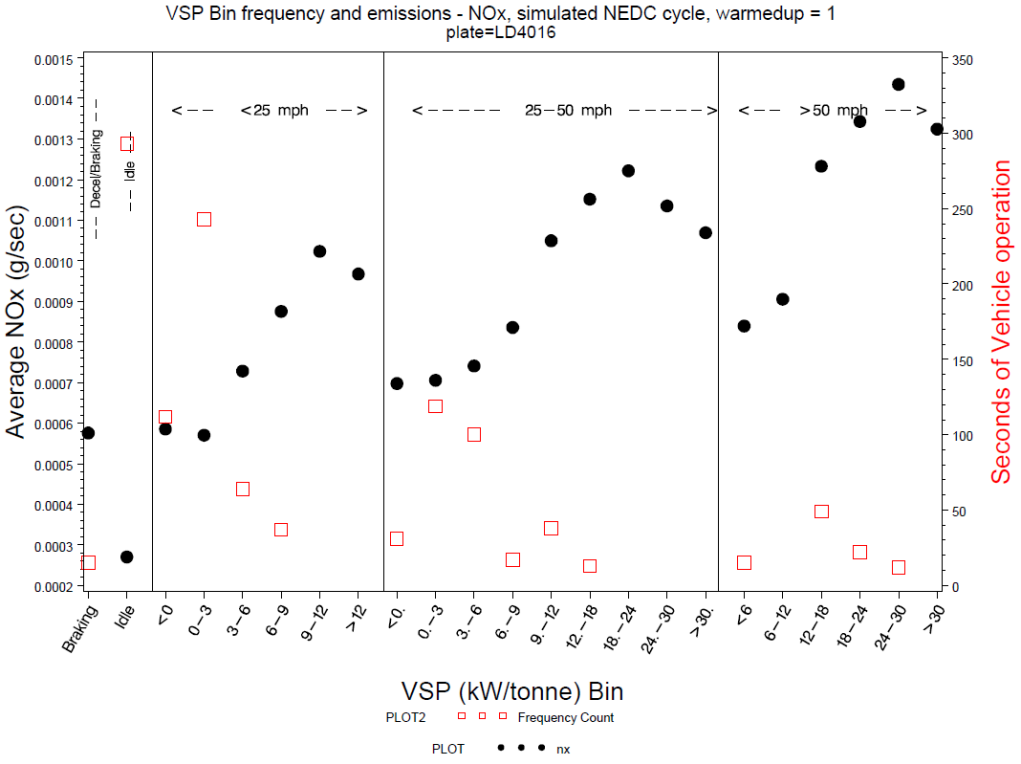
EC JRC

cycle-equivalent emissions levels

FTP : 0.135 g/mi

NEDC : 0.111 g/mi





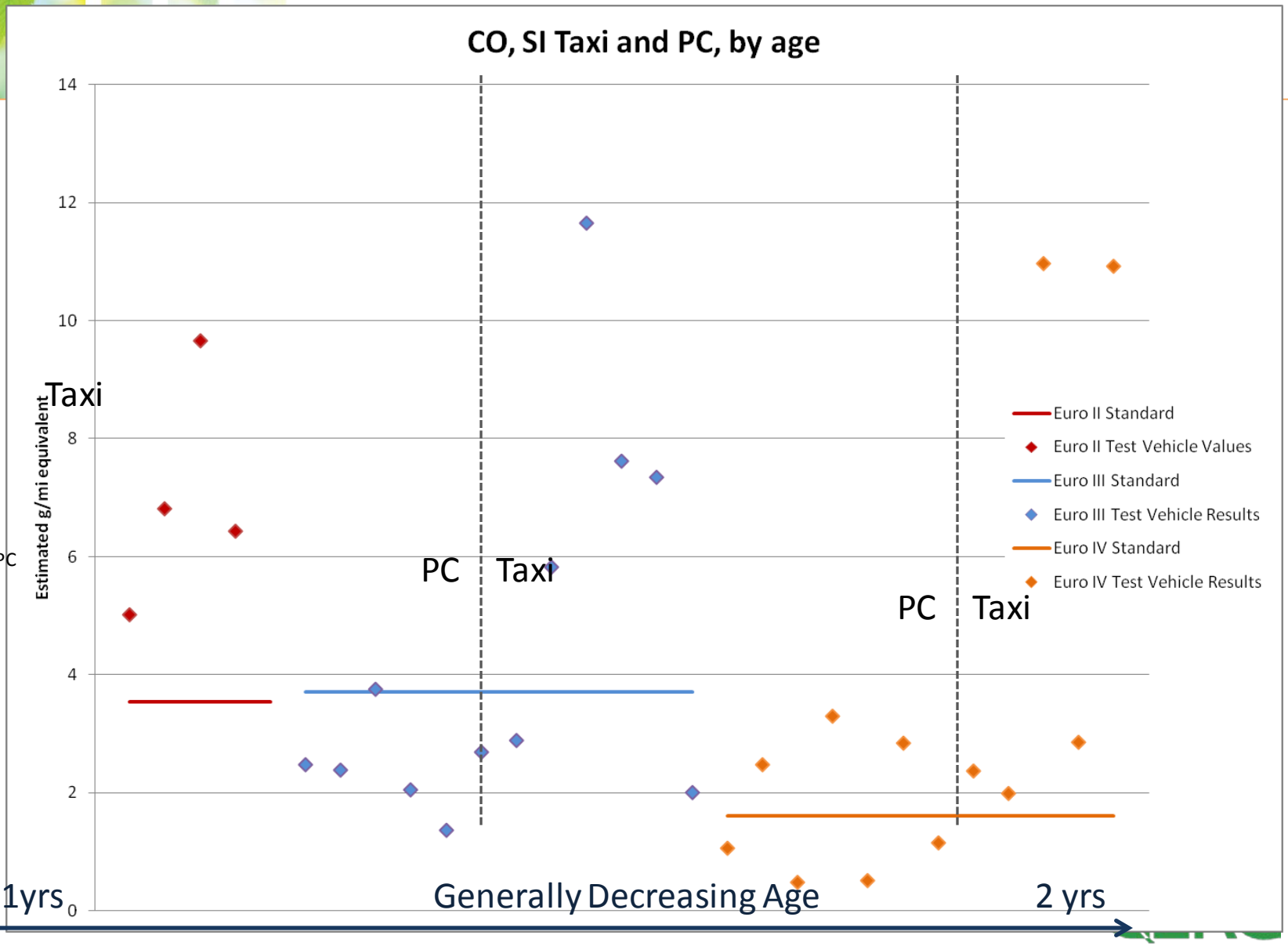
Hong Kong EPD

cycle-equivalent emissions levels

FTP : 0.118 g/mi

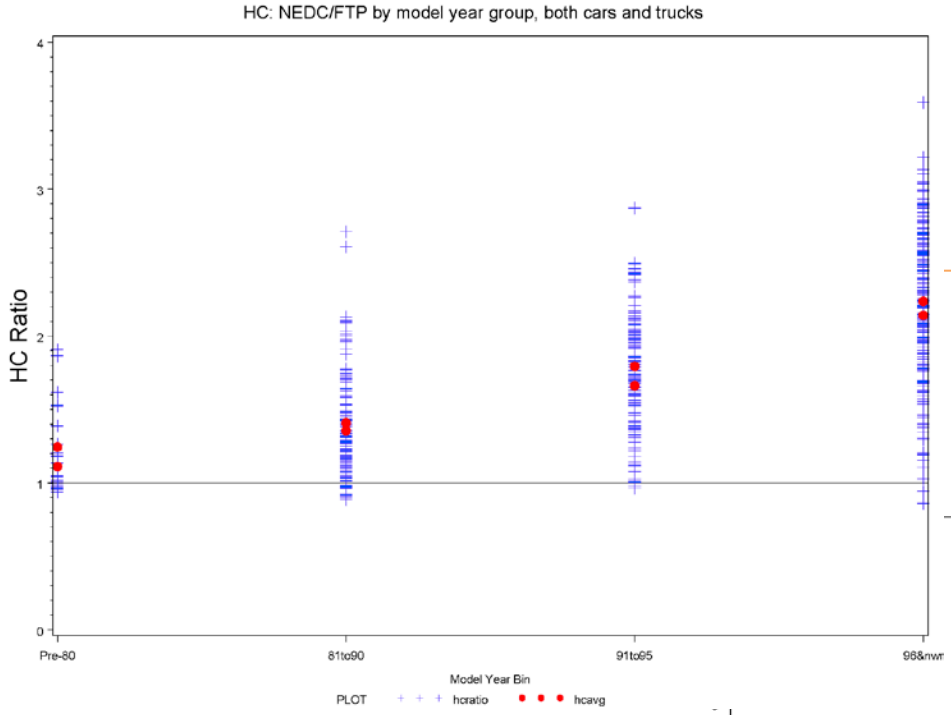
NEDC : 0.108 g/mi

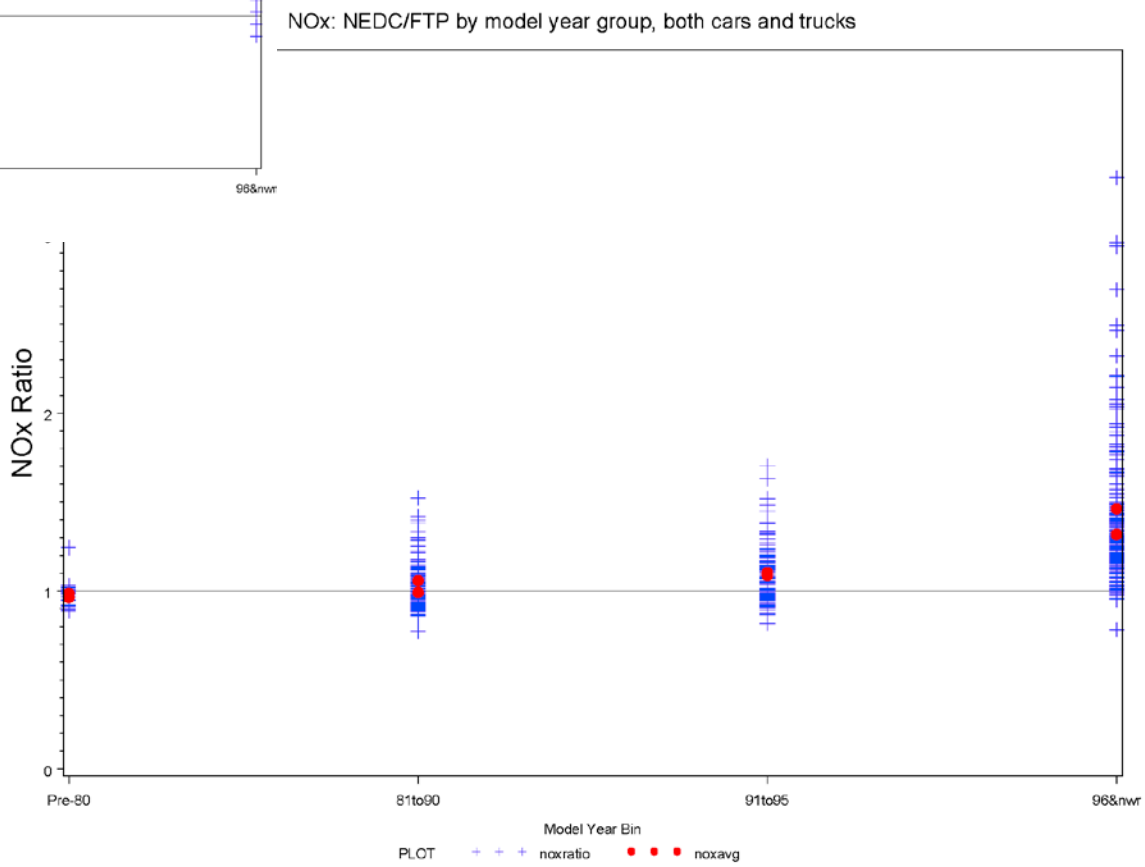
Hong Kong EPD NEDC cycle-equivalent emissions levels compared to EU standards



NEDC/FTP Nox Ratios for KC vehicles

Presented by Model Year Group





For both HC and NOx, the ratio of estimated NEDC to FTP emissions appears to increase with newer model years (ie. lower overall emission levels)

Estimated Ratios NEDC/FTP for various data

Vehicle Type/Source	Model Year	CO	NOx	HC
Car-gas (KC)	Pre-83	1.136	1.004	1.113
Car-gas (KC)	83to92	1.211	1.021	1.281
Car-gas (KC)	93to98	1.484	1.135	1.641
Car-gas (KC)	99&nwr	1.985	1.561	2.234
Car-gas, (JRC)	99&nwr	2.318	1.482	.
Car-gas, (HK)**	93to98	0.844	0.913	0.903
Car-gas, (HK)**	99&nwr	0.988	0.910	0.906
Truck-gas (KC)	Pre-83	1.035	0.959	1.048
Truck-gas (KC)	83to92	1.292	0.983	1.236
Truck-gas (KC)	93to98	1.452	1.071	1.493
Truck-gas (KC)	99&nwr	1.965	1.397	2.250
Car-Diesel, (JRC)	99&nwr	1.435	1.066	--
Truck -Diesel (HK)**	83to92	0.881	0.921	--
Truck -Diesel (HK)**	93to98	0.886	0.962	0.874
Truck -Diesel (HK)**	99&nwr	0.949	0.904	--

**- The HK data did not include cold-start data, as such all operation is assumed to be warm

We can use these ratios as a guide for relating Euro-certified vehicle emission levels to the FTP based levels in MOVES

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Initial Estimates for FTP emissions levels for vehicles certified to US and Euro standards (based on the previously presented ratios)

A comparison of Euro and US EPA emissions standards, with Euro standards presented in estimated equivalent g/mi over the FTP cycle

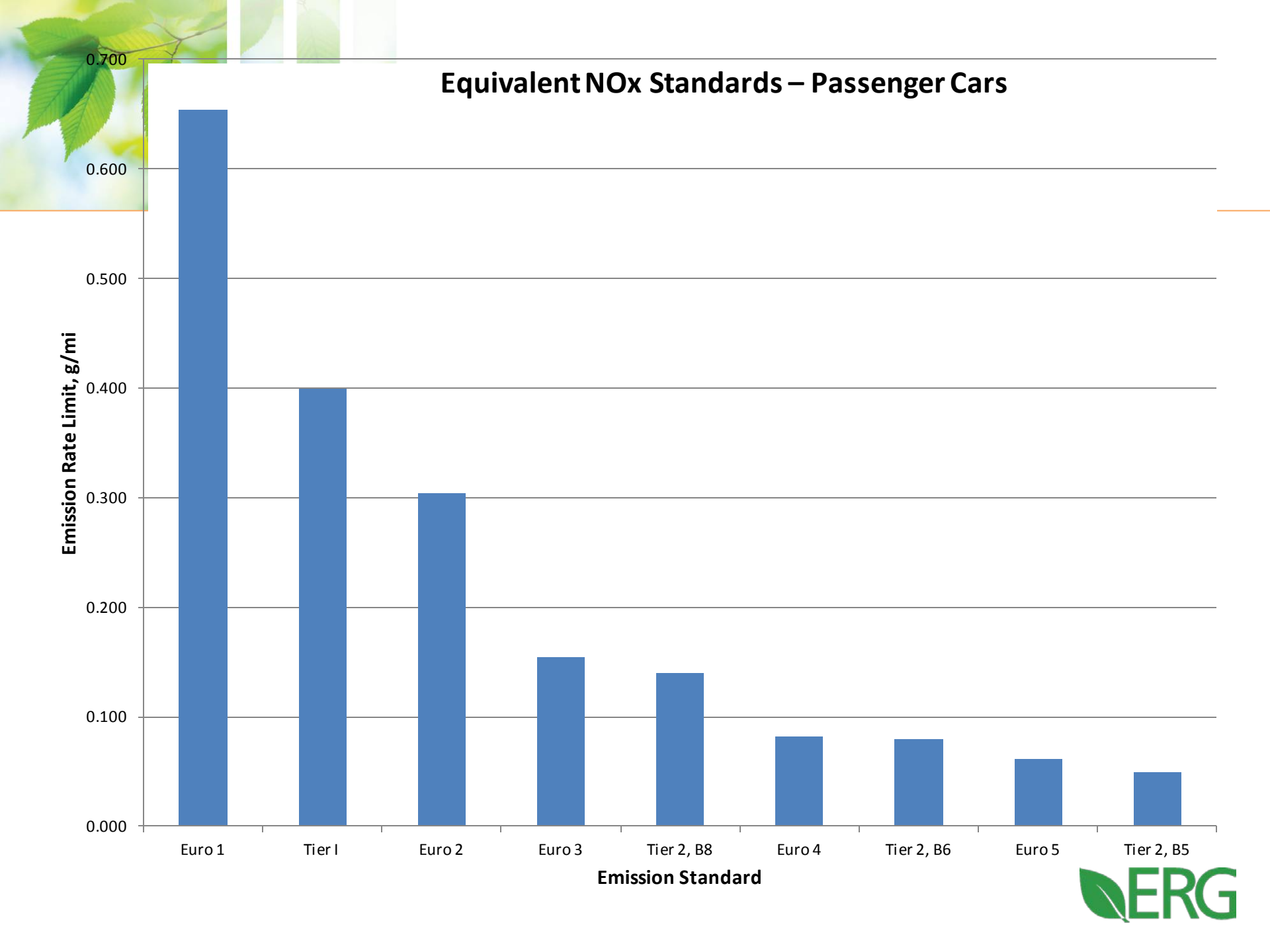
•Sorted in decreasing order by each pollutant

CO (g/mi, FTP)	
Euro 1	3.600
Tier I	3.400
Tier 2, B8	3.400
Tier 2, B6	3.400
Tier 2, B5	3.400
Euro 2	2.376
Euro 3	1.852
Euro 4	0.805
Euro 5	0.805

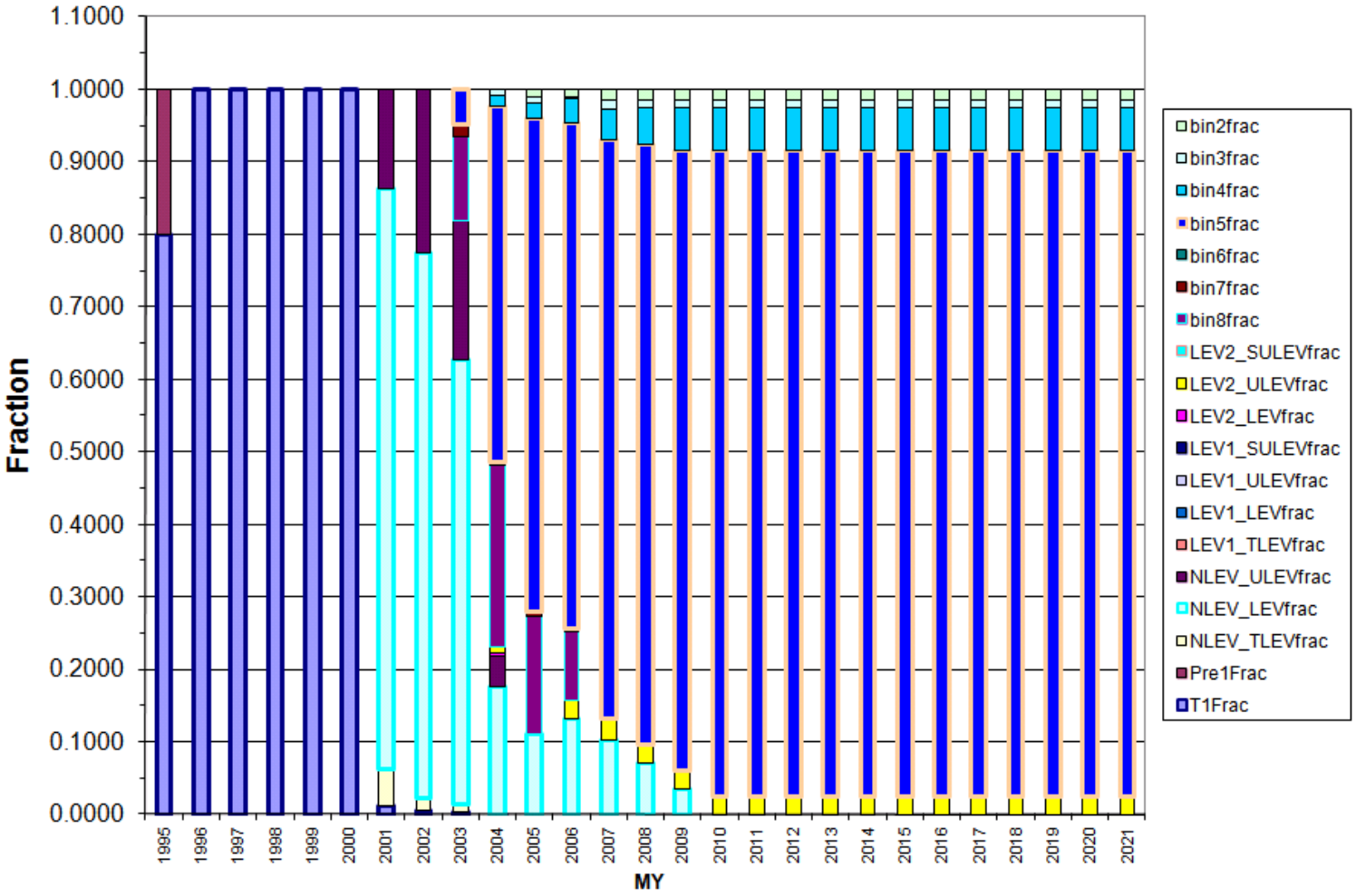
NOx (g/mi, FTP)	
Euro 1**	0.654
Tier I	0.400
Euro 2**	0.304
Euro 3	0.154
Tier 2, B8	0.140
Euro 4	0.082
Tier 2, B6	0.080
Euro 5	0.062
Tier 2, B5	0.050

HC (g/mi, FTP)	
Euro 1**	0.693
Euro 2**	0.279
Tier I	0.278
Euro 3	0.143
Tier 2, B8	0.106
Tier 2, B6	0.080
Tier 2, B5	0.080
Euro 4	0.071
Euro 5	0.071

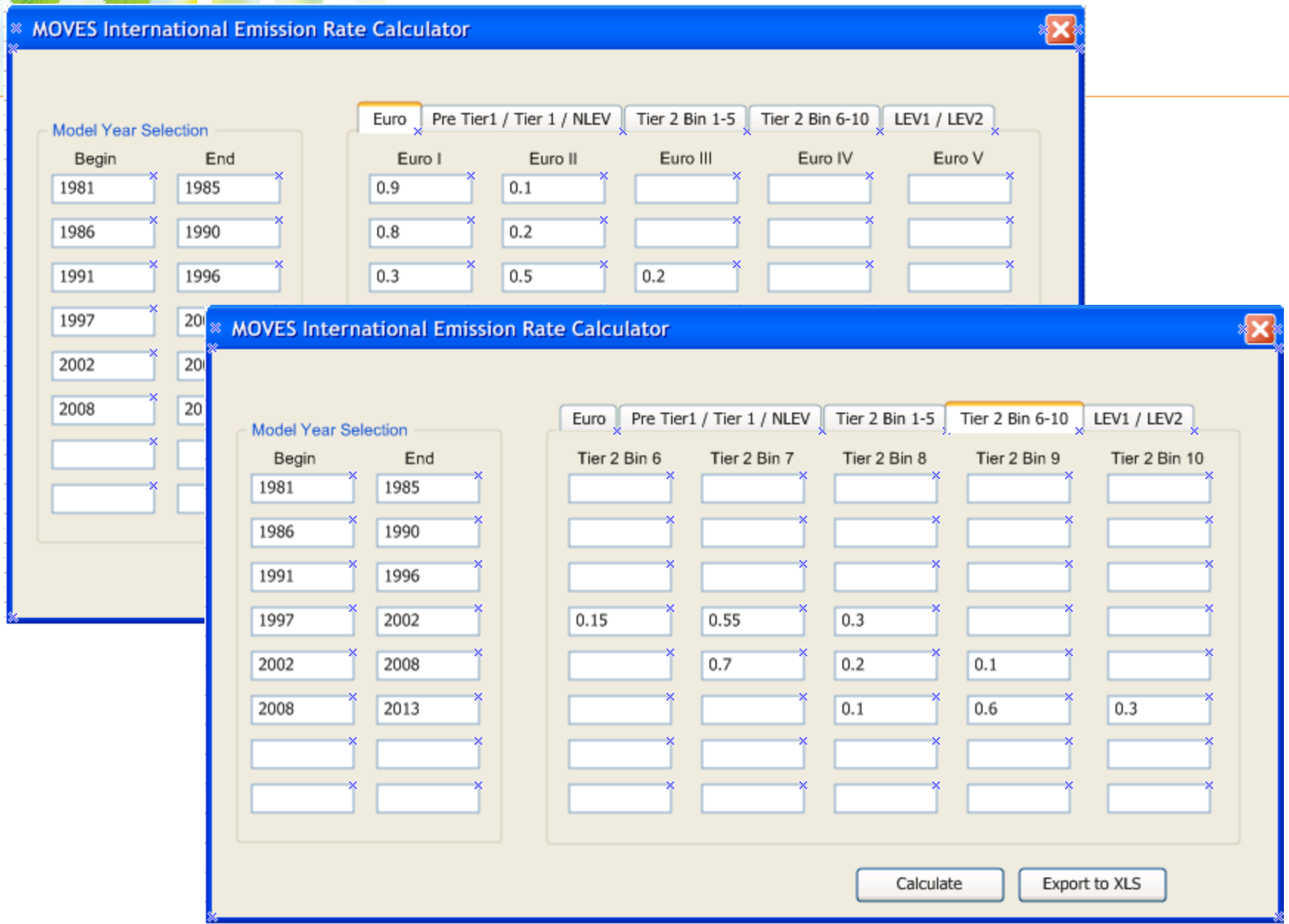
**- The Euro standard was for NOx+HC, split apart here based on subsequent ratios of separate NOx/HC standard levels


Equivalent NOx Standards – Passenger Cars
Emission Rate Limit, g/mi
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
Euro 1
Tier I
Euro 2
Euro 3
Tier 2, B8
Euro 4
Tier 2, B6
Euro 5
Tier 2, B5
Emission Standard

Develop Model Year Matrices by International Area



Proposed Input Screen for MOVES International



Future MOVES International Updates

- Addition of vehicle classes (taxis, etc)
- Additions/updates to road types or drive schedules
- As more emissions data becomes available MOVES rates can be changed directly
- Additional language support
- All updates will require extensive code testing, execution of model test cases, and documentation

Acknowledgements

- **Thank you:**
  - Hong Kong EPD – Dr. Carol Wong
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