Modeling E85 in MOVES2013

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Outline

- Introduction
- Description of dataset
- Statistical Analysis and Results
- Modeling E85 in MOVES2013

Introduction

- **Flexible Fuel Vehicles (FFVs)**
  - Designed to use higher levels of ethanol in gasoline, up to 85% by volume, known as E85
  - Flexible fuel vehicle production has been steadily increasing in the US over the past fifteen years.
  - Significant number of FFVs in use today
- **MOVES2010b and the previous versions of MOVES**
  - Do not have the capability to model E85
  - Designed to estimate the effects of ethanol in gasoline up to 10% by volume
- **MOVES2013 capable of modeling E85**
  - Increased need to model the effects of high ethanol content fuels on emissions with Renewable Fuels Standards (RFS)
  - Vehicles running on E85 expected to represent very small part of the fleet

E85 Dataset

- **Energy Policy Act (EPAct) Test Program**
  - Conducted by EPA in partnership with DOE(NREL) and CRC
  - Tested 4 Tier 2 FFVs on E0, E10, E15, E20, and E85
  - Tested on LA92 cycle with two repeat tests

MY	Make	Model	Odometer
2008	Chevrolet	Impala	5,048
2008	Chevrolet	Silverado	5,347
2008	Ford	F150	5,523
2008	Dodge	Caravan†	5,282

† Dodge Caravan was tested only on E85 fuel, and thus, was not included in the paired t-test analysis

E85 Dataset (cont'd)

- **NREL E40 Program**
  - Conducted by National Renewable Energy Laboratory (NREL)
  - Tested 9 FFVs on E10, E40, and E85
  - Tested on three-phase LA92 cycle with minimum of two replicates

MY	Make	Model	Odometer
2011	GMC	Terrain	10,000
2010	Chrysler	Town & Country	28,000
2010	Toyota	Tundra	17,000
2009	Nissan	Titan	21,000
2011	Ford	Fusion	11,000
2007	Chevrolet	Silverado	10,000
2002	Ford	Taurus	115,000
2002	Dodge	Caravan	110,000
2002	Chevrolet	Tahoe	118,000

E85 Dataset (cont'd)

- **CRC E-80 Project**
  - Conducted by the Coordinating Research Council
  - Tested 7 LEVII FFVs on E6, E32, E59, and E85
  - In two phases
    - Pilot program: 3 vehicles on LA92
    - Main program: 7 vehicles on FTP, US06, and LA92

MY	Make	Model	Odometer
2007	Dodge	Grand Caravan	30,514
2007	Ford	F-150	12,646
2007	Ford	Crown Victoria	16,345
2007	Chevrolet	Tahoe	18,555
2007	Chevrolet	Silverado	22,008
2007	Chevrolet	Uplander	17,898
2006	Chevrolet	Monte Carlo	48,761

E85 Dataset (cont'd)

- **PM Speciation Program**
  - Coordinated test program between EPA/OAR/OTAQ (Ann Arbor) and EPA/ORD/NRMRL (Research Triangle Park)
  - Tier 2 FFVs tested on E0, E10, and E85 blends
  - LA92 test cycle run as a 4-phase test
  - Two replicates for each fuel/vehicle

MY	Make	Model	Odometer
2008	Chevrolet	Impala	50,000
2008	Chrysler	Town & Country	50,000

E85 Data Summary

	EPAct	NREL E40	CRC E80	PM Speciation
Num. of vehicles	3	9	7	2
Replicates	2	2-3	1	2
Test Cycle	LA92	LA92	FTP, US06, LA92	LA92

Fuel Properties

	EPAct		NREL E40		CRC E80		PM Speciation	
	E10	**E85**	**E10**	**E85**	**E6**	**E85**	**E10**	**E85**
EtOH	10	77	10.6	75.5	6	82.9	9.3	80.5
Aromatics	26.2	5.9	20.8	7.1	11.9	2.0	21.8	5.7
RVP	8.8	8.9	8.4	5.8	7.3	7.3	9.2	8.9
T50	189.7	171.8	160.0	172.2	204.2	171.3	221.0	171.5
T90	319.7	173.9	307.8	174.2	307.8	172.5	325.2	173.5

Statistical Analysis

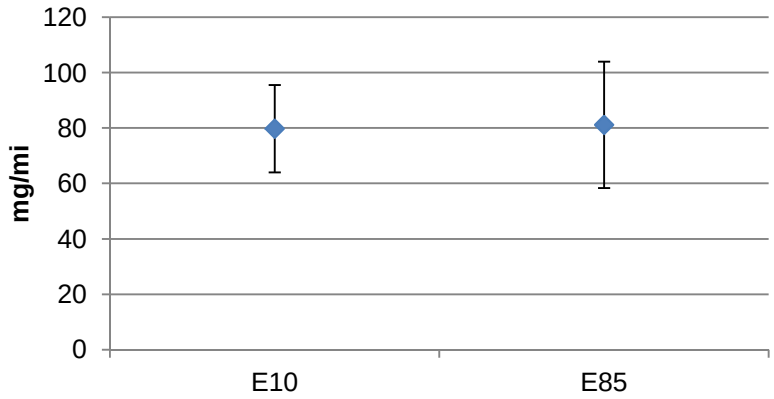
- **All available datasets combined to examine the effect of E85 on emissions compared to E10**
  - Decision made based on the results of the preliminary analysis which showed consistent emission trends across dataset
  - Fuel properties other than ethanol may be a confounding factor
- **Test cycle: LA92**
- **Test of significance using Student's paired t-tests**
  - Only the vehicles tested on both E10 and E85 were included

Results

Comparison of Emissions: E10 vs. E85 on LA92

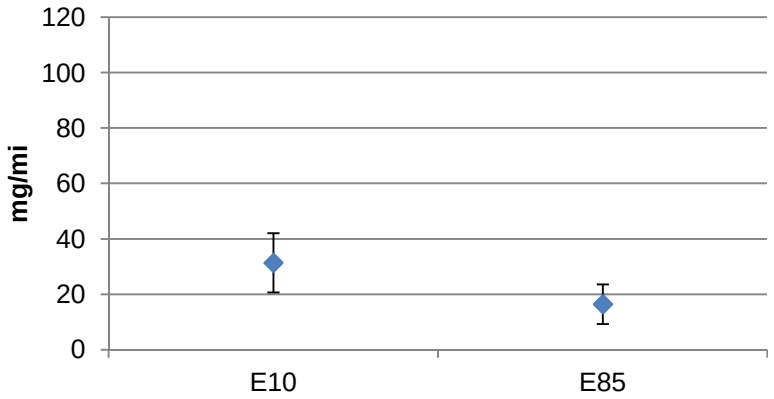
Those tests, for which the p-value is ≤ 0.05, suggest emissions are statistically different between E10 and E85 at the 95% confidence interval

THC



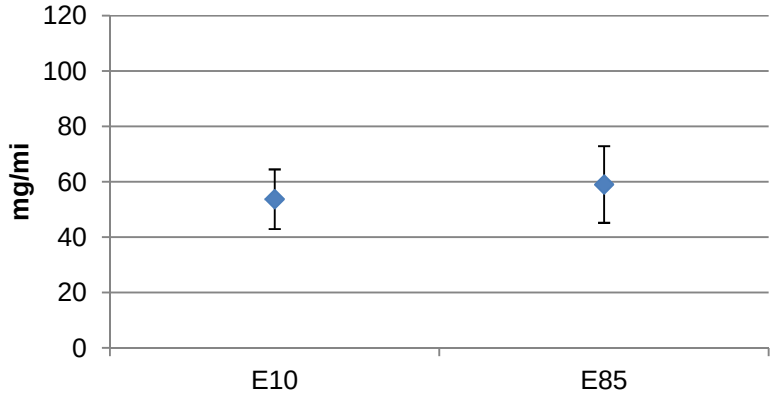
Num. of vehicles: 12
P-value: 0.7968

NMHC



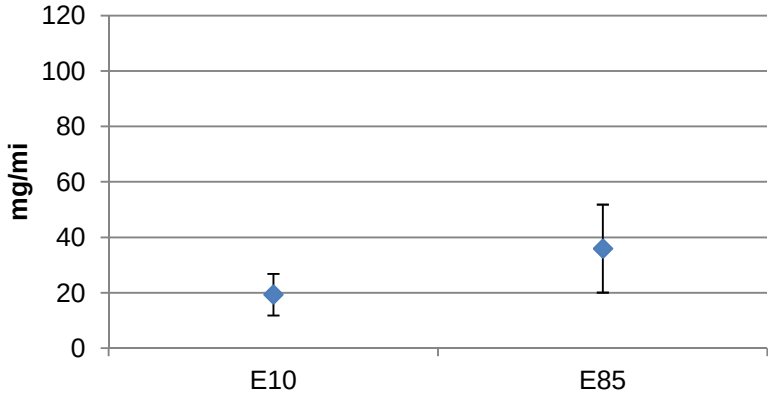
Num. of vehicles: 7
P-value: 0.0046

NMOG



Num. of vehicles: 19
P-value: 0.3056

CH4

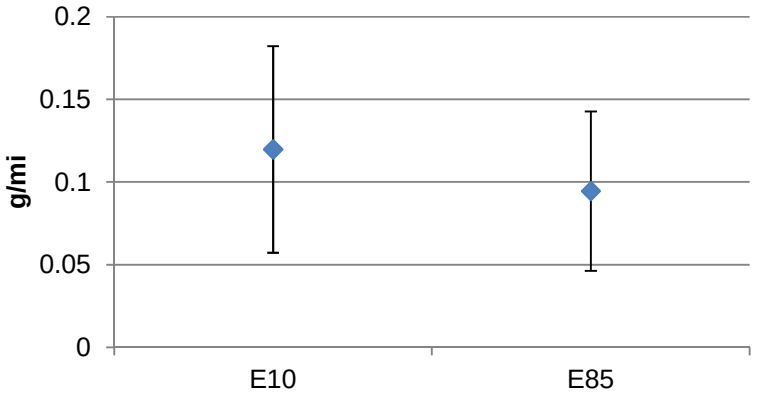


Num. of vehicles: 5
P-value: 0.0226

Comparison of Emissions: E10 vs. E85 on LA92

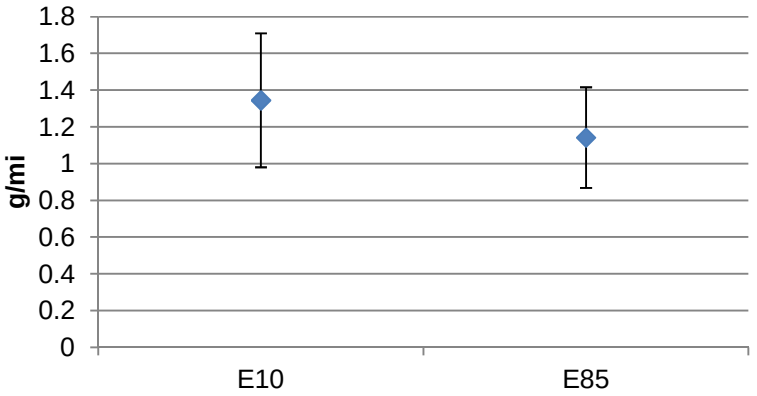
Those tests, for which the p-value is ≤ 0.05, suggest emissions are statistically different between E10 and E85 at the 95% confidence interval

NOx



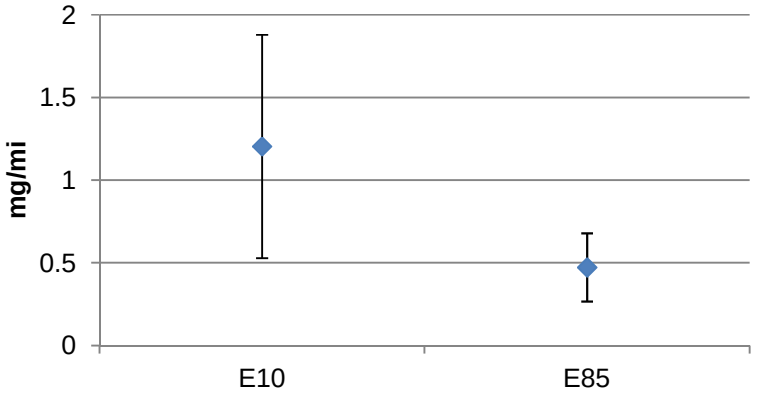
Num. of vehicles: 21
P-value: 0.1667

CO



Num. of vehicles: 21
P-value: 0.0665

PM

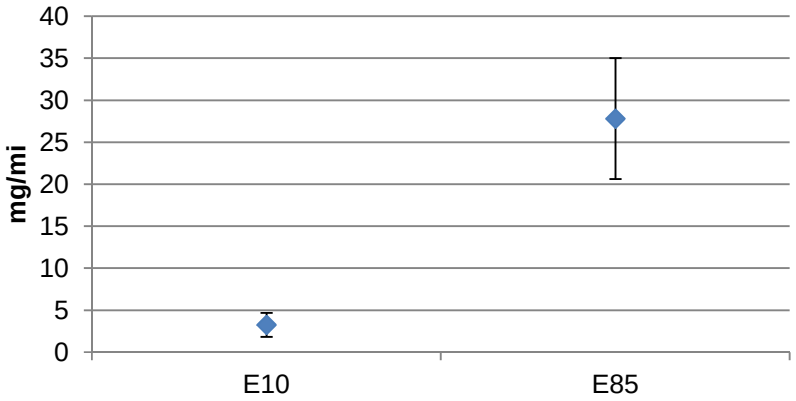


Num. of vehicles: 5
P-value: 0.2797

Comparison of Emissions: E10 vs. E85 on LA92

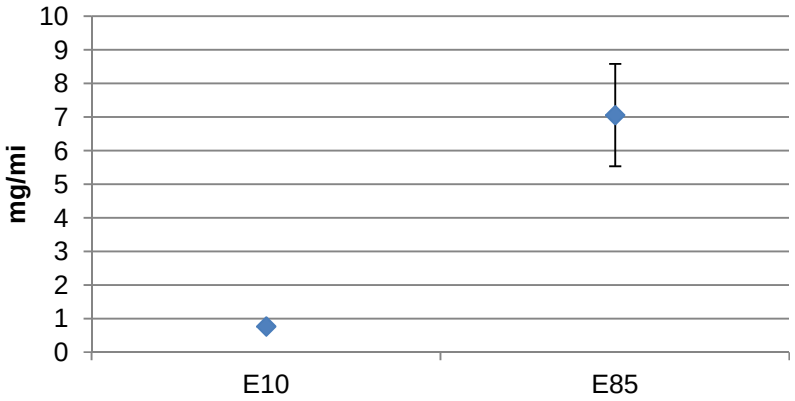
Those tests, for which the p-value is ≤ 0.05, suggest emissions are statistically different between E10 and E85 at the 95% confidence interval

Ethanol



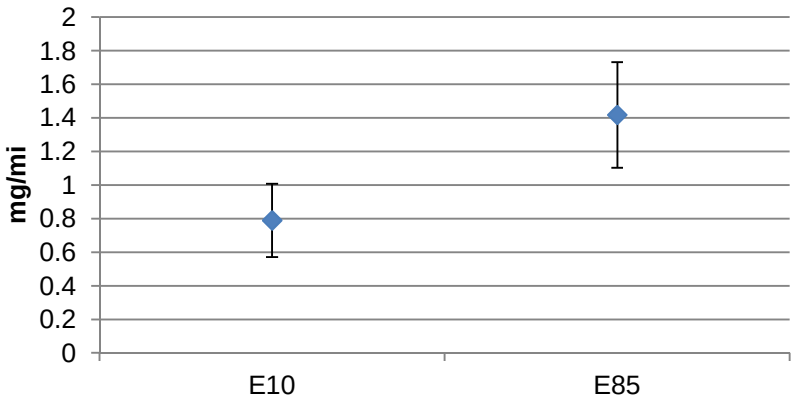
Num. of vehicles: 17
P-value: <.0001

Acetaldehyde



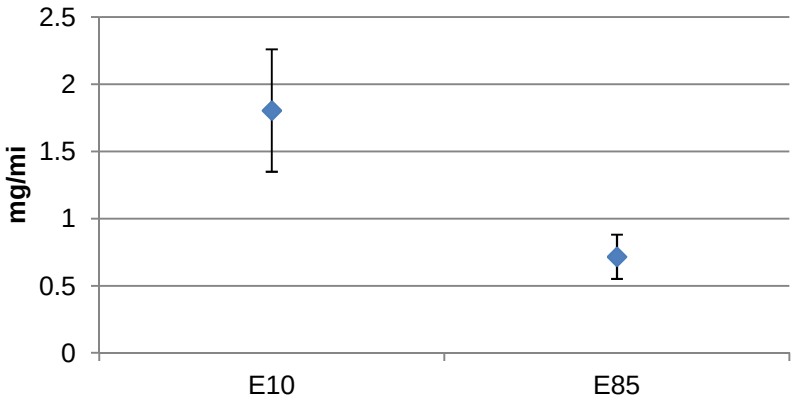
Num. of vehicles: 21
P-value: <.0001

Formaldehyde



Num. of vehicles: 21
P-value: <.0001

Benzene

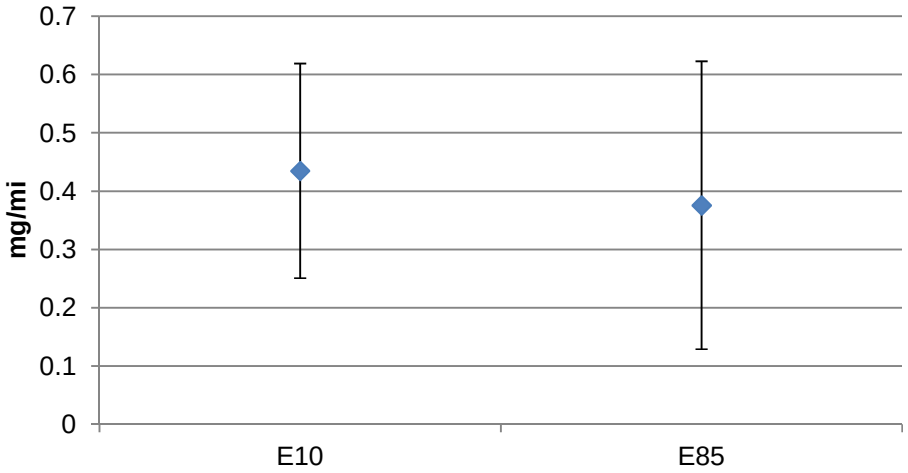


Num. of vehicles: 7
P-value: 0.0234

Comparison of Emissions: E10 vs. E85 on LA92

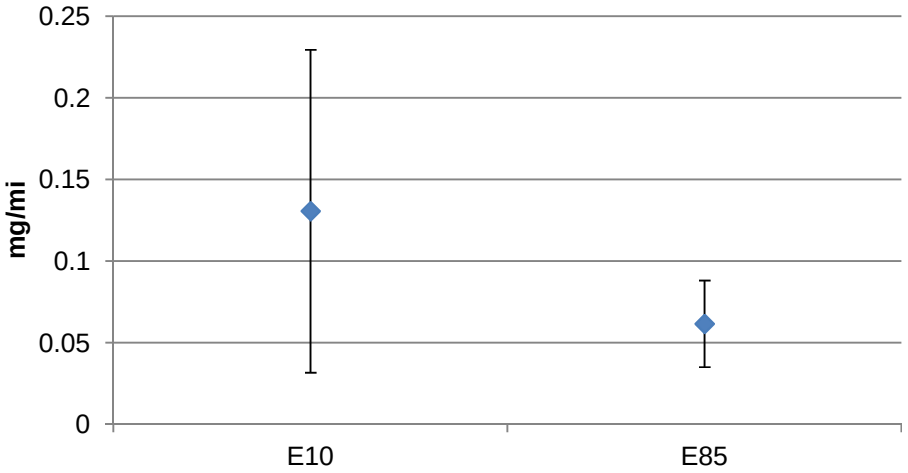
Those tests, for which the p-value is ≤ 0.05, suggest emissions are statistically different between E10 and E85 at the 95% confidence interval

1,3-Butadiene



Num. of vehicles: 6
P-value: 0.0150

Acrolein



Num. of vehicles: 19
P-value: 0.2404

Modeling E85 in MOVES2013

E85 Exhaust Emission Rates

- **THC, CO, NOx, and PM**
  - E85 analysis from EPAct, CRC E80, NREL E40, and PM Speciation Program showed that there is no statistically significant differences in emissions between E10 and E85
  - The base emission rates, IM factor, and IM coverage assumed to be same as gasoline ('*EmissionRateByAge*', '*IMFactor*', '*IMCoverage*' table)
  - Same fuel effects as E10 applied, including the effect of fuel sulfur level ('*GeneralFuelRatioExpression*' table)
- **CH4**
  - in '*MethaneTHCRatio*' table
  - E85 analysis showed statistically significant increase in methane emissions with E85 compared to E10
  - New methane to THC ratio developed for E85
  - Same age effects as gasoline applied

E85 Exhaust Emission Rates (cont'd)

- **NMHC**
  - NMHC = THC – CH4
  - Thus, NMHC expected to decrease with E85 compared to E10
  - Consistent with the results from the analysis

- **NMOG and VOC**
  - in '*HCSpeciation*' table
  - No statistically significant differences in emissions observed between E10 and E85
  - The speciation constant developed to produce no change in emissions compared to E10

E85 Exhaust Emission Rates (cont'd)

- **Major HAPs: <u>MY2001 and later</u>**
  - Based on E85 analysis from EPAct, CRC E80, NREL E40, and PM Speciation Program
  - E10 to E85 adjustment factor applied in '*GeneralFuelRatioExpression*' table

$$E85\ adjustment\ factor = \frac{\frac{Toxics_{E85}}{VOC_{E85}}}{\frac{Toxics_{E10}}{VOC_{E10}}}$$

Pollutant	E85 Adjustment Factor
Benzene	0.6672001547
Ethanol	7.5871621854
1,3-Butadiene	0.2167128288
Formaldehyde	1.5721279562
Acetaldehyde	7.1263182195
Acrolein	0

E85 Exhaust Emission Rates (cont'd)

- **Air Toxics**
  - in '*ATRatioNonGas*' and '*MinorHAPRatio*' table
  - Toxic to VOC ratios for E85 derived from phase 3 of the EPAct test program
  - Based on average of weighted LA92 from 4 FFVs
  - Not applied to "*generalfuelratioexpression*" table since EPAct algorithm not available for major HAPs (pre-2001 MY) and additional air toxics

for pre-2001 MY only

Pollutant name	Toxic/VOC
1,3-Butadiene	0.0011
Acetaldehyde	0.1644
Acrolein	0.0010
Benzene	0.0170
Ethanol	0.3724
Formaldehyde	0.0291
2,2,4-Trimethylpentane	0.0078
Ethyl Benzene	0.0055
Hexane	0.0045
Propionaldehyde	0.0025
Styrene	0.0003
Toluene	0.0177
Xylene	0.0185

E85 Exhaust Emission Rates (cont'd)

- **Policyclic Aromatic Hydrocarbons (PAHs), Dioxins, and Furans**
  - Limited E85 emissions data available
    - In the process of gathering/examining data
    - Potential update for future version of MOVES
  - Emission factors estimated by multiplying E0 ratios by the fraction of gasoline in the fuel, assuming no emission produced from ethanol combustion
  - in '*PAHGasRatio*' and '*DioxinEmissionRate*' tables
  - Resulting ratios provided in the Appendix
- **Metals**
  - In the absence of E85 data for metals, emission rates were assumed to remain unchanged from gasoline vehicles
  - in '*MetalEmissionRate*' table

E85 Evaporative Ratios

- **Toxic/VOC ratio**
  - Based on evaporative profiles from analysis of CRC E80 data
    - Four FFVs tested on E59 and E85
    - Running loss, one hour “Hot Soak” and two-day diurnal tests
    - For permeation, vapor venting, and liquid leaks
  - Composite profile created using two-day diurnal evaporative emissions tests for the four vehicles run on E85
  - Pollutants
    - Benzene and ethanol: ‘*ATRatioNonGas*’ table
    - 2,2,4-Trimethylpentane, Ethyl Benzene, Hexane, Toluene, Xylene: ‘*MinorHAPRatio*’ table
    - Naphthalene: ‘*PAHGasRatio*’ table
  - Ratios provided in the Appendix

Other tables for E85

- **Gasoline replicated for E85**
  - CrankcaseEmissionRatio
  - HCPermeationCoeff
  - NONO2Ratio
  - PM10EmissionRatio
  - RefuelingFactors
  - SCCVtypeDistribution
  - SulfateEmissionRate
  - TemperatureAdjustment
- **Replaced “placeholder” to “Ethanol(E-85)” in ‘*FuelType*’ table**
- **Fuelsupply, FuelFormulation, and FuelUsageFraction**
  - The default provided in the database based on refinery modeling
  - When user supplies local data, only RVP is required for E85 fuel; all other fuel properties need to be that of E10

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Questions?

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Appendix

MOVES

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PAH/VOC and PAH/PM ratios for E85 vehicles and trucks

PAH	Start Fraction of $OC_{2.5}$	Running Fraction of $OC_{2.5}$	Fraction of HC
Benzo(a)anthracene	0.0000186	0.0000142	0.0000001
Benzo(a)pyrene	0.0000257	0.0000196	0.0000000
Benzo(b)fluoranthene	0.0000305	0.0000233	0.0000000
Benzo(k)fluoranthene	0.0000305	0.0000233	0.0000000
Chrysene	0.0000211	0.0000161	0.0000001
Dibenz(a,h)anthracene	0.0000000	0.0000000	0.0000000
Indeno(1,2,3-cd)pyrene	0.0000192	0.0000147	0.0000000
Acenaphthene	0.0000000	0.0000000	0.0000028
Acenaphthalene	0.0000000	0.0000000	0.0000156
Anthracene	0.0000987	0.0000753	0.0000017
Benzo(ghi)perylene	0.0000496	0.0000379	0.0000002
Fluoranthene	0.0001175	0.0000897	0.0000017
Fluorene	0.0000814	0.0000621	0.0000045
Naphthalene	0.0000000	0.0000000	0.0003439
Phenanthrene	0.0002128	0.0001624	0.0000064
Pyrene	0.0001718	0.0001311	0.0000021

Dioxin Emission Factors for E85 vehicles

Pollutant	E85 EF (mg/mile)
2,3,7,8-TCDD TEQ	1.24E-10
1,2,3,7,8-Pentachlorodibenzo-p-Dioxin	5.55E-11
1,2,3,4,7,8-Hexachlorodibenzo-p-Dioxin	5.81E-11
1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	1.19E-10
1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	7.39E-11
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	8.93E-10
Octachlorodibenzo-p-dioxin	7.05E-09
2,3,7,8-Tetrachlorodibenzofuran	4.15E-10
1,2,3,7,8-Pentachlorodibenzofuran	1.98E-10
2,3,4,7,8-Pentachlorodibenzofuran	1.45E-10
1,2,3,4,7,8-Hexachlorodibenzofuran	1.64E-10
1,2,3,6,7,8-Hexachlorodibenzofuran	1.74E-10
1,2,3,7,8,9-Hexachlorodibenzofuran	4.75E-11
2,3,4,6,7,8-Hexachlorodibenzofuran	2.03E-10
1,2,3,4,6,7,8-Heptachlorodibenzofuran	1.82E-09
1,2,3,4,7,8,9-Heptachlorodibenzofuran	5.81E-11
Octachlorodibenzofuran	2.06E-09

Evaporative Ratios

Pollutant	ATRatio
Benzene	0.0066421821937343 3
Ethanol	0.610422150354423
2,2,4-Trimethylpentane	0.0082956091194804 8
Ethyl Benzene	0.001236773173437 1
Hexane	0.012763066842169 9
Toluene	0.016083092973448 4
Xylene	0.007330759744585 16
Naphthalene gas	0