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Fuel Economy & Emissions: Ethanol Blends vs Gasoline

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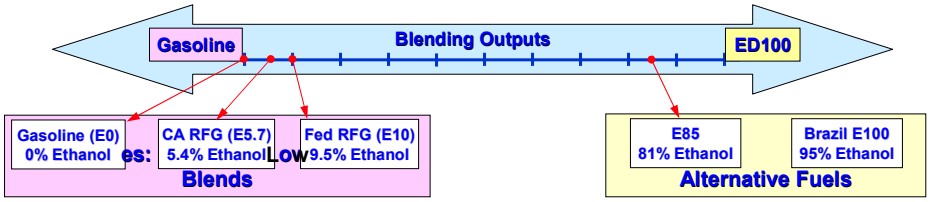
Outline

- General Trends as Ethanol is added to Gasoline
- E85 vs Gasoline Detailed Emissions/Fuel Economy Comparison
  - Test vehicle & program
  - Comparative Data – E85 vs Gasoline
    - Regulated exhaust and evaporative emissions
    - Carbon dioxide, fuel economy & thermal efficiency
  - Test fuel properties
  - Carbon balance measurement methodology
  - Emissions and fuel economy in perspective
- The Next Challenge – E85 FFV PZEV

General Trends as Ethanol is added to Gasoline



Fuel characteristics, emissions & fuel economy impacts:

- Volatility – gasoline middle, low blends higher, E85 much lower
  - High volatility increases evaporative emissions on low blends
  - Low volatility requires more cold-start fuel & increases exhaust HC and reduces evap on E85
- Permeation – gasoline middle, low blends much higher, E85 much lower
  - Evap emissions much higher with low blends & much lower on E85
- Energy density – decreases in direct proportion to ethanol concentration
  - Slight fuel economy loss at low blends & significant fuel economy loss on E85

Test Vehicle & Test Program

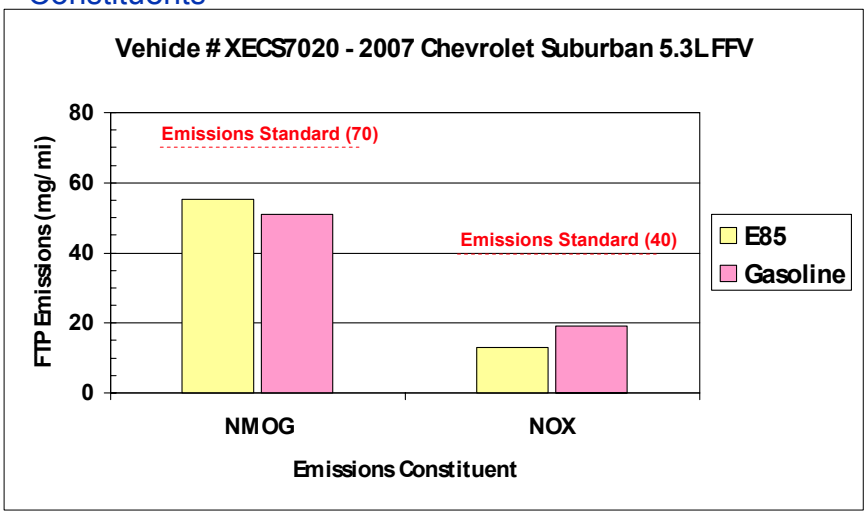
2007 Chevrolet Suburban

- 5.3L LC9 Flex fuel engine
- California emissions
  - EPA Bin 4 certified
  - Qualifies as CA ULEV$_2$
  - CA Near-zero evap
- 6000 pounds test weight class
- 31.8 gallon fuel capacity
- Equipped with catalyst & O_2 sensors aged to full useful life (120,000 miles)

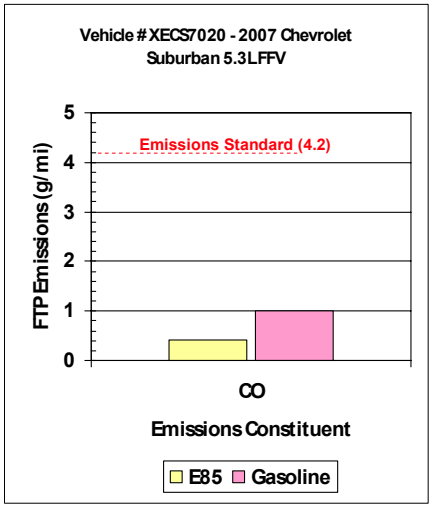
Comprehensive comparison of emissions on various blends

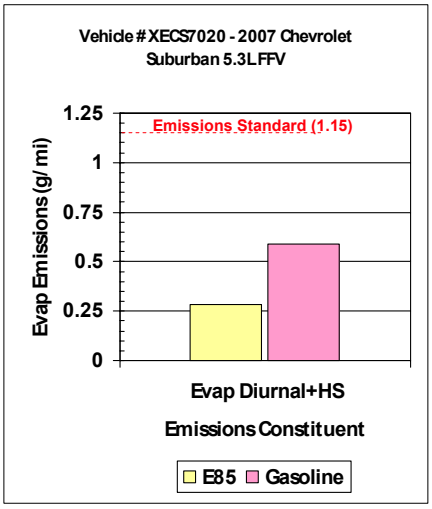
- Exhaust and evaporative emissions
- Fuel blends including gasoline, E85, E20 & E10
- Regulated emissions constituents (NMOG, CO, NOx, Evap HC)
- Toxics (benzene, acetaldehyde, 1,3 butadiene)
- HC speciation to allow ozone reactivity analysis
- Testing nearing completion

E85 vs Gasoline Emissions – Regulated Exhaust Constituents

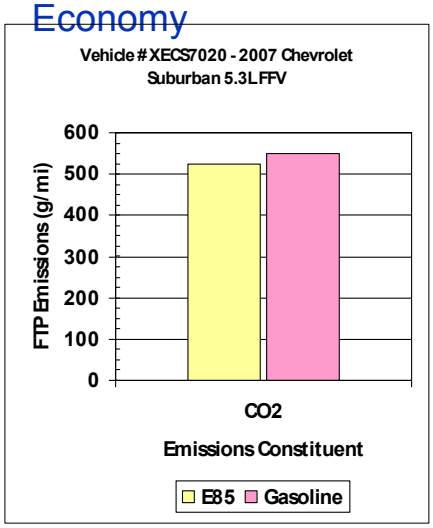


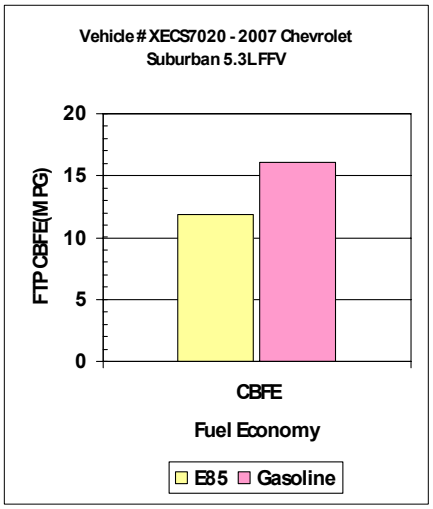
E85 vs Gasoline Emissions – Exhaust CO and Evap HC





E85 vs Gasoline Emissions – CO_2 & Fuel Economy





Key test fuel properties

EPA Tier 2 certification gasoline

- Non-oxygenated straight gasoline
- 28 ppm Sulfur
- 94 octane (R+M)/2
- LHV 114,365 BTU/gallon
- 0.744 specific gravity
  - 2816 grams/gallon total
  - 2439 grams/gallon Carbon
  - 378 grams/gallon Hydrogen

ED85 Tier 2 certification blend

- 85% denatured ethanol & 15% Tier 2 certification gasoline
- 5 ppm Sulfur
- 98 octane (R+M)/2
- LHV 82,332 BTU/gallon
- 0.783 specific gravity
  - 2964 grams/gallon total
  - 1713 grams/gallon Carbon
  - 384 grams/gallon Hydrogen
  - 867 grams/gallon Oxygen

Carbon balance fuel economy measurements

For regulatory fuel economy we do not measure the volume of fuel used

- The technique is the carbon balance method
- Exhaust emissions of hydrocarbons, carbon monoxide & carbon dioxide are measured over the test in grams/mile
- The total carbon exhaust emissions in grams/mile are calculated based on the carbon weight fraction of each measured constituent
- The carbon content of the fuel in grams/gallon is measured
- Fuel economy is calculated as the ratio of fuel grams C/gallon to exhaust grams C/mile

E85 vs Gasoline Fuel Economy & Efficiency

Parameter	Gasoline		E85	
	Emissions x CWF	Carbon	Emissions x CWF	Carbon
Carbon from HC	0.0509 g/mi x 0.866	0.04 g/mi	0.0554 g/mi x 0.817	0.05 g/mi
Carbon from CO	1.007 g/mi x 0.429	0.43 g/mi	0.413 g/mi x 0.429	0.02 g/mi
Carbon from CO_2	551.1 g/mi x 0.273	150.55 g/mi	525.1 g/mi x 0.273	143.36 g/mi
Total Exhaust Carbon Emissions		150.92 g/mi		143.43 g/mi
Fuel Carbon Content		2439 g/gal		1713 g/gal
Fuel Economy (2439/150.92)		**16.16 MPG**	(1713/143.43)	**11.94 MPG (-26%)**
Fuel Lower Heating Value		114,365 BTU/gal		82,332 BTU/gal
Energy Efficiency (114,365/16.16)		**7,077 BTU/mi**	(82,332/11.94)	**6895 BTU/mi (+3%)**

E85 emissions and fuel economy perspective

- Higher exhaust NMOG results from low volatility of E85
  - More E85 needed at cold start to offset low volatility
  - Results in moderately more NMOG before catalyst is active
  - E85 NMOG has a large fraction that is ethanol, which is much less prone to smog formation than gasoline HCs
  - These results are typical of E85
- Significantly lower NOx results from low sulfur level of E85
  - Sulfur acts to slightly impair catalyst reduction of NOx
  - These results are typical of E85

E85 emissions and fuel economy perspective

- Lower evaporative HC results from both lower permeability and low volatility of E85
  - Aromatic HCs in gasoline are primary permeation driver
  - Small gasoline fraction in E85 limits permeation
  - Lower volatility of E85 results in less vapor emissions
  - These results are typical of E85
- Lower CO_2 emissions result from lower E85 carbon content
  - E85 has 30% less carbon per gallon and E85 fuel consumption is 26% higher than gasoline
  - These results are typical of E85

Future challenge – E85 FFV PZEV

GM currently offers a range of E85 FFVs in Cars & Light Trucks

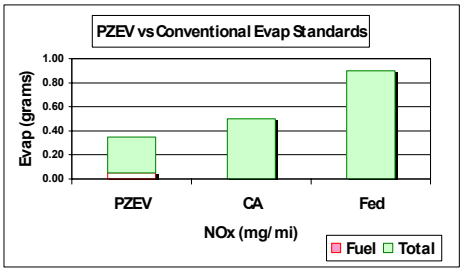
- Committed to grow FFV offerings to 50% of our 2012 MY fleet
  - Contingent on continued progress on fueling infrastructure
- Today's FFVs meet all but the most stringent California emission requirements
  - CARB PZEV emissions standards
  - Progress needed on both FFV exhaust & evaporative emissions to meet PZEV
  - GM working to solve these technical issues so that the PZEV requirements do not preclude providing a full range of E85 FFV offerings in the CA emissions states

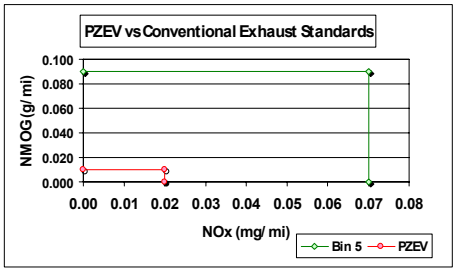
E85 FFVs and CARB's PZEV requirement

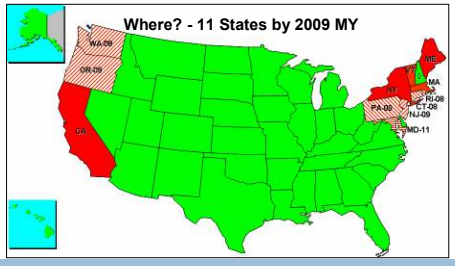
Under the CARB ZEV Mandate a growing fraction of GMs sales each model year through 2018 must be PZEV compliant:

- PZEVs are required to meet the most stringent exhaust & evaporative emissions standards
  - SULEV exhaust emissions:
    - 0.010 g/mi NMOG, 1.0 g/mi CO, 0.020 g/mi NOx
  - Zero evaporative emissions
    - Vehicle fuel evaporative emissions limited to 0.054 g
  - For E85 flex-fuel vehicles the standards apply on worst-case blends of gasoline & ethanol
    - Exhaust emissions on both gasoline and E85
    - Evaporative emissions on E10

ZEV Mandate – PZEV & AT-PZEV overview







Fleet Penetration of PZEV + AT-PZEV	2012-14	2015-17	2018-On
Max PZEV Credit Vehicle Credit ZEV States Penetration	6% 0.2 30%	6% 0.2 30%	6% 0.2 30%
Max AT-PZEV Credit Vehicle Credit ZEV States Penetration	3% 0.60 5%	4% 0.50 8%	5% 0.5 10%
Total ZEV States	35%	38%	40%
U.S. Penetration	**11%**	**11%**	**12%**

E85 FFV challenge meeting SULEV exhaust emissions

SULEV compliant vehicles need the catalyst warmed-up & near-perfect air:fuel ratio control within ~10 seconds of cold start

- E85 fuel has low volatility due to the high fraction of ethanol
  - Requires more excess fuel for cold-start than gasoline
  - Ethanol fraction of excess fuel disturbs air:fuel ratio control as it vaporizes at ethanol boiling point
  - Much more challenging than gasoline in this regard
- Significant improvements required to meet SULEV emissions on E85
  - SIDI (direct injection) fueling systems expected to help
  - More complex exhaust after-treatment anticipated
  - Improved control algorithms & calibrations also needed

E85 FFV challenge meeting Zero evap emissions

Zero evap emissions compliance requires extremely low permeation of fuel through non-metallic fuel system components

- HDPE fuel tank and elastomeric fuel lines & seals
  - Fuel evap loss standard of 0.054 grams
  - Very challenging compliance requirement on gasoline
  - E85 FFVs are certified on E10 blend to represent worst case
  - E10 permeates at roughly double the level seen on gasoline
- E85 FFVs will require metal fuel tank to comply – issues:
  - Platform redesign for crashworthiness with metal tank
  - Corrosion concerns with metal tank
  - Lack of metal fuel tank supply base
- CARB expected to change cert fuel to E10 – this will be a gasoline PZEV issue also

E85 FFV PZEV Summary

GM is aggressively expanding its FFV offerings

- We will provide a full lineup of E85 FFVs to CA states
  - In the near term we are restricting FFV volume where there is an identical PZEV model
  - In the longer term we are working on technical solutions to allow E85 FFVs to meet the PZEV requirements