Fuel Economy & Emissions: Ethanol Blends vs Gasoline

Kevin Cullen   GMPT Engineering - Compliance & Cert 248-685-6339

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

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

2007 Chevrolet Suburban

• 5.3L LC9 Flex fuel engine
• California emissions
  • EPA Bin 4 certified
  • Qualifies as CA ULEV₂
  • CA Near-zero evap
• 6000 pounds test weight class
• 31.8 gallon fuel capacity
• Equipped with catalyst & O₂ sensors aged to full useful life (120,000 miles)
E85 vs Gasoline Emissions – Regulated Exhaust Constituents

Vehicle # XECS7020 - 2007 Chevrolet Suburban 5.3L FFV

- **Vehide # XECS7020 - 2007 Chevrolet Suburban 5.3L FFV**

E85 vs Gasoline Emissions – Exhaust CO and Evap HC

Vehicle # XECS7020 - 2007 Chevrolet Suburban 5.3L FFV

- **Vehide # XECS7020 - 2007 Chevrolet Suburban 5.3L FFV**
E85 vs Gasoline Emissions – CO₂ & 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Gasoline</th>
<th>E85</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Emissions x CWF</td>
<td>Carbon</td>
</tr>
<tr>
<td>Carbon from HC</td>
<td>0.0509 g/mi x 0.866</td>
<td>0.04 g/mi</td>
</tr>
<tr>
<td>Carbon from CO</td>
<td>1.007 g/mi x 0.429</td>
<td>0.43 g/mi</td>
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<tr>
<td>Carbon from CO₂</td>
<td>551.1 g/mi x 0.273</td>
<td>150.55 g/mi</td>
</tr>
<tr>
<td>Total Exhaust Carbon Emissions</td>
<td>150.92 g/mi</td>
<td>143.36 g/mi</td>
</tr>
<tr>
<td>Fuel Carbon Content</td>
<td>2439 g/gal</td>
<td>1713 g/gal</td>
</tr>
<tr>
<td>Fuel Economy</td>
<td>2439/150.92</td>
<td>16.16 MPG</td>
</tr>
<tr>
<td>Fuel Lower Heating Value</td>
<td>114,365 BTU/gal</td>
<td>82,332 BTU/gal</td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td>114,365/16.16</td>
<td>7.077 BTU/mi</td>
</tr>
<tr>
<td></td>
<td>(16.16/114.365)</td>
<td>(7.077/82.332)</td>
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<tr>
<td></td>
<td>(-26%)</td>
<td>(+3%)</td>
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</table>

| Parameter                        | Gasoline          | E85                |
|                                  | Emissions x CWF   | Carbon             |
|                                  | 0.0554 g/mi x 0.817 | 0.05 g/mi          |
|                                  | 0.413 g/mi x 0.429 | 0.02 g/mi          |
|                                  | 525.1 g/mi x 0.273 | 143.36 g/mi        |
|                                  | 143.43 g/mi        | 143.36 g/mi        |
| Fuel Carbon Content              | 2439 g/gal        | 1713 g/gal         |
| Fuel Economy                     | (16.16/114.365)   | 11.94 MPG (+3%)    |
| Fuel Lower Heating Value         | 114,365 BTU/gal   | 82,332 BTU/gal     |
| Energy Efficiency                | (7.077/82.332)     | 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 CO₂ 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
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