History and Factors Influencing Automotive Fuel Ethanol in the U.S

GM Experience

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Outline

- Early Ethanol Usage
- Promotion of E85
- Future Production of FFVs
- GM FFVs
- E85 Usage
- E85 Specification
- Testing with fuels
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Early Ethanol Usage

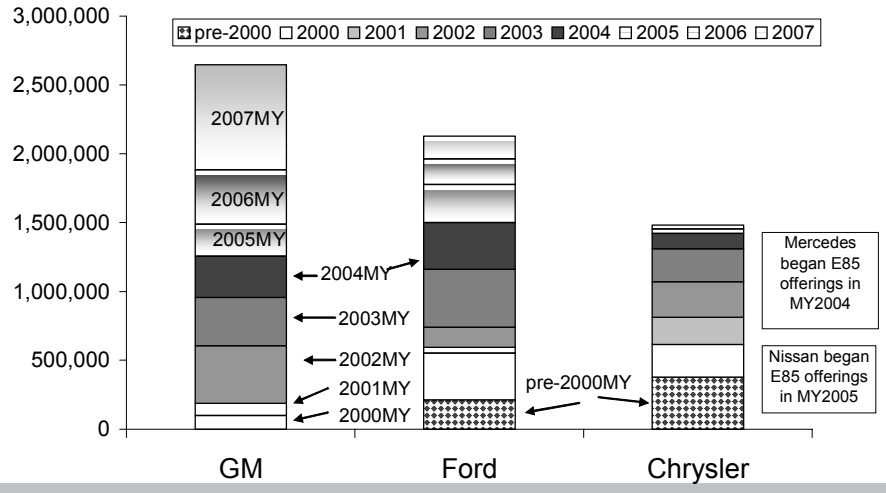
- Modern usage of ethanol as a motor fuel dates from the 1973 oil embargo
- Energy Tax Act of 1978 granted E10 a 4 cent per gallon tax exemption
- In 1979 GM was the first to announce that it would warrant E10 in its vehicles
  - By the mid-eighties ethanol related warranty costs were very low as appropriate materials were used throughout the portfolio
  - GM has been a consistent supporter of the use of E10
- The exemption was raised in 1982 to 5 cents and 1984 to 6 cents
- Clean Air Act in 1990 mandated the use of oxygenates in cities with high CO and ozone
- The 1992 Energy Policy act which set a goal of 30% for the penetration of alternative fuels in the US
- By 1994 ethanol production reached 1 billion gallons annually

The US Government Promoted the Use of Alternative Fuels Including Ethanol

- Initial alternative fuels work was on M85 (methanol) FFVs
  - It was rapidly discovered that E85 would work in M85 vehicles
- The 1988 Alternative Motor Fuel Act offered fuel economy credits for selling alternative fuel capable vehicles.
  - The fuels used had to be at least 85% alternative to receive credits
  - This gave an incentive to take M/E85 vehicles out of the lab and put them on dealer lots
- It took many years for hardware, software and diagnostics issues to be resolved.
  - The cost of FFVs had to be driven below the value of the credits
- E85 vehicles were sold in limited quantities in the mid-1990s
- High volume production began in 1998

U.S. E85 Industry Sales

GM is the leader in current and cumulative Flexfuel sales



Future Production of FFVs

- Until MY2007 FFV production tracked the minimum number of vehicles required to receive the full fuel economy credit
- In 2006 Chrysler, Ford and GM committed that 50% of production would be biofuel (mostly FFV) vehicles by 2012
  - These manufacturers increased their production of current FFVs
  - Component supplies often prevented significant increases in production beyond historic plans
  - Starting in 2009 a variety of new E85 vehicles will start to appear as a result of this commitment

The GM U.S. “Flex Fuel Club”

E85 Usage

- E85 usage avoids a number of problems discovered using E100 in Brazil
  - E100 has low vapor pressure that leads to cold start difficulties
    - E85 has tailored vapor pressure to allow starting in Canadian conditions
  - E85 does not require an auxiliary fuel tank to supply gasoline
    - This avoids increased evaporation from dual fuel system
    - No expense for a second fuel system
    - Customers are not dissatisfied from forgetting to keep gasoline tank filled
    - There is no gasoline deterioration in auxiliary fuel system

E85 Specification

- The E85 specification required significant development to ensure good performance
- Development occurred at GM with ADM assistance
  - Seasonal composition variation with additional gasoline (E70 in winter) is required to accommodate temperature changes
    - Ethanol has a lower vapor pressure than methanol
  - E85 acidity, chloride and copper content all reduced compared to ethanol for E10 blending (D4806)
  - ASTM E85 specification (D5798) approved in 1996
  - Continuous improvement since – pHe spec added in 1999
- Comprehensive specifications that are followed in the marketplace are critical for ensuring best performance and durability

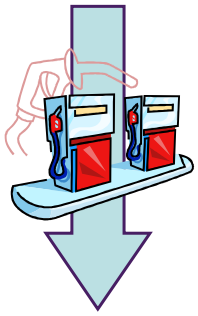
Testing With Fuels

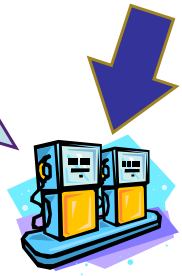
- GM has over 100 test fuels including:
  - 10 high ethanol
  - 25 certification fuels
  - 33 component durability
  - 5 Biodiesel
- Fuel proliferation and complexity are a major issue at all automakers
  - Accurate determination field fuel composition and deviations from generally accepted standards and specifications is critical for vehicle development and validation
    - Additional test biofuels are under development to represent marginal fuels that are found in the marketplace
    - Additional test fuels are being developed to comprehend alternative fuel proliferation around the world
  - Development and acquisition of precisely and repeatably formulated test fuels is a major concern

Gasoline vs. E85 Energy Content and Vehicle Range

Typical Gasoline Properties:
- **Energy density ~115K BTU/gallon**
- **Regular grade octane 87 (R+M)/2**

Pure Ethanol Properties:
- **Energy density 76K BTU/gallon**
- **Octane – about 100 (R+M)/2**



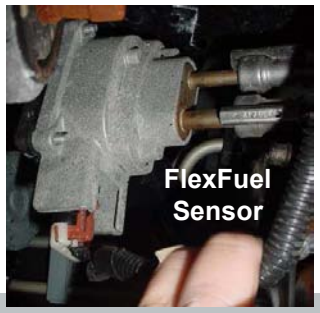


E85 fueled MPG and range are lower than gasoline by about 25%
- **Slightly better than fuel Δ energy (for normally aspirated S.I.)**

E85 blend properties:
- **Energy density ~83K BTU/gallon**
- **28% lower than gasoline**
- **Regular grade octane 96 (R+M)/2**

Typical Content Changes for E85 FFVs

- Fuel system materials improved for corrosion resistance
  - Pump, level sender, OBD pressure sensor, fuel injectors, seals
  - These changes also needed for E20 compatibility in the U.S.
- Higher fuel pump and injector flow capacity compensates for E85 energy density
- Cylinder head and valve materials
- Software/calibration to detect fuel blend and optimize operation
  - Virtual fuel sensor (software algorithm) identifies blend (or FlexFuel sensor)
  - Fueling and spark tailored to fuel characteristic (boost if turbocharged)



Content Changes

- Why are these hardware changes needed for ethanol?
  - Ethanol has a million times higher electrical conductivity than gasoline
    - Bare wires and terminals must be protected
    - Galvanic couples must be eliminated
    - Aluminum and zinc must be protected
  - Ethanol is a excellent solvent and very different from gasoline
    - Polymer and elastomeric materials must be changed
  - Ethanol has two thirds gasoline's energy per unit volume
    - Pump and injector flows must be dramatically increased
- Why are software changes required?
    - The reduced energy content and vapor pressure of ethanol will result in poor starting and lean operation with standard calibrations
    - Lean operation leads to overheating and catalyst damage
- These changes apply to mid-level blends and small engines also

Future of E85

- The high octane and low flame temperature of E85 presents opportunities for engine builders
  - Turbocharging allows significant power improvements due to higher octane (knock resistance)
    - But no direct efficiency gains, MPG is still reduced by ~25%
  - Turbocharging or other power increasing technologies and downsizing offer real efficiency gains
    - Gasoline performance severely impacted due to lower octane
    - Widespread E85 availability and competitiveness is required
  - Other technologies taking advantage of E85 properties are under development
    - Direct injection offers potential improvements in power and cold start emissions
  - Full effects of lower ethanol energy density are unlikely to ever be offset
    - First Law of Thermodynamics holds for Ethanol