

High Octane Fuels Can Make *Better* Use of Renewable Transportation Fuels

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Three Major Challenges Facing the Transportation Industry Over the Next Decade

Can more sensible use of biofuels enable CAFE and RFS simultaneously?

54.5 mpg CAFE by 2025

-per U.S. EPA and U.S. DOT standards (2012 rule)

OBAMA ADMINISTRATION Fuel Economy Standards **In the year 2025**

The fleet-wide average will be **54.5 MPG**

Consumers will have saved **\$1.7 TRILLION** at the pump over the life of the program.

A family that purchases a new vehicle in 2025 will save **\$8,200** in fuel costs when compared with a similar vehicle in 2010.

Over the life of the program, the standards will:

- Save **12 billion barrels** of oil.
- Eliminate **6 billion metric tons** of carbon dioxide pollution.

This program, together with standards already put into place by this administration for Model Years 2011-2016, will result in significant cost savings for consumers at the pump, dramatically reduce oil consumption, cut pollution and create jobs.

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Fuel Economy Standards



70% less NOx

85% less NMOG

70% less PM

EPA Tier 3 Emission Regulations

Transportation Industry

Renewable Fuel Standard

Further reductions in vehicle emissions

-per EPA Tier 3 regulations (2014)

Ethanol blends can also help mitigate particle emissions

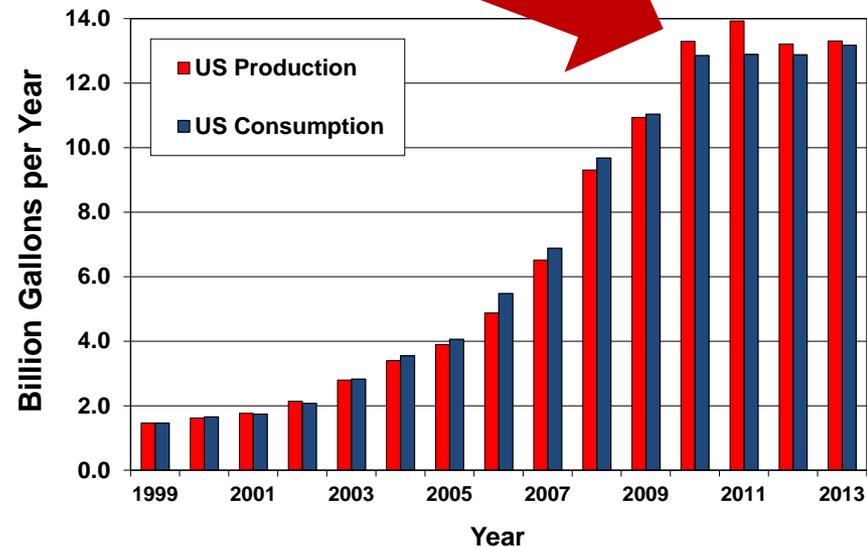


36 billion gallons /yr of renewable fuel by 2022

-per Energy Independence and Security Act of 2007

Ethanol is currently largest volume biofuel

- But, we are at the “Blend Wall”
- Over 99% of domestic ethanol is used in E10
- Where can we go from here?
 - E15
 - *Legal* in 2001 and newer vehicles
 - Several manufacturers permit E15 in their *new* vehicles
 - FFV fuel underutilized
 - What about a new *high-octane* mid-level blend?



U.S. ethanol production and consumption.
Data from Energy Information Agency
<http://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf>

Consumers Continue to Shy Away from E85

- Gasoline/E10 stations average over 2000 gal/station/day
- E85 dispensers average <200 gal/dispenser/day
 - >16M FFVs on road – **annually consume ~12 gal E85 per vehicle**
- Lower Energy Density and higher \$/BTU (compared to gasoline or E10)
 - Shortened range
 - Higher cost per mile
- How much ethanol is in my “E85?”
 - New ASTM spec for “Fuel for FFVs” allows 51% to 83% ethanol
 - Specification addresses quality and volatility of blends
 - Potential for significant variability in vehicle fuel economy
 - Contributes to consumer confusion



Consumer acceptance is key to success of any new fuel



Designation: D5798 – 11

Standard Specification for Ethanol Fuel Blends for Flexible-Fuel Automotive Spark-Ignition Engines¹

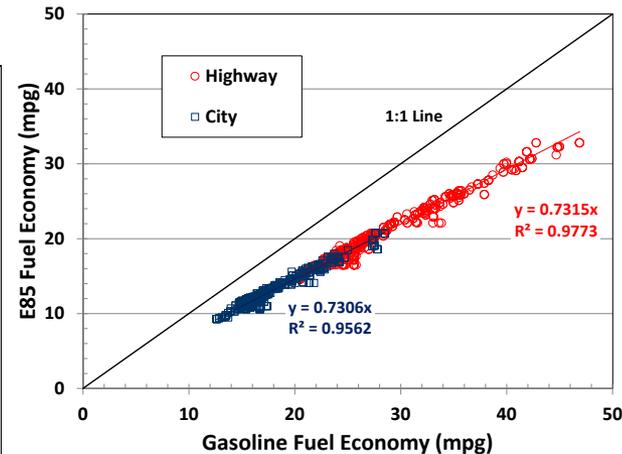
This standard is issued under the fixed designation D5798; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

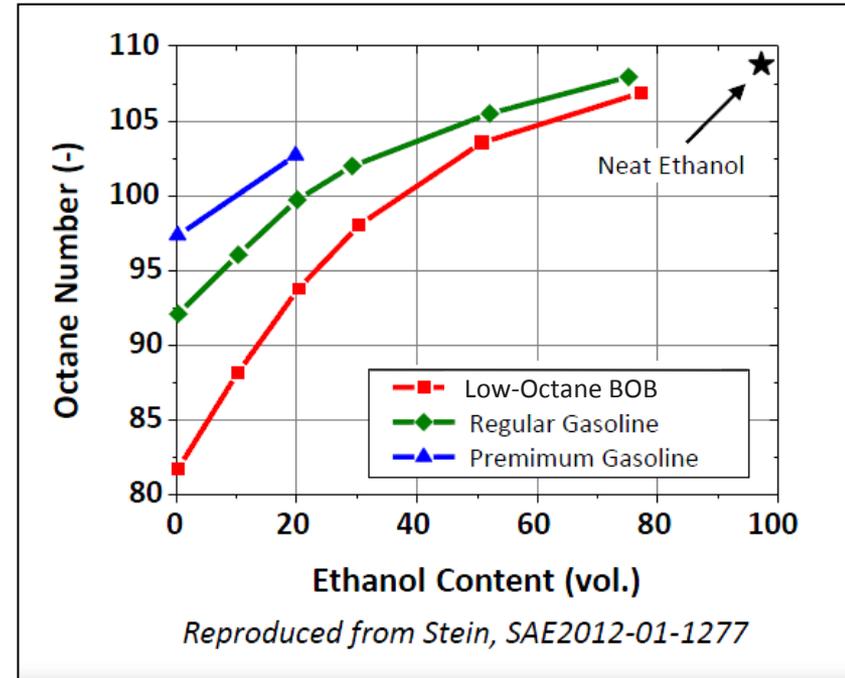
1.1 This specification covers the requirements for automotive fuel blends of ethanol and gasoline for use in ground

does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices



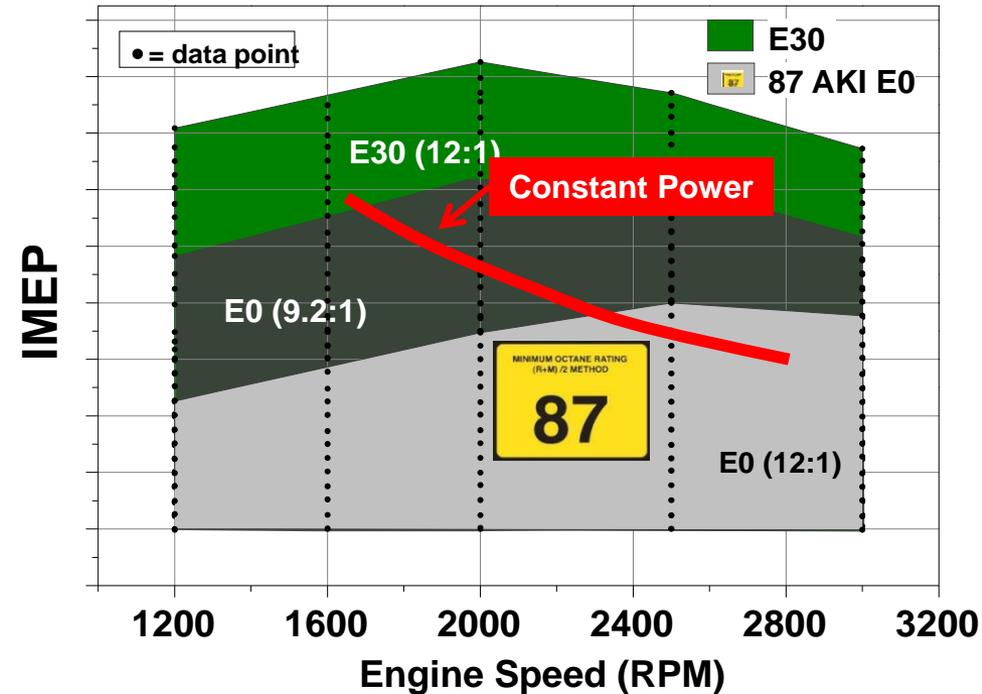
Ethanol is a very effective octane booster

- ~2/3rd of octane benefit from first 1/3rd of ethanol volume percent
- EPA opened the door for a high octane ~E30 fuel in Tier 3 rule
 - “...we allow vehicle manufacturers to request approval for ... fuel such as a high-octane 30 percent ethanol by volume blend (E30) for vehicles ... optimized for such fuel”
- Road fuel infrastructure for a mid-level ethanol blend is not trivial (but significantly less complex than many other alternatives)
 - Over 3000 E85 dispensers in service, over 16M FFVs on the road that could use an E20-E40 fuel *today*
 - Thousands of dispensers replaced annually. Prudent to start before needed



Recent Experiments Highlight Benefits of High Octane Fuel for SI engines

- Engines can make more torque and power with higher AKI fuel
- Ethanol is very effective at boosting anti-knock index (AKI or Octane Number)
- Increased torque enables downspeeding and downsizing for improved fuel economy
 - Engine and system efficiency can balance lower energy density of ethanol blends



In a high compression research engine, high-octane E30 enables doubling of available torque compared to 87 AKI E0 fuel

- Splitter and Szybist, ORNL

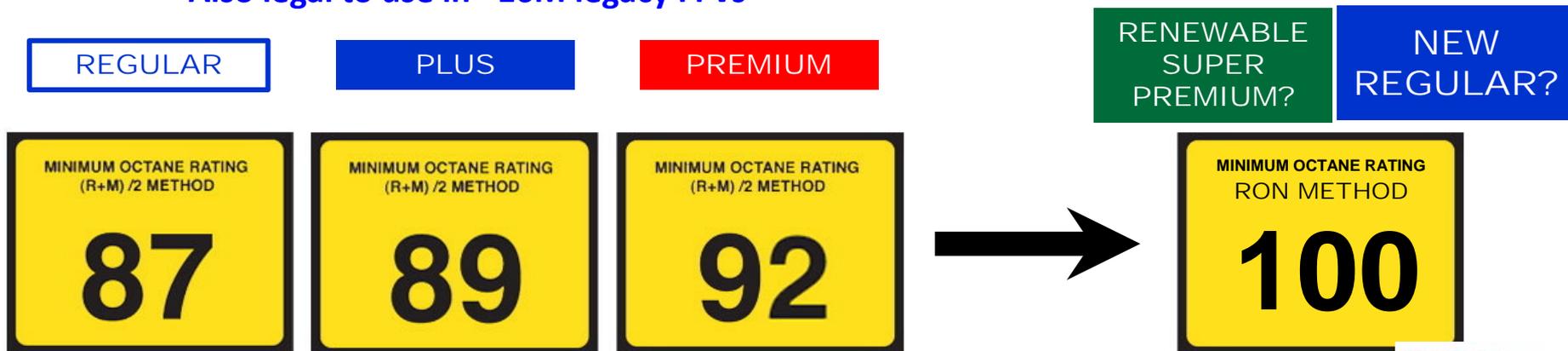
Several Promising Biofuels Could Contribute To High Octane Blends

- **Ethanol**
 - Currently largest volume fuel (>13Bgy)
 - Excellent octane, latent heat of vaporization
- **“Drop in” biomass-derived hydrocarbons**
 - Kior, Vertimass, others
- **Isobutanol**
 - Good octane, low volatility, higher energy density than ethanol
 - Can be produced in retrofitted ethanol plant
- **Alkyl-Furoates**
 - High octane compounds
- **Potential synergies from blending of above components**



A New High Octane Fuel Could Make Better Use of Ethanol's Properties, Helping The Nation Achieve Multiple Goals

- Engine efficiency can improve with increasing ethanol (in properly designed future engines/vehicles)
 - Octane number + latent heat of vaporization permit higher CR, optimized combustion phasing, increased power (downspeeding/downsizing)
- Likely that ~E20-E40 blend can return equivalent “tank mileage” as E0 or E10
 - Energy density penalty is *linear* with ethanol concentration, power and efficiency gains are *non-linear*
 - Tank mileage parity means every gallon of ethanol displaces a gallon of gasoline
 - High Octane blend in optimized vehicles could enable CAFE (fuel economy) compliance and RFS compliance simultaneously
 - **Also legal to use in ~16M legacy FFVs**



Regulations Have Required Many Changes in Fuels in Coordination with Emissions and Fuel Economy Laws for Vehicles. Some examples:

- 1974 Unleaded Gasoline
- 1979 E10 Ethanol Subsim Waiver
- 1981 Tier 0
- 1989 Phase 1 Gasoline Summer RVP Limits
- 1991 Phase 2 Gasoline Summer RVP Limits (including 1-psi E10 waiver)
- 1992 Winter Oxyfuels Program (39 cities)
- 1993 Highway diesel fuel sulfur control (500 ppm)
- 1994 Tier 1
- 1995 Phase 1 RFG and Anti-dumping
- 1996 Prohibition on lead
- 1999 NLEV
- 2000 Phase 2 RFG
- 2002 Mobil Source Air Toxics (MSAT1)
- 2004 Tier 2 Gasoline Sulfur Control (30 ppm avg, 80 cap)
- 2006 Renewable Fuels Standard
- 2006 Removal of RFG Oxy Mandate
- 2006 Ultra Low Sulfur Highway Diesel Fuel (15 ppm)
- 2006 Boutique Fuels List
- 2007 Renewable Fuel Standard (RFS)
- 2010 Ultra Low Sulfur Nonroad Diesel Fuel (15 ppm)
- 2010 Renewable Fuel Standard 2 (RFS2)
- 2010 E15 Waiver
- 2011 MSAT2 – Gasoline Benzene
- 2017 Tier 3, Gasoline sulfur <10 ppm, 30 mg/mi NMOG+NOx, **E10 cert fuel**

Regular fuel in Europe is 95 RON (similar to Premium in US)

Regulating Octane in the US would not be a new precedent

The EPA R Factor Equation Is Used to Adjust *Measured* Fuel Economy for CAFE Compliance

$$MPG = \frac{(5174 * 10^4 * CWF * SG)}{[((CWF * HC) + (0.429 * CO) + (0.273 * CO_2)) * ((0.6 * SG * NHV) + 5471)]}$$

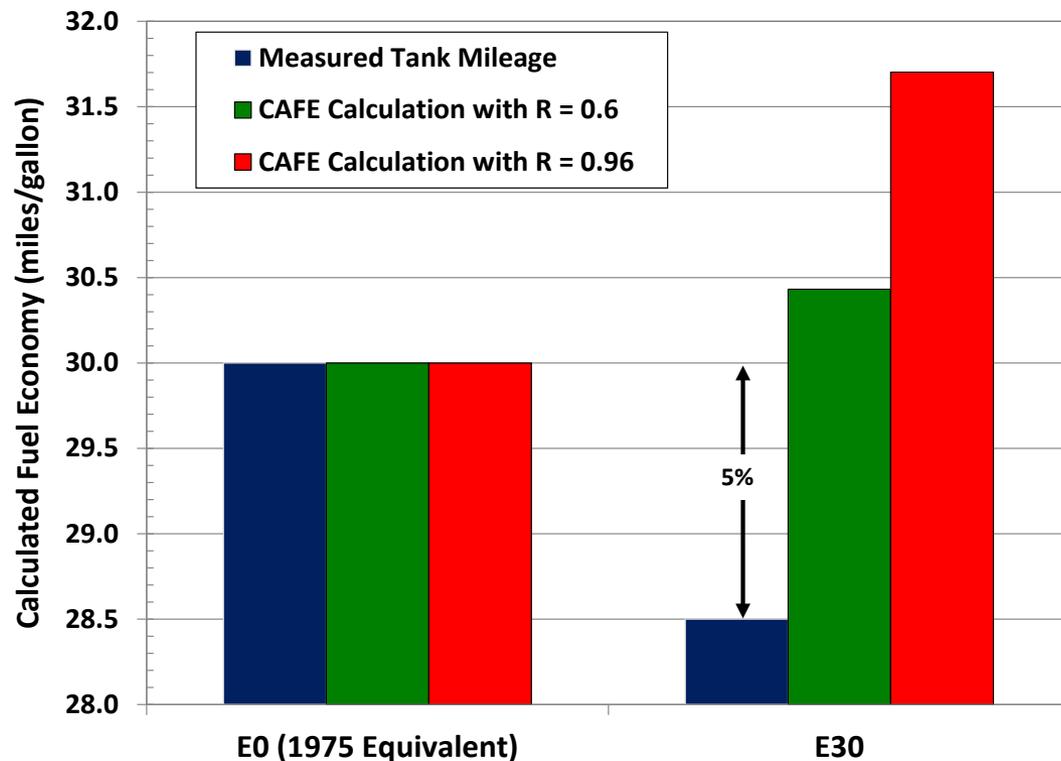
code of
federal regulations

↑
This is "R"

- Corporate Average Fuel Economy (CAFE) has been regulated since 1975
- "R" equation relates *measured* fuel economy back to 1975 E0 reference fuel (certification fuels have always been E0)
- Tier 3 requires E10 certification fuel beginning in 2017
- High Octane E20-E40 certification blend will be even more dependent on an updated R Factor

EPA “R Factor” To Be Revised for Ethanol-blended Fuels for Fuel Economy Certification

- R is currently 0.6.
- Recent publications suggest that R should be ~0.96 for today’s vehicles.
- Manufacturers will have limited incentive to certify on lower energy density fuels if R remains at 0.6.



Example for illustrative purposes. Arbitrary 30 mpg base E0 FE, arbitrary assumption that equivalent vehicle with future high compression, downspeeded engine achieves 28.5 mpg.

- **With correct R Factor, high-octane mid-level blends can offer real CAFE as well as GHG benefits.**

There are Significant Potential Benefits And Challenges To Establishing a New High Octane Regular Fuel

Benefits

- Improved Fuel Economy and GHG
- Increased Ethanol/biofuel Utilization
- High Performance Vehicles



Challenges

- Infrastructure
- “Regulatory Thicket”
- Benefits must be realized in certification
 - Tier 3 rule “opens door” for a new fuel...
 - EPA is committed to addressing “R”
- Fuel Specifications
 - D4814, D4806, D5798, new one for High Octane Fuel(s)?
 - RON, MON, AKI= (R+M)/2
 - Latent heat of vaporization
- Consumer acceptance and concerns over misfueling in the field



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ATTENTION
E15
Up to 15% ethanol

Use only in

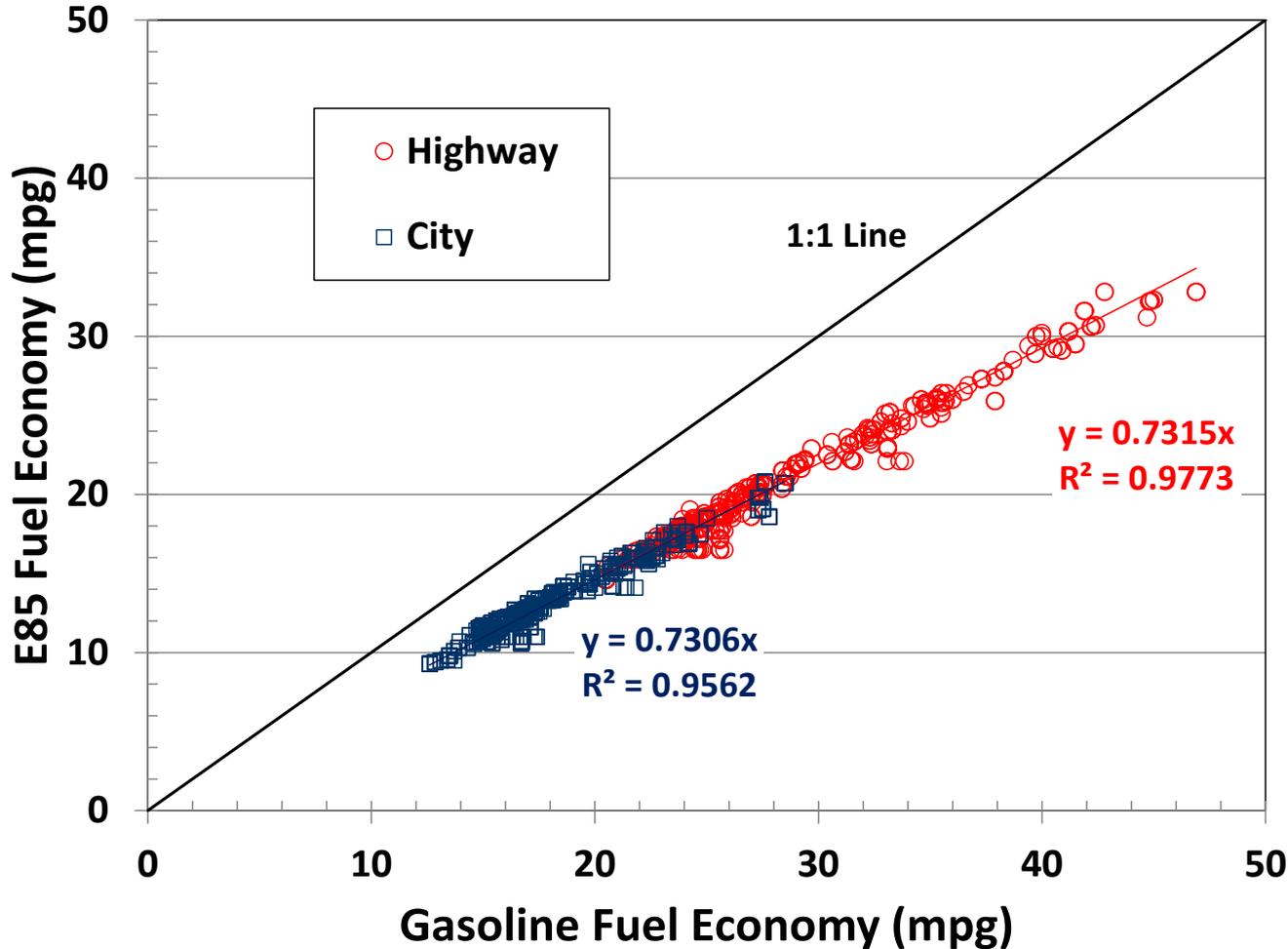
- 2001 and newer passenger vehicles
- Flex-fuel vehicles

Don't use in other vehicles, boats, or gasoline-powered equipment. It may cause damage and is *prohibited* by federal law.

Backup Slides

Modern Flex Fuel Vehicles are “ethanol tolerant” gasoline vehicles. Fleet average shows 27% lower mpg with E85.

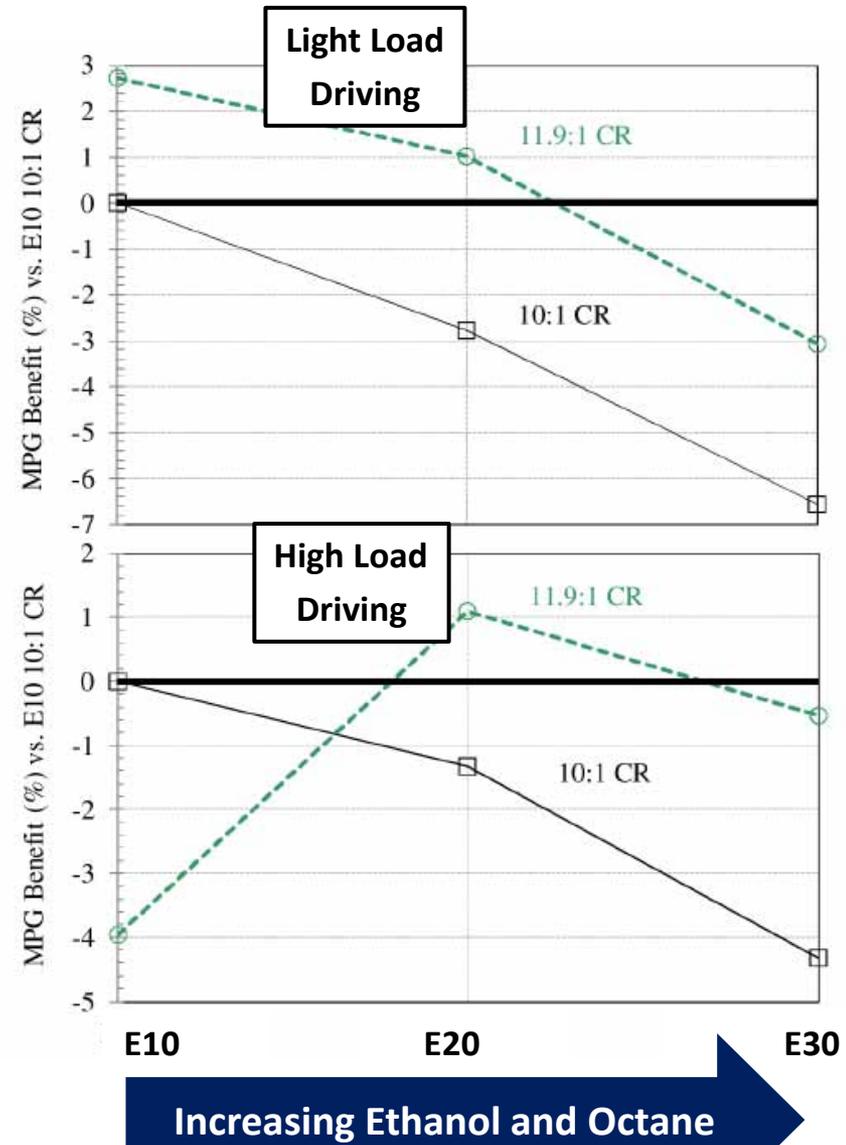
Manufacturers must protect for minimum available octane, so engines take little or no advantage of ethanol’s properties to improve power or efficiency.



EPA certification data for U.S. legal FFVs, 2000-2012. 649 vehicle records.

Ford Data Shows Improved Fuel Economy with High Octane Ethanol Blends

- Ford developed engine maps with three ethanol blends at 2 compression ratios
- Modeled vehicle fuel consumption
 - Changed shift schedule for modest down-speeding
- **At light load (highway test)**
 - Higher compression boosts fuel economy with all fuels
 - Fuel economy tracks ethanol content
- **At higher loads (US06 aggressive test)**
 - Higher compression boosts fuel economy with higher octane blends
- **Ethanol can do so much more than bring sub-octane gasoline (BOB) up to 87 AKI and displace 2/3^{rds} of a gallon of gasoline**



Fuel Economy change versus ethanol content
(from Jung, et al, SAE 2013-01-1321)

Regulation has driven more efficient and cleaner vehicles as well as been used to alter the fuel supply (US example)

