High Octane intermediate Bio-Fuel-Gasoline Blends, Opportunities for Improved Thermodynamic and System Efficiency

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Oak Ridge National Laboratory

Emerging Issues Forum
Nebraska Ethanol Board
April 16th, 2015

We would like to gratefully acknowledge Kevin Stork, program manager of the Fuels & Lubricant Technologies Program at the U.S. Department of Energy (DOE) Vehicle Technologies Office.

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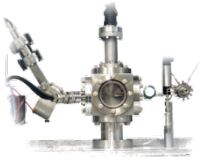
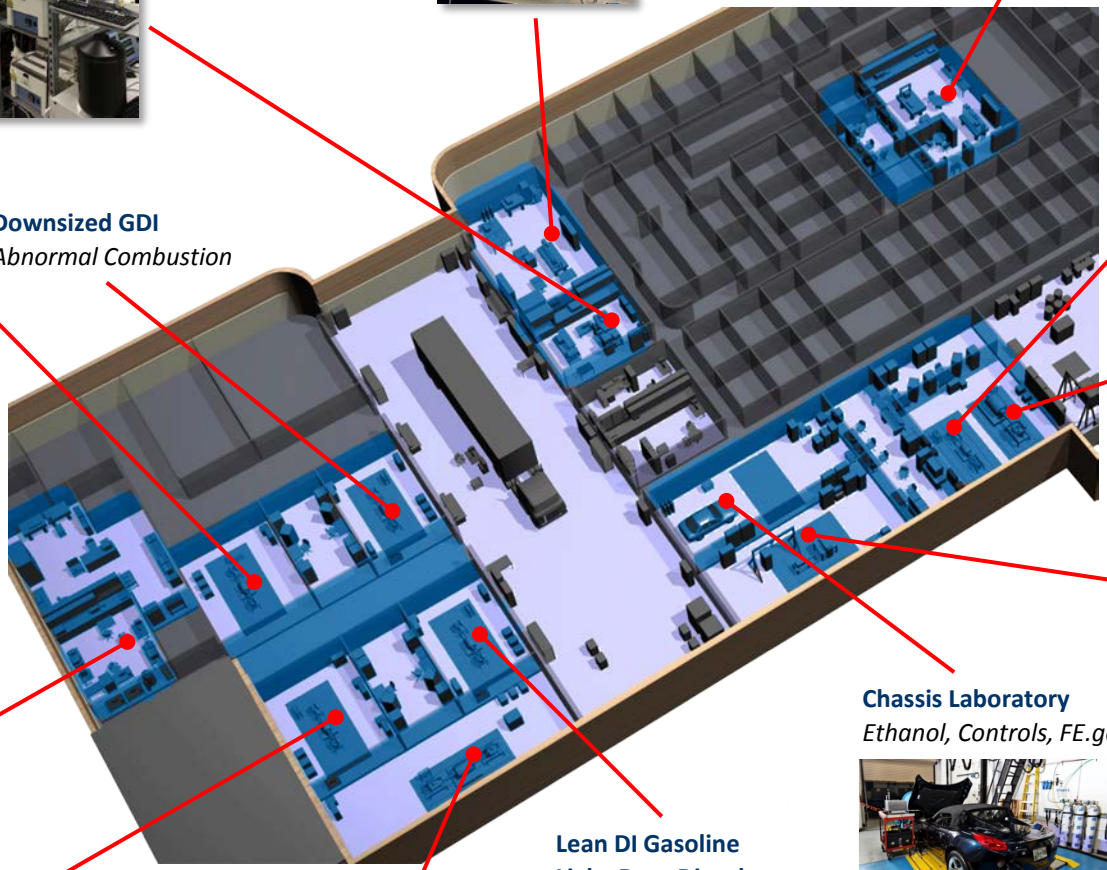
Source: http://www.ornl.gov/ornlhome/about.shtml

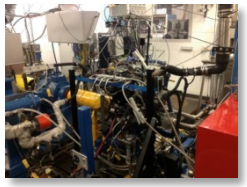
Reaction Engineering and Applied Catalysis
Catalyst Fundamentals



Laser Diagnostics
Advanced Sampling



Spark Ignition Gasoline
High Octane Fuels,
In-cylinder Reforming



Advanced Engines
Advanced Combustion,
Fuels, Variable Compression

Downsized GDI
Abnormal Combustion

Heavy-Duty Diesel
VSI Lab Benchmarking

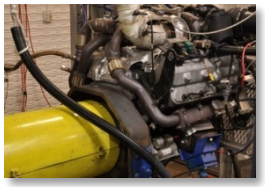
Analytical Chemistry
Bench Flow Core Reactor,
Emissions & Particulate
Characterization

Chassis Laboratory
Ethanol, Controls, FE.gov

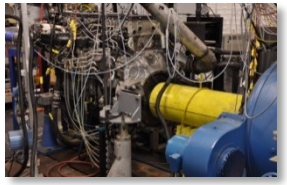
Flexible Single-Cylinder
HCCI, Fuels, Materials,
Aftertreatment, Pre-
Ignition

Lean DI Gasoline
Light-Duty Diesel
Emissions Control
Integration

Medium-Duty Diesel, Light-Duty Gasoline
Advanced Combustion, Adaptive Controls



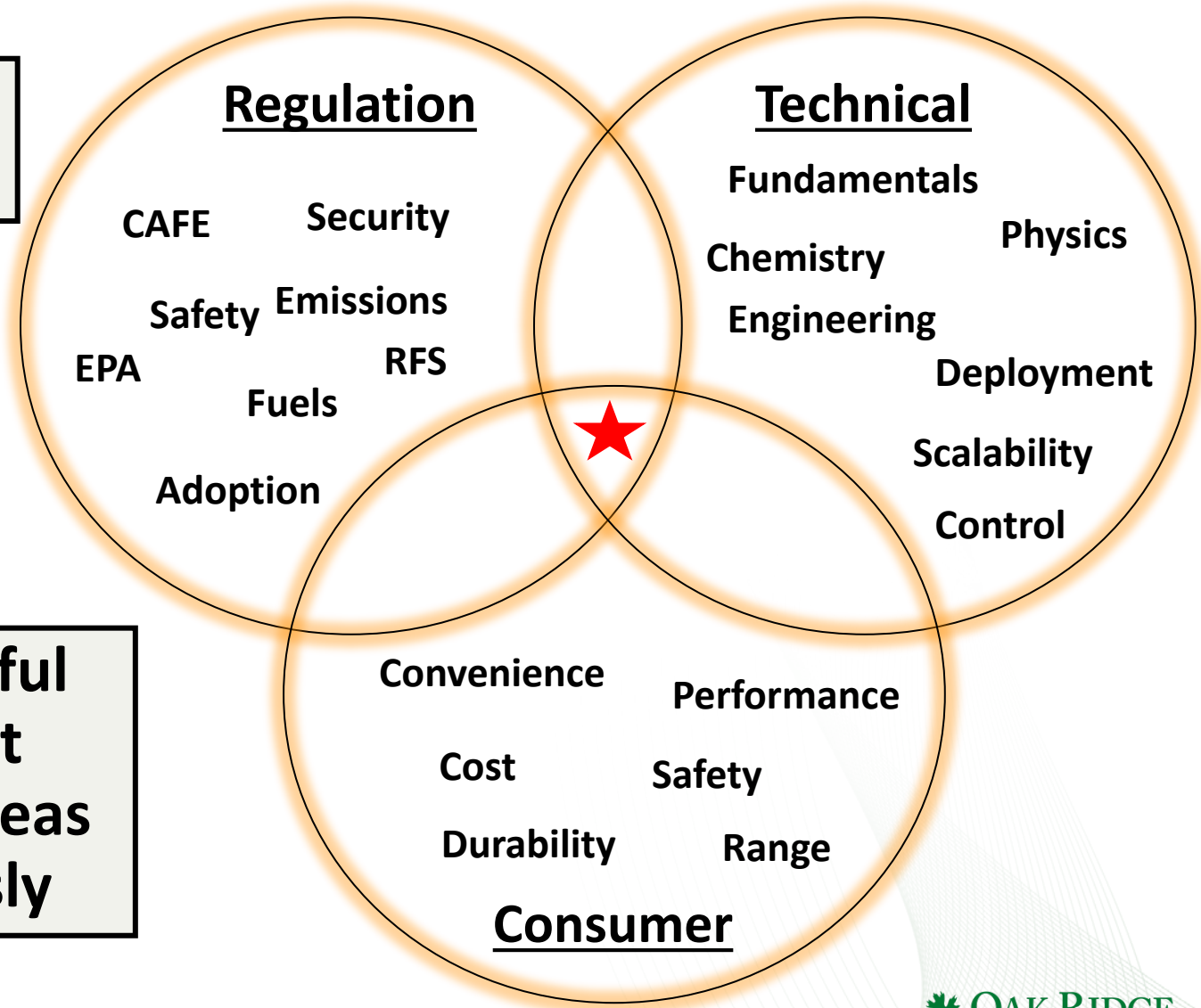
Heavy-Duty Diesel
Advanced Combustion,
Aftertreatment



Additional facilities in adjacent building

Transportation Faces Unique Challenging Criteria

- It's a 3-ring circus



- Practical, useful research must address all areas simultaneously

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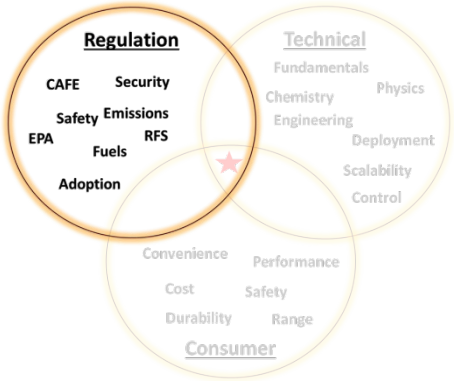
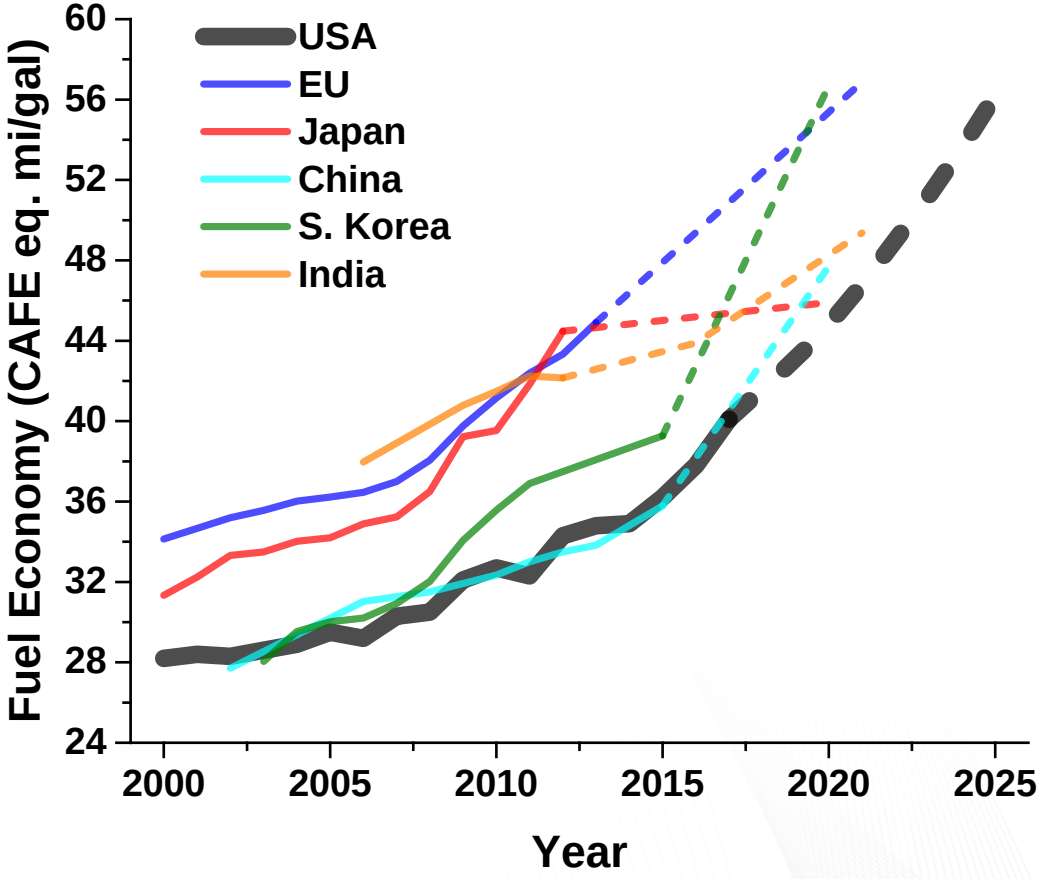
CURRENT TRANSPORTATION CHALLENGE = FUEL ECONOMY

- US is rapidly ramping up fuel economy standards
- Last-to-first approach within next 10 years
- **opportunity for research, development, and change**





Source: http://www.theicct.org/info-tools/global-passenger-vehicle-standards

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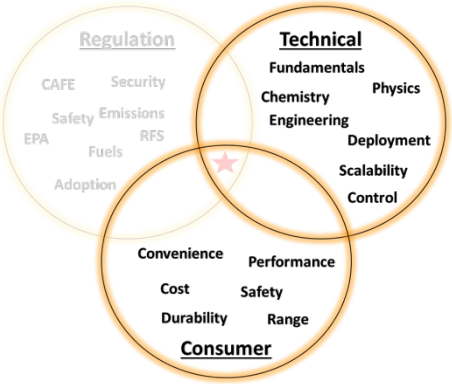
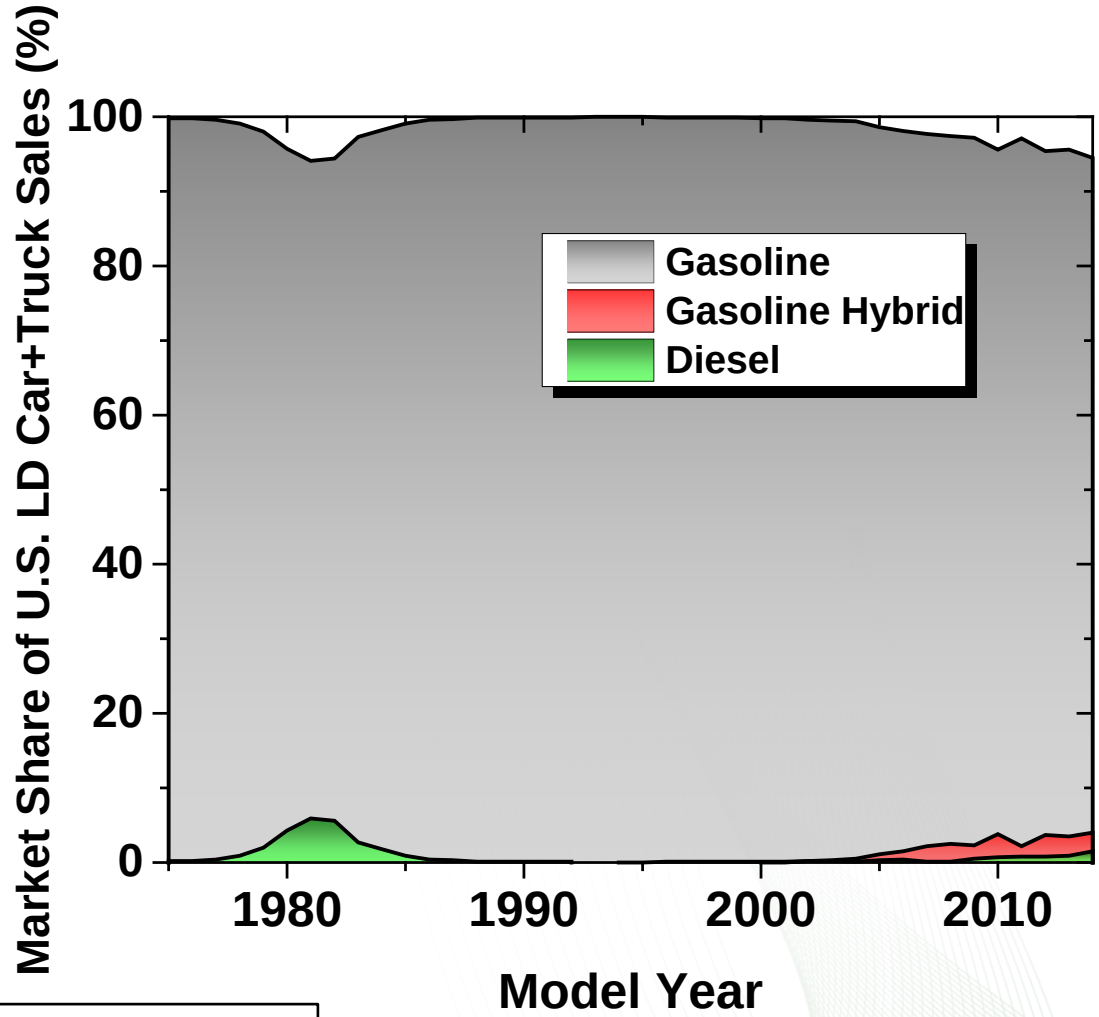
Meeting the design criteria has been though gasoline engines

- US LD market is 99% spark ignited "gasoline" powered
- Improvement to gasoline & gasoline engines preset the most meaningful strategy going forward





Source: EPA 2014 LD Trends report

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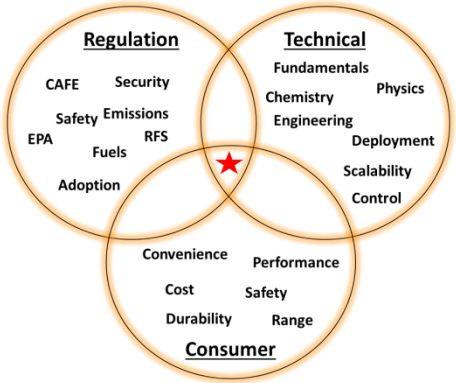
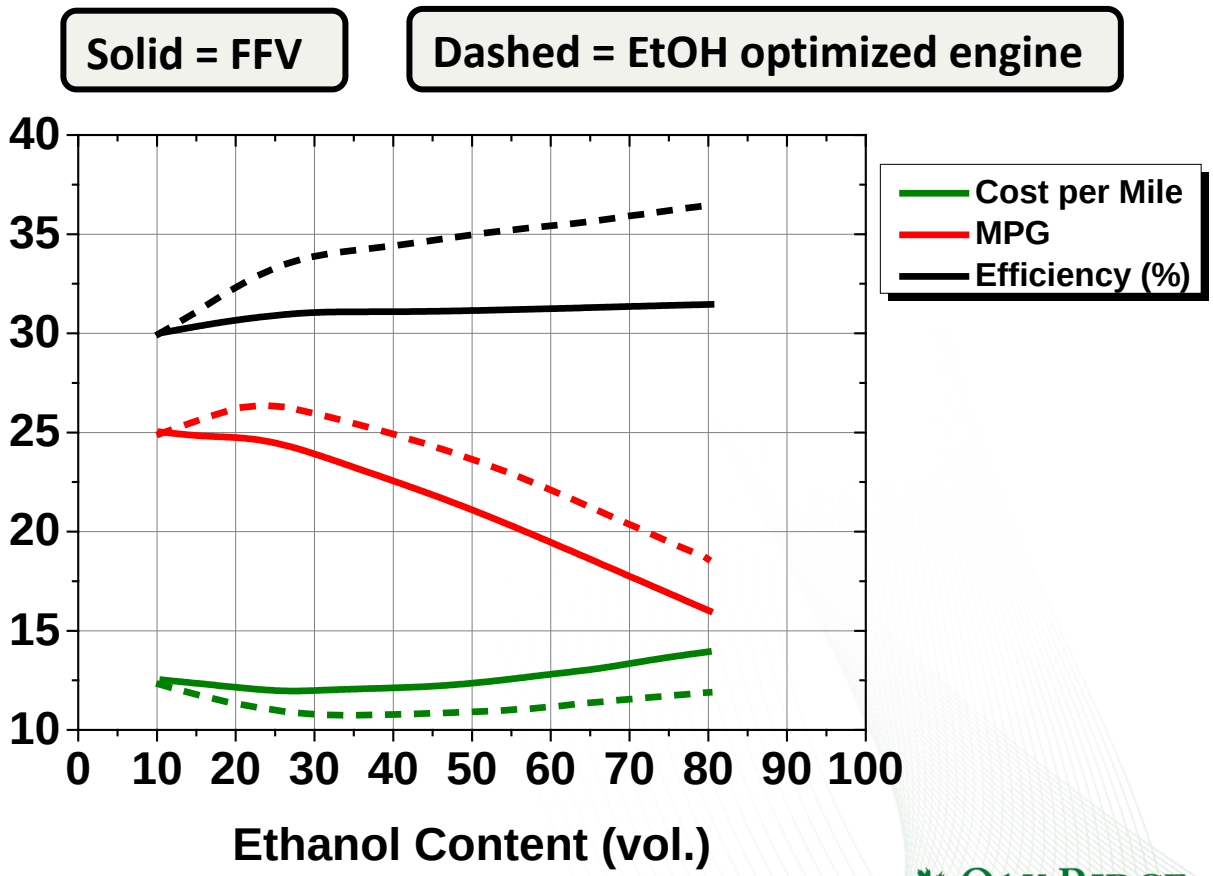
ETHANOL-GASOLINE BLENDS ARE SUBJECT TO THE 3-RING CIRCUS

- **Consumers pay more per mile to use E85**
- **Mid level blends** offer a path for increased consumer draw to ethanol though increased efficiency, and performance

mid-level blend approach requires <u>BOTH engine and fuel</u> co-optimization





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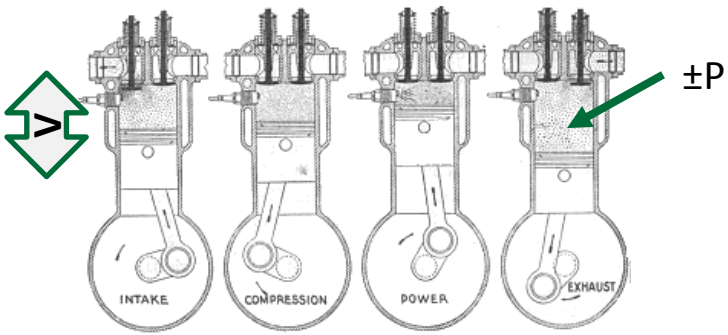
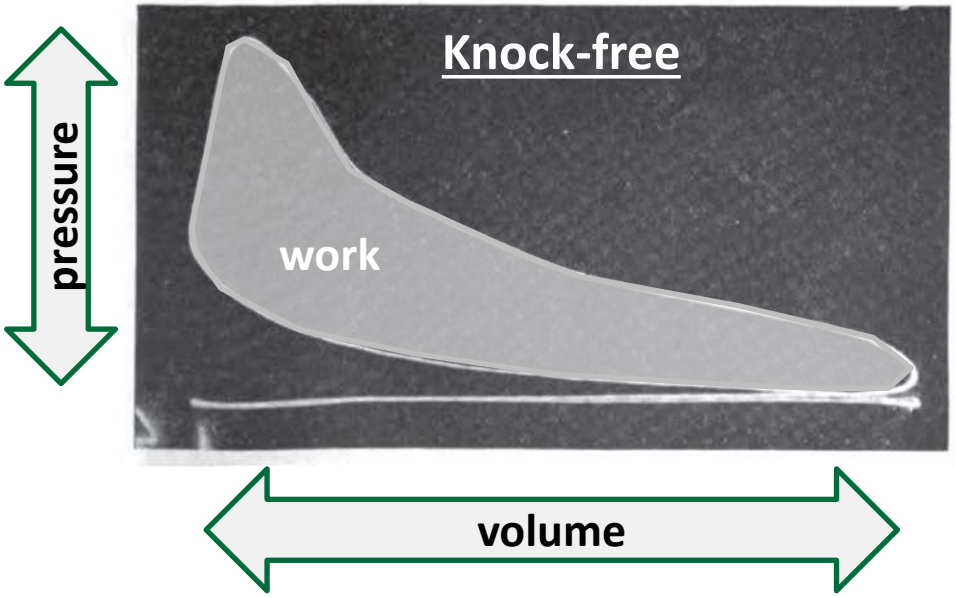
KNOCK FUNDAMENTALLY LIMITS SI ENGINE EFFICIENCY, IT HAS BEEN KNOWN AND STUDIED FOR A CENTURY, IT IS STILL AS RELEVANT TODAY AS THEN

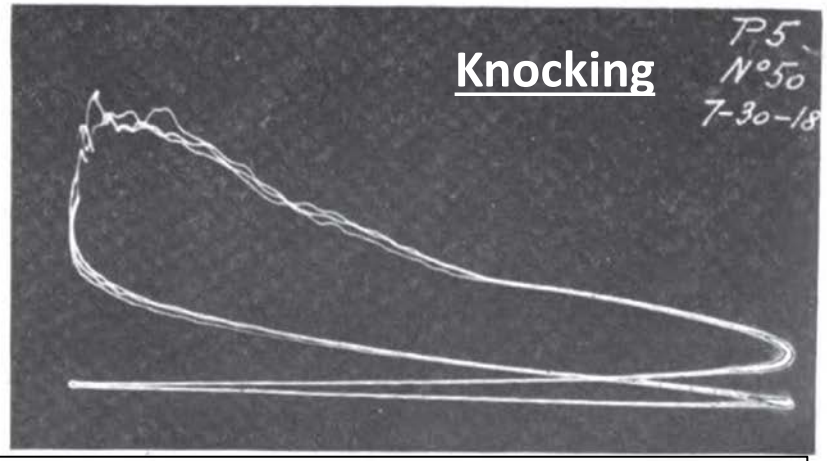
- **Efficiency is the amount of work out from the fuel energy in**



$$Work = \int P\, dv$$

Knock reduces work & efficiency potential





Surece:*Automotive Industries*, Volume 38, 1918

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Compression ratio couples efficiency and knock together

$$\eta_{thermal} = \frac{W}{E_{fuel,in}} = 1 - \frac{1}{r_c^{(\gamma-1)}}$$

BUT

Increase r_c = increase P & T

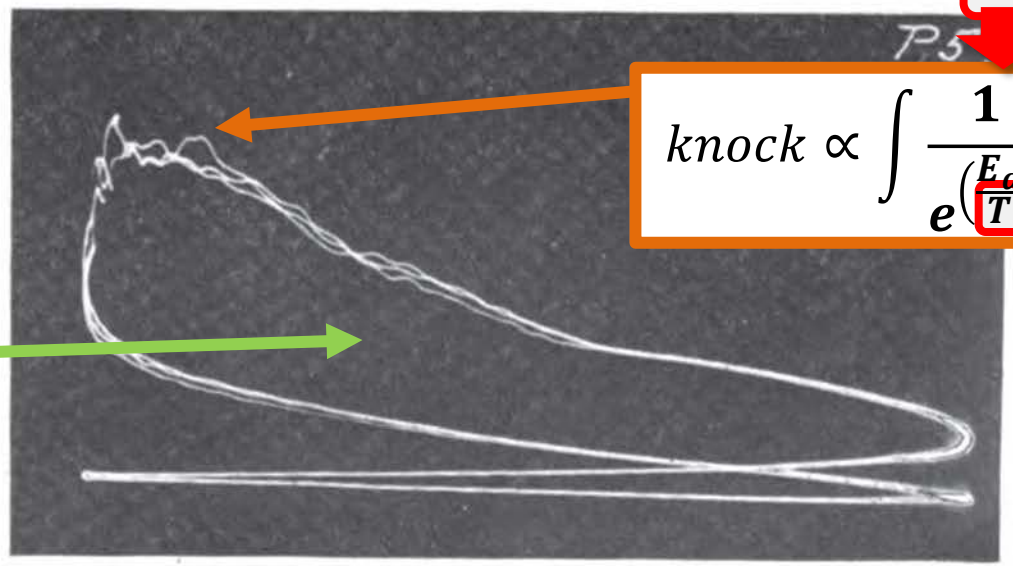
$$r_c^{(\gamma-1)} = \left(\frac{P_2}{P_1}\right)^{\frac{(\gamma-1)}{\gamma}} = \frac{T_2}{T_1}$$

$$knock \propto \int \frac{1}{e^{\left(\frac{E_a}{T}\right)}}$$

Increase r_c = increase W

$$r_c = \frac{V_1}{V_2}$$

$$W = \int P\, dv$$



Efficiency Paradox: need high r_c for efficiency, but without knock

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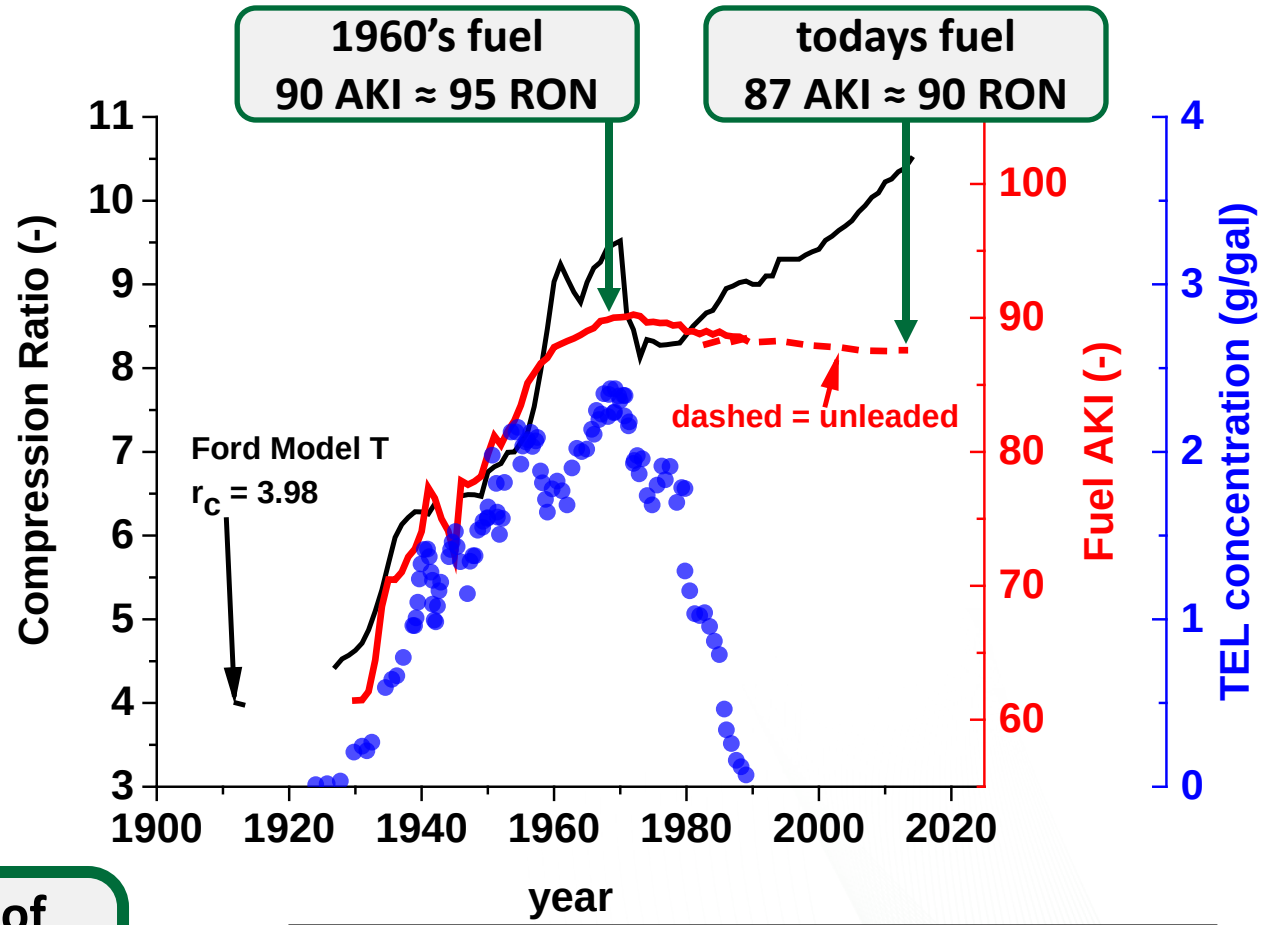
History has shown a tight coupling of fuel chemistry with engine compression ratio, Since 1980 there has been a divergence

- Historically fuel improvements have enabled engine improvements
- Removing lead halted this process
- Since 1980 fuel has been stagnant
- Improvement have been from the engine alone



Source: Data in Pawlowski and Splitter SAE 2015-01-0972

Is a diverging trajectory of fundamental dependencies sustainable?

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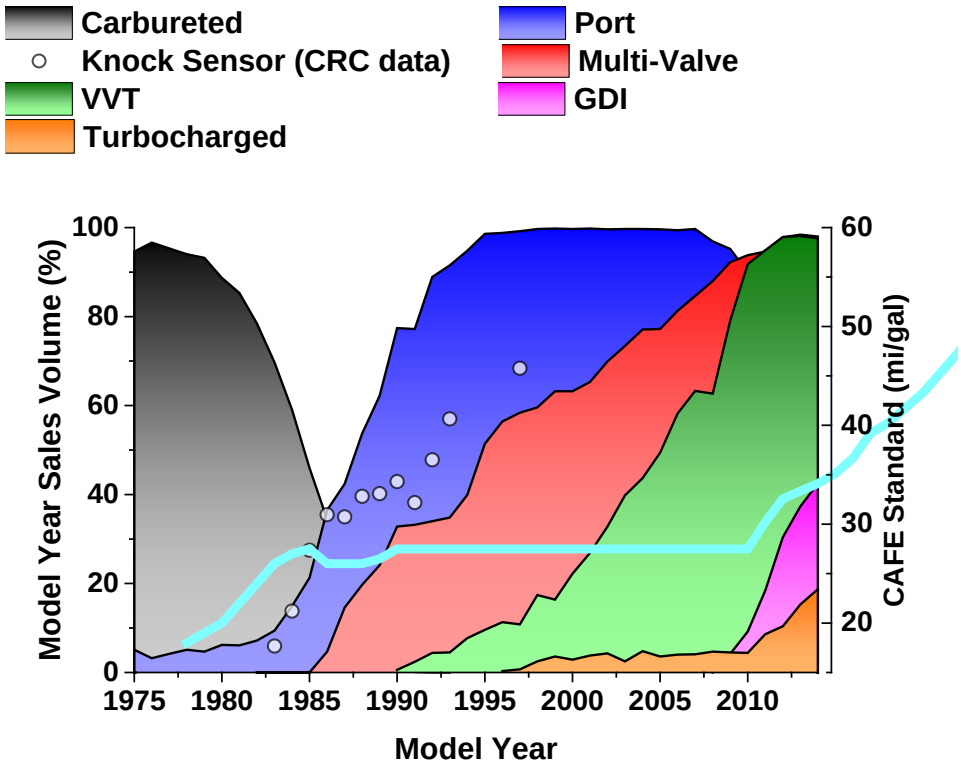
Industry trend is to leverage "other" fuel properties with a powertrain system level approach to improve fuel economy

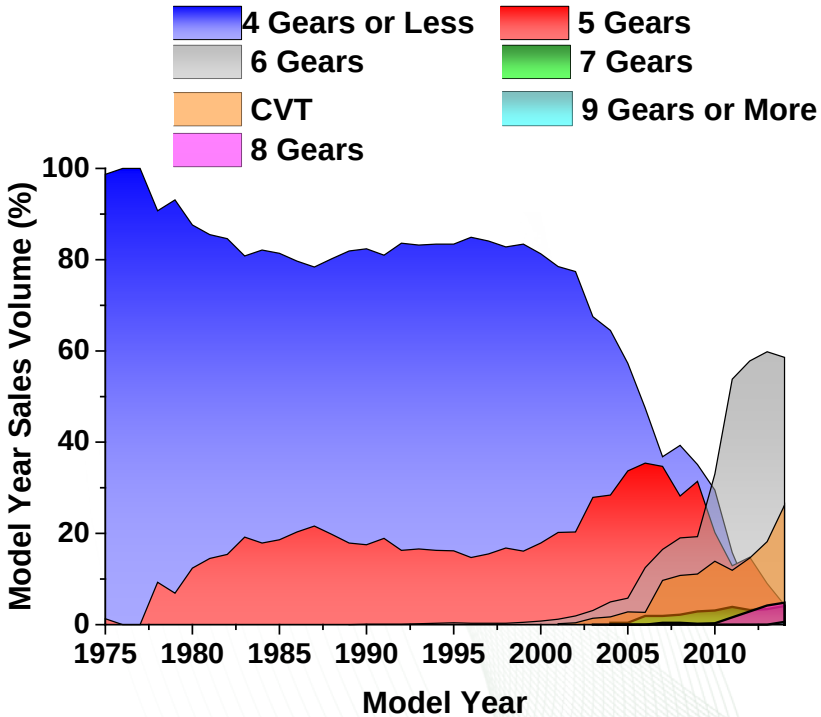
- Improve fuel/air preparation
- Sensors
- Improve breathing

GDI

- Multi-gear transmission
  - Downspeed engine

These technologies are synergistic with ethanol





Source: EPA 2014 LD Trends ; CRC 548, 566, 587, 619
http://www.bosch-presse.de/presseforum/details.htm?txtID=6406&locale=en

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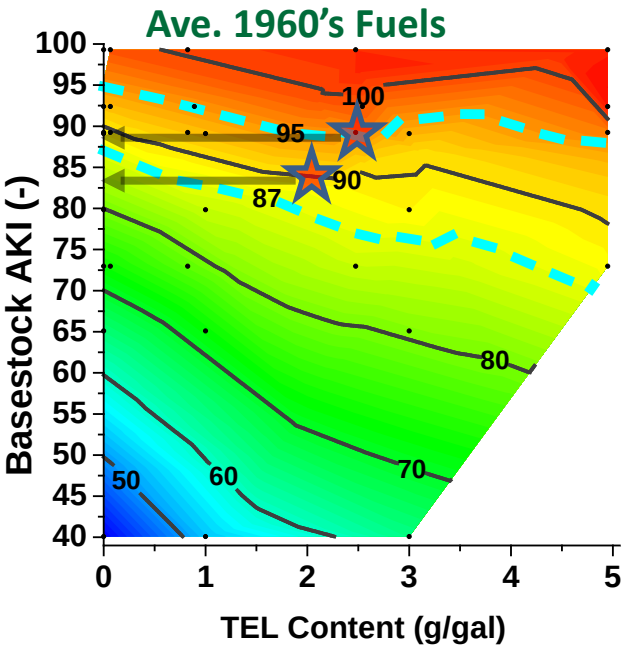
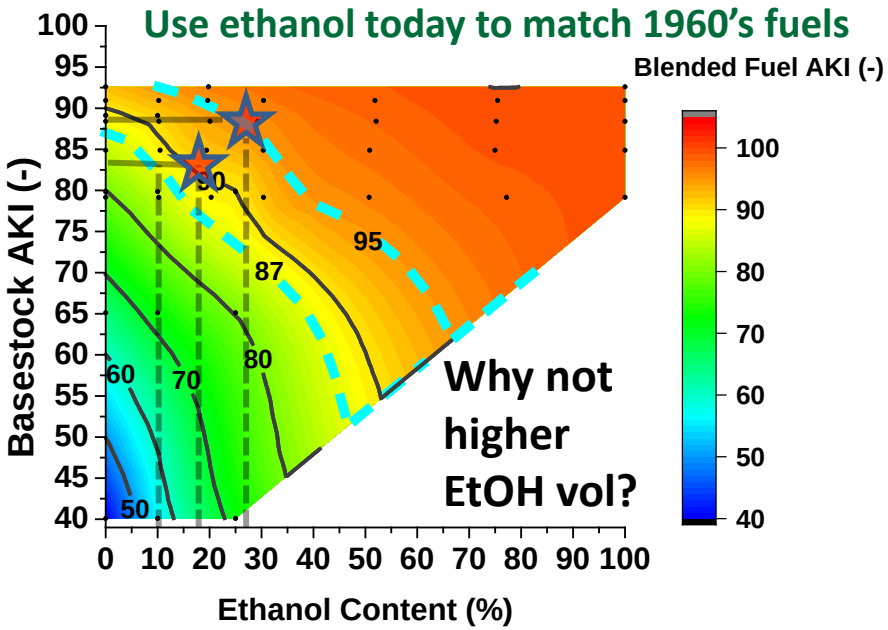
TEL IS A VERY EFFECTIVE OCTANE BOOSTER, SO IS ETHANOL

- TEL and ethanol can "upgrade" low quality fuel (e.g., BOB fuels)
- **How can we use ethanol to achieve comparable higher octane fuels?**

Possible to use 1960's & todays blendstocks to reproduce 1960's high ON fuel 1960's regular ~E18 (90AKI) 1960's premium ~E27 (95 AKI)



Source: Forster and Klein SAE 620043, Porter and Wiebe 1952



Source: Stein et al., SAE 2012-01-1277, Porter and Wiebe 1952

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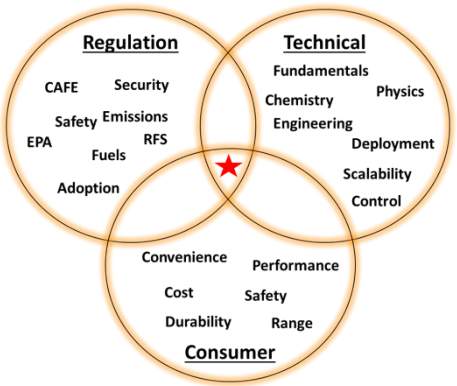
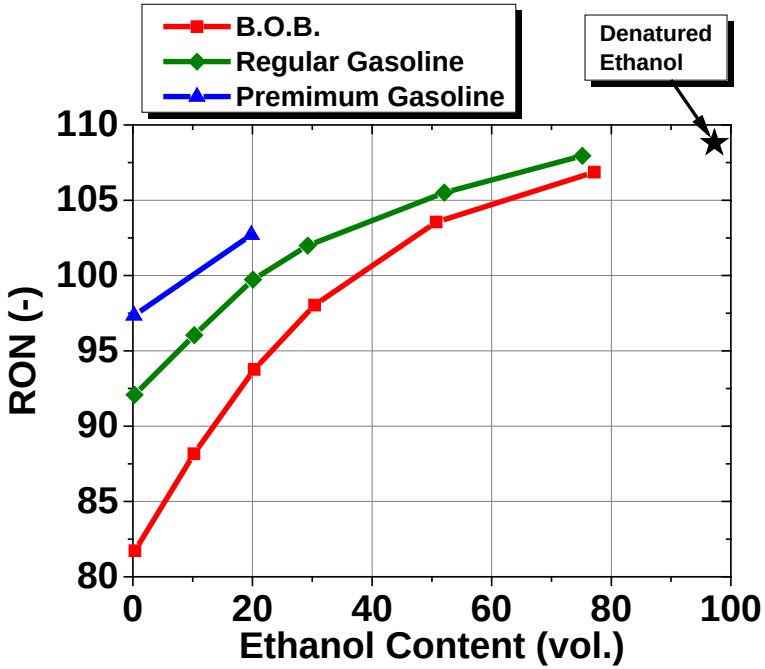
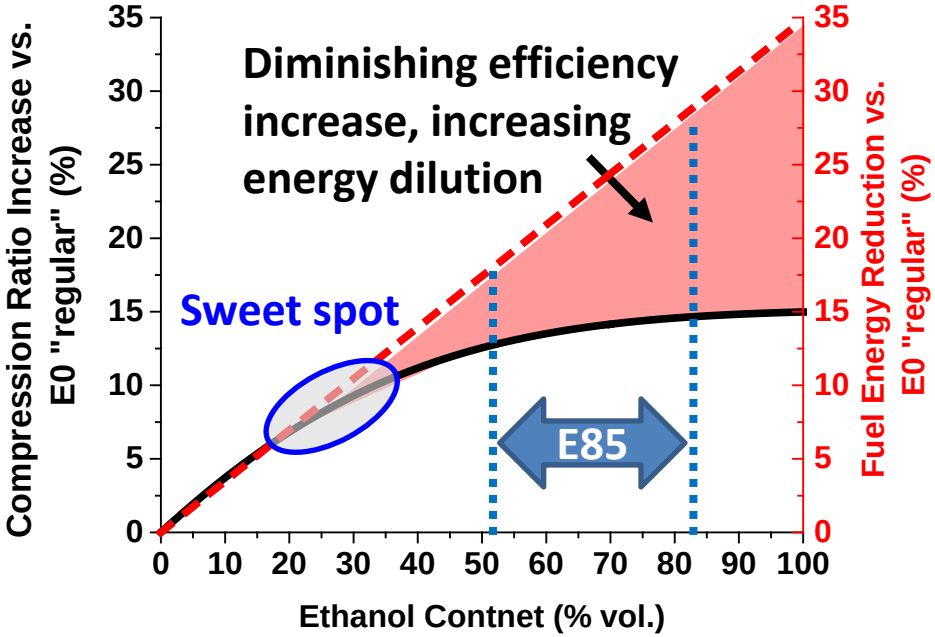
E85 IS A HIGH OCTANE FUEL, WHY DO WE NEED A "NEW" BLEND?

- If octane number is the only concern then E85 is a great choice!
- Get 2/3 of octane increase in first 1/3 of ethanol addition (i.e., non-linear)
- Fuel energy reduces lineally with EtOH







Source: Stein et al., SAE 2012-01-1277

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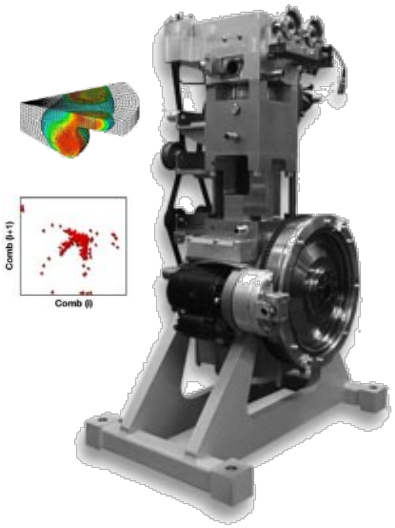
Total approach to estimate vehicle performance and system efficiency from fundamental measurements

- **ORNL currently spanning high octane fuels work from single cylinder research engines to full vehicle experiments.**



Fundamental combustion
Metric: *Indicated efficiency*

Engine-system
Metric: *Output shaft efficiency*

Full vehicle
Metric: *Fuel economy*

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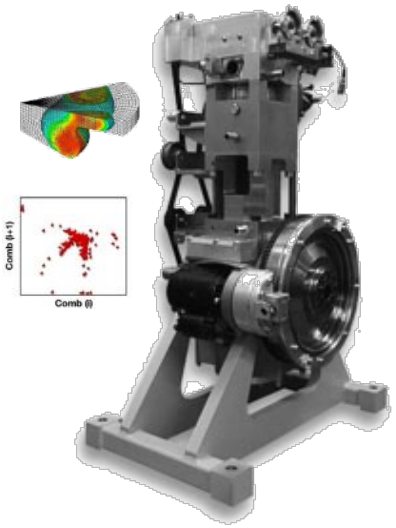

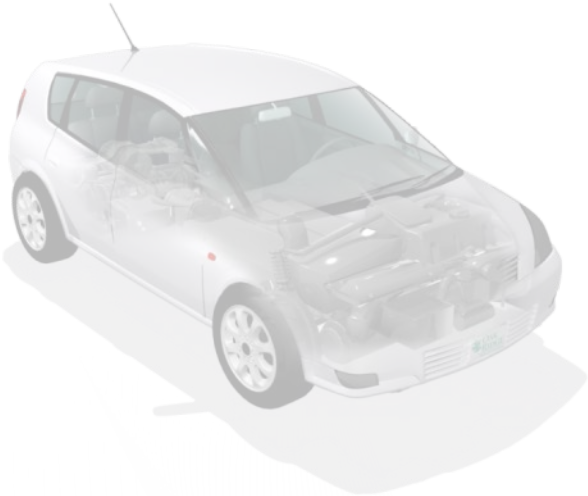

Fundamental combustion
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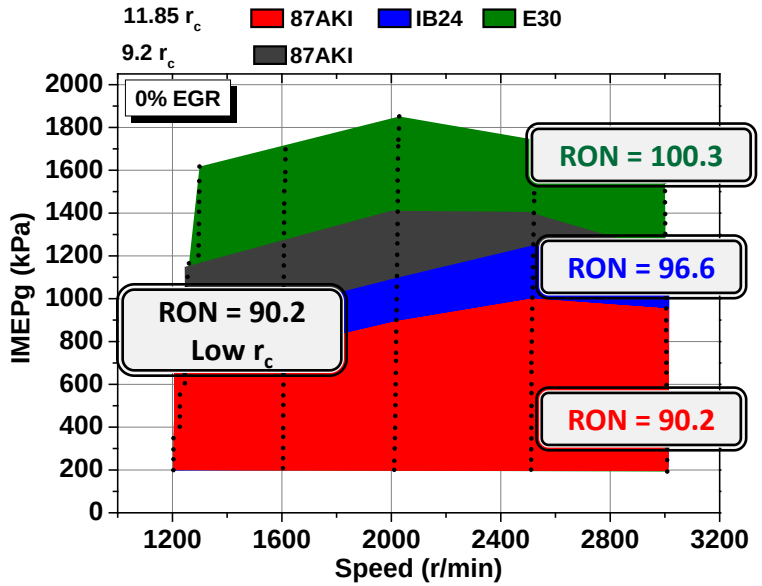
E30 Enabled a Greater Increase in Peak Engine Torque than Predicted by Octane Number Improvement



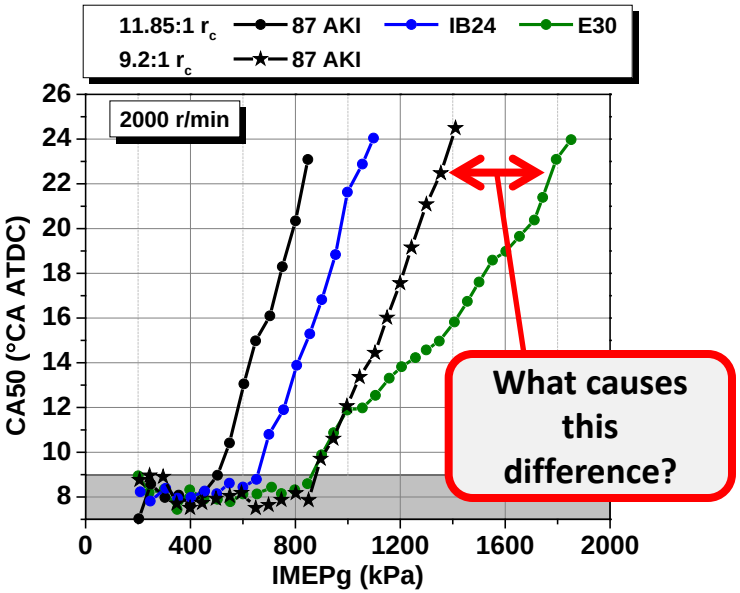
Splitter and Szybist: Energy&Fuels 2013,SAE 2014-01-1231

Optimize fuel and Engine together NOT an FFV

- Peak load trends with octane number
- Low octane fuels knock at lighter loads
  - Reduces powertrain configurations & efficiency potential

- E30 is more effective at mitigating knock than octane number alone suggests

- E30 knock behavior isn't fully understood
  - Octane sensitivity, heat of vaporization, flame speed, pressure sensitivity, ethanol-specific kinetics, etc…
- System efficiency benefits (DS + DS)



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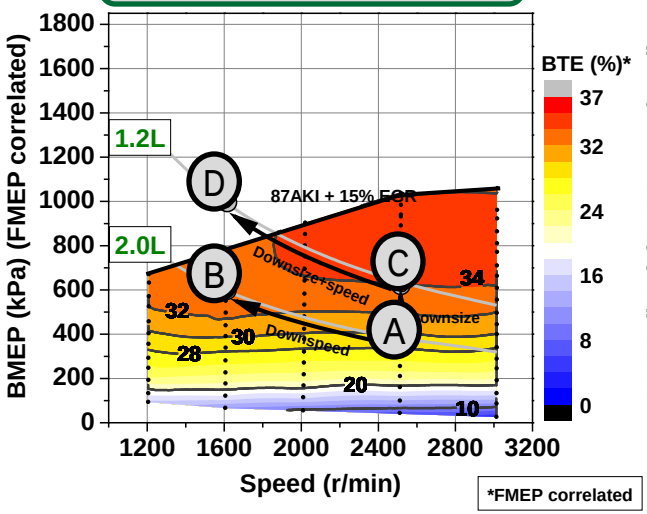
Higher Peak Torque for E30 can Enable Fuel Economy Benefits (Efficiency Outpaces Energy Density Penalty), Improved System Efficiency

Note: This analysis is simplistic and is meant to illustrate trends of downsizing and downspeeding. These results are not quantitatively representative for all driving cycles.

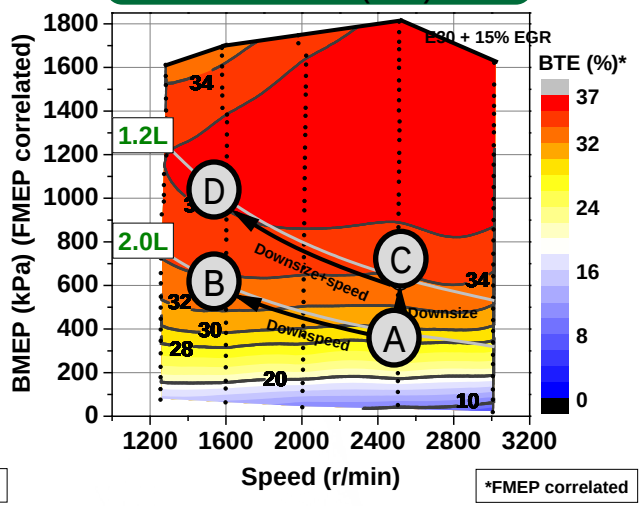
Steady cruise at 65 mph
(16 kW brake power)

- (A) Standard Configuration
- (B) Aggressive Downspeeding
- (C) Aggressive Downsizing
- (D) Aggressive Downsizing and Downspeeding

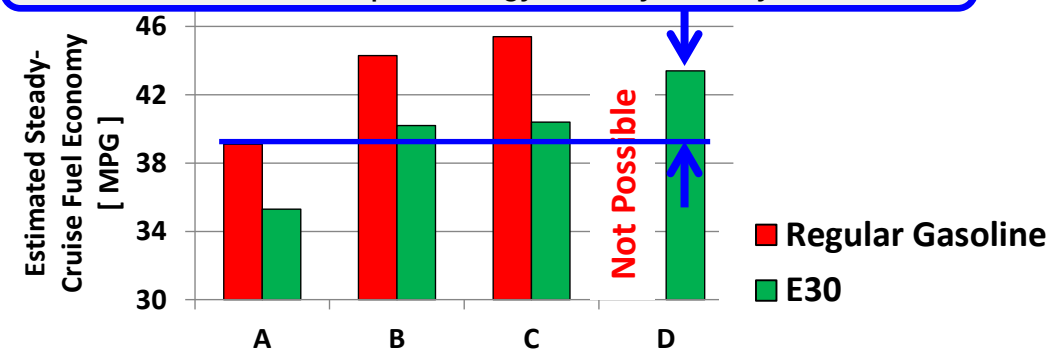
Regular Grade Gasoline



"Renewable Super Premium" (E30)



Benefits can Enable Higher Fuel Economy for High Octane Blends Despite Energy Density Penalty



Splitter and Szybist: Energy&Fuels 2013

- DS + DS options with high compression are more limited for low octane fuel
- E30 enabled potential for much more aggressive DS + DS

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TAKEAWAYS

- **Engines and fuels are fundamentally coupled**
- High octane fuels offer the potential for increasing engine efficiency
  - Ethanol is an attractive means to increase octane number
- Intermediate ethanol-gasoline blends offer the potential for increasing octane number with bio-derived products in a demonstrated and known manner
- **Specifying "*THE*" fuel should not be the end goal**
  - Focus on fuel *performance*; New fuel spec for "RSP" should relate to engine anti-knock performance, not necessarily Exx.
    - **Performance specification can likely be met with array of components (ethanol, butanol, bio-derived HCs, refinery streams)**
    - **Need to make data based decisions on future fuel formulations that compliment policy and consumer requirements with technology**
- **Automotive and fuel industries need make a partnered effort to bring new high octane optimized high-efficiency engines to market**

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Questions

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