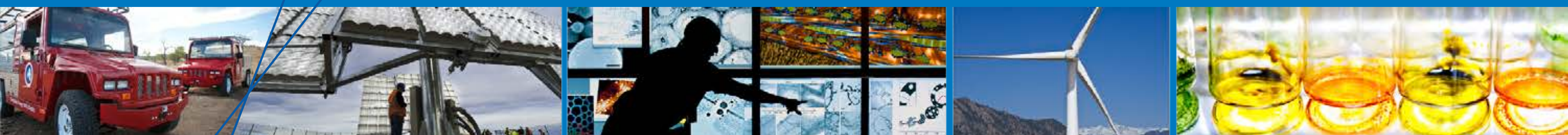
Fuels to Enable More Efficient Engines



Robert L. McCormick & Bradley T. Zigler

4th International Conference on Biofuels Standards: Current Issues, Future Trends

Gaithersburg, Maryland, USA

November 13, 2012

Regulation of More Efficient Vehicles

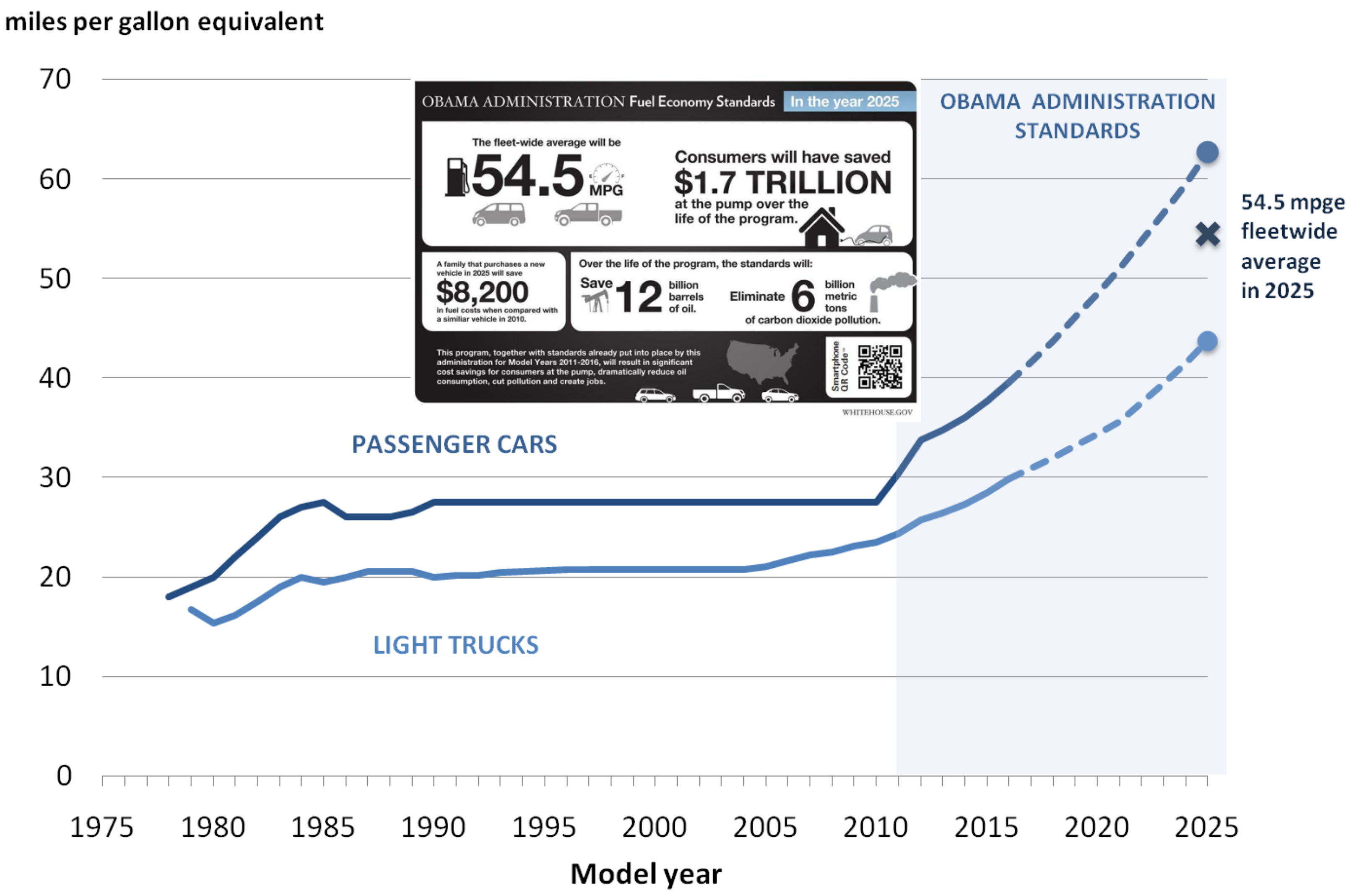
EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years 2017-2025 Cars and Light Trucks – *August 2012*

- Average industry fleetwide level of 163 grams/mile of carbon dioxide (CO_2) in model year 2025,
- Equivalent to average fleet fuel economy of 54.5 mpg

- Greenhouse gas emission limit will be met mainly by increasing vehicle fuel economy

http://epa.gov/otaq/climate/documents/420f12051.pdf

Research Challenges: Fuel Economy Standards



MY1978-2011 figures are NHTSA Corporate Average Fuel Economy (CAFE) standards in miles per gallon. Standards for MY2012-2025 are EPA greenhouse gas emission standards in miles per gallon equivalent, incorporating air conditioning improvements. Dashed lines denote that standards for MY2017-2025 reflect percentage increases in Notice of Intent.

Research Challenges: Global Targets

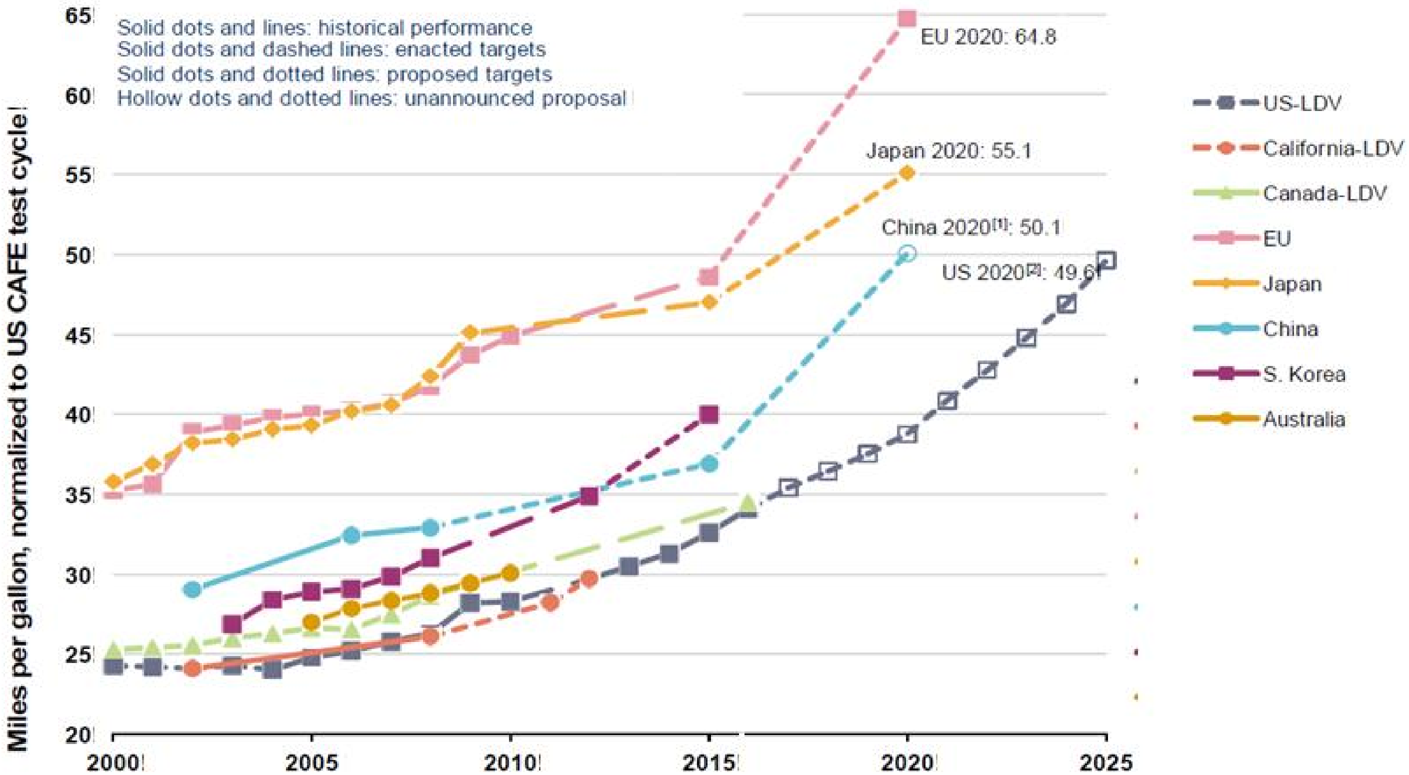


Figure: *Global Comparison of LDV Fuel Economy/GHG Emissions Standards (ICCT;August 2011)*

2020 Fuel Efficiency Standards	
E.U.	**64.8 mpg**
Japan	**55.1 mpg**
China	**50.1 mpg**
U.S.	**49.6 mpg**

Portfolio of Technologies Leading to 54.5 MPG

Turbo-charging, direct fuel injection, downsized

Start/stop

Regenerative braking

Low rolling resistance tires

Electric powered steering

Electric infrastructure

Light weighting

8 speed transmissions

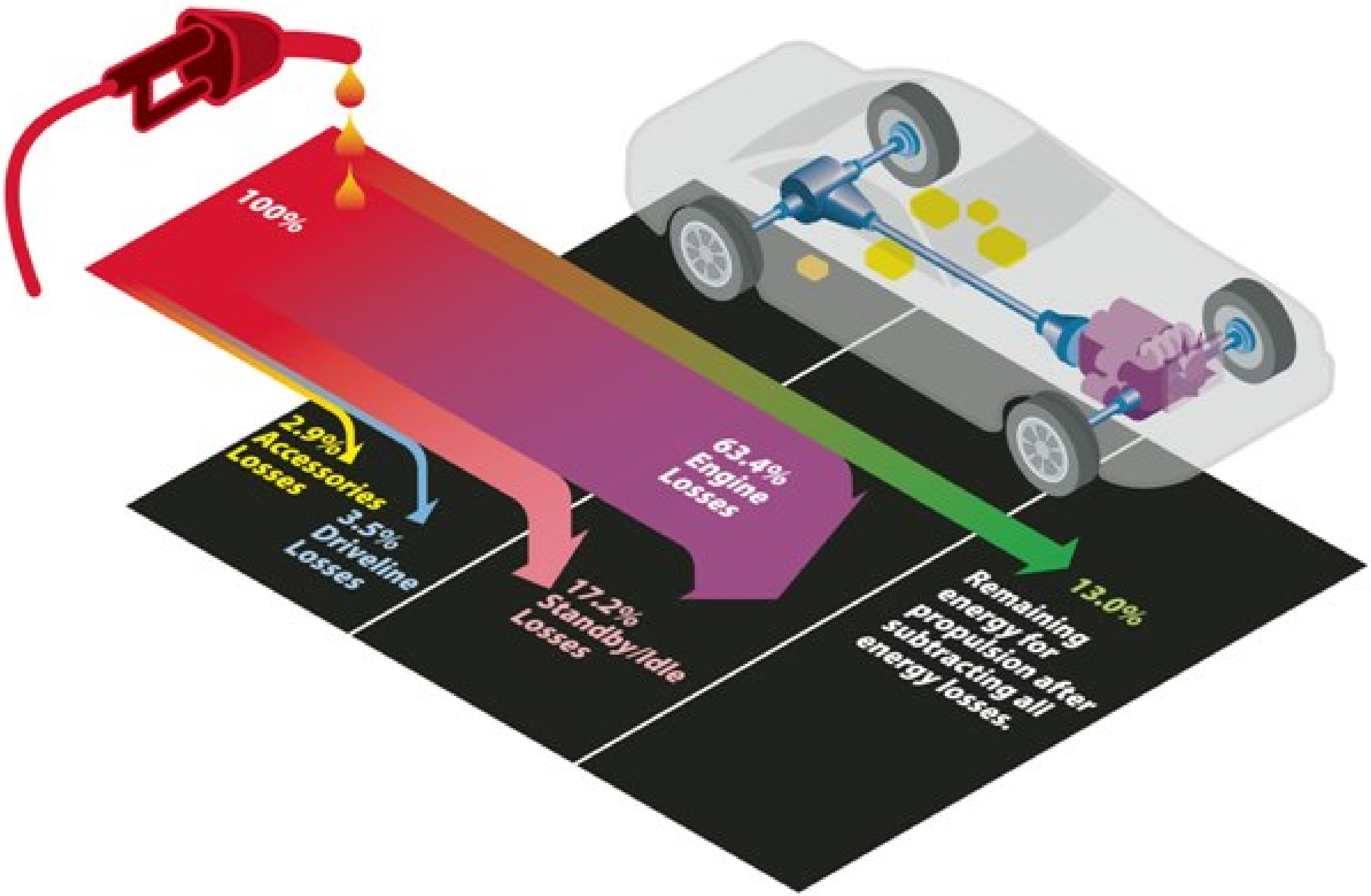
Degree of electrification (power electronics & energy storage)

Variable cylinder mgmt

Improved aerodynamics

Diesel, alternative fuels, H2, etc.

Internal Combustion Engine (ICE) Vehicles Have Room for Improvement



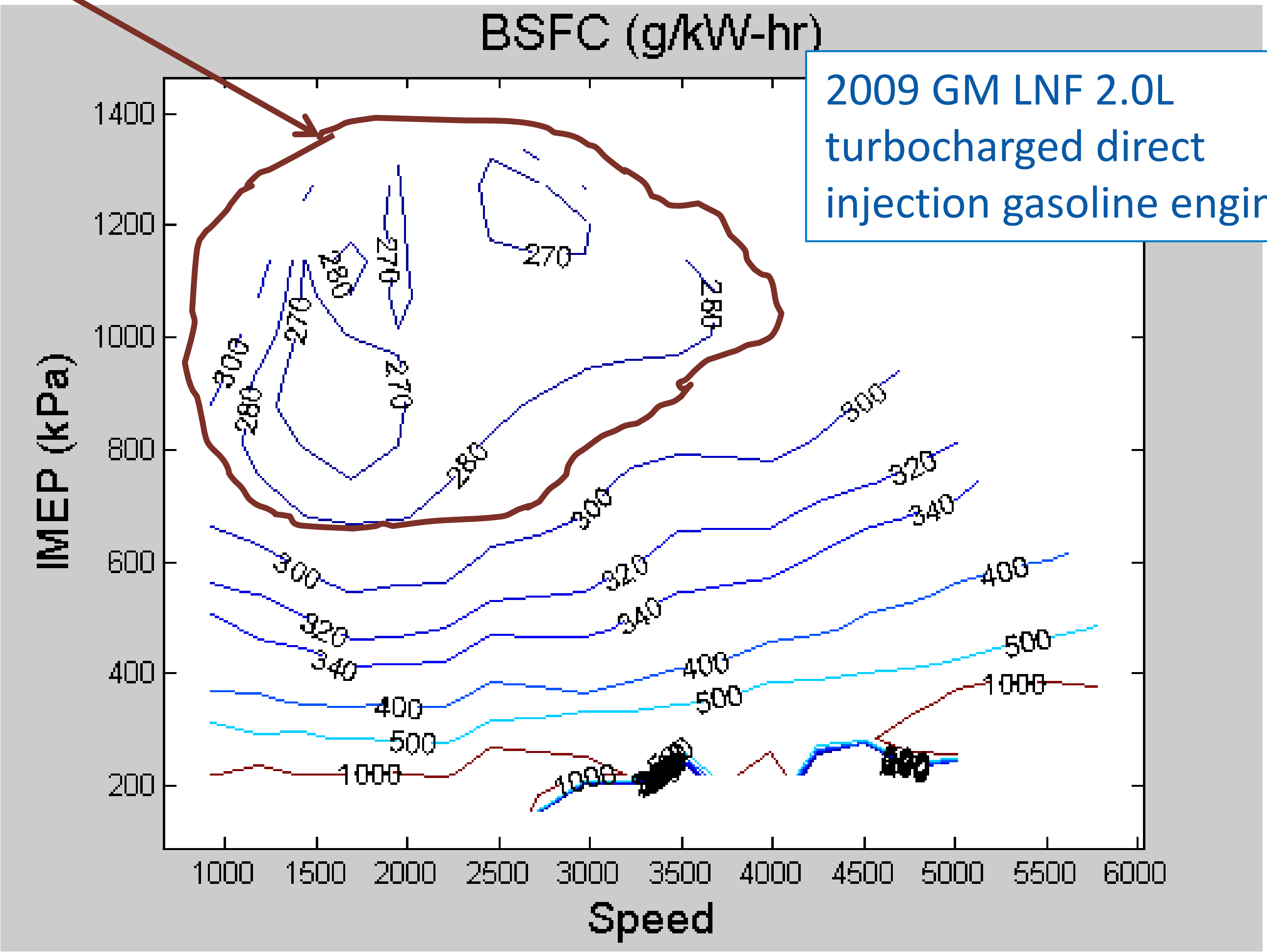
Approaches to Increasing Engine Efficiency

- Engine downsizing
  - Smaller engines operating at low-speed and higher load are more efficient
  - Optimized with 6 to 9 speed transmission
- Turbocharging
  - Recovering energy from the engine exhaust
  - Required for engine downsizing
- Direct injection
  - Fuel evaporates in the combustion cylinder, cooling the air-fuel mixture
  - Also required for engine downsizing
- Increased compression ratio
  - Greater thermodynamic efficiency

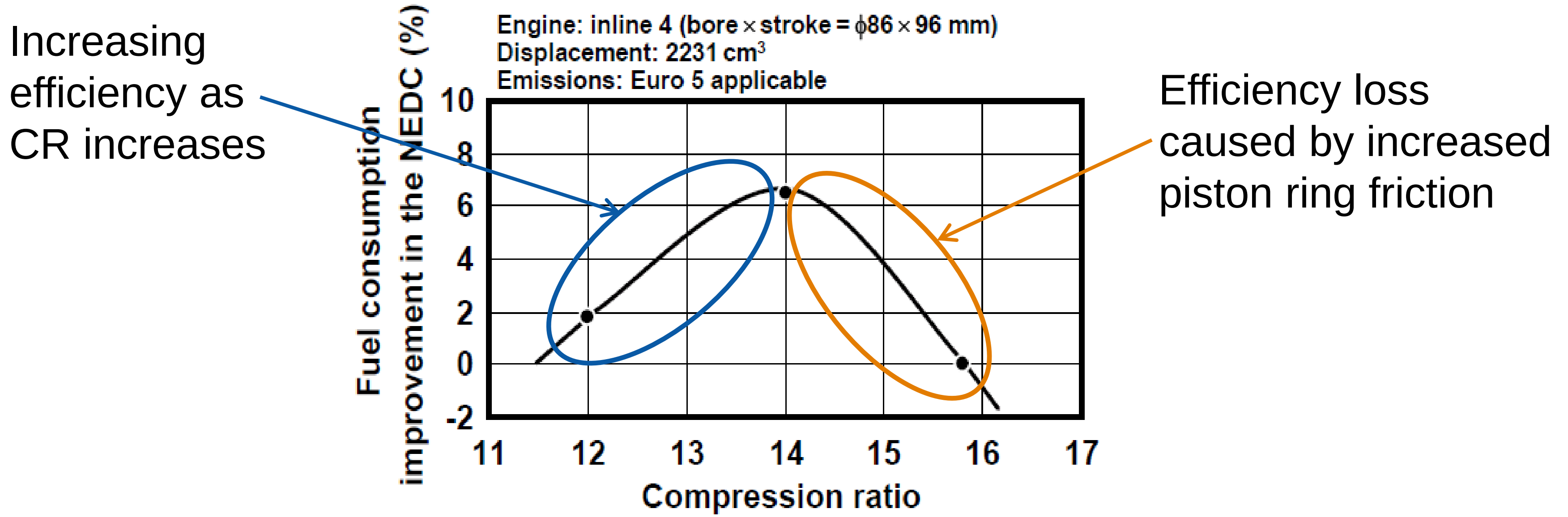
Lower Fuel Consumption at Low Speed – High Load

Most knock limited region – and highest fuel economy

2009 GM LNF 2.0L turbocharged direct injection gasoline engine



Effect of Increasing Compression Ratio



- Higher compression ratio yields higher temperature and hence higher efficiency
- An optimal CR exists (typically in the teens) and depends on other engine design features (primarily piston bore size)
- Current engine CR about 10 or lower

Toyota, Aachen Colloquium October 2010

Octane Number and Engine Knock

- ON is a measure of resistance to autoignition caused by high temperature and pressure
- Autoignition is knock and can damage the engine
- Higher ON is required for higher CR, turbocharged engines
- Measured using methods developed in the 1920:
  - Research Octane (RON) – cool and slow
    - Best predictor for small modern engines
  - Motor Octane (MON) – hot and fast

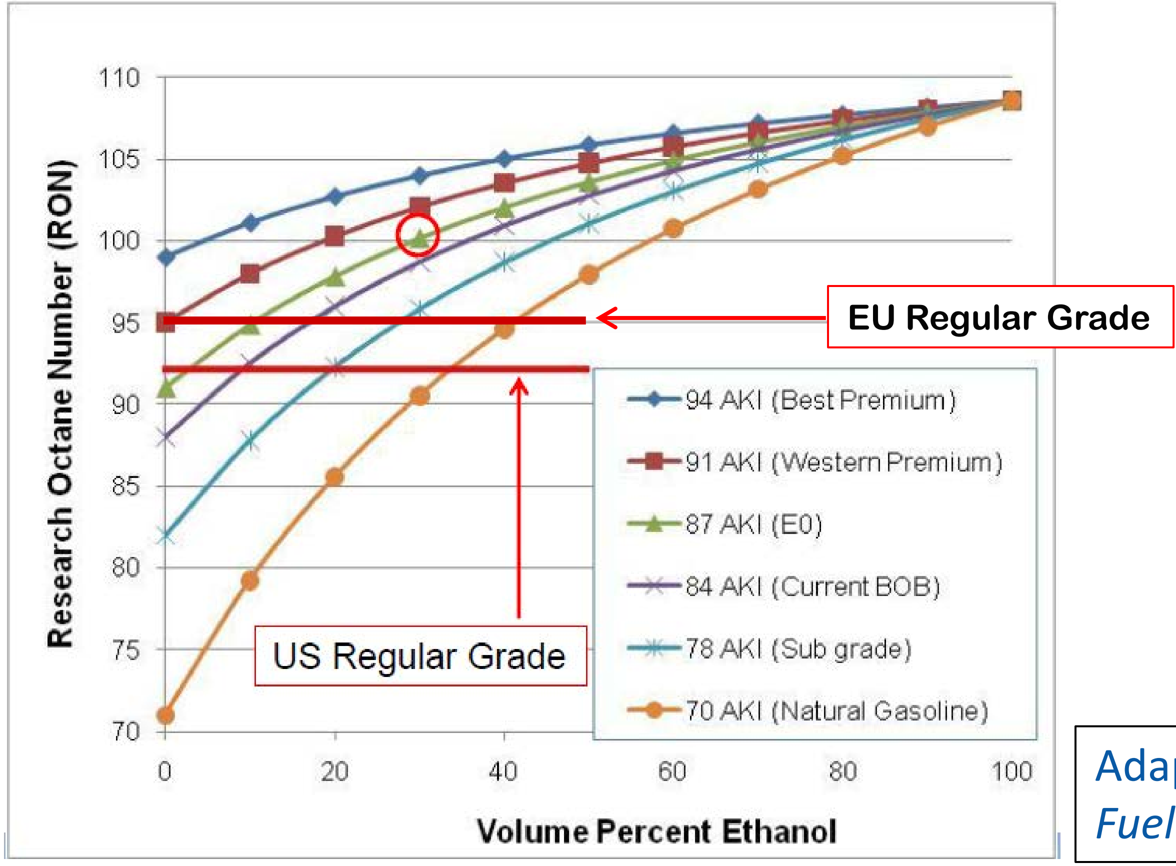
	RON	MON	AKI
Typical US Regular	92	83	87.5
Ethanol	109	90	99.5
Isobutanol	105	90	97.5
Iso-octane	100	100	100
n-Pentane	62	62	62
Toluene	118	104	111

USA: Anti-Knock Index
AKI = [R + M]/2 > 87

EU: RON > 95

China: RON > 90

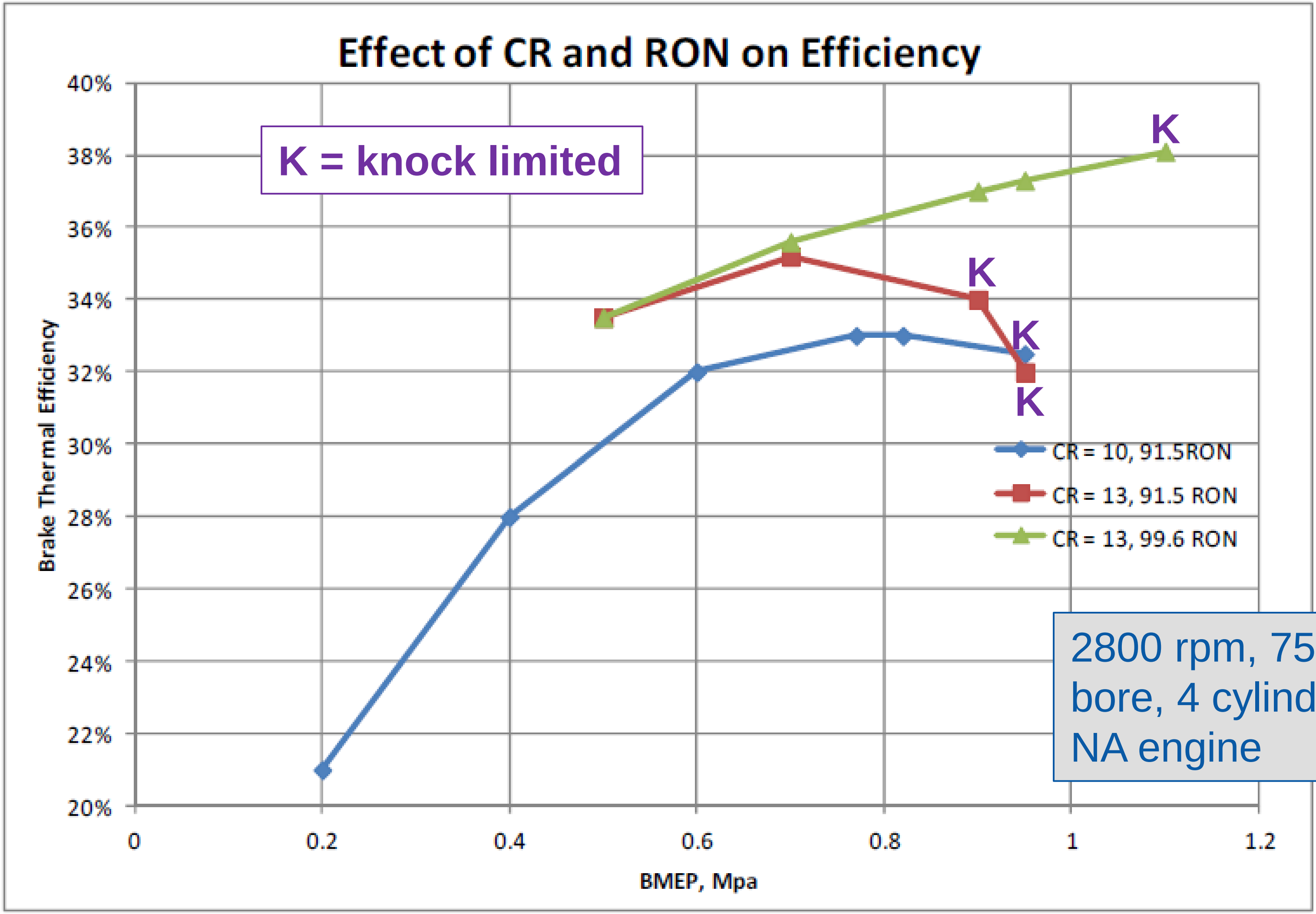
Blending Ethanol Increases RON



Adapted from Andersen, et al., *Fuel* 97 585-594 (2012)

- Ethanol significantly increases RON
- Especially at lower blend levels in low octane gasoline
- One of the higher ON streams available for gasoline blending

Efficiency Benefits of Increased CR and RON

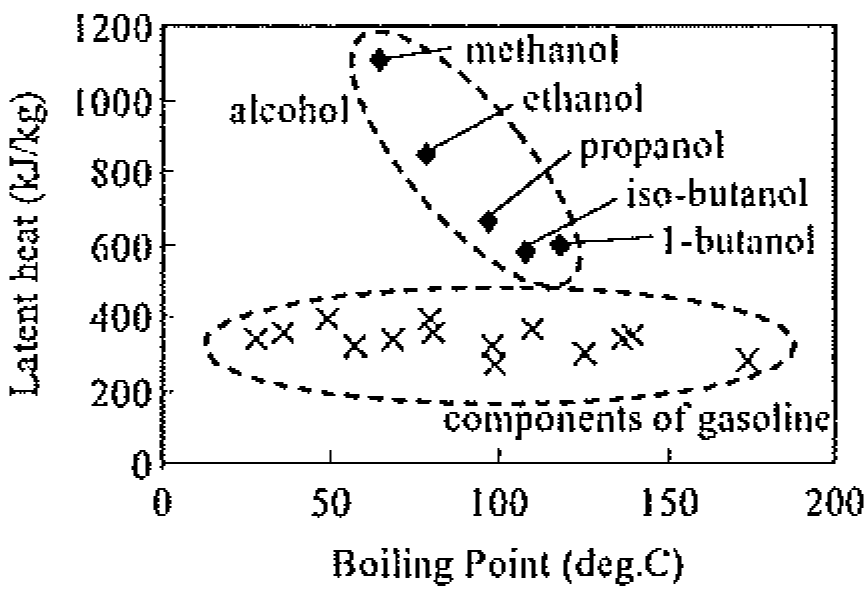


2800 rpm, 75 mm bore, 4 cylinder NA engine

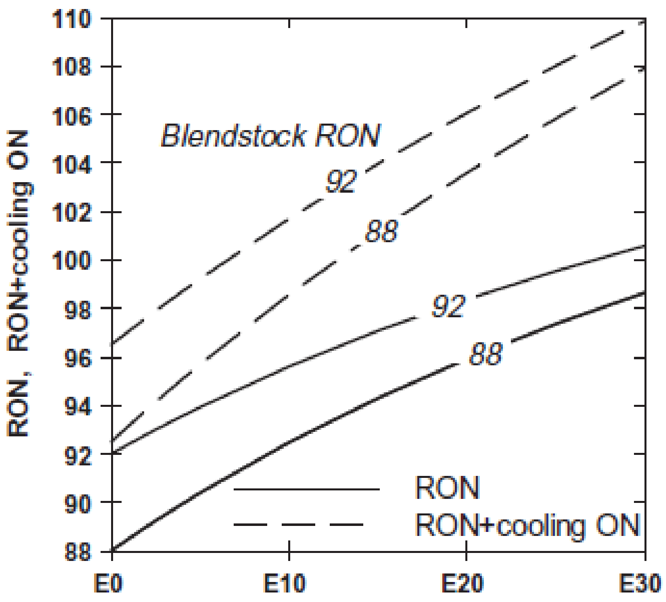
CRC Project No. CM-137-11-1b www.crcao.org after Nakata et al., SAE 2007-01-2007

Heat of Vaporization Effect

- For direct injection engines fuel evaporation occurs in the cylinder – cooling the charge and reducing knock tendency
- Alcohols have significantly higher heat of vaporization (HoV)
- Not captured by ON measurements

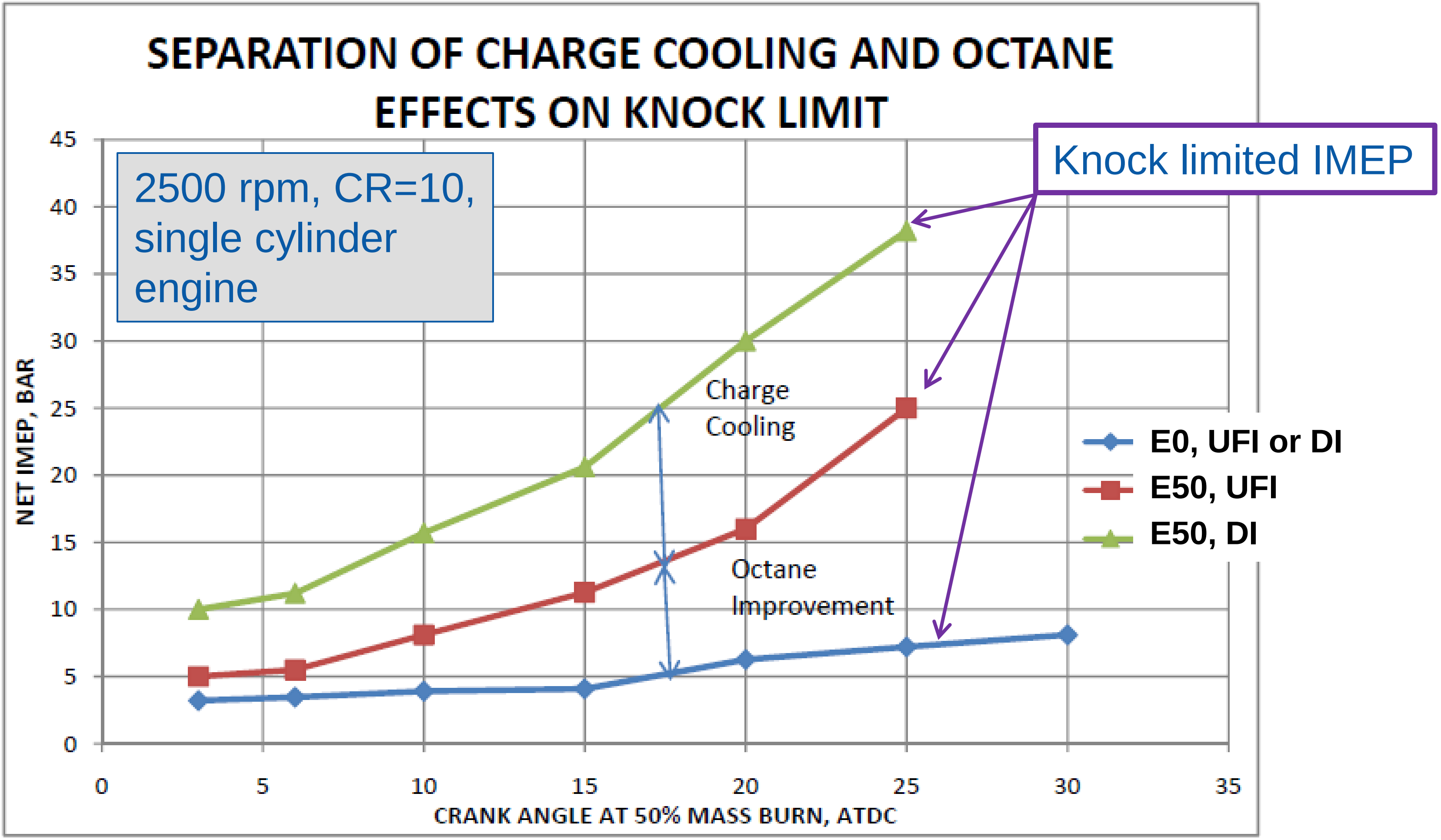


Nakata, et al. *Int. J. Engine Res.* 12 274-281 (2011)



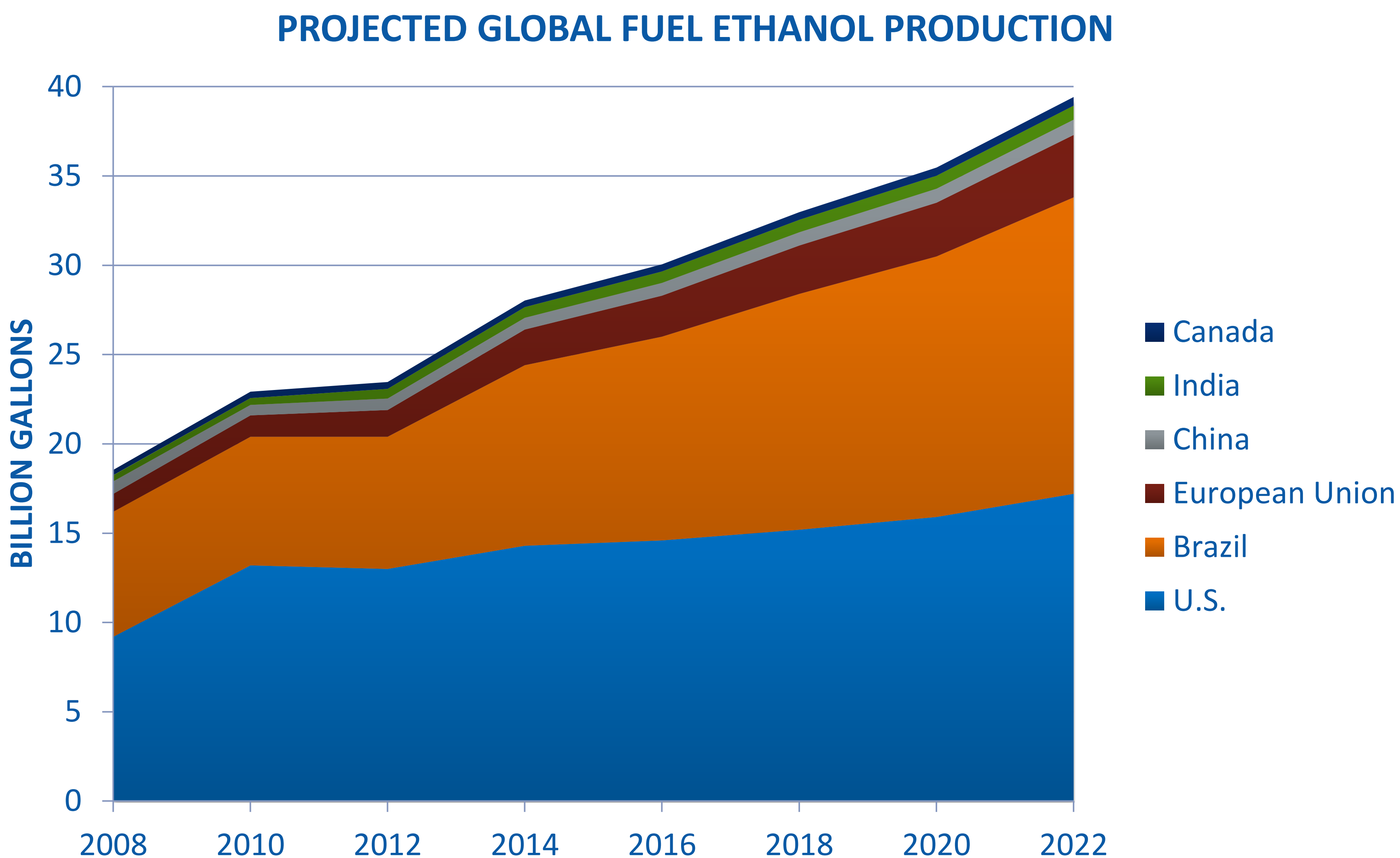
Andersen, et al., *Fuel* 97 585-594 (2012)

Ethanol has High "Effective" RON



CRC Project No. CM-137-11-1b www.crcao.org after Stein, et al. SAE 2012-01-1277

Ethanol to Blend Advanced Fuels



Sources: 2012 EIA Annual Energy Outlook (U.S.); FAPRI-ISU 2011 World Agricultural Outlook (All other countries)

Research Recommendations

Focus efforts on newest engine technologies

- Turbocharged DI engine data is limited
  - Sequential turbocharging with two stage cooling; cooled EGR at all loads.
- Range of engine bore size and power
- Efficiency and knock limits
- Define ON and HOV requirements

Developing rational fuel specification

- Meaningful property measurement methods
- Related to combustion performance
- Encompass both chemical knock resistance and charge cooling
- Distillation curve and driveability effects

Summary and Conclusions

- Ethanol has unique fuel characteristics
  - High octane
  - High heat of vaporization
- Ethanol has a high Effective RON
- Properly formulated ethanol/hydrocarbon blends provide fuel characteristics required by advanced engines
- Advanced engines using advanced fuels provide greater vehicle efficiency
  - Increase in miles per gallon/kilometers per liter
  - Considerable reduction in GHG
- **Bioethanol enables advanced, high efficiency engine technologies**