Ford’s Perspective on Future Engines and Their Fuels

(or should we say “Future Fuels and Their Engines”)

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Ford is adopting an aggressive strategy for both gasoline and diesel engines to reduce fuel consumption in major markets in the Near-term.
Outline

• Gasoline Fuel / Engine Technology
• CO₂ & Emissions Requirements
• Sustainability Strategy
• Ford EcoBoost
  – Performance and Fuel Economy Benefits
  – Challenges – Knock at High Load
  – Future Technology Development
  – Future Fuel Opportunities - Octane
• Alternative Fuel / Engine Technology
  – Renewable Fuel
  – Ethanol
  – CNG
  – Hydrogen
• Diesel Fuel / Engine Technology
  – Engine Technologies and Future Challenges
  – Cetane Impact
  – Alternative Diesel Fuel Challenges and Opportunities
• Summary
RON Influence on Naturally Aspirated Engine Design and Performance

- Pre-1960, SI Engines evolved to take advantage of improving Octane.
- Post-1960, despite constant RON, GDI and other technologies have improved efficiency and performance.
Charge Cooling Benefits of GDI

GDI charge cooling enables a higher CR for efficiency and higher charge density for performance compared to PFI engines.
CO₂ & Emissions Requirements

Aggressive CO₂ fleet targets will require advanced technologies for a variety of P/T combinations and vehicle applications. With LEV III, North American emissions standards will remain the most challenging in the world.

Sustainability plays an increasingly important role in relation to strategic direction.

Simultaneously meeting CO₂ requirements and LEV III standards will be a major challenge and requires significant improvements in a variety of P/T technologies.
Market Drivers

In addition to regulatory requirements, market requirements such as affordability while fully meeting customer expectations are important.
EcoBoost

- Improved power & torque relative to naturally-aspirated, port fuel injected engines, allows significant downsizing and a corresponding fuel economy benefit.

Ford’s EcoBoost technology delivers a cost effective, near-term, high volume CO₂ solution, without compromising customer-focused attributes.
Future GTDI Opportunity with Higher Octane

- Increased octane improves efficiency in current engines through reduced spark retard and enrichment at higher loads.
- Increased octane could enable future engines to increase CR and efficiency.

Effect of Octane on ISFC

<table>
<thead>
<tr>
<th>CR</th>
<th>Base OCT, Base CR</th>
<th>High OCT, Base CR</th>
<th>High OCT+, High CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1%</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>11</td>
<td>2%</td>
<td>3%</td>
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<td>7%</td>
<td>8%</td>
</tr>
<tr>
<td>16</td>
<td>7%</td>
<td>8%</td>
<td>9%</td>
</tr>
</tbody>
</table>

CR Efficiency vs. CR

ISFC [g/kw-hr]

IMEP [bar]

Better octane potential in today’s engine

Better octane impact in tomorrow’s high CR engine
Renewable Fuels requirements are increasing significantly in the U.S. and Europe.

**EU RED:** Mandating Member States: 10% of all energy in transport sector from renewable sources by 2020.
Potential Benefits of Ethanol - Improved Octane

Octane increase of ethanol blended into gasoline is non-linear\(^1\) and diminishes at high concentrations.

Use ethanol to increase octane of market fuel (rather than maintain it)  
\(\rightarrow\) Higher CR

<table>
<thead>
<tr>
<th></th>
<th>E100</th>
<th>Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octane (RON)</td>
<td>108</td>
<td>91 - 98</td>
</tr>
<tr>
<td>Heat of vaporization (kJ/kg)</td>
<td>840</td>
<td>~ 350</td>
</tr>
<tr>
<td>NHV (MJ/kg)</td>
<td>26.9</td>
<td>~ 43.5</td>
</tr>
<tr>
<td>Stoichiometric A/F</td>
<td>9.0</td>
<td>~ 14.6</td>
</tr>
<tr>
<td>NHV of stoich fuel quantity(^1)</td>
<td>1.0 x base</td>
<td>base</td>
</tr>
<tr>
<td>Heat of vaporization at stoich(^1)</td>
<td>3.9 x base</td>
<td>base</td>
</tr>
</tbody>
</table>


Opportunity: Maintain blendstock RON.  
\(\rightarrow\) E10 = 95+ RON

Reality: Blendstock RON reduced.  
\(\rightarrow\) E10 = 92 RON

~ 43.5  
26.9  
9.0  
3.9 x base  
3.9 x base

Future RON?
As ethanol blends increase in support of Renewable Fuels standards, mitigation actions are needed to account for lower energy content relative to non-ethanol containing fuels.
Gaseous Fuels – Compressed Natural Gas (CNG)

Benefits
- Higher global CNG than oil reserves
  - Proven reserves in the US increasing!
- Competitive price
- High octane (120+)
- 20-25% TTW CO₂ benefit vs. gasoline
- Home Fueling possible
- Bio-Methane production is efficient from a variety of renewable sources

Challenges:
- Gaseous fuels must be compressed
- Fuel tank package limits range
- Added weight (~300 lb on Focus; ~500 lb on Transit bi-fuel vehicles)
- High vehicle on cost
- Lack of fueling station infrastructure

- Retail vehicle market is inhibited by package, cost and limited fuel stations.
- Fleet vehicle market leverage benefits and are less sensitive to trade-offs.
Ford CNG Fueled Vehicles

Growing Interest in CNG: Ford offers a CNG option for Transit Connect, E-Series vans, F-Series Super Duty trucks and a variety of stripped chassis commercial applications.

Ford currently offers several CNG Prep capable vehicle lines for fleet markets and has leveraged global research efforts for next generation CNG technology.
Hydrogen Internal Combustion Engine Vehicles

Hydrogen Shuttle Bus Fleet

Fleet volume: 30 vehicles, leases ongoing since 2007
6.8L Supercharged Hydrogen Internal Combustion Engine (H2 ICE), Port Fuel Injection
Emissions: 2010 Phase II Heavy Duty Compliant without aftertreatment
350 bar/5000 psi Hydrogen Fuel Storage System
Vehicle Range: 150 - 200 miles
Compliant to Canadian and Federal standards
Performance & Reliability equivalent to Ford CNG Shuttles

Unique Properties of Hydrogen:
- High Knock Resistance
- Wide Flammability Limit: 4-75% by volume
- High Laminar Flame Velocity: 2 m/s at Stoichiometry
- Very Short Quench distance (¼ of gasoline/air mix)
- Low ignition Energy: 0.02 MJ/kg
- Storage Challenges and Developing Infrastructure

Engine Performance:
- 310 ft-lb @ 3000 rpm
- 235 hp @ 4000 rpm
Many Diesel Technologies Affected by Fuel Properties

Combustion System

- Boosting
- EGR System
- Controls

Fuel Injection Equipment

Aftertreatment

Engine Operating Modes

- Torque
- Load
- Noise, CO/HC
- pHCCI
- Power
Removing sulfur enabled cleaner and more efficient Diesel powered vehicles.

**Fuel Sulfur**
- 2006: 500 ppm
- 2007: ULSD 15 ppm

**Aftertreatment**
- 2010: DPF
- 2010: Urea-SCR

**Emissions**
- 2010: 99%+ lower PM
- 2010: 90% lower NOx

**Fuel Economy**
- 2010: Improved fuel economy with 2010 products
Future Diesel Engine Challenges

Future Diesel engines will need to meet all three of these requirements while providing the optimal CO$_2$ solution.

- Reduce engine-out emission while improving efficiency: advanced combustion (LTC)
- Enable high aftertreatment efficiency
- Compatible with alternative diesel fuels
Global Cetane Number

- WWFC Approved by Auto Manufacturers and Associations worldwide
- WWFC recommends fuel quality specs matched to emissions level and performance requirements

Available at: http://www.autoalliance.org

- U.S. minimum and average Cetane Numbers are the lowest in the world.
- U.S. emissions standards are the world’s toughest.

Source: Alliance of Automobile Manufacturer Fuel Survey Summer 2010 SGS Fuel Survey 2010
Alternative Diesel Fuels

Biomass
Low CO₂
Renewable

PROS: High cetane
Lower PM emissions
Improved lubricity

CONS: Reduced heating value
Oxidative stability
Cold flow properties
Fuel-in-oil dilution

Example: Biodiesel

Natural gas
Lower CO₂
Abundant
Low cost

Conversion/Refining Process

Hydrocarbons
Examples: Renewable diesel, FT diesel, BTL, HVO

PROS: High cetane
Fungible (pipeline)
No aromatics

CONS: Higher production cost

Oxygenated compounds

• Both paths may help satisfy the cetane spec in the Worldwide Fuel Charter.
• Issues for both paths need to be addressed.
Sustainability Framework for CO₂ Reduction

- Traditionally, industries work toward optimizing their individual technology pathways.
- Achievement of future CO₂ reduction goals will require a strong joint effort between the Automotive and Energy industries.
Summary - Engines and Fuels as a System

- The most energy efficient future will require systems solutions across industries and governments – engines, fuels and regulations.

- For gasoline engines, octane will continue to limit engine efficiency but many other fuel properties also impact the vehicle and customer.

- For Diesel engines higher and more consistent cetane is a critical enabler for new combustion modes, improved efficiency and performance.

- Renewable fuels will increase in use and importance, and have their own unique challenges and opportunities.

- Gaseous fuels, both renewable and fossil based, are also growing in importance and justify optimized engine technologies.