Overview of the DOE Fuel and Lubricant Technologies R&D

Kevin Stork, Technology Manager
Vehicle Technologies Office

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Outline of the talk

• Goals, strategy, budget request
• Fuels – what we do, why, examples/successes
• Lubes – what we do, why, examples/successes
• Directions for FY15
• Summary
Accomplishments

- Demonstrated 2% fuel economy improvement with advanced additives, relative to Mobil 1 (2015 goal)
- Demonstrated RCCI operating range of 75% of non-idling portions of the city (UDDS) and highway (HWFET) light-duty federal drive cycles
- Full-scale production and strong sales of 11.9L natural gas engine supported under FY 2010 solicitation – “launch quality best to date” (CWI)

Future Directions

- Maintain lubricant research activities
  - Develop retrofittable, low-friction lubes for use as drop-in replacement in existing engines
- Demonstrate expanded operational range of advanced combustion regimes to >95% of LD Federal Test Procedures
  - Investigate potential engine efficiency improvements from increased octane from fuel properties
  - Determine optimum set of fuel properties for low temperature combustion
- Continue fit-for-service evaluations of alternative fuels – with emphasis on candidate “drop-in” biofuels
- Expand work in natural gas

FY 2020 Goals

Demonstrate cost effective lubricant with 4% fuel economy improvement relative to Mobil 1

Demonstrate expanded operational range of advanced combustion regimes to >95% of LD Federal Test Procedures

Funding in millions

<table>
<thead>
<tr>
<th></th>
<th>FY 2013</th>
<th>FY 2014</th>
<th>FY 2015</th>
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<tbody>
<tr>
<td>Fuel and Lubricant Technologies</td>
<td>$17.0</td>
<td>$16.0</td>
<td>$27.4</td>
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Status

- On-track to meet goals for both fuels and lubricants
What is *end use* fuels R&D?

- **Enabler of advanced combustion**
  - Kinetically-controlled combustion regimes
  - Knock-resistant fuels for future SI engines
  - Improved fuel characterization for modern & future engines (i.e., beyond octane & cetane)

- Evaluation of suitability of new candidate fuels and fuel components for use as practical fuels
  - Alternative fuels, biofuels, other novel blendstocks
  - Adequacy or inadequacy of existing fuel production, distribution and refueling infrastructure w/r/t new fuels – e.g., technical incompatibilities & market barriers
  - Attempt to characterize (and avoid) negative, potentially-unforeseen, consequences

- Development (vs. Research) can include
  - Financial assistance for alternative fuel vehicle engines and platform integration – e.g., increasing availability of medium-duty natural gas engines
  - Specific technical problems seen as barriers – e.g., methodology or tool development, etc.
Why conduct *end use* fuels R&D?

• Identify and overcome *pre-competitive* barriers to use of new technologies
  • Assure alternative fuels have properties we want prior to major policy commitment
    – Just because you *can* make *something*, doesn’t mean you should
  • Interface between development and deployment
  • Bridge the Valley of Death

• What It takes
  • Concerted, coordinated effort of government, autos, and energy companies
  • Though difficult... *there is ample precedent for this!*
  • A current (and rare) confluence of interests related to fuel effects – beginning with octane
## Fuel Can Change: Historical Precedent

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
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<tbody>
<tr>
<td>1974</td>
<td>Unleaded Gasoline</td>
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<tr>
<td>1979</td>
<td>E10 Ethanol Subsim Waiver</td>
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<td>1989</td>
<td>Phase 1 Gasoline Summer RVP Limits</td>
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<tr>
<td>1991</td>
<td>Phase 2 Gasoline Summer RVP Limits (including 1-psi E10 waiver)</td>
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<td>1992</td>
<td>Winter Oxyfuels Program (39 cities)</td>
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<td>1993</td>
<td>Highway diesel fuel sulfur control (500 ppm)</td>
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<tr>
<td>1995</td>
<td>Phase 1 RFG and Anti-dumping</td>
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<tr>
<td>1996</td>
<td>Full prohibition on lead</td>
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<tr>
<td>2000</td>
<td>Phase 2 RFG</td>
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<td>2002</td>
<td>Mobil Source Air Toxics (MSAT1)</td>
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<tr>
<td>2004</td>
<td>Tier 2 Gasoline Sulfur Control (30 ppm avg, 80 cap)</td>
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<tr>
<td>2006</td>
<td>Renewable Fuels Standard</td>
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<td>2006</td>
<td>Removal of RFG Oxy Mandate</td>
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<td>2006</td>
<td>Ultra Low Sulfur Highway Diesel Fuel (15 ppm)</td>
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<td>2006</td>
<td>Boutique Fuels List</td>
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<td>2007</td>
<td>Renewable Fuel Standard (RFS)</td>
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<td>2010</td>
<td>Ultra Low Sulfur Nonroad Diesel Fuel (15 ppm)</td>
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<td>2010</td>
<td>Renewable Fuel Standard 2 (RFS2)</td>
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<td>2011</td>
<td>MSAT2 – Gasoline Benzene</td>
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<tr>
<td>2012</td>
<td>E15 Subsim Waiver</td>
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<td>2017</td>
<td>Tier 3 Gasoline Sulfur Control (10 ppm avg)</td>
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Why conduct *end use* fuels R&D?

Regulation has driven past fuel changes

And it still will...
- e.g., CAFE increase – Possible entrée to co-development of fuels & engines?

But...
- Are there additional, non-regulatory drivers?

- *Is it possible to pursue GHG reduction as aggressively as criteria pollutant reductions have been (and are) pursued?*
What is engine/fuel co-development?

- What it traditionally meant...
  - “I have a nifty compound that I want to use as (or in) fuel!”

- What it increasingly means – and should mean...
  - “Let’s explore and exploit potential synergies available from existing (or potential) technologies in engines and fuels!”

- Enables: pushing boundaries of what we can do – within constraints of infrastructure, sunken investment and market conditions
  - What do fuel properties enable? – e.g., expansion of speed-load map of RCCI, downsizing and higher power output
  - What are the constraints? What can & can’t we do with what we already have (or can have)?
Current regulatory context justifies engine/fuel co-development

Current regulation is driving the necessary technology development for the joint optimization of (bio)fuels and engines

**Fuel Economy Standards**

2025 CAFE Standards  
(U.S. EPA and U.S. NTSA standards)

**Emissions Regulations**

70% NOx, 85% NMOG  
< 10 ppm sulfur in gasoline  
(U.S. EPA Tier 3 regulations)

**Renewable Fuels Standard**

36 billion gallons by 2022  
(EISA 2007)

Recent technology advances in sensors, onboard computers, and engine technologies are enabling new pathways
Current interest is high!

- Past year has seen some important industry-government dialogue on non-petroleum fuels – especially NG and biofuels
- It is clear that not all areas would fall under Fuels & Lubes at DOE
- Several topic areas of mutual interest have emerged:

**Natural Gas:**
- Pathways Modeling
- Codes and Standards
- On-board Storage
- Compressors
- Effects on Catalysts

**Biofuels:**
- Fuel Properties for Future Engines (!)
- Lifecycle Analysis
- Modeling tools for future/emerging combinations of engines and fuels
An Example of Engine-Fuel Co-development: High-Octane Fuel

- Nearest-term opportunity for engine-fuel co-development
- Could provide route to CAFE standard attainment
- Builds on several years of work sponsored by both VTO and BETO at ORNL, NREL and ANL, and testing and analysis by industry
- Moving towards a more cohesive program in FY 2015
- Benefits of notional high octane fuel for future SI engines
  - Enables higher compression ratio directly
  - Can include additional benefits – e.g., charge cooling
  - May be a cost-effective route to improved fuel economy
  - Potential market for renewables
  - Potential carbon reductions
Example: High-Octane Fuel

- Issues/barriers for high-octane fuels
  - Some octane sources are incompatible with current vehicles – e.g., ethanol greater than 10% or 15% in gasoline
  - Even for compatible octane, current vehicles largely waste the octane during normal operation – possible cost issue?
  - Currently, high-octane components are compensated with sub-octane base fuel blendstock – would this happen with higher ethanol levels (for example)?
  - No uniform octane requirements for gasoline across the U.S.
    - Regulation of AKI is at state level
    - Potential to call it a CAFE/GHG strategy, but controversial and would likely lead to big fight;
    - Tight timeline as mechanism for meeting current CAFE standards
  - Current de facto measure of octane (AKI or (R+M)/2) is lacking as a measure of what we are looking for in a fuel
    - Research Octane Number more representative of modern engines than is Motor Octane Number, but fuel is regulated and sold according to AKI
  - Uncertain impacts on: refineries, infrastructure, life-cycle GHGs, misfueling, etc.
1. **Predictive modeling** - Integration of (continuum) component parasitic friction loss models into subsystems and vehicle level packages – ‘what if’ parametric studies

2. **Develop Science/Mechanistic Based Models** of Parasitic Losses and Durability/Reliability and friction and wear

3. **Lubricant Technology Development** – Develop advanced lubricants (base fluids and additives) that reduce frictional losses while maintaining or exceeding other performance metrics (durability, reliability, corrosion, deposits, etc.)

4. **Engineered Surface Technology Development** – Develop advanced engineered surfaces (textures, designs, materials and coatings) that mitigate parasitic losses from a systems approach. Go beyond current ferrous based tribological systems.

5. **Validation of Modeling and Technologies** – Develop protocols to improve the fidelity of models and technologies. Improve correlation between lab-scale tests and engine/vehicle tests. Develop high fidelity databases for models and simulation of parasitic losses. Lab-Rig-Engine-Vehicle Validation Studies
U.S. Department of Energy

The turnover to new vehicle technologies proceeds slowly, but improved lubricants can be rolled out quickly. The DOE Lubes Program aims at making these lubricants more fuel efficient.

Key pathways to friction reduction are reduced oil viscosity and improved friction and wear additives.

This would save $12.4 billion per year, equivalent to 124 million barrels of oil.

Experts project that these losses can be reduced from 16.5% to 13% with improved lubricants.

These vehicles consume 9.7 million barrels of oil per day, with a value of $354 billion per year.

16.5% of this fuel energy is lost to friction.

There are 240 million cars and trucks in the USA, with an average lifespan of 16 years.

DOE Research Portfolio
- Models for friction and wear
- Rapid, accurate testing methods
- Improved base oils and additives
  - Nano-technology
  - Ionic liquids
  - Self-renewing, smart additives
  - Improved mechanical design
- Validation and demonstration
The opportunity for natural gas

- U.S. is approaching zero net imports of natural gas
- Natural gas expected to remain the low-cost fuel on an energy basis through 2040
- Use of natural gas is growing in transportation – driven by bus and municipal fleets
- Many groups have identified similar barriers to further expansion of use:
  - Lack of refueling infrastructure
  - Lack of choice in engines and trucks that use natural gas
  - Limited driving range of trucks between refueling
  - Heavy, bulky, expensive on-board fuel storage
  - Potential hazards and lack of familiarity with gaseous fuel
  - Many competing markets for natural gas: Can’t use same BTU twice!
- Many barriers have pre-competitive aspects
Directions for FY 2015

• High performance, low carbon fuels for high efficiency engines
  • Emphasis on high-octane fuel study – low-hanging fruit
    • Renewable Super Premium (co- w/ BETO)
    • Refinery-based fuels and blendstocks
  • Co-optimization of fuel properties and combustion
  • Natural Gas
    • Heavy duty trucks, marine, rail
    • Removal of barriers to expanded use

• Next-Generation Lubricants
  • Evaluation methods development, correlation to end use
  • New base oils and VI behavior
  • Friction and wear reducing additives
    • Liquid, solid, nano
Now is the time for beginning serious co-development of engines & fuels

- Regulatory climate
- The will to act
- Octane may be a good starting point, advanced combustion a close second

Natural gas likely to be the low cost fuel choice at least through 2040
- How best to use it?

Lubricants provide a potential drop-in retrofit for existing vehicles in many cases (depends on vehicle class and part lubricated – e.g., engine oil, but perhaps not light-duty automatic transmission fluid)

- Many Vehicles × Small per Vehicle Savings = Large Benefit
- May be low-hanging fruit
- May be necessary for meeting future CAFE
- Opportunities for co-evolution of lubricant and engines/vehicles
Summary, cont’d.

Fuels
• Exhaust emissions will remain the key factor in fuel requirements
• Fuel chemistry can enable more efficient combustion modes
• Octane will play a role
• Ethanol and natural gas aren’t used optimally with today’s engines

Lubricants
• Lubricants have huge potential due to retrofit capacity
• High-VI base oil will help on cold starts
• Improved additives required for lower viscosity base oils
• Co-development of the engine and lubricant will yield the greatest benefit
Kevin Stork

Kevin.stork@ee.doe.gov

Web site:
http://energy.gov/eere/vehicles/vehicle-technologies-office