Fuel-Engine Co-Optimization with Ethanol for High Efficiency Engines

Robert L. McCormick
robert.mccormick@nrel.gov
Washington DC
November 13, 2017
The Message

• Liquid fuels will make a substantial contribution in the market for decades to come
• High efficiency engines benefit consumers, support economic development, and protection of the environment
• Fuel-Engine Co-Optimization has identified renewable high-octane fuels that allow production of much more efficient engines
• An ASTM standard for a high octane (100 RON) test fuel to be used in high efficiency engines was developed by a broad industry stakeholder group
• These engines are based on known technology, but are not on the market today because low-cost fuel is not available
Goal: better fuels and better vehicles sooner

Fuel and Engine Co-Optimization

- What fuel properties maximize engine performance?
- How do engine parameters affect efficiency?
- What fuel and engine combinations are sustainable, affordable, and scalable?
- Are there optimal fuel and engine combinations – highest combined efficiency/GHG reduction?
Goal: better fuels and better vehicles sooner

Fuel and Engine Optimization

- What fuel properties maximize engine performance?
- How do engine parameters affect efficiency?
- What fuel and engine combinations are sustainable, affordable, and scalable?
- Are there optimal fuel and engine combinations – highest combined efficiency/GHG reduction?

Up to 15% fuel economy improvement for boosted spark ignition and mixed mode

Light-duty

Up to 15% fuel economy improvement for boosted spark ignition and mixed mode

Fuels

- Diversifying resource base for resiliency and reliability
- Providing economic options to fuel providers to accommodate changing global fuel demands
- Increasing supply of domestically sourced fuel by up to 25 billion gallons/year
External Advisory Board

USCAR
David Brooks

American Petroleum Institute
Bill Cannella

Fuels Institute
John Eichberger

Truck & Engine Manufacturers Assn
Roger Gault

Advanced Biofuels Association
Michael McAdams

Flint Hills Resources
Chris Pritchard

EPA
Paul Machiele

CA Air Resources Board
James Guthrie

UL
Edgar Wolff-Klammer

University Experts
Ralph Cavalieri (WSU, emeritus)
David Foster (U. Wisconsin, emeritus)

Industry Expert
John Wall (Cummins, retired)

- EAB advises National Lab Leadership Team
- Participants represent industry perspectives, not individual companies
- Entire board meets twice per year; smaller groups meet on targeted issues
Current fuels **constrain** engine design

**Brake Thermal Efficiency (%)**

- **RON 100.9**
  - Higher peak efficiency
- **RON 90.7**
  - Higher peak load

**Brake Mean Effective Pressure (kPa)**

*Engine: Ford Ecoboost 1.6L 4-cylinder, turbocharged, direct-injection, 10.1 CR source: C.S. Sluder, ORNL*
Engine Knock Limits Engine Efficiency

- Fuel with adequate knock resistance is required to prevent engine knock
- Knock occurs when unburned fuel/air mixture auto-ignites – a small explosion in the engine
- Knock can cause engine damage

Higher knock resistance:
- Higher research octane number (RON)
- Higher octane sensitivity (RON – MON)
- Higher evaporative cooling
- Higher flame speed
What is Octane Number?

- Pump octane is the average of research octane (RON) and motor octane (MON) – also known as \((R + M)/2\)
  - Two tests to cover the full range of engine operating conditions 80 years ago when this was introduced
- For modern technology engines, RON is the better measure of performance (knock prevention)
- There is no nationwide (ASTM) standard for minimum octane number in the United States – significant limitation on engine efficiency
Strategies to Increase Engine Efficiency:

• Increased compression ratio
  • Greater thermodynamic efficiency
• Engine downsizing/downspeeding
  • Smaller engines operating at low-speed/higher load
  • Less friction at lower engine speeds
• Turbocharging
  • Recovering energy from the engine exhaust
  • Increase specific power allowing smaller engine
• Direct injection
  • Fuel evaporation cools the air-fuel mixture

All of these strategies can take advantage of more highly knock resistant fuels (higher octane number, octane sensitivity, heat of vaporization, flame speed, and other properties)
Developed by ASTM workgroup with members from the automotive, petroleum, biofuels and other industries

Describes properties of fuels for high efficiency SI engines

Standard serves as a platform to align fuel formulations for these future engine technologies

Planned to serve as basis for commercial high octane fuel standard

Designation: D8076 – 17a

Standard Specification for 100 Research Octane Number Test Fuel for Automotive Spark-Ignition Engines¹
Benefits of Biomass-Sourced Fuel

**Technical**

Tailor fuel properties desired in the blendstock
Add value to refiners – blend up low quality (inexpensive) petroleum blendstocks
Help refiners balance global trends in transportation fuel use

**Societal**

Reliable domestic energy options that are affordable & efficient
Strengthens energy security by increasing supply, diversity, reliability
Retain $260 billion in the U.S.
Add 1.1M direct jobs
Expand U.S. science/technology leadership

**Environmental**

Reduce emissions, including CO₂ emissions, by 450 million tons (7%) annually
Improved soil, water, and air quality

Co-Optima High Performing Boosted SI Blendstocks Identified

Properties provided by chemical families:

- Alcohols
- Furans
- Alkenes
- Aromatics
- Ketones
- Cycloalkanes
- Alkanes
- Ethers
- Esters

Representative Tier 3 blendstocks:

- Ethanol
- N-propanol
- Isopropanol
- Isobutanol
- Cyclopentanone
- Diisobutylene
- Furan mixture
- Aromatics

RON = Research octane number; S = Sensitivity (S = RON – MON); HOV = heat of vaporization; LFS = laminar flame speed
• Ethanol has high RON
  o RON = 109
  o Relatively low cost source of octane
• Other properties also benefit knock resistance
  o Octane sensitivity
  o Heat of vaporization
  o Flame speed
• E25 blend would likely provide adequate RON for high efficiency engines
Summary – The Message

• Liquid fuels will make a substantial contribution in the market for decades to come
• High efficiency engines benefit consumers, support economic development, and protection of the environment
• Fuel-Engine Co-Optimization has identified renewable high-octane fuels that allow production of much more efficient engines
• An ASTM standard for a high octane (100 RON) test fuel to be used in high efficiency engines was developed by a broad industry stakeholder group
• These engines are based on known technology, but are not on the market today because low-cost fuel is not available