NREL
NATIONAL RENEWABLE ENERGY LABORATORY





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

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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 better v soo

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

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External Advisory Board

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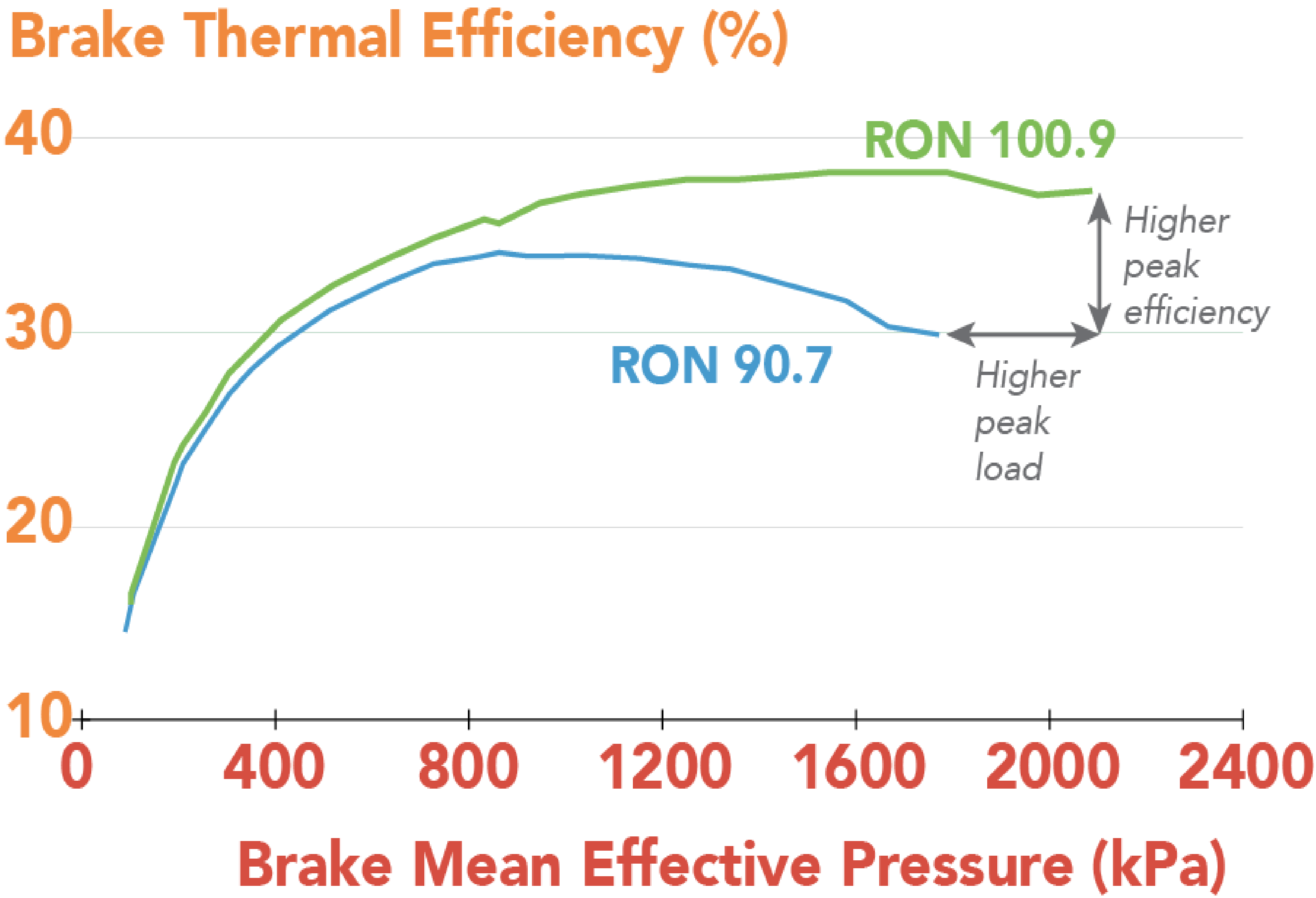
David Foster (U. Wisconsin, emeritus)

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

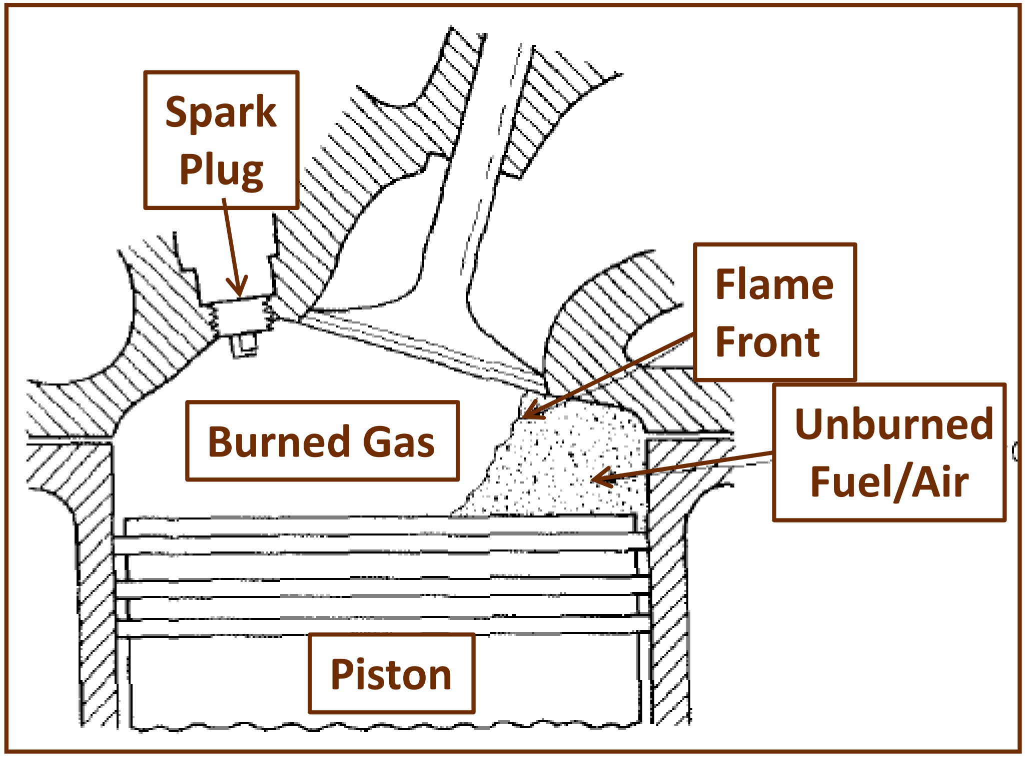
Current fuels **constrain** engine design



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

Engine Knock Limits Engine Efficiency

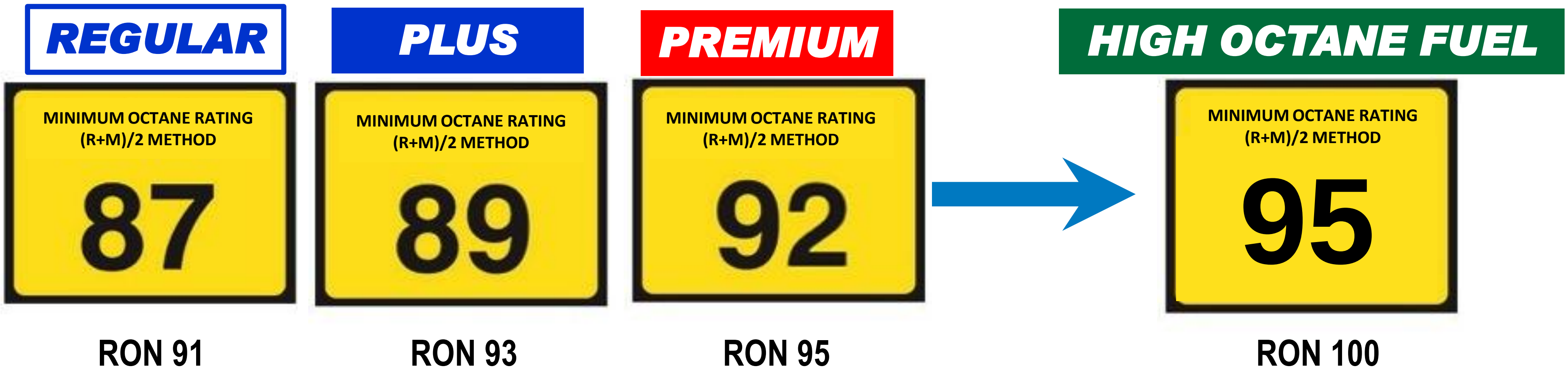
- Fuel with adequate knock resistance is required to prevent engine knock
- Knock occurs when unburned fuel/air mixture auto-ignites – a small explosion in the engine
- Knock can cause engine damage



<u>Higher knock resistance:</u>

- 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

How Can Better Knock Resistance Enable Better Engines?

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*

ASTM Standard for 100 Research Octane Number Test Fuel

- 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

ASTM INTERNATIONAL

Designation: D8076 – 17a

Standard Specification for
100 Research Octane Number Test Fuel for Automotive Spark-Ignition Engines[1]

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 CO_2 emissions, by 450 million tons (7%) annually

Improved soil, water, and air quality

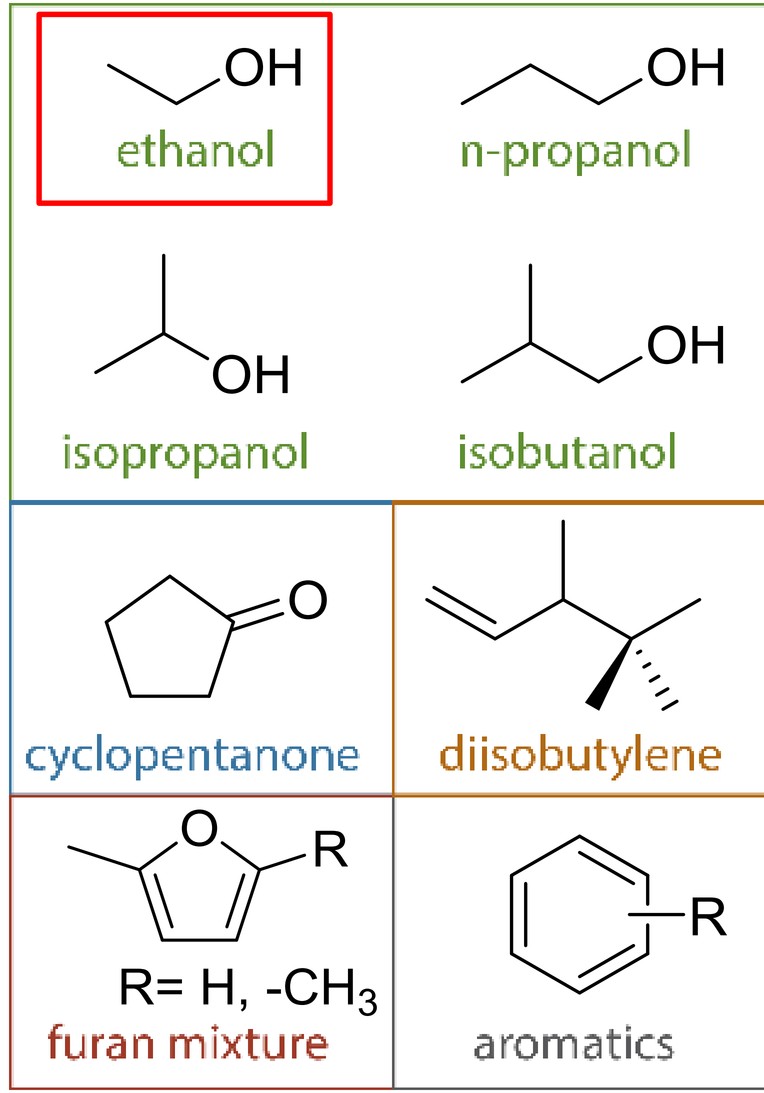
Reference: http://onlinelibrary.wiley.com/doi/10.1002/bbb.1728/pdf

Co-Optima High Performing Boosted SI Blendstocks Identified

Properties provided by chemical families:

	RON	S	HOV	LFS
Alcohols	✔	✔	✓	✔
Furans	✔	✔		
Alkenes	✔	✔		
Aromatics	✔	✔		
Ketones	✔	✔		
Cycloalkanes	✔	✓		
Alkanes	✔			
Ethers	✔			
Esters	✔			

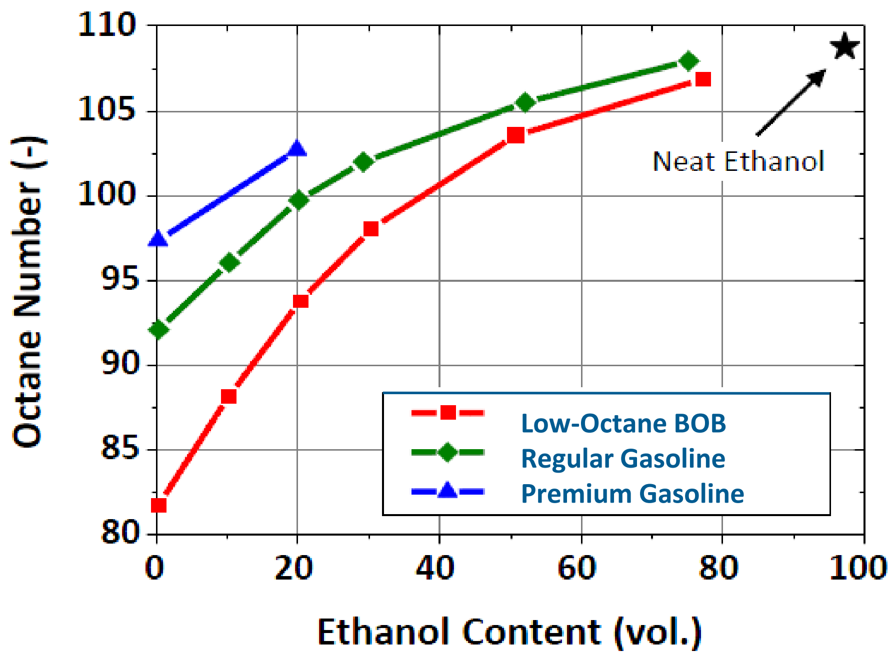
Representative Tier 3 blendstocks



RON = Research octane number ; S = Sensitivity (S = RON – MON) ; HOV = heat of vaporization ; LFS = laminar flame speed

Ethanol Is Available Today

- Ethanol has high RON
  - RON = 109
  - Relatively low cost source of octane
- Other properties also benefit knock resistance
  - Octane sensitivity
  - Heat of vaporization
  - Flame speed
- E25 blend would likely provide adequate RON for high efficiency engines



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Summary – The Message

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