Co-Optimization of Fuels & Engines

Octane and Internal Combustion Engine Advancements from a Long(er) Term Perspective:

Insights from the Co-Optima Project

Fuels2018

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The octane game: Auto industry lobbies for 95 as new regular

April 17, 2018 @ 11:00 am

GM, Ford and Fiat Chrysler are seeking just one grade of fuel: 95. That would eliminate today's grades, generally 87 octane for regular, 88-90 for midgrade and 91-94 for premium. *Photo credit: BLOOMBERG*

Related Stories

New 1.5-liter Ford engine can run on just 2 cylinders

UPDATED: 4/18/18 11:06 am ET - adds details

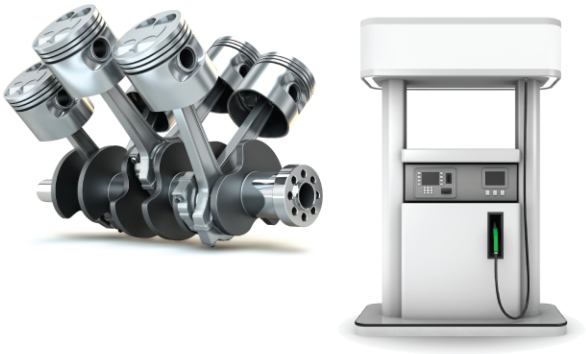
The auto industry is finally getting traction on its quest to make 95 RON octane gasoline -- basically the same grade as Europe's regular and the lowest grade of premium here -- the new regular in the United States.

In **testimony** Friday before the House Energy and Commerce Committee's environment subcommittee, Dan Nicholson, General Motors' vice president of global propulsion systems, said making 95 octane the new regular aligns the U.S. with Europe and is one of the most affordable ways to boost fuel economy and lower greenhouse gas emissions.

Key Takeaway Messages

ICEs and liquid fuels

will be around a long time



And their efficiency/emissions can be improved significantly

95 RON

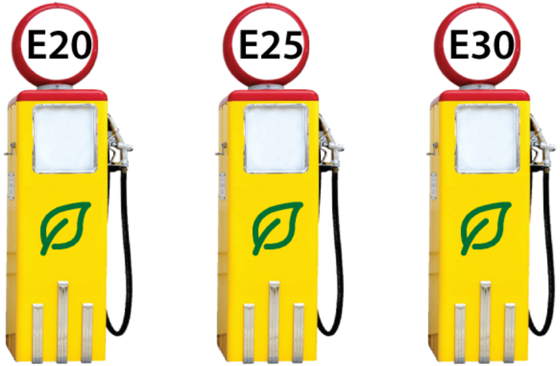
is directionally a good start for boosted SI engines

MINIMUM OCTANE RATING
RON METHOD
95
PRESS

But we need to consider octane sensitivity/other properties and advanced engine needs

Ethanol

is one viable path to high RON, lower GHG fuels



But other bio-blendstocks could provide additional longer-term options/flexibility

Goal: better fuels and better vehicles **sooner**

Fuel and Engine Co-Optimization

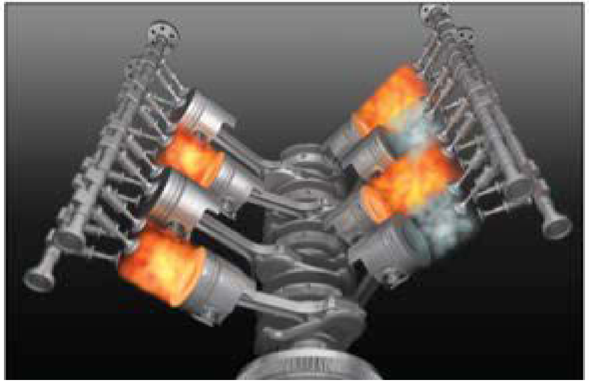
- What fuel properties maximize engine performance?
- How do engine parameters affect efficiency?
- What fuel and engine combinations are sustainable, affordable, and scalable?

Key Co-Optima Research Questions

What fuels do engines *really* want?

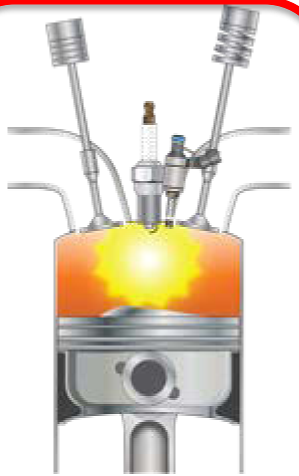
What fuels *should* we make?

What will work in the real world?



Two Parallel R&D Projects

Light-Duty



Boosted SI

Higher efficiency via downsizing

Near-term

Multi-mode SI/ACI

Even higher efficiency over drive cycle

Mid-term

Medium/Heavy-Duty

Mixing Controlled

Improved engine emissions

Near-term

Kinetically Controlled

Highest efficiency and emissions performance

Longer-term

High-level goals and outcomes

Light-duty

10% fuel economy (FE) improvement* from boosted SI and multi-mode SI/ACI

Heavy-duty

Up to 4% FE improvement (worth $5B/year)*

Potential lower cost path to meeting next tier of criteria emissions regulations

Fuels

Diversifying resource base

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

Cross-cutting goals

Stimulate domestic economy

Adding up to 500,000 new jobs

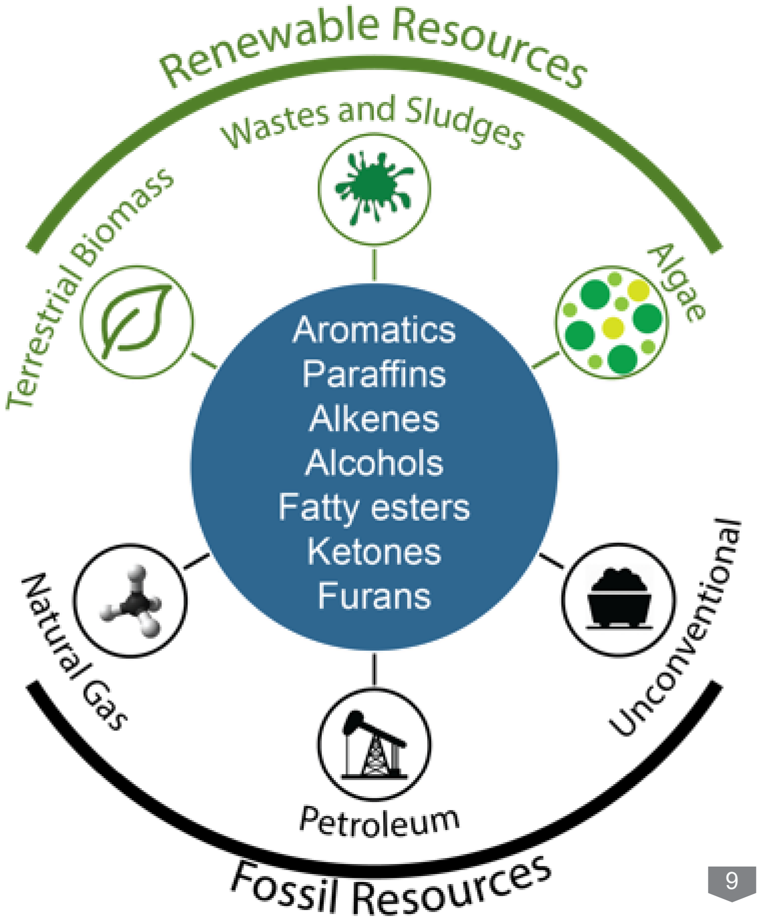
Providing clean-energy options

* Beyond projected results of current R&D efforts; 2030 target. The team is actively engaging with OEMs, fuel providers, and other key stakeholders to refine goals and approaches to measuring fuel economy improvements

Approach

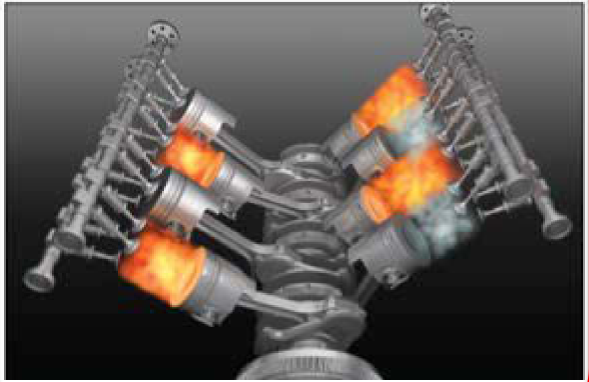
Objective: identify fuel properties that optimize engine performance, <u>independent of composition,</u>* allowing the market to define the best means to blend and provide these fuels

* We are not going to recommend that <u>any</u> specific blendstocks be included in future fuels



Foundational Technical Questions

What fuels do engines *really* want?



What fuels *should* we make?

What will work in the real world?

Question 1: What fuels do engines really want?

Approach:

Conduct engine experiments and simulations that delineate fuel property impacts on engine performance

Focus: boosted SI engines

Fuel Properties Impacting Boosted SI Efficiency

Octane Index (Knock): RON, Octane Sensitivity

Charge Cooling: Heat of Vaporization

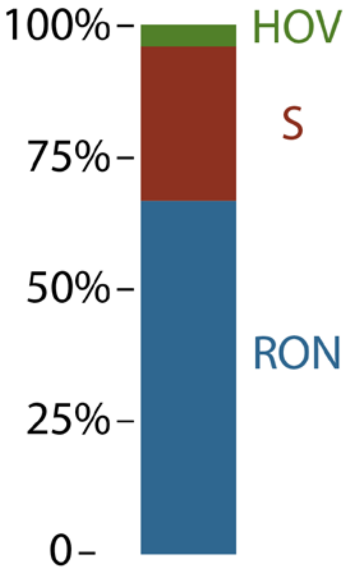
$$\text{Merit (efficiency)} = \alpha \cdot f(RON) + \beta \cdot f(K, S) + \gamma \cdot f(HOV) + \varepsilon \cdot f(LFS) + \zeta \cdot f(PMI) + \eta \cdot f(T_{c,90,conv})$$

- $\alpha \cdot f(RON)$ — RON
- $\beta \cdot f(K, S)$ — Octane Sensitivity
- $\gamma \cdot f(HOV)$ — Heat of Vaporization
- $\varepsilon \cdot f(LFS)$ — Flame Speed
- $\zeta \cdot f(PMI)$ — PM Emissions
- $\eta \cdot f(T_{c,90,conv})$ — Catalyst Light-off Temp (cold start)

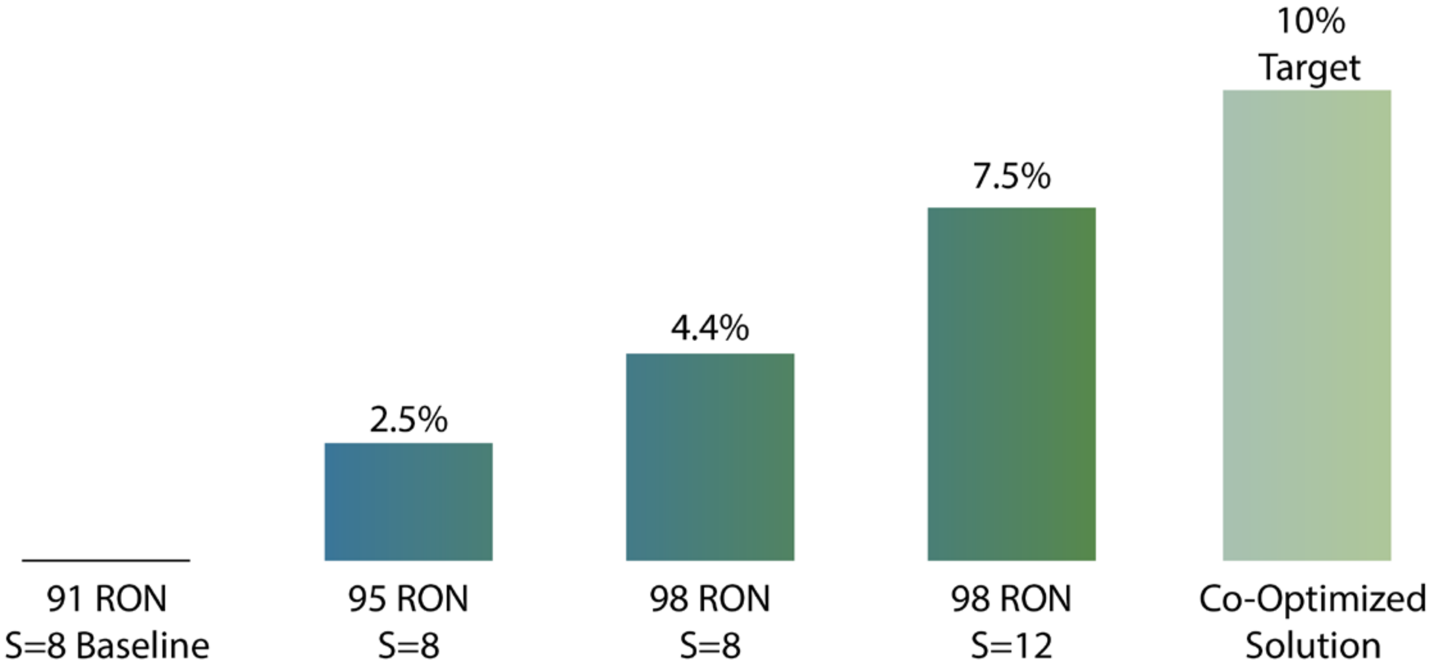
Burn Rate/ Dilution Tolerance: Flame Speed

Emissions Penalties: PM Emissions, Catalyst Light-off Temp (cold start)

Average contribution to merit function for highest scoring blendstocks



Efficiency Improvement: Boosted SI Engines



S = sensitivity = RON - MON; Engine efficiencies calculated for conditions appropriate for boosted downsized engines (K = -1.25)

Source: Miles, Paul. "Efficiency Merit Function for Spark Ignition Engines: Revisions and Improvements Based on FY16–17 Research." Technical Report. U.S. Department of Energy, Washington, DC. 2018. DOE/GO-102018-5041.

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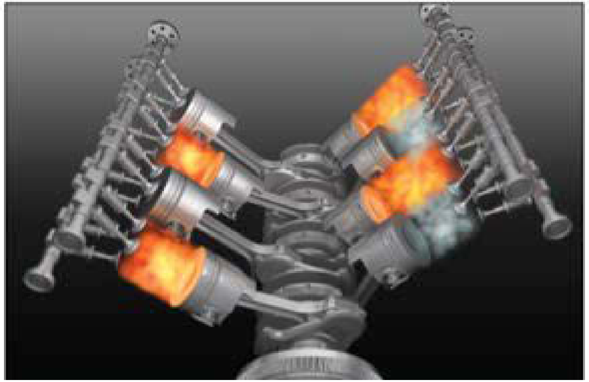
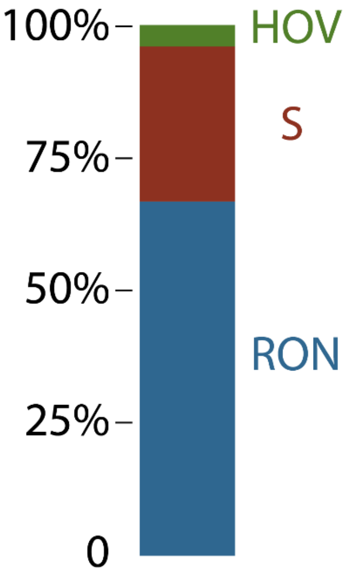


Current Boosted SI Blendstock Evaluation

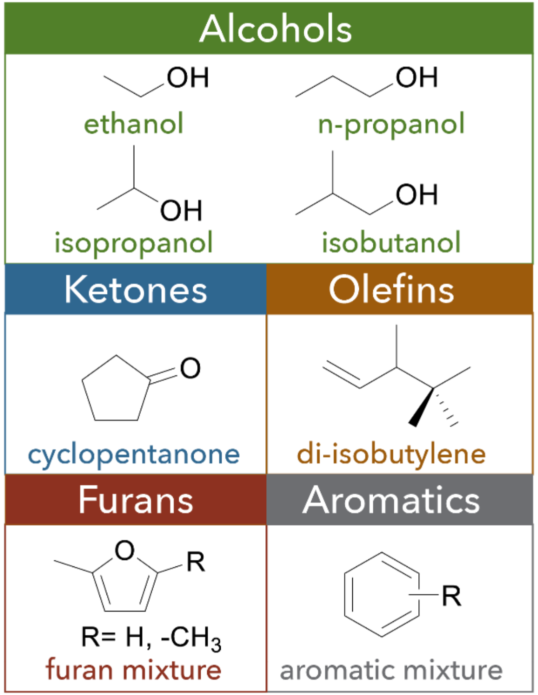
Average contribution to merit function for highest scoring blendstocks



Properties provided by chemical families:

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

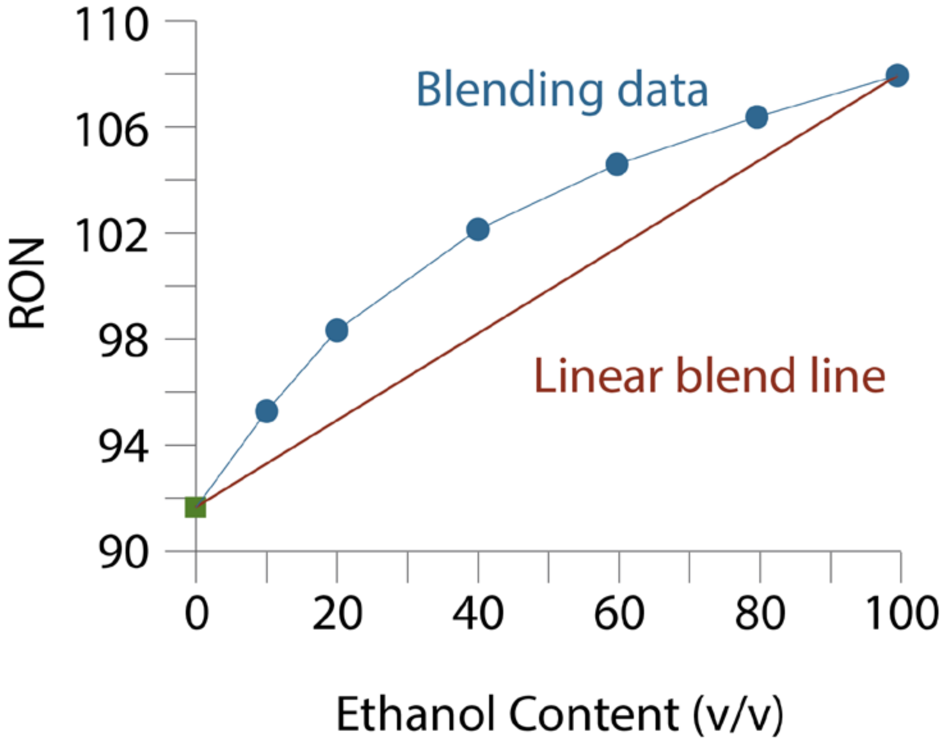
Blendstocks from 5 chemical families selected for more detailed evaluation



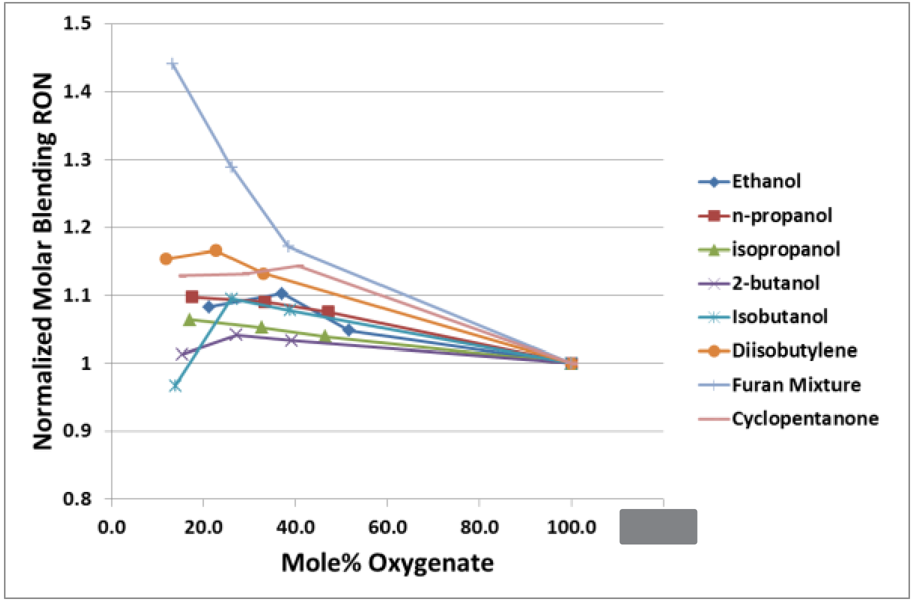
RON = Research octane number ; S = Sensitivity (S = RON – MON) ; HOV = heat of vaporization

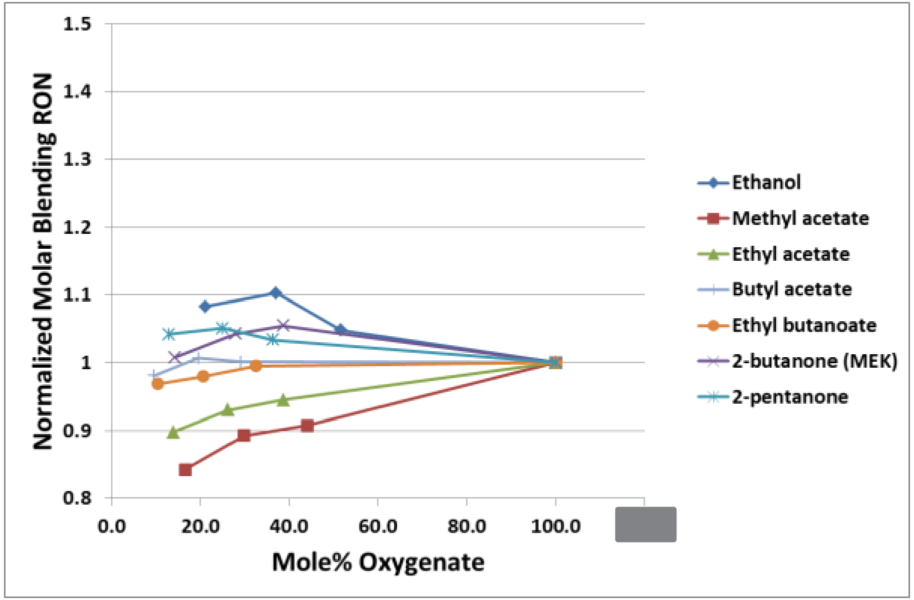
Understanding Blending Effects

- Many blendstocks exhibit beneficial non-linear blending behavior
  - “Effective” blending number is higher than pure component’s
- Value proposition:
  - Determine molecular basis for non-linear RON and S blending
  - Identify blendstocks with greatest potential to impart advantageous properties



RON Blending Behavior





- Comprehensive blending studies in gasoline surrogate w/ and w/o ethanol
- Non-linear blending is norm
  - May be either synergistic (furans) or antagonistic (esters)

Capitalizing on Synergistic Blending

Blendstock volumes required to produce 95 RON fuel from 88 RON BOB

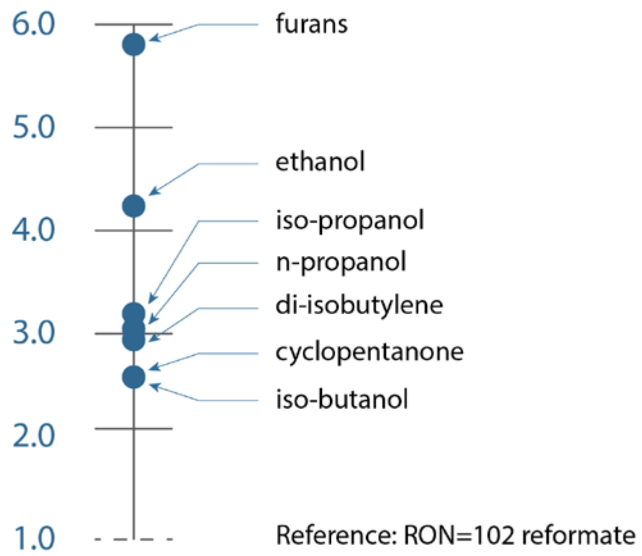
	Blendstock (vol)	88 RON BOB (vol)
furans	0.09	0.91
ethanol	0.12	0.88
iso-propanol	0.16	0.84
n-propanol	0.17	0.83
di-isobutylene	0.17	0.83
iso-butanol	0.19	0.81
cyclopentanone	0.19	0.81
reformate (RON=102)*	0.50	0.50

In this BOB, furans are 5.8× as effective on a volumetric basis than reformate

* reference

Four-component surrogate BOB; Blending data from: R.L. McCormick et al., SAE Int. J. Fuels Lubr., 10:442-460, 2017.

Performance-based volume parity factor for producing 95 RON fuel



Thus, furans can be more expensive than reformate (per gallon) and provide a more affordable option for consumers

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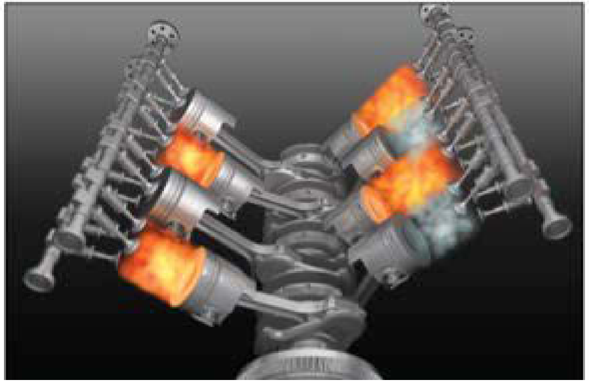

What fuels *should* we make?

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The Role of Analysis in Co-Optima

Bioblendstock Level

What are the scalability, cost, and environmental drivers?

Is a given bio-blendstock viable in the near term?

What are the key research challenges that must be overcome?

Transportation Sector Level

What will be the influence on fleet:

- Energy consumption
- Emissions – air pollutants, GHG
- Water consumption

What are potential impacts on infrastructure?

Feedstock Supply

How can companion markets build feedstock supply and what will be price impact?

Refinery Integration

What would the value proposition be to a refiner for integrating a certain bioblendstock?

Goal: Identify Key Bioblendstock Research Challenges

Technology Readiness

- State of technology: Fuel production
- State of technology: Vehicle use
- Conversion technology readiness level
- Feedstock sensitivity
- Process robustness
- Feedstock quality
- # of viable pathways

Environmental

- Carbon efficiency
- Target yield
- Life cycle greenhouse gas emissions
- Life cycle water
- Life cycle fossil energy use

Economics

- Target cost
- Needed cost reduction
- Co-product economics
- Feedstock cost
- Alternative high-value use

Other Factors

- Regulatory requirements
- Geographic factors
- Vehicle compatibility
- Infrastructure compatibility

Technology Readiness, Environmental and Economics: Assessed only for blendstocks produced from biomass

Other Factors: Assessed for both fossil and renewable blendstocks

Summary

- Co-Optima research and analysis have identified fuel properties that enable advanced LD and HD engines
  - 95 RON will directionally improve boosted SI efficiency, but higher RON and S provide additional benefits
  - The optimal fuel properties for future engines are still uncertain
- There are a large number of blendstocks readily derived from biomass (and petroleum) that possess beneficial properties
  - Some may provide longer term options in addition to ethanol
- Key research needs have been identified for performance, technology, economic, and environmental metrics

More Info Available

https://www.energy.gov/sites/prod/files/2018/04/f50/Co-Optima_YIR2017_FINAL_Web_180417_0.pdf

Thank You!