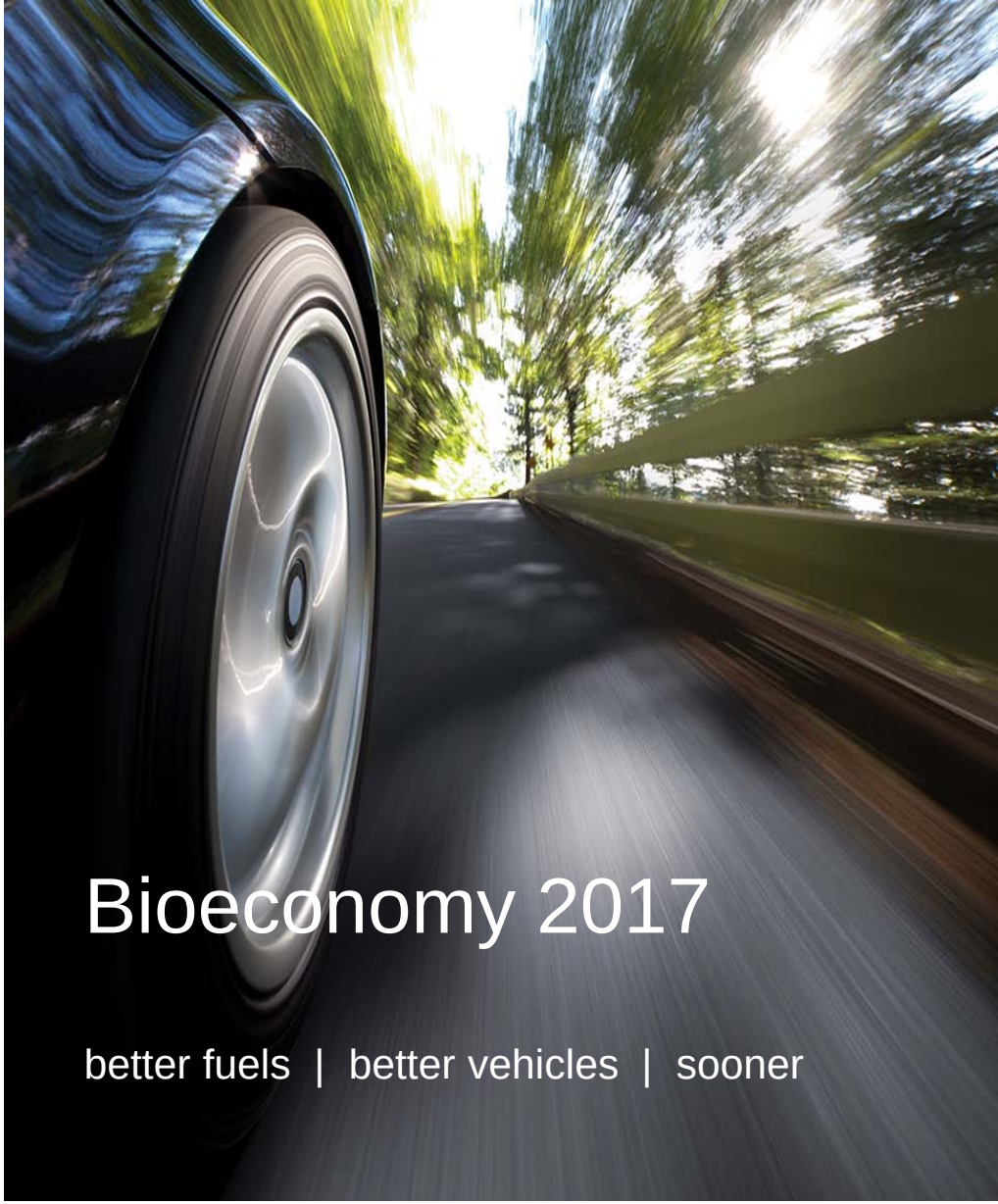
Co-Optimization of
Fuels & Engines

Creating a Win-Win-Win with the Next Generation of Fuels and Vehicles:

The Early-stage Research Perspective

John Farrell (NREL)

July 12, 2017



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Goals and Outcomes

Light-duty

Up to 15% fuel economy (FE) improvement*
Phase 1: boosted SI; Phase 2: multi-mode SI/ACI

Heavy-duty

Up to 1-4% FE improvement (worth $1-5B/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

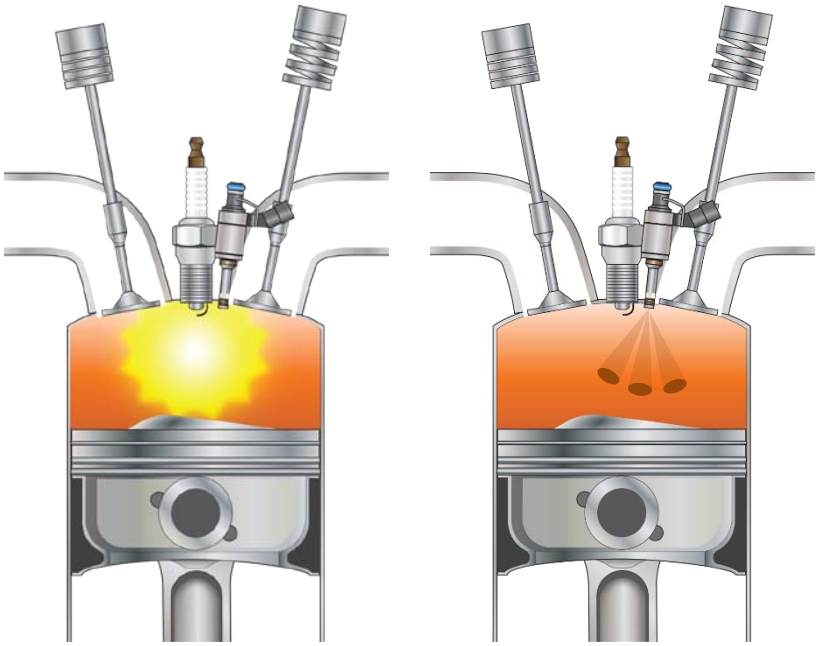
Adding up to 500,000 new jobs

Providing clean-energy options

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

Two Parallel R&D Projects

Light-Duty



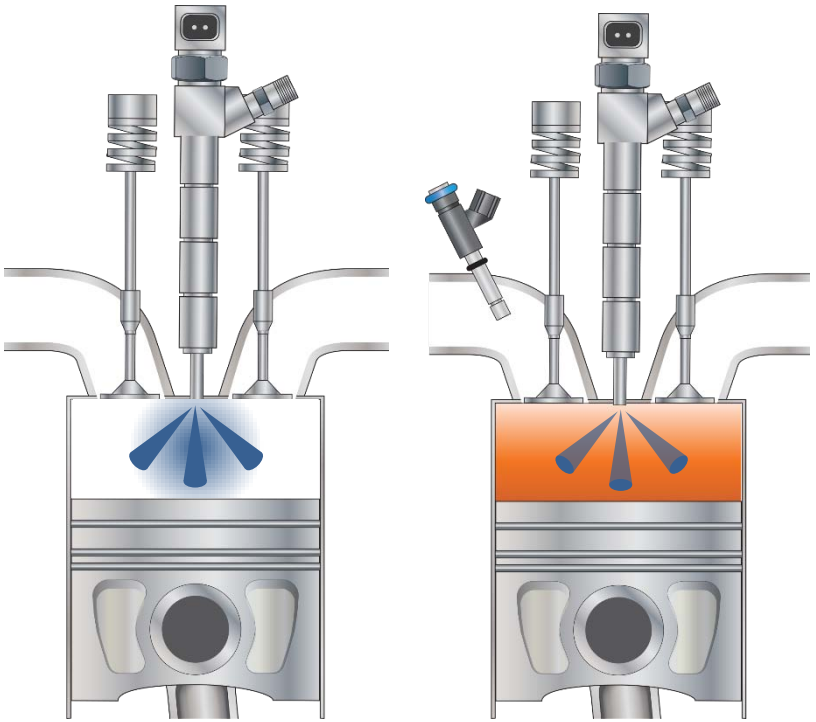
Boosted SI

Near-term

Multi-mode SI / ACI

Mid-term

Medium and Heavy-Duty



Mixing Controlled

Near-term

Kinetically Controlled

Longer-term

Co-Optima Initiative

Leveraging expertise and facilities from 9 national labs and 13 universities

Budget:
FY16: $26M
FY17: $24.5M
Universities: $7M*

*** Funding for 3-year effort**

Overview of approach

Co-Optima is focused on identifying fuel properties that optimize engine performance, independent of composition,* allowing the market to define the best means to blend and provide these fuels

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

New fuel specs would be analogous to today's gasoline spec, in contrast to (e.g.) E85

In support of this, we are pursuing a systematic study of blendstocks (biomass derived or otherwise) to identify a broad range of feasible options

Objective is to identify blendstocks that can provide target ranges of key fuel properties, identify tradeoffs on consistent and comprehensive basis, and share information with stakeholders

We will explicitly seek to identify biomass based blendstock options since they have the potential to increase domestic fuel sources, and additional environmental benefits but

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,

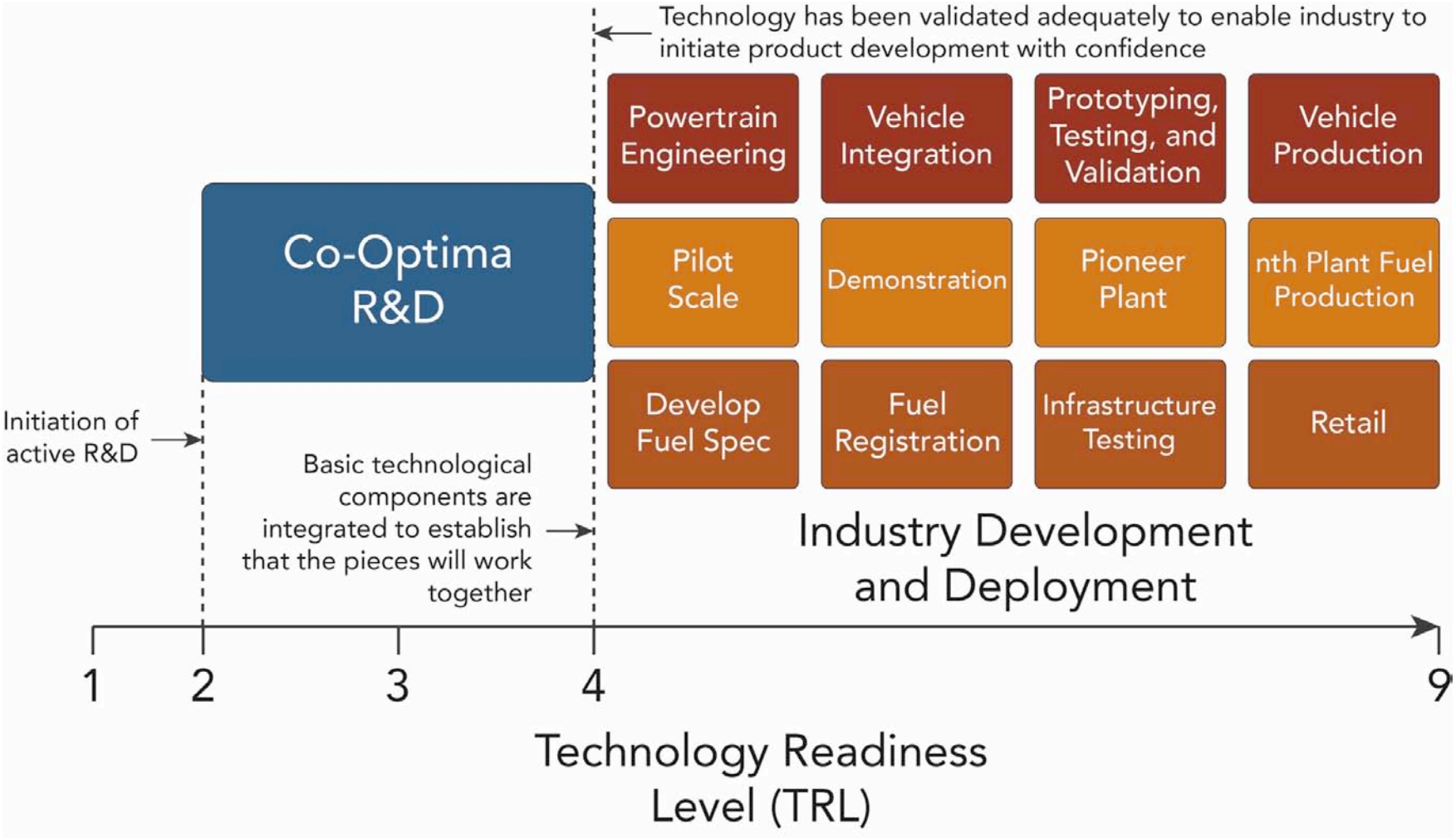
Expand U.S. science/ technology leadership

Environmental

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

Improved soil, water, and air quality

Engagement with Industry



Stakeholder Engagement Activities

Listening Days

- Two held – 2015 and 2017
- 2015 summary available on-line*

Companies/Organization Visits

- Individual visits to OEMs, fuel providers, retail organizations, biofuel companies, etc.
- ~ 60 visits to date

Monthly webinars

- 129 individual stakeholders
- 77 organizations

* https://energy.gov/sites/prod/files/2016/04/f30/co-optima_listening_day_summary_report_0.pdf

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

“Real world consideration” reports

Five reports being published examining issues relevant to new fuel/vehicle introductions

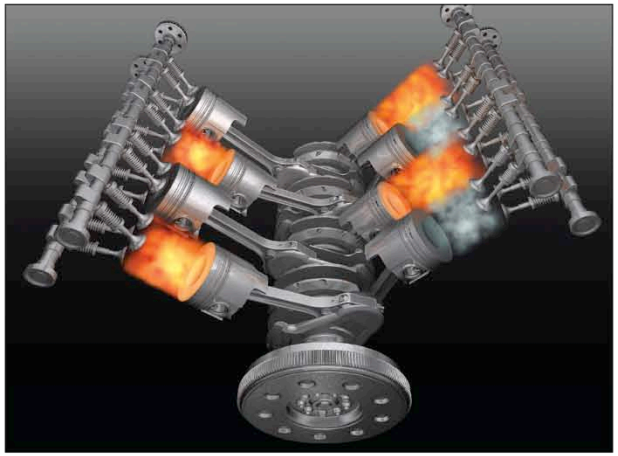
1. Misfueling mitigation*
2. Impact of laws and incentives§
3. Lessons learned from first generation ethanol§
4. Fuel and vehicle distribution§
5. Fuel and vehicle introduction§

* http://www.nrel.gov/docs/fy17osti/66918.pdf

§ in press

Co-Optima Technical Challenges

What fuels do engines *really* want?

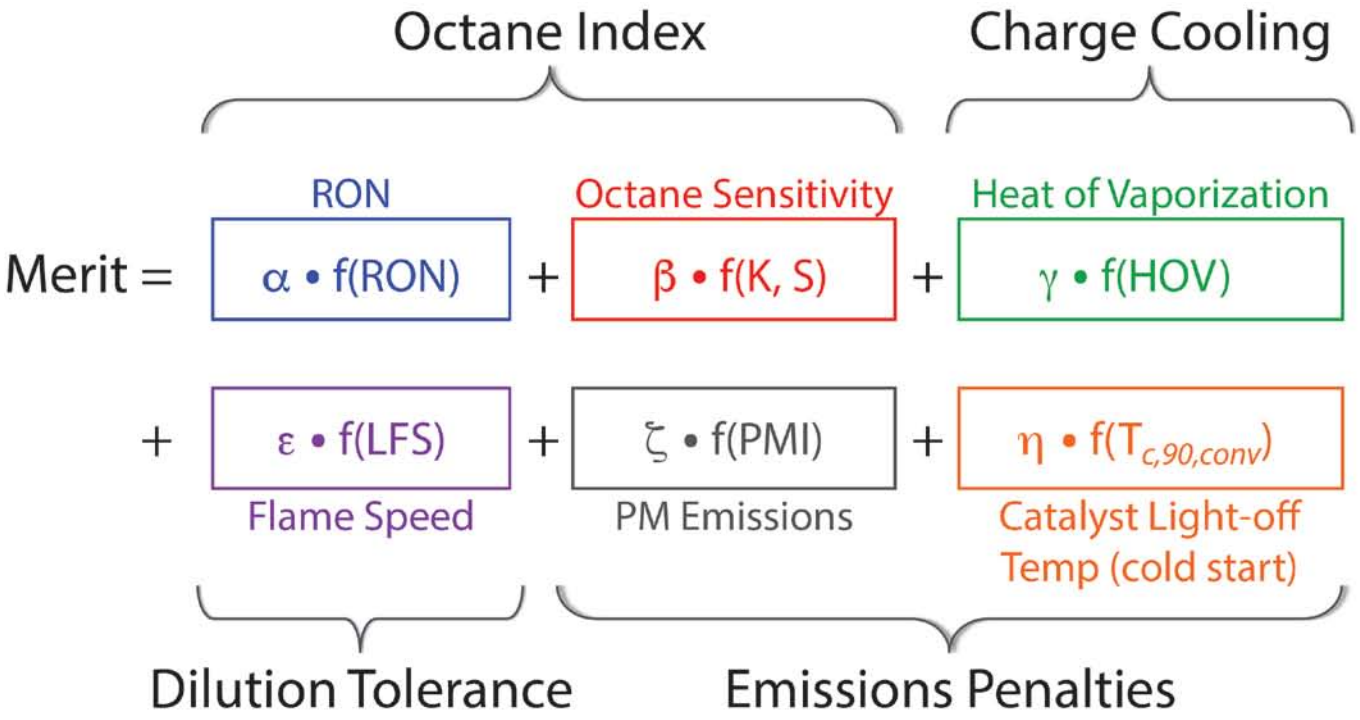


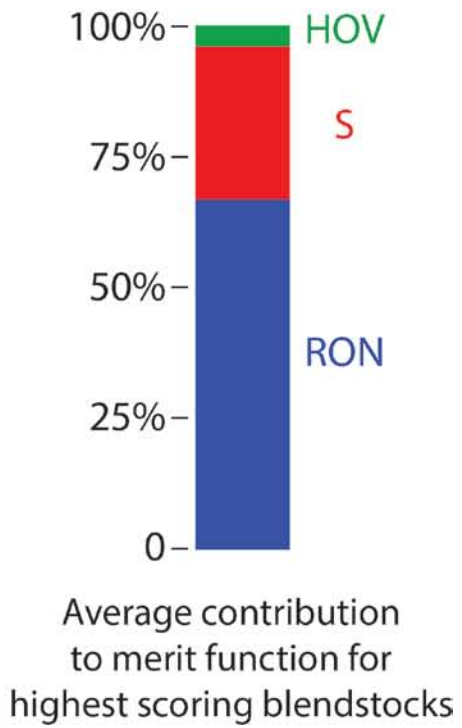
What fuels *should* we make?

What will work in the real world?

What Do Engines Really Want? – More Than Octane

Merit function, validated by experiments and simulations, quantifies impact of fuel properties on efficiency and performance of boosted spark ignition engines





Average contribution to merit function for highest scoring blendstocks

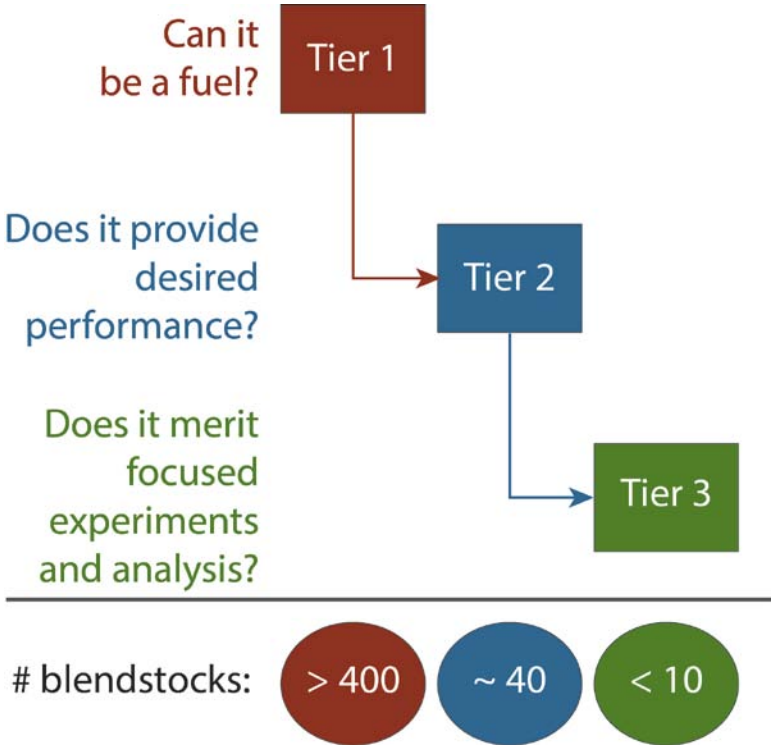
Most important fuel properties for efficiency: RON, sensitivity, HOV*

* Sensitivity = RON – MON; HOV = heat of vaporization

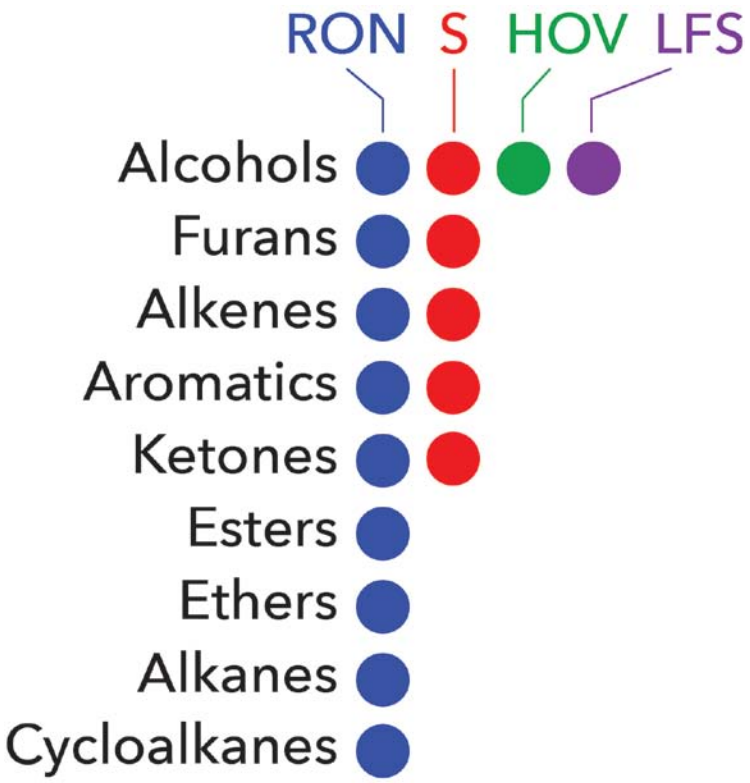
What Fuels Should We Make? Comprehensive Blendstock Survey Completed

Five chemical families of blendstocks identified that provide key fuel properties required for high boosted SI engine efficiency that also meet key fuel quality specifications

- > 470 blendstocks screened (Tier 1)
- 41 blendstocks surveyed in Tier 2; performance evaluated at blends up to 30% in petroleum blendstocks
- Main deliverable from Tier 3 evaluations: data, tools, analysis to facilitate stakeholder decisions based on consistent comparisons



High performing boosted SI blendstocks identified



- Blendstocks from five chemical families can provide properties needed for high efficiency boosted SI operation
- Eight representative blendstocks selected for in-depth Tier 3 characterization

Representative Tier 3 blendstocks

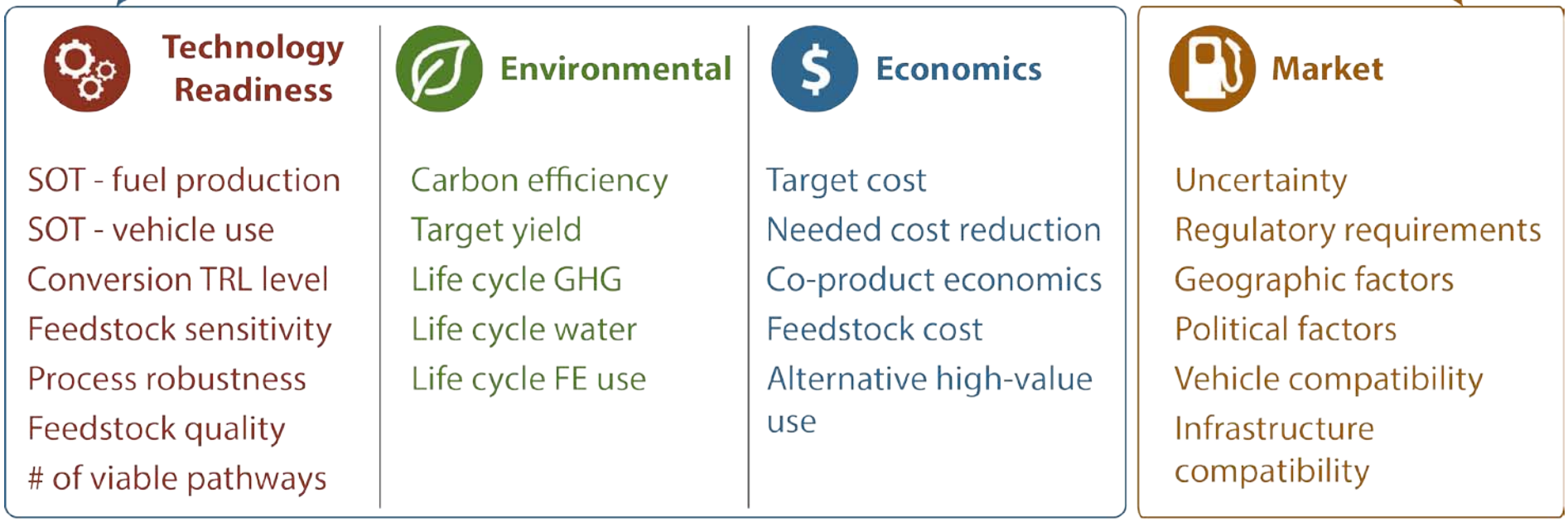
ethanol	n-propanol
isopropanol	isobutanol
cyclopentanone	diisobutylene
furan mixture	aromatics

Tiered approach to blendstock screening, selection, and evaluation

Blendstocks with feasible pathways to large scale production by ~2025-2030 identified via integrated systems-level analyses of 23 metrics representing economic, environmental, technology, and market factors

Assessed only for blendstocks produced from biomass

Assessed for blendstocks derived from both fossil and renewable sources



SOT = state of technology; TRL = technology readiness level; GHG = greenhouse gas; FE = fossil energy

Summary

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Back up slides

Summary

Relevance

- Better integration of fuels and engines research critical to accelerating progress towards economic development, energy security, and emissions goals

Approach

- Focused on identifying fuel properties that optimize engine performance, independent of composition, allowing the market to define the best means to blend and provide these fuels
- Leverages expertise and facilities from nine national laboratories and two DOE offices

Technical Accomplishments

- Major accomplishments span development of merit function, fuel database, new insight into fuel property impacts on engine efficiency, etc.
- Many additional accomplishments will be discussed in detail in subsequent presentations

Proposed Future Research

- Complete merit function development and establish fuel specification for boosted SI
- Expand advanced gasoline research to include multi-mode SI-ACI combustion
- Initiate more focused ACI research and approach for medium- and heavy-duty

Collaborations

- Strong industry engagement including industry-led external advisory board, monthly stakeholder phone calls, and annual stakeholder meeting
- Collaboration across nine national laboratories, two DOE office, and thirteen universities

Overall Co-Optima Objectives

- Identify engine parameters and fuel properties that can significantly increase fuel economy across light, medium, and heavy duty fleets
  - Focus is on precompetitive, early TRL research
  - We are not looking to define or recommend commercial solutions
- Develop technical knowledge needed for new fuel specifications
- Conduct comprehensive and consistent survey of blendstock candidates to identify broad range of options that can be blended into petroleum base stocks and yield target values of key properties
- Demonstrate blendstock candidates that can be produced from renewable domestic feedstocks that are affordable, scalable, sustainable, and compatible
- Identify implications to the refueling infrastructure for the various blendstock options
- Develop tools that allow us to do the work faster and more efficiently
- Identify options that provide “wins” for broad range of stakeholders

Governing Hypotheses

Central Engine Hypothesis

There are engine architectures and strategies that provide higher thermodynamic efficiencies than are available from modern internal combustion engines; new fuels are required to maximize efficiency and operability across a wide speed / load range

Central Fuel Hypothesis

If we identify target values for the critical fuel properties that maximize efficiency and emissions performance for a given engine architecture, then fuels that have properties with those values (regardless of chemical composition) will provide comparable performance

Main elements of approach

- Identify key fuel properties that impact efficiency for advanced SI and CI combustion approaches
  - Utilize “efficiency merit function” to identify most important property impacts
  - Utilize final validated merit function as technical basis for fuel property specification
- Apply tiered approach to identify blendstock options that provide key fuel properties
  - Identify barriers to widespread commercial introduction
  - Focus on options with viable routes to near-term commercial use (petroleum- or bio-based)
  - Identify blendstocks that provide value when produced from biomass
- Identify ways to co-optimize, i.e., identify options that provide “wins” for broad range of stakeholders