Improving Ethanol-Gasoline Blends by Addition of Higher Alcohols

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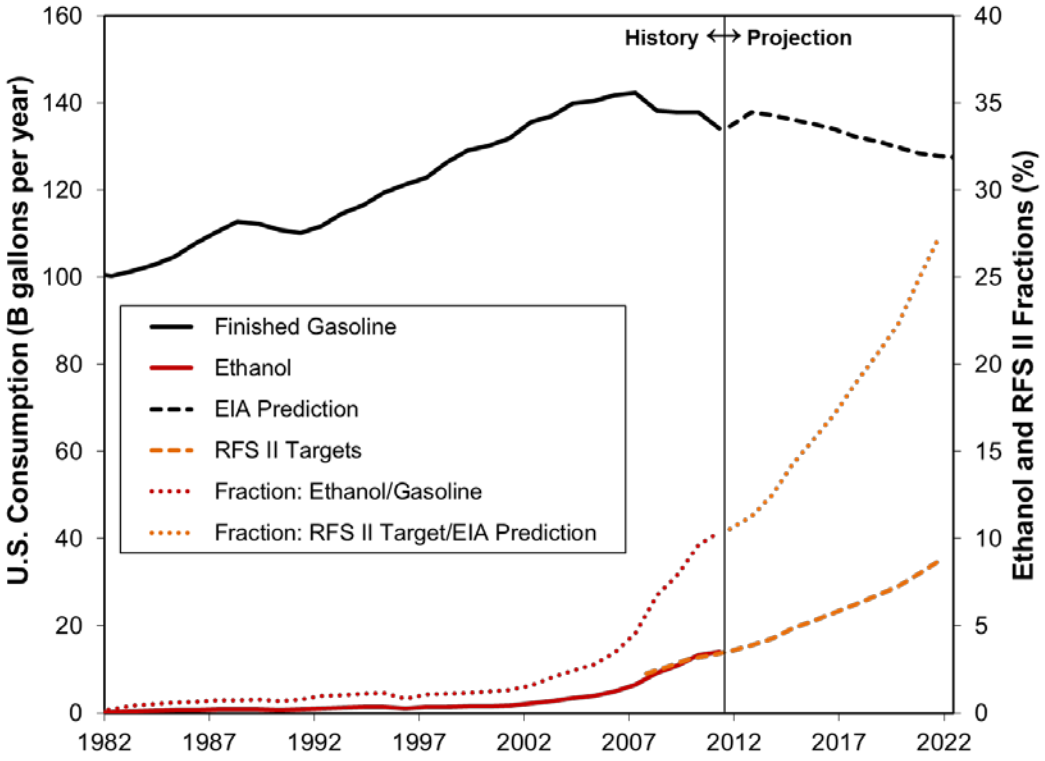
Introduction and Motivation



2022 Scenario

RFS II renewables: 35 B gal.[1,2]

Predicted U.S. gasoline consumption[3]:

- 130 B gal. (reference case)[4]
- 120-145 B gal. (high/low oil price)[4]

24-29% renewable fraction in 2022

[1]Ethanol equivalent gallons

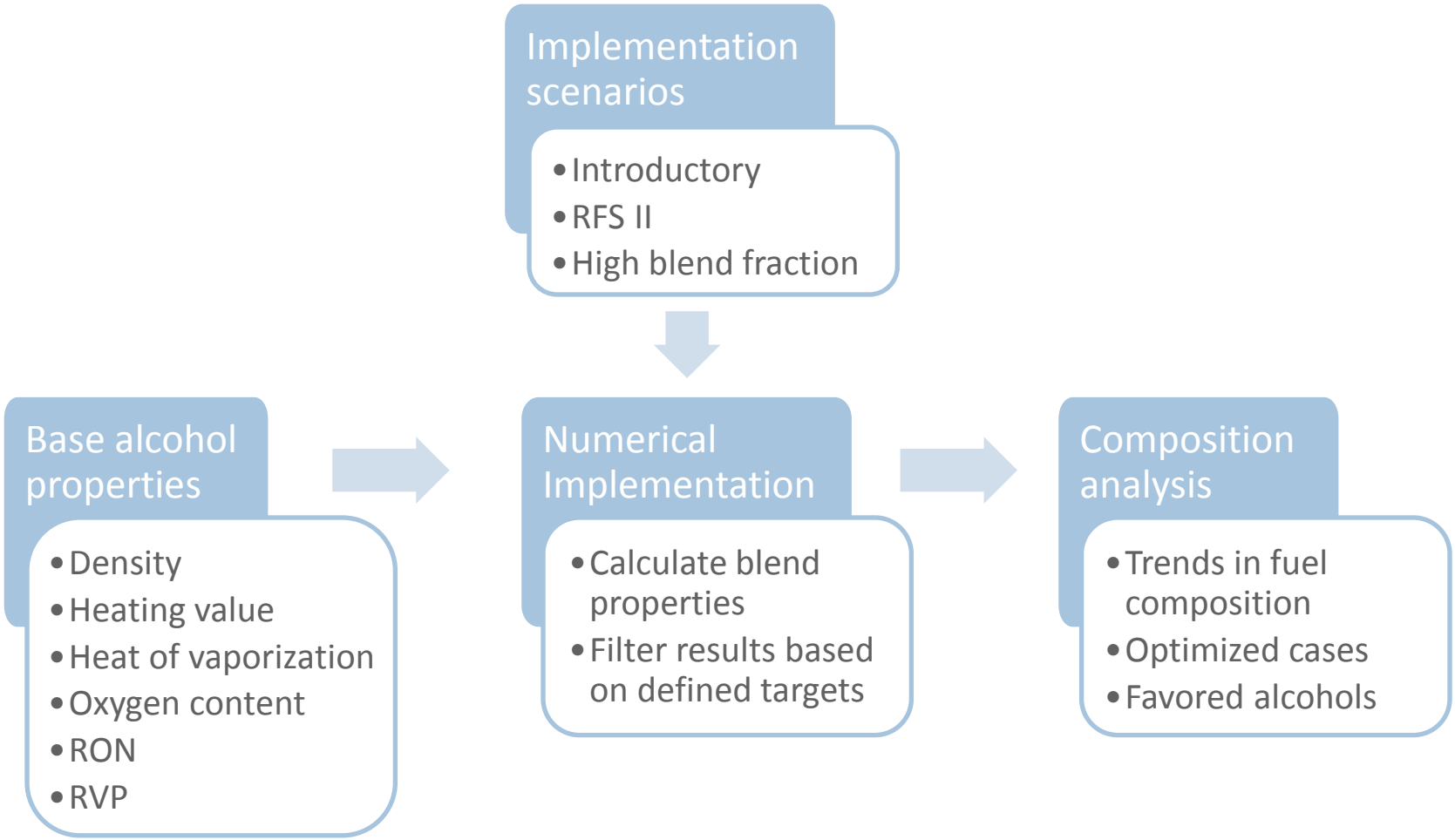
[2]RFS II total renewables of 36 B gal. (1 B gal. biodiesel)

[3]Motor gasoline + energy corrected E85

[4]*Annual Energy Outlook 2012* (U.S. EIA)

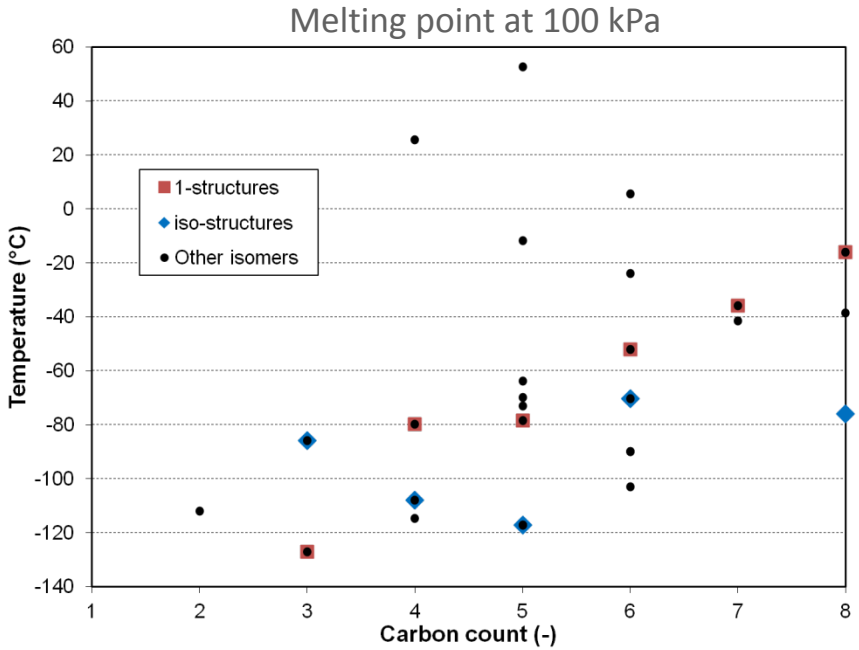
Can mixtures of ethanol, gasoline, and higher alcohols offer superior performance to ethanol/gasoline blends and be a fuel option to satisfy RFS II ?

Evaluation Process



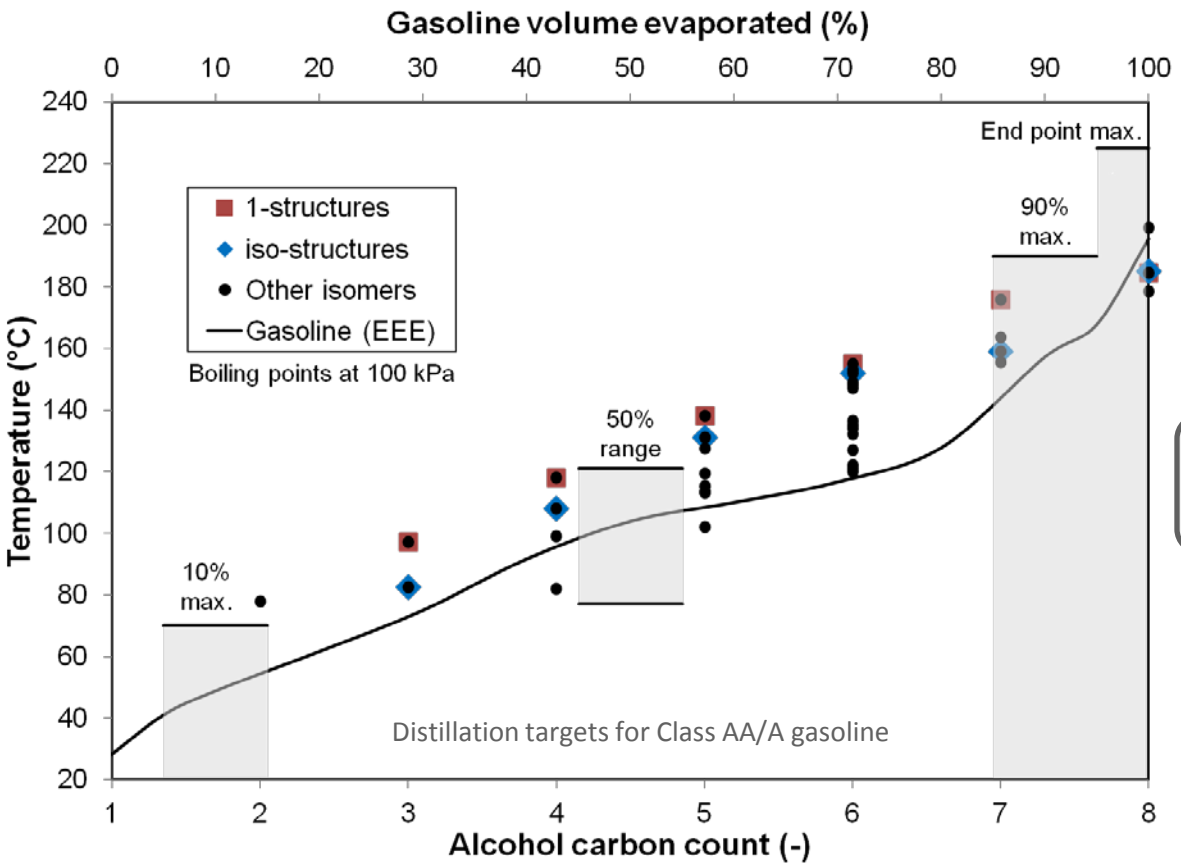
Higher Alcohols: Practical Considerations

- Isomer availability
- Production pathways
  - RFS II requirements for renewables
- Fuel handling
  - Melting point (liquid at ambient)
  - Peroxide formation tendency
  - Toxicity
- Fuel Properties
  - Boiling point / fuel distillation
  - Vapor pressure (RVP)
  - Octane number
  - Energy content



- Methanol not considered in blends
- Focus on C_3-C_8 alcohols

Higher Alcohols: Boiling Point



Drivability Index (DI)

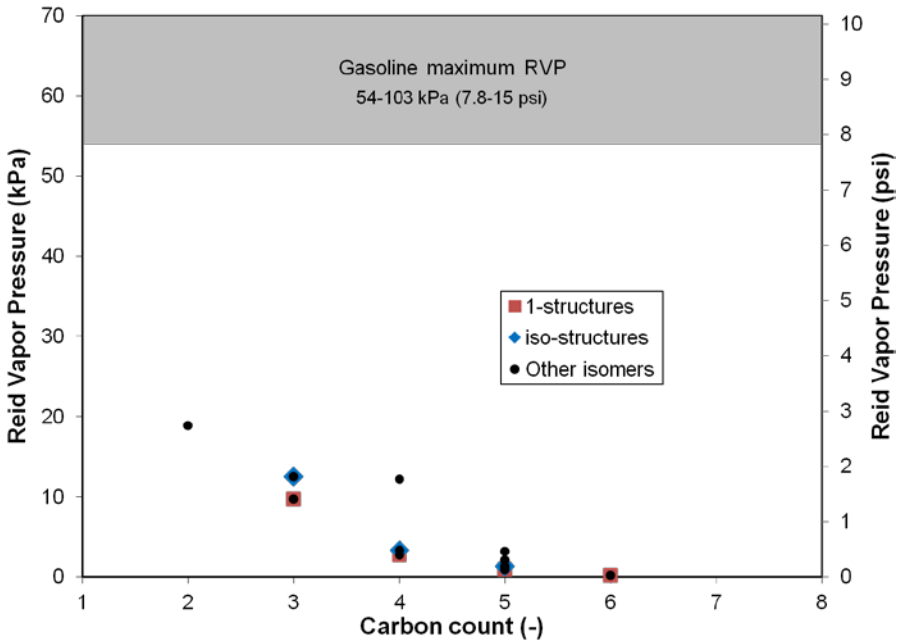
$$DI\ (°C) = 1.5T_{10}+3T_{50}+T_{90}+1.33[EtOH\%]$$

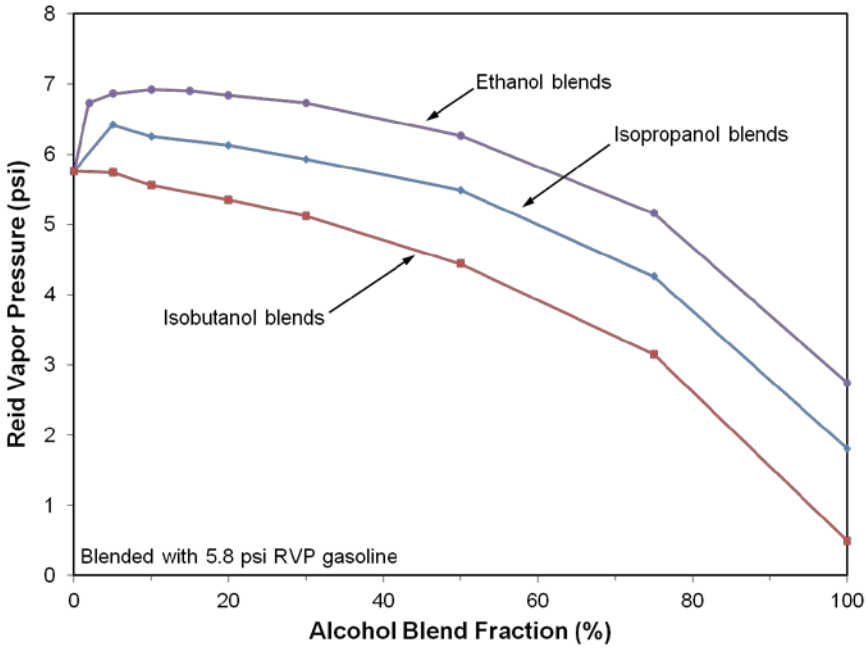
Maximum DI[1]: 569-597 °C

Blending considerations: ASTM distillation limits and Drivability Index

[1]ASTM D4814, Class E-AA gasoline

Higher Alcohols: Vapor Pressure

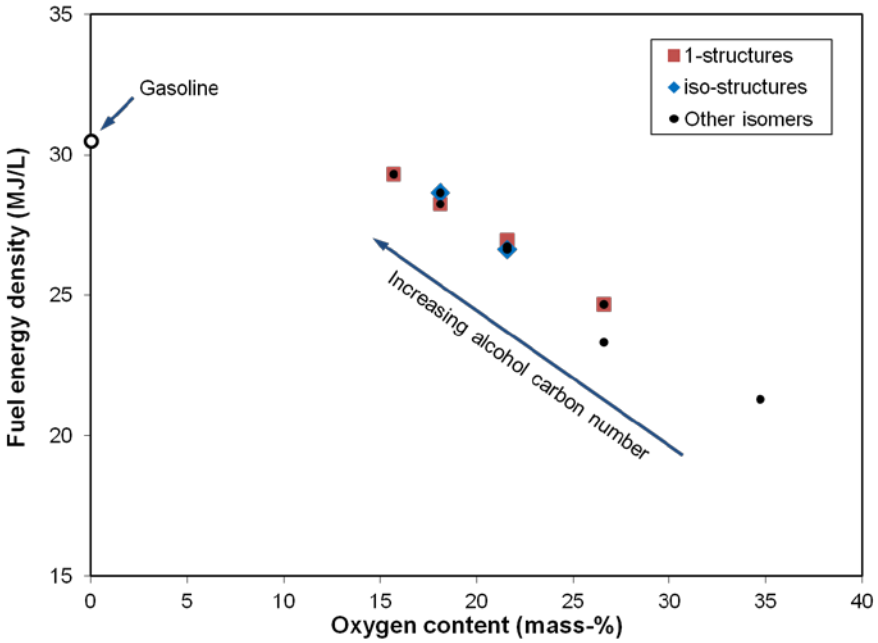


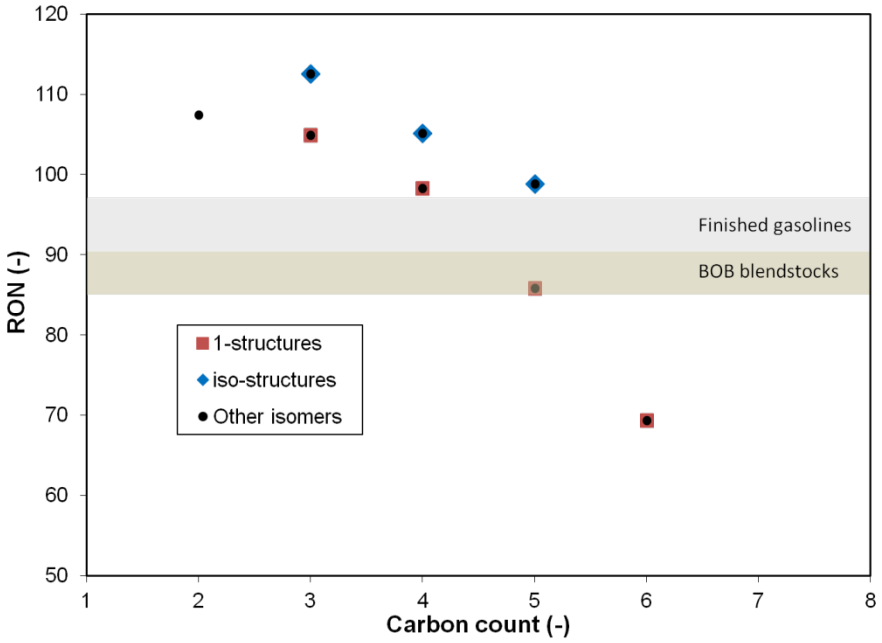


Neat alcohols have low RVP, but exhibit azeotropic behavior with gasoline

- High RVP at low alcohol fractions
- Low RVP at high alcohol fractions

Higher Alcohols: Energy Density & Knock Resistance





Energy density - knock resistance tradeoff with alcohol carbon number

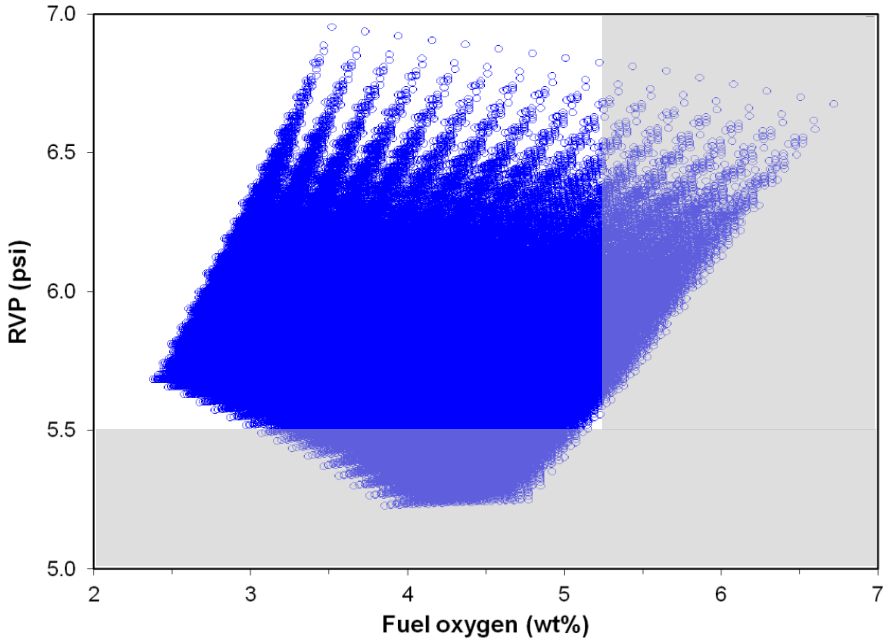
- Energy density of C_2-C_6 alcohols less than that of gasoline
- Octane number of iso- structures higher than n- structures

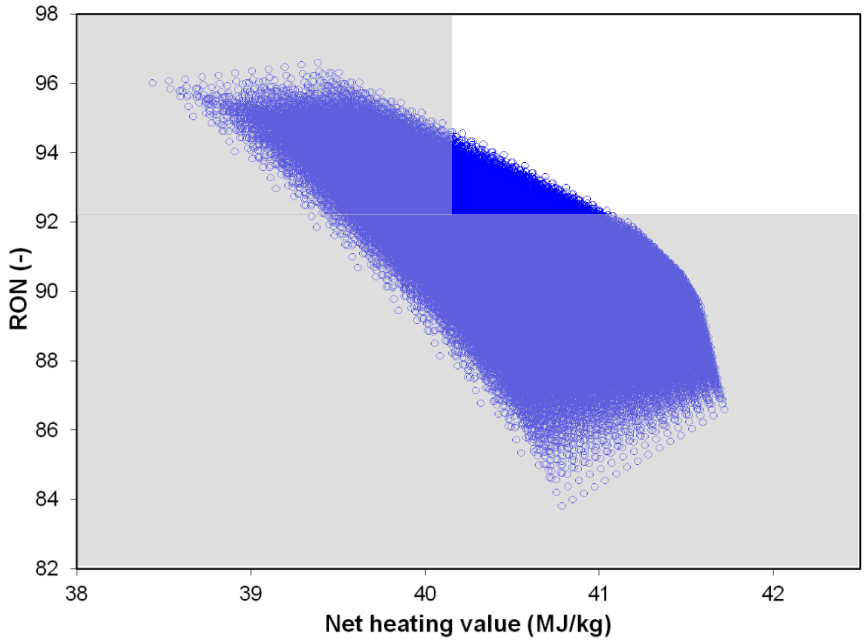
Fuel Implementation Scenarios

	E10/E15 Alternate	RFS II Fuel	E85
Ethanol Equiv. Content (min.)	E10	E25[1]	E74[2]
Alcohol Fraction	10-25% (typ.)	10-49% (typ.)	>50%[3]
RVP	< 7.8 psi[4] > 5.5 psi[5]	< 7.8 psi[4] > 5.5 psi[5]	< 8.5 psi[5] > 5.5 psi[5]
RON[6] (min.)	92.2 (E10)	92.2 (E10)	100
LHV[6] (min.)	40.2 MJ/kg (E15)	38.5 MJ/kg (E25)	29.7 MJ/kg (E74[2])
Oxygen (max.)	5.25 wt% (E15)	-	-
Blendstock	BOB (5.8 psi RVP, 89 RON, 42.8 MJ/kg LHV)		
Alcohols	Ethanol, normal (C_3-C_6) and iso (C_3-C_5) structures		

[1]2022 RFS II target yields approx. 25% ethanol-equiv. renewables
[2]Annual average ethanol content of E85 is 74% (U.S. EIA)
[3]From D5798 minimum ethanol content for E85
[4]Maximum RVP for D4814 Distillation Class AA gasoline
[5]RVP limits for D5798 Class 1 E85
[6]Calculated from BOB blendstock and ethanol

E10/E15 Fuel: Sweep of alcohol combinations

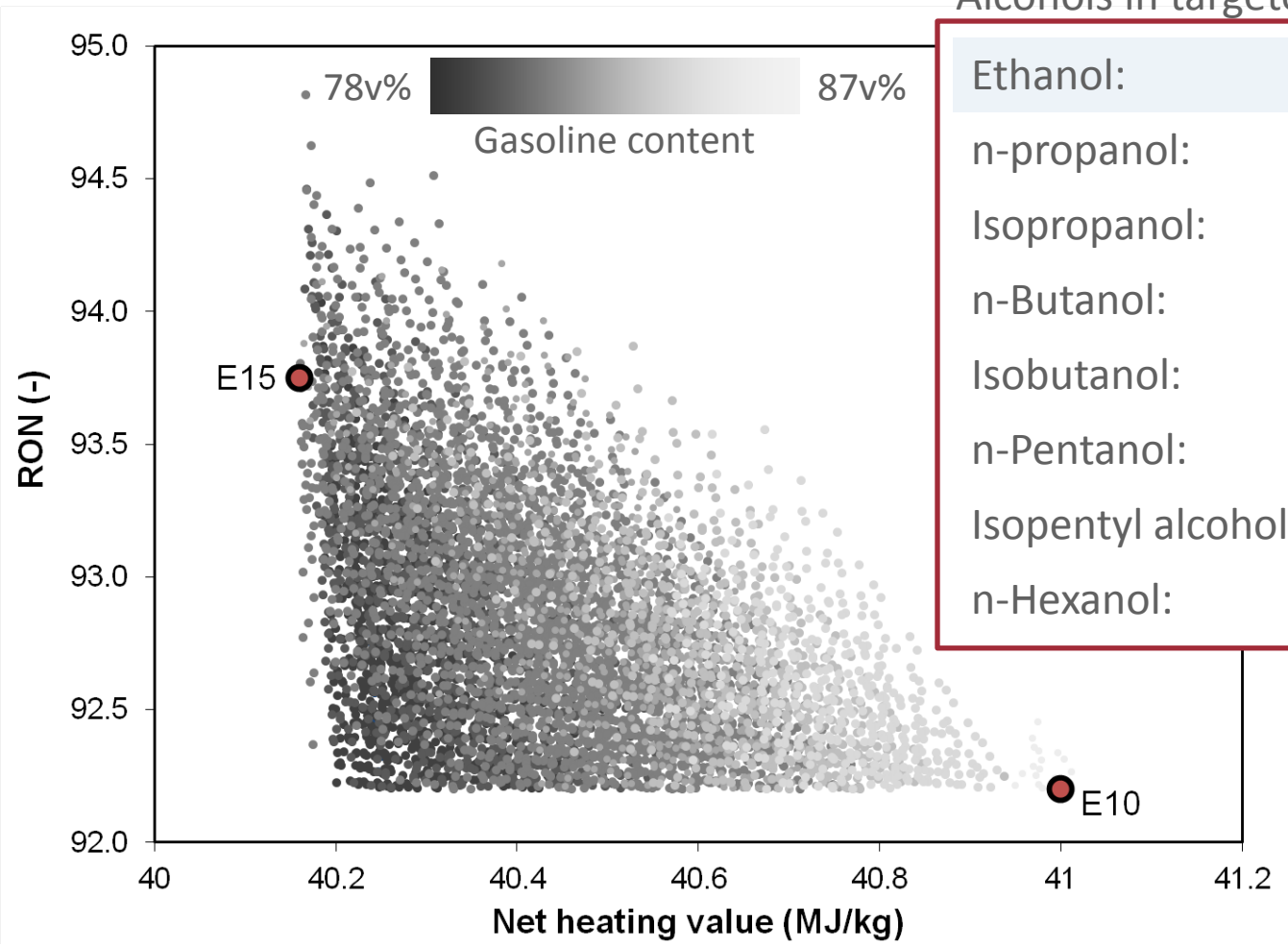




RVP > 5.5 psi (E85 min.)
$[O_2]_{fuel}$ < 5.25 wt% (E15)

RON > 92.2 (E10)
LHV > 40.2 MJ/kg (E15)

E10/E15 Fuel: Targeted Conditions

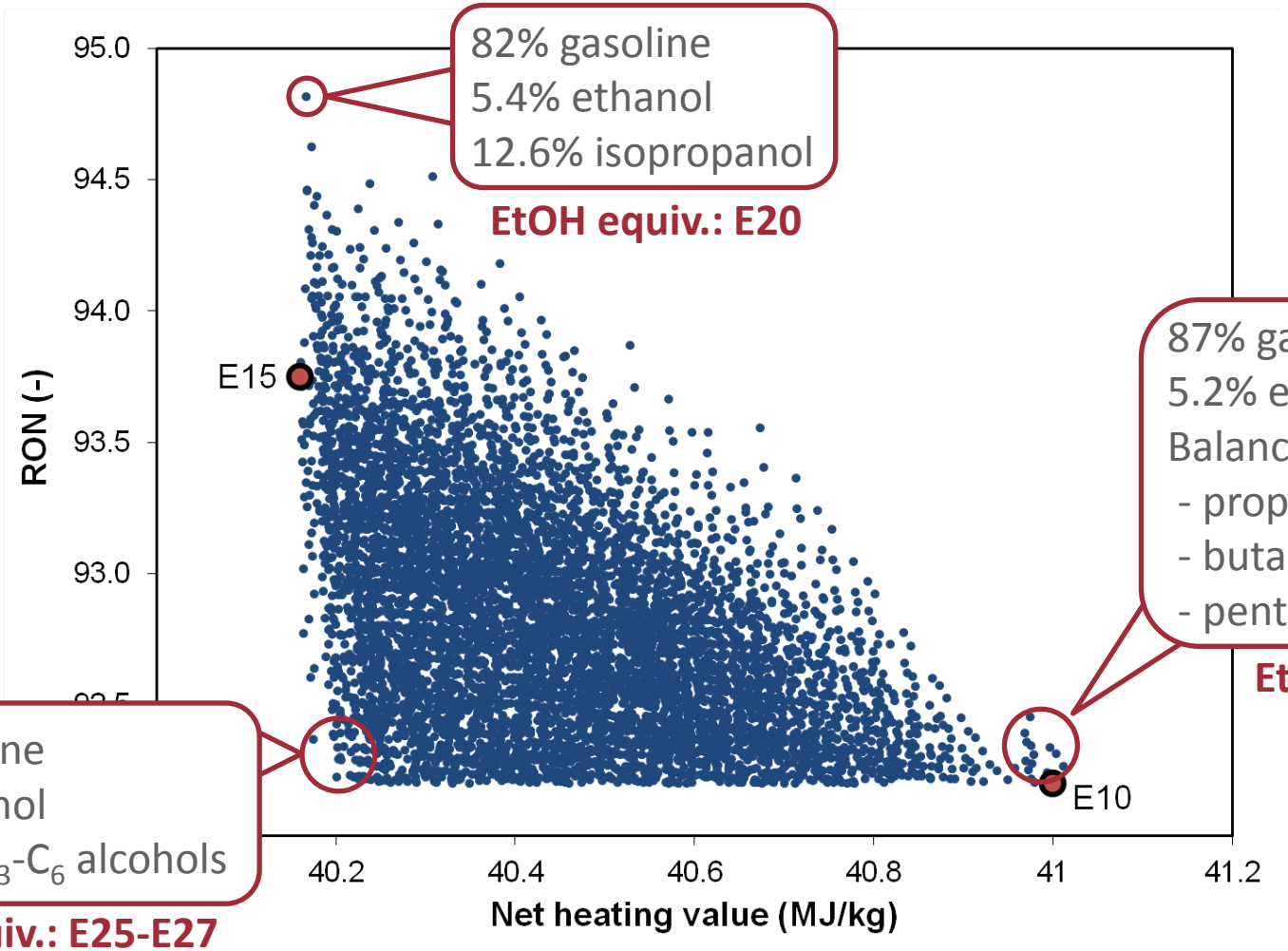


Alcohols in targeted blends:

Ethanol:	5-13.6 v%
n-propanol:	0-12.6 v%
Isopropanol:	0-12.6 v%
n-Butanol:	0-14 v%
Isobutanol:	0-14 v%
n-Pentanol:	0-8.4 v%
Isopentyl alcohol:	0-14.7 v%
n-Hexanol:	0-6.3 v%

Blends include base gasoline, ethanol, and 1-6 other alcohols

E10/E15 Fuel: Targeted Conditions



Conclusions

- **Developed analytical framework for multi-component fuel blend assessment**
- **Demonstrated potential of higher alcohols in combination with gasoline/ethanol mixtures**
  - Potential for increased gasoline displacement
  - Composition variable based on desired blend properties
  - Small ethanol fraction increases RVP, allowing addition of higher alcohol while remaining within targeted RVP range
- **Further opportunities:**
  - Alcohol combinations based on production methods
  - Influence of gasoline blendstock and desired finished fuel
  - Integration of other fuel components

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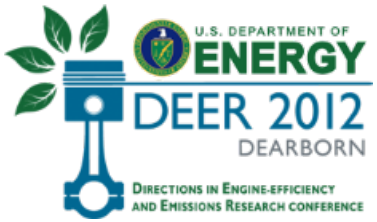

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