Ethanol and the Economics of Octane

The Superior Solution

ETHANOL SUMMIT
OF THE AMERICAS

Geoff Cooper
Renewable Fuels Association

October 20, 2017

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Today's Presentation

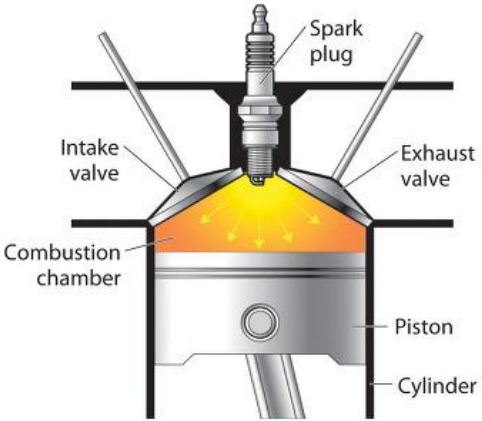
- What is octane and why is it important?
- Options for boosting octane in gasoline
- Ethanol's octane advantage
- The economics of octane

What is Octane?

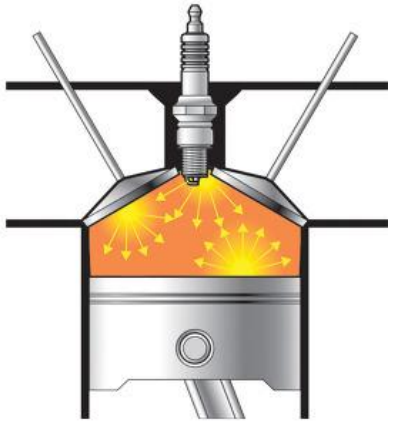
- Spark-ignition gasoline engines work by **compressing** an **air-fuel mixture** and then **igniting the mixture** (with a spark plug) at a **specific instant** during the cylinder's compression stroke.
- A fuel's **octane number** is the **standard measure** of its **ability to resist pre-ignition** (or **"knocking"**) in the cylinder of a gasoline engine.

Chevrolet LT4

Higher Octane = More Knock Resistance



Normal combustion



Premature combustion

- Pre-ignition occurs when there is too much pressure in the combustion chamber and the air/fuel mixture is incorrect.
- This causes uneven combustion and “knocking,” which can lead to poor performance and engine damage.
- The higher the octane number, the more compression the fuel can tolerate without pre-igniting.
- Engines with high compression ratios require high octane gasoline.

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Measuring Octane

RON

- Research Octane Number
- Knock resistance at low-load operations (e.g., highway driving)
- Posted on pump in most of the world (e.g., Europe and Asia)

MON

- Motor Octane Number
- Knock resistance at high-load (e.g., acceleration, hauling)
- MON is always less than RON

AKI

- Anti Knock Index…also called (R+M)/2
- Equal to (RON + MON)/2
- Posted on the pump in North America

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Pure Component Octane Versus Blending Octane

- Pure component octane:
  - Anti-knock performance (RON or MON) of an individual, pure compound ***by itself***
- Blending octane:
  - Anti-knock performance (RON or MON) of a blending compound ***when it is a component of a gasoline blend***

U.S. Octane Standards for Finished Gasoline

Octane standards in the U.S. are set by individual states.

Gasoline Grade	AKI
Premium	91-93
Mid-grade	89
Regular	87

Note: Octane standards are about 2 AKI points lower in some states in the High Plains and Rocky Mountain region.

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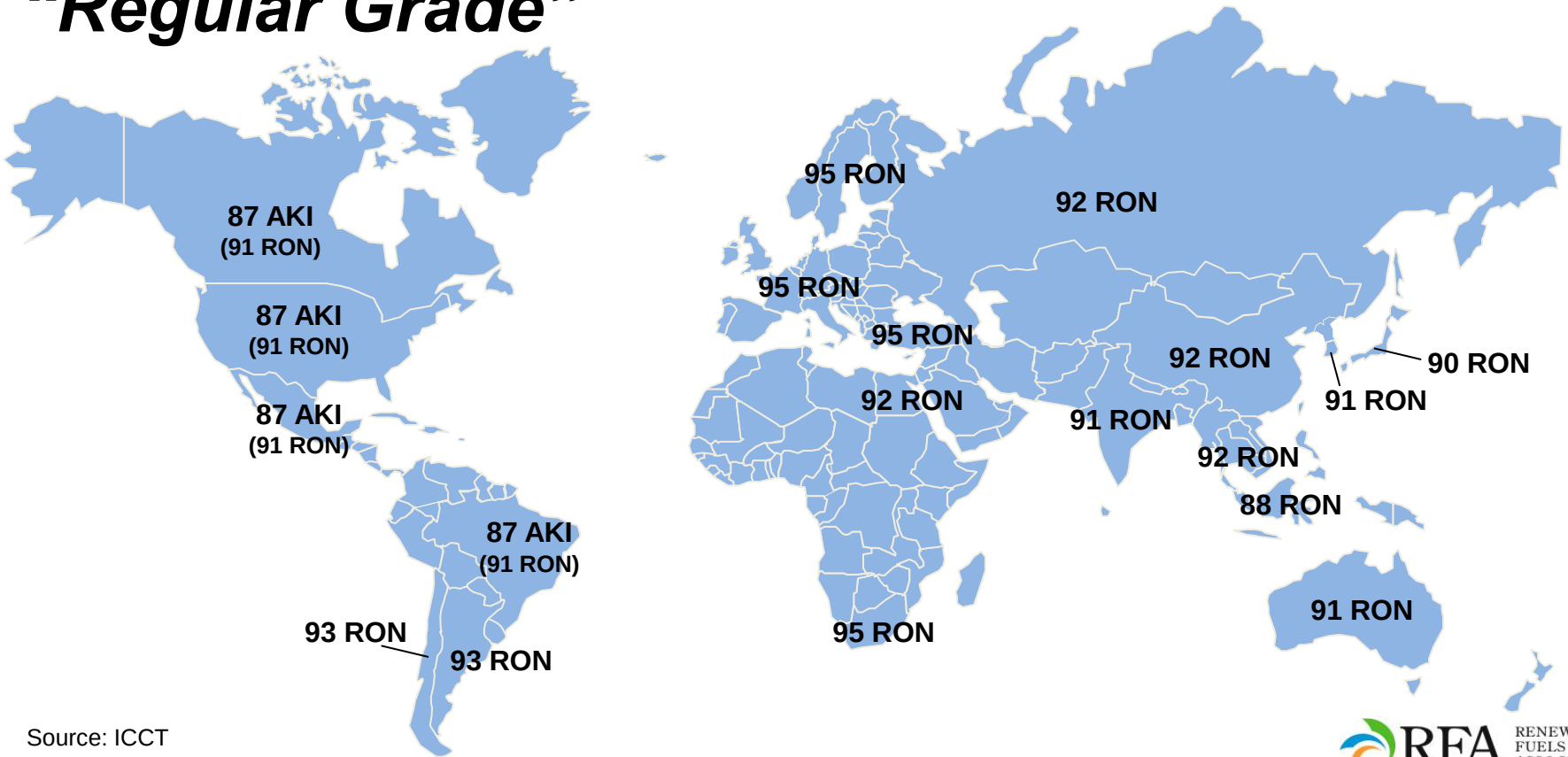
International Octane Standards

"Regular Grade"



Source: ICCT

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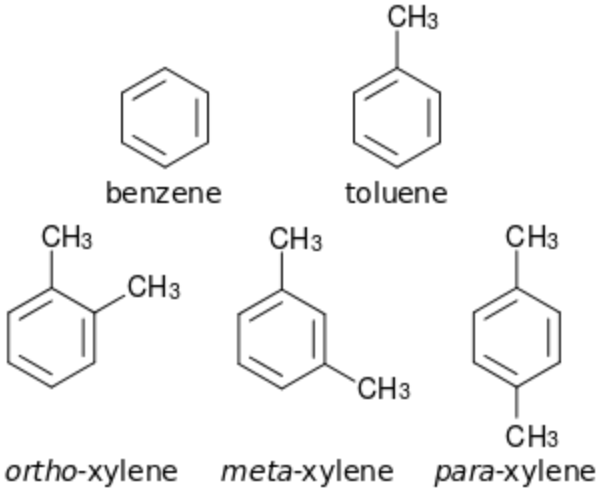
Octane and Gasoline Blending

- The “naturally occurring” octane in the crude oil fractions that become gasoline is far less than what engines need.
- Refiners “create” the additional required octane by:
  - Carrying out chemical processes that “upgrade” low-octane hydrocarbon molecules into high-octane molecules; and/or
  - Purchasing and blending high-octane blendstocks.
- Making octane in the refinery is costly and energy intensive.
- Refiners must balance octane needs with other specifications and properties.
  - e.g., volatility, sulfur content, benzene content

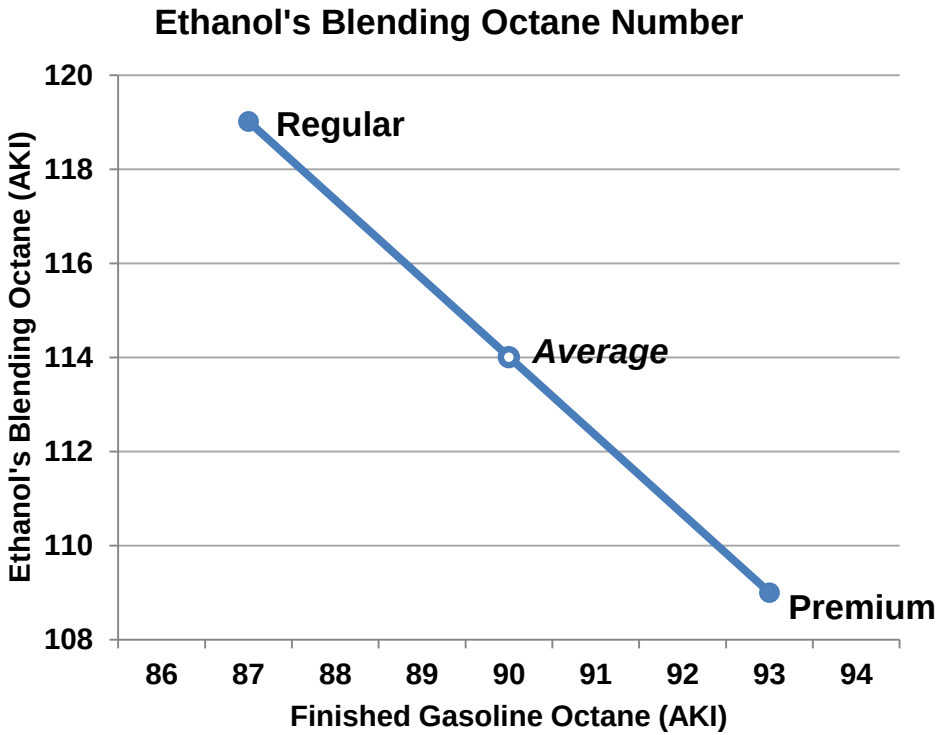
Key Hydrocarbon Refining Octane Sources

- **Alkylate**
  - Blending octane = 93-95 AKI
  - Low volatility, no sulfur, no benzene
- **Reformate**
  - Blending octane = 87-100 AKI
  - Low volatility, some sulfur, contains benzene
- **Aromatics** (Benzene, Toluene, Xylene)
  - Blending octane = 94-107 AKI
  - Upgraded from reformate
- **Butane**
  - Blending octane 92-94 AKI
  - Very high volatility



Source: MathPro, Inc.

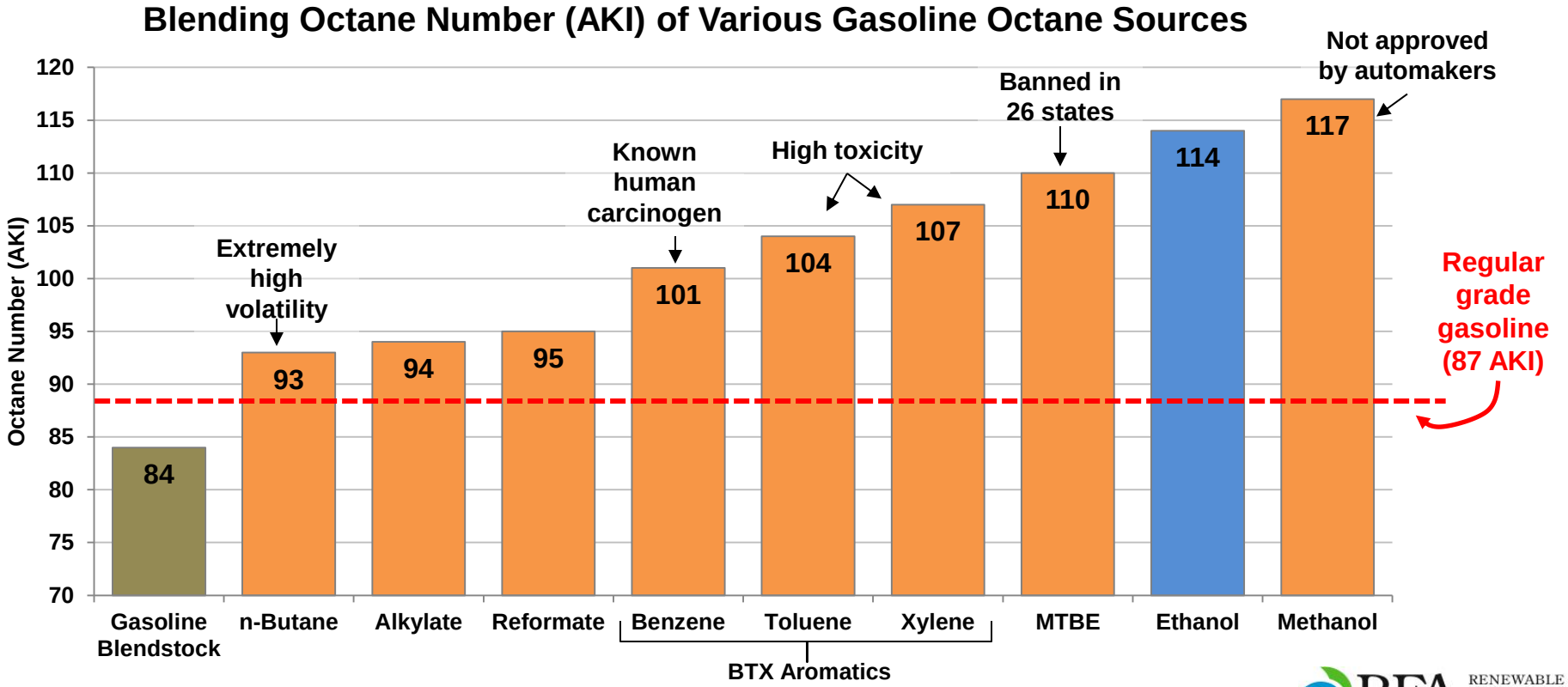
Ethanol's Octane Advantage



- Ethanol's pure component octane number is **100 AKI**.
- But it's blending octane number is **109-119 AKI**, depending on the octane of the finished fuel.
- Ethanol's blending octane number is highest when used with lower-octane hydrocarbon blendstock.

Source: MathPro, Inc.

Ethanol's Octane Advantage



Source: RFA; DOE; MathPro, Inc.

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Ethanol Blending in the Past

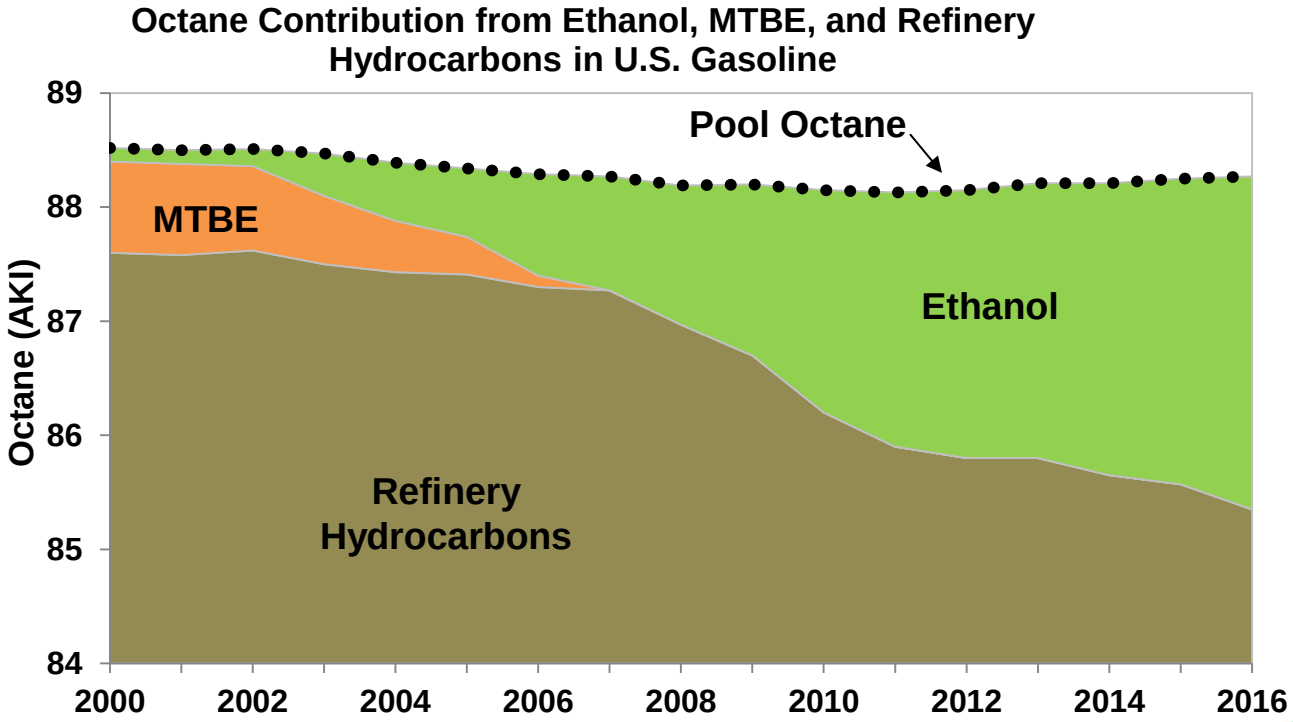
- Prior to circa 2002, ethanol was used mainly as a **volume extender** not as an **octane enhancer.**
  - Refiners did not assume gasoline would be blended with ethanol downstream.
  - Gasoline (E0) leaving the refinery already met state octane specifications.
  - Ethanol was “splash-blended” far downstream of refinery in some locations (mostly Midwest).
  - Result of “splash-blending” was gasoline with more octane than required to meet specifications for “regular grade.”

Ethanol Blending Today

- Regulations and policies significantly expanded the use of ethanol in 2002-2010 timeframe.
  - Winter oxygenated gasoline; Reformulated gasoline; State MTBE bans; RFS
- By 2010, most gasoline in the U.S. blended with 10% ethanol.
- Thus, refiners reconfigured operations to capture ethanol's octane benefit and avoid octane "give-away."
  - Began widespread production of sub-octane gasoline Blendstocks for Oxygenate Blending (BOBs) designed for blending with 10% ethanol
  - BOB + Oxygenate = Finished Fuel

	Blending Octane (AKI)	Share of Blend	Octane (AKI)
Regular grade BOB	84	90%	75.5
Ethanol	117	10%	11.7
Finished E10			**87.2**

Ethanol has rapidly emerged as a significant source of octane in U.S. gasoline



Source: MathPro, Inc.

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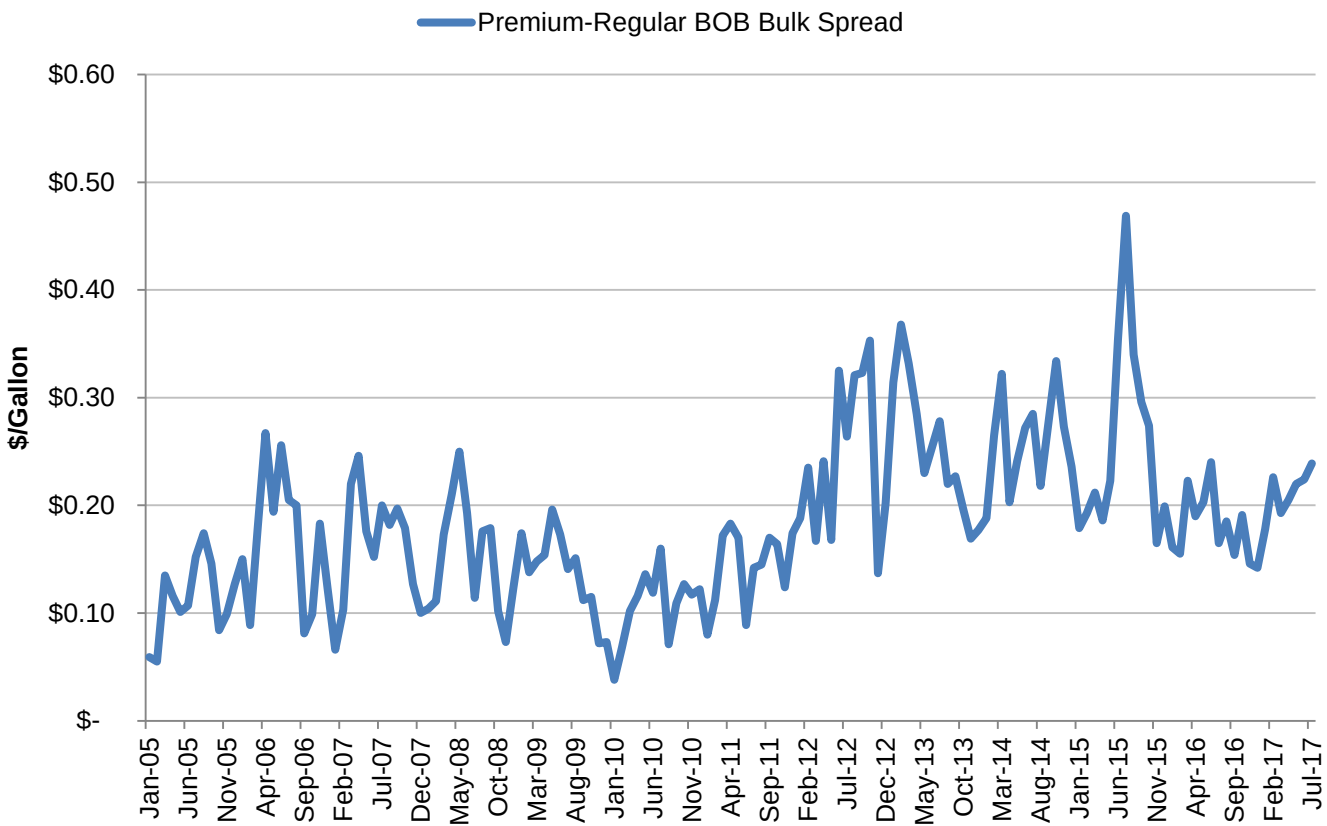
The Economics of Octane

- **What is the economic value of octane?**
  - A common measure used in the U.S. is the “Premium-Regular Bulk Spread”
  - Difference between bulk spot prices for premium (90 AKI) and regular grade (84 AKI) gasoline BOBs
    - (PRM – REG)/6 pts AKI = value per AKI point of octane
  - Considered by refiners to represent the market value of octane
  - Good indicator of refining cost to produce incremental octane

Premium-Regular Price Spread



Annual Averages (Bulk)

	Spread ($/Gal.)	PRM % Increase over REG
2005	0.11	7%
2006	0.17	9%
2007	0.16	8%
2008	0.15	6%
2009	0.14	9%
2010	0.11	5%
2011	0.14	5%
2012	0.24	9%
2013	0.25	9%
2014	0.26	10%
2015	0.26	16%
2016	0.18	13%
2017	0.21	14%

Source: EIA

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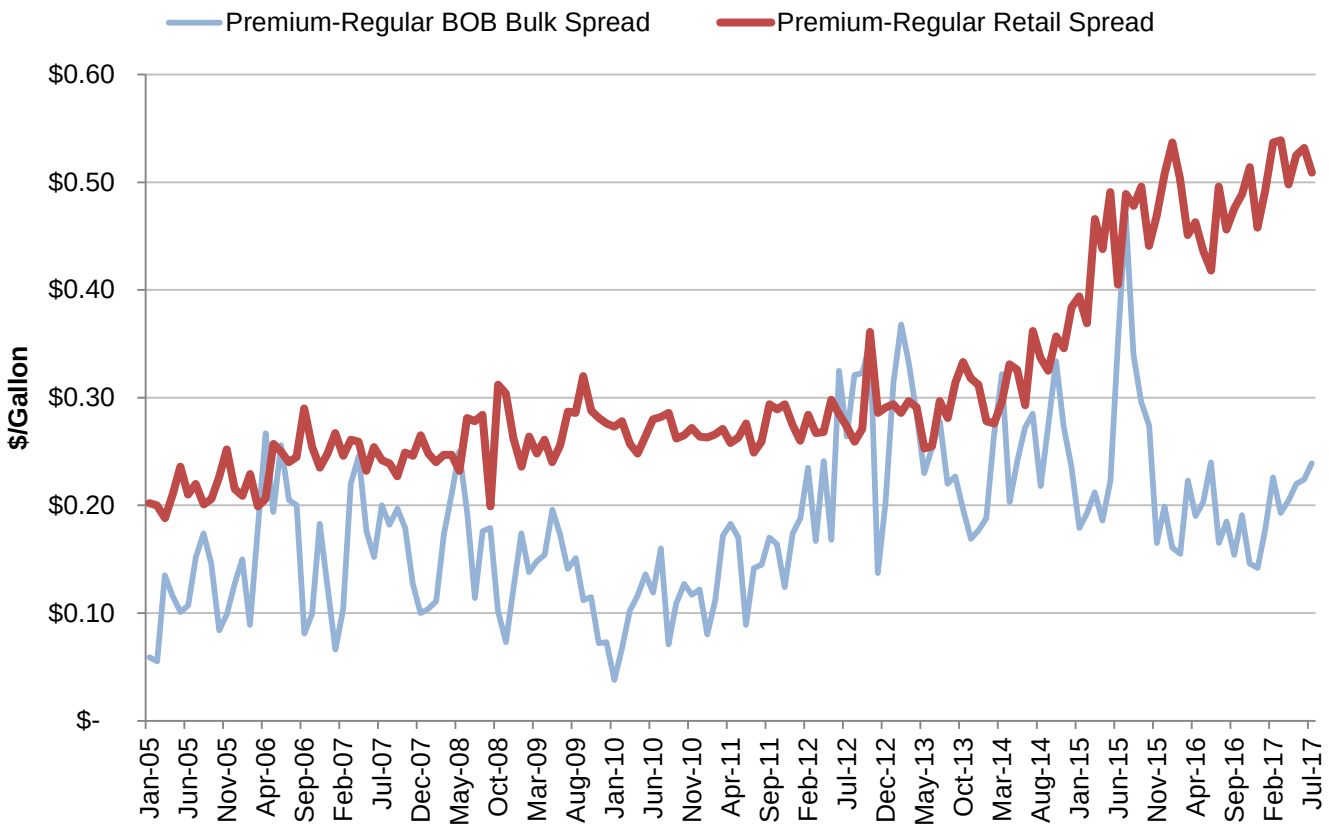
Premium-Regular Price Spread



Annual Averages (Retail)

	Spread ($/Gal.)	PRM % Increase over REG
2005	0.21	12%
2006	0.24	12%
2007	0.25	11%
2008	0.26	11%
2009	0.27	15%
2010	0.27	12%
2011	0.27	9%
2012	0.28	9%
2013	0.29	10%
2014	0.33	12%
2015	0.45	24%
2016	0.47	29%
2017	0.52	28%

Source: EIA

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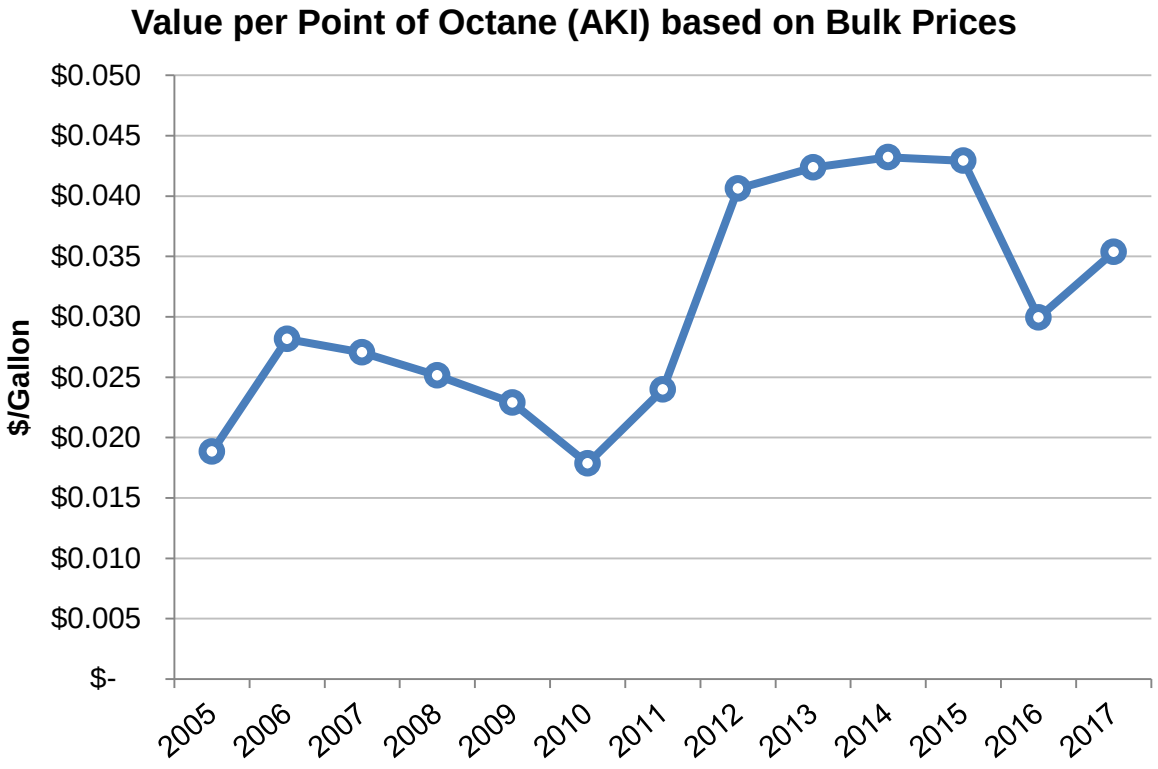
Value of Incremental Octane



- Based on current Premium–Regular BOB bulk spread, each point of incremental octane (AKI) is worth **3.5 cents per gallon** to the refiner
- Ethanol's current theoretical octane value is **$1.05/gallon** over 84 AKI BOB price!
  - (114 – 84) x 3.5 cpg

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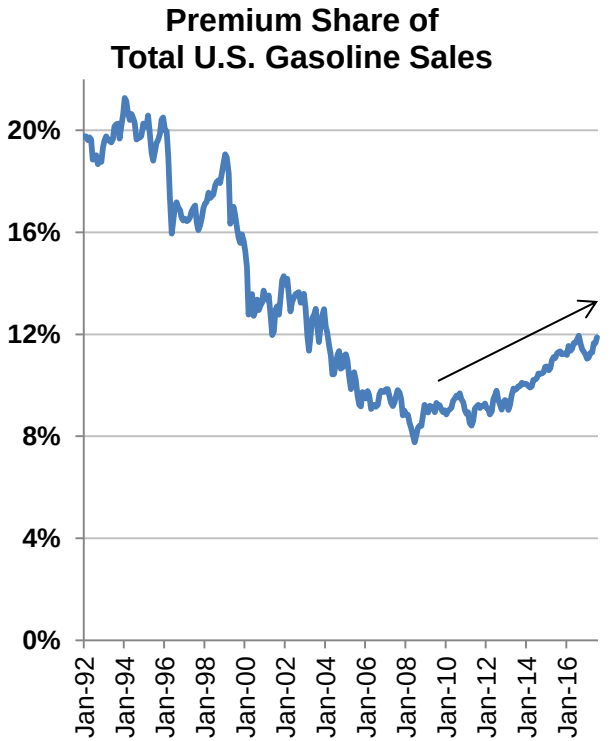
Why is the Value of Octane Increasing?

Constrained Supply

- Increased volume of light tight oil (LTO) and condensate
  - Produces lower quality gasoline blendstock (more low-octane naptha)
- Octane loss from tighter sulfur standards
- Refining industry slow to add octane-producing capacity

Increased Demand

- Higher domestic demand for *all* gas grades
- Demand for premium is rising (as share of total)
  - Higher compression and turbo charging
- Increased export demand for gasoline and high-octane blendstocks



Source: EIA, MathPro, Inc.

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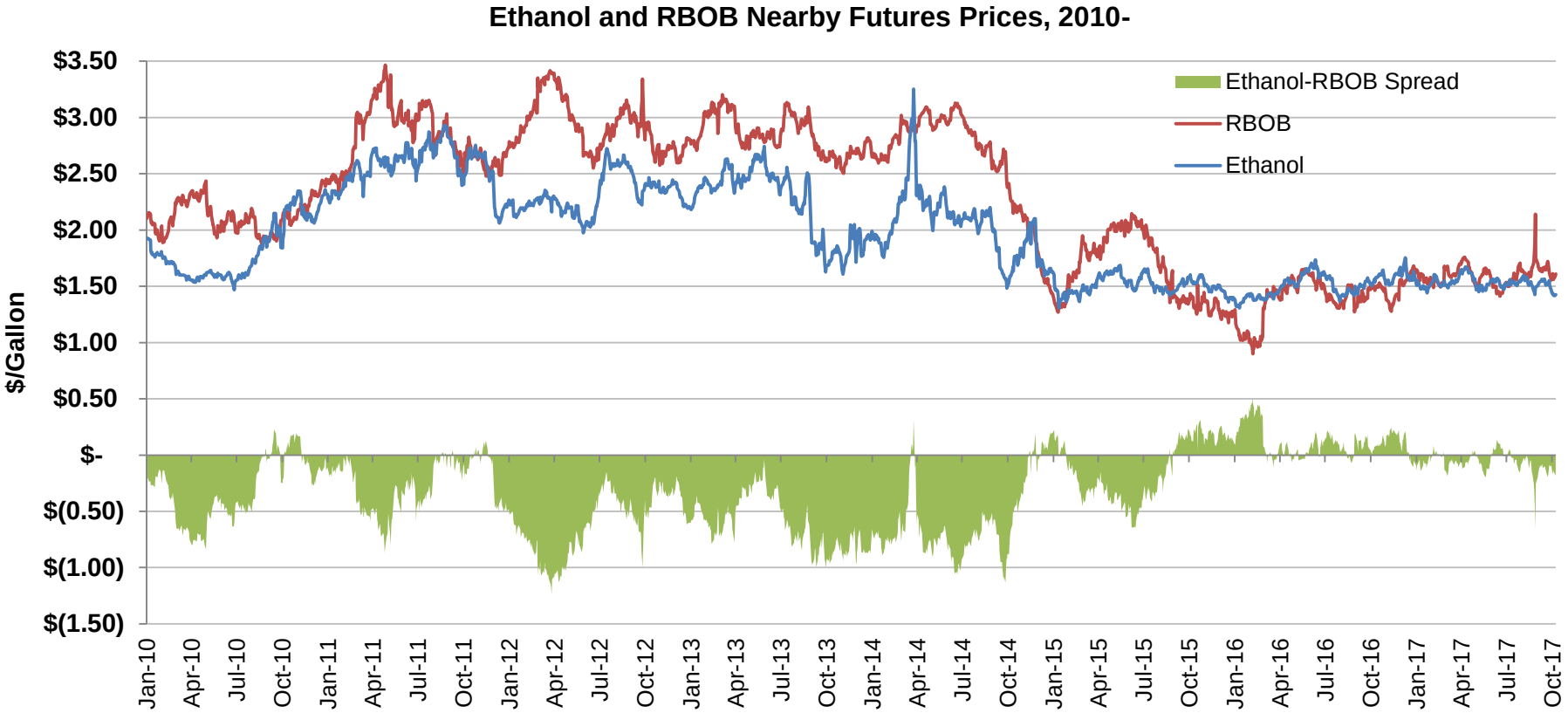
Ethanol Consistently Priced Below RBOB Gasoline



Source: CME

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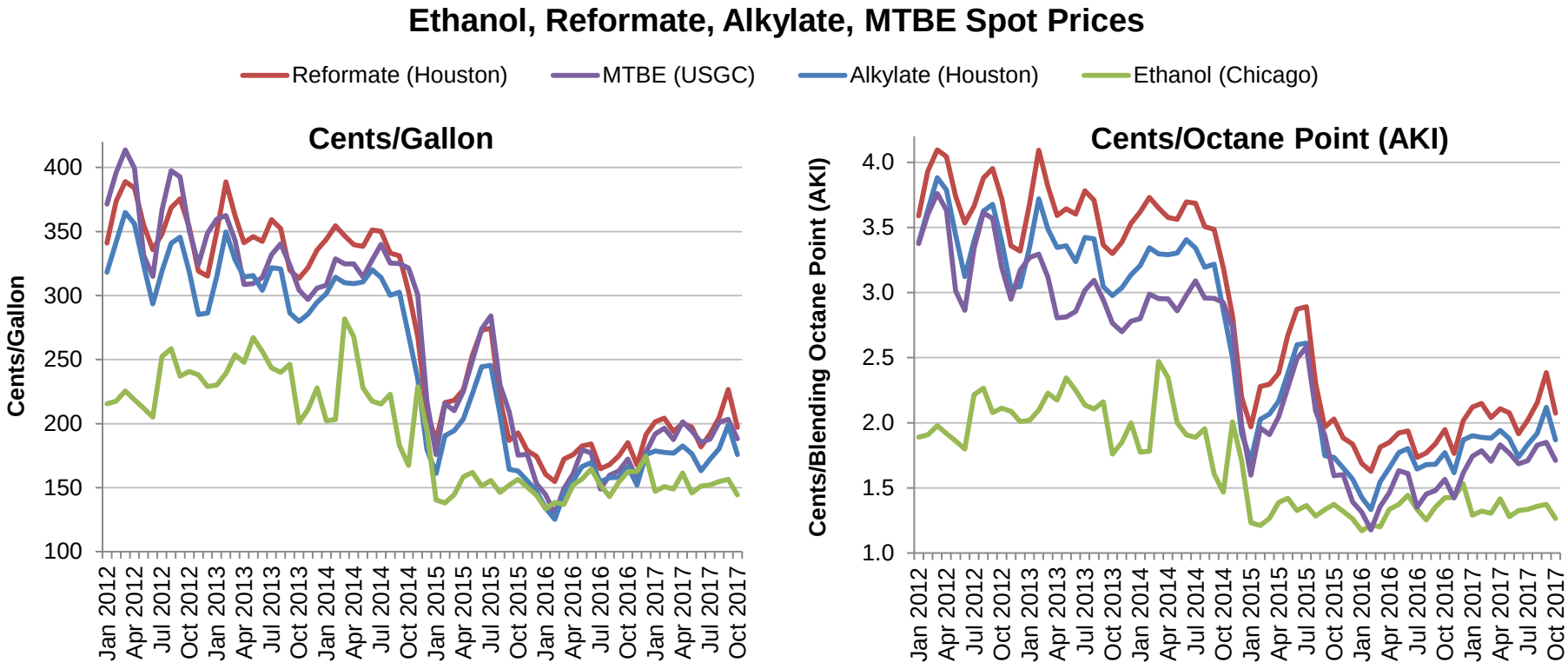
Ethanol Priced Far Below Other Octane Sources



Source: Argus

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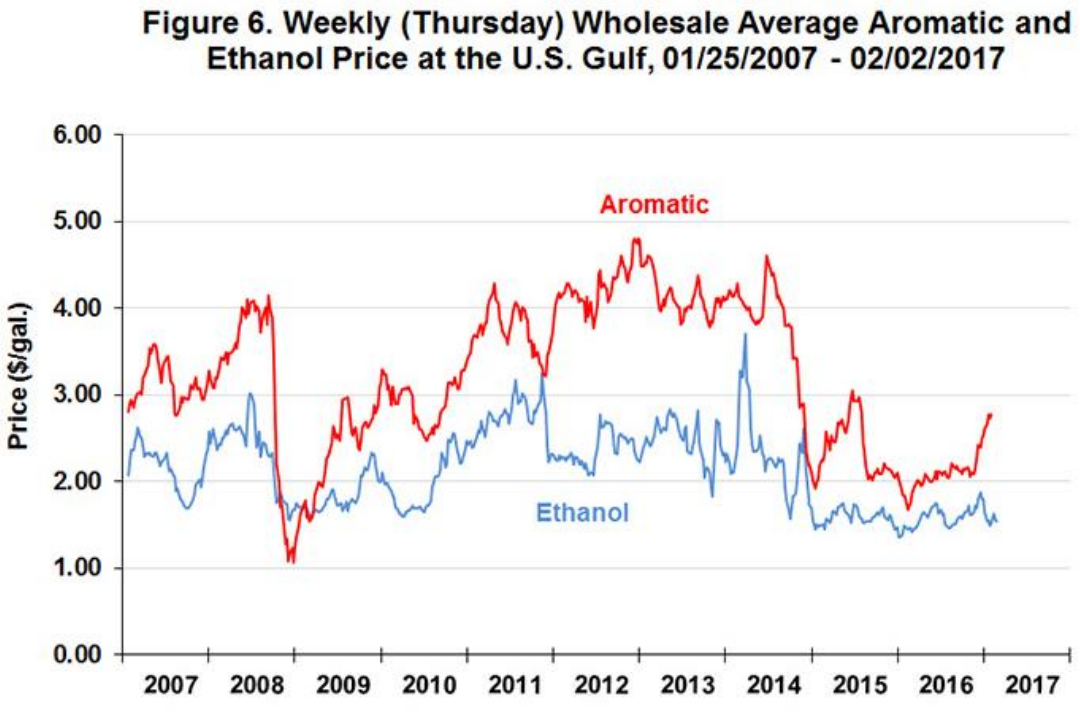
Ethanol Priced Far Below Other Octane Sources



- University of Illinois analysis compares ethanol prices to an average price for the BTX aromatics from 2007-2017.
- “Over the entire period, the price premium of the aromatics relative to ethanol averaged $1.06 per gallon.”

Source: Irwin, S., and D. Good. "On the Value of Ethanol in the Gasoline Blend." *farmdoc daily* (7):48, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, March 15, 2017.

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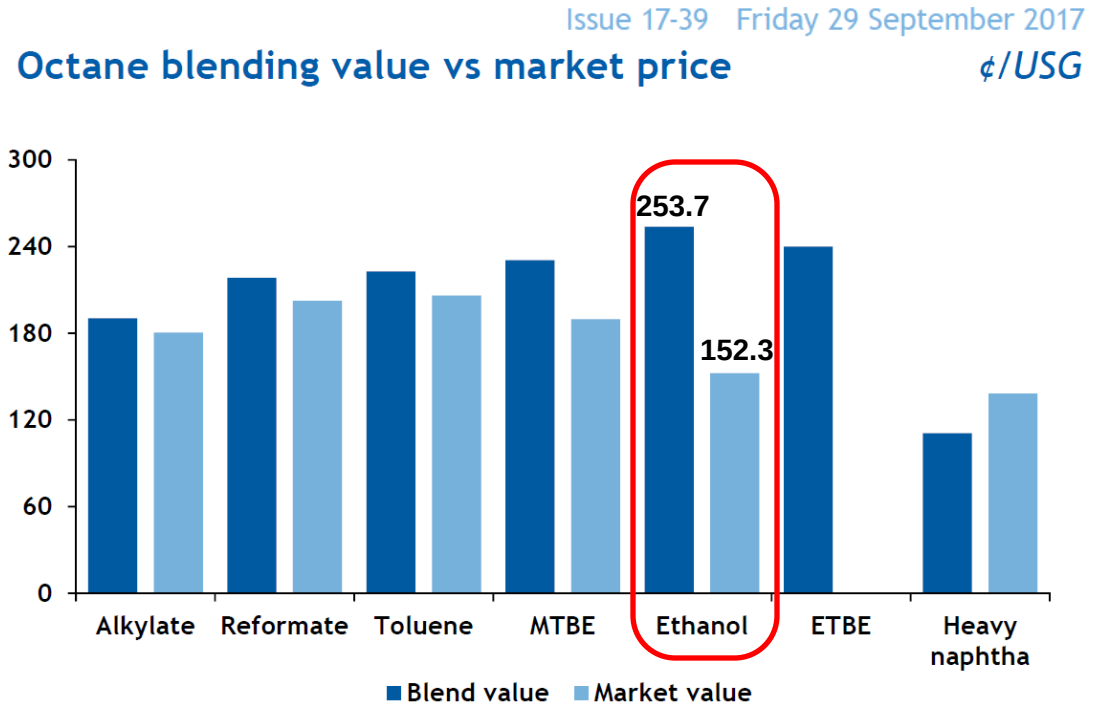
Ethanol Priced Far Below Other Octane Sources

- Argus reports weekly market prices and a calculated **“octane blending value”** for various octane sources.
- In addition to octane number, the “octane blending value” formula takes into account energy density, RVP, and other important blending factors.



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Proof of the Ethanol Advantage

- QuikTrip station in Kansas on April 7, 2017
- 87 AKI ethanol-free gasoline priced **20% above** 87 AKI E10 and just **1.5% below** 91 AKI premium E10!

- Buc-ee's station in Texas on June 27, 2017
- 87 AKI ethanol-free gasoline priced **53% above** 87 AKI E10 and **22% above** 93 AKI premium E10!

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Summary

- Octane is a critical consideration for efficient operation of spark-ignition engines
- Refiners can meet octane standards by “creating” octane at the refinery or purchasing octane boosters from other sources
  - Producing octane at the refinery is costly and energy intensive
- Demand for octane is increasing globally; supply is tightening
- **Ethanol is a superior octane booster due to its:**
  - Extremely high RON and blending octane numbers;
  - Economic competitiveness; and
  - Benign effects on the environment and human health