Ethanol and the Economics of Octane

The Superior Solution

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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.
Higher Octane = More Knock Resistance

- 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.
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
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.

<table>
<thead>
<tr>
<th>Gasoline Grade</th>
<th>AKI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Premium</td>
<td>91-93</td>
</tr>
<tr>
<td>Mid-grade</td>
<td>89</td>
</tr>
<tr>
<td>Regular</td>
<td>87</td>
</tr>
</tbody>
</table>

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

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Ethinol’s Octane Advantage

Blending Octane Number (AKI) of Various Gasoline Octane Sources

<table>
<thead>
<tr>
<th>Octane Number (AKI)</th>
<th>Gasoline Blendstock</th>
<th>n-Butane</th>
<th>Alkylate</th>
<th>Reformate</th>
<th>Benzene</th>
<th>Toluene</th>
<th>Xylene</th>
<th>MTBE</th>
<th>Ethanol</th>
<th>Methanol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>84</td>
<td>93</td>
<td>94</td>
<td>95</td>
<td>101</td>
<td>104</td>
<td>107</td>
<td>110</td>
<td>114</td>
<td>117</td>
</tr>
</tbody>
</table>

- **Gasoline Blendstock**: 84
- **n-Butane**: 93
- **Alkylate**: 94
- **Reformate**: 95
- **Benzene**: 101
- **Toluene**: 104
- **Xylene**: 107
- **MTBE**: 110
- **Ethanol**: 114
- **Methanol**: 117

- **Regular grade gasoline (87 AKI)**
- **Banned in 26 states**
- **High toxicity**
- **Known human carcinogen**
- **Extremely high volatility**
- **Not approved by automakers**

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

<table>
<thead>
<tr>
<th></th>
<th>Blending Octane (AKI)</th>
<th>Share of Blend</th>
<th>Octane (AKI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular grade BOB</td>
<td>84</td>
<td>90%</td>
<td>75.5</td>
</tr>
<tr>
<td>Ethanol</td>
<td>117</td>
<td>10%</td>
<td>11.7</td>
</tr>
<tr>
<td>Finished E10</td>
<td></td>
<td></td>
<td>87.2</td>
</tr>
</tbody>
</table>
Ethanol has rapidly emerged as a significant source of octane in U.S. gasoline
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
### Annual Averages (Bulk)

<table>
<thead>
<tr>
<th>Year</th>
<th>Spread ($/Gal.)</th>
<th>PRM % Increase over REG</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>0.11</td>
<td>7%</td>
</tr>
<tr>
<td>2006</td>
<td>0.17</td>
<td>9%</td>
</tr>
<tr>
<td>2007</td>
<td>0.16</td>
<td>8%</td>
</tr>
<tr>
<td>2008</td>
<td>0.15</td>
<td>6%</td>
</tr>
<tr>
<td>2009</td>
<td>0.14</td>
<td>9%</td>
</tr>
<tr>
<td>2010</td>
<td>0.11</td>
<td>5%</td>
</tr>
<tr>
<td>2011</td>
<td>0.14</td>
<td>5%</td>
</tr>
<tr>
<td>2012</td>
<td>0.24</td>
<td>9%</td>
</tr>
<tr>
<td>2013</td>
<td>0.25</td>
<td>9%</td>
</tr>
<tr>
<td>2014</td>
<td>0.26</td>
<td>10%</td>
</tr>
<tr>
<td>2015</td>
<td>0.26</td>
<td>16%</td>
</tr>
<tr>
<td>2016</td>
<td>0.18</td>
<td>13%</td>
</tr>
<tr>
<td>2017</td>
<td>0.21</td>
<td>14%</td>
</tr>
</tbody>
</table>
### Premium-Regular Price Spread

#### Annual Averages (Retail)

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

Source: EIA
Value of Incremental Octane

Value per Point of Octane (AKI) based on Bulk Prices

- 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!
  
  \[(114 – 84) \times 3.5 \text{ cpg}\]
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 and RBOB Nearby Futures Prices, 2010-

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.”

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.
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!
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