Octane and Refining

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Addressing strategic challenges with interconnected capabilities

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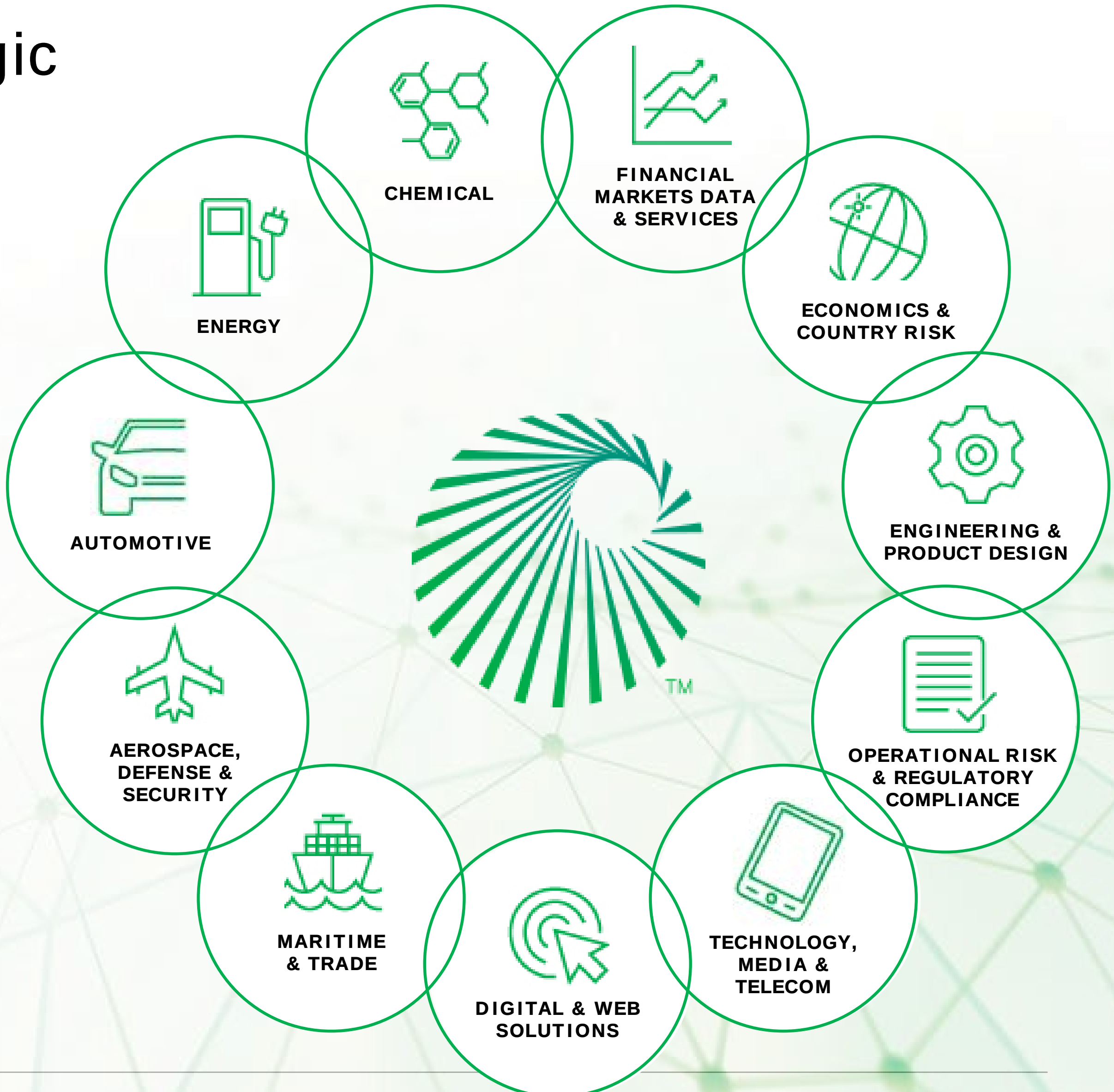


What's happening with octane?

- Octane links CAFE, RFS, and gasoline quality
  - Octane improvement could be important enabler of more efficient engines
  - Octane improvement could provide incentive for higher ethanol blends
  - Gasoline quality improvements put pressure on refinery-sourced octane
    - Tier III sulfur reduction
    - Possible future aromatics limits
- Automakers interested in harmonizing global gasoline quality
  - North America octane below Europe, but similar to Japan
  - Would global strategy converge on Euro grade 95 RON? Or higher?
- If octane increases, how would refiners respond?

What are gasoline and refined products?

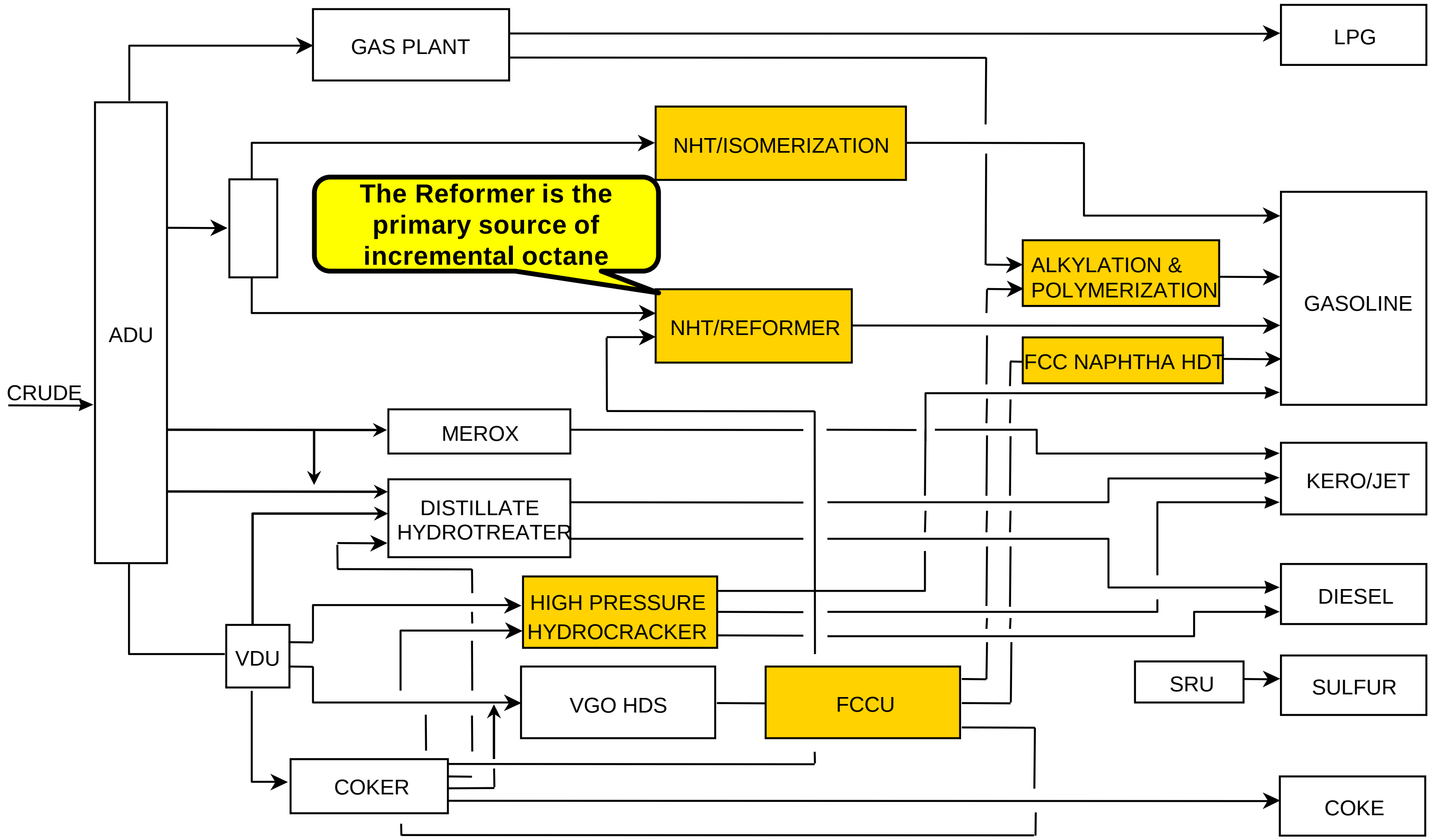
- Gasoline is a key refinery product – others include LPG, jet fuel, diesel, fuel oil, asphalt and lube oils
- Gasoline and other products, like crude oil, are complex mixtures of many hydrocarbons.
- Gasoline must conform with physical, performance, and environmental specifications for operation of automobiles
  - Physical – density, sulfur, …
  - Performance – octane, stability, …
  - Environmental – emissions, toxics, …
- Products are blends of multiple components from different refinery processes
  - To meet the required specifications
  - Goals are minimum giveaway at the least cost..

How are gasoline components produced?

Mainly, by processing crude oil in refineries.
But some come from the petrochemical and biofuels industries.

Refineries are typically quite complex

Important Processes Affecting Octane



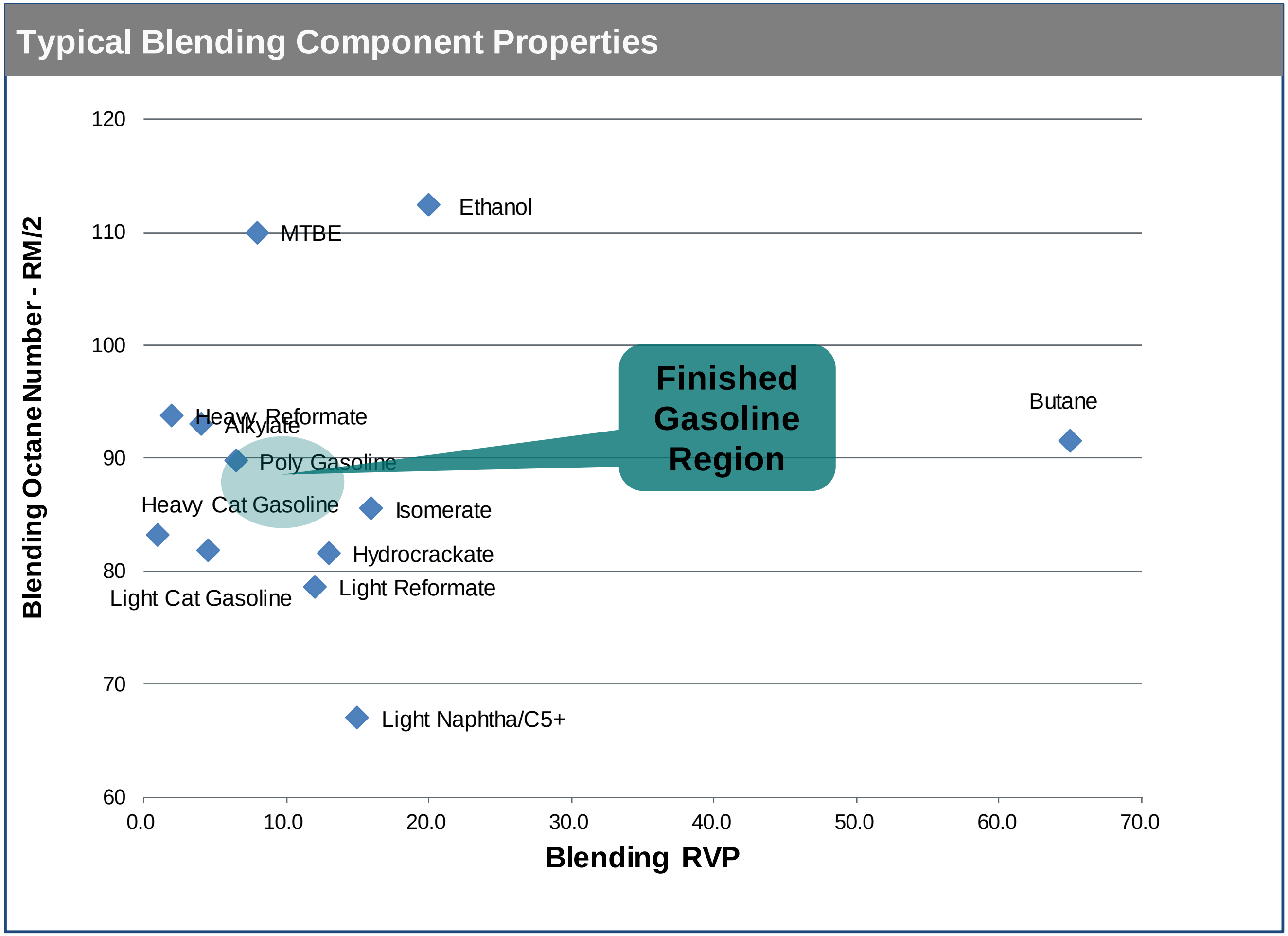
Refineries usually have a large number of gasoline blending components available

- Butane
- Natural Gasoline
- Light Straight Run Naphtha
- Heavy Naphtha
- Isomerate
- Lt Hydrocrackate
- Light Cat Gasoline
- Heavy Cat Gasoline
- Light Reformate
- Heavy Reformate
- Alkylate
- Polymer Gasoline
- Toluene
- MTBE/TAME (but not now sold in US)
- Ethanol

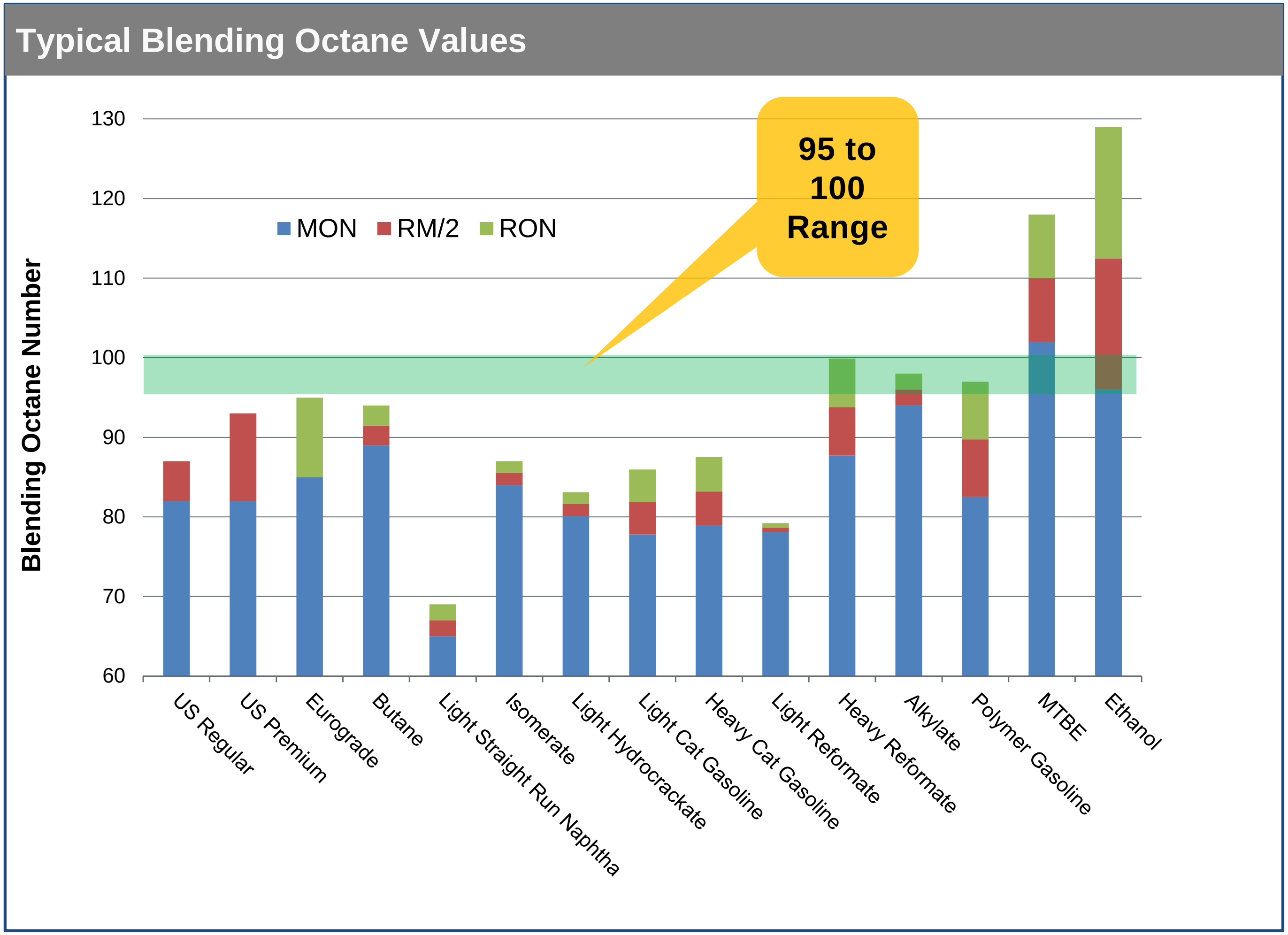
Gasoline has to meet specifications for many properties:

- *Octane, vapor pressure, distillation, sulfur, benzene, oxygenates, contaminants, cleanliness, …*

Octane and vapor pressure are the two key specs: the diversity of properties shows the refiner's challenge



Every component has different RON, MON, and AKI (RM/2)

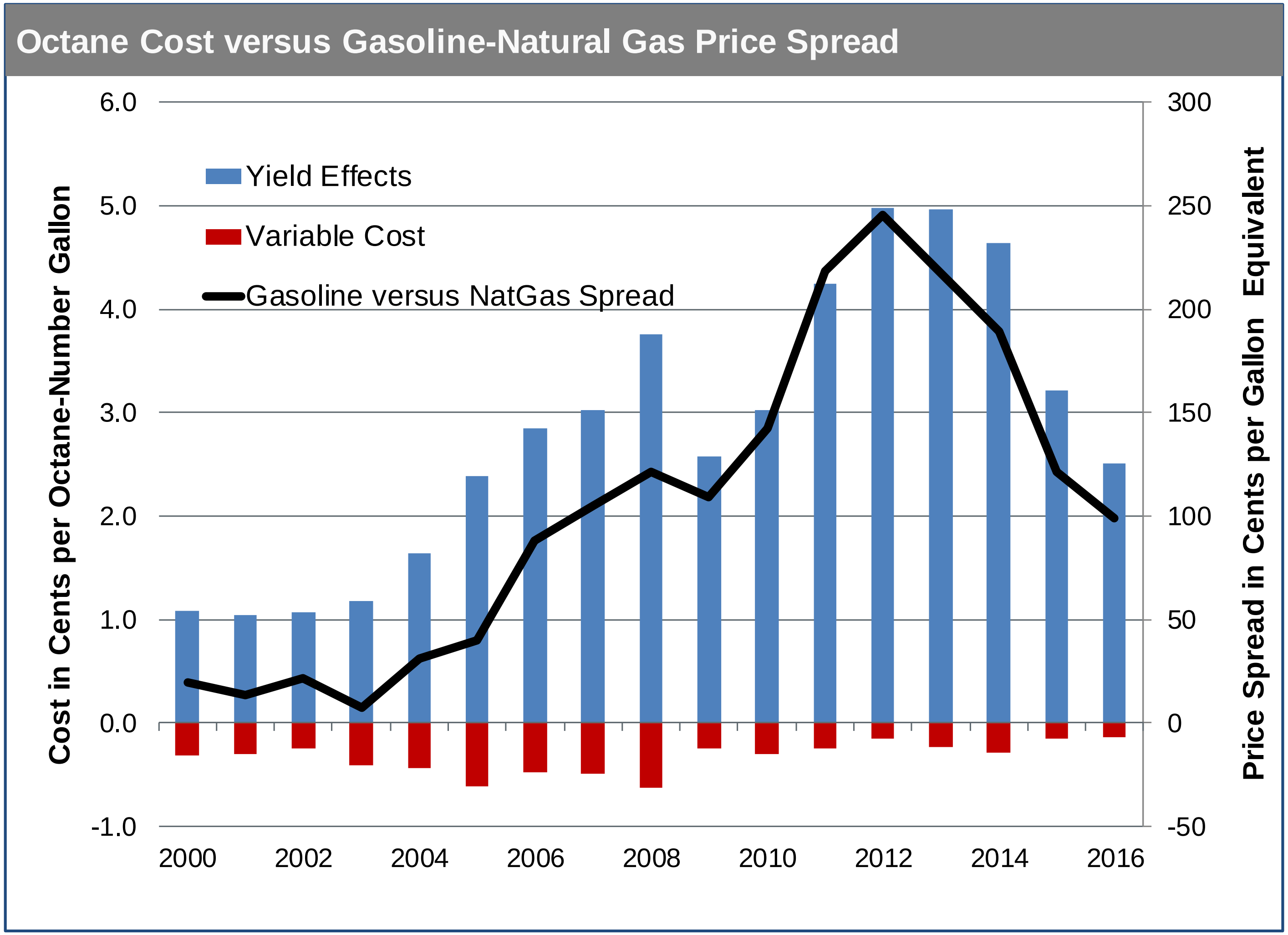


Very few refinery components exceed 95 RON – limiting the capability of refiners to improve pool octane to that level

In refining, marginal costs typically drive market prices

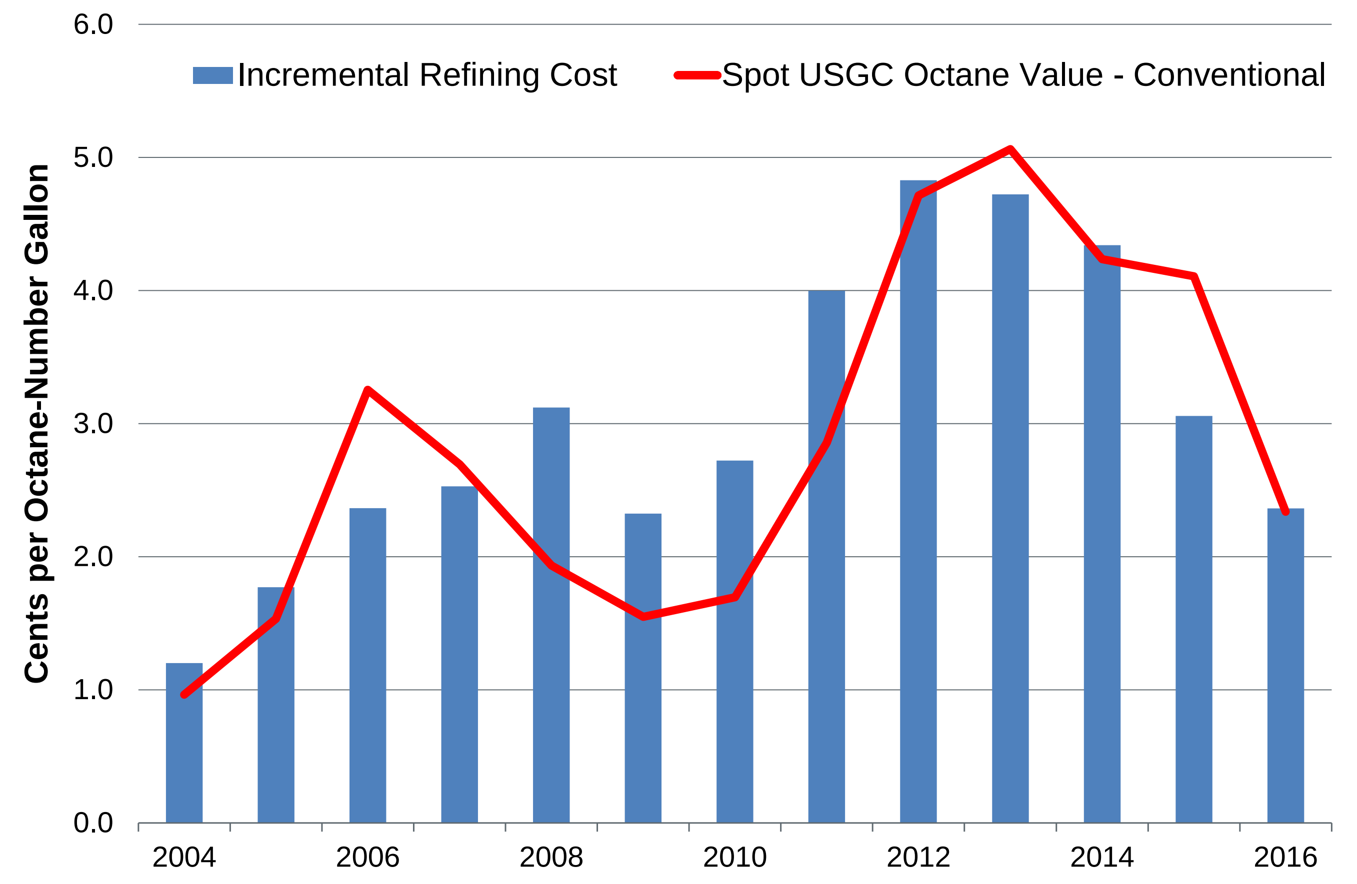
- **Catalytic Reforming units are the primary controllable octane source in the refinery**
  - Refiners can optimize unit throughput and severity (octane of product)
  - Higher octane results in higher costs
    - Reformers convert naphtha feedstock into high-octane, high-aromatics reformate with significant byproducts of hydrogen, fuel gas, and LPG
    - The largest cost is the loss from converting naphtha (related to oil prices) to gas and hydrogen (related to natural gas prices)
    - A wide spread between oil and gas raises octane costs and values
- **Operation of other octane-producing units are less controllable**
  - FCC, hydrocracker operations tied to overall refinery balance
  - Alkylation operation determined by feedstock from FCC

Yield effects are the most important driver of incremental octane costs

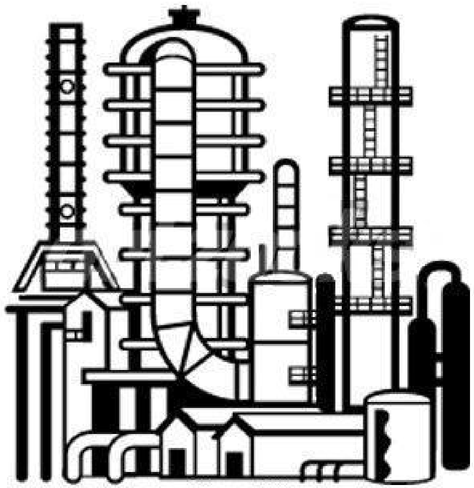


Premium gasoline prices and octane values follow the cost to produce premium gasoline

Octane Cost verus Octane Price

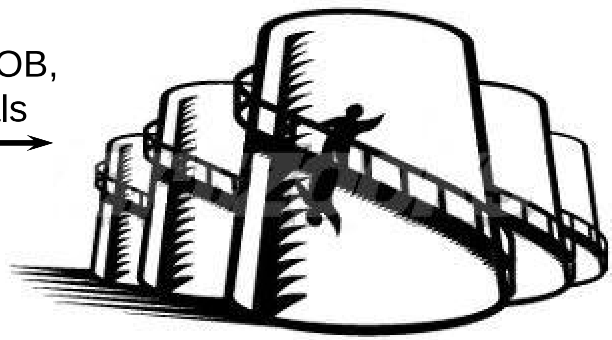


Ethanol is a high-octane component, but blending logistics are complex



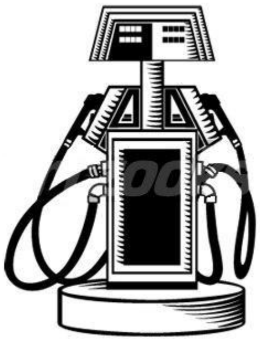
Refinery produces BOB, is shipped to terminals

Terminals store inventory of Ethanol



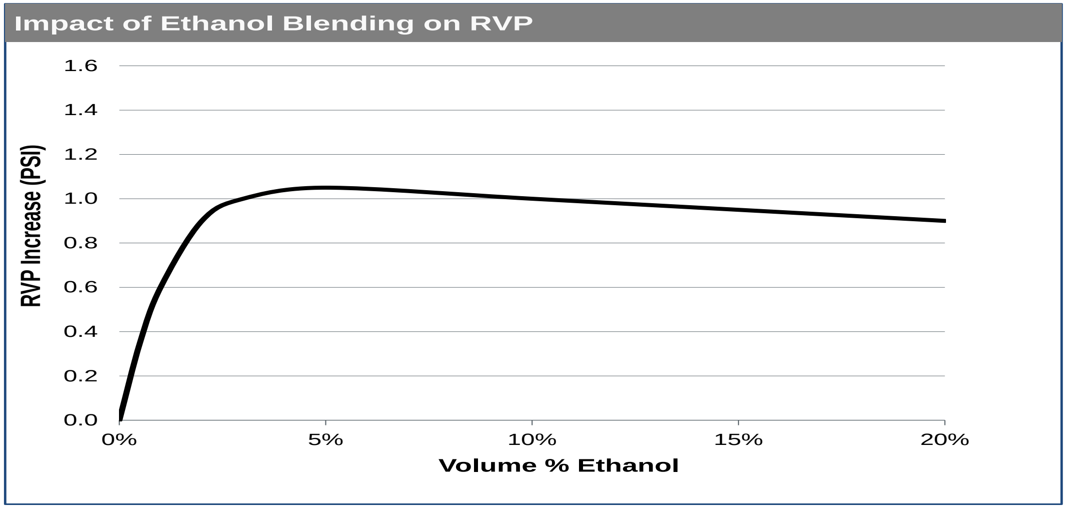
Ethanol blended with BOB to produce finished gasoline – inline or splash blending

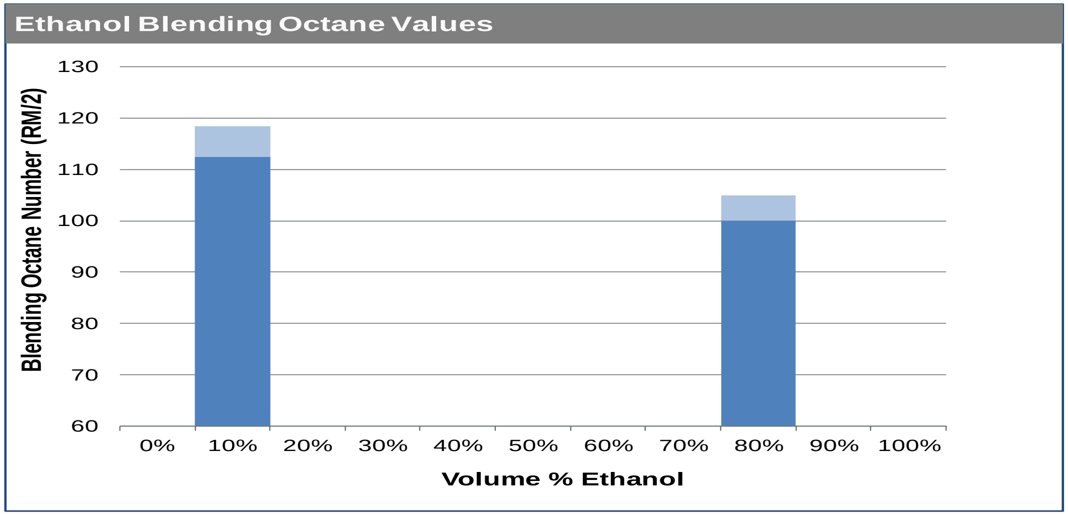
Finished gasoline transported to Gas Station



High-volume ethanol blends are a potential route to higher pool octane, but impacts are non-linear

- Ethanol boosts blend RVP by roughly 1 PSI at 2-3% (by volume) – the driver for the 1 psi RVP waiver
- In lower-concentration (up to 10%) ethanol blends, blending octane is in the 112-118 range
- Ethanol's octane improvement declines as concentration increases
- E85 measured octane is typically in the 100-105 range
- Ethanol RON impact much higher than AKI
- Despite non-linearities and blending issues, high-ethanol blends could be one way to raise pool octane

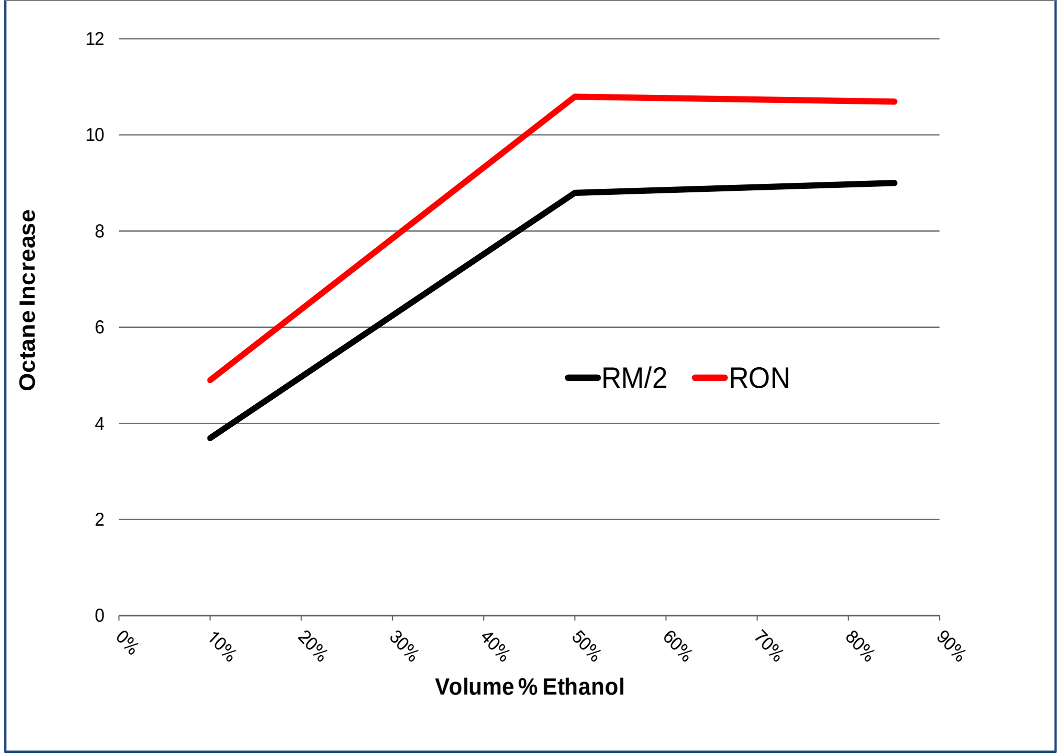




High-volume ethanol blends face a number of potential roadblocks

- Ethanol is an effective octane improver
  - Current RBOB RON is ~ 89
  - 95 RON achievable with E15-E20
  - 100 RON with higher volume blends and higher octane BOB
- But many barriers exist
  - E10 blend wall – potential product liability issues
  - RFS 15 billion gallon corn ethanol limit – no change despite significant improvements in carbon footprint
  - RVP waiver not fully available in excess of 10% blends
  - Investments in gasoline retail infrastructure needed

Impact of Ethanol Blending on Octane



Source: Szybist, Foster, Moore, Confer, Youngquist and Wagner SAE publication 2010-01-0619, published 04/12/2010

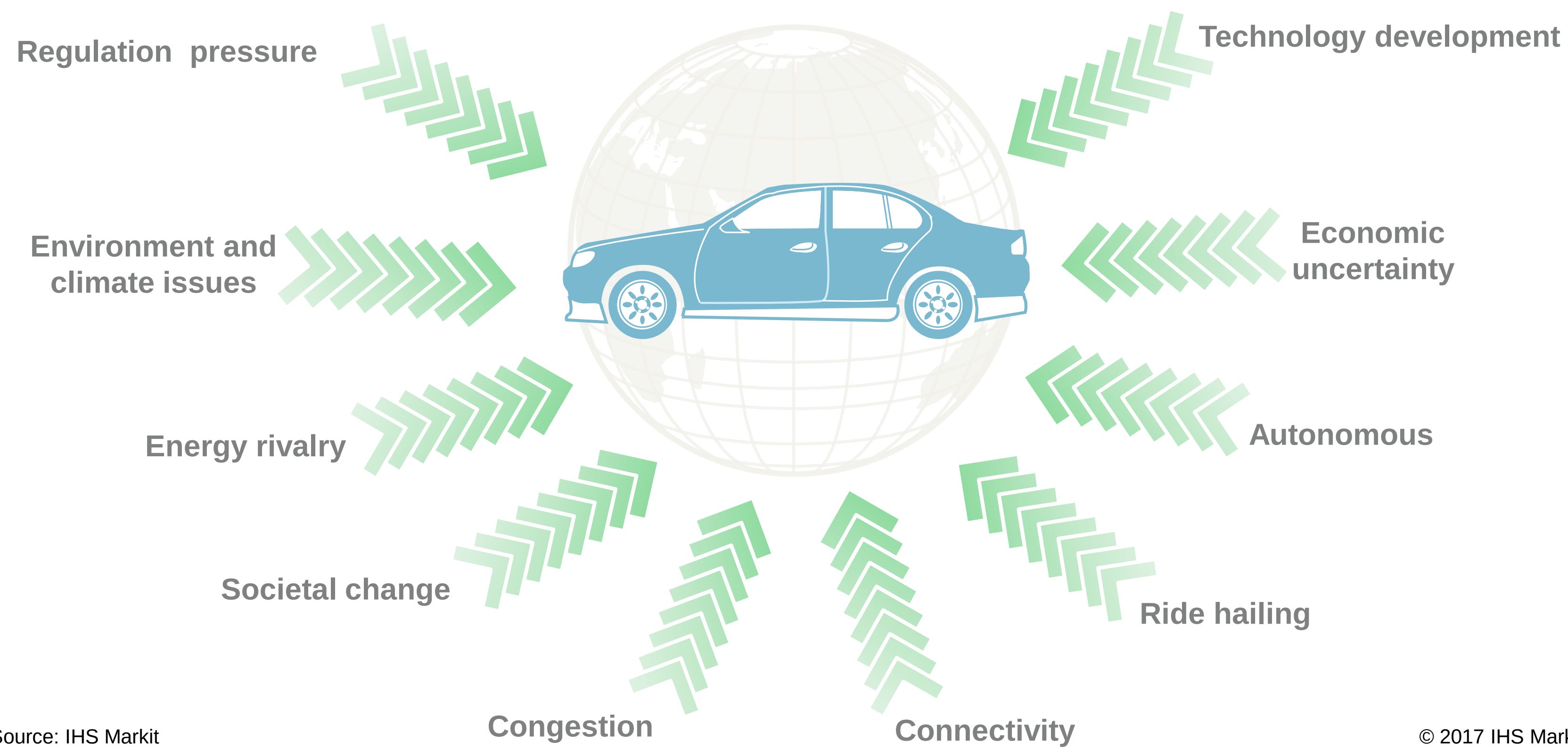
Pressure to increase octane will remain…

- **Automakers – higher octane opens avenues to higher efficiency**
- **Biofuels industry – higher octane could create incentives for higher-ethanol blends**
- **Refiners – unless ethanol solves the problem, refiners would bear the additional operating and capital costs. But is the alternative a world of battery-powered vehicles?**

Reinventing the Wheel (RTW) – IHS Markit Study

Disruptive forces are in play that could radically alter long-established trends in the auto industry and have profound repercussions for oil, chemicals, and electric power

Key global factors impacting the automotive industry ecosystem



Source: IHS Markit

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