Octane

Pathway to a Compromise?

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ABOUT THIS REPORT

Over the course of the last forty years, automobile manufacturers have had to comply with a variety of increasingly stringent Federal and State requirements. CAFE (Corporate Average Fuel Economy) regulations were enacted in the 1970s to require higher fuel efficiency in motor vehicles. Beginning in 2005 through the passage of the RFS (Renewable Fuel Standard) increasing volumes of biofuel blending have been mandated into the U.S. gasoline pool.

These two regulatory programs have created costly and formidable compliance challenges. As the compliance costs have escalated, stakeholders and legislators have examined some alternative programs to combine certain aspects of the two regulatory programs to provide cost efficiencies going forward. A widely discussed proposal and legislative initiative is to provide improvements in automobile fuel efficiency with the introduction of high compression engines. These high compression engines would require the use of higher-octane fuel. In effect, the U.S. automobile fleet would realize continued improvements in fuel efficiency and the required higher-octane fuel would provide opportunities for larger volumes of biofuel blending.

This report presents an overview of the role of octane in the U.S. transportation fuel system and an estimate of the cost of transforming the U.S. gasoline fuel system from one in which about 89 percent of sales can be characterized as "regular" and "midgrade" gasoline into a fuel system where, over time, nearly 100 percent of sales can be characterized as "higher-octane" gasoline. Several methodologies to estimate the cost of this transformation were used, and the merits and demerits of each system for calculating the cost is discussed in the report.

Note that this assessment focuses only on the cost of transforming the U.S. gasoline pool to a higher-octane fuel. Under some circumstances this transformation could provide substantial economic and environmental benefits through the widespread adoption of relatively low-cost fuel-efficient high compression internal combustion engines in all new car sales in the U.S. These benefits could range from reduced cost of automobiles to consumers (as compared to several regulatory outcomes for existing fuel efficiency regulations) as well as lower emissions of greenhouse gasses (GHGs). Estimates of these external benefits are beyond the scope of this report, but also should be evaluated as part of the policy process in selecting a higher-octane fuel.

ABOUT EPRINC

The Energy Policy Research Foundation, Inc. (EPRINC) was founded in 1944, and is a not-for-profit, non-partisan organization that studies energy economics and government policy initiatives with special emphasis on oil, natural gas, and petroleum product markets. EPRINC is routinely called upon to testify before Congress as well as providing briefings for government officials and legislators. Its research and presentations are circulated widely without charge through posts on its website. EPRINC's popular Embassy Series convenes periodic meetings and discussions with the Washington diplomatic community, industry experts, and policy makers on topical issues in energy policy.

EPRINC has been a source of expertise for numerous government studies, and both its chairman and president have participated in major assessments undertaken by the National Petroleum Council. In recent years, EPRINC has undertaken long-term assessments of the economic and strategic implications of the North American petroleum renaissance, reviews of the role of renewable fuels in the transportation sector, and evaluations of the economic contribution of petroleum infrastructure to the national economy. Most recently, EPRINC has been engaged on an assessment of the future of U.S. LNG exports to Asia and the growing importance of Mexico in sustaining the productivity and growth of the North American petroleum production platform.

EPRINC receives undirected research support from the private sector and foundations, and it has undertaken directed research from the U.S. government from both the U.S. Department of Energy and the U.S. Department of Defense. EPRINC publications can be found on its website: www.eprinc.org.

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EPRINC welcomes discussion on all of our research.

For comments or questions regarding this report,
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Links to previous EPRINC downstream reports:

EPRINC's Updated Primer on Gasoline Blending

The Biofuel Mandate: Technical Constraints and Cost Risks

CAFE, Gasoline Prices and the Law of Diminishing Returns: A New Agenda for the Midterm Evaluation.

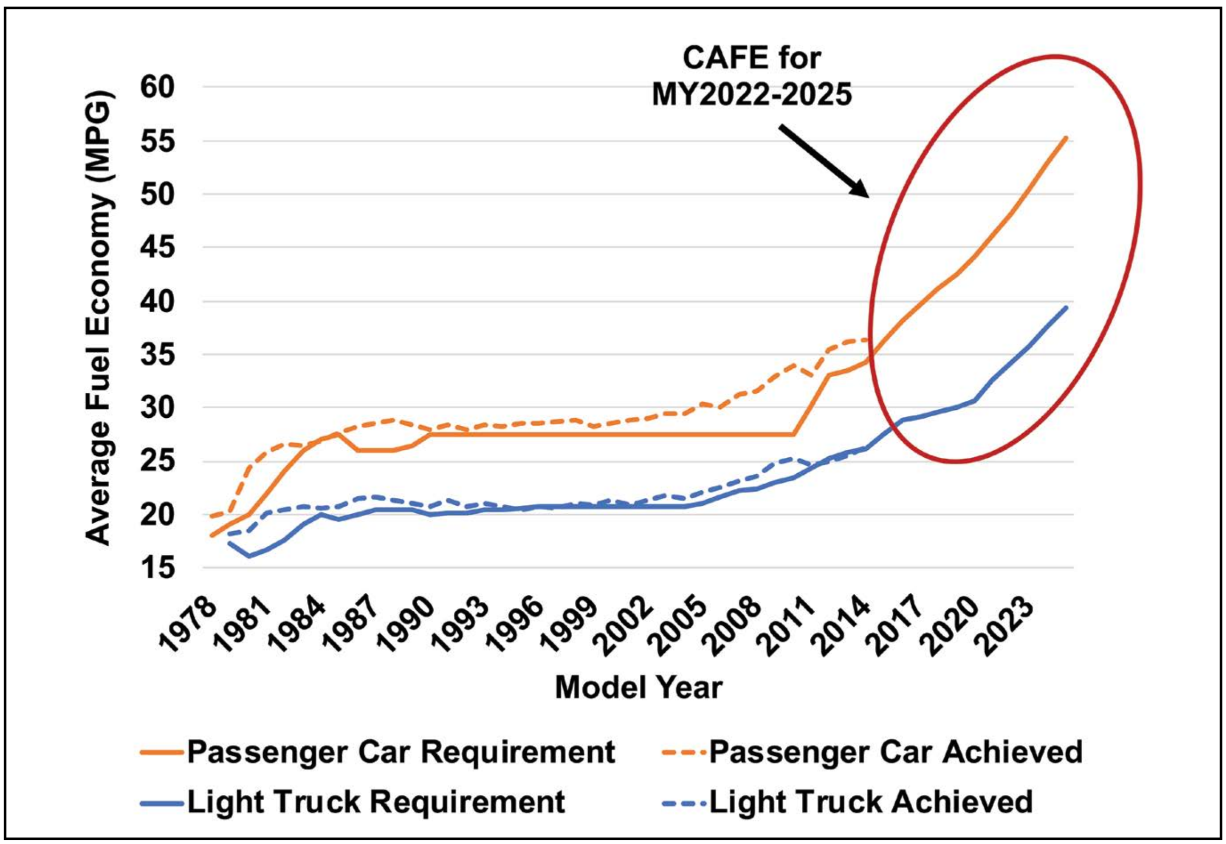
TABLE OF CONTENTS

BACKGROUND

Corporate Average Fuel Economy (CAFE) standards were initially enacted as part of the 1975 Energy and Policy Conservation Act (EPCA), and most recently amended by the U.S. Congress in 2007. Regulatory authority provided in the legislation formed the basis of the Obama administration's May 2009 directive to raise fuel consumption efficiencies and lower GHG emissions in three phases for automobiles and light trucks sold in the U.S. The Obama Administration's directive was for model years (MY) 2010 to 2025. This timeframe was broken into three stages with the third stage for MY2022-2025 being the most aggressive. Each stage has been preceded by a review period to assess progress, possibly amend, and then finalize standards for the subsequent stage.

On August 2, 2018, EPA and the U.S. National Highway Traffic Safety Administration (NHTSA) jointly released the Safe Affordable Fuel Efficient (SAFE) Vehicles Proposed rule. This rule seeks to amend CAFE and tailpipe greenhouse gas (GHG) emissions standards for passenger cars and light trucks. EPA has concluded that the targeted MY2022-2025 (see Figure A) were too costly and should be revised. The result is the proposed SAFE Rule that is subject to a one hundred-twenty-day comment period and subsequent finalization. Several alternatives are under consideration with the agencies' preferred option of retaining MY2020 standards through MY2026.

Figure A
CAFE: Required vs Achieved MPG



Analysis Based on NHTSA Data EPRINC

BACKGROUND continued

On November 18, 2018, the Environment Subcommittee of the U.S. House Energy and Commerce Committee released a Discussion Draft of its 21st Century Transportation Fuels Act (21CTFA). The legislation seeks to sunset and provide other reforms to the Renewable Fuel Standard (RFS), a law first enacted the 2005 Energy Policy Act (EPAct05), and then strengthened by the 2007 Energy Independence Security Act (EISA). These acts, among other measures, required the blending of increasing volumes of biofuels into gasoline and diesel fuel as a strategy to enhance U.S. energy security by substituting domestic biofuels for petroleum imports.

At the time of the RFS authorization, U.S. transportation fuel consumption was forecast to increase significantly through 2030. In addition, prior to the onset of the Shale Revolution in 2008, the expectation was that the U.S would continue to rely on rising crude oil imports in order to satisfy domestic demand growth. The RFS was seen as a way of mitigating reliance on foreign imports.

Mandated volumes of ethanol (the dominant biofuel) can be blended into the U.S. gasoline pool without major operational setbacks as long as the amount does not exceed 10 percent of the total volume. Once this threshold is crossed, then a range of technical constraints and cost risks quickly emerge. This is what is known as the "blendwall." As long as actual U.S. consumption would adhere to those forecasts made at the time the RFS was passed, then the original RFS mandated volumes would be well below the 10 percent limit.

However since the enactment of the RFS, U.S. transportation fuel demand has flattened rather than risen, and is expected to decline (per the EIA) through 2040. Despite the Agency's preemptive actions, the mandated volumes still present both increased technical constraints as well as cost risks in the production and distribution of transportation fuels to the national economy.

Using its RFS waiver authorities, EPA has annually lowered mandated volumes closer to the 10 percent limit of actual demand. Despite the Agency's preemptive actions, the mandates volumes still pose both increased technical constraints and cost risks in the production and distribution of transportation fuels to the national economy.

Different legislative proposals to remedy the RFS have been offered. The 21st Century Transportation Fuels Act has been the beneficiary of the most extensive preparation, including three stakeholder roundtables and six subcommittee hearings. The proposed legislation is comprehensive, seeking to not only sunset the RFS, but also to introduce and mandate higher octane (95 RON) fuels.[1] In this way there would be pathways for continued and possible expanded use of ethanol, a high-octane component, as well as a mechanism some long-term gains in automobile efficiency.

The RFS is a complicated program involving a wide range of incentives to encourage blending of biofuels into U.S. transportation fuels. However, it is the volumetric mandate that has become the primary controversial issue since blend volumes are not adjusted for either technical constraints or cost risks, as is the case when fuels are produced under traditional market pricing signals. The Committee's Discussion

[1]Octane is a measure of a gasoline's capability to resist pre-combustion, also known as "knocking." Knocking degrades the power that an internal combustion engine (ICE) generates. If continued for an extended period of time, knocking will damage an engine to the point of making it unusable.

There are two principle octane-rating methodologies: RON (Research Octane Number) and MON (Motor Octane Number). RON measures a gasoline's capability to resist knocking while accelerating; MON calibrates its rating based on the simulation of high-speed driving. In the U.S., the posted octane number is AKI (Anti-Knock Index), the average of the RON and MON numbers. Globally however, RON is the prevalent posted octane metric.

Octane-enhancing components can be obtained from petroleum and non-petroleum sources. Petroleum refinery produced components include reformate (the dominant one), alkylate, and isomerate. Non-petroleum additives include metals (such as TEL – tetra ethyl lead or MMT – Manganese Tricarbonyl), ethers (MTBE, ETBE, or TAME), and ethanol (corn-derived being the prevailing one).

Draft attempts to organize a "Grand Compromise" providing relief from the volumetric mandate, but also some long-term improvement in automobile fuel efficiency through a requirement for higher compression automobile engines.

The potential legislation would achieve these objectives by requiring higher octane fuel (needed for high compression engines). Higher octane fuel also would offer an opportunity for increased sales of ethanol since it can be an effective blending component to raise octane in gasoline. By any standard, it is a complicated political bargain seeking to improve automobile efficiency, find more opportunities to increase ethanol sales, and to seek a full sunset of the RFS. To date, the so-called "Grand Compromise" proposal has not yielded sufficient support for a successful legislative initiative. It should not be confused with a least-cost solution, which previous EPRINC research concludes would involve merely eliminating volumetric mandates for biofuel blending.

Moving the entire automobile fleet to a higher octane fuel would not achieve the same fuel efficiency as the requirements mandated under the legacy Obama CAFE standards that are now under review. But it would bring about gradual but sustained fuel efficiency improvements to the entire automobile fleet as new higher compression engines entered the market. Accomplishing this sort of massive change in U.S. fuel specifications would take time, estimated to be between fifteen to twenty years. If this proposed higher octane standard were promulgated, it would also preserve a single national standard for fuel efficiency; in turn, this would likely result in motor vehicle production cost savings, which is a more favorable outcome than one where state agencies would require different standards from manufacturers.

If all new U.S. automobiles were produced with higher compression engines, it would eventually improve the fuel efficiency of the U.S. auto fleet by about 3 percent according to auto industry studies. In addition, there is independent research that supports the view that the cost to manufacture higher compression engines is relatively small having a minimal impact on the sales price of new automobiles, especially when compared to the considerably higher cost of implementing alternative powertrains such as plug-in hybrids or fully-electric vehicles.

If the estimate on the cost of higher compression engines is correct, then the only difference is that consumers of new automobiles would be required to use a more expensive fuel. Whether a more expensive fuel is justified in terms of public benefits or whether it represents a unique political compromise on the current debate over the future of volumetric mandates for blending biofuels into U.S. transportation fuels is beyond the scope of this report. As stated above, a political compromise does not yet have adequate support to generate a viable legislative initiative. At some point legislation may be possible, and as part of that effort a systematic and careful review should be undertaken to estimate whether the public benefits of the cost are supported by commensurate benefits.

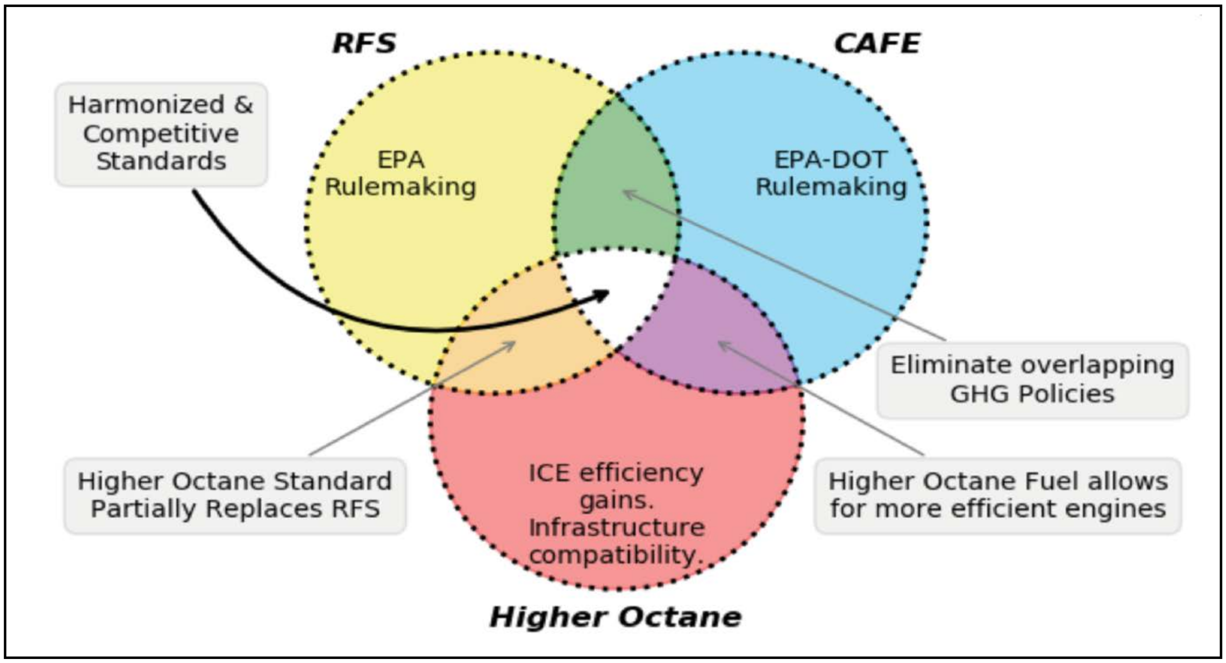
Refineries are complex industrial processing facilities, and any calculation on the cost of altering the fuel mix is fraught with establishing a reasonable set of assumptions on meeting the standard through a large set of alternative production processes. In the end, we are left with a range of estimated costs, and in all likelihood more work will be required to more accurately estimate the cost of such a major transformation in the U.S. fuel system.

INTRODUCTION

Since the 1970s, automobile manufacturers have been facing rising Federal and State regulatory requirements to meet higher fuel efficiency standards. Compliance has been primarily achieved through technological advances in the design of automobile engines, transmissions, and advances in weight reduction of materials. Sometimes, these advances have been accompanied by modifications to engine fuels.

As CAFE standards have come under review, there has emerged an opportunity to link CAFE and reform of the Renewable Fuel Standard (RFS) to bring some convergence to these two important public policy concerns; the proponents view is illustrated in Figure B. Some auto manufacturers have proposed an alternative to the Trump Administration's proposed standard (i.e., retaining 2020 auto standards through 2026) for all new automobiles sold in the U.S. This standard would require all new cars and light trucks to be installed with higher compression engines. Auto manufacturers already produce these sorts of engines worldwide, and have publicly stated that the technology can be introduced into the U.S. at minimal cost over current engine technology used in the U.S.

Figure B
Proponents' View of a "Grand Compromise"



EPRINC

Higher compression engines would permit the U.S. auto fleet to eventually operate at improved fuel efficiency levels over that of the current fleet; however, this would not be as high as the level required for model years (MY) 2022-2025 under the CAFE standards that were established in 2009 by directive of the Obama administration. Along with some other measures, many automobile manufacturers believe this initiative is a feasible approach to maintain a single national fuel efficiency standard for autos sold in the U.S., and that it is a more achievable and cost-effective solution.

A second feature of the proposal is that it would provide new opportunities for higher volumes of ethanol sales since ethanol can yield a higher-octane rating for gasoline at relatively low cost. A critical attribute of higher compression engines is that they need gasoline with an octane rating roughly equivalent to “premium” that is sold in the U.S. today. Although these engines would raise the fuel efficiency of the entire U.S. auto fleet by the prevailing estimate of about 3 percent, it would also result in the ultimate removal of all “regular” gasoline as a choice for consumers. Furthermore, this move would also be accompanied by technology and fuel systems that could safely combust these higher ethanol volumes in all new vehicles, perhaps allowing for ethanol blends as high as 20 percent.

To date, ethanol sales have been hindered by a combination of relatively flat demand for liquid transportation fuels in the U.S. and technical constraints and higher costs of marketing gasoline with ethanol at greater than 10 percent volume. While ethanol can help to lower emissions of greenhouse gas emissions (GHG), it also can contribute to increased ground level ozone and smog. Regulations that limit the Reid vapor pressure (RVP) of gasoline can limit higher blends of ethanol used in some regions of the U.S., and EPA is proceeding with a rule making to change RVP standards to accommodate higher volumes of ethanol use.

Ethanol gasoline blending is further complicated by the fact that ethanol use in the U.S. is required by law to achieve certain volumetric targets regardless of cost considerations or technical constraints. The fuel mandate is supported by prominent U.S. agricultural interests who remain adamant that no reduction or adjustment should be made to the volumetric mandate, especially for ethanol made from corn. Several independent research studies (including some by EPRINC), and agencies of the U.S. Government have documented that the RFS contributes to inefficient refinery operations and higher costs to consumers in the production and distribution of transportation fuels.

The RFS has, on occasion, contributed to substantial increases in gasoline and diesel prices. Evidence of the contribution of the mandate to higher gasoline and diesel fuel prices can be documented by evaluating prices for gasoline sold into export markets. Such sales are outside the RFS program and routinely discount to wholesale prices transacted in the domestic market before any blending of biofuel components. EPRINC’s research shows that the volumetric mandate have raised gasoline prices from 3 to 12 cents per gallon depending upon a range of economic and fuel demand conditions. The mandate distorts traditional least-cost manufacturing decisions on the production of transportation fuels.

Value of U.S. Corn Crop Dedicated to Ethanol production

Research by EPRINC and other independent analysts have documented that ethanol is an important and cost-effective blending component in the production of gasoline. Ethanol produced from corn would likely continue to be used in about 10 percent of gasoline volume even in the absence of a volumetric mandate, although it would adjust to pricing and market conditions. However for much of the U.S. farming community involved in corn production, the mandate is seen as an essential element of a program for preserving access to the fuels market.

The value of corn production in excess of blending above 10 percent is substantial. As can be seen in Table 1:

- The implied ethanol mandate for 2017 was 15 BGY (billion gallons per year); assuming that this was only derived from U.S. produced corn ethanol, this would represent 31.1 million harvested acres of corn as applied to corn ethanol, or 35.9 percent of the total 2017 U.S. corn harvest.

- According to the EIA, U.S. 2017 finished gasoline consumption was 142 billion gallons, implying an E10 blend using 14.3 billion gallons of ethanol.

▸ The difference is about 713.8 million gallons, or, 284 million bushels, or 1.6 million acres of U.S. corn production.

▸ The USDA estimated the average corn price to be $3.40 per bushel. At that price the 2017:
Total revenue from corn to farmers is $51.5 billion; of which,
The value of feedstock for ethanol production is $18.5 billion, or 36 percent of total revenue; and
The value in excess of 10 percent blending is $970.8 million, or about 2 percent of total.

▸ U.S. transportation fuels policy can have an important consequence on the potential growth in corn sales.

Table 1
Value of U.S. Corn Crop In Excess of E10 Blending Requirements 2017

U.S. Corn Crop Details	
Billion Bushels of Corn Harvested:	15.1
Harvested Corn Acreage	86.7
Yield per Acre:	174.4
Allocated for Corn Ethanol	
Acreage Requirement:	31.1
Percentage of Total:	35.9%
According to EIA Data	
Finished Gasoline Consumption (Billion Gallons):	142.9
Implying Ethanol Consumption Based on E10 Blends (Billion Gallons):	14.3
Corn Ethanol RVO in Billion Gallons	15.0
Difference RVO-E10 in Million Gallons (+/-):	713.8
Difference RVO-E10 in Million Bushels:	285.5
Difference RVO-E10 in Million acres of U.S. Corn Production:	1.6
USDA Estimate of Average Corn Price Per Bushel:	$3.40
Total Implied Revenue of Corn Feedstock for Ethanol Production in Million Dollars in excess of E10:	$970.8

Analysis Based on USDA Data EPRINC

PERSPECTIVE ON COSTS WITHIN THE RFS

For any assessment of an alternative to the current fuel mandate, it is important to establish the cost structure and the potential for price risks associated with the volumetric mandate of the existing RFS program. The cost structure for meeting the mandate under the RFS depends on a range of external considerations that are difficult to predict. There are points across the petroleum- and bio-fuels supply chains where cost estimates can be made. However, an aggregated view using unweighted average RIN prices multiplied by total number of retired RINs gives a view of the cost that is passed on to the consumer.

Estimated Total RIN Cost to Consumers

If RIN retirements from the years 2013 to 2017 are taken from EPA's EMTS website (https://www.epa.gov/fuels-registration-reporting-and-compliance-help/public-data-renewable-fuel-standard), and multiplied by the average (unweighted) RIN price for the respective year, then we get a stylized view of the total RIN obligations for each year: $10.7, $8.3, $10.6, $16.2, and $12.6 billion respectively. This can be seen in Table 2 on this page.

This is a gross estimation of cost. There is no accounting for income to RIN generators. Actual RIN expenditures by Obligated Parties probably differ based on an individual Obligated Party's RIN management strategy and the timing of RIN purchases, sales, or retirements.

Using the analysis presented in Table 2, the RFS program added 8 cents per gallon to gasoline in 2013; this rose to 11 cents in 2016, and then declined to 9 cents in 2017. While the final accounting has not been completed for 2018, the cost of the RFS program is expected to be considerably lower than previous years due to sharp drop in RIN values during the year because of shifts in policy.

However due to a set of waiver authorities, EPA continues to have partial discretion through 2022 over volumetric mandates. Even under the most lenient circumstances, this will continue to levy some cost per gallon of gasoline. In 2022, this discretion becomes full in the event there is no RFS Reform. In this scenario, there is considerable uncertainty and cost risk depending on the composition of the Presidential administration and EPA's leadership.

Table 2
Renewable Fuel Standard Implied Economic Cost

	RIN Price*					RIN Retirements ('000s)					Total Annual Implied Economic Cost ('000s)				
	2013	2014	2015	2016	2017	2013	2014	2015	2016	2017	2013	2014	2015	2016	2017
D3 - Cellulosic Ethanol	0.42	0.64	1.36	1.69	2.87	415	32,984	139,013	189,742	228,162	$174	$21,110	$189,474	$320,664	$654,824
											0.0%	0.3%	1.8%	2.0%	5.2%
D4 - Biomass Diesel	0.73	0.56	0.76	0.92	1.01	2,636,806	2,599,603	2,744,291	3,883,871	3,071,752	$1,924,868	$1,455,778	$2,085,661	$3,573,161	$3,102,469
											17.9%	17.5%	19.7%	22.0%	24.7%
D5 - Advanced Biofuel	0.64	0.53	0.72	0.90	1.00	551,121	142,517	145,159	97,943	140,068	$352,717	$75,534	$104,515	$88,149	$140,068
											3.3%	0.9%	1.0%	0.5%	1.1%
D6 - Conventional Ethanol	0.64	0.48	0.56	0.82	0.70	13,237,335	14,056,166	14,632,002	14,937,680	12,379,473	$8,471,894	$6,746,960	$8,193,921	$12,248,898	$8,665,631
											78.8%	81.3%	77.5%	75.5%	69.0%
D7 - Cellulosic Diesel	0.42	0.64	1.36	1.69	2.87	384	45	190	481	1,667	$161	$29	$259	$813	$4,785
											0.0%	0.0%	0.0%	0.0%	0.0%
Total											**$10,749,815**	**$8,299,410**	**$10,573,831**	**$16,231,684**	**$12,567,778**
of which:															
Cellulosic											$335	$21,139	$189,733	$321,477	$659,610
Advanced											$352,717	$75,534	$104,515	$88,149	$140,068
Combined											$353,053	$96,673	$294,248	$409,626	$799,678

* Average Annual Unweighted RIN Price

Analysis based on PFL, EcoEngineers, and EPA Data

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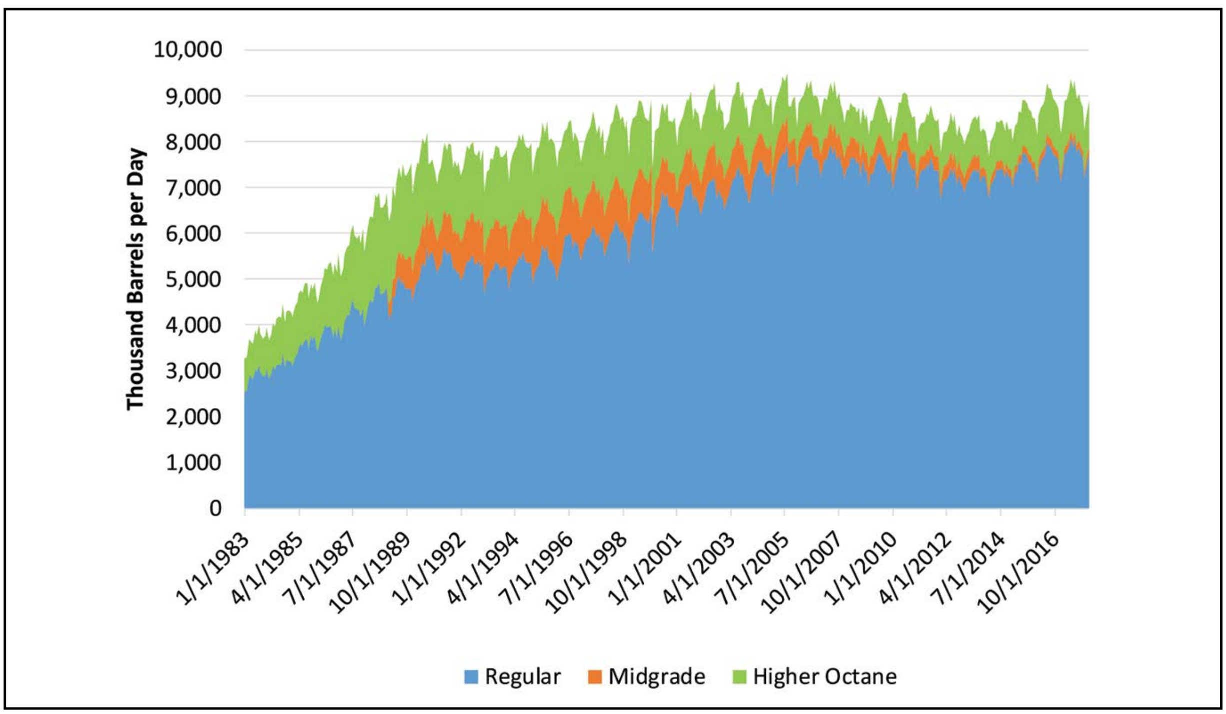
GRAND COMPROMISE

The "higher compression" proposal has elements of a grand compromise. The production of these sorts of engines, with their requirement for higher octane fuel, offers the potential to expand the market for ethanol since it is generally a low-cost solution for higher-octane gasoline. It also provides longer-term improvement in the fuel efficiency of the U.S. automobile fleet that could be a pathway for reaching agreement on a single national fuel efficiency standard. A central feature of the compromise is that high compression engines not only require higher octane fuel, but the automobiles will be compatible with and have warranties that permit higher ethanol blends. A further feature of this initiative is that agriculture interests might abandon their requirement for sustained ethanol mandates in exchange for market-driven demand. To date U.S. agricultural interests have shown little interest in trading the RFS mandate for an opportunity to sell more ethanol, absent a mandate.

COST ESTIMATES

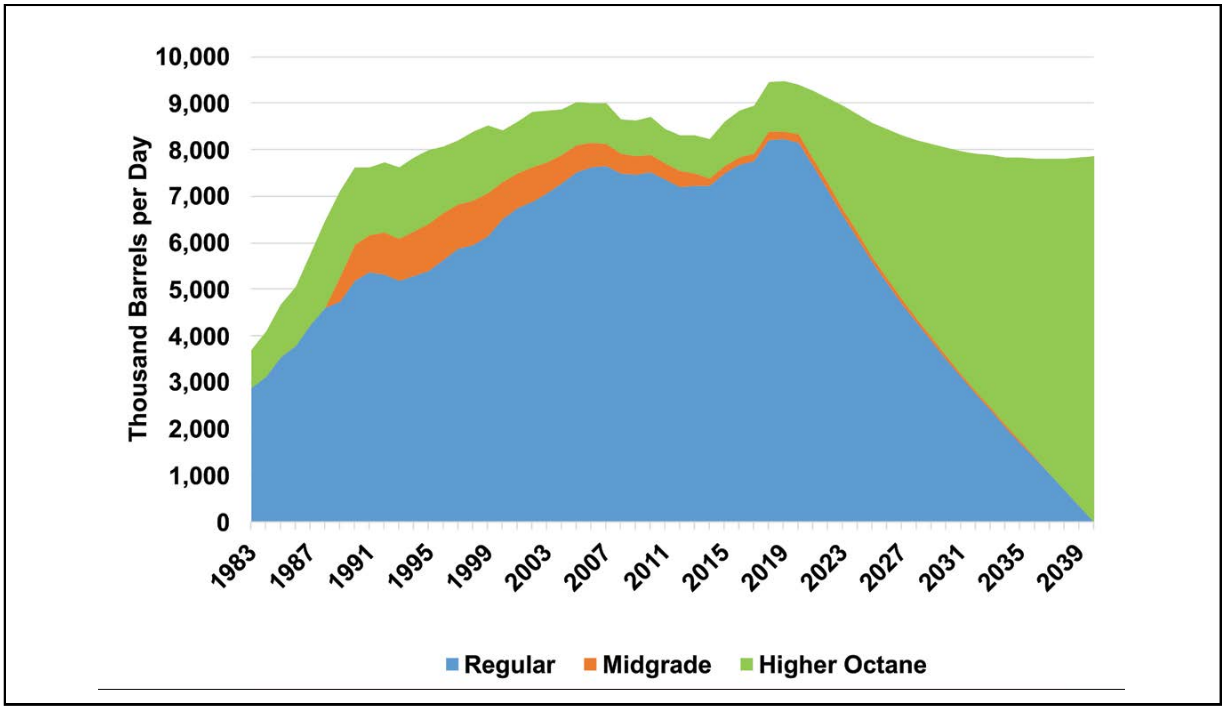
Putting aside public policy concerns of producing and distributing ethanol under market vs. administrative criteria, one issue that policy makers will want to understand is the cost of moving the U.S. fuel system from where it is today (as shown in Figure C) to a point in the future where it is 100 percent higher octane fuel (as shown in Figure D). For purposes of this analysis, EPRINC has defined premium fuel as 95 RON / 91 AKI octane and greater and assumes the transition will occur over fifteen years. Some experts have suggested the turnover could take place more quickly; others assume longer. Also, note that the transition is not to the highest octane available in the U.S.; instead it is a high octane fuel available worldwide matching specifications of gasoline used in high compression engines globally.

Figure C
U.S. Gasoline Sales By Grade



Analysis Based on EIA Data EPRINC

Figure D
U.S. Gasoline Sales By Grade — Forecast



Analysis Based on EIA Data EPRINC

There are a myriad of scenarios and variables affecting the potential implementation of the proposed 95 RON / 91 AKI standard. Higher octane gasoline components can be sourced in many ways including through the use of additives such as ethers. In this analysis, EPRINC limits the calculations to two scenarios: an All-Reformate one and an Ethanol-Dominant one.

In the All-Reformate scenario, refiners would transition to refinery-sourced higher-octane gasoline relying on the increased production of components known as reformates. Higher ethanol blends would not be an option here. Using EIA's 2018 Annual Energy Outlook forecast that shows demand decline for gasoline, the cost of this alternative would be largely driven by the cost of constructing and operating reformers.

Table 3 presents the All-Reformate scenario. Using $8,240 per barrel per day for a reformer's capital cost and 12 cents per gallon of operating costs (sourced from Oil & Gas Journal), EPRINC estimates that the total cost of undertaking the transition under this scenario to be approximately $10.4 billion, and that there will be an additional annual expense of $2.3 billion processing costs. The additional reformate blended into finished gasoline is estimated to add production costs of 4 cents per gallon, but could range up to 8 cents (fixed and variable costs; everything else held constant). In this scenario, annual ethanol consumption would be at a constant of 10 percent of sold finished gasoline, declining from 14.5 BGY in 2018 to 12.0 BGY in 2037, the final year of expected implementation.

It is important to note that these figures should be considered as the upper bound of a range. Refiners generally find ways to mitigate expenses as they seek to optimize and debottleneck production, and to increase efficiencies. EPRINC is undertaking further research to evaluate lower cost solutions using reformates.

The 21CTFA Draft makes provisions for E20, a gasoline blend that contains ethanol up to a level of 20 percent. If higher compression engines are mandated through the passage of legislation such as 21CTFA, they would presumably be manufactured to specifications that are capable of handling E20. Note that ethanol can be produced at a lower cost than gasoline, although it is accompanied by a lower BTU value. Therefore, it is important to consider the Ethanol-Dominant scenario.

Table 3
All-Reformate Assumptions

Capital cost in TBD	$8,240	
Capital cost in GPY	$0.54	
	Capital cost of all reformate (000,000s)	**Operating cost of all reformate - annual (000,000s)**
	$10,353	$2,311
	@ Capital Recovery @20% Pretax	
Per Reformate Gallon	$0.11	$0.12
Total per Reformate Gallon		$0.23
Total per Finished Gasoline Gallon		**$0.04**

Analysis based on OGJ/PennWell Data EPRINC

Table 4 shows the Ethanol-Dominant Alternative scenario. Here all costs are considerably higher than those of the All-Reformate scenario, but not the total cost per finished gallon. While the installed equipment costs of ethanol refineries are somewhat scalable, they are not as scalable as those of petroleum refining; in addition, biorefinery production expenses are less responsive to large economies of scale. Currently, capital costs for an ethanol refinery are $32,193 per barrel per day of capacity, and processing costs are 44 cents for each additional ethanol gallon. When fully implemented, capital expenses would total $8.6 billion with an additional $1.8 billion per year to cover operating expenditures. Because of its higher-octane content, less ethanol would be blended into finished gasoline. Therefore, the incremental production cost is projected to be 3 cents per gallon, but could be as much as 6 cents. In this scenario, annual ethanol blends in finished gasoline could rise almost 3 BGY from 14.5 BGY in 2018 to 18.1 BGY in 2037, the final year of expected implementation.

Note that in both examples, feedstock costs are not part of the analysis. As discussed in the next section, feedstock costs represent the critical component in any comparative analysis. The comparison above calculates the cost of processing the material into a higher-octane fuel from petroleum feedstock or producing ethanol (which has an inherently higher-octane rating) from corn. The following section calculates the role of feedstock cost and energy content in a comparative analysis of the two alternatives for producing a higher-octane fuel.

Table 4
Ethanol-Dominant Assumptions

Capital cost in TBD	$32,193	
Capital cost in GPY	$2.10	
	Capital cost of all Corn Ethanol (000,000s)	**Operating cost of all corn ethanol - annual (000,000s)**
	$8,633	$1,801
	@ Capital Recovery @20% Pretax	
Per Ethanol Gallon	$0.42	$0.44
Total per Ethanol Gallon		$0.86
Total per Finished Gasoline Gallon		**$0.03**

Analysis based on Iowa State-CARD Data — EPRINC

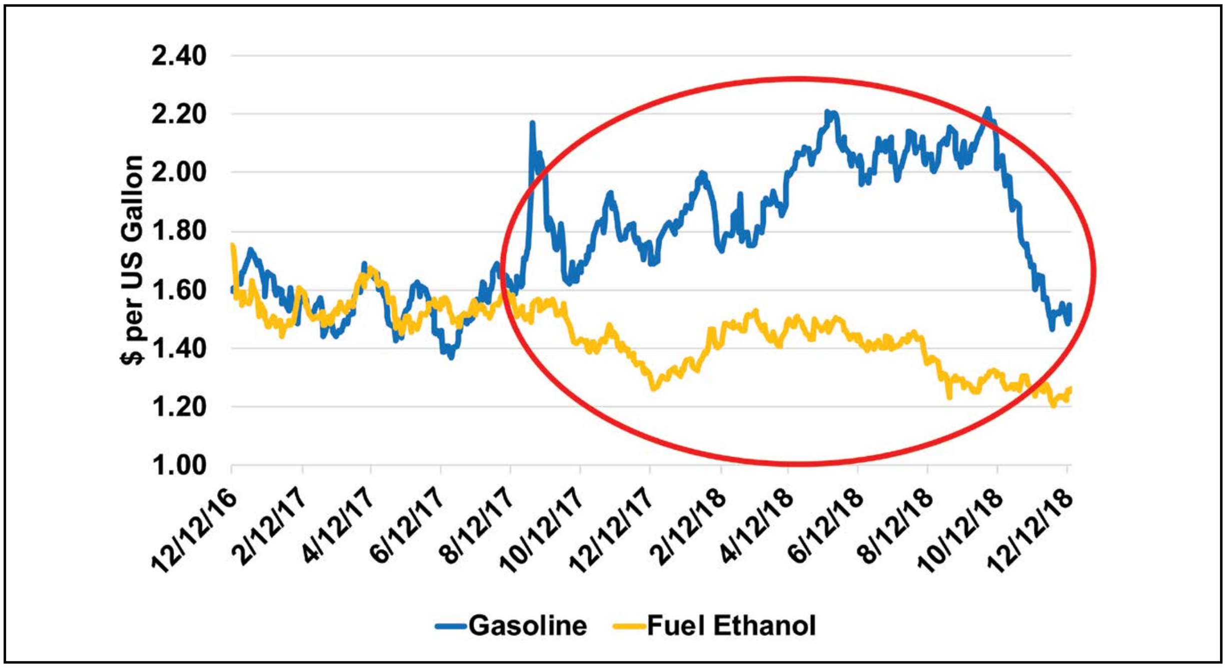
ADDRESSING UNCERTAINTY

A central feature of markets is that they adjust quickly to changes in demand, costs, and technological advances. The two scenarios presented here are highly stylized. Note how small changes in critical aspects of the cost calculation can alter the least-cost solution.

Crude oil and corn prices, the feedstocks for reformates and fuel ethanol, respectively, dominate their particular economic advantages, and the markets for these feedstocks are governed by different dynamics. The particular uncertainties of these markets underscore the pitfalls of relying upon point estimates when implementing fuels policy.

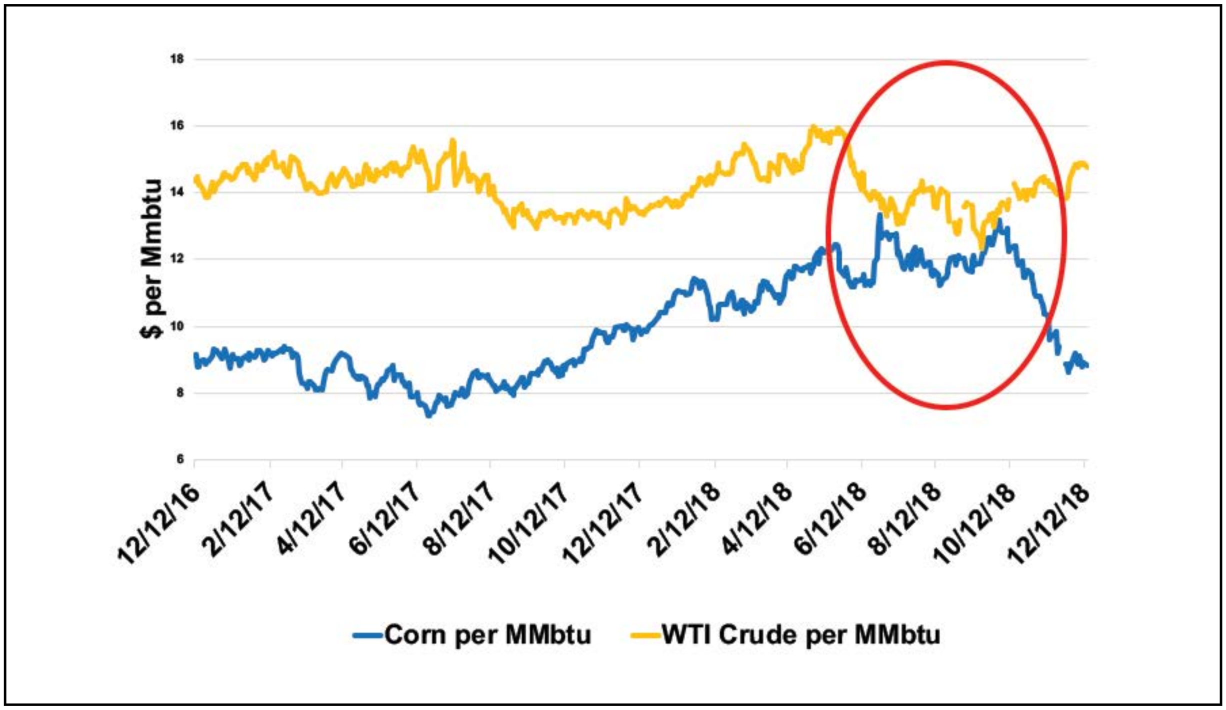
Under current conditions ethanol can substantially lower the cost of meeting the higher-octane standard. This is because the prevailing price of corn, ethanol's feedstock, has been low for some time (see Figure H on page 15). Driven by this, wholesale ethanol prices have averaged 57 cents less per gallon than those of gasoline during 2018 on a volume basis illustrated in the adjacent exhibit (Figure E).

Figure E
Gasoline And Fuel Ethanol: 12/12/2016 to 12/14/2018



Analysis Based on CME and EIA Data EPRINC

Figure F
Adj WTI Crude vs Adj Corn: 12/12/2016 through 12/14/2018



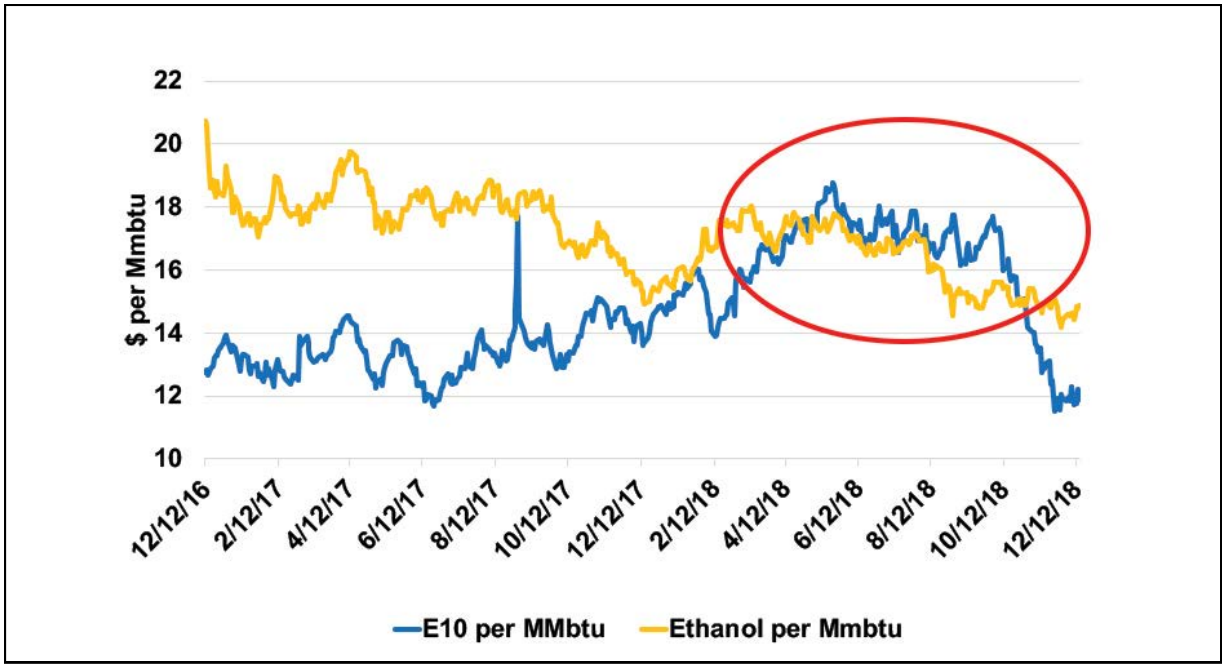
Analysis Based on CME Data EPRINC

This analysis can be expanded to account for the energy relationship of ethanol vs gasoline (ethanol has about 70 percent of the energy of non-ethanol-blended gasoline).

After falling steeply in late 2014 and 2015 and leveling in 2016 due to rising supplies from the shale production, oil prices rose considerably from the middle of 2017 through October 2018. Concurrently after a period of contracted supply/demand balances brought on by shortages due to droughts from 2011 to 2013, there is now an oversupply of corn.

Combined in the last two years, these dynamics have driven the two feedstocks to be close in energy parity. This can be seen from late June to early October 2018 in Figure F, which compares the benchmark prices of crude oil and corn on an energy basis, from late June to early October 2018.

Figure G
Adj E10 vs Adj Ethanol: 12/12/2016 through 12/14/2018



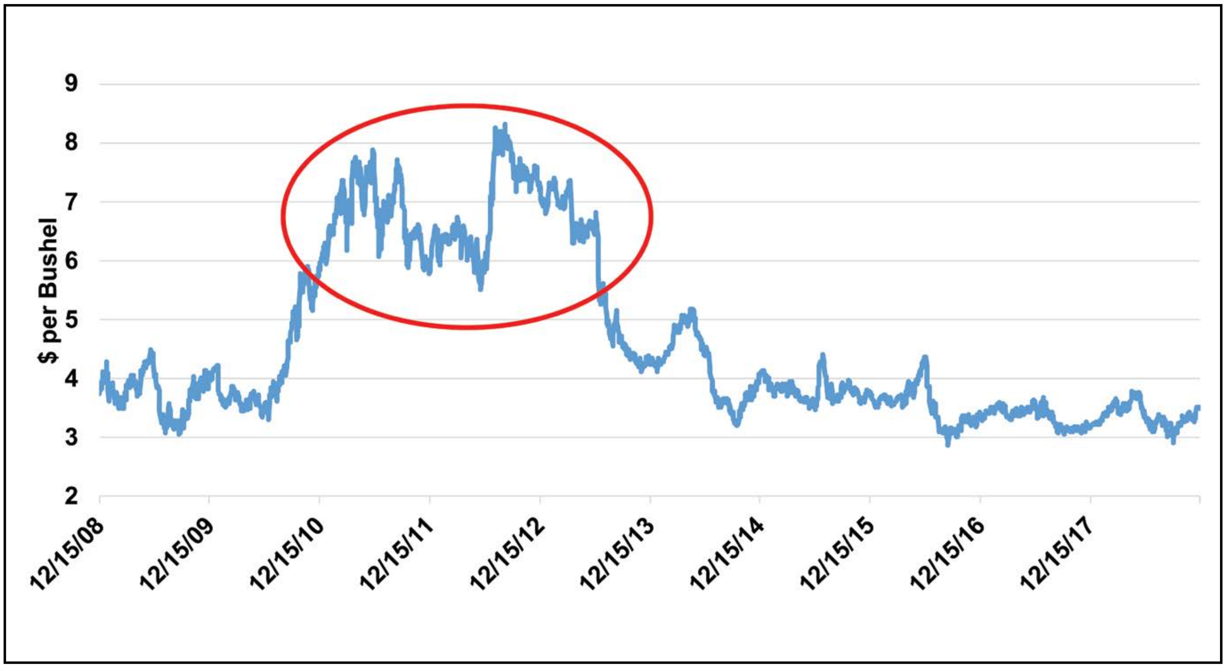
Analysis Based on CME Data EPRINC

Figure G presents E10 vs ethanol in the same fashion. In particular in Figure G, E10 gasoline has been more expensive on an energy basis than ethanol from late April through the end of October 2018.

With the onset of increasing U.S. crude oil production in late 2018 combined with somewhat better than expected Iranian export volumes, and retreating demand, crude oil prices have declined substantially since October 2018. This has removed ethanol's advantage on an energy basis, but its octane cost advantage on a volume basis continues, albeit at a slightly lower differential of 53 cents since the beginning of October 2018 (Figure D).

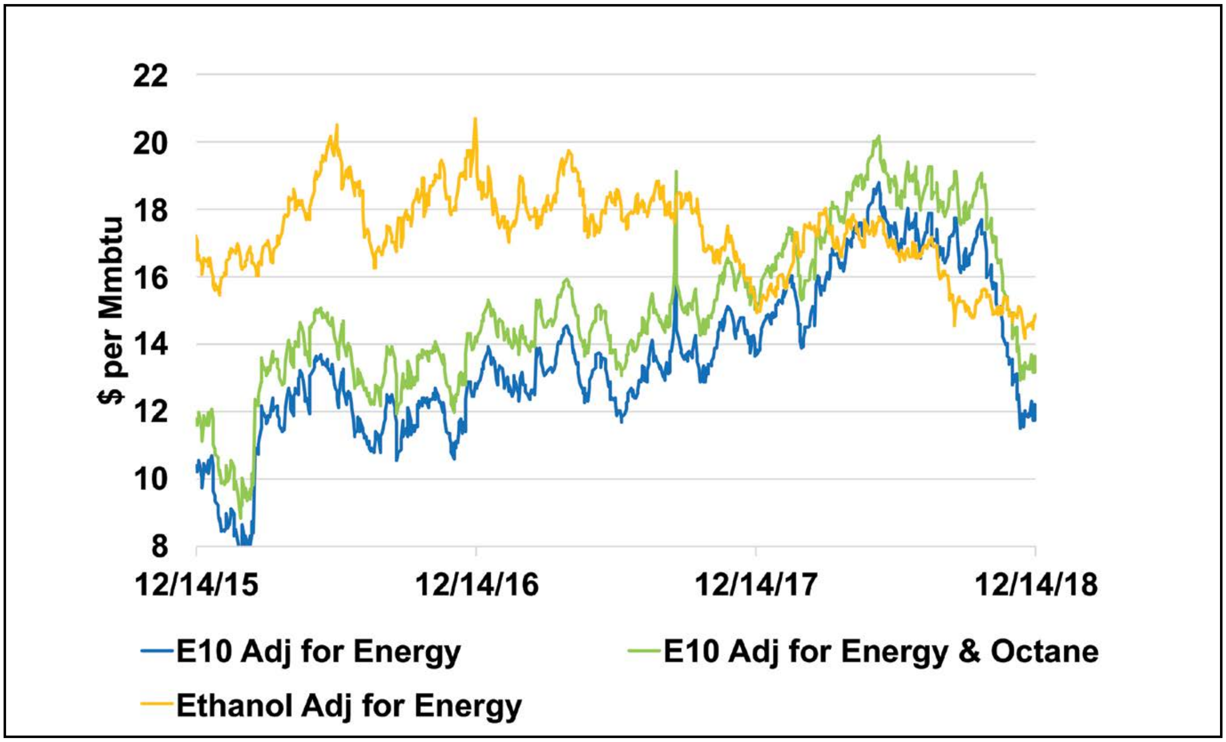
However, the capital cost of constructing an ethanol facility (as shown in Table 4) is not trivial, and a relative shift in feedstock cost (e.g. price of corn) can make higher octane fuel production more expensive. For example, if corn prices were to rise from $3.80 per bushel (close to where they are today) to $5 to $8, a range that was prevalent from 2011 to early 2014 (see Figure H), and the WTI Crude benchmark stays flat near $50 per barrel then ethanol's critical cost advantage would disappear.

Figure H
Corn: 12/14/2008 to 12/14/2018



Analysis Based on CBOT and USDA Data EPRINC

Figure I
E10 vs Ethanol Adjusted for Energy & Octane



Analysis Based on CME Data EPRINC

As discussed above, ethanol is inherently a higher-octane fuel. Under this possible "grand compromise," opportunities for higher ethanol-blended gasoline volumes would face few technical constraints since all new automobiles would require higher octane fuel, and would have full warranty protection to operate with ethanol blends up to 20 percent by volume of gasoline.

As shown in Figure I adjacent to this text, higher octane provides a modest boost to the competitive position of ethanol on a strict cost basis as it does not require additional processing to lift its octane ratings because it is already a higher-octane fuel. The green line in Figure I shows the improvement in ethanol's competitive position vs. E10. Note that in 2018 ethanol is a more cost-effective solution for producing higher octane fuel compared to raising the content of reformates in gasoline at the refinery.

DISTRIBUTION COST CONSIDERATIONS – WHOLESALE AND RETAIL

Currently E10 is ubiquitous and available nationally. Fueling infrastructure - from petroleum- and bio-refineries, through the pipelines and rail networks, to the terminal/blending facilities and filling stations – produces, blends, and delivers the fuel stably and securely. The current regulatory regimen is accommodative while also enforcing operational parameters. In this environment, corn ethanol is cost-effective as an oxygenate and octane enhancer because of its low feedstock costs as well as having no unknown distribution, marketing, and regulatory challenges.

Additional octane introduced to this system from reformates will encounter no substantive constraints. However, ethanol-blended gasoline above 10 percent that is moved throughout the current E10 fuel infrastructure will likely encounter distribution and marketing infrastructure costs as well as regulatory hurdles.

Since corn ethanol is transported from producing regions to consuming ones by rail, there will be an increased need for more dedicated tank cars. At terminals and filling stations tankage will need to be increased either through expansions or additions. At filling stations in particular, modifications to existing underground tanks in order to accommodate higher ethanol blends range in cost between $5 and $25 thousand. Additional underground tanks, if segregation of fuels is necessary, can cost between $100 and $120 thousand. EPRINC estimates that a conversion of a high-volume station with eight pumps requiring one additional storage tank would be approximately $280 thousand. Given the generally low margins of filling stations, it could take up to twenty years to recover this capital expense. Spread across 125 to150 thousand U.S. filling stations, these are formidable expenses for these low-growth businesses.

Additional calculations need to be made on the likely cost to those service stations requiring higher ethanol-blend-certified pumps, seals, and hoses to their fueling equipment. EPRINC's initial estimate of these modifications could be between 3 and 5 cents per gallon depending on the extent of retrofits and number of stations that require these.

Furthermore, higher ethanol blends face a lattice of conflicting regulations at both the federal and state levels. EPA has approved the sale of 15 percent ethanol blends for motor vehicles MY2001 and later; however, the gasoline tanks at many filling stations are either not certified by EPA for these blends, or owners, themselves, do not know if their tanks are certified or warranted. In addition, higher ethanol blends are not certified in most states. In California in particular, it takes up to six years for testing and approval of new gasoline formulations, and given that California's Air Resources Board (CARB) models show higher NOx emissions from blends above E10, it is unlikely that the state will certify ethanol-gasoline blends above E10.

Lastly, while corn acreage yields have grown considerably over the last forty years, more octane from corn ethanol will likely require more corn either diverted from existing corn production or necessitate expanding more acreage from as-yet uncultivated land. These second-order effects under an "Ethanol-Dominant" scenario will likely present additional challenges, either from opposition of environmental groups that oppose bringing more land under corn cultivation or possible rising costs of corn production.

CONCLUSION

Putting aside the difficulty of building a viable coalition for reform of CAFE and RFS, policy makers will want to have a careful assessment of the costs of moving the entire U.S. gasoline supply to a higher octane. This preliminary analysis shows that it can likely be accomplished at a cost of 3 to 8 cents per gallon across a wide range of implementation scenarios at the refinery gate.

Although considerable work remains to understand the costs of distribution and final sales at retail stations for higher ethanol blends, distribution of large volumes of gasoline containing more than 10 percent ethanol would likely yield additional costs somewhere between 3 to 5 cents per gallon. Since the program is implemented over 15 to 20 years, gasoline production, distribution, and marketing systems would have considerable time to adjust. Transforming the regulatory program to one where blending decisions are driven by relative prices offers a substantial reduction in price risks to consumers as a larger array of solutions are available to meet fuel specifications.

Moving the U.S. gasoline pool to a higher octane fuel will add costs. However, the cost structure needs to be compared to the cost (and price spike risks) associated with continuing the existing program under mandated volumes, which is relatively low now, but under a range of likely outcomes and discretionary shifts in policy could easily exceed 10 cents a gallon.

In general, the distribution of cost risks associated with the mandated program is likely to be higher because the current program relies entirely on administrative volumetric targets in which cost minimizing practices in response to price signals and technological advances are limited.

This would not be the case in a program where manufacturers are free to adjust their production process to meet a higher octane standard free of mandates in the use of blending components or manufacturing processes. As previously stated, the "Grand Compromise" proposal should not be confused with a least-cost solution, which previous EPRINC research concludes would involve merely eliminating volumetric mandates for biofuel blending.

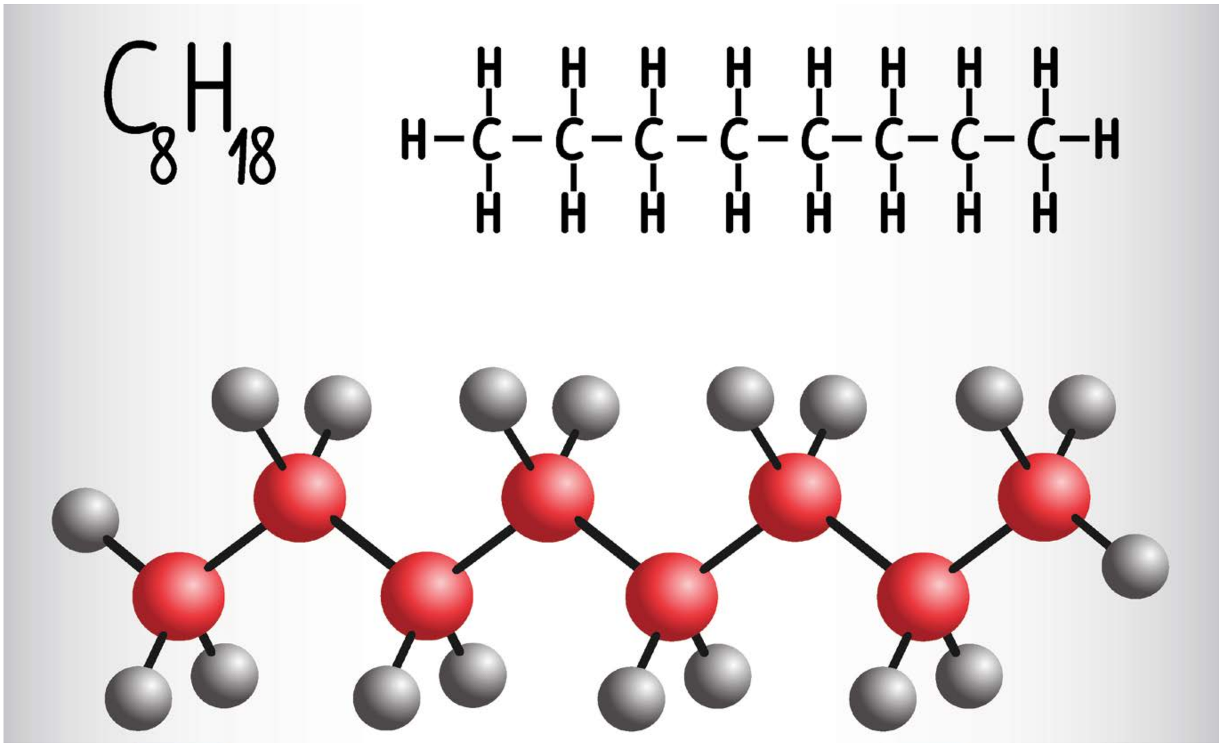


TABLE OF ABBREVIATIONS

Octane-Related

RON	Research Octane Number
MON	Motor Octane Number
AKI	Anti-Knock Index

Agencies and Related Designations

CARB	California Air Resources Board
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
NHTSA	U.S. National Highway Traffic Safety Administration

Fuels, Blends, and Additives

E10	Gasoline with 10% ethanol
E20	Gasoline with 20% ethanol
ETBE	Ethyl Tert-Butyl Ether
MTBE	Methyl Tertiary Butyl Ether
TAME	Tert-Amyl Methyl Ether
MMT	Methylcyclopentadienyl Manganese Tricarbonyl
TEL	Tetra Ethyl Lead
TML	Tetramethyl Lead

Legislation

21CTFA	Discussion Draft of 21st Century Transportation Fuels Act
CAFE	Corporate Average Fuel Economy Standards
EPAct05	U.S. Energy Policy Act of 2005
EISA	U.S. Energy Independence and Security Act of 2007
EPCA	U.S. Energy Policy and Conservation Act of 1975
RFS	Renewable Fuel Standard
SAFE	Safe Affordable Fuel Efficient Act

Metrics

MBD	Million Barrels per Day
TBD	Thousand Barrels per Day
BGY	Billion Gallons per Year
MGY	Million Gallons per Year
GPY	Gallons per Year
BTU	British Thermal Units

Miscellaneous

GHG	Greenhouse Gases