

Fuels Institute

**Analysis of the
Potential for
Increasing
Octane in the
U.S. Fuel Supply**

MARCH 2019



ACKNOWLEDGEMENTS

The Fuels Institute would like to recognize Stillwater Associates LLC, MathPro Inc., Amicus Policy Group, LLC, and the U.S. Department of Energy's Co-Optimization of Fuels & Engines Initiative for their significant contributions to the understanding of the potential for high octane fuels. In addition, the Fuels Institute thanks them for reviewing and providing valuable input into the preparation of this paper.

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Introduction

It is generally accepted and demonstrated through testing and market experience that spark ignition (SI) engines can be designed to deliver greater efficiency and lower emissions if they are calibrated to perform on high octane gasoline. While this fact is not debated, there are several relevant questions that remain:

What gasoline octane rating will deliver the optimum improvement in engine efficiency and emissions reductions in the most cost-effective way to benefit consumers?

- What regulatory structures might need to be adjusted to facilitate the availability of fuel with the desired octane rating?
- How will the desired high octane fuel (HOF) be produced?
- How will the desired HOF be delivered to consumers?
- How will the market transition to delivering HOF-optimized vehicles and offering HOF at retail facilities in requisite volumes in an appropriate time-frame?
- What will be the ultimate effects of HOF to consumers, various stakeholders and the market in general?
- How might consumers react to the introduction of HOF-optimized vehicles and HOF?

In 2016, the Fuels Institute commissioned Stillwater Associates, MathPro Inc., and Amicus Policy Group LLC to study the potential for establishing a market for HOF

in the United States. The study was designed to address three critical areas:

- What HOF formulations are feasible and scalable and how much might it cost to produce them?
- What regulations would need to be adopted or enacted to create a market for HOF and how long might this process take?
- What adjustments might be required within the distribution and retail sector of the market to accommodate the new HOF, how long could this take and how much might it cost?



This report was commissioned shortly after the U.S. Department of Energy launched the Co-Optimization of Fuels & Engines (Co-Optima) Initiative, which coordinates efforts across nine different national laboratories and thirteen universities to better understand the opportunities presented by developing engines and fuel chemistries that could deliver improved efficiency.

Since the initiation of these independent yet complementary projects, some members of the automotive and fuel producing industries began discussing public policy options for introducing HOF and HOF-optimized vehicles. The United States Center for Automotive Research (USCAR) commissioned and released analysis of fuel formulations that might deliver enhanced efficiency and improved performance of the vehicle fleet. The findings of this research have led to consideration of potential legislation to establish a minimum octane requirement in the United States of 95 RON (research octane number).

The research conducted by Co-Optima, the Fuels Institute and USCAR forms the primary basis of understanding relative to the potential for a HOF market. This white paper leverages findings from each of these initiatives and specifically presents the detailed analysis of the Fuels Institute-commissioned Stillwater et al. report within the context of evolving policy discussions relative to HOF. The paper presents information derived from Co-Optima and USCAR solely for additional background and context for the educational benefit of the reader. The analysis presented in this paper is exclusively that of the Fuels Institute and does not reflect the opinion of any third party sources of information.

The Fuels Institute prepared this report so that stakeholders could better evaluate various options for a HOF market for their ultimate effect on fuel production capacity and cost, regulatory timelines and infrastructure requirements and potential impact on the consumer. The analysis should not be construed as reflecting a preference for or against any approach or as advocating for or against the establishment of a HOF market. The Fuels Institute is agnostic regarding the development of the market and seeks only to provide business and policy decision makers with objective analysis upon which to consider their options.

In preparing this paper, the Fuels Institute is leveraging, among others, the following resources:

- “Transitioning the U.S. Gasoline Pool to a Single High-Octane Fuel: A Baseline Analysis,” prepared for the Fuels Institute by Stillwater Associates LLC, MathPro Inc. and Amicus Policy Group, LLC (hereafter referenced as Stillwater et al.¹)
- Research conducted by the Co-Optimization of Fuels & Engines (Co-Optima) Initiative, a collaborative research project of the U.S. Department of Energy and nine national laboratories
- Stakeholder input derived from two HOF workshops conducted by the Fuels Institute and Co-Optima in July 2018
- Fuel market data sourced from NACS, OPIS and U.S. Energy Information Administration
- Experience and input from the Fuels Institute Board of Advisors

¹ Leister, Michael, D Hirshfeld, J. Kolb, and E. Shapiro; “Transitioning the US Gasoline Pool to a Single High-Octane Fuel: A Baseline Analysis,” Fuels Institute Report, October 2018. (aka, Stillwater et al.)

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Overview of Octane

In general, the public is uninformed concerning the role of octane in gasoline and the internal combustion engine (ICE). The Fuels Institute report commissioned to Stillwater et al. and the Co-Optima initiative provide a basic and more advanced understanding of the role of octane in fuel and its benefits to the performance of an ICE. This basic understanding is critical for anyone considering the potential development of a high octane fuel (HOF) market.

WHAT IS OCTANE?

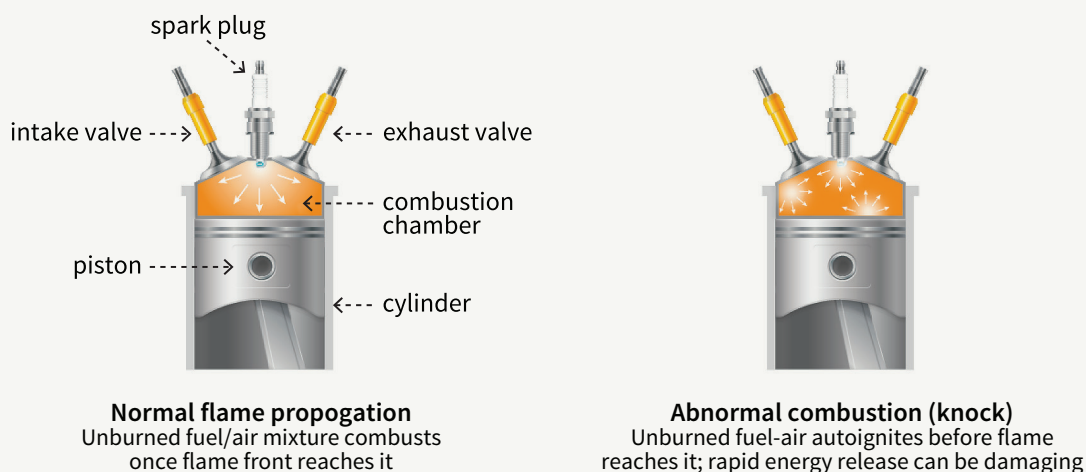
Octane is a measure of a fuel’s ability to resist auto-ignition (“knock”) while being compressed. A gasoline internal combustion engine works by compressing an air-fuel mixture in its cylinders, thereby raising the mixtures’ temperature and pressure, and then igniting the mixture with a spark, at a specific instant during compression. The resulting combustion releases heat energy, which the engine converts into the mechanical energy that powers the vehicle.

“Auto-ignition” – spontaneous ignition of the fuel – may occur at a sufficiently high temperature and pressure (a consequence of compression) in the engine cylinders. Spontaneous uncontrolled auto-ignition –

perceived by the driver as “knocking” – is highly undesirable. It reduces fuel economy, robs the engine of power, and may damage the engine. Hence, gasoline must be formulated to minimize the likelihood of auto-ignition – or, in other words, to maximize its “anti-knock” performance – over the full operating range of specified engines and vehicles. Figure 1 from Co-Optima provides a visual description of engine knock.

Spark ignition (SI) engines are most efficient at high load and low speed, but these conditions exacerbate the potential for knock and limit efficiency. Fuels with higher octane ratings are better able to mitigate knock and enable higher efficiency. (Figure 2)

FIGURE 1: A PRIMER ON KNOCK²

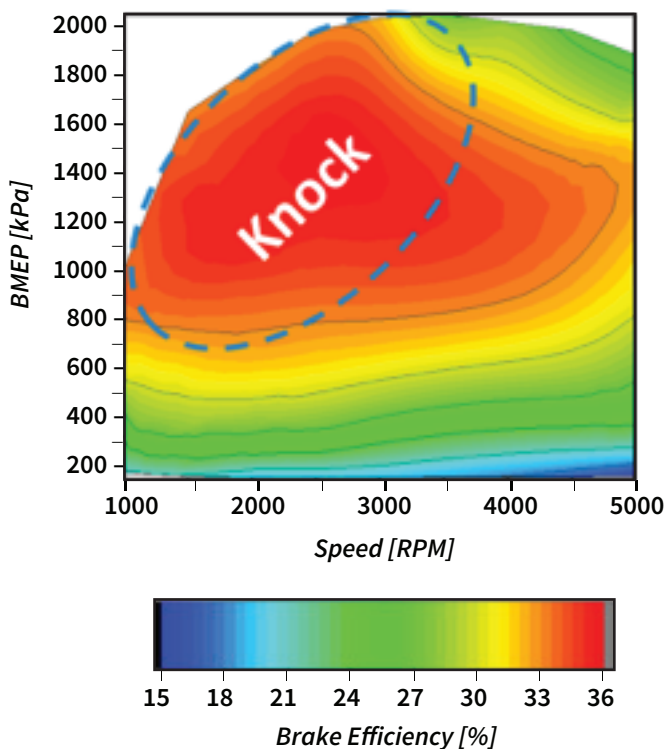


KNOCK IN UNBURNED GAS IS PROMOTED BY INCREASED TEMPERATURE, PRESSURE, AND TIME

Source: Co-Optimization of Fuels & Engines Initiative

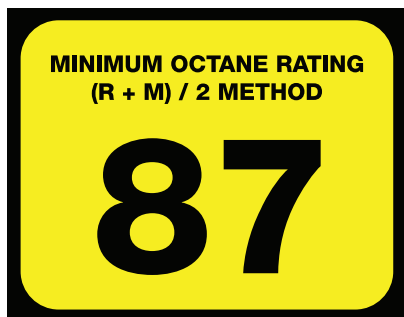
² Farrell, John, “Octane and Advanced Spark Ignition Engines: Insights from the Co-Optima Project,” Presentation delivered July 2018, Fuels Institute and Co-Optima Octane Road Show

FIGURE 2: WHAT LIMITS ENGINE EFFICIENCY?



Source: Co-Optimization of Fuels & Engines Initiative

FIGURE 3: AN OCTANE LABEL IN THE U.S. PRESENTS THE AKI OF THE FUEL USING THE (R+M)/2 METHOD



Octane ratings are measured in two ways: Research Octane Number (RON) and Motor Octane Number (MON). Both tests are conducted in a single cylinder octane engine, but under different operating conditions.³ The difference between RON and MON is known as octane sensitivity (S). The RON test results are more reflective of the operating conditions in modern engines and are becoming the preferred method for measuring the anti-knock properties of fuel.

In the U.S., gasoline is marketed with an octane value calculated as an average of RON and MON and designated on fuel pumps as (R+M)/2. This value is known as the Anti-Knock Index (AKI). Canada and Brazil also market gasoline based upon its AKI; Europe and most of the rest of the world market gasoline based only on its RON value.⁴

Fuel octane has become increasingly important as automakers seek to achieve greater fuel efficiency and lower emissions from ICEs. To achieve established targets, engineers are turning to smaller engines with higher compression ratios and turbochargers. Compression ratio (CR) is the ratio of the compression chamber’s largest internal volume (when the piston is at the bottom of the stroke) to its smallest internal volume (when the piston is at the top of the stroke).⁵ The greater the CR, the higher the theoretical efficiency but the greater the risk of knock and the higher relative octane value required in gasoline.

Co-Optima developed an equation (known as the engine efficiency “merit function”⁶) to establish a quantitative relationship between fuel properties and engine efficiency. The merit function (Figure 4) demonstrates that the two fuel properties that have the greatest impact on fuel efficiency for a turbocharged (“boosted”) engine are RON and Sensitivity, accounting for more than 90% of the efficiency improvement from representative high performance fuel blendstocks.

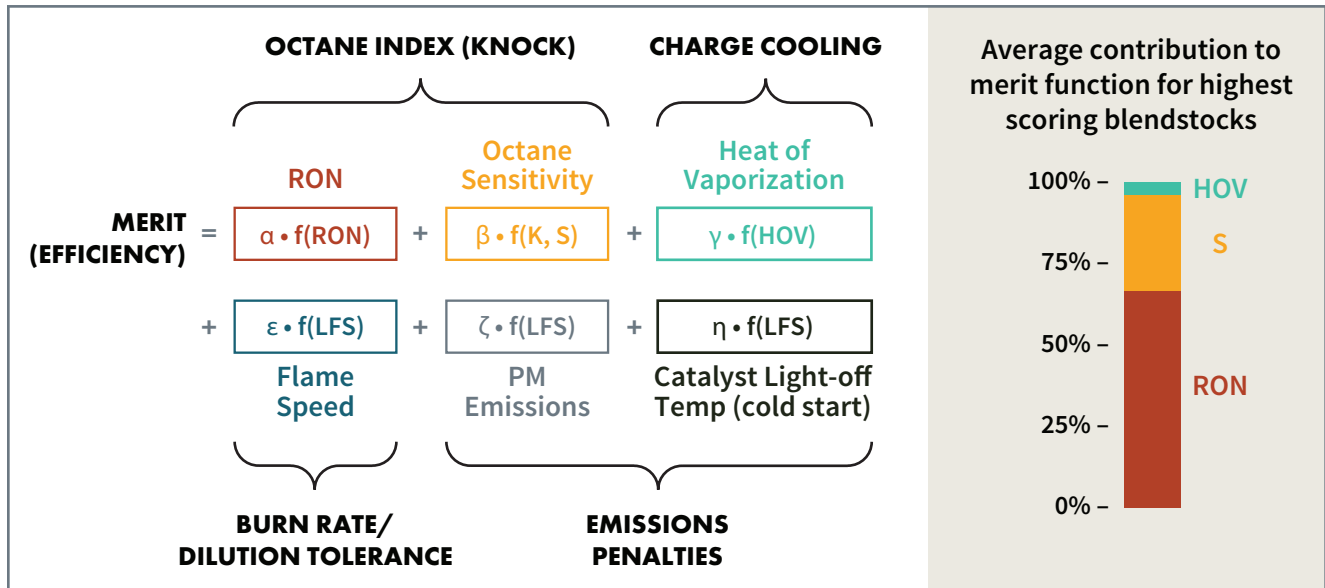
³ RON is measured with engine speed at 600 rpm, air temperature at 125 degrees F and spark timing at 13 degrees before top dead center (“BTDC”). MON, considered a more “severe” testing method, uses hotter intake air temperature (300 degrees F), higher engine speed (900 rpm) and earlier spark timing (19-26 degrees BTDC). (Farrell) The MON test is used to determine a fuel’s resistance to knock during standard rapid acceleration, hill climbing, hauling a heavy load, etc. (Stillwater et al.)

⁴ Stillwater et al.

⁵ Ibid.

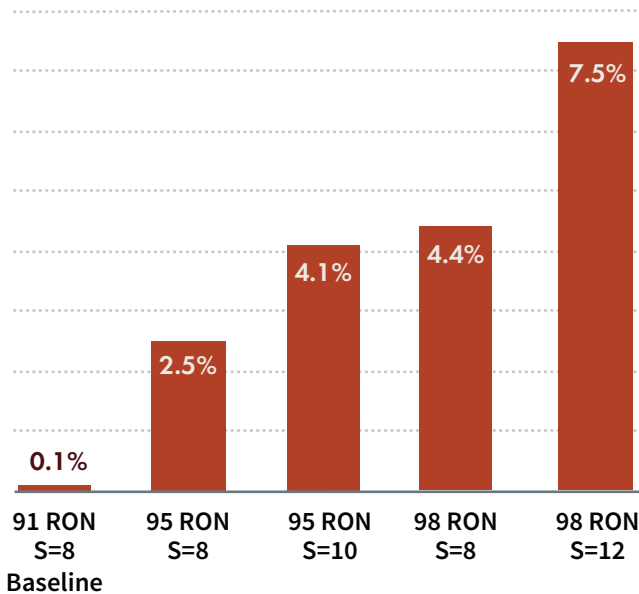
⁶ Miles, Paul. “Efficiency Merit Function for Spark Ignition Engines: Revisions and Improvements Based on FY16–17 Research.” Technical Report. U.S. Department of Energy, Washington, DC. 2018. DOE/GO-102018-5041.

FIGURE 4: CO-OPTIMA MERIT FUNCTION FOR EFFICIENCY OF FUEL BLENDSTOCKS



Source: Co-Optimization of Fuels & Engines Initiative

FIGURE 5: EFFICIENCY IMPROVEMENT: BOOSTED SI ENGINES



Source: Co-Optimization of Fuels & Engines Initiative

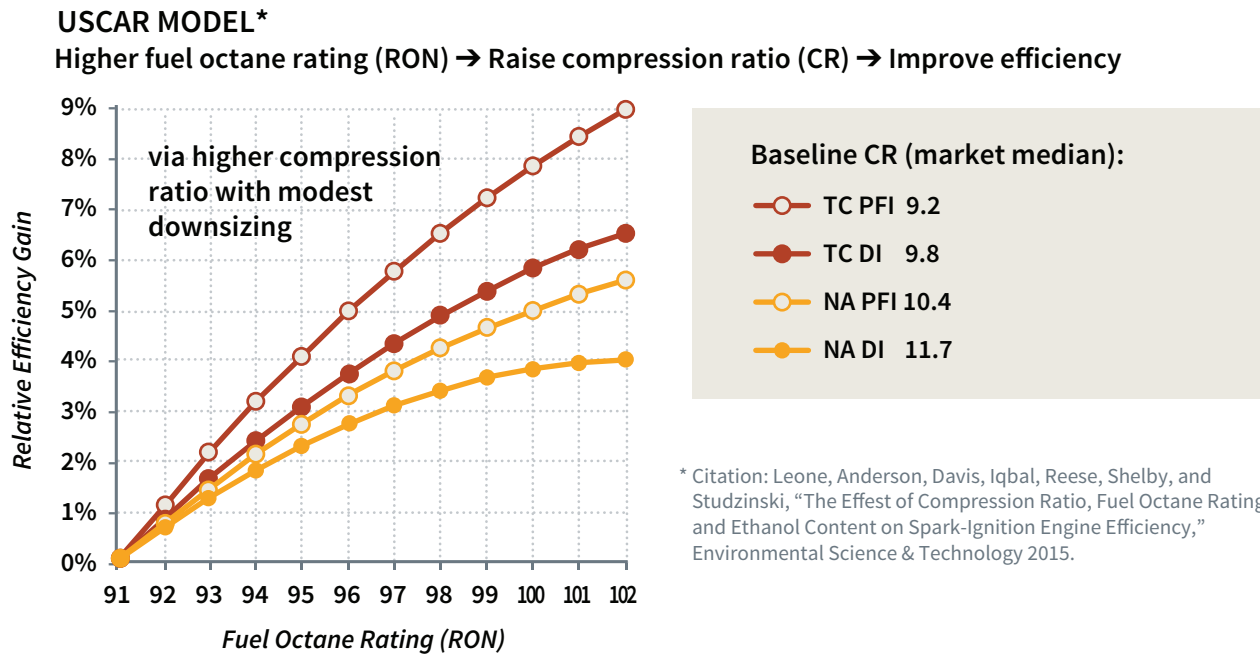
In using this merit function, Co-Optima was able to calculate the anticipated efficiency improvement one could expect from a boosted SI engine when operating on fuels with different RONs and sensitivities (Figure 5).

The importance of RON and S for modern engines is further evidenced by the formula used to derive a fuel’s octane index (OI), which is expressed as $OI = RON - KS$, where the K-factor is an “engine-dependent constant that depends on design parameters and operating conditions.”⁷ In generic terms, this means that the operating conditions of the engine (largely dependent upon its design, such as downsized and boosted) affect the knock resistance of the fuel. The AKI, which averages RON and MON, does not explicitly take into consideration engine operating conditions, but rather represents the average knock resistance over two disparate cycles. Consequently, focusing on the octane index provides a more accurate characterization of a fuel’s resistance to knock in modern engines.

Further evidence of the need for higher octane to enable more efficient engines is provided by the United States Council for Automotive Research (USCAR). At a presentation to the SAE⁸ Government-Industry Conference in January 2018, USCAR representatives

shared the graphic presented as Figure 6, which clearly shows that relative efficiency gains increase with an increase in RON of the fuel, regardless of the type of engine being tested.⁹

FIGURE 6: ENGINE EFFICIENCY FROM HIGHER OCTANE FUEL (HOF)¹⁰



Source: USCAR, "Well-to-Wheel Analysis of Higher Octane Fuels: Cost and CO2 Emissions"¹¹

8 SAE – Formerly the Society of Automotive Engineers

9 In this graphic, the engines represented include a turbo charged port fuel injected engine with a CR of 9.2; a turbo charged direct engine with a CR of 9.8; a naturally aspirated port fuel injected engine with a CR of 10.4; and a naturally aspirated direct injected engine with a CR of 11.7. Each one benefited from gasolines with higher RON.

10 Anderson, James, A. Iqbal and W. Studzinski, "Well-to-Wheel Analysis of Higher Octane Fuels: Cost and CO2 Emissions," Presentation delivered to SAE Industry-Government Conference, January 2018, on behalf of USCAR.

11 In Figure 6, the engine configurations presented in the data are described with abbreviations which refer to the following: TC – Turbo Charged; NA – Naturally Aspirated; PFI – Port Fuel Injection; DI – Direct Injection. The numbers following each of the engine descriptions refer to the engine's compression ratio.

HISTORY OF OCTANE IN THE UNITED STATES

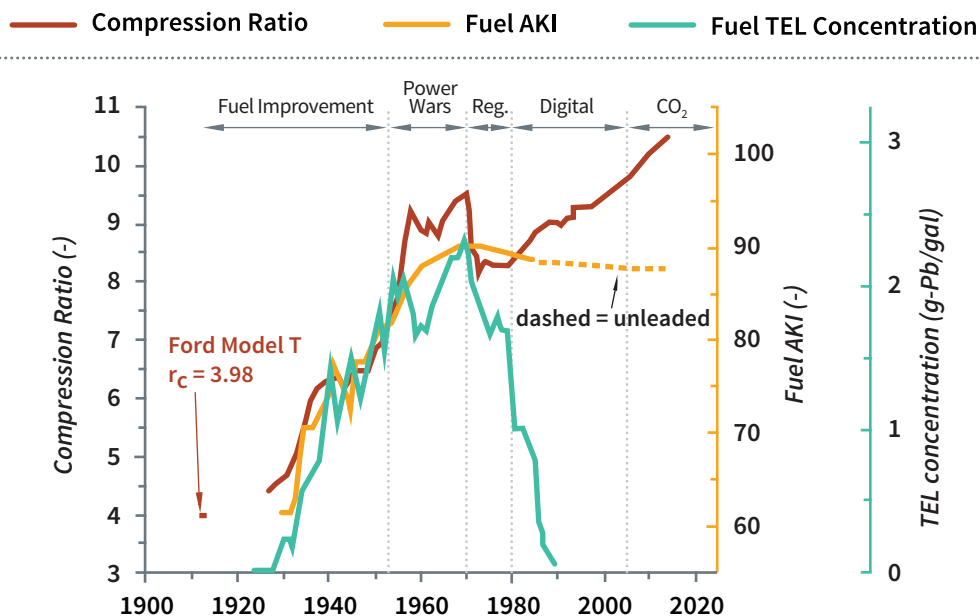
To better understand the fuel octane market in the U.S., it is helpful to understand its history. Refineries have used a variety of methods to increase the octane in gasoline. Prior to 1974, the primary and least expensive source of incremental octane was the additive tetra-ethyl lead (TEL, or lead for short). Between 1960-1980, regular grade gasoline containing lead had an octane rating that averaged 89.4 AKI/93 RON. Premium fuel containing lead during that same period averaged 95.2 AKI/99 RON. However, air- and soil-borne lead caused by vehicle emissions presents a significant risk to public health and the environment. In addition, lead was poisonous to catalytic converters, which were necessary to address tailpipe emissions of smog precursors. Consequently, unleaded fuel was introduced in 1975 and all new vehicles as of that year were required to operate on unleaded fuel only. The removal of lead resulted in a slight decline in the average octane rating of the U.S. gasoline pool.

After the removal of lead, refiners were able to replace octane in gasoline through a number of ways, including

increasing the use of high-octane refinery-produced alkylate and reformat, but also by using methyl tertiary butyl ether (MTBE).¹² Following concerns regarding the environmental implications of MTBE, especially when it was released into groundwater through leaks and spills, refiners turned increasingly to ethanol as the incremental octane source of choice. Today, nearly all gasoline sold in the U.S. is blended with 10% ethanol.

Current gasoline octane ratings in the U.S. vary considerably from regular unleaded with an 85 AKI in the Rocky Mountain region to premium with a 93 AKI in some eastern markets. On average, regular unleaded typically has a S of 8.3 and premium unleaded typically has a S of 10. This would equate to a RON value for regular that is about 4 points higher than the AKI and about 5 points higher for premium. (There is no federal requirement for octane in the U.S. – octane is determined by an industry standard. However, these standards are sometimes referenced in state regulations.)

FIGURE 7: REMOVAL OF LEAD AND RESULTING FUEL OCTANE



Source: Splitter, Pawlowski, Wagner, “Historical Analysis of the Co-evolution of Gasoline Octane Number and Spark-Ignition Engines,” January 2016

12 In addition to providing a source of octane, MTBE was later used to satisfy the oxygen content requirements for federal and California reformulated gasolines.

FIGURE 8: MEASURED OCTANE AND OCTANE RATINGS OF NORTH AMERICAN GASOLINE GRADES (AKI)

COUNTRY & REGION	AVERAGE MEASURED OCTANE (AKI)		PREDOMINANT POSTED OCTANE (AKI)		
	Premium	Regular	Premium	Midgrade	Regular
UNITED STATES					
PADD 1	92.8	87.4	93	89	87
PADD 2 Eastern	92.8	88.4	93	89	87
Western	91.8	87.7	91	89	87
PADD 3 East & Central	93.1	87.3	93	89	87
West Texas & New Mexico	91.3	87	91	89	87
PADD 4 Mountain States	91.7	86.4	91	87	85
PADD 5 California, Arizona & Nevada	91.2	87.8	91	89	87
Oregon, Washington & Hawaii	92.5	88.1	92	89	87
Alaska	90	87.1	90	-	87
CANADA	91.4	87.7	91	89	87
MEXICO	92.5	87.1	92	-	87

NOTES:

- 1 The octane ratings apply to finished gasoline (after ethanol blending).
- 2 Eastern PADD 2 comprises Illinois, Indiana, Kentucky, Michigan, Ohio, Tennessee, and Wisconsin.
- 3 Western PADD 2 comprises Iowa, Kansas, Minnesota, Missouri (most of), Nebraska, North Dakota, Oklahoma, and South Dakota.
- 4 PADD 4, the Mountain States region, comprises Colorado, Idaho, Montana, Utah, and Wyoming.

SOURCES: Derived from *Alliance of Automobile Manufacturers North American Fuel Surveys* and various internet sites.

Source: Stillwater et al.

Consequently, automobile manufacturers have to calibrate their engines to tolerate and run acceptably on all variations of octane in the market. Engines that prefer higher octane fuels but must be able to accommodate lower octane fuel sacrifice efficiency and performance. This applies even to “premium recommended” and “premium required” vehicles.

“Premium recommended” vehicles can operate on lower octane fuel but will perform best and with better efficiency when using premium fuel. “Premium required”

vehicles must use premium gasoline to achieve best performance and possibly avoid risking damage to the engine from auto-ignition.¹³

Despite requirements or recommendations, because there is no system to prevent a consumer from using a lower octane fuel than recommended or required (referred to as “misfueling”), even these vehicles are designed to protect themselves from potential auto-ignition, compromising performance and efficiency.

THE EUROPEAN UNION OCTANE STANDARD

The European Union has been referenced as a potential model for a U.S. octane standard. In 2009, the European Committee for Standardization, or Comite' European de Normalisation (CEN), adopted EN 228, establishing a minimum octane rating of 95 RON for gasoline sold within the EU. (Member states may continue to permit 91 RON, however.) This decision essentially formalized what was already the norm in the market. A fuel survey conducted in 2003 found that 81% of the fuel sold within the EU was 95 RON,¹⁴ which is approximately equivalent to 91 AKI in the United States. (98 RON gasoline is sold in the EU as a premium fuel.)

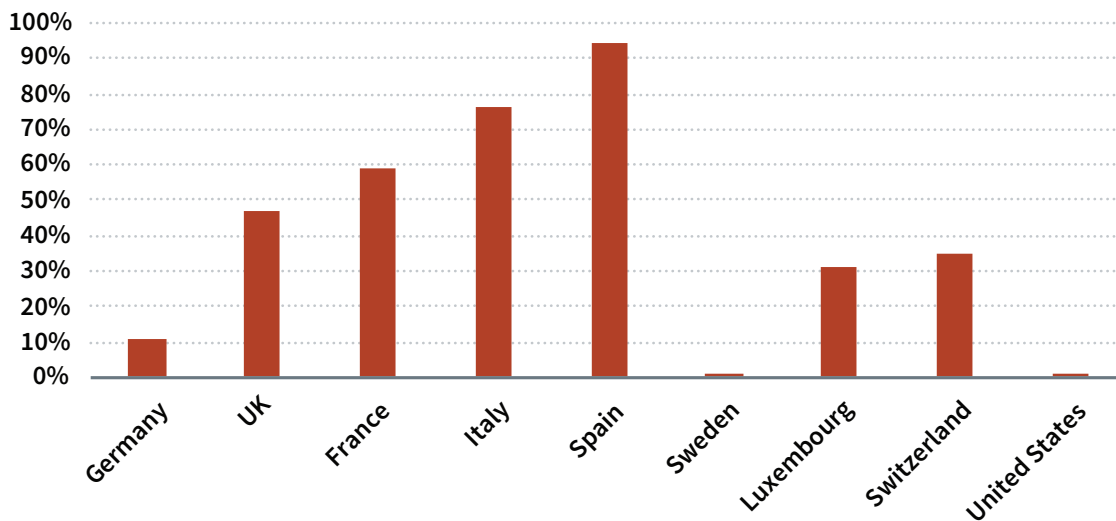
One reason why EU octane levels exceed those of the U.S. can be attributed to the history of lead in gasoline. As noted above, the U.S. began phasing lead out of its fuel supply in 1974. The EU, however, did not begin to introduce unleaded fuel until 1987 and, by 1993 when the share of the U.S. fuel supply containing lead was less

than 1%, in some markets in the EU lead (which was the least expensive source of incremental octane) remained present in more than 90% of the gasoline supply.

In referencing the EU, some indicate it would be preferable for the U.S. to mirror the prevailing global standard for octane and to limit the variability of octane within its borders, thereby enabling more efficient engine design. Both arguments are valid, but the experience in the EU and the U.S. is markedly different and should be recognized. In 2009, the CEN established a baseline that was consistent with 81% of the fuel in the market; to transition to a similar standard, the U.S. must substantially raise the octane baseline of its market. In the U.S. in 2017, regular 87 AKI (approximately 91 RON) comprised 87% of supplied gasoline and premium (91 AKI, approximately 95 RON) approximately 11% of supplied gasoline.¹⁵

FIGURE 9: SHARE OF LEADED GASOLINE, 1993^{16,17}

Share of Gasoline Market that was Leaded in 1993



Sources: Thomas, "The Elimination of Lead in Gasoline," Nriagu, "The Rise and Fall of Leaded Gasoline"

14 Gmucova, Natalia, Analyst Europe and CIS, Stratas Advisors, Background communications with Fuels Institute regarding European octane standard, July 2018.

15 The market share percentages presented here derive from the U.S. Energy Information Administration's data of Prime Supplier Sales Volumes. (https://www.eia.gov/dnav/pet/pet_cons_prim_dcu_nus_m.htm) A prime supplier is defined as "A firm that produces, imports, or transports selected petroleum products across State boundaries and local marketing areas, and sells the product to local distributors, local retailers, or end users."

16 Thomas, V.M., "The Elimination of Lead in Gasoline," Annual Review, Energy Environment. 1995. 20: 301-24

17 Nriagu, Jerome, "The Rise and Fall of Leaded Gasoline," The Science of the Total Environment, 92 (1990) 13-28

Recent Legislative Discussions

Fuels Institute staff have been involved in discussions regarding HOF for years through industry meetings and conferences. In 2017, Fuels Institute Executive Director John Eichberger spoke on three separate panels with different automotive engineers. In those sessions, the engineers separately told audiences that to design an engine for optimum efficiency and performance they would need fuels with minimum RONs and Sensitivities of 98 RON 10 S, 100 RON 12 S and 102 RON 14 S. Such input contributed to the design of the Fuels Institute-commissioned report written by the Stillwater et al. team.

In late 2017, it became known that some stakeholders within the automobile manufacturing and fuel refining industries had begun discussing the possibility of pursuing legislation to establish a HOF market to enable more efficient engine design for new vehicles. The following is a general summary of provisions that have been under consideration by stakeholders and Members of Congress:

- Require new vehicles sold as of a certain model year to be required to run on a minimum HOF of 95 RON or higher.
- Establish a federal minimum octane level for HOF of 95 RON, with potential for higher octane fuels to be introduced. 95 RON HOF would increase market share with fleet turnover.
- Establish misfueling prevention requirements to prevent new vehicles from fueling with anything other than compliant HOF.

This proposal seeks to expedite the introduction of HOF vehicles by leveraging the capabilities of the existing fuel market. This market-efficient approach would result in efficiency and performance benefits for new vehicles. Here are some of the key benefits of this approach:

- **Market Access:** 95 RON is substantially similar to today's 91 AKI fuel, which is currently available in all markets and typically at all retail facilities. 95 RON

currently is and can continue to be produced with 10% ethanol, which eliminates any compatibility issues with the fuel distribution and retail system and presents no misfueling concerns relative to legacy vehicles fueling with the new HOF. Further, 95 RON can be sold in all 50 states without regulatory changes other than labeling and a change in octane definition (i.e., authorizing sale of fuel based upon RON as opposed to current requirements to label fuels based exclusively upon AKI).

- **Lower Cost Efficiency Gains:** According to advocates of this approach, optimizing engines to run on 95 RON will deliver sufficient improvements in vehicle fuel efficiency to enable automakers to leverage more cost effective options to satisfy the Corporate Average Fuel Economy (CAFE) requirements, notwithstanding potential amendments proposed in summer 2018. According to USCAR, 95 RON optimized vehicles will be able to meet these standards at a cost that is \$400 per vehicle lower than competing fuel efficiency options.¹⁸
- **Lower CO2 Emissions:** Based upon its well-to-wheels analysis, USCAR estimates that converting the vehicle and fuels markets to a 95 RON standard would deliver greater overall reductions in CO2 emissions compared to the current market or a 98 RON market, incorporating emissions attributed to fuel production and vehicle operation.¹⁹

¹⁸ USCAR

¹⁹ Ibid.

- California Compliant:** California regulations effectively prevent the sale of fuels with octane ratings higher than 95 RON. California’s Predictive Model limits ethanol to not more than 10.9% due to NOx emission constraints. Further controls within the CA Reformulated Gasoline (CA RFG) program limit the ability of refiners to produce gasoline with octane greater than 95 RON due to the impact of refinery octane components on the emissions performance of the vehicles used to develop the model. Unfortunately, the model was last updated 10 years ago and more than half of the fleet represented are model year 1989 or older. Updating the CA Predictive Model to accommodate new fleet dynamics and to evaluate the emissions performance of new fuel formulations would require significant investment of time and resources. There does not seem to be much interest on the part of California regulatory bodies to undertake that effort.²⁰

But the proposal also represents compromises relative to what automotive engineers had been advocating, introduces potential political challenges to implementation relative to the effect it might have on the biofuels industry and raises some potential consumer issues. Some of these factors are presented below:

- Octane Sensitivity:** The 95 RON proposal does not include a requirement for octane sensitivity. As presented above, Co-Optima research has demonstrated that sensitivity is a key fuel property in delivering efficiency. However, establishing a sensitivity standard (which would essentially be establishing both a RON and MON standard) would complicate the transition to 95 RON and increase production costs. Consequently, the current negotiations opt for a more efficient market transition to a higher octane fuel, while sacrificing additional potential vehicle fuel efficiency that could be gained by mandating a specific sensitivity.
- Limited Biofuels Expansion:** Some refiner stakeholders who have indicated potential support of this proposal have simultaneously indicated it must include reform or repeal of the Renewable Fuel

Standard (RFS). The RFS has been instrumental in increasing the volume of ethanol and biodiesel that has been blended into the fuel supply. The prospect of significant reform or repeal of that program has spurred potential opposition to the proposal from the biofuels industry which does not see a 95 RON standard as providing any incentive for the market to blend more than 10% ethanol into gasoline. The ethanol industry has been supportive of introducing HOF, but it has typically believed that HOF would include more ethanol and have a higher octane than 95 RON. In addition, while advocates of the proposal believe it provides opportunities for ethanol to increase its market size, an octane standard would provide no benefit to producers of biomass-based diesel who significantly benefit from the RFS.

- Impact on Retail Fuel Prices:** A decision to require all new vehicles to operate only on 95 RON HOF could expose all new vehicle consumers to additional fuel prices at the pump. Given that 95 RON is substantially similar to today’s premium, and the national average retail price difference between regular and premium fuel in the U.S. is often in excess of \$0.50 per gallon, it is possible that consumers could be required to purchase much more expensive gasoline. Further, it is generally expected that as the vehicle fleet turns over and becomes more heavily represented by HOF-required vehicles, legacy fuels such as regular and midgrade gasoline would begin to fade from the market. In such a situation, legacy (pre-HOF) vehicle owners would be required to purchase HOF although their vehicles would not require it.

Research conducted separately for USCAR and the Fuels Institute indicates that converting the gasoline market to 100% 95 RON fuel would increase overall production costs by about \$0.05 per gallon compared with the production of the entire fuel pool in 2016. However, the transition to 100% production of 95 RON fuel could take approximately 20 years.²¹ During this transition period, new vehicle owners could be required to spend more per gallon than legacy vehicle owners.

20 Stillwater et al.

21 Ibid.

Negotiators are considering packages that could address some of these issues to deliver the greatest value to consumers, but there are substantial headwinds. Some primary stakeholders testified at a hearing of the House of Representatives Energy and Commerce Committee on April 13, 2018. Excerpts from their prepared testimony is presented below:

Dan Nicholson, VP General Motors –

“We have an opportunity to play a large role in offering consumers the most affordable option for fuel economy improvement and greenhouse gas reduction. We believe a higher efficiency gasoline solution with a higher Research Octane Number (RON) is very important to achieving this. USCAR research shows that 95 RON makes sense from the viewpoints of both refiners and fuel retailers... Without this new fuel, we will continue to endure the impacts of fuel variation and forego related available fuel economy improvement opportunities.”

Chet Thompson, CEO, American Fuel and Petrochemical Manufacturers (AFPM) –

“If done correctly – through free market principles, the sunseting of the RFS, and implemented over a reasonable phase-in-period – higher octane fuels have the potential to benefit all stakeholders. Higher octane fuels, specifically 95 RON, would help auto companies improve the efficiency of the internal combustion engine and comply with fuel efficiency standards. It would provide the biofuel industry with the opportunity to expand its market share. It would end the RFS for refiners and provide product flexibility for the marketers. And it could benefit consumers by creating a transparent and competitive market for all liquid fuels to compete.”

Tim Columbus, Counsel to SIGMA and NACS²² –

“NACS and SIGMA consider an “octane solution,” which will require automobiles to be built to use fuel with a minimum of 95 Research Octane Number (“RON”) after a date to be determined (presumably post-2022), to be a viable option to consider as part of RFS reform. Given

those automobiles’ need to run on 95 RON fuel, this solution would spur demand for 95 RON fuel, which is already being sold in the marketplace today. Such a plan should be phased in gradually and maintain a strong market for renewable fuels such as ethanol and biodiesel. This is achievable even if it includes gradual off-ramps for RFS mandates.”

Emily Skor, CEO, Growth Energy – *“While we support the move to higher octane fuels, a 95 RON fuel could easily be met with today’s premium gasoline, and there would be little to no incentive to move to biofuel blends above 10 percent. Additionally, we cannot assume that a modest increase in octane to 95 RON will be the necessary driver to continue to grow demand for American-made biofuels and for corn without the access to the market provided by the RFS. Only with a stable RFS and with a significant boost in octane, coupled with a midlevel ethanol blend, can these substantial benefits be achieved.”*

In summer 2018, the EPA released the “Safer Affordable Fuel Efficient (SAFE) Vehicles Proposed Rule for Model Years 2021-2026.” The proposal seeks to increase fuel efficiency requirements consistent with the Obama-era program through 2020, but then freeze efficiency at this level through model year 2026. This approach has somewhat reduced the urgency with which a HOF legislative proposal was being considered by Congress. With potentially less stringent efficiency requirements in the near term, there appears to be more time available to complete negotiations, consider the implications of various details and to develop a comprehensive approach to address concerns expressed by stakeholders.

As of September 2018, there had been no HOF-related legislation introduced in Congress.

22 SIGMA and NACS are trade associations representing fuel marketers and retailers. They were formerly known as the Society of Independent Gasoline Marketers of America and the National Association of Convenience Stores.

High Octane Fuel Research

Prior to the development of a legislative approach to establish a 95 RON market in the U.S., discussions about and research into the issue of HOF and optimized engines had been ongoing for many years. These initiatives were substantially influenced by automotive industry public statements (such as those described above) calling for higher octane fuels.

As mentioned in the introduction, in 2015 the U.S. Department of Energy launched the Co-Optimization of Fuels & Engines initiative. This program pulled together nine of the DOE-funded national laboratories to work collaboratively and simultaneously tackle “fuel and engine innovation to co-optimize performance of both elements and provide dramatic and rapid cuts in fuel use and emissions.”²³ The Co-Optima objective is to “identify fuel properties that optimize engine performance, independent of composition, allowing the market to define the best means to blend and provide these fuels.”²⁴

The objective of [the Fuels Institute] study was to develop a better understanding of what fuel formulations could deliver HOF in a cost effective and scalable manner, how these formulations could be delivered to consumers, what regulatory and market adjustments would be required, how long this might take and how much it might cost.

Shortly thereafter, in September 2015 the Fuels Institute Board of Advisors decided to commission a research project to evaluate the market potential for HOF fuels. Ultimately commissioned to Stillwater Associates LLC, MathPro Inc. and Amicus Policy Group LLC, the objective of that study was to develop a better understanding of what fuel formulations could deliver HOF in a cost effective and scalable manner, how these formulations could be delivered to consumers, what regulatory and market adjustments would be required, how long this might take and how much it might cost.

Together, these projects along with research conducted by USCAR evaluating 95 RON, form the basis of the

fundamental understanding for how the fuels and vehicles market might evolve to operate on and benefit from a HOF market. This section presents results from these various research initiatives to provide a better understanding of what HOF might be possible and how it might be delivered to consumers.

OPTIONS FOR HOF

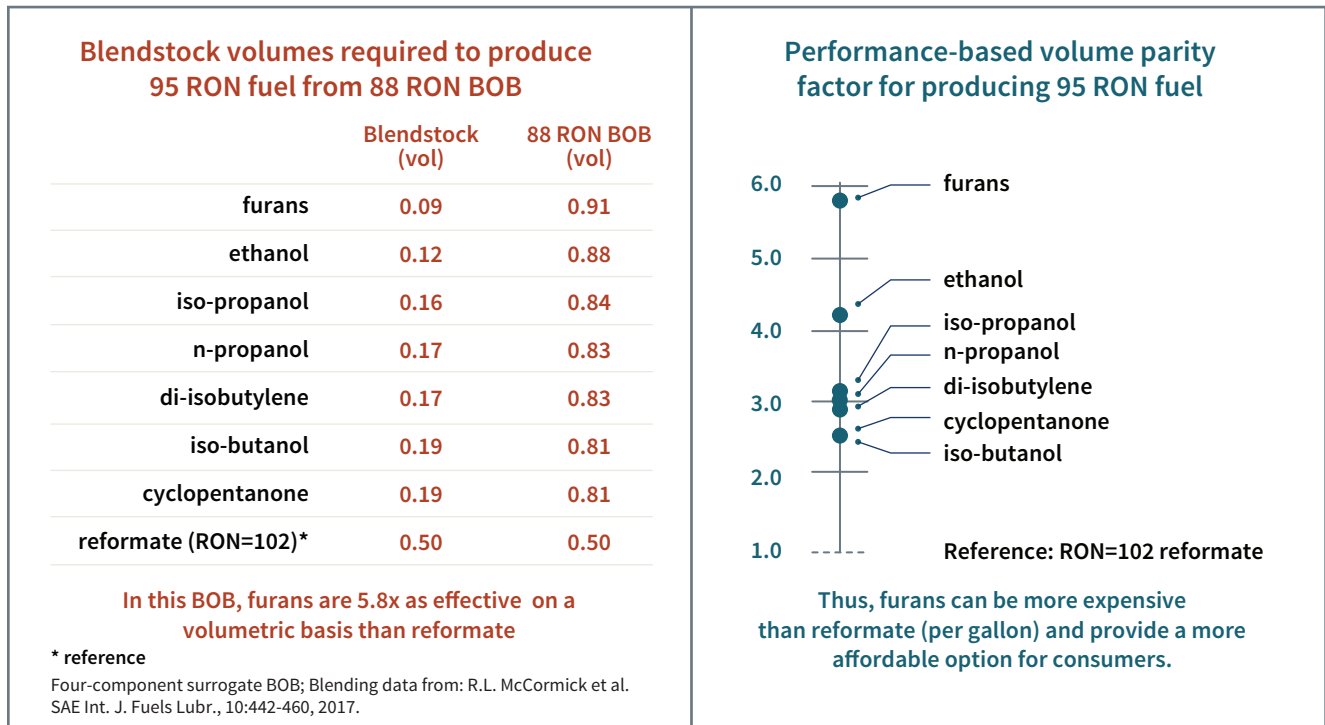
The Co-Optima project performed a rigorous screening project to identify viable candidate fuel components that could deliver a desirable HOF and evaluated the viable candidates through the merit function presented previously. This evaluation found five chemical families that would contribute value to both RON and sensitivity (alcohols, furans, olefins, aromatics, ketones) and only one that would also contribute to positive heat of vaporization (alcohols). From there, researchers evaluated the blending behavior of certain chemicals (or “blendstocks”) and sought to determine the ability of each to boost octane in finished gasoline.

Many blendstocks exhibit nonlinear octane blending when added to a petroleum base fuel (“blendstock for oxygenate blending,” or “BOB”). These blendstocks can be very “potent,” in that a relatively small volume can contribute a large increase in octane (see Figure 10). As such, these blendstocks may represent attractive options to refiners looking to boost octane most cost-effectively. It is important to note, however, that these desirable nonlinear blending effects depend both on the blendstock and composition of the BOB. Co-Optima researchers have developed models that capture these blending effects, and refinery analyses that assess the economic benefits to refiners from these blendstocks are the subject of a forthcoming Co-Optima public report.

23 <https://www.nrel.gov/docs/fy16osti/66146.pdf>

24 Farrell

FIGURE 10: CAPITALIZING ON SYNERGISTIC BLENDING



Source: Co-Optimization of Fuels & Engines

While additional work remains, the Co-Optima research has already provided insight into the availability of blendstocks that could be used to increase fuel octane and enable more efficient engine design. The availability and scalability of each blendstock, along with its corresponding cost to the market, must be evaluated by fuel producers to determine the feasibility of using such products in the production of finished gasoline. But there clearly has been significant work completed to provide insight into options available for refiners. If a HOF market is to develop, fuel producers will be able to reference the results of Co-Optima’s work to identify octane blendstocks that could deliver the best value to the market.

Concurrently, the work conducted for the Fuels Institute by the Stillwater et al. team focused on the production feasibility of HOF through the existing refining and fuel blending system. The project leveraged MathPro Inc.’s proprietary refinery LP model to evaluate the production and cost implications associated with delivering sufficient

volumes of certain HOF formulations. The model was used to represent the aggregate U.S. refining complex, not to conduct a refinery by refinery assessment. Consequently, within the results of this model there will be refineries that are better positioned to deliver the fuels modeled and others that would encounter difficulties to modify their operations to deliver these fuels.

The project evaluated the ability of the refining industry to deliver the following fuel products:

- 95 RON produced as E10
- 98 RON produced as E10, E20 or E30
- 100 RON produced as E10, E20 or E30
- 102 RON produced as E20 or E30

In addition, the model evaluated the production and cost implications associated with producing each fuel at 25%, 50% and 100% of the total fuel supply. These fuels were chosen to serve as benchmarks for analysis, with ethanol concentrations mirroring infrastructure compatibility listings.²⁵

For evaluation of the 95 RON E10 product, the model assumed all fuel products would be converted to 95 RON E10 with a possible 98 RON E10 premium fuel that would be introduced at 25% and 50% market volumes. For the other fuel products, the model assumed the HOF would be added to the existing fuel pool (including all compositions of regular, midgrade and premium grade gasolines) and coexist until decreasing demand for the

lower octane, legacy gasoline blends resulted in their departure from the market. This transition would be facilitated by a requirement that all new vehicles as of a certain date would be optimized and restricted to using only HOF.

The refinery model delivered a number of results relevant to the future market opportunities for HOF. In addition to the contribution of octane through the blending of different volumes of ethanol, the model returned volume implications of refinery-based octane blendstocks like alkylates, reformates and iso-octene. Figure 11 shows the primary gasoline blendstocks that contribute to the octane value of finished gasoline.

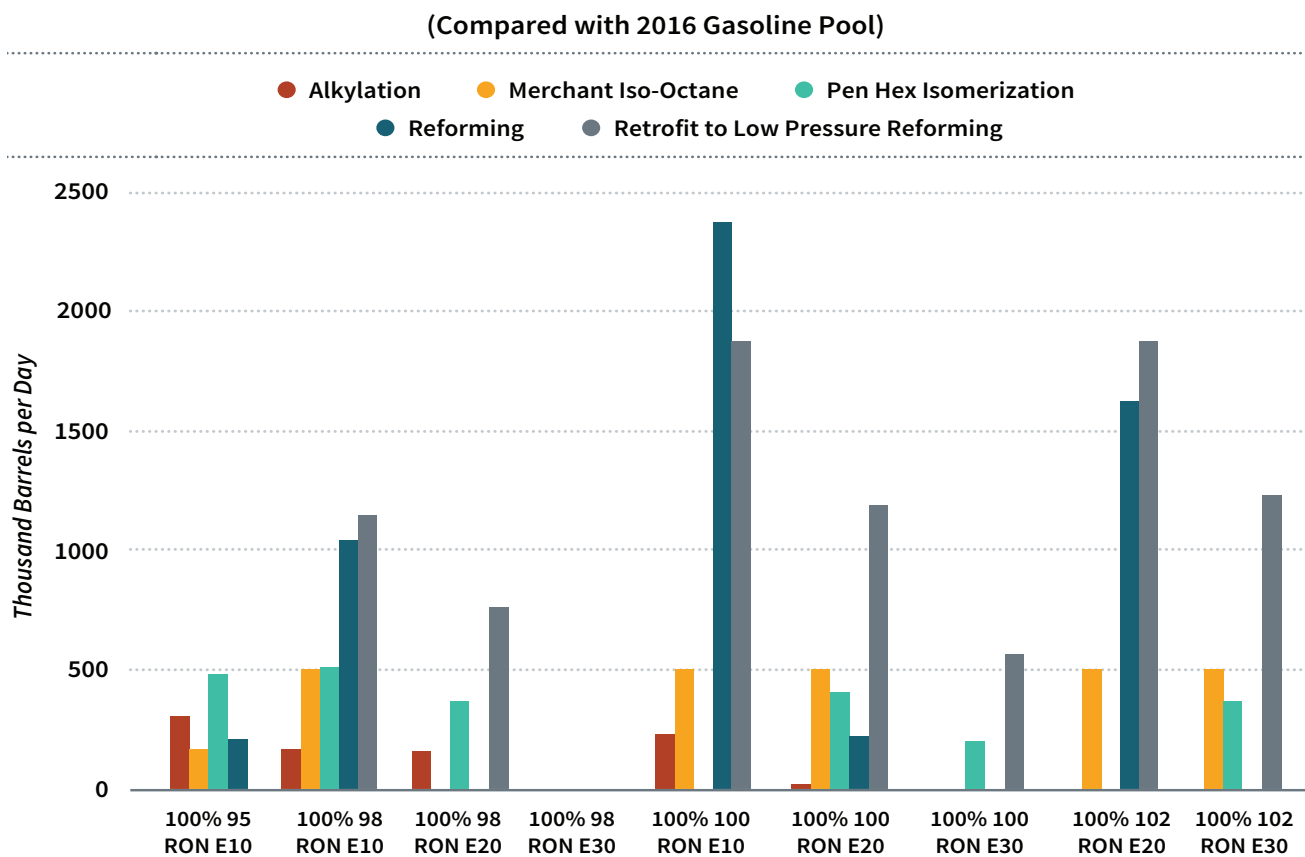
FIGURE 11: PRIMARY GASOLINE BLENDSTOCKS

BLENDSTOCK	Typical AKI Range	Typical Volume Share	SOURCING		Refining Process
			Refinery-Produced	Purchased	
HYDROCARBONS					
Butanes	92	2%–4%	●	●	Crude Distillation, Catalytic Cracking
Natural gasoline	60–70	2%–3%		●	
LSR Naptha	60–70	8%–10%	●		Crude Distillation
Alkylate	93–95	10%–12%	●		Alkylation
Isomerate	82–84	5%–4%	●		Isomerization
Reformate	90–100	2%–7%	●	●	Catalytic Reforming
FCC Naptha	84–85	33%–35%	●		Catalytic Cracking (FCC)
Light Hydrocrackate	83–85	< 5%	●		Hydrocracking
Toluene	104	< 1%	●	●	Aromatics Extraction
Pyrolysis Gasoline	84–85	< 1%		●	
Iso-octane	98–100	<i>de minimis</i>		●	
OXYGENATES					
Ethanol	117	10%		●	
ETBE	110	0		●	
MTBE	109	0		●	

Source: Stillwater et al.

²⁵ Fuel storage and dispensing equipment must be listed by a nationally recognized testing laboratory as compatible with the fuel being stored and dispensed. Underwriters Laboratories, which lists such equipment, has approved standards for E10, E25 and E85 fuels. By modeling E10, E20 and E30, the screening analysis covers the range of equipment compatibility, which enables the results to be used in the overall scenario analysis, and represents fuels that would enable the production of the desired HOF blends.

FIGURE 12: ADDITIONAL REFINERY BLENDSTOCKS REQUIRED FOR SELECT CANDIDATE FUELS



Source: Fuels Institute based upon data provided by Stillwater et al.

Recognizing these available octane blendstocks, the refinery screening model returned the required additional volume of each when producing the various HOF formulations evaluated. Figure 12 presents the results when converting the entire fuel pool (100%) to the relative HOF.

As can be seen from this graphic, due to its high blending octane value, as ethanol volumes increase the required additional volume of refinery blendstocks to boost octane is reduced. This has implications for the resulting cost of production – more ethanol reduces the cost of refinery production to deliver the required octane. These savings are partially offset in the cost of the finished gasoline by the required purchase of additional ethanol volumes. In this model, the cost

of ethanol was set at \$80 per barrel, which equates to approximately \$1.90 per gallon. For comparison, in 2017 regular unleaded BOBs averaged between \$1.60 - \$1.73 per gallon on the spot market, depending on the specific market (New York, Gulf Coast, Los Angeles) and whether it was conventional or reformulated.²⁶

Figure 13 presents the aggregate additional refinery investment (including expected upgrades to refinery operations, expansion of blendstock production capacity and purchase of octane blendstocks, including ethanol) that would be required to deliver the candidate fuels in the model. These additional annual costs are compared with the costs required to produce the gasoline pool in 2016.²⁷

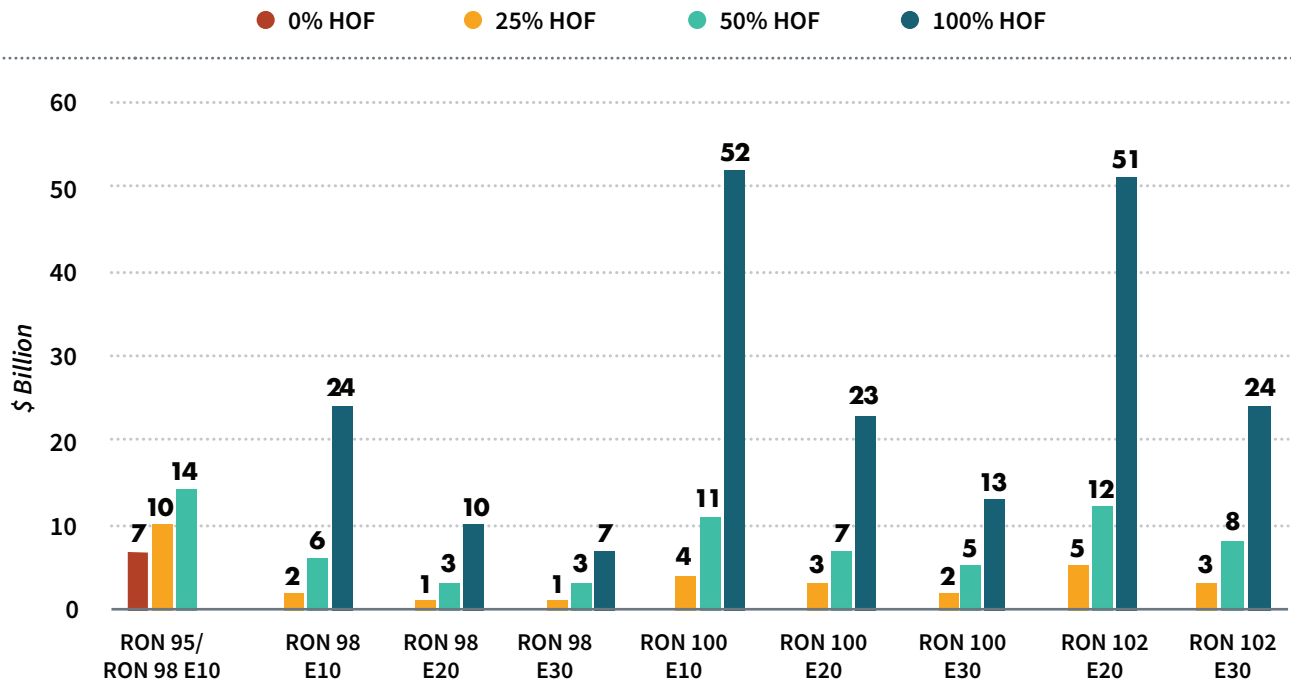
Figure 14 presents the same data on a per gallon basis.²⁸

26 https://www.eia.gov/dnav/pet/pet_pri_spt_s1_a.htm

27 Annual refining costs are defined as the sum of additional refinery operating expense, capital charges associated with additional refinery investments (these are estimated assuming a real, after-tax rate of return of 10%), and cost of additional ethanol purchases. The additional investments required to increase ethanol production are not specifically modeled in this analysis. It is assumed such investments will be recovered through the sale of ethanol at the modeled \$80/barrel.

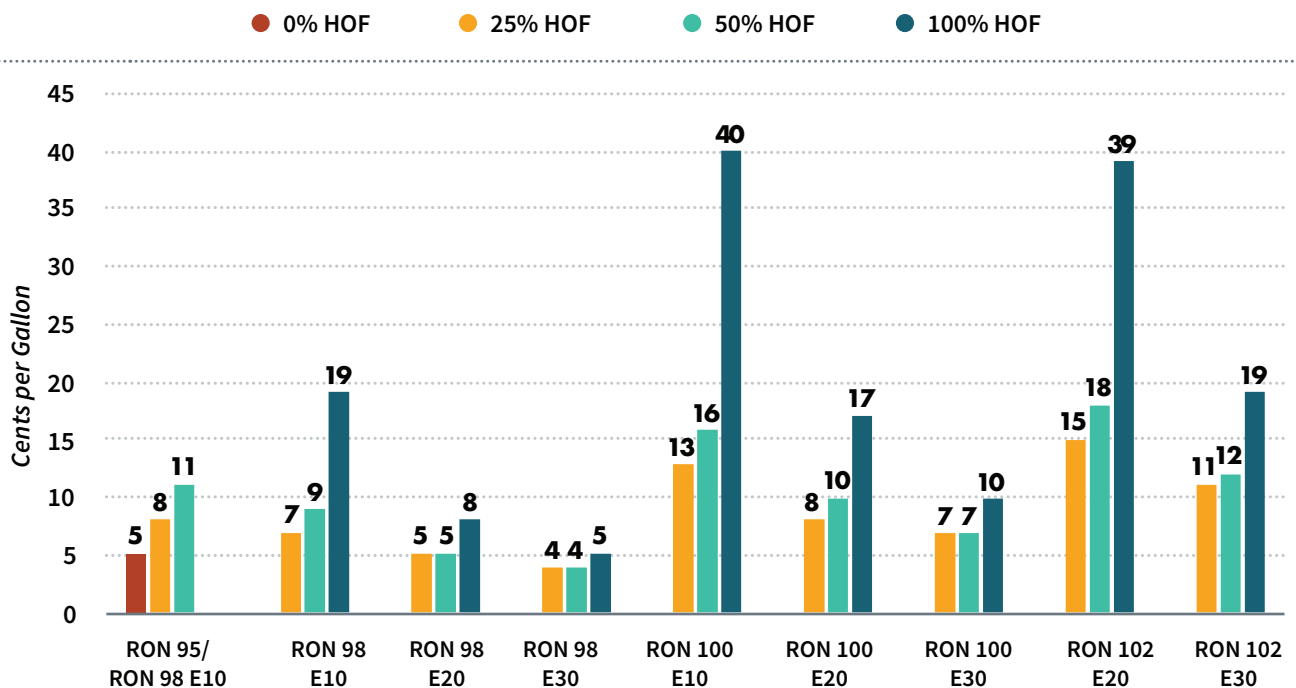
28 The per gallon cost was calculated by dividing the aggregate costs presented in Figure 13 with the total gasoline pool volume that was produced in 2016. Changes in gasoline demand projected into the future were not taken into consideration when developing this benchmark data.

FIGURE 13: AGGREGATE ADDITIONAL PRODUCTION COSTS ABOVE 2016 GASOLINE POOL



Source: Fuels Institute based upon data provided by Stillwater et al.

FIGURE 14: PER GALLON ADDITIONAL PRODUCTION COSTS ABOVE 2016 GASOLINE POOL



Source: Fuels Institute based upon data provided by Stillwater et al.

The results of this refinery screening model present a potential benchmark of production and associated costs to produce the required volumes of viable candidate HOF formulations. From this benchmark, it is possible to evaluate alternative scenarios depending on the variability of HOF market scenarios. For example, if a 98 RON fuel blend were to be produced with 15% or 25% ethanol, the results of this model provide the range within which the cost of producing those fuels would fall. Likewise, if ethanol prices were to exceed or fall below \$80/barrel, it is possible to adjust the findings based upon market volatility. The results of this screening analysis should be viewed as a tool with which to evaluate other potential HOF scenarios.

AVAILABILITY OF ETHANOL

The finished gasolines modeled within this study are considered by the authors to be viable, meaning that the constituent components of the fuels can be produced in requisite volumes. The refining industry can expand alkylate production, increase reformate production and purchase iso-octene (although the latter would require investment in new merchant plants). And, based upon past experience and consistent trends, the ethanol industry should be able to expand production to satisfy demand from projected corn production.²⁹

Under the most ethanol-intense fuel scenarios modeled in the screening analysis, the nation would need to increase its ethanol production significantly. In 2017 the United States consumed 14.5 billion gallons of fuel ethanol, primarily as E10.³⁰ By 2050, due to reduced gasoline demand associated with fuel efficiency improvements, annual demand for ethanol in an E10 market would decrease to 11.4 billion gallons. By comparison, an E20 market in 2050 would require 22.3 billion gallons of ethanol and an E30 market would require 33.8 billion gallons.³¹ To determine whether the

corn and ethanol industries could deliver such volumes, produce Stillwater et al. leveraged publicly available data and research to present a projection of production volumes based upon the following assumptions:

- In 2016, the United States planted 86.7 million acres of corn. The projection assumes this acreage does not change through the forecast period.
- In 2016, corn production yielded 174.6 bushels per acre. From 1936 – 2016, corn yield improved annually at the average rate of 2 bushels per acre. This 80-year average annual improvement was assumed to continue. From 1982 to 2014, ethanol production efficiency improved 0.0095 gallons per year. This 32-year average annual rate of improvement was assumed to continue.
- In 2016, 35% of corn yield was used to produce ethanol. The use of additional corn yield for ethanol production was calculated in two scenarios:
 - Scenario 1 – The industry continues to use 35% of corn yield to produce ethanol
 - Scenario 2 – All new corn yield above 2016 is dedicated to ethanol production

Based upon these historic trends and these assumptions, Figures 15 and 16 present the potential future of production and availability of ethanol in the two scenarios.

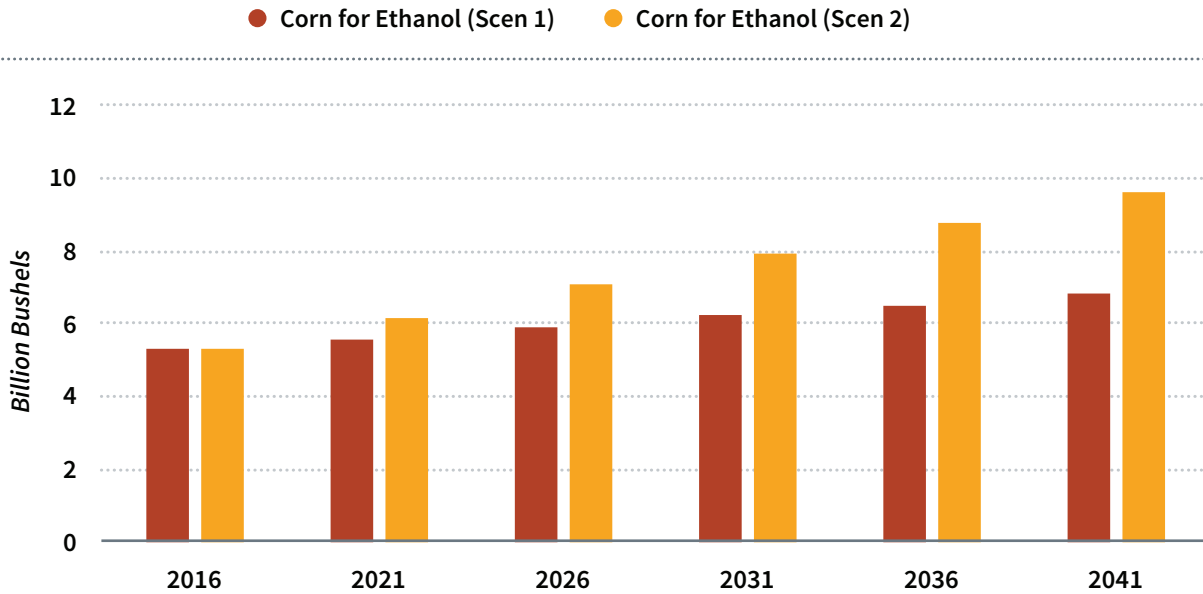
The results of this refinery screening model present a potential benchmark of production and associated costs to produce the required volumes of viable candidate HOF formulations.

29 The analysis contained in the Stillwater et al. report focuses exclusively on corn-derived ethanol. Should production of cellulosic ethanol become commercially viable at scale, the ability of the industry to deliver requisite volumes of ethanol would be enhanced.

30 <https://www.eia.gov/totalenergy/data/browser/?tbl=T10.03#/?f=A&start=1981&end=2017&charted=7-18>

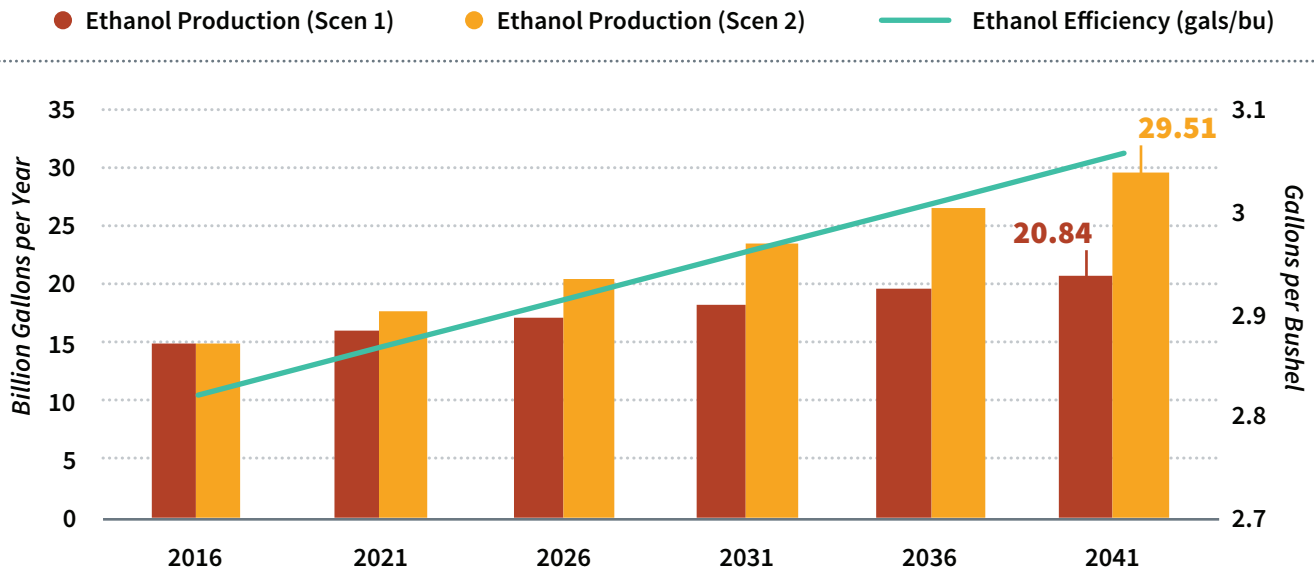
31 Stillwater et al. adjusts the total finished gasoline demand for E20 and E30 by +2.5% and +5.0%, respectively, over demand for finished E10 to account for the lower energy content of the ethanol used in the finished product.

FIGURE 15: BUSHELS OF CORN AVAILABLE FOR ETHANOL PRODUCTION



Source: Fuels Institute based upon data provided by Stillwater et al.

FIGURE 16: POTENTIAL ETHANOL PRODUCTION THROUGH 2041



Source: Fuels Institute based upon data provided by Stillwater et al.

The projections presented in the Stillwater et al. report indicate that even without expansion of acreage to produce additional corn, or the addition of cellulosic ethanol volumes, the nation is very close to having the ability to produce enough ethanol to convert the market to E20 HOF without increasing the percent of corn that is dedicated to fuel production (i.e., Scenario 1). Should the additional corn produced due to improvements in yield be dedicated to ethanol production, the industry should easily be able to satisfy an E20 market, although additional acreage may be required to satisfy an E30 market.

This data is presented to address concerns expressed by some stakeholders that the ethanol industry may not be able to deliver requisite volumes to satisfy a HOF market that was comprised of mid-level ethanol blended fuel. It is apparent from this analysis, however, that it certainly might be capable of satisfying an E20 market and delivering sufficient product to support a sizeable market for E30.



Converting the Market to HOF

How to produce a fuel is a major consideration underlying a potential transition of the market, regardless of which fuels might be involved in such a transition. But perhaps equally or even more daunting is the question of how to implement the new fuel program and ultimately deliver it to consumers. After evaluating the history of fuel formulation changes in the United States, the Stillwater et al. team determined that the only feasible strategy for successfully introducing HOF and HOF-optimized vehicles was through a federal mandate that would apply to all 50 states.

HISTORY OF FUEL MARKET TRANSITIONS

Review of successful transitions to unleaded gasoline, ultra low sulfur diesel fuel, low sulfur gasolines, Reformulated Gasoline and the transition to E10 within the Renewable Fuel Standard indicate all of these programs were driven by government requirements and included provisions that could be helpful in developing a regulated transition to HOF. Voluntary market transitions, however, such as E85 and E15, have not achieved the necessary market conversion required for a HOF market to deliver the desired value.

Consequently, the team evaluated the regulatory activities that would be required and the potential timelines necessary for completion of such activities. The following represent a benchmark scenario to achieve regulatory and market conversion. The analysis was informed by past experiences with fuel regulatory programs. However, it is recognized that some provisions presented in the analysis could be eliminated or expedited (such as vehicle certification, fuel registration, equipment compatibility determination, etc.) depending on the formulary nature of the HOF being introduced and its similarity to existing fuels in the market.

The transition to unleaded fuel was a fundamental consideration in developing this analysis. It represented a transition in which all new vehicles as of a specific date were required to use the new fuel, thereby forcing

the availability of the fuel to increase in time to satisfy consumer demand. In the case of the unleaded fuel phase-in, all model year 1975 vehicles had to be equipped with catalytic converters and required to use unleaded fuel. It then took 10 years for unleaded gasoline to attain 57% of the total gasoline pool and another 10 years to attain 97% of the gasoline pool. Meanwhile, it took 18 years from introduction of these new vehicles until they represented 90% of the vehicles on the road.³²



32 Stillwater et al.

FIGURE 17: PACE OF LIGHT DUTY VEHICLE FLEET CONVERSION

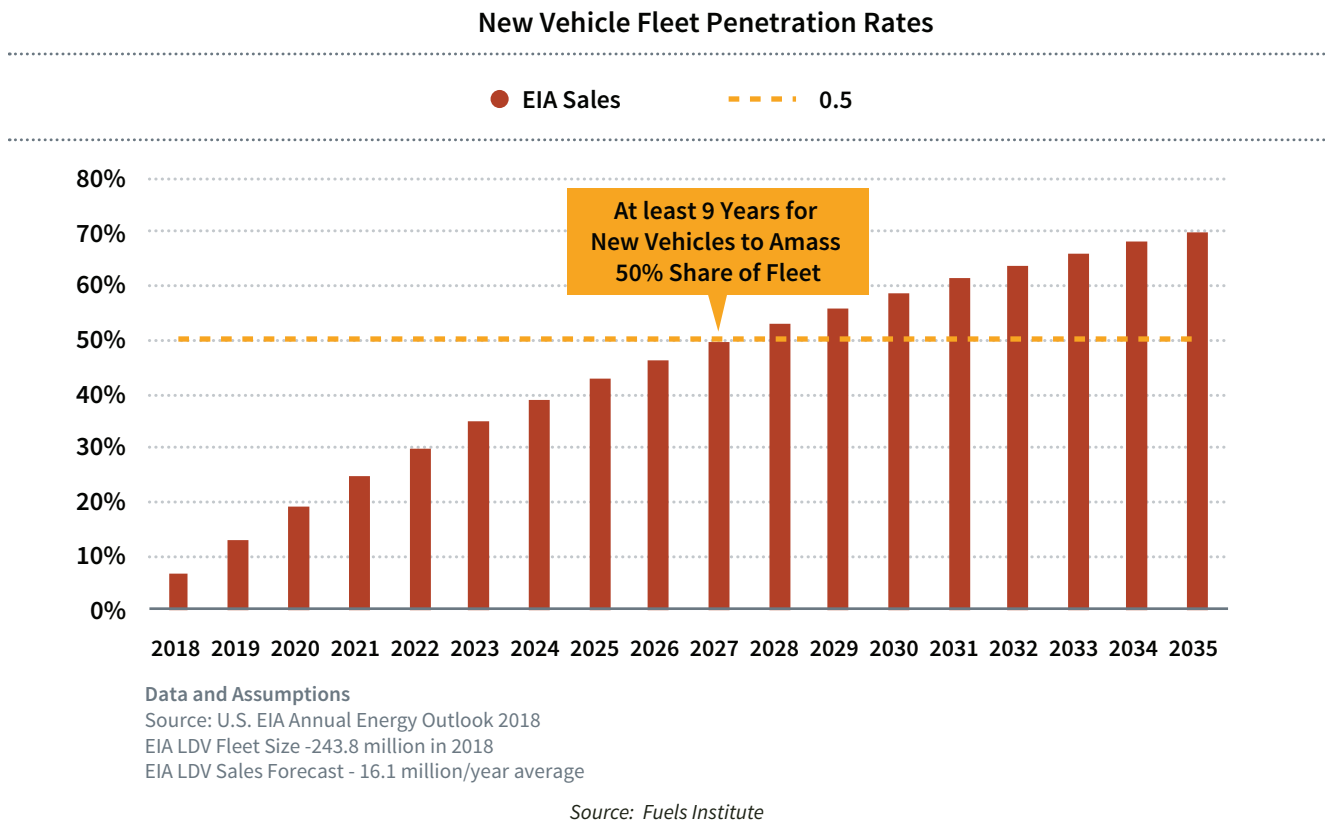


Figure 17 presents a Fuels Institute analysis of the time it takes for a new vehicle technology to gain share of the vehicle fleet. It is based upon assumption that 100% of vehicles sold in 2018 and beyond would be equipped with something not previously available in the fleet. Sales and fleet forecasts are based upon the U.S. Energy Information Administration’s (EIA) Annual Energy Outlook 2017.

This analysis...underscores the time it will take to transition the vehicle fleet to demand HOF, even under the scenario of a government mandate.

This analysis, and the example associated with the transition to unleaded, underscores the time it will take to transition the vehicle fleet to demand HOF, even under the scenario of a government mandate.³² The pace of fleet turnover to HOF vehicles would serve as a proxy

signal to the market regarding the pace at which demand for HOF will increase. But this transition will only begin once the regulations are put into place, and Stillwater et al. demonstrate that this could take some time.

REGULATORY REQUIREMENTS AND TIMELINES

Figure 18 presents a benchmark assessment of the steps and time required to develop, propose and finalize a fuels regulation to require the transition to HOF. Again, depending on the composition of the HOF and its similarity, or lack thereof, to existing fuels this timeline could be accelerated by eliminating some steps or leveraging existing data and analytics. Timelines could also be affected by the manner in which rulemaking is initiated. For example, legislation enacted by Congress could streamline or complicate some components of the process.

33 The analysis assumes scrappage rates of older vehicles (currently averaging about 6% in EIA’s forecast) does not change. It is possible that a government mandate for a new technology could alter consumer evaluations concerning the useful life of their vehicles and either slow or accelerate the scrappage rate, which would influence fleet turnover projections.

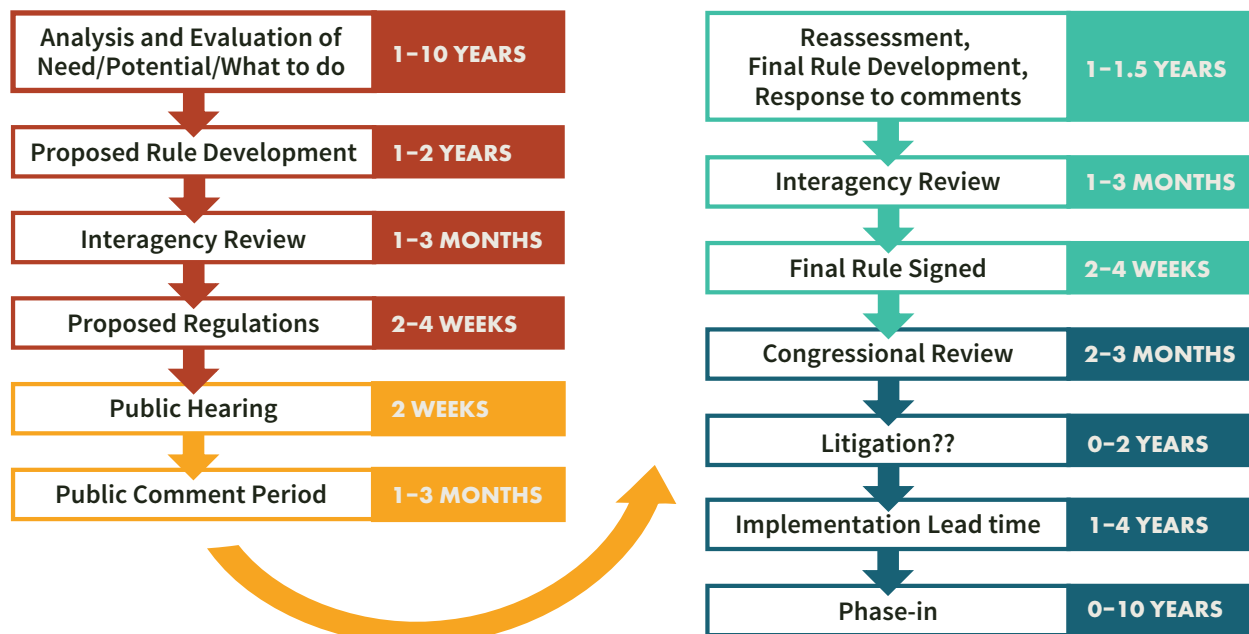
FIGURE 18: TIMELINE TO ENACT A FINAL RULE

	Key Party	Time Required	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Potential New Fuel Identified	Proposer		♦									
Health Effects Testing	Proposer/EPA	2 years	♦♦♦♦	♦♦♦♦								
Vehicle Fuel Testing	Vehicle Fuel Providers	2-3 years	♦♦♦♦	♦♦♦♦	♦♦♦♦							
Infrastructure, Tank, Dispenser Testing	UL/Equip Manu	2 years		♦♦♦♦	♦♦♦♦							
Fuel Registration	Fuels/EPA	1/2 year				♦♦						
Fuel Waiver/Sub Sim Determination	EPA	1 year				♦♦♦♦						
Modify Fuel Regs	EPA	1-2 years					♦♦♦♦	♦♦♦♦				
ASTM/NCWM Standard Development	ASTM Members	2-3 years						♦♦♦♦	♦♦♦♦	♦♦♦♦		
Modify State Regs	States	2-4 years							♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Modify Station Codes	Fire Marshalls	2 years						♦♦♦♦	♦♦♦♦			
Promulgation of Codes	EPA								♦			

Source: Stillwater et al.

As further example of the requirements involved in developing and finalizing a rule to convert the fuels market to HOF, Figure 19 recreates a timeline presented by the U.S. Environmental Protection Agency (EPA) at FUELS2018, the FuelsInstitute annual meeting.

FIGURE 19: TYPICAL MAJOR FUEL RULEMAKING TIMELINE³⁴



Source: Machiele, Paul, U.S. Environmental Protection Agency

34 Machiele, Paul, "Global, Federal and State Regulations", presentation delivered to FUELS2018 – Fuels Institute’s Annual Conference, May 2018.

Once the final rule is in place, the transition of the market can begin. In Figure 20, Stillwater et al. are presenting a timeline that would ultimately result in 90% of the vehicles on the road being required to fuel with HOF. Note that this figure includes provisions for deployment of technology to prevent misfueling. It is assumed that all new vehicles will, at some point when HOF is broadly available, be prevented by technology from fueling with non-HOF gasoline. Effective misfuelling prevention may require the development and deployment of technology both on the vehicles and at the point of refueling. Further, if the HOF being introduced is formulated with

more than 15% ethanol, it will be necessary to prevent legacy vehicles (i.e., non-HOF or non-flex fuel vehicles) from fueling with the new fuel. In such a situation, this misfueling prevention will be required immediately upon introduction of HOF. Stillwater et al. do not comment on what misfueling prevention strategies might be deployed, but note that should misfueling prevention be required for both HOF vehicles and legacy vehicles, something other than nozzle size distinction (as was successfully used in the transition to unleaded gasoline) will be required.

FIGURE 20: TIMELINE AFTER RULES ARE ENACTED

DISP=Dispenser Manufacturers | Stations=Retail Fueling Stations | ASTM=ASTM Fuel Specification Bodies | TERM=Terminal Operators | PIPE=Pipeline Operators

	Responsible Party	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Develop Misfueling Prevention Standards	OEMs/DISP	◆◆◆	◆◆◆	◆◆◆																				
Vehicle Manufacturers Gear up for HOF	OEMs	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆																		
Begin Production of 100% HOF Vehicles with MP	OEMs					◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆
25%, 50%, 90% of Fleet Converted to HOF Vehicles with MP	OEMs										◆ 25%				◆ 50%									◆ 90%
Dispenser Manufacturers Incorporate MP Standard	DISP				◆◆◆																			
Begin Conversion to Dispensers with MP	Stations				◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆							
Dispensers Have MP Capability	DISP																							◆
Make Refinery Changes Including Tanks	Refiners	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆																		
Make Terminal and Pipeline Tank Changes	TERM/PIPE	◆◆◆	◆◆◆	◆◆◆	◆◆◆	◆◆◆																		
98 RON Fuel Becomes Available	ALL						◆																	
Begin Forced Use of 98 RON in HOF Vehicles	EPA										◆													

Source: Stillwater et al.

IMPLEMENTATION SCENARIOS

Once the rules are established, it will be necessary to distribute the fuel and deliver it to consumers. One of the primary considerations of the Fuels Institute when commissioning Stillwater et al. to prepare their report on HOF was the infrastructure transition required to satisfy demand for the new HOF. Often overlooked, the ability of terminals, pipelines and fuel dispensing facilities (i.e., retailers) to handle and deliver a new fuel can add significantly to the complexity of the transition.

For purposes of this study, the Fuels Institute and Stillwater et al. agreed to develop three scenarios for a HOF market. The team acknowledged that the RON value of the fuel to be distributed was not relevant to determining distribution logistics and equipment compatibility,³⁵ but the composition of the desired HOF was very important. The team considered a scenario in which the octane floor in the market was increased to satisfy a HOF vehicle fleet, but it was determined that adding a HOF to the existing fuel pool and slowly increasing HOF market share as the fleet transitioned was the best scenario to model. At the time the Fuels Institute commissioned the Stillwater team to prepare this report, the automotive industry had been advocating for HOF that had an octane rating of at least 98 RON. Public discussions about raising the octane floor to 95 RON had not materialized. Consequently, the team agreed to model the following three fuels³⁶:

- 98 RON E10
- 98 RON E20
- 98 RON E30

These scenarios would apply equally to a 95 RON market or any HOF with a higher RON value. However, should 95 RON be produced using only E10 (which would be substantially similar to today's premium gasoline), additional investments in storage capacity to accommodate an additional fuel grade or to enhance equipment compatibility would be unnecessary.

Likewise, if a new HOF fuel were introduced to replace a currently available fuel, some of the infrastructure investments associated with accommodating a fourth gasoline could be mitigated.

Distinguishing the scenarios based upon ethanol concentration was driven primarily by equipment compatibility issues. These issues are relevant to a HOF transition, regardless of the desired octane rating of the HOF. All distribution and retailing equipment is compatible with E10 – that is the ubiquitous fuel currently available in the market. Consequently, the transition challenges would be significantly mitigated should HOF be E10 and limited primarily to investments in additional storage infrastructure to accommodate an additional grade of gasoline.

With regards to E20, as the market has worked to accommodate more renewable fuels, equipment has been offered to the market that is certified as compatible with E25. This equipment often does not represent a significant change in price, but is currently not in use in the majority of the market and would therefore require equipment upgrades. Finally, any fuel containing more than 25% ethanol must be stored and dispensed in equipment certified as compatible with E85. Currently, there is no equipment certifications available for ethanol blends between E25 and E85. E85 equipment, however, carries with it a significant increase in price and, like E25 equipment, is not currently in use in most of the market. Hence, each fuel blend triggers different equipment requirements and this analysis provides a benchmark to help inform decisions concerning a market transition.

With these three fuels in mind, the scenarios for analysis were designed to include the following assumptions:

All new vehicles by a certain time will be HOF-optimized. Once HOF is sufficiently available in the market, misfueling prevention technology will be activated to prevent HOF vehicles from fueling with legacy fuels.

³⁵ While the RON value is extremely important to vehicle performance, it is not materially relevant to the fuel distribution system.

³⁶ As noted previously, Co-Optima has demonstrated that the efficiency and performance improvements associated with 95 RON would range from 2.5% - 4.1%, depending on the sensitivity of the fuel. By comparison, the improvements associated with 98 RON would range from 4.4% to 7.5%, depending on the sensitivity of the fuel.

HOF will be added to the existing fuel pool, resulting in potentially four distinct octane levels concurrently being available in the market. Lower octane fuels will fade from the market as demand decreases with the market growth of HOF vehicles and HOF demand.

HOF will be introduced via federal mandate and apply to all 50 states. Some states may have to amend their laws and regulations to comply. Canada would similarly have to coordinate its regulations to preserve the fluid market conditions of the two countries.

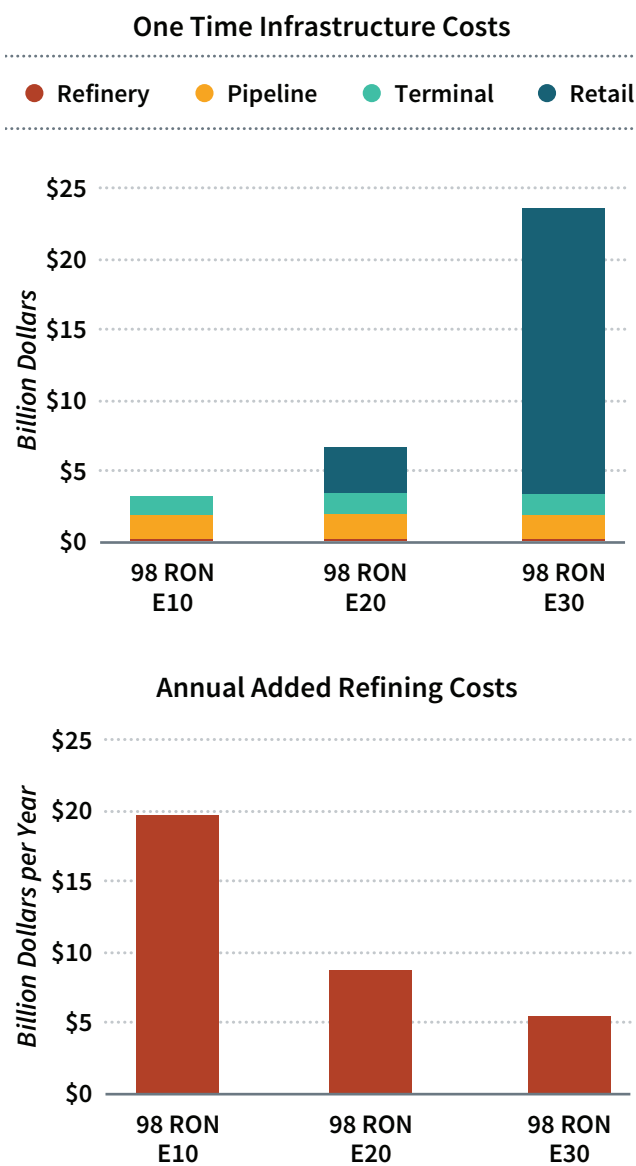
All existing federal regulations would remain in place. For example, the RFS would continue in its current form, the EPA-proposed Renewable Enhancement and Growth Support (REGS) rule would not be finalized and E15 would not receive a 1 psi vapor pressure waiver.

Figure 21 presents a top-level overview of the infrastructure investment and refinery production costs associated with each of the modeled scenarios. Again, costs to produce additional volumes of ethanol to supply an E20 or E30 market are assumed to be recovered through the ethanol purchase price of \$80 per barrel and are presented as part of the additional refining costs. Stillwater et al. did not specifically model the capital investments required to increase ethanol production, but roughly estimate investment could range from \$12.5 - \$47 billion.

The implications of each HOF scenario on the market would be:

- 98 RON E10** – Although E10 is compatible with all vehicles and distribution equipment, the new HOF would represent an additional fuel product that must be segregated throughout the system, from the refinery to the consumer’s vehicle. This would require additional tank capacity to be added at refineries, terminals and pipelines. Retailers, however, would be free to decide which fuel grades they wished to sell and would likely not be required to invest in additional equipment. Estimated one-time upfront investment costs for the market to accommodate this scenario total about \$3.2 billion. Based on the refinery screening study, it is estimated that the annual cost to produce 98 RON E10 once virtually all vehicles and fuel is HOF would be about \$20 billion more than the production costs associated with 2016 fuel pool.

FIGURE 21: SUMMARY OF PRODUCTION AND INFRASTRUCTURE COSTS BY SCENARIO



Source: Fuels Institute based upon data provided by Stillwater et al.

- 98 RON E20** – If the HOF was E20, the majority of fuel dispensers in the nation would have to be upgraded to be compatible with the new fuel. This equipment can be acquired at minor additional cost compared with E10 compatible equipment, but replacements would be required. Misfueling prevention would be required to prevent legacy vehicles from fueling with the new HOF, which in this analysis would require an investment in dispenser technology but actual required procedures may differ from this assumed reliance on new technology. In addition, many retailers

would be unable to adequately demonstrate that their underground storage tank systems were fully compatible with the new fuel and would be required to upgrade these systems, at potentially significant costs. Terminals also would have to increase capacity to store more ethanol. In all, Stillwater et al. estimate one-time upfront investment costs to accommodate E20 would total about \$6.6 billion. Based on the refinery screening study, it is estimated that the annual cost to produce 98 RON E20 once virtually all vehicles and fuel is HOF would be about \$8.0 billion more than the production costs associated with 2016 fuel pool.

- 98 RON E30** – The only equipment currently permitted to store and dispense fuels containing more than 25% ethanol are those certified as compatible with E85. This equipment often carries a significant price premium. All of the considerations associated with delivering E20 to market would apply to E30, but equipment costs would be significantly higher. Stillwater et al. estimate the one-time upfront investment to accommodate E30 would total about \$24 billion. Based on the refinery screening study, it is estimated that the annual cost to produce 98 RON E30 once virtually all vehicles and fuel is HOF would be about \$5.7 billion more than the production costs associated with 2016 fuel pool.

These estimated costs associated with each scenario represent the upfront investments to prepare the distribution system and the final additional annual cost to produce fuels to satisfy demand as forecast by EIA in its Annual Energy Outlook 2017. But throughout the transition to a HOF market, the fuel production industry will incur recurring production costs to increase the available volumes of HOF. To better ascertain what the costs of each scenario would be to the market, Stillwater et al. calculated the net present value of each scenario.

Figure 22 presents an overview of the costs of each scenario from 2027 (when Stillwater et al. estimate HOF will be required in the market) and 2050 (when HOF is predicted to represent more than 90% of the gasoline pool and vehicle fleet). To reflect the time value of money, the estimated annual costs were discounted back to the present using a rate of 5%.

FIGURE 22: NET PRESENT VALUE OF SCENARIOS 2027–2050

SCENARIO	Total New Fuel Volume (B gallons)	Total Ethanol Volume (B gallons)	Refinery Front End Infra Costs (\$B)	Pipeline Front End Infra Costs (\$B)	Terminal Front End Infra Costs (\$B)	Retail Front End Infra Costs (\$B)	New Fuel Production Costs (\$B/year)	NPV 5% (\$B)
E10	106	11.4	\$0.219	\$1.65	\$1.35	\$0	\$19.7	\$178
E20	108	22.3	\$0.219	\$1.65	\$1.61	\$3.12	\$8.3	\$78
E30	111	33.8	\$0.219	\$1.65	\$1.675	\$20.0	\$5.7	\$73

Source: Stillwater et al.

What this analysis demonstrates clearly is that however a transition to HOF might be implemented, it will take time and that the costs of the transition will be spread throughout the market inconsistently depending on what fuel is used to satisfy the HOF demand.

The net present value (NPV) analysis demonstrates that the lowest cost alternative for delivering a HOF to consumers over a 23-year transition period would be to leverage HOF comprised of E30. The reduced costs of refinery production would deliver a lower per gallon incremental price increase throughout the time period, which would offset the higher upfront infrastructure costs required to legally accommodate E30.³⁷

However, this NPV masks the fact that the costs incurred by the market would not be applied equally across all stakeholders. While the fuel production costs associated with E30 would be lowest among the scenarios analyzed, these costs would be passed through to consumers on a per gallon basis and, in essence, socialized throughout society. The upfront equipment expense, however, of more than \$20 billion would disproportionately fall on smaller companies operating retail fueling facilities. These entities would incur substantial economic challenges to upgrade their facilities and may or may not be able to efficiently recover such investments.

By contrast, the E10 scenario would result in the highest overall costs to society in the form of higher annual fuel production costs, but these costs would be spread throughout society in the form of elevated per gallon fuel

prices. Smaller entities operating retail fueling facilities would not face the financial challenges to upgrade equipment that would be required with the other scenarios.

What this analysis demonstrates clearly is that however a transition to HOF might be implemented, it will take time and that the costs of the transition will be spread throughout the market inconsistently depending on what fuel is used to satisfy the HOF demand. An E10 market will cost more in the long run, but the costs will be spread across billions of gallons of fuel each year and would not present a significant financial burden to smaller market operators. The E30 market will cost less in the long run, but small entities might need assistance to finance the infrastructure investments required to accommodate the fuel formulations.

This analysis, which focuses on a new HOF blend of 98 RON, also is relevant to a potential transition to 95 RON. While 95 RON fuel may not present the infrastructure compatibility challenges associated with a higher ethanol-blended fuel or the introduction of a distinct new fuel, the increase in producing increasing volumes of 95 RON fuel will have an impact on the overall costs to the market. The transition analysis for 98 RON demonstrates the time it might take to increase vehicle and HOF market share, making it possible to model the costs associated with a transition to 95 RON.

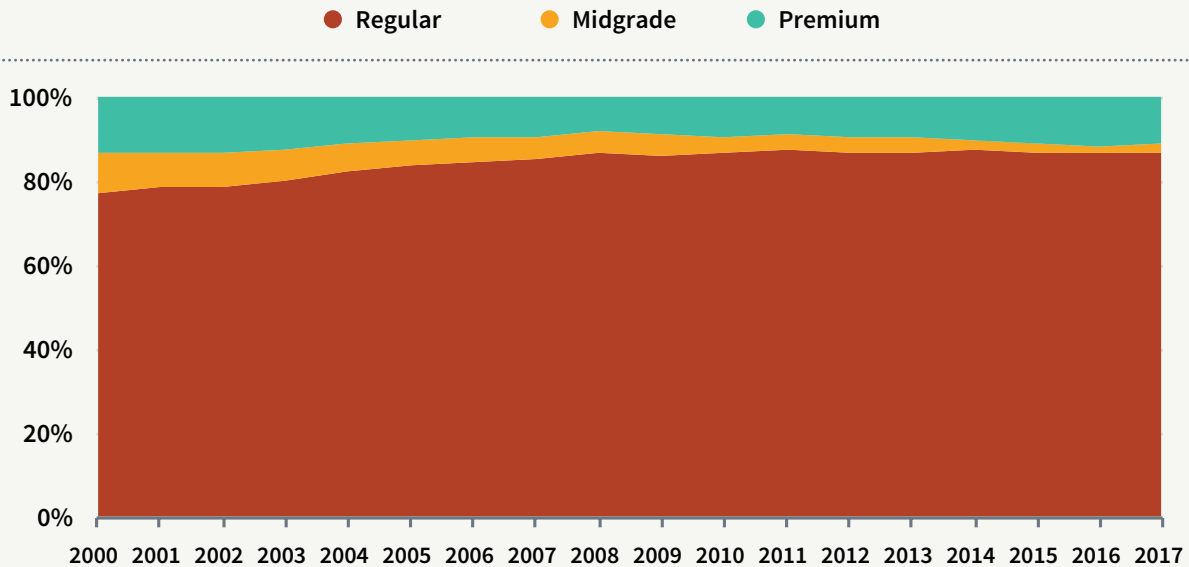
³⁷ It should be noted that the additional investments required to increase ethanol production are not specifically modeled in this analysis. It is assumed such investments will be recovered through the sale of ethanol at the modeled \$80/barrel.

Current Fuels Market

To understand how a transition to a HOF market might affect consumers, it is important to understand the gasoline market as it exists today and how this currently affects consumer behavior.

The U.S. market is and has been dominated by regular unleaded gasoline. As shown in Figure 23, regular grade (as reported by EIA as prime supplier sales volume) has in fact increased its share of total gasoline volumes from about 77% in 2000 to a high of nearly 88% in 2014. Meanwhile, premium gasoline volumes, which dropped during the Great Recession, have recovered in recent years but still trail volume levels recorded at the beginning of the century. Overall, since 2000 regular grade gallons sold each day have increased 19% while premium gallons have dropped 1%. In 2017, regular gasoline represented nearly 87% of all gasoline sold by prime suppliers.³⁸

FIGURE 23: HISTORY OF GASOLINE GRADE VOLUMES (2000–2017)



Source: U.S. Energy Information Administration

38 The volumes represented in this data are assumed to be comprised of E10.

EIA data on gasoline sales and consumption has been challenged by many market participants as inaccurate, but it represents the best publicly available data. Additional data provided by NACS demonstrates the performance of gasoline at the retail level and supports the overall findings of the EIA data analysis presented above. According to the NACS State of the Industry Report of 2017 Data, regular gasoline represented 83.5% of the fuel sales for the top performing quartile of convenience retailers in the industry. For lower performing retailers, it represented as much as 89.4% of fuel sales. Meanwhile,

premium accounted for at most 9.3% of sales volume and for some as low as 5.6% of volume.

As indicated in Figure 25, premium gasoline in 2017 sold for a price significantly higher than regular unleaded. Price differentials for the quartiles ranged from as low as 50 cents per gallon to as high as 63 cents. According to EIA, the retail price spread between premium and regular has averaged 27.6 cents per gallon since 2000. In recent years, however, the price spread has increased greatly and in 2017 averaged 50.4 cents per gallon.

FIGURE 24: VOLUMES OF REGULAR AND PREMIUM SUPPLIED (2000–2017)³⁹

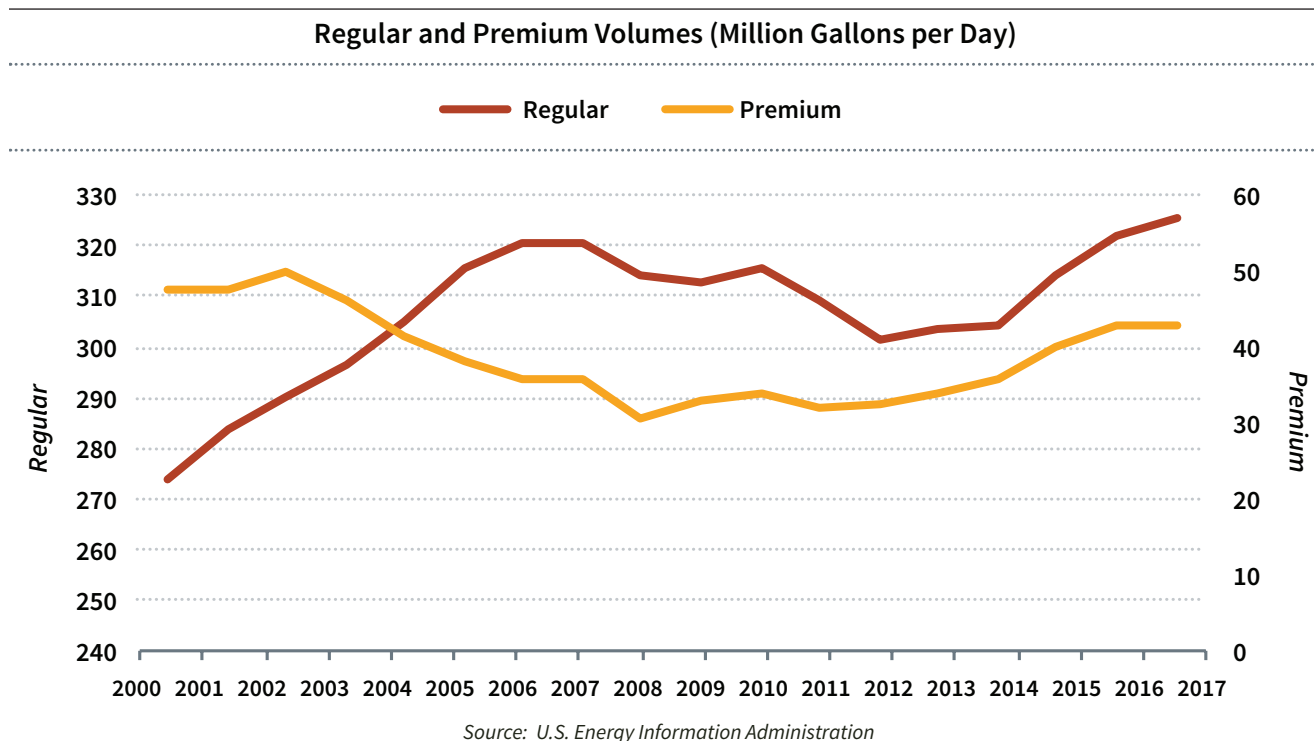


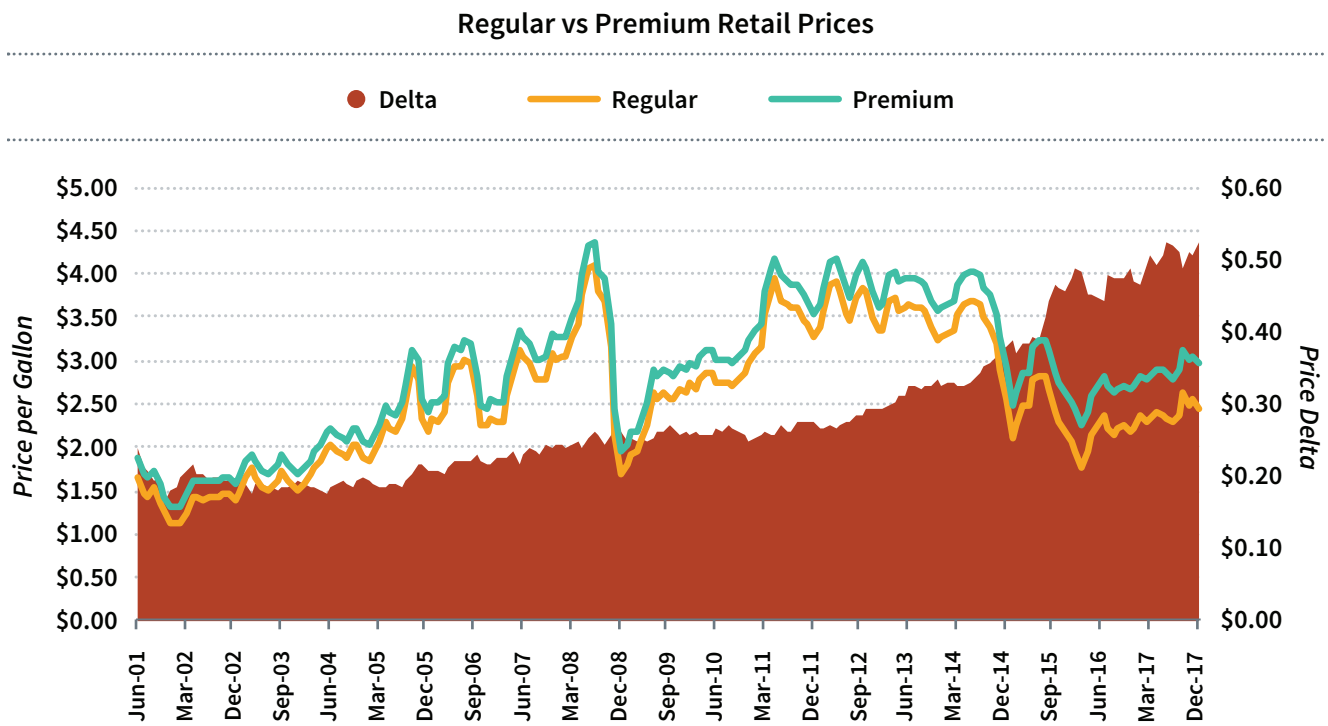
FIGURE 25: CONVENIENCE FUEL RETAILING SALES PERFORMANCE, 2017

	BOTTOM QUARTILE			THIRD QUARTILE			SECOND QUARTILE			TOP QUARTILE		
	Share	Price	Margin	Share	Price	Margin	Share	Price	Margin	Share	Price	Margin
REGULAR	86.2%	\$2.22	\$0.181	87.4%	\$2.16	\$0.174	89.4%	\$2.28	\$0.189	83.5%	\$2.30	\$0.198
MID-GRADE	6.6%	\$2.47	\$0.288	5.6%	\$2.44	\$0.364	4.9%	\$2.52	\$0.303	6.5%	\$2.58	\$0.349
PREMIUM	6.9%	\$2.85	\$0.287	6.9%	\$2.72	\$0.343	5.6%	\$2.78	\$0.357	9.3%	\$2.85	\$0.415

Source: NACS State of the Industry Report of 2017 Data

³⁹ The U.S. Energy Information Administration defines “Premium” gasoline as those blends having an anti-knock index (AKI) of greater than 90. As presented earlier in this paper, in some markets “Premium” gasoline has a posted AKI of 93. For this reason, the spread between Regular and Premium could vary from the average presented here.

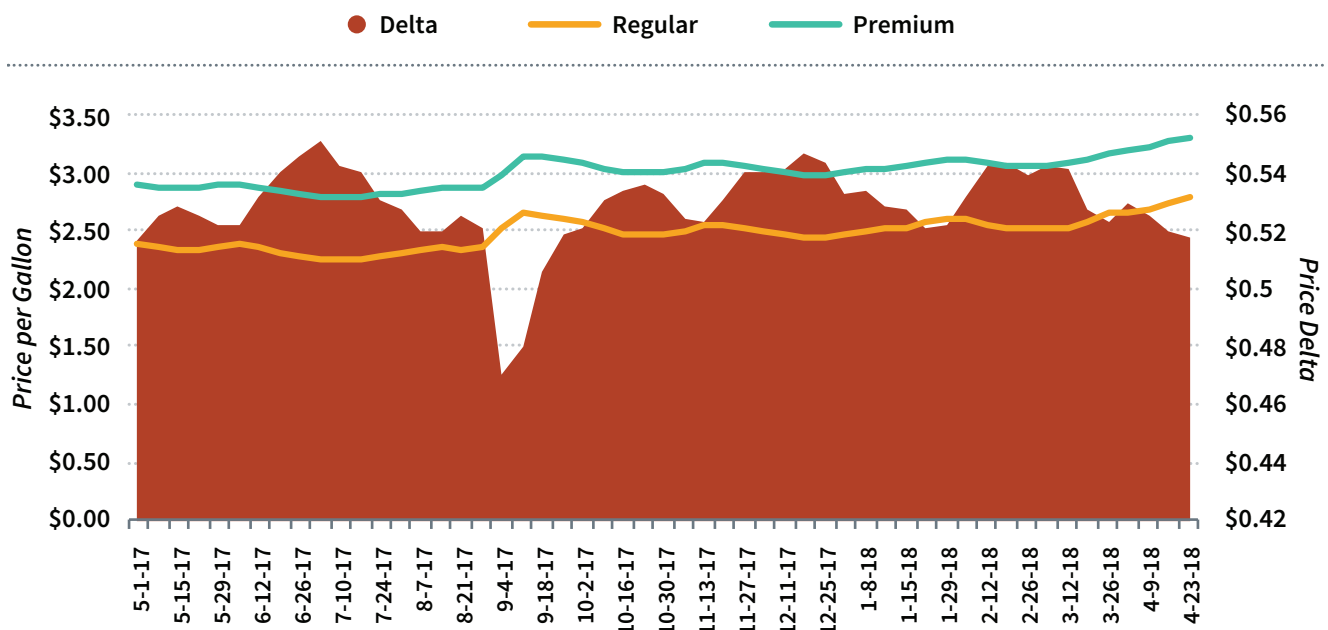
FIGURE 26: REGULAR AND PREMIUM PRICE SPREAD (2001–2017)



Source: U.S. Energy Information Administration

This data is further supported by OPIS/IHS Markit data. Between March 2017 and April 2018, the average spread between regular and premium across the nation was 53.8 cents per gallon.

FIGURE 27: REGULAR AND PREMIUM PRICE SPREAD (MARCH 2017–APRIL 2018)



Source: OPIS/IHS Markit

This differential in retail prices is not necessarily an indication of product value, but more reflective of market realities. Premium fuel consumers are deemed to be not as price sensitive as those consumers who purchase regular gasoline, which allows the market to command a higher price than might be required by the cost of the product. The elevated retail margins generated by premium compared with regular gasoline presented in Figure 25 above is a clear indication of the markup associated with premium fuel.

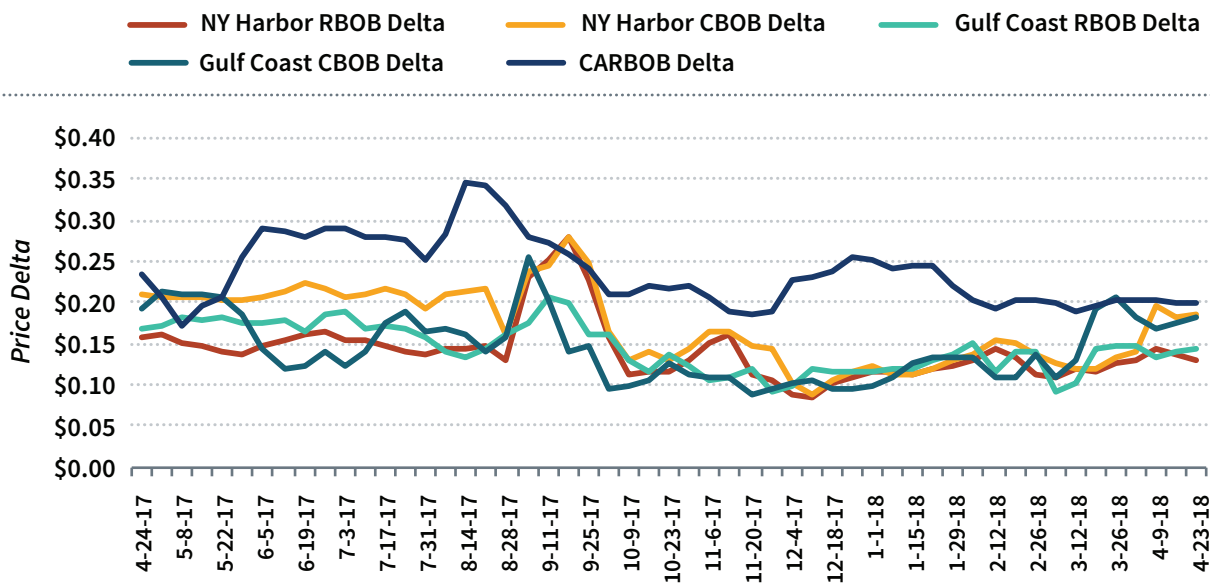
Because retail margins do not necessarily reflect costs associated with fuel production, it might be more instructive to look at the wholesale price differentials for an indication of what the production cost differentiation might be. Figure 28 presents the spot wholesale price differentials between regular and premium fuel for conventional and reformulated

gasolines in three major markets from April 2017-2018. The average deltas ranged from 14 – 23 cents per gallon.⁴⁰

However, while wholesale price differentials might be a more accurate way to compare the value of gasoline grades, consumers do not see these prices – they only see the price signs posted in front of retail dispensing facilities. Hence, when considering how consumers might react to the transition to a HOF market, retail prices should be top of mind.

While wholesale price differentials might be a more accurate way to compare the value of gasoline grades, consumers do not see these prices – they only see the price signs posted in front of retail dispensing facilities.

FIGURE 28: WHOLESALE SPOT PRICE DIFFERENTIALS BETWEEN PREMIUM AND REGULAR BOBS



Source: OPIS/IHS Markit

40 It is worth noting that the octane value of CARBOB premium gasoline is lower than the octane value of premium fuels in many other markets.

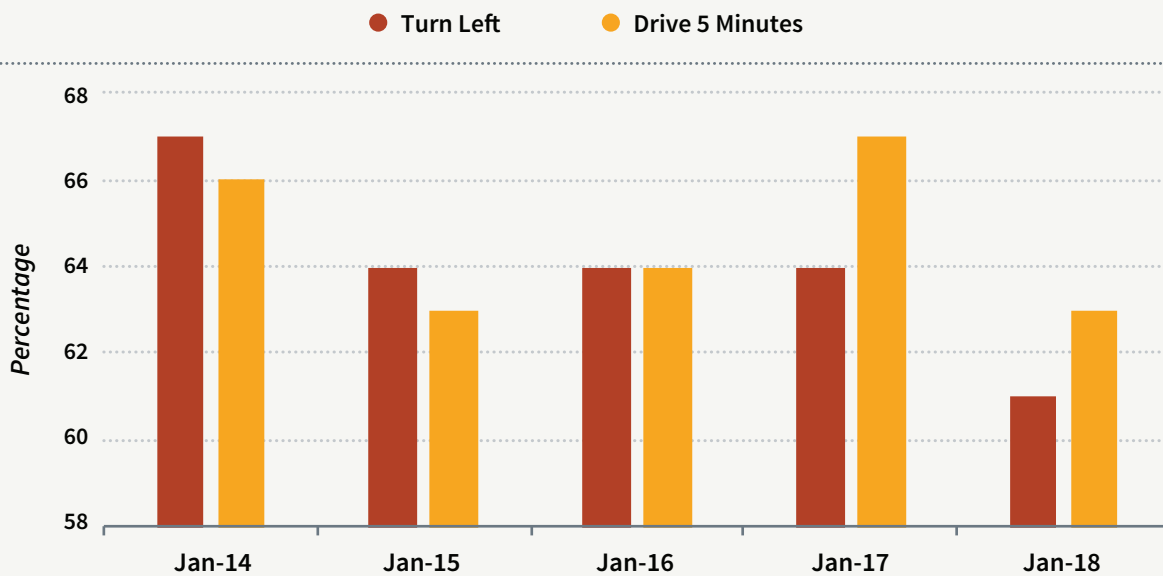
Consumers Perception and Behavior

With the history of premium fuel commanding a higher price than regular unleaded, the implications of HOF on consumers is a very important factor that must be addressed. The refinery screening study presented above projected that the costs associated with moving to a HOF market comprised of 95 RON E10 would increase production costs by 5 cents per gallon and a transition to 98 RON would result in production cost increases of 5 – 19 cents (depending on the ethanol volume of the HOF).

But these cost projections reflect costs the market would incur once the transition to HOF is complete and economies of scale accrue fully to HOF production. According to the Stillwater et al. report, it could take up to 23 years before this transition is complete. During this time frame, the price differentials between regular unleaded and HOF are likely to begin with a similar relationship that currently exists between regular and premium fuel. Over time, the differential would likely narrow until the market stabilizes into a HOF-dominant market at which point production costs might more closely reflect those projected in the refinery screening model.

During this time frame, understanding the consumer sentiment and communicating effectively with the consumer will be critical to the potential market success of the HOF transition. The Fuels Institute and NACS have long histories of tracking consumer sentiment as it relates to retail fuel prices. According to NACS, over the last several years on average two-thirds of consumers decide from which retailers to buy gasoline based upon the posted price – and they state they are willing to make sacrifices to save money at the pump. Figure 29 demonstrates what consumers say they are willing to do to save 5 cents per gallon.

FIGURE 29: WHAT WILL CONSUMERS DO TO SAVE 5 CENTS PER GALLON?⁴¹



Source: NACS/Penn Schoen Berland

41 <https://www.convenience.org/Topics/Fuels/Documents/How-Consumers-React-to-Gas-Prices.pdf>

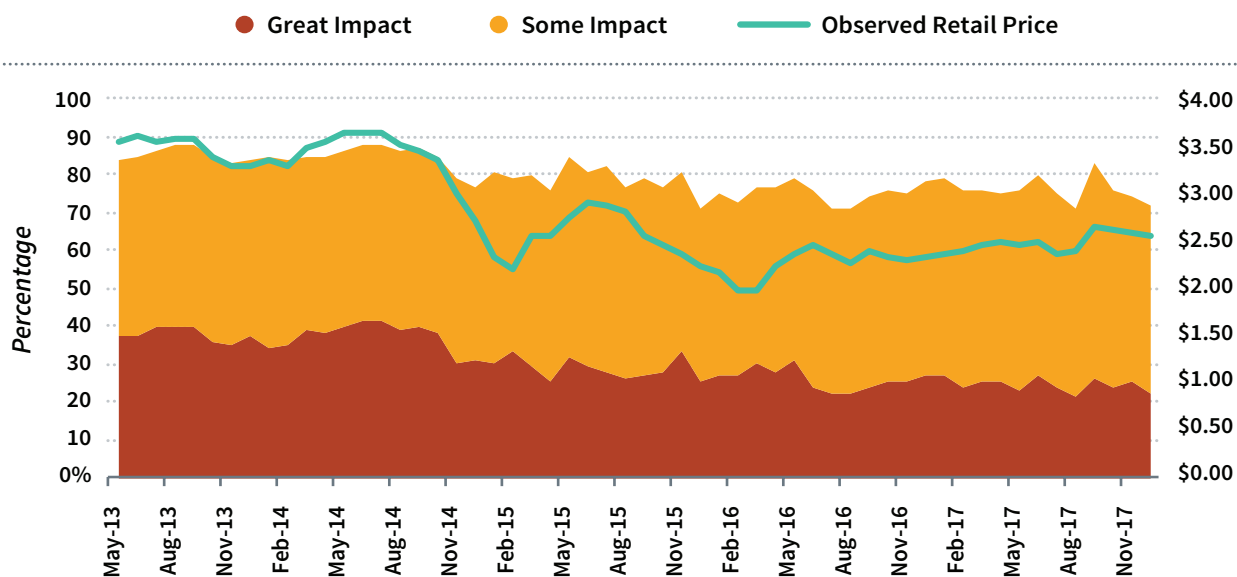
In addition, fuel prices affect the overall mood of consumers. For five years (2013-2017) NACS asked consumers every month to what extent retail gasoline prices affected their feelings about the economy. Over that time period, on average 80% of consumers reported that gas prices had some impact or great impact on their feelings about the economy.

Given this sensitivity to retail fuel prices, properly communicating with consumers the rationale and value behind a transition to HOF will be critical. Yet, how this

will be achieved is not straightforward because, according to Fuels Institute surveys, it seems that consumers do not understand octane.

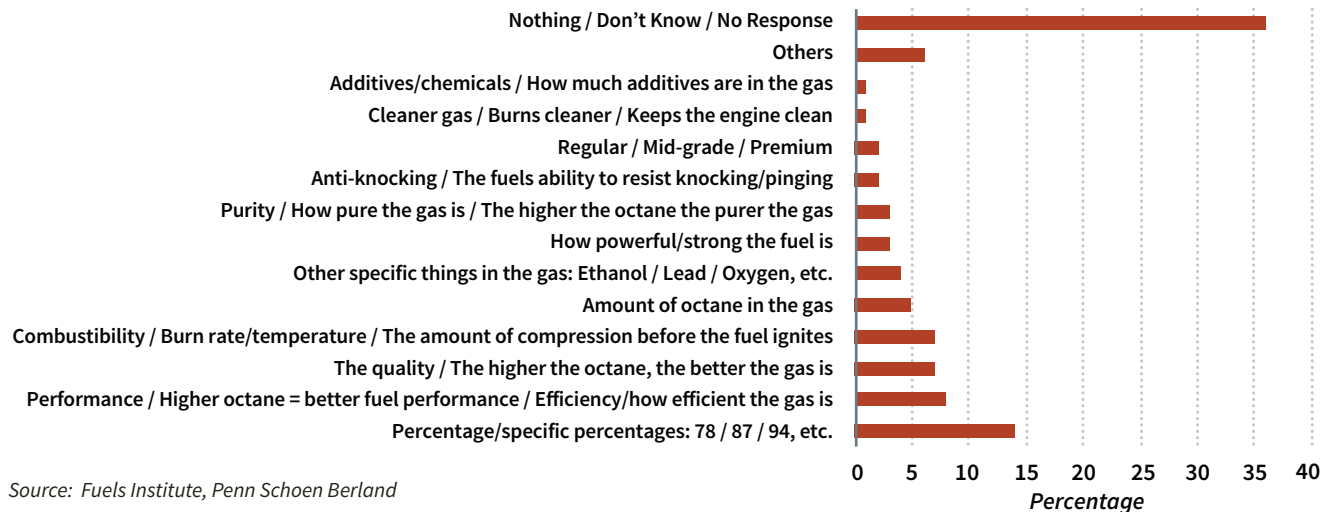
In May 2016, the Fuels Institute asked consumers, “What is an octane grade as it relates to gasoline?” Figure 31 presents a grouping of their open-ended responses. One-third honestly replied that they did not know the answer and only 2% accurately identified that octane referred to the anti-knock properties of gasoline. The rest provided answers that were not accurate or did not provide an indication that they truly understood what octane is.

FIGURE 30: IMPACT OF GAS PRICES ON THE ECONOMY⁴²



Source: NACS/Penn Schoen Berland

FIGURE 31: CONSUMER KNOWLEDGE OF OCTANE

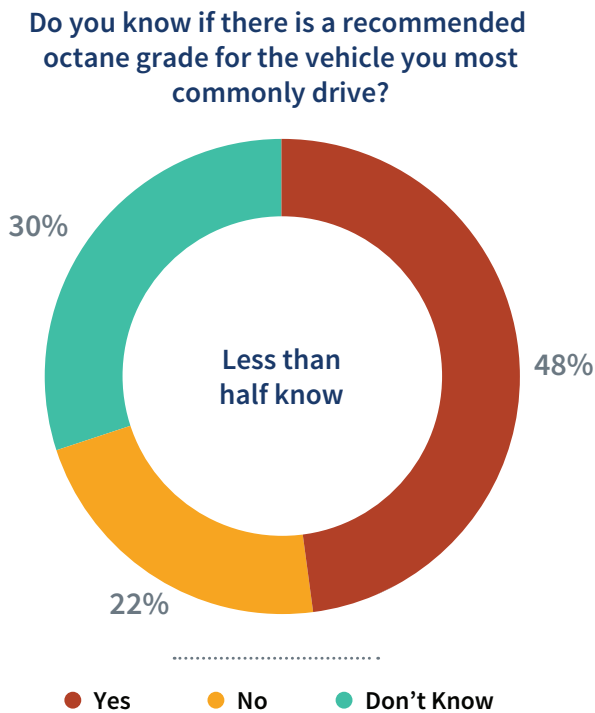


Source: Fuels Institute, Penn Schoen Berland

42 <https://www.convenience.org/Topics/Fuels/2018-Consumer-Fuels-Report-Survey-Results>

Clearly, education will be required to ensure consumers appreciate the benefits that will be provided through a transition to HOF. This is even more important when consumer knowledge and perception about their vehicle fuel requirements are taken into consideration. Adjusting pump labels from the current AKI (R+M/2) method to a RON method will increase the posted number which might infer to the consumer increased value when in fact the octane rating of the fuel has not materially changed. Those seeking to introduce a HOF and market the fuel according to its RON value should take these issues into careful consideration and develop strategies to mitigate potential negative reactions to the transition. How consumers are educated, by whom and at what point in the vehicle/fuel purchase decision will be a critical element to a successful program.

FIGURE 32: CONSUMER KNOWLEDGE OF VEHICLE OCTANE RECOMMENDATION

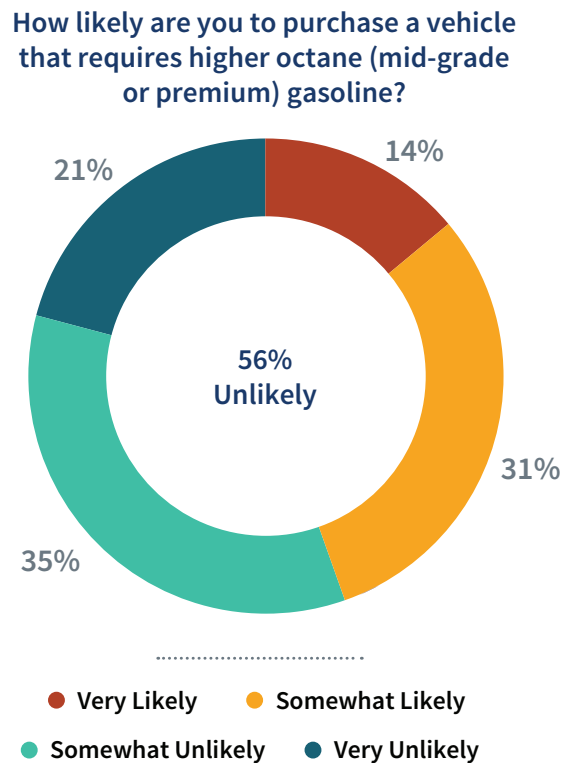


Source: Fuels Institute, Penn Schoen Berland

The Fuels Institute found that less than half of consumers surveyed even knew if their vehicle has a recommended gasoline octane grade and 56% said they were unlikely to purchase a vehicle that would require midgrade or premium gasoline (Figure 32). The response to the latter question is clearly related to their recognition that premium gasoline currently commands a higher price than regular.

The combination of consumer sensitivity to retail fuel prices and their lack of knowledge about the value of octane to their vehicles represents a significant challenge to the successful transition to a HOF market. It is not an insurmountable challenge, but it is one that will require coordinated communications and education strategies across stakeholder communities and government agencies.

FIGURE 33: CONSUMER WILLINGNESS TO PURCHASE A VEHICLE THAT REQUIRES HIGHER OCTANE GASOLINE



Source: Fuels Institute, Penn Schoen Berland

Conclusion

Research conducted by the Co-Optima initiative, and other esteemed entities, demonstrates that providing a gasoline with sufficient octane to prevent auto-ignition will enable the automotive industry to enhance the efficiency and performance of internal combustion engines. How such a fuel and engine are introduced into the market, however, remains a challenge to be overcome.

The Fuels Institute report prepared by Stillwater et al. provides a common benchmark upon which potential production and implementation scenarios may be compared and assessed. It presents an overview of the role of octane in an engine, which must be understood by those contemplating potential changes to the market. It then evaluates past fuel transition experience to determine that the only way to ensure the market converts fully and efficiently is through a federal mandate. This type of market analysis is essential to developing any strategies for transitioning the market to take advantage of the benefits provided by HOF.

The refining screening analysis then demonstrates that producing different HOF formulations is feasible and scalable. However, depending on the composition of octane blendstocks, the costs can vary greatly in terms of capital investment and ultimate per gallon production cost differentials. These costs are production estimates, which are not a proxy for retail price implications. Further, it must be fully understood that the additional production costs associated in this analysis are reflective of those costs associated once the market has fully converted to HOF, which could take up to 20 years. During that transition, production costs are likely to be higher than the numbers presented in this analysis on a per gallon basis. Further, many factors beyond production affect the ultimate price consumers may pay at the pump, but understanding the implications of HOF on production (which are expected to be passed through to the consumer) is a fundamental starting point.

These costs are production estimates, which are not a proxy for retail price implications.

The analysis of implementation scenarios demonstrates that the composition of the fuel, specifically the concentration of ethanol in the finished gasoline, will have implications for infrastructure investment requirements, timelines for rulemaking and the ultimate transition to a new market equilibrium. The costs could be relatively minor or significantly expensive, with the burden of these investments being borne primarily by fuel retailers. Which fuel is brought to market should be carefully considered since financial support mechanisms might be required to ensure a successful transition.

The regulatory process to facilitate this transition could take as long as 10 years to reach publication of a final rule, unless the candidate HOF is deemed substantially similar to an existing registered fuel. In which case, the rulemaking could be expedited and be completed in two to four years. Full transition to a HOF-dominant market, with widespread fuel availability and an essentially complete HOF-optimized vehicle market, could take an additional 15 – 20 years due to the slow pace of fleet turnover. Benefits could begin to accrue for new vehicle owners in the earliest years of the transition, assuming the retail price of the new fuel is not unacceptably high relative to legacy fuels.

Consumer sensitivity to retail fuel prices should not be underestimated, and if the transition to HOF might increase prices at the pump, then educating consumers regarding the benefits associated with the transition will be critical, especially given their limited knowledge about octane.

The impact on consumers must be carefully understood and messaged appropriately. Consumer sensitivity to retail fuel prices should not be underestimated, and if the transition to HOF might increase prices at the pump, then educating consumers regarding the benefits associated with the transition will be critical, especially given their limited knowledge about octane. Fully understanding the efficiency gains that could be achieved by optimizing engines to the target HOF and how this relates to or potentially offsets possible increased prices at the pump will be important messages to convey to consumers.

There are no definitive answers about what will happen in any transition scenario – anyone who proposes to “know” how much HOF will cost at some point in the future is ignoring reality. The models presented in the Fuels Institute’s Stillwater et al. study provide a benchmark for reference, a starting point from which those considering a transition strategy can further evaluate their options.

The Fuels Institute encourages those interested in a potential HOF market to read its report on octane, “Transitioning the U.S. Gasoline Pool to a Single High-Octane fuel: A Baseline Analysis,” available for download at no cost through fuelsinstitute.org.

In addition, interested stakeholders should visit energy.gov/eere/bioenergy/co-optimization-fuels-engines and read the analyses published by the Co-Optima initiative.

Finally, interested stakeholders are encouraged to read the appendix of this report, which summarizes the input of attendees at two high octane fuel workshops hosted jointly by the Fuels Institute and Co-Optima in July 2018. This input provides additional perspective that is very relevant to the issues associated with HOF and should be understood by those interested in the potential for this market.

Appendix

STAKEHOLDER PERSPECTIVES

As with all potential market transition concepts, the idea of introducing a HOF market generates diverse reactions from various stakeholder communities as well as among individuals within each community. In July 2018, the Fuels Institute partnered with leaders of the Co-Optima initiative to convene two workshops of interested stakeholders. Following overview presentations of research done and evaluated by each organization, attendees were asked to provide their thoughts on three critical questions:

- What are the pros and cons/challenges and opportunities of introducing a high octane fuel and optimized engine?
- What are options for ensuring a successful introduction and what potential hurdles must be identified and addressed?
- What key technical and/or analysis questions need to be answered to ensure stakeholders have the requisite information to make informed decisions about changes to the gasoline specification?

The following summarizes the feedback from attendees generated by these three questions. The feedback received does not encompass all stakeholder communities or all perspectives, only those who attended these workshops, but it provides some context with which to begin evaluating how the market participants might view the issue. This summary is presented without additional commentary by the Fuels Institute or the Co-Optima leadership team. It has been compiled from notes taken by the Co-Optima team during workshop discussions and combined into a narrative by the Fuels Institute staff. It is presented in this appendix as an additional resource with which interested stakeholder may evaluate the potential for a HOF market.

QUESTION 1:

What are the pros and cons/challenges and opportunities of introducing a high octane fuel and optimized engine?

The proposed transition to a 95 RON market and the resulting increase in vehicle efficiency of 2% - 4% that would result generated significant discussion. Some question if it is worth the costs of the transition to deliver this level of efficiency improvement and, if so, for whom was it worth? They claimed that the benefits of the proposal had not yet been clearly defined. Others noted that a significant market benefit would be generated by creating a sustainable and fungible liquid products market.

Others noted that this gain in efficiency associated with 95 RON could represent just a starting point and that longer term benefits could be much more significant. In addition, if the advocates who claim that 95 RON was



the best strategy to achieve compliance with the CAFE program were correct, then one might credit to 95 RON all the benefits that would be generated with achieving the standards of that program. In this respect, it was stated that satisfying CAFE with liquid fuels might represent the path requiring the lowest consumer investment.

Producing HOF in a cost-efficient manner is further complicated due to increased reliance on oil produced from fracking fields. Due to its composition, this oil has a lower octane value than other crude supplies and this could make boosting octane more challenging and costly in terms of requiring higher investments in additional octane blendstocks. In addition, because the refinery screening model was an average of the aggregate refining industry, some noted that the impact on the market associated with the potential closure of some refineries that were not capable of upgrading to produce HOF should not be underestimated.

Stakeholders at the workshops acknowledged that some of these issues could be offset by increasing the amount of ethanol blended into the gasoline pool, but some questioned if the projected market potential for ethanol was actually sustainable. There was uncertainty regarding if ethanol production would reach a threshold and then leave the market short of available octane. There were also concerns about the compatibility of the infrastructure and suggestions that this challenge may not be receiving sufficient attention in the discussion of HOF.

Some stakeholders noted that the investment in HOF could be rendered obsolete if the transition to cost-competitive electrified powertrains were to materialize. Others, however, suggested that extending the liquid fuels market to achieve fuel efficiency targets would delay the maturation of the electric vehicle market and mitigate the potential issues associated with battery costs and disposal, electric grid upgrades, etc.

QUESTION 2:

What are options for ensuring a successful introduction and what potential hurdles must be identified and addressed?

To achieve a successful transition, some noted that the refining industry must leverage existing and available technology. Optimizing crude oil slates with refinery capabilities and maximizing the efficiency of chemical production facilities would be essential. In addition, some noted that the industry must avoid creating the potential for MTBE-like events, through which the industry became very dependent upon a gasoline component that could present future challenges to the market.

The financial implications for each sector of the market must be better understood and communicated. It will be essential to understand in advance the full impact of HOF on the supply chain, ranging from the refineries to pipelines and terminals, to distributors and retailers. It was acknowledged that each sector has an expectation for a return on investment and it will be important to help articulate that return.

Consumer buy-in was considered essential. Stakeholders suggested that a transition to HOF must be supported by a unifying message that may have to capitalize on message themes that more closely resonate with consumers. For example, perhaps instead of focusing on economic or power/performance, develop some messages regarding potential environmental benefits or other topics about which consumers care personally. It was also suggested to consider a strategy to get consumers thinking about miles per dollar rather than dollars per gallon.

On the consumer impact side as well was a concern that the impacts of additional production costs will be most severe in the early stages of the transition until economies of scale help reduce the relevant cost of HOF. This increase in fuel prices could be viewed as regressive in nature and that consideration must be given how to either mitigate disproportionately negative impact on lower income individuals or how to ensure that the benefits are experienced by all consumers as quickly as possible.

Stakeholders also had concerns about the potential for stranded capital investments should demand for liquid fuels decline over time due to efficiency improvements or

successful market expansion of competing technologies. They questioned what the future looks like for vehicle miles traveled, the use of vehicles in metropolitan areas as alternative transportation models expand in popularity and HOF might help achieve CAFE which in turn would reduce demand for HOF.

QUESTION 3:

What key technical and/or analysis questions need to be answered to ensure stakeholders have the requisite information to make informed decisions about changes to the gasoline specification?

The topics presented in response to this question largely fell in line with stakeholder perspectives on the first two questions presented above. The following represents the general interest of the workshops for additional information:

- To really appreciate what will be required to produce HOF, it is critical to better understand the types of crude that will be processed by the refineries. As the U.S. increases its use of fracking-sourced crude, this increases difficulty to produce HOF and will put additional pressures on the market.
 - What is the potential and overall impact of a mid-level ethanol market? Can the ethanol industry efficiently satisfy the potential increase in demand? What would be the associated regulatory, infrastructure and environmental impact?
 - What is the true impact on emissions if the composition of the fuel changes? How would different HOF formulations impact both tailpipe and overall greenhouse gas emissions?
- What is the impact on real-world fuel economy of HOF scenario? This question seems to focus on whether HOF will be able to meaningfully assist with CAFE compliance and, if it does, what does this mean for long term demand for HOF and the potential return on investments to transition the market.
 - How much do we really understand about consumer perceptions? Surveys are unavoidably challenging for determining what consumers actually do. A respondent may answer a question based upon what they want to do or what they want others to believe as opposed to what they actually do. Stakeholders wanted to better understand what to expect with consumers in order to develop a strategy to most effectively manage consumer relations.
 - What are the full implications of HOF on infrastructure? What are the various dynamics that will contribute to conversion, including market driven issues that might create opportunities for upgrades and overall costs to the market?
 - In order to fully understand the implications for the refining sector, the production volumes anticipated and the associated costs, a complete refinery-by-refinery analysis that can be compared with the aggregate screening analysis is required.



E About the Fuels Institute

The Fuels Institute, founded by NACS in 2013, is a 501(c)(4) non-profit research-oriented think tank dedicated to evaluating the market issues relating to vehicles and the fuels that power them. By bringing together diverse stakeholders of the transportation and fuels markets, the Institute helps to identify opportunities and challenges associated with the new technologies and to facilitate industry coordination to help ensure that consumers derive the greatest benefit.

The Fuels Institute commissions and publishes comprehensive, fact-based research projects that address the interests of the affected stakeholders.

Such publications will help to inform both business owners considering long-term investment decisions and policymakers considering legislation and regulations affecting the market. Research is independent and unbiased, designed to answer questions, not advocate a specific outcome. Participants in the Fuels Institute are dedicated to promoting the facts and providing decision makers with the most credible information possible, so that the market can deliver the best in vehicle and fueling options to the consumer.

For more about the Fuels Institute, visit fuelsinstitute.org

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The Fuels Institute was founded in 2013 by NACS, the international association that advances convenience and fuel retailing. Through recurring financial contributions and daily operational support, NACS helps the Fuels Institute to invest in and carry out its work to foster collaboration among the various stakeholders with interests in the transportation energy market and to promote a comprehensive and objective evaluation of issues affecting that market and its customers both today and in the future. NACS was founded August 14, 1961, as the National Association of Convenience Stores, and represents more than 2,100 retail and 1,600 supplier company members.

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