Office of the Chief Economist
U.S. DEPARTMENT OF AGRICULTURE

Assessing Future Market Opportunities and Challenges for E15 and Higher Ethanol Blends

May 2022

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Abstract

This report was prepared as part of an effort to understand the barriers and opportunities to expand the use of higher blends of ethanol in the US gasoline market, and especially 15% ethanol blends. The report evaluates market conditions and provides an analysis of barriers for higher ethanol blends, including technical, regulatory, consumer acceptance, and economic challenges.

JEL Codes: D25, O33, Q16, Q35, R4

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List of Abbreviations

AB	advanced biofuel
AFDC	Alternative Fuels Data Center
AFV	alternative fuel vehicle
BBD	biomass-based diesel
BIP	Biofuel Infrastructure Partnership
CAA	Clean Air Act
CAFE	Corporate Average Fuel Economy
CARD	Center for Agriculture and Rural Development
CaRFG3	California Phase 3 Reformulated Gasoline
CB	cellulosic biofuel
CCC	Commodity Credit Corporation
CNG	compressed natural gas
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act
EIA	U.S. Energy Information Administration
EV	electric vehicle
FCEV	hydrogen fuel cell electric vehicle
FFV	flex fuel vehicle
GHG	greenhouse gas
HBIIP	Higher Blends Infrastructure Incentive Program
HEV	hybrid electric vehicle
ICE	internal combustion engine
MTBE	methyl tert-butyl ether
MY	model year
NACS	National Association of Convenience Stores
PHEV	plug-in hybrid electric vehicle
RF	renewable fuel
RFS	Renewable Fuel Standard
RIN	Renewable Identification Number
RVO	renewable volume obligation
RVP	Reid vapor pressure
SRE	small refinery exemption
USDA	U.S. Department of Agriculture
UST	underground storage tank
VOC	volatile organic compound

I. Introduction

Ethanol consumption in the United States has seen a dramatic increase since 2000. It became the primary alternative fuel oxygenate when in the early 2000s, as a number of States banned the use of methyl tert-butyl ether (MTBE). The Renewable Fuel Standard (RFS) came into effect under the Energy Policy Act (EPAct) in 2005 and was expanded in 2007 under the Energy Independence and Security Act. Between 2005 and 2010, ethanol sales more than tripled. Today, virtually all gasoline sold in the United States contains 10 percent ethanol (E10) (AFDC, n.d.). After 2010, ethanol consumption leveled off. Due to increasing vehicle fuel efficiency and the growing popularity of hybrid and electric vehicles, gasoline consumption is projected to decline through 2050 by 19 percent (EIA, 2020a). If E10 continues to be the standard blend, ethanol consumption will decline as well. However, if the standard blend increases to 15 percent or higher, ethanol consumption could continue to rise while simultaneously reducing greenhouse gas (GHG) emissions associated with combusting transportation fuels (Milovanoff, Saville, Posen, & MacLean, 2020).

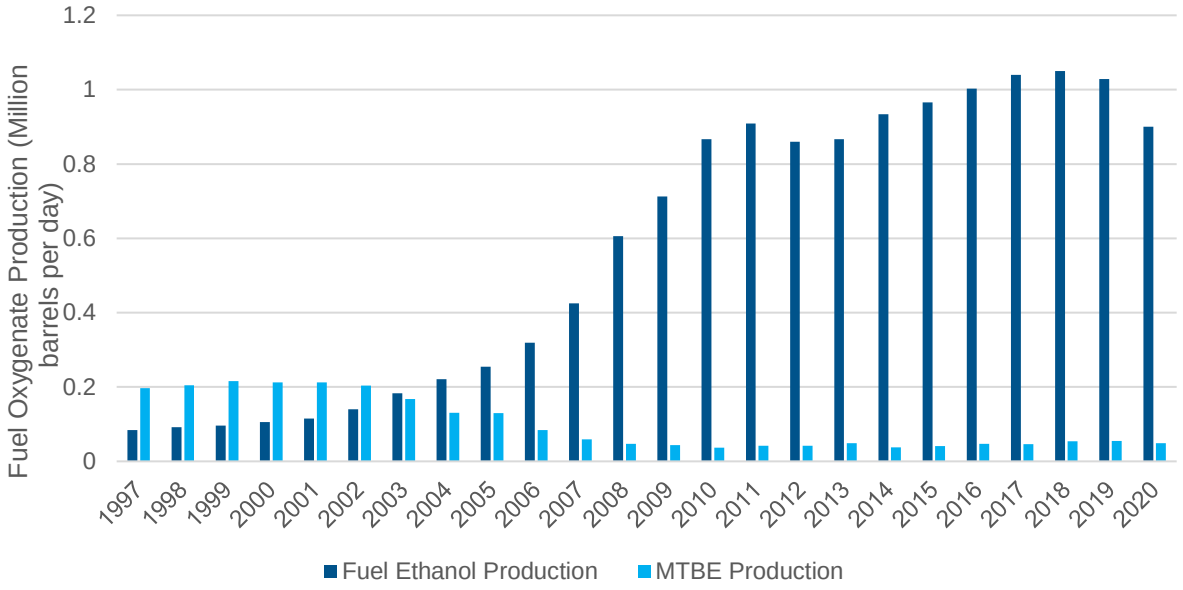
Transitioning to ethanol blends above E10 can also support energy independence if the feedstock used is domestically sourced and lower oil and gasoline imports ensue. E15 is already a viable fuel option for most vehicles; about 93 percent of all light-duty vehicles can safely refuel with E15 (RFA, 2020a). Nonetheless, while there is potential for expansion to higher blends, there are technical, legal, and economic challenges (e.g., consumer acceptance, legal and contractual considerations for retail fueling stations, vehicle warranties, and investments in wholesale and retail distribution infrastructure) that need to be evaluated and addressed.

II. Background

Following the 1990 Clean Air Act (CAA) amendments, refineries were required to produce oxygenated gasoline and reformulated gasoline in addition to conventional gasoline. The new gasoline regulations were specific to places with carbon monoxide and/or ground-level ozone pollution issues. In response to the new gasoline requirements, methyl tert-butyl ether (MTBE) and ethanol were widely used to add oxygen, dilute aromatic content, and improve octane in the 1990s. However, following State bans of MTBE in the early and mid-2000s due to ground water contamination concerns, MTBE quickly declined as a fuel additive in the United States.[1] As a result, ethanol replaced MTBE as the major fuel additive in the United States by 2008. This use of ethanol as the major fuel additive was sealed by the RFS, which spurred ethanol production volumes to double in the 3 years from 2007 to 2010 (Figure 1).

[1] MTBE that is still produced is exported mainly to Mexico, Chile, and Venezuela (EIA, 2018).

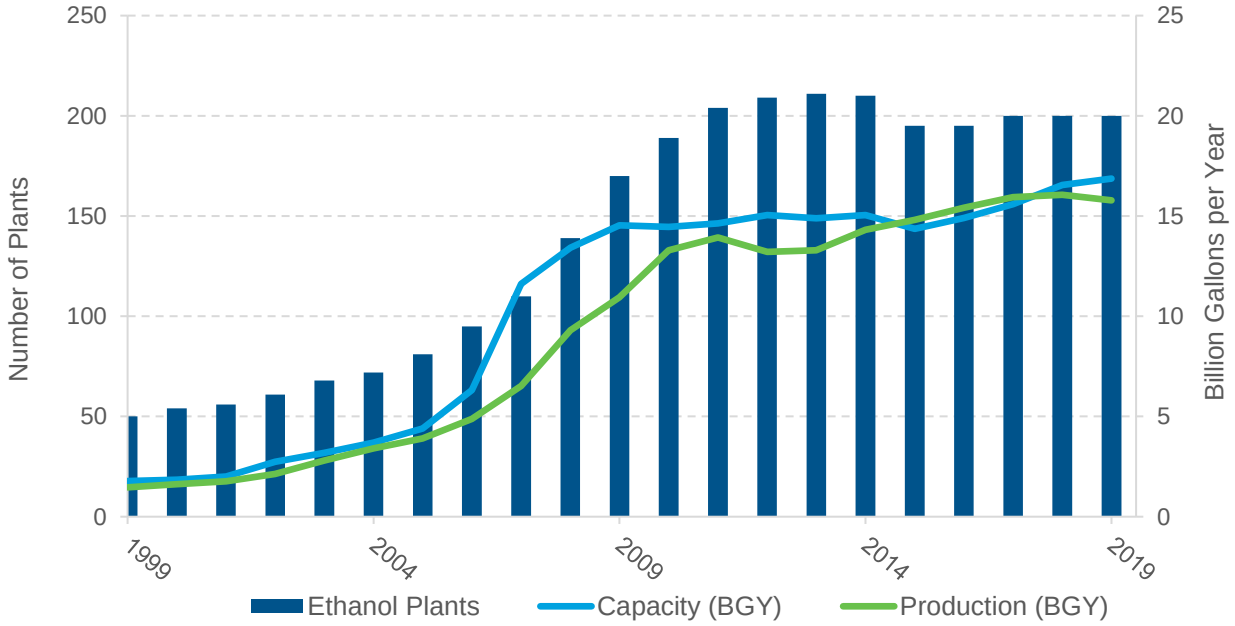
Figure 1. United States MTBE and Ethanol Production



Source: (EIA, 2021c)

Ethanol production grew rapidly from the 1990's through the early 2010s but has leveled off since then (Figure 2). Capacity, on the other hand, has continued to slowly trend upward (AFDC, 2020a). Production is geographically concentrated in Iowa, Nebraska, and Illinois. These three States account for nearly half of the fuel ethanol produced in the United States. (See Appendix B: Ethanol Capacity and Number of Facilities by State) (EIA, 2020b).

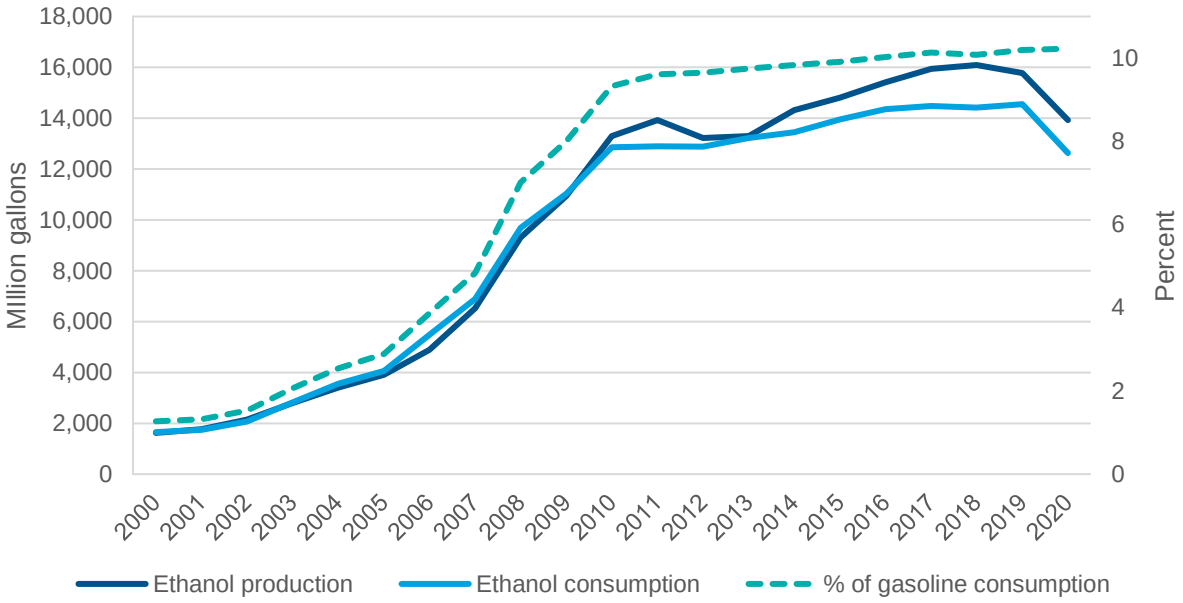
Figure 2. United States Ethanol Plant Count, Capacity, and Production



Source: (AFDC, 2020a)

Fuel ethanol consumption has also leveled off and, since 2013, domestic consumption has trailed production, allowing for net exports. In recent years, fuel ethanol production and consumption have both remained relatively stagnant (Figure 3), at nearly 15.8 and 14.6 billion gallons, respectively, in 2019 (EIA, 2021a). The average blend rate of ethanol to gasoline has increased over time and was 10.2 percent in 2019. While most gasoline sold in the United States contains 10 percent ethanol (E10), higher blends account for limited sales, and E15 sales are increasing.

Figure 3. U.S. Ethanol Production, Consumption, and Blend Rate to Gasoline Consumption



Source: (AFDC, 2020b; EIA, 2021d; EIA, 2021e)

Beyond the evolution of the ethanol market, another key to exploring the potential to expand the adoption of higher ethanol blends is understanding the market structure of U.S. retail fueling stations. There are about 150,000 fueling locations, which can be classified into four broad categories (NACS, 2021a):

- **Convenience stores:** 121,538 convenience stores and truck stops sell an estimated 80 percent of the fuel and are the dominant fueling outlet.
- **Kiosk fueling sites**: 15,638 fueling kiosks sell fuel along with a small assortment of other items.
- **Hypermarkets**: 6,494 supermarkets and big-box outlets such as Walmart, Costco, Sam's Club, and Kroger sell fuel. The amount of fuel sold at hypermarkets is typically five times more than at the average fueling location, which sells about 2,600 gallons/day.
- **Service stations**: Until the early 1970s, service stations were the dominant fuel retailer; however, only an estimated 3,000 to 8,000 locations sell fuel at present (including small-volume locations like marinas).

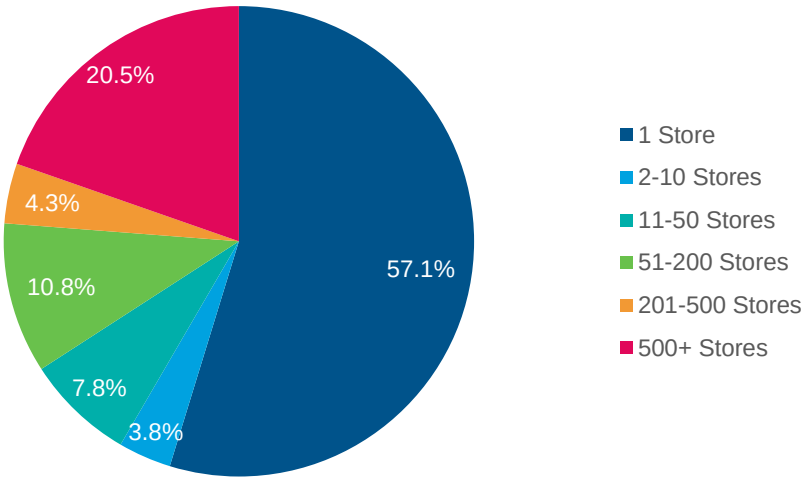
Fueling stations have been on a long-term declining trend. Some estimates suggest that compared to today, there were twice as many (around 300,000) fueling outlets in the 1920s that sold much smaller volumes of fuel (NACS, 2021a). According to the National Association of Convenience

Stores (NACS), the total number of fueling stations at convenience stores in the United States is also decreasing. In 2016, there were over 124,000 fueling stations at convenience stores (2016). Comparatively, in 2019, there were 121,998 (NACS, 2021a; NACS, 2016).

Convenience store fueling stations have also experienced ownership consolidation. Since 2016, single station owners and owners of below 50 stores have decreased (from 72.2 percent in 2016 to 68.7 percent in 2020) while larger entities have increased (owners of 51-200 stores increased from 5.5 percent in 2016 to 10.8 percent in 2020 and owners of over 500 stores increased from 16.7 percent in 2016 to 20.5 percent in 2020) (NACS, 2021a; NACS, 2016). Single-station ownership is the lowest it has been since 2010 (when it was 56.7 percent) (NACS, 2021a; NACS, 2021c). Still, as showcased in Figure 4, the nearly 70,000 single station owners make up the majority (57.1 percent) of the market.

Moreover, many single ownership stations do not have the resources to brand their stores separately from the brand of fuel they sell and promote on the canopy, often leading to misperceptions that their business is owned and operated by a major oil company (NACS, 2021a). Contract agreements are thus mainly associated with single owner operators. Oil companies (roughly 15 major ones) provide fuel to 50 percent of stations via contract agreements (NACS, 2021b). The remaining 50 percent of convenience stores that sell fuel have established their own fuel brand and purchase fuels either on the open market or via unbranded contracts with a refiner/distributor (NACS, 2021a). Although it is illegal to prevent a station from selling alternative fuels, there have been concerns that contract agreements with oil refiners have limitations that can discourage the sale of higher ethanol blends (Lindenberg & Oller, 2014). Nonetheless, since 2016 branded stations have participated in the Biofuel Infrastructure Partnership (BIP) program. These dynamics can prove important for expanding the adoption of higher ethanol blends.

Figure 4. Ownership of U.S. Retail Fueling Stations in 2020



Source: (NACS, 2021a)

There are significant financial barriers with expanding infrastructure to facilitate consumption of higher level ethanol blends. While virtually all stations have equipment necessary for storing and dispensing E10, it is difficult to discern how many have fueling equipment compatible with ethanol blends above E10. Before offering ethanol blends above E10, station owners will need to evaluate their equipment to guarantee operability and, according to 40 CFR § 280.32 (Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks (UST), Compatibility), demonstrate that higher blends are compatible with their UST system.

In considering fuel infrastructure upgrades, single-station owners will face more significant financial barriers compared to large multi-station ownership entities. Single-station owners do not have the same capital and resources available for station modifications or new construction, nor can they take advantage of economies of scale in acquiring new equipment. In consideration of these financial challenges, the Higher Blends Infrastructure Incentive Program (HBIIP: see Section V for more detail) provided targeted assistance, which made available approximately 40 percent of the funds for applicants owning 1 to 10 fueling stations or locations.

On the infrastructure side, financial incentives and assistance programs will likely play a key role in the future expansion potential of the market for higher ethanol blends across the United States. On the demand-side of the industry, key to the adoption of higher ethanol blends will be consumer acceptance of higher-level ethanol blends. Retailers that offer higher ethanol blends have in some cases used marketing campaigns to encourage sales and in others favorable price differentials (Fuels Institute, 2018).

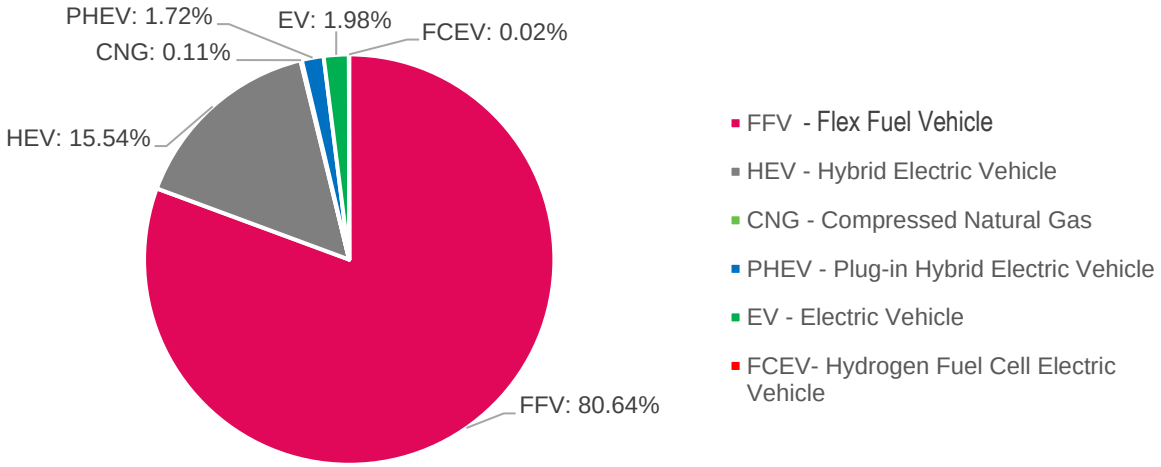
III. Current Market for E15 and Higher Ethanol Blends

1. Ethanol Blends

Of the gasoline sold in the United States, approximately 95 to 98 percent is sold with concentrations of E10 (AFDC, n.d.; EIA, 2016). Historically, the second most common ethanol blend available at retail stations is E85, which is an ethanol-gasoline blend ranging from 51 percent to 83 percent ethanol by volume. However, in 2019, E15 sales surpassed those of E85 for the first time (RFA, 2020b).

Flex fuel vehicles (FFVs) are the only vehicles approved to safely operate on gasoline with any blend of ethanol up to E85. FFVs are a popular option among alternative fuel vehicles (AFVs), because when necessary FFVs can also rely on gasoline. As shown in Figure 5, as of December 2018, FFVs were the most common light-duty AFV in the United States, representing over 80 percent of AFV registrations (AFDC, 2020c).

Figure 5. Light-Duty AFV Registrations, as of December 2018



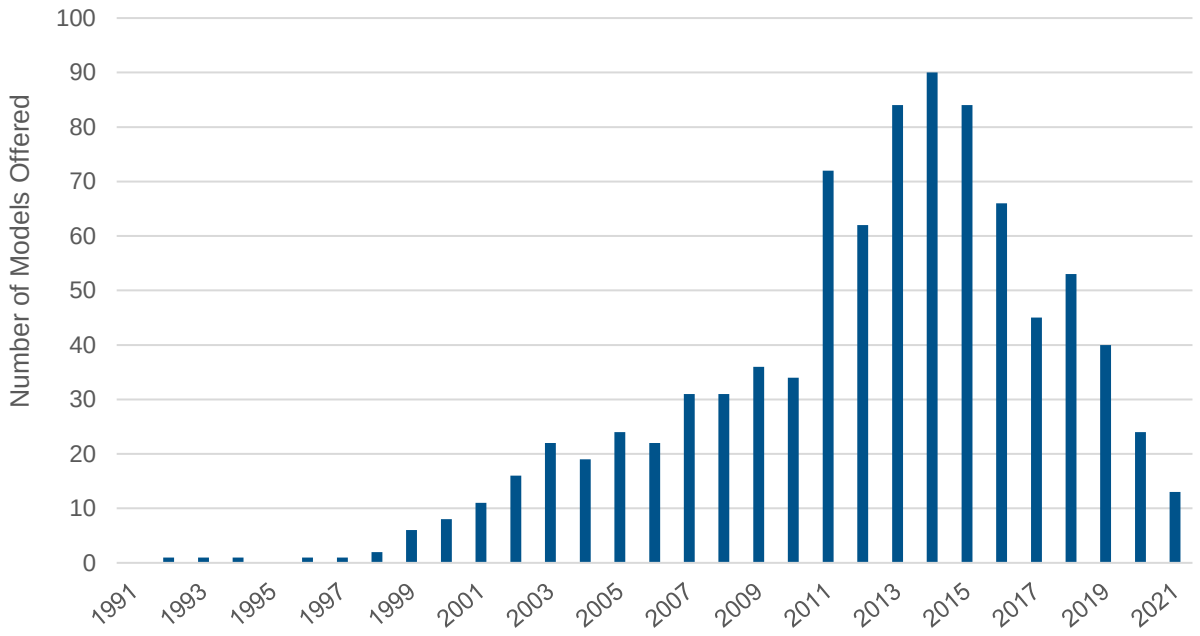
Source: (AFDC, 2020c)

The use of FFVs is especially popular among fleets operated by State government agencies. This use is attributed to EPAct and ensuing regulations that require certain State fleets to acquire AFVs (AFDC, 2019a). As a result, 45 States have adopted laws or regulations requiring the use of AFVs in State fleets. Some States, such as Kansas and Illinois, have gone further by adopting policies that mandate the use of FFVs in State fleets (AFDC, 2021a). In 2018, FFVs constituted nearly 93 percent of regulated fleet AFV acquisitions (AFDC, 2019a).

Despite the popularity of FFVs among private owners and fleets of AFVs, light-duty FFV offerings from vehicle manufacturers have decreased since model year (MY) 2015, as seen in Figure 6 (AFDC, 2020d). In MY 2021, FFV offerings fell to 13 models (ORNL, n.d.), representing an 80-percent decrease since 2015. Factors assumed to have contributed to this decrease include relatively low gasoline prices, the Volkswagen diesel emissions scandal, and the phase-out of Corporate Average Fuel Economy credits for FFVs (AFDC, 2020c). Furthermore, actual consumption of E85 among flex-fuel vehicle owners remains limited. EPA continued to use the F-Factor of 0.14 for FFVs in 2020, implying that only 14 percent of their fuel consumption was E85 (EPA, 2020).[2] An increase of the F-factor would positively impact FFV offerings in the future via the Corporate Average Fuel Economy (CAFE) program.

[2] The Environmental Protection Agency (EPA) applies a weighing factor (F-factor) to FFVs that has represented the projected portion of fuel that is E85.

Figure 6. Light-Duty FFV Offerings



Source: (AFDC, 2020c; ORNL, n.d.)

As E85 is no longer stimulating the growth needed to increase ethanol consumption, attention has switched to the potential in mid-level blends, notably E15. It is estimated that 93 percent of the vehicles on the road, consuming 97 percent of gasoline, are approved to use E15. This estimate includes light-duty vehicles built for MY 2001 or newer, along with FFVs (RFA, 2020a). Table 1 identifies the auto manufacturers that have approved E15 in their vehicles over time, based on the auto manufacturer's owner's manuals. Automakers were initially cautious with offering relevant warranties (only GM approved E15 in all models starting in 2013). However, by 2020, automakers that warrant all models for E15 use sold 83 percent of new cars in the United States. Reluctance with offering mid-level blends has been more pronounced; BMW is the only manufacturer to approve ethanol blends up to E25 in their vehicles (RFA, 2021). Nonetheless non-flex fuel vehicles have been shown to adapt up to 30 percent ethanol blended (E30) gasoline without compromising engine performance or fuel efficiency (Alsiyabi, Stroh, & Saha, 2021).

Table 1. E15 Approval in Conventional Vehicles by Automaker

MODEL YEAR:	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Market Share*
BMW Group**											
BMW											1.9%
Mini											0.2%
Daimler Group											2.3%
Fiat Chrysler Automobiles											12.8%
Ford Motor Co.											14.5%
GM											17.3%
Honda											9.5%
Hyundai											8.3%
Mazda											1.9%
Mitsubishi											0.7%
Nissan											
Infiniti											0.6%
Nissan†											6.1%
Subaru‡											4.2%
Tata Motors											0.7%
Toyota Motor Corp.											
Lexus											1.9%
Toyota											12.3%
Volkswagen Group											
Audi											1.3%
Porsche											0.4%
Volkswagen Group											2.2%
Volvo Car Group											0.7%
All Others											0.2%

E15 Approved by Automaker in All Models

E15 Approved by Automaker in Some Models

E15 Approved by EPA Only; Not Approved by Automaker

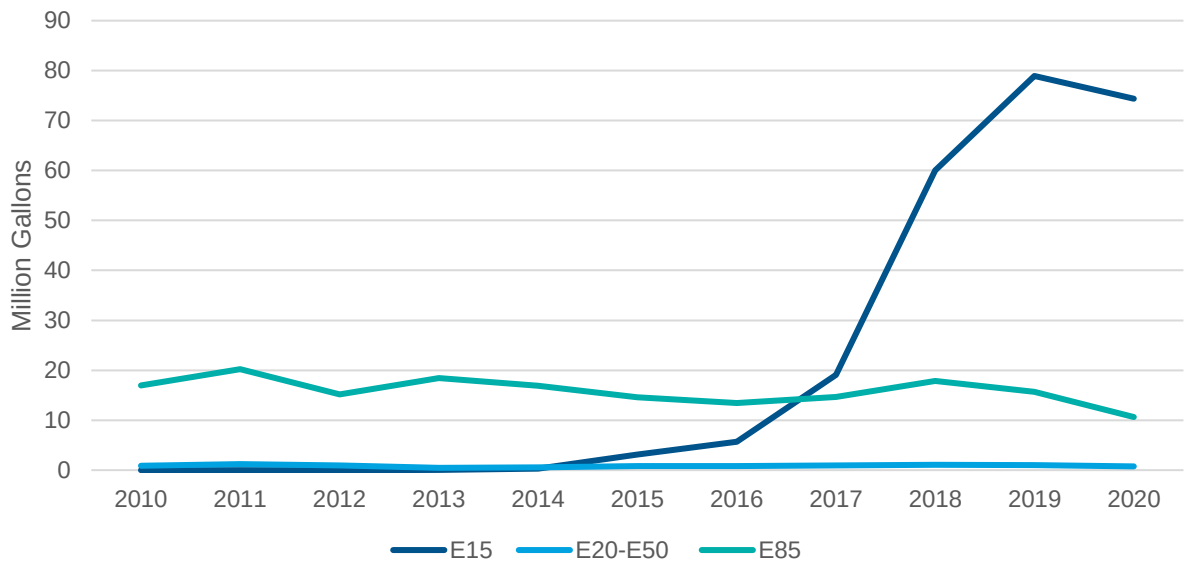
* Internal combustion engine (ICE) models only
** Approves the use of up to 25% ethanol blends
† Approves the use of E15 in Rogue/Rogue Sport, Altima, Maxima, Versa & Titan. Approves the use of E10 in GT-R & NV Passenger/Cargo. Manuals not available to-date: Armada, Frontier, Murano, Pathfinder, Sentra & Z Coupe.
‡ Approves the use of E15 in Outback, Legacy, Impreza, Ascent & Crosstrek (2.0L engine). Approves the use of E10 in Forester & Crosstrek (2.5L engine). Manuals not available to-date: WRX/WRX STI & BRZ.

Source: (RFA, 2021)

A 2019 ruling by the U.S. Environmental Protection Agency (EPA) that permitted the year-round sale of E15 was expected to encourage the growth of the E15 market going forward (EPA, 2019a; RFA, 2020b; Stock, 2018). Indeed, following EPA's decision, an RFA analysis found a jump in

E15 sales for 2019, surpassing the sale of E85 for the first time. In Minnesota, the only State that tracks monthly sales of E15, sales increased over 30 percent between 2018 and 2019 (Minnesota Commerce Department, 2021). In 2018, E15 sales accounted for 2.4 percent of total gasoline sales in the State. Blend rates of E20-50 on the other hand have remained limited and stagnant even in the Midwest. In Minnesota, they accounted for 0.04 percent of total gasoline sales in 2018 and averaged 0.034 percent in the last decade. These dynamics for higher ethanol blend sales in Minnesota are showcased in Figure 7 (Minnesota Commerce Department, 2021).

Figure 7. Higher Ethanol Blend Volumes in Minnesota



Source: (Minnesota Commerce Department, 2021)

A 2019 ruling by the U.S. Environmental Protection Agency (EPA) permitted the year-round sale of E15. This decision was challenged and in July 2021 the D.C. Circuit court struck down EPA's 2019 interpretation which would have expanded E15 sales in summer months. Recently, on April 12, 2022, the US, in response to tight energy markets, announced that the Environmental Protection Agency (EPA) will issue a national emergency waiver to make E15 available in conventional gasoline markets this summer. The long-term resolution of this issue will have implications for the marketability and expansion of E15. Gas stations are less likely to invest in infrastructure for a fuel that can only be sold for a portion of the year.

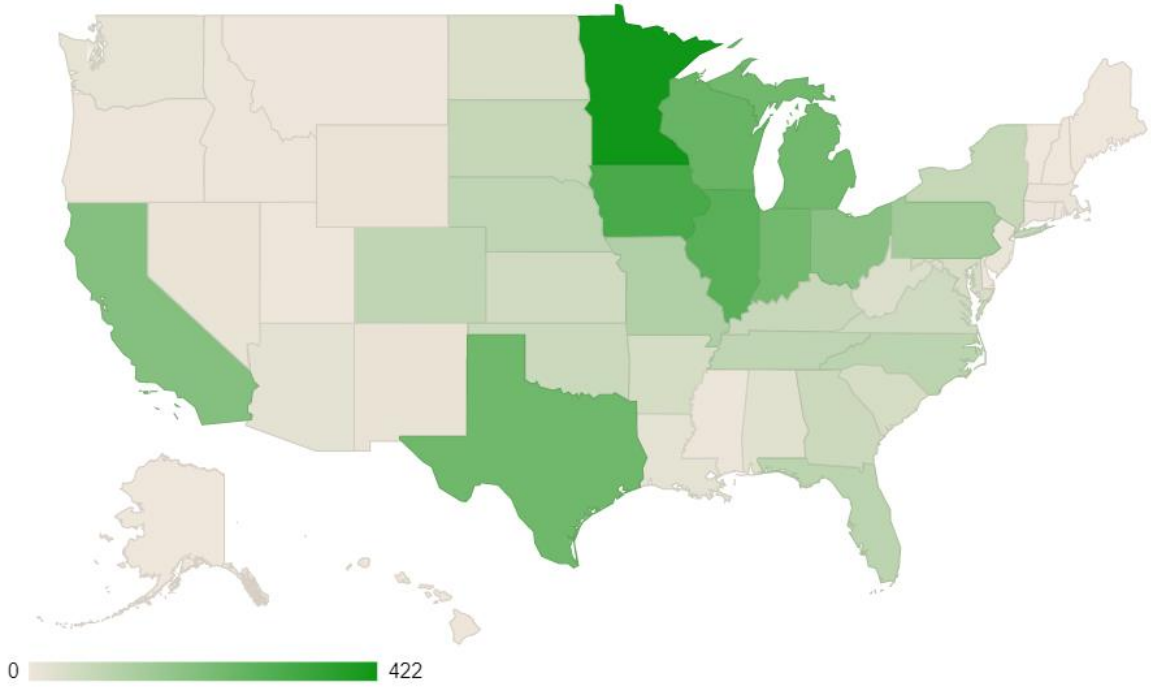
2. Existing Infrastructure

Compared to the 150,000 public fueling stations in the United States that sell E10 (NACS, 2021c), there are 3,975 public E85 stations available in the country (AFDC, 2021b). [3] As shown in Figure

[3] This figure was calculated based on the number of public conventional refueling stations (142,000) and the percentage of stations offering E10 (i.e., 95 percent). Public refueling station counts were sourced from the Transportation Energy Data Book: Edition 39 (ORNL, 2021). The lower estimate of the percent of public fueling stations offering E10 was used (i.e., 95 percent) (EIA, 2016).

8, most E85 stations are concentrated in the Midwest. Minnesota leads the Nation in the number of E85 fueling stations (410), followed by Iowa (309), and Illinois (267) (AFDC, 2021c).

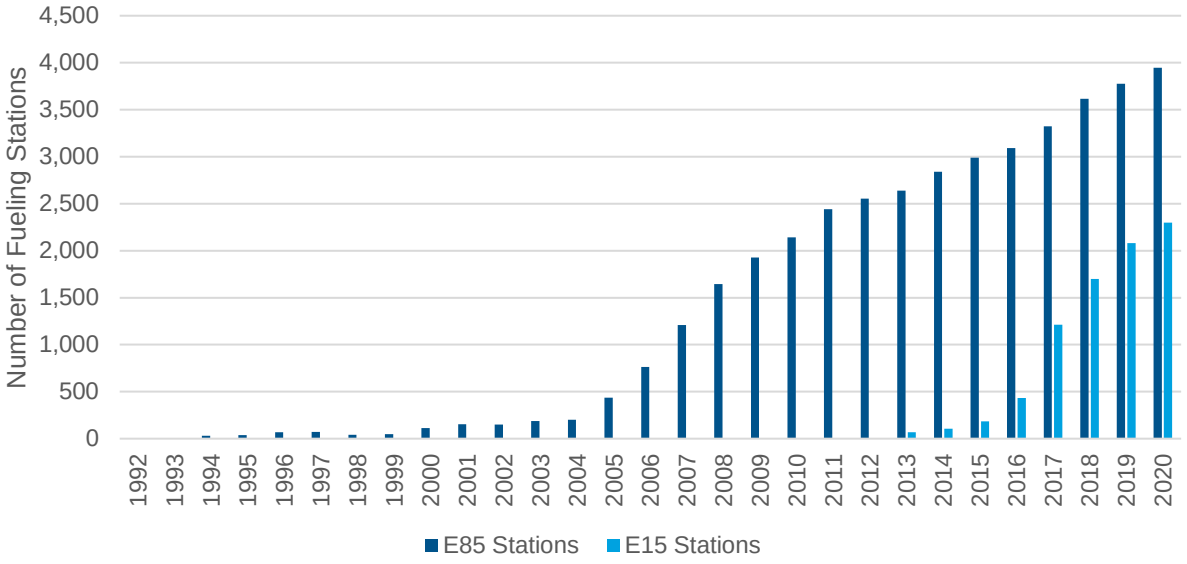
Figure 8. Concentration of E85 Fueling Stations by State in 2020



Source: (AFDC, 2021c)

Figure 9 shows that over the last 15 years, the number of E85 fueling stations (both public and private) in the country has increased from 436 to 3,975 (AFDC, 2021d; AFDC, 2019b), indicating that fueling infrastructure exists but FFV sales and E85 demand have not kept up pace.

Figure 9. Number of E85 and E15 Fueling Stations

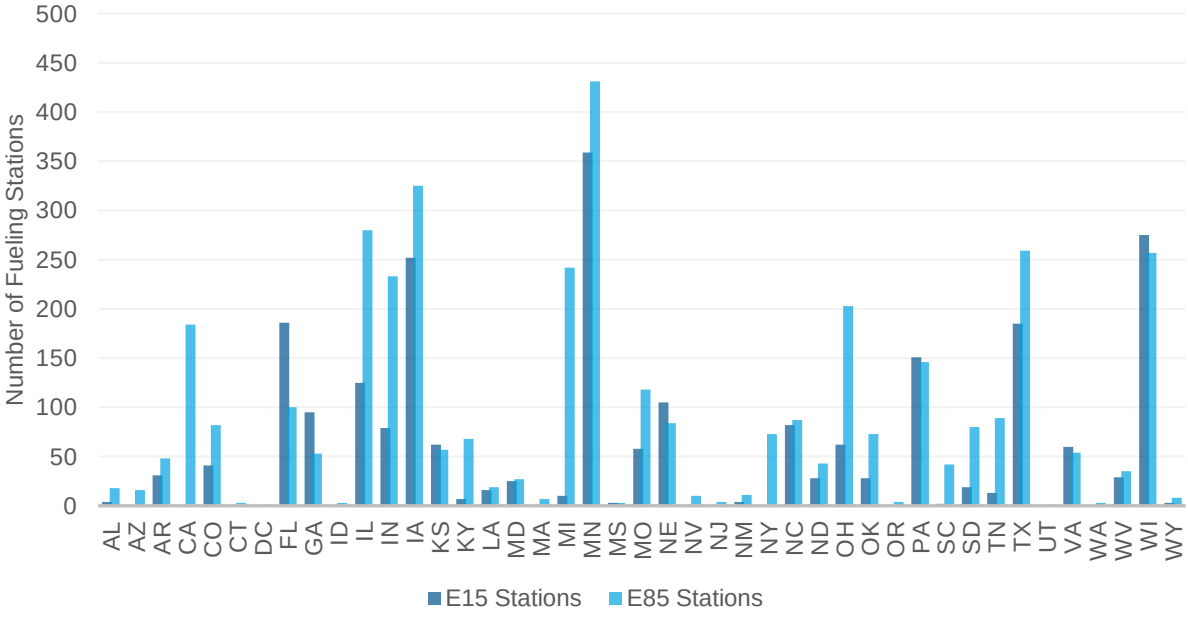


Source: (AFDC, 2021d; AFDC, 2019b; Growth Energy, 2021b)

Blender pumps used for blending E85 can also produce mid-level ethanol blends (i.e., blends above E10 and up to E50), thus stations offering mid-level blends are typically concentrated in areas with existing E85 infrastructure (Figure 10). As noted in an *Energy Economics* article, the greatest potential for higher ethanol blends is approximated as a function of current location of E85 pumps and flex vehicles (Pouliot & Babcock, 2014). Of all the stations that offer ethanol blends, over 1,300 sell both E15 and E85 (Growth Energy, 2021b). Growth Energy estimates that between 2014 and 2020, the number of retail E15 stations in the United States grew from approximately 104 to over 2,300 (Figure 9).[4] Five States--Minnesota, Wisconsin, Iowa, Florida, and Texas--account for over 50 percent of the total E15 retail stations (Figure 10). As the market for E15 grows, it is expected that offtake will increasingly occur through dedicated E15 pumps and pre-blended E15 fuel. Pre-blended E15 supply has certainly been increasing. The first terminals started to offer E15 in 2016 (White, 2019); today E15 is offered at 230 terminal locations (Figure 11). By comparison, the Oil Price Information Service reports that there are 1,296 terminals storing transportation fuel nationwide, of which over 1,200 either store or can store ethanol (Moriarty K. , 2016).

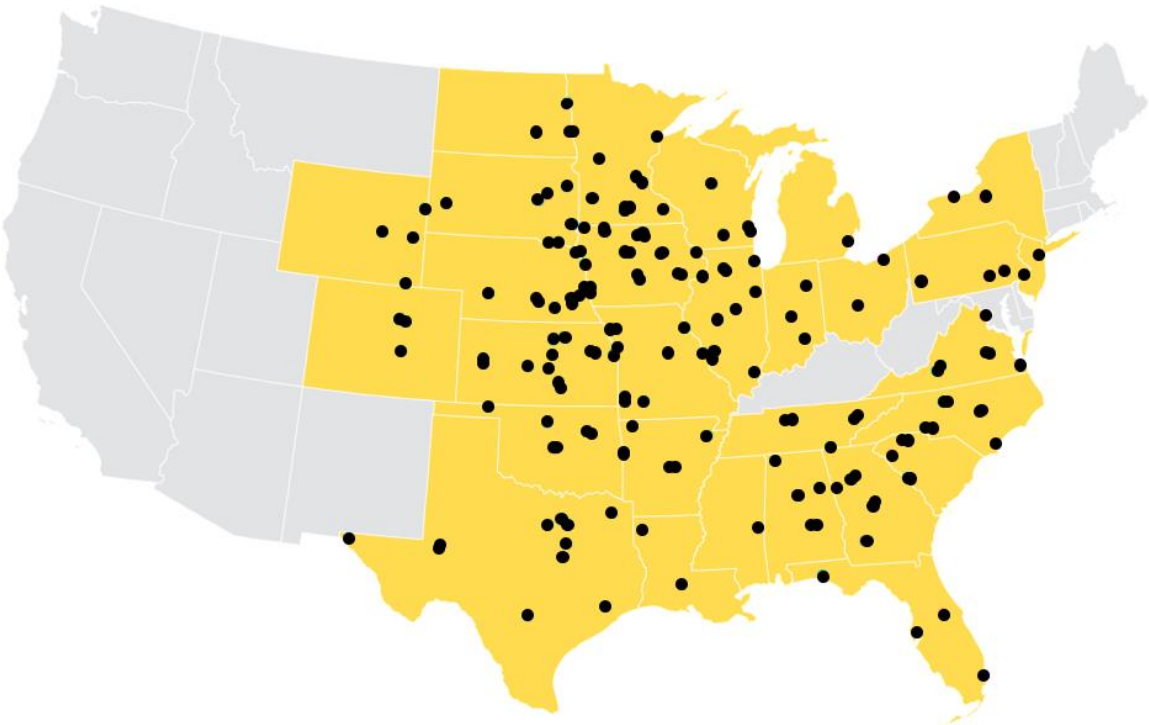
[4] The AFDC does not track the number of stations with E15, data from Growth Energy was used instead. The AFDC only tracks the number of E85 stations and the number of E85 stations that also offer midlevel blends.

Figure 10. E85 and E15 Retail Stations by State in 2020



Source: (AFDC, 2021c; Growth Energy, 2020)

Figure 11. Terminals Offering E15 in 2020



Source: (Growth Energy, 2020)

IV. Current Costs of Installing E15 and Higher Ethanol Blend Equipment

Many service stations appear to already have the basic equipment necessary for storing and dispensing ethanol blends above E10. Yet, some existing infrastructure is old enough to no longer have manufacturer information, making it difficult to discern if the fueling equipment is compatible with ethanol blends above E10. In such cases, before offering E15 or higher blends, station owners need to have their equipment evaluated or replaced to guarantee proper operability.

The market for ethanol service station equipment is well developed and includes tanks, dispensers, hanging hardware, valves, and other equipment compatible with blends above E10 available from multiple manufacturers (NREL, n.d.). An important factor to consider is that higher ethanol blends are more corrosive than traditional gasoline. While E25 equipment use the same metals as in E10 equipment, the elastomers differ. Upgraded metal does need to be used in some E85 equipment. When evaluating existing infrastructure and replacement options, fueling equipment made with unplated steel, stainless steel, thermoset-reinforced fiberglass, black iron, and bronze can handle the corrosivity of ethanol blends up to E85 (EERE, 2013). Equipment made with zinc, brass, lead, and aluminum are sensitive to the corrosiveness of E85 and can degrade overtime.

Today, E25, E85, and E100 compatible equipment are readily available (EERE, 2013) along with UL certified tanks and associated piping. Manufacturers have also issued statements of compatibility with Federal code. Nonetheless there is no guarantee that a given station will have the necessary equipment installed to safely store and dispense E15 and E30. The options to guarantee fueling equipment compatibility with ethanol blends include confirming that the installed equipment is third-party listed or certified for the appropriate ethanol blend or obtaining equipment or component manufacturer approval via a written statement of compatibility in accordance with 40 CFR § 280.32.

Time and costs associated with the replacement of infrastructure are the primary barriers stations face across all higher-level ethanol blends. Nonetheless, there is consensus among industry leaders, equipment manufacturers, and other stakeholders that transitioning to ethanol blends between E11 to E25 will be easier and less costly than blends above E25 (Moriarty, Kass, & Theiss, 2014; Monroe, Kass, & McConnell, 2019). As an order of magnitude, if 20 percent of existing stations were upgraded to E11-E25 blending capacity with medium above ground modifications, the cost increase is $1.9 billion; the cost increases to $10.62 billion for extensive UST conversions. Comparatively, these numbers become $5.7 billion and $14.44 billion respectively to move to E26-E85 blending capacity (Monroe, Kass, & McConnell, 2019). Federal support to upgrade station infrastructure for storing and dispensing mid- and high-level ethanol blends up to now has been $200 million.

1. Service Station Components

The average service station has approximately 60 pieces of equipment that work together to handle fuel and vapor. While many of these pieces are accessible from above ground, others are not (EERE, 2016). A schematic of typical fuel dispenser and underground piping is presented in Appendix C (EERE, 2016). A summary of equipment that may need to be replaced to store and

dispense ethanol blends above E10 are outlined in Table 2. Below ground upgrades are very expensive. Even if a station does not need to change out a tank, it may need to change some part of the UST system as it relates to the delivery equipment, inventory control, leak detection and containment. Changing incompatible pipes for example bears a significant cost. Examples of equipment and manufacturers that are compatible with ethanol blends are available in Appendix D.

Table 2. Overview of Station Components

Equipment	Description
Storage Tank System	Used for fuel storage and delivery; usually underground but can be above ground. While associated with the tank, it also includes fuel delivery equipment and pipes, inventory control, leak detection and containment.
Dispenser	Equipment needed to dispense fuel in vehicles. Blender pumps have been the most common type of dispenser sold. They allow stations to draw fuel from two separate tanks and blend at various ratios to create a variety of fuel blends.
Hanging Hardware	Includes hoses, nozzles, breakaways, and swivels
Shear Valves	Stops the flow of fuel from the underground storage tank to the dispenser. They prevent fuel release in the event of an accident dislodging the dispenser or a fire.
Submersive Turbine Pumps	Draws fuel from the tank and into the piping that delivers the fuel to the dispenser

Source: (Monroe, Kass, & McConnell, 2019)

2. Tanks

Since 1990, virtually all USTs and lines sold in the United States have been designed and manufactured to meet the requirements needed to safely store E100 (Moriarty & Yanowitz, 2015a). Fiberglass tanks typically have a 30-year warranty, while steel tanks have a 10-year warranty assured by manufacturers to guarantee protection against corrosion (Geyer, 2007). As stations replace older tanks, the share of higher ethanol blend compatible tanks in the retail fuel distribution system will continue to increase. Tanks installed in the 1990s or earlier have reached the end of their warranties and should be replaced to safely store fuel. Appendix D has a list of tanks and manufacturers that produce tanks compatible with ethanol blends E10 through E100 (EERE, 2016).

When stations are considering adding higher ethanol blends, they may use an existing compatible tank (which may now store diesel, mid-grade gasoline, regular gasoline, or premium gasoline) or add a new tank at a much higher upfront cost. If they choose to use an existing tank, the station will have to consider new challenges to its business model, cash flow, and user demand expectations. If they add a new tank, multi-compartment tanks, for multiple fuel storage and delivery, are available. Larger stations have more tanks (5 instead of 3); thus, they can repurpose a tank instead of installing a new one.

3. Dispensers and Blender Pumps

There are multiple dispenser options to sell ethanol blends above E10. While retrofitting an existing dispenser with an E25 UL-listed kit has been promoted as an option (EERE, 2013), retailers typically have not chosen this option. They have instead chosen to install UL-listed E25 dispensers or UL listed E85 blender pump dispensers. Dispensers UL listed for ethanol blends can cost between $11,000 and $30,000, depending on manufacturer and blending capability (Clean Fuels Foundation, 2011). E10 UL-listed dispensers can cost between $10,000 and $18,000, while E85 UL listed blender pump dispensers can cost $30,000 (Moriarty K. , 2010). In 2017 almost 40 percent of fuel dispensers sold in the United States were compatible with E25 (Monroe, Kass, & McConnell, 2019). RFA states that the average cost to replace a dispenser with an E25 compatible option is under $20,500 per dispenser (RFA, n.d.).

Blender pumps have been the most common type of dispenser sold. They allow stations to draw fuel from two separate tanks and blend at various ratios to create a variety of fuel blends. While E10 blender pumps are compatible in cost to E10 dispensers, E85 blender pumps come at a higher cost but offer more options. Many service stations already use E85 blender pumps on-site to offer E85 blends or to create mid-level blends. E85 blender pumps cost approximately $10,000 more than traditional fuel dispensers with prices on average $20,000 to $25,000 per blender pump (Clean Fuels Foundation, 2011).

If a station wants to use the blender pump in a mid-level ethanol application, the station will need to blend E85 with conventional gasoline to achieve a blend of ethanol between E11 and E50. ASTM has developed a set of best practices for mid-level blending for station owners that are interested in blending mid-level fuels on-site (ASTM International, 2020). UL-listed E85 dispenser and hanging hardware should be used (EERE, 2013). While blender pumps can give FFV drivers more fuel options, most E85 blender pumps are concentrated in the Midwest due to the concentration of ethanol production and consumption.

While blender pumps have an incremental cost that might deter stations from installing them, there are financial incentive programs available to make fueling infrastructure more affordable. For example, the U.S. Department of Agriculture's HBIIP provides funds for installing or upgrading fuel dispensers for higher biofuel blends (USDA, 2020c). Links to Federal and State ethanol-related programs and incentives are available in Appendix A.

4. Cost Summary

Table 3 presents estimated station conversion costs for stations with and without compatible equipment. For stations that do not have higher ethanol blend compatible tanks or lines installed, replacing those pieces of equipment can pose significant costs.

Table 3. Incremental Conversion Costs per Station

	Stations with Compatible Equipment		Stations without Compatible Equipment	
	E11-E25	E26-E85	E11-E25	E26-E85
$ Increase for blending above E10	$13,000	$38,000	$71,000	$96,000
$ Increase for stations replacing tanks and lines	NA	NA	$310,000	$365,000

NA=not applicable

Source: (Monroe, Kass, & McConnell, 2019)

Multiple scenarios exist that can impact expected prices. Some stations may have very minimal conversion costs, while others may have to replace almost all existing infrastructure. A major renovation for a station is replacing underground tanks and lines resulting in costs that are very high in comparison to minor component upgrades. Some station owners may elect to instead convert an existing tank. However, others may not, to prevent the loss of a particular portion of the market, given the fuel or grade currently stored in the tank. Others may alternatively install multi-compartment tanks which allows for multiple fuel storage and delivery from the same tank.

Table 4 exemplifies different cost scenarios. The higher end of the cost range includes projects with a new tank, multiple new dispensers, and other substantial changes to the station configuration.

As can be seen in Tables 3 and 4, there are two major breakpoints in infrastructure upgrade costs. The first relates to equipment compatible with E11-E25 and equipment compatible with blends above E25. The cost break that occurs once ethanol blends are above E25 is primarily due to stations needing to acquire E85-rated UL-listed equipment. The second relates to replacing or adding new underground tanks and lines which will have significantly higher upgrade costs (Monroe, Kass, & McConnell, 2019). As mentioned earlier, if 20 percent of existing stations require medium above ground upgrades to move to E11-E25 blending capacity, upgrade costs sum up to $1.9 billion; costs increase to $10.6 billion for extensive upgrades, meaning USTs are replaced. To move to E26-E85 blending capacity in 20 percent of existing stations, outlays increase to $5.7 billion and $14.4 billion for above and below ground upgrades respectively.

It is likely that station owners may select upgrades compatible with ethanol blends below E25 due to the lower station conversion costs (see Table 3) and the decline in FFV sales. The financial barriers will be a heavier burden for single-station owners (Monroe, Kass, & McConnell, 2019), which represent 57 percent of the market. To minimize costs, stations owners will look to undergo equipment replacements or conversions during their normal replacement and maintenance cycle.

Table 4. Conversion Cost Scenarios for Average Size Stations in the United States.

	E0-E11	E11-E25	E26-E85
Light Conversion Scenario			
New equipment: hanging hardware, underground pumps, drop tubes, pipe dope No changes necessary to dispenser pumps, underground lines/tanks	$18,000	$21,000	$21,000
Retrofit Dispensers - (Gilbarco only) this scenario does not include dispensers	NA	NA	NA
Medium Conversion Scenario			
New Dispensers New Equipment: hanging hardware, underground pumps, drop tubes, pipe dope	$81,000	$93,000	$112,200
Retrofit Dispensers (Gilbarco only) New equipment: hanging hardware, underground pumps, drop tubes, pipe dope No changes necessary to underground lines/tanks	NA	$30,000	NA
Extensive Conversion Scenario			
New Dispenser Pumps New Equipment: hanging hardware, underground pumps, drop tubes New Tanks, New Lines	$369,000	$379,000	$398,000
Retrofit Dispenser Pumps New equipment: hanging hardware, underground pumps, drop tubes New Tanks, New Lines	NA	$314,000	NA

NA=not applicable

Source: (Monroe, Kass, & McConnell, 2019)

V. The Role of Government Policies

The complex landscape of the U.S. fuel industry, including its market forces, regulations, fueling infrastructure, and consumer awareness, make the introduction and adoption of new fuels a nontrivial task. Policies to help increase E15 and higher ethanol blends can be instrumental. They can come in many forms such as financial incentives (including grants, loan guarantees, cost shares, rebates, or tax credits), technical fuel standards, mandates, and other regulatory policies. The following section presents Federal and State policies that can support the increase of E15 and higher level ethanol blends.

1. State Mandates

States can independently mandate State-level ethanol blend rates so long as they do not exceed summer or wintertime RVP requirements under the CAA (EPA, 2014b). A handful of States (for example Minnesota, Missouri, and Oregon) opted for specific E10 blending mandates that require all gasoline to be blended with 10 percent ethanol. To encourage E15 adoption, States may

implement ethanol mandates requiring higher ethanol blends. The first attempt at such a mandate occurred in 2020 when the Minnesota House considered (but did not pass) Bill HF3699 which would have required fuel retailers to offer gasoline with a minimum ethanol content of 15 percent (Minnesota Legislature, 2020). While this approach could help move States towards higher blends, it could also create a patchwork of different mandates across States relative to ethanol blend levels. A Federal policy would allow for consistency across States, provide more opportunities for optimization of the blend stock in the national supply chain, and could reduce costs.

2. State Financial Support

While most States have not directly provided financial support for E15, Iowa, Oklahoma, and Nebraska have implemented programs that actively promote E15 and other mid-level blends. Iowa has two policies: The Renewable Fuels Infrastructure Program and the Biofuel Retailers' Tax Credit. The Renewable Fuels Infrastructure Program provides fuel retailers 3- and 5-year cost-share grants of: (1) up to 50 percent of the total project up to $30,000; or (2) 70 percent up to $50,000, respectively, for installing E15 infrastructure (Iowa Department of Agriculture & Land Stewardship, n.d.). The Biofuel Retailers' Tax credit offers tax incentives to fuel retailers for each gallon of mid-level ethanol fuel sold (Iowa Department of Revenue, 2019). Oklahoma has a similar tax credit program called the Ethanol Fuel Retailer Tax Credit, allowing E15 retailers to be eligible for a tax credit (PFM Group Consulting, 2017). Nebraska approved Legislative Bill 585 in 2019, which created the Renewable Fuel Infrastructure Program that provides grants for retail infrastructure installations that dispense E15 or E85 through cost-share grants of the same magnitude as the Iowa infrastructure program (Nebraska Legislature, 2019).

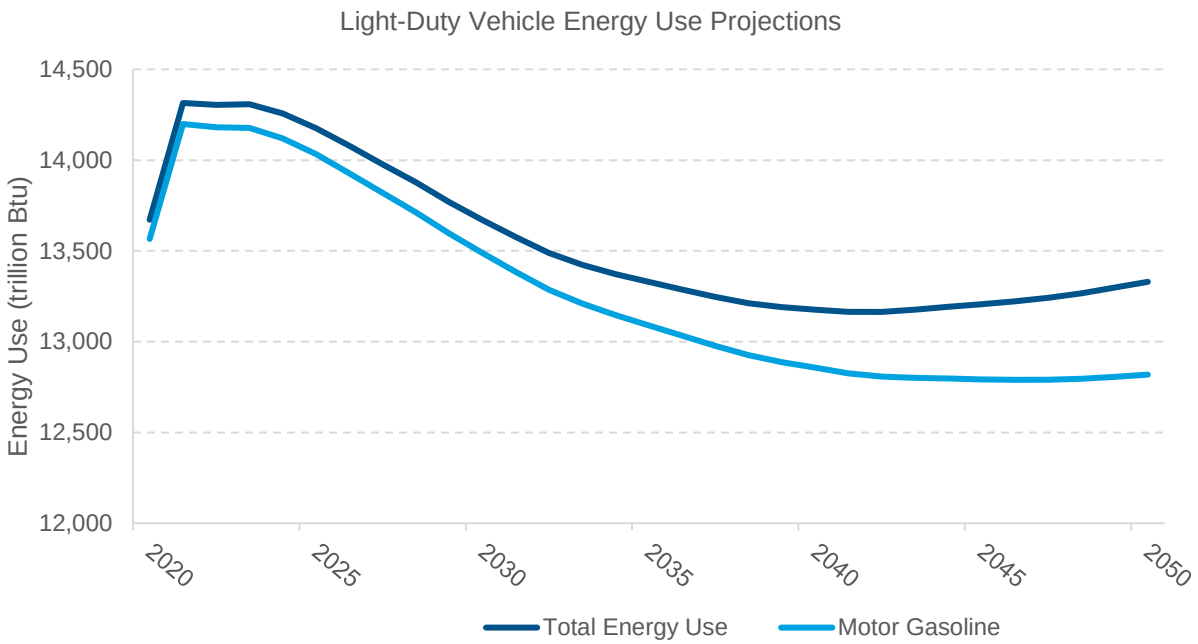
3. RFS

The RFS program sets annual targets for biofuels to be blended into transportation fuel and assigns to each blended biofuel gallon a renewable identification number (RIN). These RINs are tradable and used by obligated parties to prove compliance with RFS blending mandates (EPA, n.d.). The conventional RF volume target[5], currently caps volume at 15 billion gallons per year. This target is achieved due to the ubiquity of E10 in the fuel supply and is insufficient to accommodate a switch from E10 to mid-level ethanol blends or even E15. Thus, the current structure of the RFS, combined with the commercialization stage of cellulosic fuels, does not incentivize ethanol blends higher than E10. To illustrate this point, if all light-duty motor vehicles were to switch from E10 to E15, this would result in a 50-percent increase in ethanol consumption, which is not supported given the current RFS renewable volume obligations (RVOs). An increase to the mandate on the other hand could lead to investments by obligated parties in stations equipped to sell higher ethanol blends, including E15 (Pouliot & Babcock, 2014). With that said, light-duty motor gasoline consumption is projected to decline through 2050 (Figure 12). As gasoline consumption declines, so will ethanol consumption. A switch from E10 to E15 (or a higher mid-level ethanol blend) could enable the current RFS target to be maintained despite a reduction in gasoline consumption. A couple *Energy Economics* papers have even supported that an increase in the blend wall to E15

[5] EPA sets annual blending targets for total renewable fuel (RF), cellulosic biofuel (CB), biomass-based diesel (BBD), and advanced biofuel (AB). Corn-based ethanol is considered to a be a conventional RF. The annual volume requirement for conventional RF is determined by subtracting from the total RF volume the sum of the CB, BBD, and AB volumes.

could paradoxically increase petroleum gasoline consumption (Qiua, Colsonb, & Wetzstein, 2014; Zhanga, Qiub, & Wetzstein, 2010).

Figure 12. Light-Duty Vehicle Energy Use Projections



Source: (EIA, 2021b)

4. Ethanol Waivers

In 2019, EPA adopted a new statutory interpretation to the 1-pound-per-square-inch waiver under the CAA for summertime Reid vapor pressure (RVP) restrictions, which removed the prohibition on selling E15 in populated areas during the 4 summer months (EPA, 2019b). However, as discussed above, a July 2021 decision by the D.C. Circuit Court struck down the waiver (that allowed summer sales of E15) saying that EPA had exceeded its authority (American Fuel and Petrochemical Manufacturers v. Environmental Protection Agency, 2021). While the ruling is unlikely to go into effect immediately because of a court practice to offer time for appeals (NACS, 2021d), the uncertainty about the future will likely affect E15 uptake. Biofuel advocates have expressed their intent to appeal the decision and to work towards a legislative or administrative solution (Growth Energy, 2021a). In response to tight energy markets in 2022 and as a means to increase fuel supplies, offer more consumer choices, and reduce gasoline prices, the United States announced on April 12, 2022, that the Environmental Protection Agency (EPA) is planning to issue by June 1, 2022, a national, emergency waiver to make E15 available in conventional gasoline markets from June 1 to September 15 (White House, 2022). EPA is also considering additional action to facilitate the use of E15 year-round, including continued discussions with States that have expressed interest in allowing year-round use of E15 and considering modifications to E15 fuel pump labeling (White House, 2022; Bryan, 2022).

Originally, RVP Federal regulations were established by EPA to reduce volatile organic compound emissions from gasoline due to higher temperatures during summer months - specifically, June 1 to September 15 (EPA, 2011). The Clean Air Act included a waiver for E10, allowing the fuel to be one psi greater than the limit for other fuels, and sold year-round in all States. Higher blend ethanol fuels, whose psi did not exceed that of E10 (Johnson, et al., 2015), did not have a similar waiver, limiting retailers' ability to sell these fuels during the summer in conventional gasoline markets. This limitation was a barrier to E15 uptake. EPA's 2019 statutory interpretation made the year-round sale of E15 legal nationally eliminating the need for retailers to change over blendstocks and dispensing equipment between E10 and E15 twice a year. Prior to 2019, for volatility to be controlled during the summer, E15 had to be blended with lower volatility gasoline blendstock than that used in E10. To bypass this requirement. some retailers (Stock, 2018) sold E15 for use only in flexible-fuel vehicles during the summer months, however, this still impacted sales. If the RVP waiver for E15 is reinstated permanently, it will place retailers nationwide in a better position to offer E15 to their customers year-round.

5. Control of Air Pollution From Motor Vehicles

New vehicle emissions standards are set by EPA. The Tier 2 program was finalized in 2000, and more recently, the Tier 3 program began in 2017.[6] Vehicle manufacturers are required to test their vehicles to ensure emissions are within compliance of the program with the test fuel EPA dictates. Prior to 2014, vehicle emissions standards were set using 100 percent gasoline (E0); however, as E10 became more prevalent in the market, EPA decided to use E10 as the Tier 3 gasoline test fuel. During the development of the new rule, there was discussion about using E15 as the test fuel, rather than E10, but at the time the consensus was that the shift toward higher ethanol content fuels had yet to scale sufficiently (EPA, 2014a).

As the Federal regulatory body of vehicle emissions in the United States, EPA has a significant influence over vehicle manufacturers and the overall on-road fuels industry. If in the future, the agency decided to replace E10 with E15 as the test fuel, this would incentivize vehicle manufacturers to consider higher ethanol blends when designing new vehicles. Furthermore, during the approval process of the E15 summertime waiver in conventional gasoline markets, the agency identified that E20 was also safe for use in existing cars. Thus, a switch to E20 as a test fuel could be an option in the future as well. At this point, more research and testing are needed to determine whether E30 can be used in non-FFVs.

6. Federal Financial Support

The potential for expansion to higher blends will depend on financial support along the retail fuel supply chain. Since 2016 two Federal programs, the Biofuel Infrastructure Partnership (BIP) and the Higher Blends Infrastructure Incentive Program (HBIIP), have made funds available for infrastructure updates. Given the crucial role of retail stations in responding to consumer demand, investing in blending options, and deciding on the fuel mix supplied, the BIP program initially focused on support for dispensers and tanks at retail stations. HBIIP followed suit, but further supported related/attached equipment, additional components of the whole underground storage

[6] More information on EPA's Emission Standards for light-duty vehicles and trucks can be found at: https://www.epa.gov/emission-standards-reference-guide/epa-emission-standards-light-duty-vehicles-and-trucks-and

tank system components, as well as other infrastructure needed to store and dispense ethanol blends above E10. Furthermore, it expanded support to fuel distribution facilities (including terminal operations, depots, and midstream partners) for higher biodiesel blends (greater than B5). Going up the supply chain, incentives could be provided to retail equipment manufacturers to help reduce their cost and eventually lead to lower non-subsidized equipment cost due to economies of scale in cost reductions (NREL, 2015). Financial incentives, such as some form of equipment rebates and/or tax credits, could provide another avenue to encourage owners of retail fueling stations to upgrade their equipment. Regardless of where the support will be provided, the financial commitment will have to be expanded substantially. Federal support up to now (i.e., $200 million) has only begun to put in place the infrastructure upgrades. Estimates of the total investment needs are much larger and start off at $1.9 billion (Monroe, Kass, & McConnell, 2019).

How the Biofuel Infrastructure Partnership and Higher Blends Infrastructure Incentive Program are Reducing the Cost to Upgrade the Fueling Supply Chain to Accommodate the Sale of Higher Blends

The HBIIP is administered by USDA's Rural Development. In 2020, HBIIP dedicated $100 million of Commodity Credit Corporation (CCC) funds towards covering up to 50 percent of eligible costs for vehicle fueling facilities, fuel terminal operations, midstream partners, distribution facilities, and other eligible entities to upgrade infrastructure needed to safely supply higher biofuel blends to help (USDA, 2020a). Covered costs included upgrading of fuel dispensers (gas and diesel pumps) and attached equipment, underground storage tank system components (e.g., tanks, pumps, ancillary equipment, lines, gaskets, and sealants), and other infrastructure required at a location to ensure the environmentally safe availability of higher biofuel blends. The program's stated intention is to significantly increase the sale and use of higher biofuel blends and targeted to make available approximately $86 million of the $100 million available to vehicle fueling facilities for infrastructure support of ethanol blends higher than E10 (USDA, 2020a).

Furthermore, in recognition that smaller ownership entities (with less than 10 stations) which operate 60.9 percent of all retail stations face more significant financial barriers relative to larger multi-station ownership entities, HBIIP established a targeted assistance goal for applicants owning 1 to 10 transportation fueling stations/locations with an allocation of about 40 percent of the funds. This priority allocation was established to distribute a portion of program funds among a greater number of owners and perhaps indirectly, across a broader geographic region. A consideration for geographical diversity and markets underserved by higher blends was also afforded to applicants/participants to work in concert with the targeted assistance goal to distribute program funds more broadly (USDA, 2020a).

In October 2020, USDA announced that $22 million of the $100 million had been invested via HBIIP in 14 States and estimated an increase in ethanol demand by roughly 150 million gallons per year (USDA, 2020b). Of the 40 award recipients, 26 were owners of less than 10 stations. By December 2020, about $78 million had been awarded, of which $64.3 million supported fueling stations and fleet facilities towards upgrades for ethanol blends above E10. However only $16.8 million of the original targeted assistance goal of $40 million were awarded to owners of less than 10 stations.

The remaining 22 million were made available in a second round of solicitation in December 2020, with an allocation of approximately $15 million supporting infrastructure upgrades for ethanol blends above E10 (USDA, 2020c). On April 2021, USDA announced that $18.4 million was awarded in 20 States and estimated to expand the availability of higher blend renewable fuels by approximately 218 million gallons per year (USDA, 2021).

Previously, the Biofuel Infrastructure Partnership (BIP) program served a similar purpose. Through the BIP, 20 States received grants, which were matched by States and private partners, with the goal of expanding higher blend infrastructure (USDA, 2015; USDA, n.d.). BIP invested approximately $80 million, which supported 3,500 new pumps at over 800 refueling stations around the country.

VII. Challenges and Opportunities

Beyond the infrastructure costs as outlined in Section IV, transitioning from E10 to E15 and higher-level ethanol blends will face additional challenges. In the following section, we focus on three challenges where tangible solutions can be envisioned. These challenges include consumer acceptance and awareness of mid-level ethanol blends, the legal and contractual challenges that retail stations face, and the economics of retail fueling stations.

1. Consumer Acceptance

From either a policy or business perspective, understanding how receptive consumers will be to E15 and higher-level ethanol blends is important to future choices. Given the dearth of in-depth studies evaluating this transition, it is useful to look at consumer behavior with respect to conventional fueling choice and how these behaviors could translate to E15 and higher-level ethanol blends.

According to a 2018 study from the Center for Agriculture and Rural Development (CARD) at Iowa State University, choosing E15 will likely require a price discount relative to E10 on an energy parity basis. Given E15's lower energy content (about 1.75 percent) compared to E10, the study estimates that at 2018 prices, E15 must be priced 4.3 cents per gallon lower than E10 to make it equal on a per mile-driven basis (Lade, Pouliot, & Babcock, 2018). Comparatively, the E15 differential from E10 in Minnesota was 5.5 cents (Minnesota Commerce Department, 2021). This differential might be further explained by pricing dynamics that exist when two goods vary in perceived quality (Stole, 2007). To the extent that concerns, or confusion remain for some consumers, firms should be able to charge higher premiums on E10 (Roach, 2019).

Typically, ethanol has been less expensive relative to gasoline since 2010, such that higher ethanol blends generally cost less per gallon. However, when wholesale ethanol prices are higher relative to gasoline, as occurred in 2016 and 2020, E15 can cost more than E10. In this situation, RIN prices can play a significant role in reducing or eliminating the differential, as higher RIN prices reduce the price of ethanol (Lade, Pouliot, & Babcock, 2018).

Given the small difference in E15's energy content from E10, and E15's one-point octane advantage over E10, it is also possible that consumers would simply compare E15 to E10 on a price basis in which case E15 uptake would be quicker. Protec Fuel Management has suggested that retailers could price E10 and E15 equally to avoid any consumer skepticism due to the price difference (Fuels Institute, 2018). Indeed, the evidence in BIP-funded stations shows that the differential between E10 from E15 has reduced over time from 12 cents in 2016 to 6 cents in 2019, while sales continued to increase (NREL, 2021). According to Growth Energy, consumers value E15's one-point octane advantage and react more positively to the name unleaded or regular 88 (Growth Energy, 2019; Regan, 2017). Placement within the station and the dispenser configuration can also significantly impact sales (Fuels Institute, 2018). The demand for E15 is sensitive to convenience costs, as has been modeled for E85 (Pouliot & Babcock, 2014).

It can be anticipated that consumers would adopt E15 with similar rates as E10 if there was a price incentive to do so. When choosing a motor fuel, consumers have generally shown that they are primarily motivated by price and convenience. According to a 2016 Reuters poll, more than 93

percent of participants stated that cost affects the type of fuel they purchase, while 80 percent of participants stated that fueling station location is an important factor (Prentice, 2016). Additionally, consumer education campaigns could help address potential concerns about engine performance and degradation to ensure a smooth adoption curve. According to the 2016 Reuters poll, approximately 50 percent of drivers had little to no knowledge of ethanol blending (while the national blend rate was 9.43 percent). The remaining 50 percent of participants stated that they were aware that ethanol was blended into gasoline, but they were unaware to what extent (Prentice, 2016). Lastly, unlike the switch to other fueling alternatives, for example electricity, the switch from E10 to mid-level ethanol blends will not alter the customer refueling experience. The only caveat is that a gallon of ethanol contains approximately 30 percent less energy than a gallon of gasoline. This means as ethanol blends increase, fuel economy will decrease, and drivers will need to refuel more frequently. However, given the energy loss in shifting from E10 to E15 is 1.75 percent, the impact on consumer refueling behavior is probably minimal (AFDC, n.d.).

2. Legal and Contractual Considerations

It is estimated that approximately 50 percent of fueling stations in the United States sell branded fuel (NACS, 2021b) via contractual agreements. Contracts often establish three requirements: monthly fuel volume requirements, wholesale price requirements, and image or brand requirements. While contracts are typically 10 years in duration, they can be as short as 3 years and as long as 20 years. Such contracts influence station offerings because based on the first requirement, retailers are given a minimum volume of fuel that they need to sell each month. According to the third requirement, this fuel can only be purchased from a branded distributer or supplier (NACS, 2021b). Such restrictions can make it difficult for branded stations to invest in E15 (Roach, 2019). Nonetheless, as demand for E15 and higher blends expands, both stations and branded fuel suppliers may find it profitable to start adding them to their fuel offerings. One sign this may be happening has been the participation of branded stations in the BIP and HBIIP programs. Furthermore, with a favorable policy landscape (most notably a E15 summertime waiver in conventional gasoline markets), some oil suppliers, particularly in the Midwest, considered increasing supplies of higher ethanol blends to determine if they have the potential to lead to sustainable profit (Bair & Hirtzer, 2020).

California also poses some unique challenges to E15 adoption (EIA, 2019). It consumes the largest share of the Nation's gasoline (11 percent in 2019) and a significant share of the Nation's E85. Through the California Phase 3 Reformulated Gasoline (CaRFG3) regulations, California has set more restrictive standards for RVP than EPA sets and does not currently allow E15. Further regulatory work would need to be done to evaluate if E15 could adhere to California's air quality requirements as E85 currently does. If it could, regulations would need to be changed accordingly, and California's reformulated gasoline blendstock would need to be re-formulated for E15 to adhere to these changes. The California Air Resources Board is currently working with the ethanol industry to conduct a multimedia evaluation on higher ethanol blends, focused on E15 (California Air Resources Board, 2019).

3. Economic Considerations

Financial investment will be necessary to retrofit many retail fueling stations to dispense mid-level ethanol blends. As retail station owners consider adding mid-level ethanol blends to their fuel

offerings, whether the motivation stems from direct consumer demand or to induce demand, there will be challenges that require different solutions depending on the ownership structure of each station.

As discussed in the previous section, over half of the fueling stations in the United States have single-station ownership. These stations are sensitive to the size of financial investments, particularly with respect to equipment upgrades. The upgrades necessary to retrofit a fueling station may not make financial sense given the tight margins in the industry and the more limited resources of single owner stations. Furthermore, single station owners are not in an optimal position to bargain with equipment manufactures when ordering equipment. Looking through the list of E15 stations, the data confirm, albeit anecdotally, that multiple-station owners have been better positioned to switch to E15. For example, out of the 195 stations in Iowa that sell E15, 164 (84 percent) are operated by multiple-station entities (Iowa Corn Growers Association, n.d.). Multiple-station owner companies have more resources and personnel to take advantage of grant programs, and higher capital expense budgets to upgrade fueling stations to offer additional fuel options. They may also have a greater understanding of consumer demand data and may be more capable of analyzing data to support the introduction of higher ethanol blends. Owners of multiple stations can also take advantage of economies of scale savings through bulk purchasing of new equipment. Furthermore, they often have larger stations with more tanks (5 instead of 3), making it much easier to repurpose a tank for E15 rather than install a new one, which is more costly and requires longer term planning. It will be important during policy design to recognize that smaller ownership entities (with less than 10 stations) face more significant financial barriers relative to larger multi-station ownership entities. HBIIP targeted assistance goal to applicants owning 1 to 10 transportation fueling stations/locations with a 40-percent funding carve out and thus also directed program funds among a greater number of applicants.

VI. Conclusion

From 2000 to 2010, ethanol consumption increased almost 700 percent. The pace slowed down considerably from 2010 to 2015 to 8 percent and declined to just 3 percent from 2015 to 2019. In tandem, ethanol production capacity plateaued. This was partly attributed to what is termed the "blend wall," which the EIA defines as "the maximum ethanol blend that will not damage the engines and fuel systems of vehicles that can't use a gasoline-ethanol blend higher than E10" (EIA, 2020c). This definition of the blend wall, however, is dated and does not account for the fact that modern vehicles (MY 2001 and newer) can safely use ethanol blends up to E15.

Looking forward, there are concerns about possible ethanol demand reductions given the projected reduction in gasoline demand in the coming decade. Given the decline in FFVs and lack of growth in E85 sales, mid-level ethanol blends, in particular E15, are options to expand future ethanol markets. Furthermore, transitioning to ethanol blends between E11 to E25 will be easier and less costly than blends above E25. The current structure of the RFS, combined with the commercialization stage of cellulosic fuels, does not serve to incentivize ethanol blends higher than E10. Federal and State policies are providing incentives for the conversion of refueling infrastructure. Finally, resolution and clarity relative to the permissibility of E15 to be sold year-round will have implications for the marketability and expansion of E15. Gas stations are less likely to invest in infrastructure for a fuel that can only be sold for a portion of the year.

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VIII. Appendixes

Appendix A. Related Ethanol Laws and Incentives

Federal

- Advanced Biofuel (AB) Feedstock Incentives
- AB Production Grants and Loan Guarantees
- AB Production Payments
- Advanced Energy Research Project Grants
- Alternative Fuel and Advanced Vehicle Technology Research and Demonstration Bonds
- Alternative Fuel Definition
- Alternative Fuel Infrastructure Tax Credit
- Alternative Fuel Labeling Requirements
- Biodiesel and Ethanol Infrastructure Grants
- Biofuel Compatibility Requirements for Underground Storage Tanks (USTs)
- Biomass Research and Development Initiative
- Ethanol Infrastructure Grants and Loan Guarantees
- Improved Energy Technology Loans
- Renewable Fuel Standard (RFS) Program
- Second Generation Biofuel Plant Depreciation Deduction Allowance
- Second Generation Biofuel Producer Tax Credit
- State Energy Program (SEP) Funding
- Value-Added Producer Grants (VAPG)
- Vehicle Acquisition and Fuel Use Requirements for Federal Fleets
- Vehicle Acquisition and Fuel Use Requirements for Private and Local Government Fleets
- Vehicle Acquisition and Fuel Use Requirements for State and Alternative Fuel Provider Fleets
- Vehicle Incremental Cost Allocation

Alabama

- Biofuel Production Jobs Tax Credit
- Biofuel Research and Development Funding

California

- Employer Invested Emissions Reduction Funding - South Coast
- Alternative Fuel and Vehicle Incentives

Connecticut

- Biofuels Research Grants

Delaware

- Alternative Fuel Tax Exemption
- Medium- and Heavy-Duty Emissions Reductions Funding

District of Columbia

- Alternative Fuel Vehicle (AFV) Conversion and Infrastructure Tax Credit

Georgia

- Alternative Fuel and Advanced Vehicle Job Creation Tax Credit
- Biofuel Production Tax Exemption
- Ethanol Blending Regulation

Hawaii
- Renewable Fuels Production Tax Credit

Illinois
- Diesel Emission Reduction Grants
- School Bus Retrofit Reimbursement
- Biofuels Tax Exemption

Indiana
- Diesel Vehicle Retrofit and Improvement Grants
- Vehicle Research and Development Grants

Iowa
- Ethanol Blend Retailer Tax Credit
- Mid-Level Ethanol Blend Retailer Tax Credit
- E85 Retailer Tax Credit
- Biofuel Infrastructure Grants
- Alternative Fuel Production Tax Credits

Kansas
- AFV Tax Credit
- Alternative Fueling Infrastructure Tax Credit
- Renewable Fuel Retailer Tax Incentive
- Biofuel Blending Equipment Tax Exemption
- Biofuel Production Facility Tax Exemption
- Cellulosic Ethanol Production Financing

Kentucky
- On-Farm Biofuel Production Grants
- Ethanol Production Tax Credit
- Alternative Fuel Production Tax Incentives - Kentucky Enterprise Initiative Act (KEIA)
- Alternative Fuel Production Tax Incentives - Kentucky Business Investment (KBI)
- Alternative Fuel Research, Development, and Promotion

Louisiana
- Provision for Green Jobs Tax Credit
- RFS

Maryland
- Alternative Fuel Infrastructure Grants

Michigan
- Alternative Fuel Development Property Tax Exemption

Minnesota
- Ethanol Fuel Blend Dispensing Regulations

Missouri
- Medium- and Heavy-Duty Shuttle and Transit Bus Grants

Montana
- AFV Conversion Tax Credit
- Ethanol Production Incentive
- Ethanol Production Facility Property Tax Exemption
- Biodiesel Blending Tax Credit
- Alternative Fuel and Vehicle Production Property Tax Incentive

Nebraska

- Cellulosic Ethanol Investment Tax Credit
- Biofuels Innovation Grants
- Ethanol and Biodiesel Tax Exemption

Nevada

- Heavy-Duty Vehicle Emissions Reduction Grants

New Mexico

- Diesel Emission Reduction Funding
- Alternative Fuel Tax Exemption
- Biofuels Production Tax Deduction

New York

- AFV Research and Development Funding

North Carolina

- Ethanol Blend Requirement
- AFV, Idle Reduction Technologies, and Diesel Retrofits Funding
- Alternative Fuel and Idle Reduction Grants
- Alternative Fuel Tax Exemption
- AFV Fund

North Dakota

- Ethanol Production Incentive
- Advanced Biofuel Incentives

Ohio

- Alternative Fueling Infrastructure Incentive
- Diesel Emissions Reduction Grant Program

Oklahoma

- Ethanol Fuel Retailer Tax Credit
- Ethanol Sales Tax Exemption
- Biofuels Tax Exemption

Oregon

- Renewable Fuels Mandate

Pennsylvania

- Renewable Fuels Mandate

South Carolina

- Biofuel Blending Capability Requirements and Liability

South Dakota

- Ethanol and Biobutanol Production Incentive
- Ethanol Infrastructure Grants

Tennessee

- Supply of Petroleum Products for Blending with Biofuels
- Biofuel Blending Contract Regulation

Texas

- Clean Vehicle and Infrastructure Grants
- Clean Fleet Grants
- Clean School Bus Program
- Diesel Fuel Blend Tax Exemption

Vermont

- Fuel-Efficient Vehicle and Emission Reduction Incentives

Virginia

- Alternative Fuel Tax Exemption
- Green Jobs Tax Credit
- Government AFV Incentive
- Agriculture and Forestry Biofuel Production Grants

Washington

- RFS

Wisconsin

- Alternative Fuel Tax Exemption
- Renewable Fuel Producer Excise Tax and Inspection Exemption

Wyoming

- Alternative Fuel Export Tax Exemption

Appendix B. Ethanol Capacity and Number of Facilities by State

State	Annual Capacity (gal/yr)	Number of Facilities
Iowa	4,243	42
Nebraska	2,204	25
Illinois	1,779	14
Minnesota	1,284	21
Indiana	1,173	14
South Dakota	1,080	16
Ohio	630	7
Wisconsin	583	9
North Dakota	470	5
Kansas	434	10
Texas	385	4
Michigan	351	5
Missouri	276	6
Tennessee	225	2
California	215	4
New York	150	2
Colorado	122	3
Georgia	120	1
Pennsylvania	110	1
Idaho	60	1
Mississippi	57	1
Arizona	50	1
Oregon	40	1
Kentucky	33	1

Source : (NREL, 2020)

Appendix C. Typical Fuel Dispenser, Underground Storage Piping

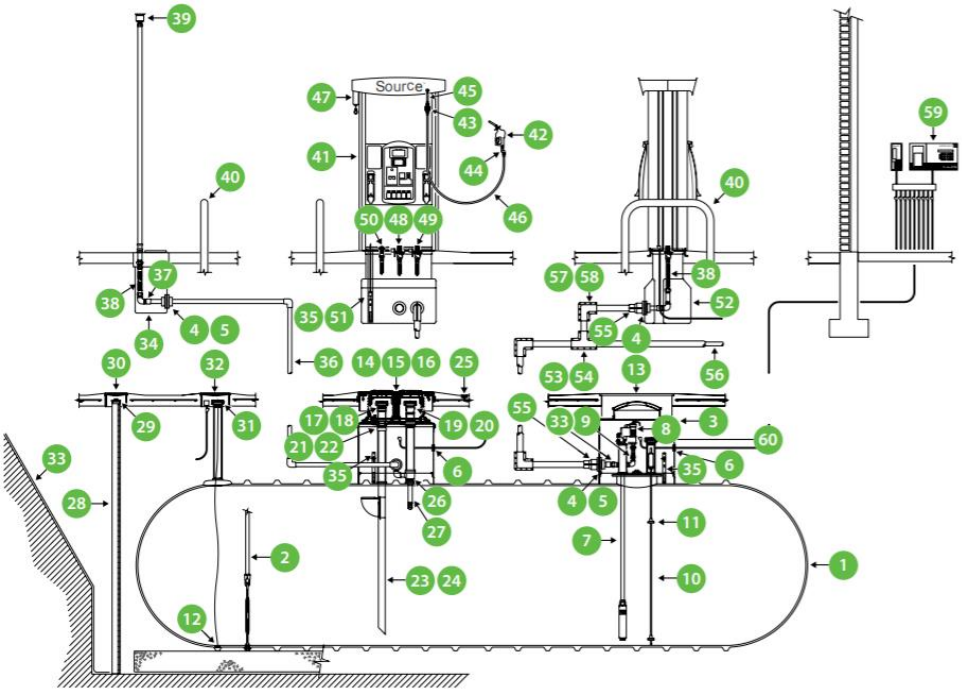

Illustration by Source North America

#	Equipment	#	Equipment	#	Equipment
1	Tank	21	Face seal adaptor	41	Dispenser
2	Tank straps	22	Jack screw kit	42	Nozzle
3	Sump and cover (tank)	23	Overfill prevention valve	43	Breakaway
4	Sump entry fitting (boot)	24	Drop tube (often a part of #23)	44	Swivel
5	Sump penetration fittings	25	Fuel grade ID #	45	Whip hose
6	Flexible entry boots	26	Extractor tee	46	Hose
7	Submersible turbine pump	27	Monitoring well screen (pipe)	47	Hose retractor
8	Mechanical line leak detector	28	Ball float vent valve	48	Stabilizer bar kit
9	Ball valve	29	Well cap-monitoring	49	Shear valve
10	Magnetostrictive probe	30	Manhole-monitoring	50	Shear valve-vapor (stage II only)
11	Float kit	31	Interstitial cap	51	Sensor tube
12	Interstitial sensor	32	Manhole	52	Dispenser sump
13	Manhole-composite	33	Roll filter fabric	53	Pipe-secondary containment tee
14	Manhole-multi-port spill containment	34	Transition sump-vent	54	Pipe-product tee
15	Spill bucket	35	Sump sensor	55	Concentric reducer
16	Fuel grade ID tag	36	Pipe	56	Pipe-secondary containment
17	Fill adaptor (top or side)	37	Pipe adaptor	58	Pipe-product elbow
18	Fill cap (top or side)	38	Flexible connector	57	Pipe-secondary containment elbow
19	Vapor adaptor	39	Vent	59	Console
20	Vapor cap	40	Steel bumper	60	Probe cap adaptor

Source: (EERE,2016)

Appendix D. Equipment Compatibility with Ethanol Blends[7]

Tank Manufacturer Compatibility

	E10	E100		E10	E100
Manufacturer	✔	✔	*Continued from below*		
FIBERGLASS[a]			Highland Tank	✔	✔
Containment Solutions	✔	✔	J.L. Houston Co.	✔	✔
Owens Corning (single wall 1965-1994)	✔	✘	Kennedy Tank and Manufacturing Co., Inc.	✔	✔
Owens Corning (double wall 1965-July 1, 1990)	✔	✘	Lancaster Tanks and Steel Products	✔	✔
Owens Corning (double wall July 2, 1990-December 31, 1994)	✔	✔	Lannon Tank Corporation	✔	✔
Xerxes (single wall prior to February 1981)	✘	✘	Mass Tank Sales Corp.	✔	✔
Xerxes (single wall February 1981-June 2005)	✔	✘	Metal Products Company	✔	✔
Xerxes (single wall since July 2005)	✔	✔	Mid-South Steel Products, Inc.	✔	✔
Xerxes (double wall prior to April 1990)	✔	✘	Modern Welding Company	✔	✔
Xerxes (double wall April 1990 and after)	✔	✔	Newberry Tanks & Equipment, LLC	✔	✔
STEEL[b]			Plasteela	✔	✔
Acterra Group Inc.	✔	✔	Service Welding & Machine Company	✔	✔
Caribbean Tank Technologies Inc.	✔	✔	Southern Tank & Manufacturing Co., Inc.	✔	✔
Eaton Sales & Service LLC	✔	✔	Stanwade Metal Products	✔	✔
General Industries	✔	✔	Talleres Industriales Potosinos, S.A. de C.V.	✔	✔
Greer Steel, Inc.	✔	✔	Tanques Antillanos C. x A.	✔	✔
Hall Tank Co.	✔	✔	Watco Tanks, Inc.	✔	✔
Hamilton Tanks	✔	✔	We-Mac Manufacturing Company	✔	✔

Letters stating compability:

a. Petroleum Equipment Institute
www.pei.org/ust-component-compatibility-library
b. Steel Tank Institute
www.steeltank.com/FabricatedSteelProducts/ShopFabricatedTanks/SteelandAlternativeFuels/tabid/465/Default.aspx

Source: (EERE,2016)

[7] All tables provided by the U.S. Department of Energy's AFDC, *Ethanol Equipment Options*, retrieved from https://afdc.energy.gov/fuels/ethanol_equip_options.html. For equipment that is not listed, compatibility can be determined by contacting the original equipment manufacturer.

Pipe Manufacturer Compatibility

Manufacturer	Product	Model	Ethanol Compatibility
Piping—All Companies have UL 971 listing for E100			
Advantage Earth Products	Piping	1.5", 2", 3", 4"	E0-E100
Brugg	Piping	FLEXWELL-HL, SECON-X, NITROFLEX, LPG	E0-E100
Franklin Fueling	Piping	Franklin has third-party certified piping compatible with up to E85. Contact manufacturer for specific part numbers.	E0-E85
OPW	Piping	FlexWorks, KPS, Pisces (discontinued)	E0-E100
NOV Fiberglass	Piping	RedThread IIA, Ameron Dualoy	E0-E100
NUPI	Piping	Smartflex	E0-E100
OMEGAFLEX	Piping	DoubleTrac (brass and stainless steel fittings)	E0-E100

Letters stating compability:

Petroleum Equipment Institute
www.pei.org/ust-component-compatibility-library

Source: (EERE,2016)

Associated UST Manufacturer Compatibility

Manufacturers introduce and discontinue models over time. If you do not see your equipment on this list please contact the manufacturer. Note X in these lists can be substituted for any value.

Federal code requires compatibility of this equipment with specific fuels. This is achieved through either third-party listing or a letter from the manufacturer stating compatibility. Husky has UL listing for E85. The following companies have issued letters stating compatibility: Bravo, Morrison Brothers, Vaporless Manufacturing, Veeder-Root, and Western Fiberglass. Please contact other manufacturers for a compatibility letter or to inquire if they have UL E85 listed products. Compatibility letters are available at: *www.pei.org/ust-component-compatibility-library*

Manufacturer	Product	Model	Ethanol Compatibility
Bravo Systems	Fiberglass fittings	Series F, FF, FPE, FR, Retrofit-S, D-BLR-S, D-INR-S, FLX, FLX-INR, FPS, TBF	E0-E100
Bravo Systems	Spill buckets	B3XX	E0-E100
Bravo Systems	Tank sumps & covers	B4XX	E0-E100
Bravo Systems	Transition sumps	B5XX, B6XX, B7XX, B8XX	E0-E100

Bravo Systems	Under dispenser containment sumps	B1XXX, 7XXX, B8XXX, B9XXX	E0-E100
Cimtek	Filter	300MB-10, 300MB-30, 400MB-10, 400MB-30, 475XLMB-10	E0-E15
Cimtek	Filter	300BHA-01, 400BHA-01, 400BHA-05, 800BHA-01	E0-E85
Clay and Bailey	AST emergency vent	354, 365, 366, 367, 368, 369, 370	E0-E85
Clay and Bailey	AST manhole	API-650	E0-E85
Clay and Bailey	AST overfill prevention valve	1228	E0-E85
Clay and Bailey	AST spill containment	all	E0-E85
Clay and Bailey	Fill cap	94, 232, 233, 234, 235, 254	E0-E85
Franklin Fueling	All	Franklin has third-party certified equipment compatible with up to E85. Contact manufacturer for specific part numbers.	
Husky	Pressure vacuum vents	4620, 4885, 5885, 11730, 11735, 11740	E0-E85
Morrison Bros	Anodized farm nozzle	200S	E0-E85
Morrison Bros	Anti-syphon valve	912	E0-E85
Morrison Bros	AST adaptor	927	E0-E85
Morrison Bros	Ball valves	691BSS	E0-E85
Morrison Bros	Caps	305C	E0-E85
Morrison Bros	Clock gauge with alarm	918	E0-E85
Morrison Bros	Clock gauges	818	E0-E85
Morrison Bros	Combination vent/ overfill alarm	922	E0-E85
Morrison Bros	Diffuser	539TO, 539TC	E0-E85
Morrison Bros	Double tap bushing	184	E0-E85
Morrison Bros	Drop tubes	419A	E0-E85
Morrison Bros	Emergency vents	244	E0-E85

Morrison Bros	Expansion relief valve	076DI, 078DI	E0-E85
Morrison Bros	External emergency valves	346DI, 346FDI, 346SS, 346FSS	E0-E85
Morrison Bros	Extractors	560/561/562/563	E0-E85
Morrison Bros	Flame arrester	351S	E0-E85
Morrison Bros	Float vent valves	317	E0-E85
Morrison Bros	Frost proof drain valve	128DIS	E0-E85
Morrison Bros	In-line check valve	958	E0-E85
Morrison Bros	Internal emergency valves	272DI, 72HDI	E0-E85
Morrison Bros	Overfill alarm	918TCP	E0-E85
Morrison Bros	Overfill prevention valve	9095A-AV, 9095SS	E0-E85
Morrison Bros	Series tank monitor adaptor and cap kits	305XPA	E0-E85
Morrison Bros	Solenoid valves (3" must be all teflon version)	710SS	E0-E85
Morrison Bros	Spill containers	515/516/517/518	E0-E85
Morrison Bros	Strainer	285	E0-E85
Morrison Bros	Swing check valves	246ADI, 246DRF	E0-E85
Morrison Bros	Tank monitor adaptor and cap kits	305XPA	E0-E85
Morrison Bros	Vapor recovery adaptor	323	E0-E85
Morrison Bros	Vapor recovery caps	323C	E0-E85
Morrison Bros	Vent-double outlet (small UST)	155	E0-E85
Morrison Bros	Vent-pressure vacuum	548, 748, 749	E0-E85
Morrison Bros	Vent-updraft	354	E0-E85
National Environmental Fiberglass	Sumps-dispenser	All	E0-E85
National Environmental Fiberglass	Sumps-tank	All	E0-E85
National Environmental Fiberglass	Sumps-transition	All	E0-E85

OPW	AST anti-siphon valve	199ASV	E0-E85
OPW	AST ball valve	21BV SS	E0-E85
OPW	AST check valve	175, 1175	E0-E85
OPW	AST emergency shut off valve	178S	E0-E85
OPW	AST emergency vent	201, 202	E0-E85
OPW	AST emergency vent	301	E0-E85
OPW	AST mechanical gauge	200TG	E0-E85
OPW	AST overfill prevention valve	61fSTOP A or M versions	E0-E85
OPW	AST overfill prevention valve	61*f*STOP	E0-E25
OPW	AST pressure vacuum vent	523V, 623V	E0-E100
OPW	AST solenoid valve	821	E0-E25
OPW	AST spill container	211-RMOT, 331, 332	E0-E85
OPW	AST swing check valve	all	E0-E85
OPW	AST tank alarm	444TA	E0-E85
OPW	AST vapor adaptor	1611AVB-1625	E0-E100
OPW	AST vapor cap	1711T-7085-EVR, 1711LPC-0300	E0-E100
OPW	Ball float vent valve	53VML, 30MV	E0-E100
OPW	Check valve	70, 70S	E0-E100
OPW	Dispenser sumps & accessories	FlexWorks	E0-E100
OPW	Drop tube	61FT	E0-E25
OPW	Drop tube	61T, 61TC, 61TCP	E0-E15
OPW	Drop tube	61TSS	E0-E100
OPW	Extractor fittings and plug	233, 233VP	E0-E100
OPW	Face seal adaptor (threaded riser adaptor)	FSA	E0-E100
OPW	Fill adaptor-side	61AS	E0-E100

OPW	Fill adaptor-top	633T, 633TC	E0-E100
OPW	Fill Cap	634TT-7085-EVR, 634LPC, 634TT-4000	E0-E100
OPW	Fill cap-side	62TT	E0-E100
OPW	Fill-swivel adaptor	61SALP-MA, 61SALP-1020-EVR	E0-E100
OPW	Flexible connectors	FCxx	E0-E100
OPW	Float kit	61SOK-0001	E0-E15
OPW	Jack screw	61JSK, 71JSK	E0-E100
OPW	Manhole	Conquistador, Fiberlite, 104A, 104FG, 104C, 6110,6120	E0-E100
OPW	Monitoring well cap kit	634TTM	E0-E100
OPW	Monitoring well probe cap	62M, 116M, 62M-MA	E0-E100
OPW	Multi-port spill containment	6511, 6421, 6511, 6521, 6561, 6571, Fiberlite	E0-E100
OPW	Overfill prevention valve	71SOM, 61SOM, 61SOCM-4000	E0-E100
OPW	Overfill prevention valve	71SO, 71SO-C, 71SO-CT, 61SOC, 61SOP, 61SOR	E0-E15
OPW	Pressure vacuum vent	523V, 623V	E0-E100
OPW	Spill container (bucket)	1-2100, 1SC-2100, 1C-2100,1C-2200, EDGE, '1-2105, 101-BG2100	E0-E100
OPW	Tank bottom protectors	6111, 61TP	E0-E15
OPW	Tank sumps & accessories	Fiberlite, FlexWorks	E0-E100
OPW	Transition sumps & accessories	FlexWorks	E0-E100
OPW	Vapor adaptor	1611AV, 1611AVB	E0-E100
OPW	Vapor Cap	1711T-7085-EVR, 1711LPC	E0-E100
OPW	Vapor-swivel adaptor	61VSA-MA, 61VSA-1020-EVR	E0-E100
Vaporless Manufacturing	Leak detector	99LD-2000/2200/3000 without stainless steel tubing/fittings	E0-E20
Vaporless Manufacturing	Leak detector	99LD-2000/2200/3000 with stainless steel tubing/fittings	E0-E100

OPW	Fill adaptor-top	633T, 633TC	E0-E100
Vaporless Manufacturing	Overfill prevention valve	OPF-2/3 with stainless steel tubing/fittings	E0-E100
Veeder-Root	Continuous interstitial tank system	P/N 857280-100, 857280-200, 857280-30X	E0-E15
Veeder-Root	Electronic line leak detector	Series 8484, 8590	E0-E15
Veeder-Root	Ground water monitoring	P/N 794380-621, 794380-622, 794380-624	E0-E15
Veeder-Root	Interstitial and secondary containment monitoring	P/N 794380-XXX, 794390-XXX, 847990-00X, 857080-XXX	E0-E15
Veeder-Root	Interstitial and secondary containment monitoring	P/N 794380-321, 794380-323, 794380-333, 794380-344, 794380- 345, 794380-351, 794380-430	E0-E85
Veeder-Root	Magnetostrictive probe	Mag Plus Series 8463XX, Mag Series 8473XX	E0-E15
Veeder-Root	Tall tank probe	Mag-FLEX 889560-XXX, MAGXL-XXX	E0-E90
Veeder-Root	Vapor monitoring	P/N 394390-700	E0-E15
Western Fiberglass	Co-flex piping	all	E0-E100
Western Fiberglass	Cuff fittings	all	E0-E100
Western Fiberglass	Sumps (dispenser, tank, transition, vapor, vent)	all	E0-E100
Western Fiberglass	Co-flow hydrostatic monitoring systems	all	E0-E100

Letters stating compability:

Petroleum Equipment Institute
www.pei.org/ust-component-compatibility-library

Source: (EERE,2016)