DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

# Potential Impacts of Increased Ethanol Blend-Level in Gasoline on Distribution and Retail Infrastructure

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# Preface

Fuels used in light-duty vehicle transportation have undergone a diversification in the United States over the past few decades. These fuels include liquid and gaseous fuels and electricity, which are derived from solid, liquid, gaseous, and renewable energy sources. The search for relevant and appropriate transportation fuels has been driven by economic, national security, and environmental concerns. Fuel economy improvements can lead to significant annual fuel cost savings for Americans,[1] and producing fuels from domestic resources has the potential to increase U.S. jobs, support rural economies, reduce tailpipe carbon dioxide ($CO_2$) emissions, and, by keeping energy financial resources in the United States, add to U.S. energy security and resiliency. The three reports U.S. DRIVE is publishing in 2019 on behalf of its Fuels Working Group (FWG) focus on an assessment of the potential of a range of higher octane conventional and renewable fuels to enable increased light-duty vehicle efficiency and reduced well-to-wheels (WTW) greenhouse gas (GHG) emissions and their potential impact on fueling infrastructure.

Liquid fuels continue to hold significant potential in light-duty vehicle transportation for several reasons: (1) liquid fuels have high energy density; (2) energy companies know how to make liquid fuels on the billion-gallon annual scale efficiently; (3) there exists a ready means to transport and dispense such fuels; and (4) transitioning the market of vehicles to a new or modified fuel is simplified for liquid fuels. Auto manufacturers are interested in knowing in advance the fuels likely to be developed and deployed successfully because vehicles can take from 5 to over 10 years to design, develop, and bring to market. Additional factors, such as the large current vehicle population and 15-to-20 year vehicle lifetime, confirm that conventional engine technologies will continue to comprise a significant portion, if not the majority, of the nation's light-duty vehicle fleet for the next several decades.

Varying fuel composition to increase its octane rating for spark-ignition engines (e.g., gasoline) is widely recognized as a potential means to address economic, national security, and environmental concerns associated with transportation energy. Such fuels can enable higher fuel economy and achieve associated reductions in carbon emissions from vehicles. For example, blending with low-carbon biofuels, some of which have inherently high octane ratings, can increase the finished fuel octane ratings and reduce its environmental impact.[2] Producing fuels with elevated octane ratings through the modification of fuel composition, however, may have the unintended consequence of increasing energy use and associated emissions from fuel production, due, for example, to both the conversion of biomass to biofuels and/or the production of different base gasoline blend stocks.

U.S. DRIVE, a government-industry consortium that includes the U.S. Department of Energy, energy companies (including utilities), and auto manufacturers, works in 16 technical areas collaborating to find new solutions to pre-competitive research questions regarding new energy sources, efficiency, and emissions. In the arena of future fuels, U.S. DRIVE Partners' expressed an interest to learn more about potential new high-octane liquid fuels for conventional and hybrid vehicles. Energy companies are interested in ensuring customers have access to fuels with which to operate their vehicles, and auto manufacturers are interested in ensuring the public can purchase vehicles that meet both government

[1] Greene, D., and J. Welch. 2017. The impact of increased fuel economy for light-duty vehicles on the distribution of income in the U.S.: A retrospective and prospective analysis. Knoxville, TN: Howard Baker Center for Public Policy. Online at http://bakercenter.utk.edu/white-paper-onthe-impact-of-increased-fuel-economy-for-light-duty-vehicles, accessed June 21, 2017.

[2] Han, J., et al. 2015. *Well-To-Wheels Greenhouse Gas Emissions Analysis of High Octane Fuels with Various Market Shares and Ethanol Blending Levels*, Report ANL/ESD-15/10. Argonne National Laboratory, Argonne, IL.

vehicle fuel economy requirements and customer desires. Therefore, U.S. DRIVE is interested in learning if a vehicle and engine were designed as a system, a more optimal fuel that addresses economic, national security, and environmental concerns could be realized.

Toward these ends, U.S. DRIVE formed the FWG, to study fuel effects on combustion, and the FWG evaluated several fuel and engine combinations to determine if more optimal fuel/engine combinations could be designed and deployed in the future. In the broadest perspective, the research compares various high-octane number fuels in the context of engine performance and their relative life-cycle carbon impacts, as well as potential impacts on fueling infrastructure and associated costs. The FWG specifically examined three areas: (1) how these fuels might function in conventional spark-ignition engines under a variety of operating conditions; (2) what the life-cycle impact on efficiency and environmental metrics, including GHG emissions, for such fuels might be; and (3) how these fuels fit within the existing U.S. fuel refinery and transport infrastructure.

With regard to the first area of research, the FWG built on an existing Coordinating Research Council (CRC) study, AVFL-20, that explored the potential vehicle energy use, volumetric fuel economy, and tailpipe $CO_2$ emissions effects of different research octane ratings (research octane number, RON), octane sensitivity (OS), and ethanol content in gasoline.[3] Because there are potential non-ethanol biofuel pathways to increased octane that were not included in the scope of AVFL-20, the FWG set about to address these gaps by expanding on the AVFL-20 project to include fuels with non-ethanol bio-derived feedstocks.

In the second area of research, the FWG examined life-cycle impacts, specifically the changes in tailpipe $CO_2$ emissions in relation to changes in fossil $CO_2$ emissions from fuel production (both petroleum and renewable biofuels). The FWG understood that because production of gasoline with increased octane ratings together with production of renewable biofuels at the national scale may require additional energy input, this energy requirement is important to consider in combination with potential energy savings enabled in the light-duty vehicle engines that automakers produce. Conducting a life-cycle analysis (LCA) or WTW assessment, for each of the potential pathways towards a high-octane fuel is an effective means of estimating the energy consumption and GHG emissions impacts for each pathway. Completing an LCA for each fuel blend examined in the engine studies report uses estimates of vehicle energy efficiency for typical driving patterns and potential energy production requirements for each fuel blend.

In the third area of research, the FWG identified other important considerations in assessing the potential of a fuel blend to a succeed in the marketplace. Specifically, the FWG is interested in understanding the compatibility of potential high-octane biofuel formulations with the existing refinery, transport, and fueling infrastructure. Developing a fuel that requires an entirely new fueling and fuel transport infrastructure is clearly an obstacle.

The following report addresses compatibility of gasoline containing increased ethanol blend levels with existing refinery, transport, and fueling infrastructure, and while it stands alone for its method, results, and conclusions and so may be viewed individually, it is best read, considered, and understood in association with the companion reports, entitled *Well-to-Wheels Energy and Greenhouse Gas Emission*

[3] Sluder, et al., Report # AVFL-20, Coordinating Research Council, November 2017. https://crcao.org/reports/recentstudies2017/AVFL-20/AVFL20_Final%20Report_11032017.pdf.

*Analysis of Bio-Blended High-Octane Fuels for High-Efficiency Engines*,[4] and *U.S. DRIVE Fuels Working Group Engine and Vehicle Modeling Study to Support Life-Cycle Analysis of High-Octane Fuels*.[5] As such, this report is part of a larger coordinated effort on the part of the U.S. DRIVE Partnership.

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4 Sun, P., Elgowainy, A., Wang, M. 2019. *Well-to-Wheels Energy and Greenhouse Gas Emission Analysis of Bio-Blended High-Octane Fuels for High-Efficiency Engines*. Prepared by Argonne National Laboratory, Argonne IL. https://www.energy.gov/eere/vehicles/downloads/us-drive-fuels-working-group-high-octane-reports.

5 Sluder, C.S., D.E. Smith, J.E. Anderson, T.G. Leone, and M.H. Shelby. 2019. *U.S. DRIVE Fuels Working Group Engine and Vehicle Modeling Study to Support Life-Cycle Analysis of High-Octane Fuels*. Prepared by Oak Ridge National Laboratory and Ford Motor Co. https://www.energy.gov/eere/vehicles/downloads/us-drive-fuels-working-group-high-octane-reports.

# Executive Summary

Increasing octane ratings of fuel used in gasoline vehicles is widely recognized as a potential means to improve fuel economy and achieve associated reductions in carbon emissions. Producing fuels with elevated octane through the modification of fuel composition, however, may have the unintended consequence of increasing carbon emissions from fuel production. The U.S. DRIVE Fuels Working Group (FWG) conducted studies that compare various high-octane fuels in the context of engine performance [1], and the relative lifecycle carbon impacts of those fuels [2].

The U.S. DRIVE FWG efforts include this report, which assesses the impact of high-octane fuels on fuel distribution and retail infrastructure across the United States. Key issues for infrastructure analysis include materials compatibility with high octane fuels and cost of any necessary upgrades. Most of the existing U.S. infrastructure tolerates gasoline fuels containing up to 10% ethanol (E10), and some routes to high octane are entirely backward-compatible with this infrastructure. In general, hydrocarbon fuel components manufactured from conventional petroleum sources that are presently found in E10 gasoline fuels are fully compatible. For purposes of this study, bio-derived non-oxygenated fuels compatibility is predicted through Hansen Solubility methodology. Non-hydrocarbon routes to achieving a fuel with higher octane—such as increasing ethanol above 10% in finished fuel—would require some level of equipment upgrades at many U.S. refueling stations.

This study focuses on evaluation of changes to vehicles, retail equipment, and terminals to implement the fuels studied in the first two sections of this report. The objectives include understanding the effects of adopting a new fuel on other stakeholders, such as retail fueling sites and terminals, as well as determining if there are other considerations that may aid in the adoption of a new fuel, such as targeting a specific range of ethanol content.

The information used in this analysis was gathered from public sources, including U.S. Environmental Protection Agency (EPA) web pages, published papers, and presentations. Because little cost information is available in public sources regarding upgrading retail station equipment, quotes were obtained from equipment installers and were based on the average station configuration including the number of fuel dispensers and underground tanks.

Retail equipment requirements are based on a patchwork of U.S. federal, state, and local regulatory requirements. Thus, the approval process for installations and equipment replacements vary from state to state and even between locations within a state. The fuel compatibility of this equipment is determined by a third party independent listing authority (e.g., Underwriters Laboratory [UL]) or a letter of compatibility from the manufacturer. Most underground tanks and lines currently sold in the United States meet UL listings up to 100% ethanol inclusive, meaning that all stations in the United States will eventually have major underground equipment that is compatible to ethanol blends higher than E10. There are many pieces of equipment that must be changed, in addition to the dispenser and underground tanks/lines, but these additional items are generally accessible without breaking aboveground concrete. There is no pubic database or other aggregated data resource available to lend insights regarding the percentage of existing underground equipment certified to store fuel blends above E10. Because the cost of replacing underground tanks and lines is considered a major renovation of a station with attendant costs that are high compared to those associated with minor upgrades of components, such as drop tubes, sumps, and underground tank pumps, a sensitivity analysis was conducted to compare expected costs of converting 0% and 20% of underground tanks and lines at stations in 2040. The 20% level is intended to demonstrate the sizable impact of replacing underground tanks and lines at only one-fifth of existing U.S. refueling stations.

These results are based on cost estimate information compiled to evaluate the financial impact and associated ethanol compatibility break points for converting station equipment to achieve compatibility with various levels of ethanol content in gasoline. It should be noted that the analysis involved many assumptions associated with estimating relevant costs. The costs used for this evaluation were based on Michigan, Wisconsin, and Ohio pricing; costs gathered for other regions ranged from being significantly higher to significantly lower when compared with the three noted states. These cost estimate pricing values are intended to reflect probable break points only rather than to be interpreted as precise cost estimates and are not intended to be relied upon for actual deployment. If a fuel requiring transformation of existing refueling station equipment were to occur, additional variables including regional cost differences, equipment replacement frequency, specific station configurations, and additional challenges and evaluations, would require more analytic specificity for the purpose of understanding the current retail market equipment compatibility.

Evaluating the costs to upgrade a hypothetical "average" station by 2025 revealed obvious cost break points for ethanol content: (1) greater than E10, and (2) greater than E25. Generally, service station fuel dispensers are UL certified for up to E10, up to E25, or up to E85. The E25 value is driven by costs for the UL listings for dispensers beyond which an E85-rated dispenser is required. In 2017, nearly 40% of all dispensers sold in the United States were E25 compatible. There have been recent discussions of changing the UL dispenser rating from E25 to E40. If this were to occur, the E25 breakpoint from this analysis would shift accordingly to E40. Replacing underground tanks and lines are the largest potential costs for a station as shown in Table ES-1 below. Replacing underground equipment on a hypothetical 20% of stations costs almost seven times more than not having to replace major equipment for E25 levels and three times the cost for >E25 ethanol blends. More importantly, the costs per affected station are 10 to 28 times higher than unaffected stations $13,000 or $38,000 which would be particularly significant for owners of single stations.

**Table ES-1. Estimated Incremental Station Cost for Equipment Replacement to Accommodate Increased Ethanol Content.**

| | Nationwide Station Costs | | | | | |
|---|---|---|---|---|---|---|
| | **With Proper confirmation of Equipment Capability** | | | **Without Proper Equipment Capability 20% stations change out tanks and lines** | | |
| | **E0-E10** | **E11-E25** | **E26-E85** | **E0-E10** | **E11-E25** | **E26-E85** |
| **$ Increase above E10** | **NA** | **$1,895,000,000** | **$5,718,000,000** | **NA** | **$10,621,000,000** | **$14,444,000,000** |
| **%** | | **30%** | **91%** | | **169%** | **230%** |
| **Increase average across all U.S. stations** | | **$13,000** | **$38,000** | | **$71,000** | **$96,000** |
| **Increase for stations replacing tanks and lines** | | | | | **$310,000** | **$365,000** |

For fuel terminals, each would individually determine necessary changes to receive, store, blend, and dispense a new fuel with an increase in higher blends of biofuel content; such solutions would be unique and specific to the location. The costs may include new storage tanks, blending positions, plumbing, and the acquisition of additional land. Table ES-2 contains a summary of the range of costs expected per terminal to accommodate conversion to E30 and the total amount for all existing 1,070 U.S. gasoline terminals. The estimated range is $1.6 million to $9.5 million per terminal.

**Table ES-2. Nationwide Estimated Cost Range for U.S. Terminals to Accommodate an Ethanol Content Increase from E10 to E30.**

| **Nationwide Terminal Cost Estimate for Fuel Ethanol Conversion E10 to E30** | | |
|---|---|---|
| **Pre-Conceptual Estimate:** | **LOW END ESTIMATE** | **HIGH END ESTIMATE** |
| Total Per Terminal | $1,600,000 | $9,550,000 |
| **Total for U.S. Terminals** | **$1,712,000,000** | **$10,218,500,000** |

*1,070 gasoline U.S. Terminals*

Evaluation of the status of candidate drop-in hydrocarbon fuels suggests that the earliest potential timeframe for implementation is unknown. Preliminary evaluations of the projected chemical compositions suggest the candidate fuels may be compatible with existing E10 equipment. Due diligence, including confirmation testing and updating the UL listing, would need to be done to ensure safe implementation. This would be accomplished through evaluation with the UL listing team after reviewing data to determine a pathway for certification.

Manufacturers of vehicles sold in the United States and Canada as of 2018 are built to varying compatibility with ethanol fuels, stating maximum ethanol concentration compatibilities at E10, E15, or E85. For example, some original equipment manufacturers (OEMs) allow E15 in their vehicles today, whereas others allow only up to E10. Fuel compatibility is determined by each OEM for each affected system in the vehicle. The material selection for vehicle component fuel compatibility is similar to that applied to equipment in refueling stations. While vehicle considerations were incorporated into this study for the purpose of ensuring completeness, a comprehensive assessment of ethanol tolerance for vehicles on the road presently could not be developed with any degree of certainty because OEMs build their vehicles to designated compatibility with ethanol fuels. The vehicle is tested and designed as an entire system to a specific ethanol blend, but not at blends higher than designated. A series of vehicle and engine tests are run with fuels specified; it would be impractical to run the series of tests at fuels outside the design scope as the validation process is costly. Component and calibration changes could be predicted for compatibility to a certain fuel ethanol blend, but physical confirmatory testing would be required with that specific fuel for certainty. While vehicle designs to E10, E15, and E85 are well established, upgrades may be required to allow for new ethanol fuel levels, such as E20, E25, or E30, and would require thorough engineering evaluation and testing, likely involving changes to software, engine calibrations, and materials.

Overall, cost burdens on station and terminal owners associated with deploying a new fuel can be minimized either by selecting a fuel that is compatible with existing infrastructure or by selecting a fuel at a desirable cost implementation breakpoint (i.e., where costs become exceedingly high at, say, E25 and above, a point below an E25 level; undertaking E25 might be selected for the purpose of controlling cost).

Implementing upgrades over time during routine station upgrades and equipment replacement can significantly ease the financial burden. However, this approach may greatly expand the timeframe within which all stations achieve the same level of equipment readiness. Timed coordination would require extensive cooperation among various stakeholders across the country and across many industries. As a result, it may be difficult to enforce mass adoption of equipment upgrades without regulation or financial assistance/incentives. The evidence suggests that the barriers to implement a new fuel can be substantial for individual locations, but not insurmountable when evaluated in aggregate.

# 1. Introduction

U.S. vehicle fuel economy requirements have spurred research into methods to achieve increased fuel economy and greenhouse gas (GHG) emissions reductions. A primary area of research is increasing engine efficiency in conjunction with potential new or modified market fuels. If a vehicle and engine were designed as a system, it may be possible to achieve improved fuel economy and more optimal life cycle carbon and attendant cost reductions. The introduction of a new fuel, however, might also impact the existing fuel and refueling infrastructure. Specifically, a new fuel may not be compatible with existing infrastructure and vehicles. In this report, costs associated with ensuring compatibility of refueling infrastructure with a new fuel are evaluated. Specifically, the research assesses the refueling infrastructure compatibility to certain high-octane fuel sets to:

1) Determine critical infrastructure and vehicle considerations for fuels sets evaluated in the 2018 reports *U.S. DRIVE Fuels Working Group Engine and Vehicle Modeling Study to Support Life-Cycle Analysis of High-Octane Fuels* [1], and *Well-to-Wheels Energy and Greenhouse Gas Emission Analysis of Bio-Blended High-Octane Fuels for High-Efficiency Engines* [2].

2) Identify cost estimates and find cost-related step break points for upgrading refueling infrastructure associated with implementing a new type of market fuel

This report also assesses impacts of the fuels studied on aspects of the U.S. fuel distribution network, including refueling retail stations, terminals, and transportation (truck, rail, and pipeline). The process for approval to upgrade the equipment to store and handle a new type of fuel must be understood to determine the requirements of switching to a different fuel in a safe manner. The report includes information obtained from interviews and quotes from various stakeholders, research groups, and existing research literature.

In the process of understanding infrastructure impacts and upgrade costs based on the composition of the fuel sets studied, an understanding of infrastructure impacts relative to fuel composition breakpoints can also be identified. Accounting for such breakpoints may aid in decisions regarding fuels introduced to the market based on a desire to decrease the effort and cost burdens of replacing equipment, which would, in turn, ease the coordination efforts for a technology shift in market fuel.

# 2. Retail Refueling Station Equipment

Refueling station equipment falls under two categories: above ground equipment and underground equipment. The concrete or asphalt driveway serves as the distinguishing line between above and below ground fuel station equipment. The above ground requipment refers to any above ground fuel storage tanks, refueling island, dispenser, and equipment attached to the dispenser. The under or below ground equipment is located below the driveway, with some components readily accessible by manhole covers. Below is a diagram of a typical refueling station with an underground storage system supplied by Franklin Fueling Sytems.

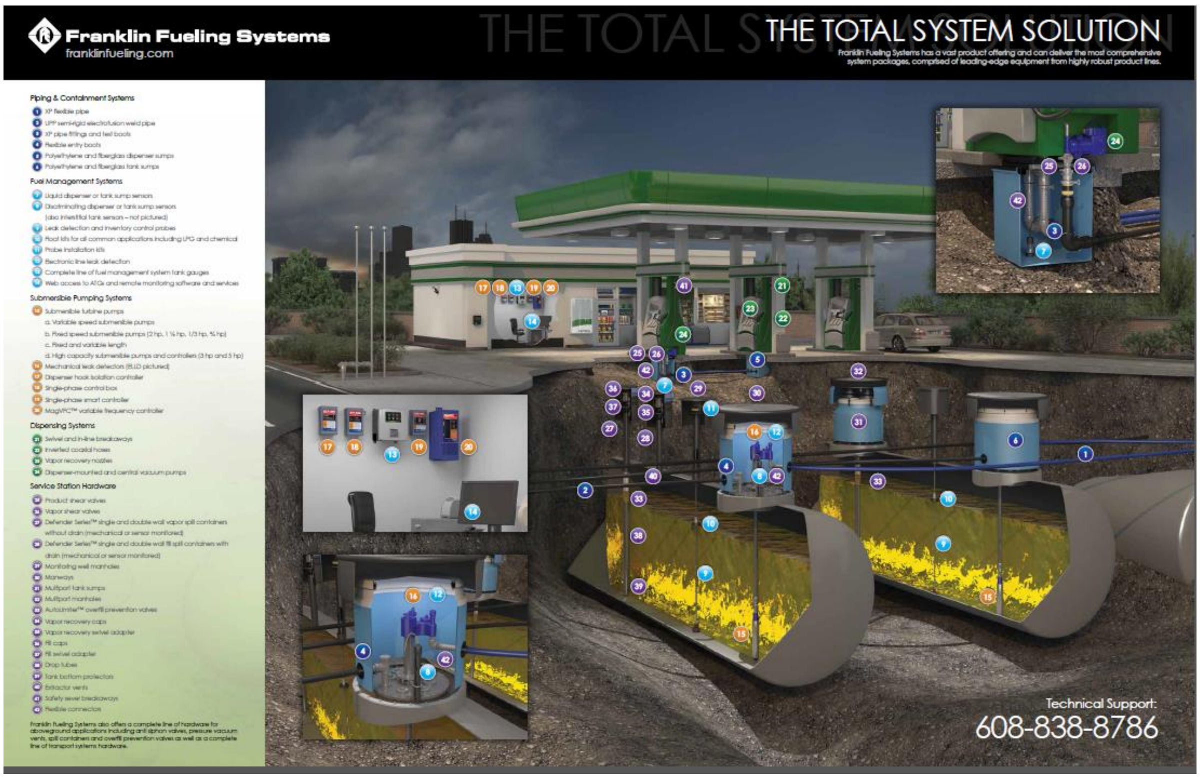


**Figure 2-1. Overview of a retail refueling site. Image source: Franklin Fueling Systems.**

## 2.1 Underground Storage

### 2.1.1 Regulation

In July of 2015, EPA released revised regulations addressing underground storage tanks (USTs) and approval of state UST programs, increasing the emphasis on operating and maintaining underground storage equipment (UST 2015 40 CFR Part 280 and 40 CFR Part 281, docket number EPA-HQ-UST-2011-0301 [3]). Each state is responsible for approval and enforcement of UST regulations. State Program Approval (SPA) involves EPA review and approval of a state's proposed program for installation approval and enforcement; approval authorizes a state to create its own guidelines and regulations for underground storage. Many states and territories have EPA-approved UST programs.

Entities in these states must follow federal guidelines and meet their respective state requirements. In a state that does not yet have an EPA-approved SPA program, the state is still the implementing agency, but must follow the EPA guidelines. As of March 2018, 38 states have approved SPA programs. More information can be found at https://www.epa.gov/ust/state-underground-storage-tank-ust-programs.

A state UST program is approved if it meets three criteria:

1. It sets standards for eight performance criteria that are no less stringent than federal standards.
2. It contains provisions for adequate enforcement.
3. It regulates at least the same USTs that are subject to the federal EPA standards.

### 2.1.2 Underground Storage Demonstration of Compatibility and Regulatory Authority

Per the Office of Underground Storage Tank regulation, for a station undergoing an equipment conversion, a regulatory authority must approve the installment and operation of the underground equipment. One or more of the following certification methods are necessary to be considered a regulatory authority [4]:

- the installer has been certified by the tank and piping manufacturers; or
- the installer has been certified or licensed by the implementing agency; or
- the installation has been inspected and certified by a registered professional engineer with education and experience in UST system installation; or
- the installation has been inspected and approved by the implementing agency; or
- all work listed in the manufacturer's installation checklists has been completed; or
- the owner and operator have complied with another method for ensuring compliance with the installation requirements that is determined by the implementing agency to be no less protective of human health and the environment.

### 2.1.3 Certification of Equipment Capability

Per the EPA regulation November 2015 [5], UST System Compatibility with Biofuels, beginning October 13, 2015, owners and operators must maintain records showing UST system compatibility with certain biofuel blends and components for as long as those substances are stored. The records should document compliance with the compatibility of the stored regulated substances containing:

- Regulated substances containing greater than 10% ethanol;
- Regulated substances containing greater than 20% biodiesel; or
- Any other regulated substance identified by the implementing agency.

The implementing agency must be contacted at least 30 days prior to switching to fuels containing blend levels greater than E10, B20, or any substance identified by the regulating agency [5]. According to 40 CFR Part 280.20 (e) “Performance standards for new UST systems” equipment must be validated and will be identified on the UST notification form given to the state or local agency 30 days prior to changing ownership of a UST or bringing a UST into use [5]. This includes switching to a fuel with an ethanol volume concentration higher than 10%, whether using existing equipment or installing new equipment to store and transfer the fuel. Appendix B of this report contains an example of the application the State of Wisconsin uses for this process. Underground storage ethanol compatibility may be demonstrated by either of two methods [6]:

1. Certification or listing by a nationally recognized, independent testing laboratory such as UL, or
2. Indication of affirmative compatibility with specific range of biofuel in writing by the equipment or component manufacturer.

If the station has records showing fuel compatibility levels of its current equipment to a UL listing, the process of certifying the station to another fuel can be very straight-forward. Many times, the station owner can contact the equipment installer to obtain records documenting the fuel compatibility, but this is not always a viable solution if the installation company is unknown. There is no law or regulation requiring station owners/operators to keep records regarding compatibility of E10 and lower compatible equipment, when it was installed. Records for compatibility of existing equipment installed at sites are often unavailable. Furthermore, many stations have changed ownership over the years and sometimes paperwork is not transferred with the ownership change. Without documentation of compatibility, conversion of existing USTs poses a liability to refueling station owners including the ability to obtain insurance. In interviews, many station owners that began offering E15 in 2016–2017 through the Biofuel Infrastructure Partner grant program stated that they hired a licensed installer to conduct an evaluation of the on-site equipment to produce documentation of the station equipment compatibility [7].

The levels of ethanol compatibility for above-ground and below-ground equipment that station owners acquire and install are primarily dictated by testing and listing certification performed by a testing authority, such as UL, or by a manufacturer's letter of compatibility. To date, most certification testing before installation of underground fuel storage equipment has been performed for either the E10 or E100 compatibility levels with a few components having E25 or E15 variants; while most above ground systems have been tested to E10, E25, E40 or E85 fuels.

EPA has set forth key UST components that must exhibit fuel compatibility when a station is upgrading a refueling station for biofuel usage [5]. Although there are many more pieces of equipment involved with re-fueling at a station, these 12 components are typically the focus in a conversion to retail site ethanol blends greater than E10 [8]:

- Tank or internal tank lining
- Piping
- Line leak detector
- Flexible connectors
- Drop tube
- Spill and overfill prevention equipment
- Submersible turbine pump and components
- Sealants (including pipe dope and thread sealant), fittings, gaskets, o-rings, bushings, couplings, and boots)
- Containment sumps (including submersible turbine sumps and under dispenser containment)
- Release detection floats, sensors, and probes
- Fill and riser caps
- Product shear valve

Additional requirements may be applicable due to specific franchise standards.

Figures 2-2 through 2-5 are photographs of refueling station underground equipment being installed.


**Figure 2-2. Installation of an Underground Storage Tank. Photo Source: Oscar W. Larson Co., Clarkston, MI.**


**Figure 2-3. The Underground Storage Tank System Being Covered Prior To Driveway and Line Installation. Photo Source: Oscar W. Larson Co., Clarkston, MI**

**Figure 2-4. The Underground Storage Tank System After Gravel Cover and Prior To Driveway Installation. Photo Source: Oscar W. Larson Co., Clarkston, MI.**

**Figure 2-5. The Underground Storage Tank System After Line Installation Prior To Driveway Installation. Photo Source: Oscar W. Larson Co.**

2.1.4 Storage Tanks

USTs are typically made of fiberglass or steel. The 2016 National Renewable Energy Laboratory (NREL) Handbook for Handling, Storing and Dispensing E85 and Other Ethanol-Gasoline Blends identifies that the Steel Tank Institute conducted independent testing and determined that steel tanks are compatible with up to 100% ethanol [9]. Figure 2-6 below compiles a listing of the letters of compatibility for each manufacturer and the applicable dates.

**Table A1: Tank Manufacturer Compatibility with Ethanol Blends**

| | 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 | ✔ | ✔ |

**Figure 2-6. Appendix A: Table A1 from NREL/TP-5400 -61684 Increasing Biofuel Deployment and Utilization through Development of Renewable Super Premium: Infrastructure Assessment [6].**

According to the Fiberglass Tank Institute in "Ethanol Compatibility with Fiberglass UST Systems," by 1990 all double-wall fiberglass underground tanks and many single-wall were compatible with all blend levels of ethanol, including E100 [10]). See dates with commentary from paper below.

- Fiberglass Tanks:

  – 1983 – The September 1983 issue of the Underwriters Laboratories (UL) Gas & Oil Equipment Directory includes multiple manufacturers with listings for fiberglass "non-metallic tanks for petroleum products, alcohols and alcohol-gasoline mixtures." The UL use of the term "alcohols and alcohol-gasoline mixtures" is defined in UL standard 1316 to include fuels with any level of ethanol or methanol up to and including 100%.

  – 1988 – In 1988, UL began listing underground fiberglass piping for 100% ethanol and methanol.

  – 1990 – By 1990, Institute member fiberglass tank manufacturers had modified their tanks constructions to handle gasoline with any level of ethanol or methanol up to 100% for all double-wall fiberglass tanks and in some cases single- wall fiberglass tanks.

  – 2006 – UL did not include fiberglass piping or tanks in the 2004 suspension of UL markings for fuel dispensing devices that reference compatibility with alcohol-blended fuels containing greater than 15% alcohol.

As noted in Figure 2-6, some single-wall fiberglass tanks were produced after 1990 by Xerxes (until 2005) and Owens Corning (until 1994). The quantity of these tanks and the locations of where they were installed are unknown. Many tank manufacturers warranty their tanks for 30 years [6]. Some states require tank replacement after the tank reaches a certain age, but this is not the case for all states, and the age at which replacement is required differs among those states that do set forth this requirement. It is difficult to determine the number of refueling stations that have verified equipment capability above E10 compatibility. Later in this report, a sensitivity analysis is presented that projects the estimated costs to upgrade station equipment to E20 and E30 levels.

2.1.5 Piping

The piping carrying liquid fuel from the UST to the above ground fuel dispenser is made of fiberglass or flex pipe. In most cases, concrete must be broken to replace and lay new piping. The underground lines are certified to a UL listing as a system that includes the pipe and pipe sealant. Pipe cement/sealant, which is the joining compound used to attach pipe to pipe joints, is not typically accessible via manhole covers. The equipment records may not list the pipe cement/sealant used during installation and there is risk that a sealant was used other than that which was supplied with the piping kit and used in the development of the UL certification and listing.

In the late 1980's and early 1990's, the secondary flex pipe between the underground tank and the pumping equipment that was widely used, and has been identified in recent station inspections during upgrades, was found to be incompatible with E10. There may be refueling stations that have underground piping in place by companies that are no longer in business, did not list equipment compatible with ethanol blends higher than E10, or do not have or maintain proper records. All underground piping sold today is compatible with the ethanol blends up to E30, the levels studied in this report.

Other key conversion components are: pipe dope (used to connect underground lines to other non-line equipment), containment sumps, pumping equipment, release detection equipment, spill prevention equipment, and overfill prevention equipment, which are usually accessible from the manhole covers. Conversion of these components can be straight forward if all components are accessible from the man hole cover opening, because removal of concrete would not be required. Of course, if the joint is not accessible via the manhole cover, concrete would need to be removed to replace the pipe dope. The sealants (including pipe dope and thread sealant), fittings, gaskets, o-rings, bushings, couplings, and boots) may need to be replaced regardless of the line compatibility. Upgrading the pipe dope is often done when converting existing equipment to equipment compatible with higher ethanol blends, and mostly because records of the compound used in the prior installation are not always available. See Figure 2-7 identifying typical pipe dope locations:

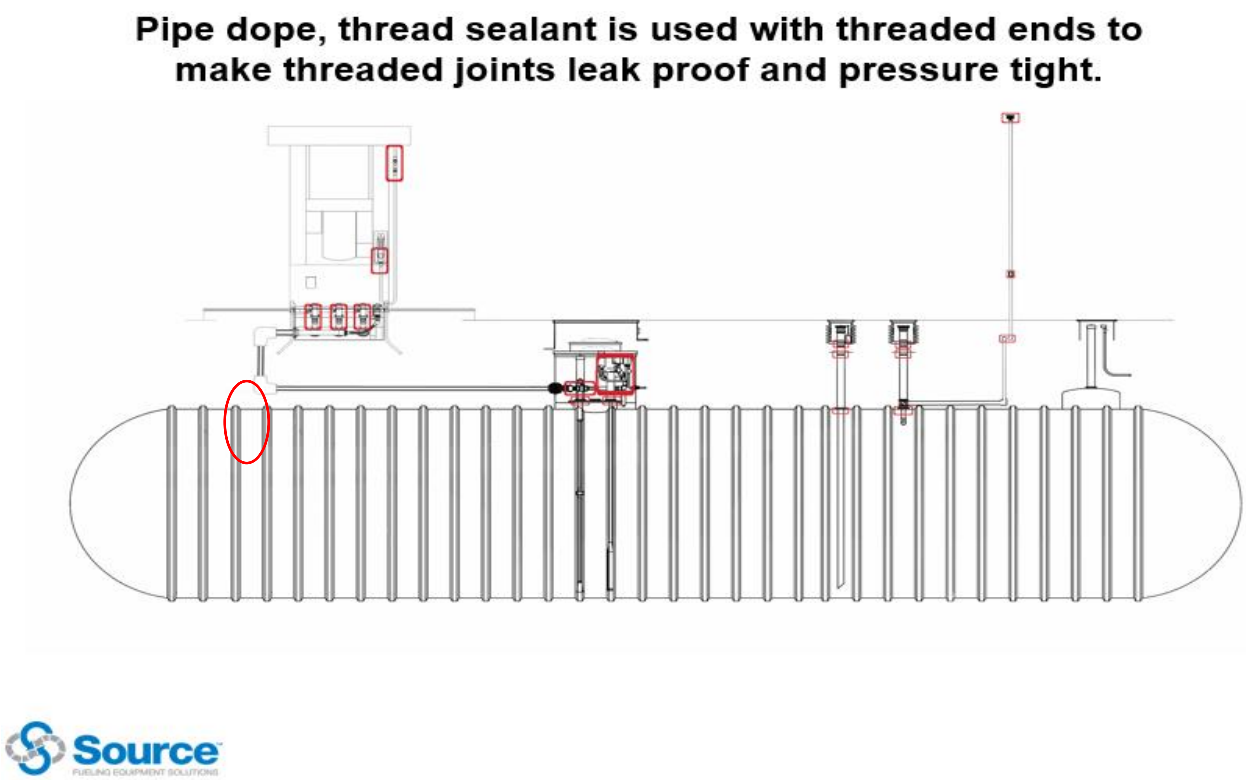


**Figure 2-7. Diagram showing areas in which pipe dope is typically applied. Photo Source: Source Refueling North America Corporation, Addison, IL.**

## 2.2 Underground Tank Configuration

Many stations in 2018 have a large underground tank for regular unleaded gasoline and 2 smaller volume tanks for premium gasoline and diesel or Ethanol Flex Fuel (E51–E83). Configurations of these USTs are a major consideration for converting equipment to allow for a new fuel offering.

## 2.3 Above Ground

In addition to the underground upgrades, above ground equipment must also be replaced or converted if it is not compatible with a new fuel if the fuel contains higher ethanol blends. The above ground equipment refers to the equipment above the concrete at a refueling station. The general life of a refueling dispenser is on average 15 years based on the dispenser sales data (specific sites may vary) while the useful life of the swivel, break away, and hose are generally three years [11]. These estimated life-spans for this equipment are based on the annual sales of dispensers versus the number of dispensers across the United States, with the understanding that the frequency of dispenser replacement will vary.

To obtain insurance, there are also requirements to prove material compatibility of the above ground components. Some components or systems are listed by a Nationally Recognized Testing Laboratory (NRTL) for fuel blends. Most listings are accepted by the authority having jurisdiction for equipment approval. For other materials not listed by a NRTL, equipment manufacturers can demonstrate compatibility by conducting testing at a NRTL or writing self-certification compatibility statements based on some level of testing.

Refueling pumps and dispensers follow UL certification. In 2009 UL identified the 3 certification pathways to address the increase in number of mid-level ethanol blends in the market [6].

1. UL 87 for gasoline and ethanol fuel blends up to E10 (defined prior to 2009 for E10 variants)
2. The new certification path in Subject 87A-E25, which addresses gasoline and mid-level ethanol fuel blends up to E25
3. The established requirements of Subject 87A-E85, which address gasoline and ethanol fuel blends up to E85

In addition to refueling dispensers, other above ground hardware includes nozzles, meters, hose assemblies, swivels, and breakaways, all of which must demonstrate capability with the fuel being stored or dispensed.

Upgrading the dispenser pump from E10 (UL 87A) to E25 (UL87A-E25) can be achieved by replacing the entire dispenser or installing an upgrade kit, if available. Each of the two main dispenser manufacturers have certified upgrade kits to retrofit E10 pumps to E25, and one of the two have the kits available for sale. Very few upgrade kits have been used in retail when stations have made conversions, and not all dispensers may be compatible to the kits available.

Wayne Dresser announced on August 30, 2016, that it will be shifting from the UL listing of E10 to the UL Listing of E25 for all Wayne Ovation™ fueling dispensers, and that it will do so by the end of 2017 for the Wayne Helix™ dispensers. This shift was stated as an "Expression of Wayne's continued intent of supplying its customers with the most flexible, reliable and future-proof equipment options." [12]. By expanding the range for base refueling pumps from 0–10% to 0–25% ethanol, a natural conversion will take place for an increasing fraction of stations purchasing new Wayne equipment, which will have dispensers capable of handling E25 blend fuels. Assuming a dispenser life of 15 years, a sales rate of approximately 43,300 refueling pumps/year in the United States—an average of 4.2 dispensers/station—and 40% market share of Wayne dispensers in the United States, 5,300 stations would be converted naturally to E25 compatible refueling dispensers per year [11]. These figures equate to 40% of the stations (Wayne market share) being converted by 2040. If Gilbarco, another major equipment supplier, also offered only E25 compatible dispensers as the base offering by 2025, all stations could have compatible dispensers by 2040, considering a 15-year life cycle.

# 3. Fuel Supply Terminal Upgrades

**Figure 3-1. Fuel Supply Terminal. Photo Source: Oscar W. Larson Co., Clarkston, MI**

Fuel terminals in the United States currently combine gasoline and ethanol at the fuel blending point (truck loading rack) to make a 10% gasoline-ethanol fuel blend. Because the ethanol handled at the terminal is denatured E100 or ED100, upgrades in materials are not of concern for the terminals. The terminal areas that need to be considered for blending a higher concentration of ethanol into gasoline are the transportation, storage, and blending. Larger ethanol storage tanks may be required to handle the increased throughput. If there is no land available for additional storage tanks, land may need to be purchased (assuming properly zoned/permitted land is available adjacent to the terminal). Plumbing from the storage tanks to the blending point and blending equipment upgrades may also need to be purchased/upgraded.

The hydrocarbon gasoline is transported by pipeline, barge, or train from the refinery. Ethanol is delivered by barge, truck, or train. Both types of fuel are stored separately until blended into the station delivery truck or vessel. Transferring gasoline to a storage tank from a pipeline is achieved by changing the positions of valves along the pipeline and piping to the storage tank. Receipt of fuel by barge, truck, or train is a more labor-intensive operation. Logistical considerations for receipt of more ethanol fuel may also require changes to the terminal.

# 4. Material Selection

## 4.1 Ethanol Capability

In considering material selection, material compatibility with ethanol blends should be evaluated and approved as a system rather than results of isolated material coupon testing in a fuel. In fuels and coupon testing, certain materials retain their physical properties better than others, indicating which materials may break down, permeate, corrode, or become brittle when exposed to such fuels, and these coupon test results are used in the design of a component or a system. Component or system level testing is the true test of conclusive material compatibility with a fuel. Results such as o-ring crush and galvanic corrosion can only be evaluated in the functional design environment, taking into consideration temperatures, pressures, movement, and flow.

Industry upgrades of materials for ethanol fuel compatibility typically are indicated with the concentration of ethanol. Fuels with ethanol concentrations between 10%–25% result in the peak volume swell for most elastomers [13]. Thus, material upgrades tend to require for ethanol concentrations of above 10%. Metal components are typically upgraded for ethanol concentration ranges above 25% due to the hydroscopic and conductive properties of ethanol due to swelling and break down of the material in fluid.

Elastomers are generally used in sealing applications where the joint is designed as a system, thus material compatibility must be evaluated as a system to verify joint integrity with certainty. Coupon testing of elastomers can be used for selection of elastomers for infrastructure and vehicle components in the design of such systems. The measured properties are percent swell, hardness, and shrinking or loss of mass upon drying. Material parameters used for selecting elastomers are percent volume swell, change in hardness, permeation, and shrinkage or loss of mass after drying. There is a great deal of material variability on fuel compatibility due to composition, processing, additives, and quality within an elastomer class. This variability makes it critical that manufacturers write letters of compatibility based on testing or that there be component certification by a NRTL.

No change in the rate of corrosion was witnessed in components or coupon testing in E10, E17, or E25 test fuels for metallic materials used in E0 [14]. Varying levels of corrosion were witnessed in coupon sampling of metallic materials with E50 or E85 test fuels, but higher levels of corrosion were witnessed in aggressive E50 and E85 testing for some metallic components galvanically coupled [14]. This difference is attributed to the conductivity and adsorption of water in the fuels with higher ethanol blend levels.

Many resources may be used for station owners to identify compatibility of components with fuels, including manufacturer statements of compatibility. Some of these resources are EPA, Association of State and Territorial Solid Waste Management officials, New England Interstate Water Pollution Control, Petroleum Equipment Institute, American Petroleum Institute, Fiberglass Tank and Pipe Institute, Petroleum Marketers Association of America, National Association for Convenience and Fueling Retail, and Underwriters Laboratories. However, federal, state and local authorities may require specific certification to meet regulations.

## 4.2 Hansen Solubility Analysis: Comparisons of Ethanol, Bioreformate and Woody Biomass Derived Fuels in Gasoline

Hansen solubility parameters were developed by Charles M. Hansen in 1967 as a way of predicting if one material will dissolve in fluid and form a solution [15]. The parameters are based on the idea that like dissolves like, where one molecule is defined as being 'like' another if it bonds in a similar way. Specifically, each molecule is given three Hansen parameters: the energy from dispersion forces between molecules, the energy from dipolar intermolecular force between molecules, and the energy from hydrogen bonds between molecules [16]. The Hansen Solubility Parameters may also be used to predict percent swell of a compound, thus predicting material compatibility with a liquid.

### 4.2.1 Solubility Analysis and Hansen Solubility Parameters and How They are Applied

The compatibility of polymeric materials with fuel chemistries is primarily manifested by the extent of volume swell that occurs when the polymer is exposed to the fuel. This volume expansion is the direct result of the mutual solubility that exists between the polymer and the fuel type. Solubility itself is driven by the degree of similarity of the weak binding forces in the solvent (fuel) and solute (polymer). Solubility analyses assign parameters to both the solute and solvent to represent these attractions, whereby solubility is proportional to the degree of similarity of these parameters to each other. For each material and fluid, the Hansen solubility parameters (HSPs) method assigns a parameter to forces associated with atomic dispersion ($\delta D$), polarity ($\delta P$), and hydrogen bonding ($\delta H$) to represent the total cohesive energy density, which is the sum of the square of these three attractive forces [16].

$$\delta T2 = \delta D2 + \delta P2 + \delta H2$$

Compounds having similar HSPs will have similar attractive affinities. This similarity (or dissimilarity) is quantified by the differences between the HSPs for the solute and solvent. This difference is termed the solubility distance ($dS$) and, for a polymer ($p$) and a liquid ($l$), is determined by:

$$d_S = \sqrt{[4(\delta_D(p) - \delta_D(l))^2 + (\delta_P(p) - \delta_P(l))^2 + (\delta_H(p) - \delta_H(l))^2]}$$

As $dS$ decreases (the polymer and fluid become more similar), the liquid becomes more soluble with the polymer. Therefore, the lower the $dS$ value, the more swelling would be expected. Since swelling correlates to compatibility, the polymer fuel combination will become less compatible with decreasing $dS$. For this study, fuels that have lower $dS$ will be less compatible for a given elastomer type.

### 4.2.2 Why Dodecane is Used in the Hansen's Solubility Method

Gasoline is a mixture of over 150 different hydrocarbon compounds ranging from C4 to C12. The polarity and hydrogen bonding are expected to be very low (if not negligible) for the compounds within gasoline. HSPs can be determined from blends by using a rule-of-mixtures approach to come up with parameters that represent the blend. The Hansen solubility team has determined that the parameters associated with dodecane ($\delta D$ = 16 MPa1/2, $\delta P$ = 0 MPa1/2, and $\delta D$ = 0 MPa1/2) are a good representative of gasoline. Studies have shown that the dodecane numbers do a good job of representing gasoline. HSPs can be calculated for E10 based on the HSPs for dodecane. The tabulated HSPs that have been included in this report do include those for E10, which is a second baseline fuel, in addition to dodecane.

A Hansen solubility analysis was performed on three fuel chemistries that were the subject to two associated studies, two containing bioreformate and one containing a wood biomass-derived fuel. These fuels are denoted as follows:

- 9% bioreformate
- 27% bioreformate
- 27% woody biomass

Using the compositional results obtained from gas chromatography, suitable HSPs were calculated for those components determined to be present in volume percentages of 1% (or higher). These components made up over 75% of the total composition and were normalized for the calculation of the overall HSPs. For many of the components, HSPs were obtained directly from the Hansen solubility database. However, a number of the components were not in the database and the HSPs for these molecules were estimated based on their key function group. For each component and polymer there are three parameters that define the solubility: the molecular dispersive forces, polarity, and hydrogen bonding. For the three fuel types, the polarity and hydrogen bonding forces are very low, corresponding to the very low polarity associated with these fuels. (In contrast, many oxygenates are highly polar and differ substantially in solubility.) In this analysis, the parameters for dodecane were used to represent pump-grade gasoline (as a baseline), as per the normal practice specified by the Hansen solubility team. The resulting parameters for the three fuels and dodecane are shown in Table 4-1 alongside four ethanol blends (E10, E20, E25, and E30).

**Table 4-1. Hansen Solubility.**

| | Hansen Solubility Parameters ($MPa^{1/2}$) | | |
|---|---|---|---|
| Fuel Type | Dispersive | Polarity | Hydrogen Bonding |
| Dodecane (gasoline representative) | 16 | 0 | 0 |
| 9% Bioreformate | 16 | 0.5 | 0.5 |
| 27% Bioreformate | 16 | 0.5 | 0.5 |
| 27% Woody Biomass | 16.3 | 0.6 | 1 |
| 10% Ethanol | 15.98 | 0.88 | 0.94 |
| 20% Ethanol | 15.96 | 1.76 | 1.88 |
| 25% Ethanol | 15.95 | 2.2 | 2.35 |
| 30% Ethanol | 15.94 | 2.64 | 2.82 |

The resulting parameters are quite similar for each of the fuels, including the baseline fuel (dodecane). These values are also similar to those obtained for E10. (In fact, for the 91 RON 27% Woody Biomass fuel, the solubility parameters are closer to E10 than that are for dodecane.) However, the HSPs become less similar with increased ethanol content. The three research fuels have slightly higher polarity and hydrogen bonding due to the aromatic composition of these fuels. The dispersive forces were similar to the gasoline representative, dodecane, but a small though significant increase in polarity and hydrogen bonding parameters were noted for the research fuels. The two fuels containing bioreformate were observed to essentially have the same parameters. The 27% Woody Biomass fuel had a slightly higher dispersive parameter and hydrogen bonding compared to the fuels containing bioreformate.

Because the parameters are similar to the baseline fuel, no drastic compatibility changes with the research fuel types should be expected. However, subtle differences may be noted. The approach used to assess compatibility is to examine differences in the solubility distances ($d_S$ values) for those elastomers and plastics with each fuel type. Relative to the baseline fuel (dodecane), an increase in $d_S$ from the baseline would indicate reduced solubility (or swell) and therefore increased compatibility. Lower $d_S$ values would indicate higher solubility (or swell) and potentially reduced compatibility. The $d_S$ values for each fuel and polymer type were calculated and are shown in Table 4-2 for elastomers and Table 4-3 for plastics.

The elastomers included in this study are fluorocarbon, silicone, acrylonitrile butadiene rubber (NBR), styrene butadiene rubber (SBR), neoprene, and polyurethane. Of these, fluorocarbons and NBR are the most commonly used, while neoprene, silicone, and polyurethane are present in limited applications.

**Table 4-2. Calculated Solubility Distances for Common Elastomers with the Research Fuel Types. Units are in $MPa^{1/2}$.**

| Elastomer Type | **Dodecane (Baseline)** | 9% Bioreformate | 27% Bioreformate | 27% Woody Biomass | 10% Ethanol | 20% Ethanol | 25% Ethanol | 30% Ethanol |
|---|---|---|---|---|---|---|---|---|
| Fluorocarbon (Viton) | **10.5** | 9.9 | 9.9 | 10 | 9.5 | 8.7 | 8.3 | 7.9 |
| Silicone | **6.8** | 6.3 | 6.3 | 6.7 | 6 | 5.4 | 5.3 | 5.1 |
| NBR | **5.9** | 5.1 | 5.1 | 4.6 | 5 | 4.3 | 4 | 3.8 |
| SBR | **5.3** | 4.5 | 4.5 | 4 | 4.3 | 3.6 | 3.3 | 3.2 |
| Neoprene | **9** | 8 | 8 | 7.7 | 7.9 | 6.9 | 6.5 | 6 |
| Polyurethane | **11.2** | 10.4 | 10.4 | 10 | 10.1 | 9.1 | 8.6 | 8.1 |

The results in Table 4-2 show that all of the research fuels (including the ethanol blends) can be expected to exhibit higher solubilities (lower $d_S$ values) compared to pump grade gasoline (dodecane test fuel). For fluorocarbon and silicone, the $d_S$ values are only slightly less than the baseline, indicating that for all practical purposes, they are expected to be fully compatible. Interestingly, the $d_S$ result for the research fuels is slightly lower indicating that these fuels will likely be slightly more compatible with fluorocarbon than E10, which is already considered compatible with this fuel type (E10). For the remaining four elastomers (NBR, SBR, neoprene and polyurethane), the drop in $d_S$ indicates that higher swelling will occur with the research fuels compared to the baseline. Of these fuels, 27% Woody Biomass would be expected to produce the most swelling. It is important to note that the level of swelling is not expected to be unusually high given the actual drop in $d_S$ compared to the baseline. However, potentially moderately increased swelling with NBR, SBR, neoprene and polyurethane should be expected, and this could impact the seal or hose performance (especially for NBR, which is used extensively in hoses, o-rings, and gaskets). Some level of experimental exposure studies would be recommended for these materials.

When compared to E10, the research fuels containing the bioreformate show nearly identical solubilities, indicating that their compatibility should be very similar to E10. The 27% Woody Biomass fuel would be expected to produce slightly higher swelling in NBR and SBR than E10, but would produce comparable swelling in neoprene. Interestingly, slightly improved compatibility would be expected for fluorocarbon and silicone.

The results for the testing of plastics are shown in Table 4-3. The plastics evaluated in this study are polyphenylene sulfide (PPS), polytetrafluoroethylene (PTFE), polyvinylidene fluoride (PVDF), polyethylene terephthalate (PET), PET co-polymer with ethylene glycol (PETG), polyoxymethylene (POM), high density polyethylene (HDPE), polybutylene terephthalate (PBT), nylon (three grades), and polypropylene (PP).

As with the elastomers, the analysis indicates that a small to moderate solubility increase (or increased swelling) can be expected with the research fuels relative to the baseline fuel. In addition, the results for the 27% Woody Biomass suggest slightly higher solubility relative to the bioreformate fuels. In general, the solubility distance is around 1 $MPa^{1/2}$ lower for the research fuels compared to the baseline case. (Notable exceptions are for HDPE and PP, in which the $d_S$ values for dodecane and the bioreformate research fuels were similar.) The expectation is that a small level of higher swelling may be observed for these materials when exposed to the research fuels. For most static sealing applications (such as Teflon or nylon washers and o-rings), this additional swelling is not likely to be noteworthy. However, for hoses and structural components even a small amount of swelling can impart stresses that impact component durability. One noteworthy observation is that the performances of these fuels closely match the results of E10, and, as such they are expected to be fully compatible in systems already used to store and transport E10. Higher ethanol content fuels, however, would be less compatible with existing systems.

**Table 4-3. Calculated Solubility Distances for Common Plastics with the Research Fuel Types. Units are in $MPa^{1/2}$.**

| Plastic Type | **Dodecane (Baseline)** | 9% Bioreformate | 27% Bioreformate | 27% Woody Biomass | 10% Ethanol | 20% Ethanol | 25% Ethanol | 30% Ethanol |
|---|---|---|---|---|---|---|---|---|
| PPS | **10** | 9.1 | 9.1 | 8.7 | 9 | 8.1 | 7.7 | 7.3 |
| PTFE (Teflon) | **3.9** | 2.8 | 2.8 | 2.7 | 2.7 | 1.6 | 1.2 | 1.2 |
| PVDF | **16** | 14.9 | 14.9 | 14.8 | 14.7 | 13.4 | 12.8 | 12.2 |
| PET (Mylar) | **9.6** | 8.7 | 8.7 | 8.4 | 8.5 | 7.4 | 6.9 | 6.4 |
| PETG | **6.4** | 5.6 | 5.6 | 5.1 | 5.5 | 4.8 | 4.5 | 4.3 |
| POM (acetal) | **13.7** | 12.6 | 12.6 | 12.4 | 12.4 | 11.1 | 10.5 | 9.9 |
| HDPE | **5** | 4.5 | 4.5 | 4 | 4.6 | 4.6 | 4.7 | 4.9 |
| PBT | **10.9** | 9.8 | 9.8 | 9.6 | 9.7 | 8.6 | 8.1 | 7.5 |
| Nylon 6 or 66 | **11.3** | 10.2 | 10.2 | 10.1 | 10.2 | 9.1 | 8.6 | 8.1 |
| Nylon 11 | **11.7** | 10.6 | 10.6 | 10.4 | 10.5 | 9.3 | 8.8 | 8.2 |
| Nylon 12 | **13.2** | 12.2 | 12.2 | 11.9 | 12 | 10.9 | 10.3 | 9.8 |
| Polypropylene (PP) | **4.1** | 4 | 4 | 3.5 | 4.1 | 4.5 | 4.8 | 5.2 |

In summary, the following conclusions can be drawn from the solubility information:

- The solubility behavior for the three research fuels evaluated in the associated U.S. DRIVE engine test research effort is expected to be roughly similar to pump grade gasoline.

- Compatibility (as determined by swell) will be lower for the research fuels, but not excessively so as to warrant major concerns when comparing the fuels for use with E10 compatible equipment.

- The two bioreformate U.S. DRIVE research fuels can be expected to produce similar compatibilities with equipment.

- The 91 RON 27% Woody Biomass fuel has slightly less compatibility (more predicted swelling) than the bioreformate fuel types.

- Empirical exposure studies are recommended for NBRs and neoprene.

- Polypropylene should be compatible with the two bioreformate research fuels.

- Empirical exposure studies are recommended for plastics being considered for structural applications.

- It would be expected that hydrocarbon-based biofuel blends will be compatible with systems already in use for E10 since the solubility results of these compounds, closely match the solubility results from E10 for elastomers and plastics.

Additional steps are suggested, including (1) Verification of the predicted material compatibility results before introducing such fuels to market; (2) EPA should determine if the fuel is a substance that falls into the category of those that must be handled separately from typical fuel pursuant to UST regulation; and (3) UL should determine what is required to include these fuels into a UL listing.

# 5. Directional Cost Estimates for Converting to New Fuel Blends

Projecting estimated costs for converting/upgrading stations to be able to receive and dispense fuels containing increased levels of ethanol requires several initial assumptions. The first assumption would be the number of stations that need to replace underground tanks and lines and/or above ground equipment, either because the existing equipment is not compatible with a new fuel or the stations do not have the documentation necessary to prove compatibility. Replacing underground equipment is especially costly, due to both the costs of purchasing and installing the new equipment, as well as the loss of sales during the down time. Replacement is also labor intensive due to the necessity to remove concrete or asphalt to access some of the equipment.

Because underground tank and line replacement comprises the most significant costs for the upgrade process, and because the actual number of stations needing to make such a change are unknown, a sensitivity analysis was conducted to demonstrate the underground tank and lines cost. The sensitivity analysis includes one bookend where the underground tanks and lines would be replaced only as necessary due to insurance purposes, state regulations on underground equipment life, or failure. In such a scenario, the date when all the U.S. stations would be in a position to offer gasoline in blends greater than E10 is unknown and impossible to determine. The other spectrum considers a forced situation where some stations that do not have the appropriate equipment or documentation would be required to update underground tanks and lines before insurance, dictated life end, or failure occurs. A value of 20% of the U.S. stations has been selected to represent this case.

5.1 Refueling Stations

Focusing on the refueling sites, there are 150,438 refueling stations in the United States [17], and 59% are owned by single-station owners [18]. Many of the convenience stores are independently owned with a franchise contract granting authority to sell branded fuel. The average profit of a store is $48,000 per year, coming mostly from in-store product sales [19]. Many of the major oil companies have divested and no longer own and operate retail locations, resulting in less than 2% of refueling stations are owned by one of the five major oil companies as of June 2014 [18]. The expense of station equipment maintenance, upgrades, and replacement often falls to the station owner regardless of branding, so the cost of significant upgrades would be onerous to many station owners. Note that retail station incremental costs to convert to fuel formulations containing higher levels of ethanol could be lower at the time the fuel is introduced to the market if the station owners elected to install equipment having higher ethanol compatibilities when replacing failed equipment prior to the market introduction of any new fuels containing higher ethanol contents. Considerations of those affected for equipment changes to accommodate a new market fuel must include those making the investment.

In the U.S. DRIVE report detailing the life-cycle assessment of fuels, it is assumed the new fuel formulation would constitute 50% of the retail gasoline sold by 2025 and 100% by 2040. Thus, the second key assumption involves using the same percentages and timing, here in the context of the conversion of station equipment. To meet 50% conversion by 2025, we have assumed that 30% of the stations that choose to sell a new fuel formulation containing more than 10% ethanol would already have above ground equipment that is E25 compatible (considering the number of flexible- fuel vehicle stations and the projected number of Wayne E25 compatible dispenser pumps), while 20% of stations would need to replace above ground equipment. For the 2025 case, we have assumed that the underground equipment of all of those stations that decide to sell the new formulation already have compatible underground storage equipment. Because any underground tanks and lines installed today are rated for exposure to above 30% or 85% ethanol, many underground tanks and lines are also expected to be compatible with any grade of ethanol fuel by 2040. However, it is difficult to predict the percent of stations that would be able to produce proper records, and thus the team has selected 20% as the number of stations in 2040 that would need to replace the underground storage equipment to create a sensitivity analysis. The costs cited in this study to replace underground lines include removal of concrete to access the equipment.

Typical dispenser hanging hardware (average 8.5/station) and tank equipment, such as underground pumps, leak detector, probe, and float (average 2/station), is generally not rated above E10, so these items would need to be updated for any blends of fuel above E10 and hence they are included in cost scenarios for every station. These estimates are expected to be high considering many would convert to the higher ethanol equipment as it is needed to be replaced, but this is difficult to confirm. A new standard may need to be developed for stage two vapor recovery above E10 fuel, which poses difficulties for the State of California, which requires an Enhanced Vapor Recovery system.

A natural refueling dispenser conversion is occurring for fuels up to E25 levels at about a 40% replacement rate due to the announcement in 2016 from Wayne Dresser to sell E0-E25 dispenser pumps as the base model beginning in 2017 [12]. The 40% conversion rate assumes Wayne retains 40% of the market share and continues to only offer the E25 dispenser as the base model.

Gilbarco Veederoot supplies roughly the other 60% of the dispensers in the U.S. refueling market. Gilbarco has a dispenser conversion kit at a fraction of the cost of a new dispenser, which offers a financially attractive option to convert existing E10 dispensers to E25, although the conversion is not available for fuels at a blend level above E25 and up to E85 levels, and maybe not for older equipment.

Table 5-1 shows the various upgrade scenarios for stations depending on the current ethanol fuel compatibility of the station equipment. It breaks out three major cost scenarios with step changes in the necessary equipment upgrades/replacement. The costs are based on quotes obtained verbally and in writing from station equipment contractors and published material [6]. Looking at the costs for increasing ethanol fraction in gasoline, two obvious break points or jump on costs become clear: Fuels with ethanol content above E10, and fuels with ethanol content above E25. Also noteworthy is the retrofit option for converting an existing E10 dispenser pump to E25 compatibility. When taking advantage of a fuel dispenser conversion kit for E25, the cost is 36% the cost of upgrading a station with new E25 dispensers and 30% of the cost with new E85 dispensers. The retrofit option could only be applied to the conversion of the Gilbarco dispensers in the early conversion up to 2025, since Wayne does not have a conversion kit available. These costs also include upgrades in hanging hardware, pipe dope, underground pumps, drop tubes, other necessary equipment, and cleaning of the tanks as discussed in the UST section of this report. The costs do not include the business interruption down time loss of revenue during construction. Many of the costs are based on Michigan pricing; the cost to replace equipment may vary greatly from region to region. For example, California and Chicago station replacement costs tend to be higher than other areas of the United States, while other areas may be significantly lower. Note that new fuel formulations containing ≤10% ethanol would very likely not require replacement of existing E10 compatible equipment.

**Table 5-1. Individual Equipment Station Upgrade Costs for U.S. Average Size Stations Increasing Fuel Compatibility.**

| Individual Station Costs for U.S. Average Station (4.25 dispensers, 2 gasoline tanks) | | | |
|---|---|---|---|
| | **E0-E10** | **E11-E25** | **E26-E85** |
| **Light Conversion Scenario per station cost:** | | | |
| **New equipment: hanging hardware, underground pumps, drop tubes, pipe dope...,<br>No changes necessary to dispenser pumps, underground lines/tanks** | $18,000 | $21,000 | $21,000 |
| **Retrofit Dispensers - (Gilbarco only)<br>this scenario does not include dispensers** | NA | NA | NA |
| **Medium Conversion Scenario per station cost:** | | | |
| **New Dispensers<br>New equipment: hanging hardware, underground pumps, drop tubes, pipe dope…,<br>No changes necessary to underground lines/tanks** | $81,000 | $93,000 | $112,214 |
| **Retrofit Dispensers (Gilbarco only)<br>New equipment: hanging hardware, underground pumps, drop tubes, pipe dope...,<br>No changes necessary to underground lines/tanks** | NA | $30,000 | NA |
| **Extensive Conversion Scenario per station cost** | | | |
| **New Dispenser Pumps<br>New equipment: hanging hardware, underground pumps, drop tubes<br>New Tanks, New Lines** | $369,000 | $379,000 | $398,000 |
| **Retrofit Dispenser Pumps<br>New equipment: hanging hardware, underground pumps, drop tubes<br>New Tanks, New Lines** | NA | $314,000 | NA |

Stations undergo equipment replacement during the normal life cycle of a station. For a station that intends to sell gasoline containing higher than 10% ethanol in the future, the most ideal time to upgrade would be during equipment replacement due to age or failure. Replacement at this point allows costs to be captured as incremental from replacing with standard E10 compatible equipment. Table 5-2 projects incremental costs to convert to a new fuel for 2040.

The percentage of retail sites undergoing natural conversion to E25 dispenser pumps is assumed to be 24% by 2025; thus 26% of stations in 2025 would need to be converted using retrofit kits (E25 only), or upgraded to higher ethanol concentration compatibility before 2025. The cases below assume the conversion of Wayne Dresser dispensers and the upgrade costs for new dispensers and other equipment in the 2025–2040 timeframe. In the case where 20% of stations require new UST equipment prior to 2040, all new station dispensers, tanks, lines, hanging hardware, underground pumps, drop tubes and other necessary equipment are included in the costs.

**Table 5-2. Incremental Station Cost above E10 Equipment Replacement Costs for Increased Ethanol Blend Fuel.**

| | Nationwide Incremental Station Costs | | | | | |
|---|---|---|---|---|---|---|
| | With Proper confirmation of Equipment Capability | | | Without Proper Equipment Capability 20% stations change out tanks and lines | | |
| | E0-E10 | E11-E25 | E26-E85 | E0-E10 | E11-E25 | E26-E85 |
| $ Increase above E10 | NA | $1,895,000,000 | $5,718,000,000 | NA | $10,621,000,000 | $14,444,000,000 |
| % | | 30% | 91% | | 169% | 230% |
| Increase average across all U.S. stations | | $13,000 | $38,000 | | $71,000 | $96,000 |
| Increase for stations replacing tanks and lines | | | | | $310,000 | $365,000 |

The incremental costs for E26 and higher blend levels are quite substantial for each stage of the conversion. Except for the 20% total station conversion for the sensitivity analysis, the increased costs of converting a station with E85 dispensers vs. E25 dispensers are not significant when considering the total costs of an entire station conversion. Because the E25 break point is based on the UL listing, if the UL listing for that particular product code were to shift in ethanol percentage, the breakpoint would shift accordingly. There have been recent discussions of modifying the current UL dispenser certification from E25 to E40; thus, the new breakpoint for station upgrades would be E40 rather than E25.

This evaluation is not meant to represent the entire market, but rather to present data representative for evaluating likely costs. As stated previously, new fuel formulations that contain ≤10% ethanol would not be expected to incur these additional costs.

## 5.2 Directional Costs to Upgrade a Terminal

Ethanol is blended into the fuel at the fuel distribution terminal after receipt at the pipeline and while it is loaded into the station delivery truck. To blend higher concentrations of ethanol into fuel, modifications at the terminal may be necessary for receipt, storage capacity, plumbing, metering, and blending. There are currently 1,070 terminals supplying gasoline in the United States.

Accurately quoting the costs for a terminal facility to handle increased or different blends of biofuels requires a detailed analysis of redesign and costing of equipment, permits, site costs, and modified terminal operations. This effort and the resulting outcome would also be unique to each terminal. In literature studies and speaking with many terminal operators, two estimates were available to evaluate the effort required for a terminal to supply market gasoline at higher grades of ethanol [20][21]. Both studies compared converting a terminal from E10 to E30. Table 5-3 below depicts the cost range expected for a terminal to supply E30 fuel at high volumes. The low estimated per terminal cost is $1.7 million and the higher estimate is $10.2 million, which includes purchasing land to install additional ethanol storage tanks (assuming that properly zoned land adjacent to the terminal is available and can be purchased).

**Table 5-3. Terminal Estimate Fuel Ethanol Conversion E10 – E30 with Detail.**

| Nationwide Terminal Cost Estimate for Fuel Ethanol Conversion E10 to E30 | | |
|---|---|---|
| **Pre-Conceptual Estimate:** | **LOW END ESTIMATE** | **HIGH END ESTIMATE** |
| Equipment | $950,000 | $6,300,000 |
| Systems | | |
| Tanks | | |
| Mechanical | | |
| Piping | $550,000 | $2,750,000 |
| Electrical | $50,000 | $150,000 |
| Engineering Costs | $50,000 | $250,000 |
| Indirects (land purchase) | $0 | $100,000 |
| Total Per Terminal | $1,600,000 | $9,550,000 |
| **Total for U.S. Terminals** | **$1,712,000,000** | **$10,218,500,000** |

*1,070 gasoline U.S. Terminals*

The costs for adding another biofuel blend into the terminal would be expected to be higher than the lowest cost and comparable to the higher estimate for increased ethanol to E30. Table 5-4 below depicts the expected cost ranges of a terminal to supply a new biofuel—the low estimate assumes a current tank is converted to store the new biofuel and the high estimate assumes new tanks are installed in the terminal facility to handle the blend component.

**Table 5-4. Terminal Estimate Conversion for FWG Biofuel Blendstocks.**

| Terminal Estimate Conversion FWG Fuel Blendstocks | | |
|---|---|---|
| **Pre-Conceptual Estimate:** | **LOW END ESTIMATE** | **HIGH END ESTIMATE** |
| Equipment | $1,900,000 | $6,300,000 |
| Systems | | |
| Tanks | | |
| Mechanical | | |
| Piping | $715,000 | $2,750,000 |
| Electrical | $50,000 | $150,000 |
| Engineering Costs | $60,000 | $250,000 |
| Indirects (land purchase) | $0 | $100,000 |
| Subtotal Per Terminal | $2,725,000 | $9,550,000 |
| 1,070 gasoline U.S. Terminals | **$2,915,750,000** | **$10,218,500,000** |

# 6. Vehicle

Vehicles sold in the United States and Canada today state maximum ethanol concentration compatibilities at E10, E15, and E85. Fuel compatibility is determined by the OEM or the supplier for each system in the vehicle that comes into contact with the fuel liquid or vapor. Specific ethanol concentration compatibility varies among both components and differ among automotive manufacturers (OEMs). The rules for coupon testing and component level testing are generally the same for vehicle components as for refueling infrastructure, described above. Vehicle components are, however, put through a robust validation process, referred to by some as Product Part Approval Process (PPAP), before vehicle launch and validation.

The material selection for fuel compatibility for vehicle components is similar to that which is applied to refueling station equipment. Elastomers and plastics are upgraded to be compatible with ethanol level concentrations up to E25, but each must be validated due to compositional and processing differences. Metallic compounds are upgraded typically to manage levels around E25, but they too must be validated as compatible with the fuel. Fuel system electrical components and wiring must be electrically isolated and designed to withstand ethanol's corrosiveness and conductivity. The components compatibility, which typically can vary for differing fuel-ethanol concentrations, are fuel system components such as the fuel pump module, fuel dampers, fuel injectors, fuel lines, fuel tanks, canisters, fuel filler tubes/hoses; engine components such as spark plugs, valve seats, and valve stem seals; software changes such as engine calibration and on board diagnostics; and adjustment of design parameters such as On Board Refueling Vapor Recovery (ORVR), running losses, and cold start. Each vehicle manufacturer needs to ensure the vehicle materials, performance, and software are equipped for a change in fuel. The costs and complexity increase with expanded ranges of ethanol concentration compatibility within the vehicle. Flex-fuel vehicles designed to run on fuel ranging from E0–E83 have been produced for many years and the necessary changes are well established by vehicle manufacturers experienced in flex-fuel vehicle design.

It is difficult to determine the actual ethanol tolerance for each on-road legacy vehicle today, and different OEMs build their vehicles to varying compatibility with ethanol fuels. The most readily available information for ethanol fuel levels acceptable in a vehicle are indicated in vehicle owner's manuals. Some OEMs allow E15 in their vehicles today where others allow only up to E10.

The table below is an evaluation by FiatChrysler Automobiles, Ford Motor Company, and General Motors Company on the complexity expected for the U.S. DRIVE fuel sets. As stated previously, some vehicle manufacturers do not allow ethanol fuel blends above E10 as permissible fuel in their vehicles per their owner's manual; thus, an evaluation of the changes needed for higher ethanol blends for such a vehicle may require vastly different upgrades to allow use of higher ethanol concentration fuels. As the fuel ethanol levels increase, the necessary vehicle upgrades grow in complexity. As stated before, vehicle design to E10, E15, and E85 are well established but upgrades to new ethanol fuel levels such as E20, E25, or E30 would need to be evaluated. Upgrades to mid-level ethanol fuels may require fewer upgrades than a full flex-fuel vehicle (E83), thus lending opportunity for less costly options in upgrades and software complexity. But there are many aspects to include in such considerations; as shown in the table below, Per Motor Vehicle Safety Standard no. 301, Fuel System Integrity, even anti-siphon mitigation should be considered, as it is required in vehicle manufactured to operate on 20% or greater ethanol fuel [22].

**Table 6-1. Vehicle Upgrade Evaluation for Increased Ethanol Blend Fuel.**

| Vehicle Upgrade Evaluation* for Ethanol Blend Fuels | | | | |
|---|---|---|---|---|
| | **E15** | **E20** | **E25** | **E30** |
| Engine Components | unnecessary | minor | moderate | moderate |
| Fuel Systems | unnecessary | minor | minor | moderate |
| Calibration | unnecessary | minor | moderate | sizable |
| Anti-Siphon | not needed | needed | needed | needed |

*GM, Ford and FCA evaluation

# 7. Summary

This report has reviewed the U.S. DRIVE fuel sets and U.S. fuels infrastructure to assess the potential impacts on retail stations, terminals, and vehicles to specific changes in gasoline formulations. If a new fuel formulation were property- and performance-based (as they are likely to be), rather than composition-specific, it is very likely that different fuel refiners and different retail stations will offer gasolines having somewhat different compositions, including varying ethanol levels.

For retail stations, both underground and above ground refueling equipment must be compatible with the fuels to which they are exposed. Equipment and materials that are not compatible would have to be replaced. This situation is concerning because replacement costs can be significant (especially for underground storage tanks) and would be borne by retail station owners, the majority of which are single-station owners (i.e., small business owners) with relatively small station profits.

Materials compatibility data presented in this report suggests that new formulations containing hydrocarbons and up to 10% ethanol would likely have very similar compatibilities as those of the current E10 gasoline formulations in the market and thus would very likely require minimal equipment replacement and associated costs (but more verification testing might be needed for some formulations). In contrast, formulations containing ethanol contents higher than 10% would require replacement of any equipment rated for only 10% ethanol. All steel tanks and all double-wall fiberglass tanks manufactured since 1990 are compatible with all levels of ethanol. However, single-wall fiberglass tanks that were manufactured and installed as late as 2005 are not rated for >10% ethanol service. The materials in above ground refueling dispensers, hoses, and pumps vary and fall into one of three UL certification classes: up to 10% ethanol; 11%–25% ethanol; and 26%–83% ethanol. One manufacturer has announced intentions to discontinue the sale of dispensing equipment that is rated lower than 25% ethanol compatibility. Also, kits are available to upgrade components from 10% ethanol compatibility to 25%.

In this report, projections were made for the costs to retail station owners and to the retail gasoline industry as a whole for replacing and upgrading equipment to the E25 and E83 levels in order to sell fuel formulations containing more than 10% ethanol. Based on the evaluation of infrastructure readiness and upgrading costs, two obvious breakpoints become apparent when upgrading to higher blends of ethanol: going above E10 and going above E25. To accommodate fuel containing 11%–25% ethanol, it was estimated that incremental costs to the retail fuel industry could range from $1.9 billion dollars (if none of the underground equipment had to be replaced) to $5.7 billion dollars (if 20% of the USTs had to be replaced). To accommodate fuel containing 26%–83% ethanol, the projections were that incremental costs could range from $10.4 billion dollars (if none of the underground equipment had to be replaced) to $14.4 billion dollars (if 20% of the USTs had to be replaced).

Note that these total retail industry costs at time of retail station sales of the new fuels could be lower if more stations elected to sell new fuel formulations containing no more than 10% ethanol or if they elected to install equipment having higher ethanol compatibilities when they are replacing failed equipment prior to the market introduction of any new fuels containing higher ethanol contents. Alternatively, the actual costs could be higher if more than 20% of the USTs need to be replaced, due either to incompatible equipment or to lack of documentation of the equipment compatibility. Because EPA requires that station owners must have documentation to prove their equipment is compatible with higher ethanol levels, it is a possibility that greater quantities of equipment would need to be replaced to enable widespread use of fuel formulations containing higher ethanol levels, because many station owners lack such documentation for their existing equipment. The costs for upgrading each station is unique based on many factors, such as the station configuration (number of underground tanks, islands, fuel types), age of underground equipment (specifically tanks and lines), location, and franchise standards. These costs necessary to upgrade equipment to offer an increased level of ethanol blend fuel range from minor to significant. It is difficult to determine the number of stations that would require significant equipment replacement costs, which are reflected below in Table 7-1, at over $300,000/station.

**Table 7-1. Incremental Station Cost above E10 Equipment Replacement Costs for Increased Ethanol Blend Fuel.**

| | Nationwide Station Costs | | | | | |
|---|---|---|---|---|---|---|
| | With Proper confirmation of Equipment Capability | | | Without Proper Equipment Capability 20% stations change out tanks and lines | | |
| | E0-E10 | E11-E25 | E26-E85 | E0-E10 | E11-E25 | E26-E85 |
| $ Increase above E10 | NA | $1,895,000,000 | $5,718,000,000 | NA | $10,621,000,000 | $14,444,000,000 |
| % | | 30% | 91% | | 169% | 230% |
| Increase average across all U.S. stations | | $13,000 | $38,000 | | $71,000 | $96,000 |
| Increase for stations replacing tanks and lines | | | | | $310,000 | $365,000 |

Each fuel terminal would also require individual analysis to accommodate blending of such a fuel. Per terminal costs were estimated to range from $1.7 billion dollars to $10.2 billion dollars for fuel formulations containing 30% ethanol. Per vehicle costs were estimated to be minor to moderate for fuels containing up to 25% ethanol and moderate to sizable for fuel formulations containing 30% ethanol.

Coordination of this conversion would require extensive cooperation among various stakeholders throughout the country and across many industries. The process of allowing stations to upgrade station equipment to ethanol levels above E10 on a voluntarily basis has merit and some mid-size brands are taking this approach. It would be difficult to enforce mass adoption of retail equipment upgrade without regulation or financial assistance/incentives. Although the barriers to implement a new fuel to market are substantial to some, they are not insurmountable when looked at in aggregate.

# 8. References


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# Appendix A: Wisconsin Department of Agriculture, Trade and Consumer Protection: STORAGE TANK ALTERNATIVE FUEL INSTALLATION/CONVERSION APPLICATION

TR-WM-132 (6/17) Formerly ERS-9 Alt Fuels (3/13)

Wisconsin Department of Agriculture, Trade and Consumer Protection
*Bureau of Weights and Measures*
P.O. Box 7837, Madison, WI 53707-7837
(608) 224-4942

*Wis. Admin. Code §ATCP 93.680*

| FOR OFFICE USE ONLY |
|---|
| Transaction #: |
| ☐ Copy to Owner |
| ☐ Copy to Inspector |
| ☐ Copy to Permit |

## STORAGE TANK ALTERNATIVE FUEL INSTALLATION/CONVERSION APPLICATION

*Personal information you provide may be used for purposes other than that for which it was originally collected (s. 15.04(1)(m) Wis. Stats.).*

**New Tank System Installation Instructions:** Use one form for each tank system. A certified installer or professional engineer shall complete part I of this form and submit it to the department at the address above as part of the plan review submittal.

**Existing Tank System Instructions:** Use one form for each tank system. A certified installer or professional engineer shall complete part I of this form and submit it to the department at the address above prior to the conversion. If approved, before commencing normal fueling operations, the operator shall complete part II of the form and provide the completed form to the certified tank system inspector performing the pre-operational inspection. Interior lined tanks typically cannot be approved for alternative fuel use. **Note:** Alternative cleaning methods shall be approved in advance by submitting form TR-WM-157 for approval.

- Part II: Storage tank conversion for ethanol blends 11 to 15%.
- Part II: Storage tank conversion for ethanol blends greater than 15%.
- Part II: Storage Tank conversion for biodiesel blends greater than 5%.

**Part I**

**OWNER INFORMATION**

| | | | | |
|---|---|---|---|---|
| CUSTOMER NAME: | CUSTOMER ID#: | | | |
| COMPANY NAME: | TELEPHONE: ( ) - | EMAIL: | | |
| SITE STREET ADDRESS (not PO Box) | ☐ CITY ☐ VILLAGE ☐ TOWN | | STATE | ZIP |

**PROJECT INFORMATION**

| | | | | |
|---|---|---|---|---|
| FACILITY NAME: | FACILITY ID#: | SITE ID#: | | |
| SITE STREET ADDRESS (not PO Box) | ☐ CITY ☐ VILLAGE ☐ TOWN | | STATE | ZIP |
| FIRE DEPT. PROVIDING FIRE COVERAGE: | | | FDID#: | |
| ☐ APPROVED ALTERNATIVE CLEANING METHOD TRANSACTION ID: | | | FINISHED PRODUCT | |

**CONTRACTOR INFORMATION**

| | | | | |
|---|---|---|---|---|
| CONTRACTOR NAME: | CUSTOMER ID#: | CONTACT PERSON: | | |
| SITE STREET ADDRESS (not PO Box) | ☐ CITY ☐ VILLAGE ☐ TOWN | | STATE | ZIP |
| TELEPHONE: ( ) - | CELL: ( ) - | EMAIL: | | |

**TANK INFORMATION**

Tank Orientation: ☐ Underground ☐ Aboveground ☐ New Tank ☐ Existing Tank → Date Installed: ________ Tank ID #: ________

Tank leak detection method: ☐ Automatic tank gauging ☐ Inventory control and tightness testing ☐ Interstitial monitoring
☐ Statistical Inventory Reconciliation (SIR) ☐ Visual (Aboveground storage tank only)

| Component: | Existing Manufacturer | Existing Model/Brand | New Equip. Manufacturer | New Equip. Model/Brand | UL Listed or Verified by Manufacturer for Fuel to be Stored | | |
|---|---|---|---|---|---|---|---|
| Note: Write "HC" and the treatment material if a hard-coat treatment is used to achieve compatibility. | | | | | | | |
| Tank construction material | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Spill bucket | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Overfill / Auto shut-off / Ball float | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Drop tube | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| STP/Suction pump | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Leak detection probes | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Sump monitoring sensors | | | | | ☐ Material Approval | | |

| PIPE INFORMATION | ☐ New ☐ Existing | ☐ Mixed (New/Existing) | Existing Pipe Install Date | | | | |
|---|---|---|---|---|---|---|---|
| Configuration | ☐ Single wall ☐ Double wall | Type: ☐ Steel ☐ Fiberglass ☐ Flexible ☐ Other: | | | | | |
| Sumps | ☐ Submersible ☐ Pipe connections | | | | | | |
| Pipe fitting/valve material | | | | | ☐ Listed (N/E) | ☐ Verified (N/E) | ☐ Link (N/E) |
| Gaskets/seals | | | | | ☐ Listed (N/E) | ☐ Verified (N/E) | ☐ Link (N/E) |
| Pipe sealant/adhesive | | | | | ☐ Listed (N/E) | ☐ Verified (N/E) | ☐ Link (N/E) |
| Flex connector | | | | | ☐ Listed (N/E) | ☐ Verified (N/E) | ☐ Link (N/E) |
| Line leak detector | | | | | ☐ Listed (N/E) | ☐ Verified (N/E) | ☐ Link (N/E) |
| Flow restrictor | | | | | ☐ Listed (N/E) | ☐ Verified (N/E) | ☐ Link (N/E) |

| DISPENSER INFORMATION | | | | | | | |
|---|---|---|---|---|---|---|---|
| Dispenser Listed: ☐ Yes ☐ No | Dedicated E85 Hose: ☐ Yes ☐ No | | | | | | |
| Blending dispenser: ☐ Yes ☐ No | Containment sump under dispenser: ☐ Yes ☐ No | | | | | | |
| Dispenser piping | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Dispenser Sump | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Dispenser sump sensor | | | | | ☐ Material approval | | |
| Gaskets/seals | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Blending valve | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Check valve | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Meter | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Emergency valve | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Fuel filters | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Break-away device | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Nozzle(s)/Swivel(s) | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |
| Hose(s) | | | | | ☐ Listed | ☐ Verified | ☐ Unknown |

**COMMENTS:**

| FEES: (Fee table on next page) | Plan Review | Inspection | Total |
|---|---|---|---|
| Alternative Fuel Conversion Fee | $ (7636) | $ (8253) | $ |

I certify by signature that I have personally examined and/or am familiar with the information submitted to verify system alternative fuel compatibility, and the information is true, accurate, and complete.

CONTRACTOR SIGNATURE

DATE SIGNED

**Failure to submit this form with all items completed will result in the tank and dispenser being subject to red-tagging and shutdown. A tank with any "unknowns" will not be approved.**

TR-WM-132 (6/17) Formerly ERS-9 Alt Fuels (3/13)

# STORAGE TANK CONVERSION FOR ETHANOL BLENDS 11 TO 15%

## Part II

**Responsibilities of Tank Owner/Operator before ethanol blends from 11% to 15% are transferred to an existing storage tank.**

- ☐ Determine equipment compatibility - Part I of this form.
- ☐ Inform the facility's UST insurance carrier of plans to convert to a gasoline-ethanol blend exceeding 10% ethanol. The UST insurance carrier may have additional requirements other than what Dept of Agriculture, Trade and Consumer Protection (DATCP) or ATCP 93 requires.
- ☐ Submit to DATCP a certificate of insurance indicating UST coverage for the new ethanol blend stored.
- ☐ Check for water in the tank. No level of water is acceptable for gasoline-ethanol blended fuels.
- ☐ All visible fittings and connections at the top of the tank are tight (no vapors escape and no water enters).
- ☐ Sump and spill containment covers secured to prevent water from entering.
- ☐ Water infiltration problems fixed if necessary.
- ☐ Fill labeling - Identify fill port and paint access cover according to API RP 1637.
- ☐ Dispenser labeling – label dispenser in compliance with ATCP 94.300. A fact sheet on labeling requirements can be found at: Alternative Fuel Labeling

**First Delivery**

- ☐ **Conversion of tanks containing fuel with an octane rating less than the converted fuel must be emptied of all product before conversion.**
- ☐ Tank filled to 80% capacity (recommended by the Renewable Fuels Association or RFA) and kept as full as possible for 7 to 10 days.
- ☐ Conduct a precision test of the tank system (0.1 gph leak rate) within seven days after tank is filled to make sure system is tight and leak detection equipment is operating properly. Report shall be available for inspector review during pre-operational inspection.
- ☐ Test for water using ATG or gauge stick (use alcohol compatible paste if you stick your tanks) at the beginning of each shift for the first 48 hours after delivery (RFA). If there is water in the tank, remove it, find out how it got there and fix it so it doesn't occur again.
- ☐ Calculate residue volume in product piping based on size, type and length. Purge the calculated residue volume as a minimum quantity of fuel to be flushed from piping.
- ☐ Change fuel filters.

**Pre-Operational**

- ☐ Notify DATCP Field Operations Inspector 5 days prior to the conversion to schedule a pre-operational inspection as required by ATCP 93.680(4)(c). An inspector territory map with contact information can be found at: Inspector Territory Map (as PDF document)
- ☐ Have dispenser calibrated with the new product prior to the pre-operational inspection. Report shall be available for inspector review during pre-operational inspection.
- ☐ Draw sample and inspect that the finished fuel is visually free of undissolved water, sediment, and suspended matter; it shall be clear and bright at the ambient temperature or 21 °C (70 °F), whichever is higher.
- ☐ Submit Tank Registration Form TR-WM-137 or TR-WM-118 along with a completed copy of TR-WM-132 Application Form and a copy of the pre-operational inspection report from DATCP Inspector to DATCP, W&M, P.O. Box 7837, Madison, WI 53707-7837 or via email: datcpweightsandmeasures@wi.gov.

TANK OWNER SIGNATURE | COMPANY

*(Note: By signing, signer is acknowledging that all the above preparatory items have been conducted.)*

PRINT TANK OWNER NAME | TITLE | DATE SIGNED

**Failure to submit this form with all items completed will result in the tank and dispenser being subject to red-tagging and shutdown. A tank with any "unknowns" will not be approved.**

| Fee Submittal | Plan Review Fee | Installation Inspection Fee | Plan Revision Fee | Re-inspection Fee |
|---|---|---|---|---|
| When submitted independent of a broader plan submittal application | $35 | $100 | $100 | $100 |

# STORAGE TANK CONVERSION FOR ETHANOL BLENDS GREATER THAN 15%

## Part II

**Responsibilities of Tank Owner/Operator before ethanol blends greater than 15% are transferred to an existing storage tank.**

- ☐ Determine equipment compatibility - Part I of this form.
- ☐ Inform the facility's UST insurance carrier of plans to convert to a gasoline-ethanol blend exceeding 10% ethanol. The UST insurance carrier may have additional requirements other than what Dept of Agriculture, Trade and Consumer Protection (DATCP) or ATCP 93 requires.
- ☐ Submit to DATCP a certificate of insurance indicating UST coverage for the new ethanol blend stored.
- ☐ Check for water in the tank. No level of water is acceptable for gasoline-ethanol blended fuels.
- ☐ All visible fittings and connections at the top of the tank are tight (no vapors escape and no water enters).
- ☐ Sump and spill containment covers secured to prevent water from entering.
- ☐ Water infiltration problems fixed if necessary.
- ☐ The tank has been cleaned of all water and sediment in accordance with API standard 2015-01 or department approved method.

| COMPANY NAME PROVIDING SERVICE: | | TELEPHONE: ( ) - | |
|---|---|---|---|
| ADDRESS: | CITY: | STATE | ZIP |

- ☐ How/where is waste and rinsate being disposed of: ______
- ☐ Fill labeling - Identify fill port and paint access cover according to API RP 1637.
- ☐ Dispenser labeling – label dispenser in compliance with ATCP 94.300. A fact sheet on labeling requirements can be found at: Alternative Fuel Labeling

**First Delivery**

- ☐ Tank filled to 80% capacity (recommended by the Renewable Fuels Association or RFA) and kept as full as possible for 7 to 10 days.
- ☐ Conduct a precision test of the tank system (0.1 gph leak rate) within seven days after tank is filled to make sure system is tight and leak detection equipment is operating properly. Report shall be available for inspector review during pre-operational inspection.
- ☐ Test for water using ATG or gauge stick (use alcohol compatible paste if you stick your tanks) at the beginning of each shift for the first 48 hours after delivery (RFA). If there is water in the tank, remove it, find out how it got there and fix it so it doesn't occur again.
- ☐ Calculate residue volume in product piping based on size, type and length. Purge the calculated residue volume as a minimum quantity of fuel to be flushed from piping.
- ☐ Change fuel filters.

**Pre-Operational**

- ☐ Notify DATCP Field Operations Inspector 5 days prior to conversion to schedule a pre-operational inspection as required by ATCP 93.680(4)(c). An inspector territory map with contact information can be found at: Inspector Territory Map (as PDF document)
- ☐ Have dispenser calibrated with the new product prior to the pre-operational inspection. Report shall be available for inspector review during pre-operational inspection.
- ☐ Draw sample and inspect that the finished fuel is visually free of undissolved water, sediment, and suspended matter; it shall be clear and bright at the ambient temperature or 21 °C (70 °F), whichever is higher.
- ☐ Submit Tank Registration Form TR-WM-137 or TR-WM-118 along with a completed copy of TR-WM-132 Application Form and a copy of the pre-operational inspection report from DATCP Inspector to DATCP, W&M, P.O. Box 7837, Madison, WI 53707-7837 or via email: datcpweightsandmeasures@wi.gov

______ ______
TANK OWNER SIGNATURE COMPANY

*(Note: By signing, signer is acknowledging that all the above preparatory items have been conducted.)*

______ ______ ______
PRINT TANK OWNER NAME TITLE DATE SIGNED

**Failure to submit this form with all items completed will result in the tank and dispenser being subject to red-tagging and shutdown. A tank with any "unknowns" will not be approved.**

| Fee Submittal | Plan Review Fee | Installation Inspection Fee | Plan Revision Fee | Re-inspection Fee |
|---|---|---|---|---|
| When submitted independent of a broader plan submittal application | $35 | $100 | $100 | $100 |

TR-WM-132 (6/17) Formerly ERS-9 Alt Fuels (3/13)

# STORAGE TANK CONVERSION FOR BIODIESEL BLENDS GREATER THAN 5%

## Part II

**Responsibilities of Tank Owner/Operator before transferring biodiesel blends greater than 5% to an existing storage tank.**

- ☐ Determine equipment compatibility - Part 1 of this form.
- ☐ Inform the facility's UST insurance carrier of plans to convert to a biodiesel exceeding 5%. The UST insurance carrier may have additional requirements other than what Dept of Agriculture, Trade and Consumer Protection (DATCP) or ATCP 93 requires.
- ☐ Submit to DATCP a certificate of insurance indicating UST coverage for the biodiesel blend stored.
- ☐ Check for water in the tank. No level of water is acceptable for biodiesel blends.
- ☐ All visible fittings and connections at the top of the tank are tight (no vapors escape and no water enters).
- ☐ Sump and spill containment covers secured to prevent water from entering.
- ☐ Water infiltration problems fixed if necessary.
- ☐ Fill labeling - Identify fill port and paint access cover according to API RP 1637.
- ☐ Dispenser labeling – label dispenser in compliance with ATCP 94.300. A fact sheet on labeling requirements can be found at: Alternative Fuel Labeling

**First Delivery**

- ☐ If tank previously contained a Class I product, then the tank shall be emptied
- ☐ Tank filled to 80% capacity and kept as full as possible for 7 to 10 days.
- ☐ Conduct a precision test of the tank system (0.1 gph leak rate) within seven days after tank is filled to make sure system is tight and leak detection equipment is operating properly. Report shall be available for inspector review during pre-operational inspection.
- ☐ Test for water at the beginning of each shift for the first 48 hours after delivery. If there is water in the tank, remove it, find out how it got there and fix it so it doesn't occur again.
- ☐ Calculate residue volume in product piping based on size, type and length. Purge the calculated residue volume as a minimum quantity of fuel to be flushed from piping.
- ☐ Change fuel filters.

**Pre-Operational**

- ☐ Notify DATCP Field Operations Inspector 5 days prior to schedule a pre-operational inspection as required by ATCP 93.680(4)(c). An inspector territory map with contact information can be found at: Inspector Territory Map (as PDF document)
- ☐ Have dispenser calibrated with the new product prior to the pre-operational inspection. Report shall be available for inspector review during pre-operational inspection.
- ☐ Draw sample and inspect that the finished bio-diesel fuel shall be visually free of undissolved water, sediment, and suspended matter.
- ☐ Submit Tank Registration Form TR-WM-137 or TR-WM-118 along with a completed copy of TR-WM-132 Application Form and a copy of the pre-operational inspection report from DATCP Inspector to DATCP, W&M, P.O. Box 7837, Madison, WI 53707-7837 or via email: datcpweightsandmeasures@wi.gov.

TANK OWNER SIGNATURE ____________ COMPANY ____________

*(Note: By signing, signer is acknowledging that all the above preparatory items have been conducted.)*

PRINT TANK OWNER NAME ____________ TITLE ____________ DATE SIGNED ____________

**Failure to submit this form with all items completed will result in the tank and dispenser being subject to red-tagging and shutdown. A tank with any "unknowns" will not be approved.**

| Fee Submittal | Plan Review Fee | Installation Inspection Fee | Plan Revision Fee | Re-inspection Fee |
|---|---|---|---|---|
| When submitted independent of a broader plan submittal application | $35 | $100 | $100 | $100 |

# Appendix B: Cost Detailing for Directional Estimates for Station Equipment Conversions

These cost calculations and estimates are not meant to represent any particular station conversion for equipment conversions to higher levels of gasoline ethanol blends. The calculations are an exercise used to determine if particualar break points of volume percent ethanol in gasoline exist for making station conversions. If a station were to undergo such a conversion, the actual costs incurred would not be expected to match any of these estimates as each station has unique configurations, equipment, and challenges.

**Table B-1. Estimated Costs for Converting Stations**

<table>
<tr><th colspan="2"></th><th colspan="2">Higher Quote</th><th colspan="2">Lower Quote</th></tr>
<tr><th></th><th>E0- E10</th><th>E11-E25</th><th>E26-E85</th><th>E11-E25</th><th>E26-E85</th></tr>
<tr><td>New Dispenser Pump</td><td>$15,000</td><td>$16,950</td><td>$21,500</td><td>$16,950</td><td>$21,500</td></tr>
<tr><td>New upgrade incremental (included above)</td><td>$0</td><td>$1,950</td><td>$6,500</td><td>$1,950</td><td>$6,500</td></tr>
<tr><td>Retrofit Dispenser (Gilbarco only) (per refueling pump)</td><td>NA</td><td>$2,100</td><td>NA</td><td>$2,100</td><td>NA</td></tr>
<tr><td>Everything at once—lines, 2 tanks, or 1 sectioned tank, concrete. Underground piping, tanks and concrete (4 dispensers; 2 products) not including dispenser pumps</td><td>$300,000</td><td colspan="2">$300,000</td><td colspan="2">$200,000–$500,000</td></tr>
<tr><td>Underground pumps, leak detector, probe, float (per tank) (piping and tanks ok)</td><td>$6,046</td><td colspan="2">$7,113</td><td colspan="2">$7,113</td></tr>
<tr><td>Shear Valves, Hoses, other (8) (per fueling point)</td><td>$661</td><td>$778</td><td>$778</td><td colspan="2">$778</td></tr>
<tr><td>Cleaning (change of fuel type—per tank); changing 14</td><td>NA</td><td colspan="2">$0</td><td colspan="2">$0</td></tr>
<tr><td>Permit—lines or tanks, break concrete</td><td>NA</td><td colspan="2">$5,000</td><td>$5,000</td><td>$0</td></tr>
<tr><td>Drawing—lines or tanks only, break concrete</td><td>NA</td><td colspan="2">$1,500</td><td colspan="2">$1,500</td></tr>
</table>

**Table B-2. Nation-Wide Station Incremental Above E10 Costs with Proper Confirmation of Equipment Capability**

| Nation Wide Station Incremental Above E10 Costs | | | | |
|---|---|---|---|---|
| | With Proper confirmation of Equipment Capability | | | |
| | Total Incremental Cost above E10 | | Avg Station Incremental Cost | |
| Phase in timing | E11-E25 | E26-E85 | E11-E26 | E26-E85 |
| **2025 cost for 50% stations readiness:<br>24% natural with E25 turn over plus 26% convert with retrofit Gilbarco** | $1,286,000,000 | $3,448,000,000 | $17,000 | $46,000 |
| **2025-2040 cost for 100% stations readiness-<br>upgrade costs pumps and equipment<br>(20% Underground tanks and line in sensitivity analysis)** | $609,000,000 | $2,270,000,000 | $8,000 | $30,000 |
| **Cost for 100% stations readiness-<br>(20% Underground tanks & lines in sensitivity analysis)** | **$1,895,000,000** | **$5,718,000,000** | $13,000 | $38,000 |

**Table B-3. Nation-Wide Station Incremental Above E10 Costs without Proper Confirmation of Equipment Capability**

| Nation Wide Station Incremental Above E10 Costs | | | | | |
|---|---|---|---|---|---|
| | Without Proper confirmation of Equipment Capability<br>Assume a 20% underground replacement (2040) | | | | |
| | Total Incremental Cost above E10 | | | Avg Station Incremental Cost | |
| **Phase in timing** | **E11-E25** | **E26-E85** | | **E11-E26** | **E26-E85** |
| **2025 cost for 50% stations readiness: 24% natural with E25 turnover plus 26% convert with retrofit Gilbarco** | $1,286,000,000 | $3,448,000,000 | 40% total—5,000 (E85 today) new dispensers (incremental from E10) 10% new dispensers before 15 year-life (total cost included) 50% total new hanging hardware, drop tubes… | $17,000 | $46,000 |
| **2025–2040 cost for 100% stations readiness- upgrade costs pumps and equipment (20% underground tanks and lines in sensitivity analysis)** | $9,335,000,000 | $10,996,000,000 | 50% total new dispensers (incremental from E10) 50% total new hanging hardware, drop tubes… 20% new tanks and lines | $124,000 | $146,000 |
| **Cost for 100% stations readiness—(20% underground tanks and lines in sensitivity analysis)** | Individual station replacing lines/tanks costs | | | $310,000 | $365,000 |
| | **$10,621,000,000** | **$14,444,000,000** | | $71,000 | $96,000 |

## Table B-4. Nation-Wide Station Costs

| Nationwide Station Costs | | | | | | | |
|---|---|---|---|---|---|---|---|
| | With Proper confirmation of Equipment Capability | | | Without Proper Equipment Capability 20% stations change out tanks and lines | | | |
| | E0-E10 | E11-E25 | E26-E85 | E0-E10 | E11-E25 | | E26-E85 |
| **Station Changes (no new tanks)** | $6,269,000,000 | $8,164,000,000 | $11,987,000,000 | $6,269,000,000 | $8,164,000,000 | | $11,987,000,000 |
| **Station Retrofit (no new tanks)** | Not Applicable | $3,286,700,000 | Not Applicable | Not Applicable | $3,286,700,000 | | Not Applicable |
| | | | | | | | |
| **Cost new in ground tanks & lines** | $0 | $0 | $0 | $0 | $8,726,000,000 | | $8,726,000,000 |
| | | | | | | | |
| **Total** | **$6,269,000,000** | **$8,164,000,000** | **$11,987,000,000** | **$6,269,000,000** | **$16,890,000,000** | | **$20,713,000,000** |
| **Total with retrofit dispensers** | **Not Applicable** | **$3,286,700,000** | **Not Applicable** | **Not Applicable** | **$12,012,700,000** | | **Not Applicable** |
| **$ Increase above E10** | **NA** | **$1,895,000,000** | **$5,718,000,000** | **NA** | **$10,621,000,000** | | **$14,444,000,000** |
| **%** | | **30%** | **91%** | | **169%** | | **230%** |
| **Increase average across all U.S. stations** | | **$13,000** | **$38,000** | | **$71,000** | | **$96,000** |
| **Increase for stations replacing tanks and lines** | | | | | **$310,000** | | **$365,000** |

**Table B-5. Assumptions for Calculations**

| Assumptions for calculations | |
|---|---|
| # stations E85 Compatible | 5000 |
| % stations convert underground equipment for sensitivity study* | 20% |
| # fuel points per station | 8.5 |
| # of dispensers/station | 4.25 |
| Stations in United States | 150,438 |
| # dispensers in United States | 639361.5 |
| Life of dispenser | 15 |
| Dispenser/year | 42624.1 |
| Wayne market share | 0.4 |
| Dispenser/year convert by Wayne | 17049.64 |
| # Wayne dispensers by 2025 | 153446.76 |
| % dispensers | 24.0% |
| Total # dispensers replaced 2018–2024 | 255744.6 |
| | |

* 20% value chosen for the sensitivity study to demonstrate the impact of replacing underground storage tanks and associated piping. The chosen value of 20% does not represent an estimate of the number of tanks in the U.S. field that are not compatible to ethanol volume percentages above 10%.