Fuels Institute

New Technology Adoption Curves

A Case Study on Delivering E25-Capable Vehicles to Market

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Foreword from the Fuels Institute

The Fuels Institute commissioned this short study to evaluate the time it would take a new technology to reach 20% market share. The project was inspired by a specific industry effort (the Ag-Auto-Ethanol Work Group and the 25x'25 Alliance) to bring to market vehicles capable of operating on gasoline blended with 25% ethanol (E25) while developing the market availability of such fuels. The effort lent itself as a viable case study to evaluate the dynamics of market penetration.

There are several new vehicle powertrain technologies under consideration for market adoption, and the Fuels Institute believes it is important for industry observers to apply rational expectations when estimating the rate at which such technologies will gain significant market share. This rate of adoption is limited by the number of vehicles sold in a year that are equipped with that technology and the rate at which existing vehicles are retired from the fleet. With the average vehicle remaining in use for approximately 11 years (according to Polk research), it will take a significant number of years for a new technology to represent a sizeable proportion of the fleet on the road.

This case study serves as an example of what will be required to achieve significant market penetration for new technologies. The study evaluates how many vehicles equipped to operate on E25 must be sold each year to achieve a 20% share of vehicles on the road by a certain moment in time, in this case the year 2025. The target year of 2025 was chosen to be consistent with the goals of the 25x'25 Alliance, which seeks to supply 25% of the nation's energy in 2025 from renewable sources. The 20% vehicle market share was a target set by Fuels Institute staff as a credible marker that would signal to the fuel distribution and marketing industry that there is sufficient consumer demand to warrant the widespread availability of the fuel E25. The study takes into consideration the more than 20 million flex fuel vehicles currently registered in the United States.

The 20% market share target was considered a valid target when comparing market dynamics associated with the fuel E85. In 2016, approximately 8% of light duty vehicles on the road were flex fuel, equipped to operate on the alternative fuel E85. These vehicles have led approximately 3,500 retail fueling stations to sell E85. To ensure E25 is available at more than approximately 3% of the retail fueling stations in America, a vehicle market share of significantly more than 8% is expected to be required. Hence, the Fuels Institute staff believes a vehicle market share of 20% would likely result in sufficient market penetration of E25 to satisfy consumer demand.

The model developed in this case study is instructive for all other vehicle technologies seeking to enter the market and should be viewed as an example of what is required to convert the current U.S. light duty vehicle fleet.

The scenarios contained in this report do not reflect any real timeline for market penetration of E25 compatible vehicles, but rather highlight that time is needed for a transition in the vehicle fleet. Actual market penetration would depend on auto and fuels industry coordination to overcome the chicken and egg aspect inherent in a simultaneous shift in vehicle technology and fuels.

The Fuels Institute teamed with the American Coalition for Ethanol, the Fuel Freedom Foundation and the Ag-Auto-Ethanol Coalition to commission Navigant Research to prepare this report.

Scope of Study

This Navigant Research report has been prepared to provide participants at all levels of the transportation fuel market, including vehicle OEMs, suppliers, retailers, trade associations, and governments, with a study to determine the required introduction timing and adoption rate necessary to reach a critical mass of vehicles capable of running on E25. In addition, the report provides a review of major demand drivers and key industry players within the competitive landscape.

The report's purpose is not to present an exhaustive technical assessment of the vehicles and technologies covered. Rather, it aims to provide an examination from an overall tactical business perspective.

Navigant Research strives to identify and examine new market segments to aid readers in the development of business models. All major global regions are included, and the forecast period extends through 2025.

Sources and Methodology

Navigant Research's industry analysts utilize a variety of research sources in preparing Research Reports. The key component of Navigant Research's analysis is primary research gained from phone and in-person interviews with industry leaders including executives, engineers, and marketing professionals. Analysts are diligent in ensuring that they speak with representatives from every part of the value chain, including but not limited to technology companies, utilities and other service providers, industry associations, government agencies, and the investment community.

Additional analysis includes secondary research conducted by Navigant Research's analysts and its staff of research assistants. Where applicable, all secondary research sources are appropriately cited within this report.

These primary and secondary research sources, combined with the analyst's industry expertise, are synthesized into the qualitative and quantitative analysis presented in Navigant Research's reports. Great care is taken in making sure that all analysis is well-supported by facts, but where the facts are unknown and assumptions must be made, analysts document their assumptions and are prepared to explain their methodology, both within the body of a report and in direct conversations with clients.

Navigant Research is a market research group whose goal is to present an objective, unbiased view of market opportunities within its coverage areas. Navigant Research is not beholden to any special interests and is thus able to offer clear, actionable advice to help clients succeed in the industry, unfettered by technology hype, political agendas, or emotional factors that are inherent in cleantech markets.

Notes

CAGR refers to compound average annual growth rate, using the formula:

CAGR = (End Year Value ÷ Start Year Value)(1/steps) – 1.

CAGRs presented in the tables are for the entire timeframe in the title. Where data for fewer years are given, the CAGR is for the range presented. Where relevant, CAGRs for shorter timeframes may be given as well.

Figures are based on the best estimates available at the time of calculation. Annual revenues, shipments, and sales are based on end-of-year figures unless otherwise noted. All values are expressed in year 2016 U.S. dollars unless otherwise noted. Percentages may not add up to 100 due to rounding.

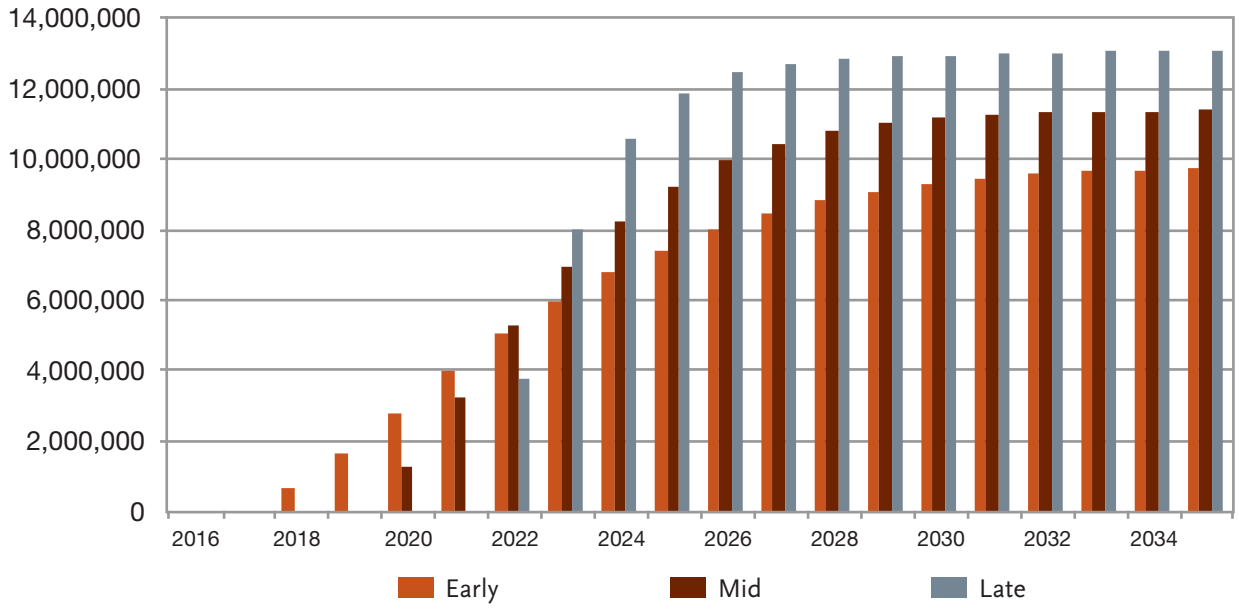
Executive Summary

The automotive industry faces regulatory pressure to reduce both fuel consumption and greenhouse gas emissions through at least the mid-2020s. While there are likely to be substantive changes to the regulations in the coming months as a result of a new presidential administration that took office in January 2017, for now the industry must proceed based on the regulations as they stand.

Meeting these requirements will require deployment of the most cost-effective technologies possible in order to keep vehicles affordable to consumers. One such approach would be the adoption of higher-octane E25 ethanol-gasoline blends. Fuels with a research octane number (RON) of 98-100 would enable engines with improved thermal efficiency, which results in improved fuel efficiency, at a modest incremental cost. However, before manufacturers invest in these technologies, there must be an assurance that the fuel will be readily available to consumers. Before retailers invest in the needed infrastructure to support another fuel type, they need an understanding of the addressable market.

This study provides an overview of the technical issues surrounding adoption of E25 as a transportation fuel. It also provides forecasts of the timing and adoption rates for E25 that would be required to make infrastructure deployment commercially viable for fuel distributors and retailers. The sooner that both E25 and compatible vehicles are introduced, the sooner they will reach the necessarily critical mass for viability.

Figure 1 E25 Light Duty Vehicle Sales by Scenario, United States: 2016-2035



(Source: Navigant Research)

Adoption of Mid-level Ethanol Fuels Blends

Ethanol as a Fuel Additive or Alternative

Ethanol or ethyl alcohol has been widely used as a primary transportation fuel or additive to fossil fuels for decades. As a synthetic liquid fuel produced from biomass feedstocks, ethanol offers a number of advantages over other alternative fuels. While it only has about 66% of the energy density of gasoline, that is more than sufficient to make it readily usable in existing spark ignition internal combustion engines with only minor modifications for higher blend concentrations. Blend concentrations below 15% can be used in unmodified gasoline engines.

Ethanol can be synthesized from most forms of biomass making it both renewable and to varying degrees carbon neutral when burned.

Currently the most common feedstocks for ethanol production are starch or sugar-based crops like corn, beets or cane. Virtually all ethanol production in the United States is sourced from corn; production of ethanol from cellulosic feedstocks continues to be developed but has not yet become commercially viable.

In the U.S. ground transportation fuels market, ethanol is primarily used in two ways. Low concentration blends known as E10, which includes up to 10% ethanol blended with gasoline, are suitable for use in virtually all spark-ignition vehicles. Since ethanol has a research octane number (RON) of 108.6, it is used as an octane booster in combination with lower quality gasoline blends as well as an oxygenating agent to aid combustion and reduce emissions.

E85 fuels, containing concentrations of ethanol up to 83%, are specifically for use in flex-fuel vehicles (FFVs). FFVs are designed to use any blend of gasoline containing 0% - 83% ethanol and can detect the concentration in the fuel tank and appropriately adjust the air-fuel mixture dynamically. FFVs also include modified wetted fuel systems materials to ensure compatibility.

As currently blended, low concentration ethanol blends provide additional octane to offset the use of other lower grade hydrocarbons in the final fuel blend, delivering an overall octane rating or anti-knock index (AKI) of pump fuels which are typically available at levels of 87, 89 or 91. Due to the lower energy density of the ethanol, volumetric fuel efficiency is decreased by 2 to 3% according to tests by the EPA. Flex-fuel vehicles can experience up to a 27% degradation in mileage when running on E85 vs gasoline, based upon a straight BTU comparison when using 83% ethanol concentration. This mileage differential varies depending on the concentration of ethanol in the fuel and the performance of the FFV in which the fuel is used.

Mid-Level Ethanol Blends

Use of mid-level ethanol blends up to 25% can provide many of the benefits of using biofuels at a lower incremental cost for both engines and fueling infrastructure. At 25% or less the corrosion and lubrication impacts of ethanol are relatively negligible. Thus stainless steel lines and valve seat hardening aren't needed. Elastomer seals still need upgrading but this cost is relatively minor. Widespread adoption of E25 could significantly increase the total offset of fossil fuel consumption.

Spurring Industry Support for E25

As of early January 2017, the Environmental Protection Agency and Department of Transportation had concluded the mid-term review of 2025 greenhouse gas emissions and fuel economy standards and reaffirmed the previous targets requiring a fleet average of 54.5 mpg by that time. President Donald Trump and his administration have indicated that it wants to roll back or eliminate many regulations but as this report is written nothing concrete has changed.

In an environment of continuing low crude oil and retail fuel prices, automakers are finding it difficult to sell high-mileage vehicles to consumers and the lowest cost technologies for improving efficiency have already or will soon be widely applied. Getting increasing incremental improvements will require more investment in new technologies such as electrification. However, with sales of plug-in electric vehicles (PEVs) well below early projections, these are proving challenging to market.

With the other investments required to meet 2025 CAFE standards, automakers are unlikely to support adoption of E25 as a fuel unless it can be leveraged to provide cost-effective improvements in both real fuel efficiency and regulatory ratings. While the cost of batteries has been declining and will continue to do so in the coming decade, the internal combustion engine (ICE) remains the most cost effective propulsion system, especially for larger utility vehicles and trucks which currently comprise two-thirds of the U.S. market.

One of the key limiting factors to improving the thermal efficiency of ICEs is the compression ratio. By increasing compression, downsizing engine displacement and adding turbo boosting, automakers can deliver greater efficiency without sacrificing performance. Unfortunately, the octane ratings of pump gasoline in the U.S. makes raising compression much beyond current levels impractical. OEMs would like to use fuels containing a minimum of 98-100 RON with a sensitivity value of at least 12. Some have suggested gasoline blended with 25% ethanol could deliver fuel with these characteristics.

Even at elevated octane levels, E25 would still have lower energy content than gasoline. Therefore OEMs would like to see a certification pathway for E25 that would give them credit for the lost energy content and subsequent increased volumetric fuel consumption.

> If such a high-octane, quality fuel were widely available, manufacturers would be willing to produce engines that are optimized to run on E25 and deliver higher efficiency.

A combination of higher compression and increased turbocharger boost from a smaller displacement would increase load levels and improve thermal efficiency. A lower cost premium fuel, matched with a more efficient engine that does not sacrifice performance or capability, would help to spur consumer adoption and drive demand for the fuel. If long term economics of blending ethanol with gasoline result in E25 being available at the same or lower retail prices as compared to E10, that would further incentivize consumers to purchase E25 optimized vehicles.

Since most legacy vehicles will not be approved to operate on E25, and optimized engines would run significantly worse on lower octane E10, some misfueling protections would be required to support this scenario. This may require upgraded dispensers at stations and possibly a new standard for the fuel fillers on vehicles, similar to how leaded and unleaded fuels were dispensed with different sized nozzles to match the fill pipes of the vehicles.

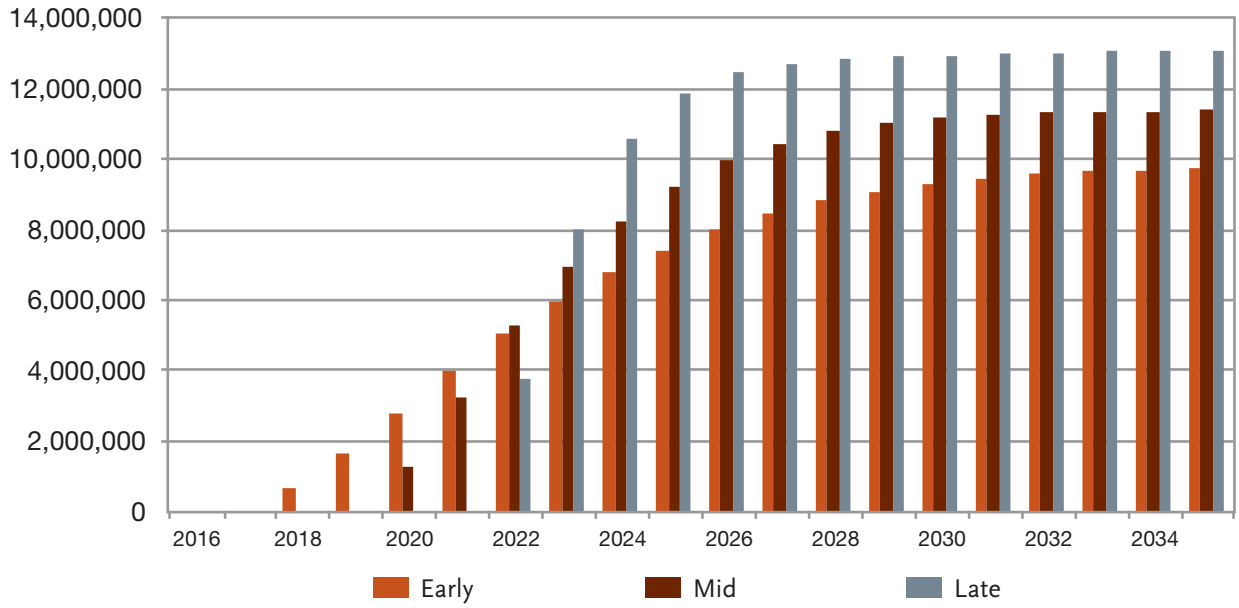
E25 Adoption Forecasts

In order for the auto industry to support development and production of E25 capable vehicles, the fuel needs to be readily available nationwide. For the fuel retail distribution industry to make E25 widely available, there needs to be a critical mass of vehicles demanding the fuel. The goal of this study was to determine how rapidly the market would have to adopt E25-capable vehicles to reach a critical mass where they represent 20% of the U.S. vehicle parc by 2025, which was considered by Fuels Institute staff as representing a sufficient vehicle market share that could inspire widespread availability of E25 at retail. Navigant Research modeled three different scenarios with vehicles becoming initially available in 2018, 2020 and 2022.

The earlier these vehicles go on sale, the slower the ramp rate can be to reach 20% penetration during the forecast period.

Navigant Research projects annual sales of 18.9 million vehicles in the U.S. in 2025 with a cumulative vehicle parc of 288 million vehicles. A combined total of 57.6 million E25 and E85 capable vehicles would represent 20% of the parc. In each scenario, E85-capable vehicle sales decline over time to just 368,000 in 2025 but more than 23 million will remain in use by that time.

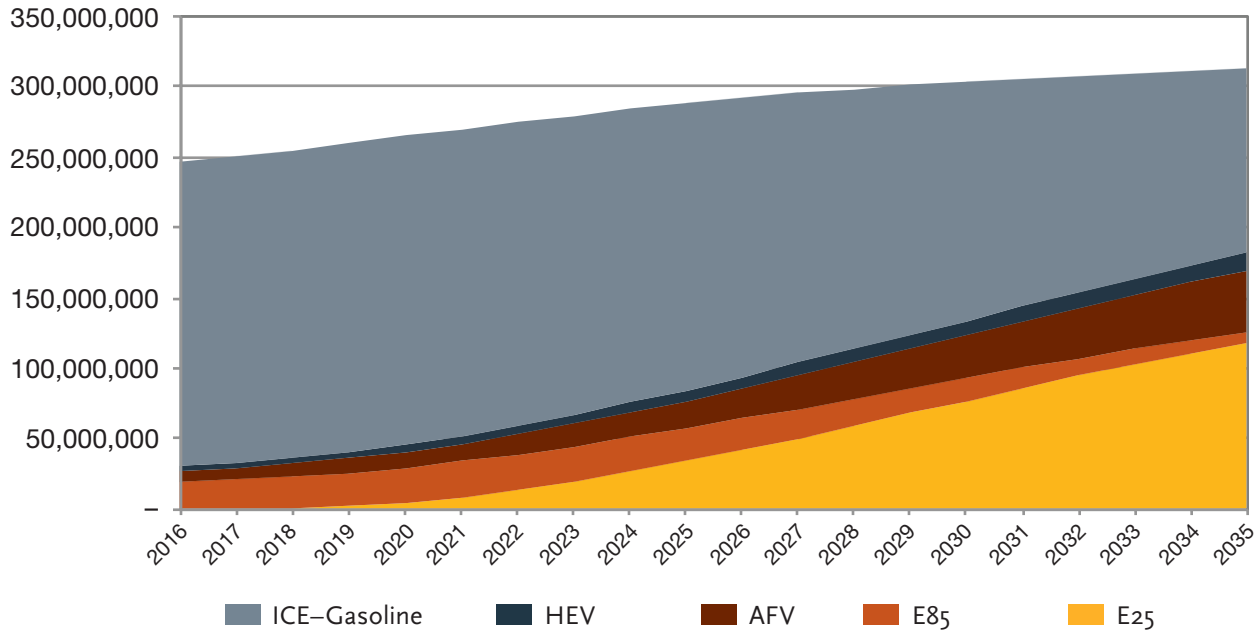
Figure 2 E25 Light Duty Vehicle Sales by Scenario, United States: 2016-2035



(Source: Navigant Research)

If E25-capable vehicles went on sale in 2018, only 629,000 would need to be sold in the first year with a gradual ramp up to 7.4 million in 2025 to hit the 20% threshold along with the E85 vehicles. Given that no manufacturer or fuel distributor has announced plans for E25 as of early 2017, and the lead times required for implementation, this scenario is almost impossible to be executed.

Figure 3 Light Duty Vehicles in Use by Technology, Early Scenario, United States: 2016–2035



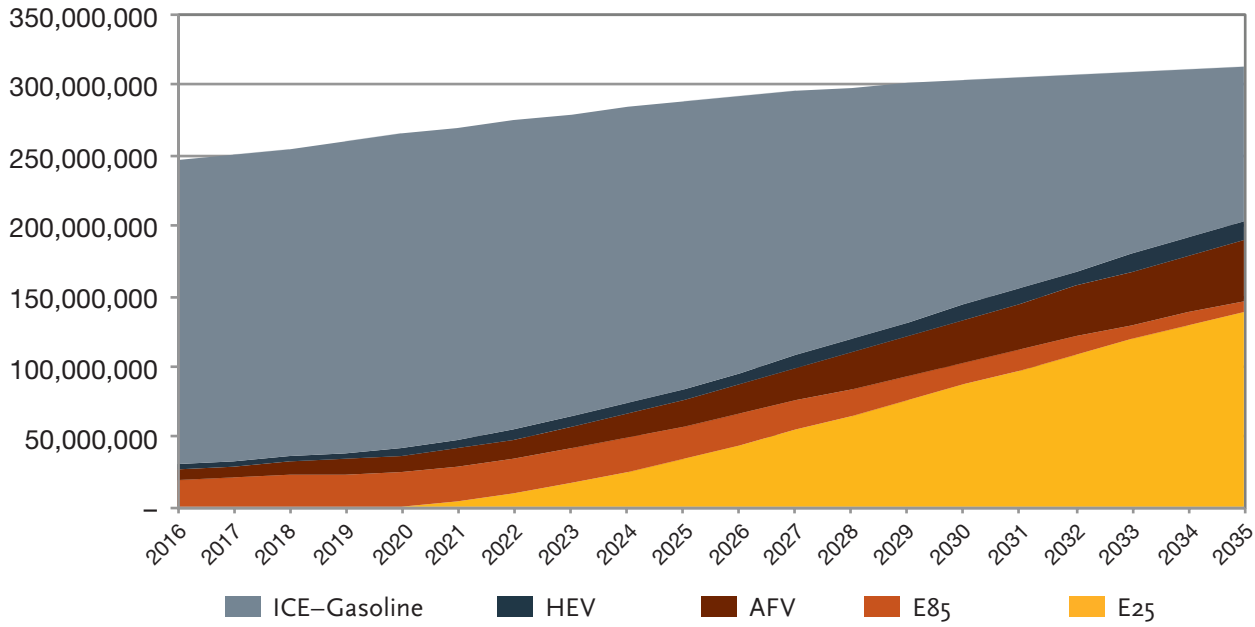
(Source: Navigant Research)

If sales were to launch in 2020, nearly 1.3 million would need to be sold in the first year, rising to 9.2 million by 2025 to hit the same cumulative volume. This is likely the earliest feasible timing for E25 introduction, but it would likely take some significant incentives in order to sell that many vehicles in the first year.

If vehicle sales don't begin until 2022, they would have to rise from 3.8 million to 11.9 million in just four years.

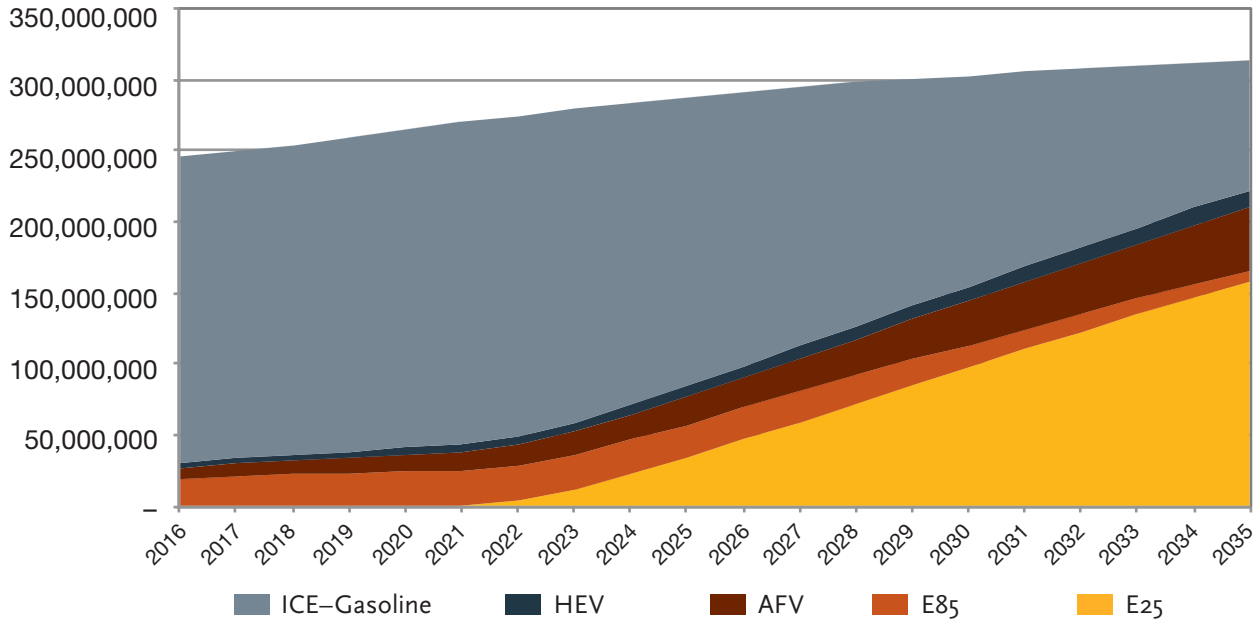
Again, this is an adoption rate that seems very improbable, especially when considering the likely increase in PEV sales in this time as battery prices drop.

Figure 4 Light Duty Vehicles in Use by Technology, Mid Scenario, United States: 2016–2035



(Source: Navigant Research)

Figure 5 Light Duty Vehicles in Use by Technology, Late Scenario, United States: 2016–2035



(Source: Navigant Research)

Conclusions

The longer the industry waits to start selling both E25 and compatible vehicles, the more difficult it will be to achieve 20% of US vehicle parc by 2025. A later start means that OEMs will not have time to ramp up production of engines optimized to operate on high-octane E25. That means existing engines modified with new seals would gain little benefit in terms of fuel efficiency or performance.

This will negate much of the incentive for OEMs to make the effort and investment, and thereby limit consumer adoption. A 2022 launch would mean 63% of 18.9 million sales in 2025 would have to be E25-compatible, a highly improbable scenario.

If E25 is to make any meaningful impact on the marketplace, it is critical to launch both fuel availability and vehicles at the earliest possible date.

Only when there is a certainty that high-octane fuel will be readily available will OEMs commit to optimizing engines to take advantage of it.

Manufacturers and retailers will also have to agree quickly on a strategy to protect against misfueling of E25-optimized engines. Whatever approach is followed will likely require a lead time of 4 - 5 years, consistent with automaker product development schedules. Regulators will also have to agree on a certification strategy and with the current uncertainty in Washington that may prove difficult.

Acronym and Abbreviation List

E25	25% ethanol blended fuel
E85	85% ethanol blended fuel
ICE	Internal combustion engine
PEV	Plug-in vehicle

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About Navigant Research

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About the Fuels Institute

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

The Fuels Institute commissions and publishes comprehensive, fact-based research projects that address the interests of the affected stakeholders. Such publications will help to inform both business owners considering long-term investment decisions and policymakers considering legislation and regulations affecting the market. Our research is independent and unbiased, designed to answer questions, not advocate a specific outcome. Participants in the Fuels Institute are dedicated to promoting facts and providing decision makers with the most credible information possible, so that the market can deliver the best in vehicle and fueling options to the consumer. For more about the Fuels Institute, visit **www.fuelsinstitute.org**.

NACS®

About NACS

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

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