

Coordinated Strategies for Ethanol and Flex Fuel Vehicle Deployment: A Quantitative Assessment of the Feasibility of Biofuel Targets

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ABSTRACT

The goal of this paper is to quantitatively assess the implications of congressionally mandated biofuel targets on requirements for ethanol blending, distribution, and usage in spark ignition engines in the U.S. light-duty vehicle fleet. The “blend wall” is a term that refers to the maximum amount of ethanol that can be blended into the gasoline pool without exceeding the legal volumetric blend limit of 10%. Beyond the blend wall, the additional ethanol fuel must be used in higher blends of ethanol like E85. Once the blend wall is reached, the existing fleet of flex fuel vehicles (FFVs) will be required to use E85 for some percentage of vehicle miles traveled (VMT) in order to achieve the Renewable Fuel Standard (RFS) targets. The feasibility of this requirement will depend on several major variables including (i) the total amount of ethanol to be used; (ii) the volumetric blend limit of ethanol in gasoline; (iii) the annual sales and fleet accumulation of FFVs; (iv) the availability of retail stations offering E85; (v) a measure of the attractiveness of E85 relative to gasoline relative to the price; and (iv) whether engine technology can be deployed to take advantage of the antiknock advantages of ethanol.

A fleet model has been developed by several researchers in the Sloan Automotive Laboratory at MIT that can simulate the interaction of these variables in the US light-duty vehicle (LDV) fleet. Different scenarios can be adjusted individually or as a set of coordinated policies to observe the effect on the total energy equivalent fuel demand. Results from the model show that in order to meet current biofuel targets the retail availability of E85 will need to increase drastically, and at a

faster rate than the current trends indicate. The certification of E15 can delay the blend wall by a few years, but results still show likely shortfalls in reaching current biofuel targets even with aggressive deployment of FFVs.

INTRODUCTION

The blend wall is a general characterization of the situation in the US whereby the amount of biofuel that is required to be blended in the gasoline fuel supply exceeds legal usable limits in vehicles and dispensing infrastructure. The Renewable Fuel Standard (RFS) is currently set to reach 35 billion gallons of ethanol by 2022 [1]. The legal limit for ethanol blended in gasoline is 10% by volume (v/v%) for use in non FFVs. Fleet modeling tools can be used to predict the occurrence of the blend wall and to suggest long term strategies to avoid the conflict between existing fuel policies. In order to confront the blend wall there will need to be (i) an increase in flex fuel vehicles capable of using E85, (ii) the deployment of E85 fueling stations and likely (iii) a reduction in biofuel targets. If the RFS targets are maintained and appropriate policies are put in place to deploy FFVs, then there must still be reasons for drivers to choose ethanol blends over gasoline. This paper will explore several strategies to meet changing biofuel targets out to the year 2035.

In the United States there are an estimated 7 million FFVs on the road today, with approximately 1 million FFVs sold in 2007. However, E85 only accounts for 1-2% of ethanol sales in the US [2]. Based on these estimates of E85 used by FFVs, and the total number of FFVs, roughly 2% of FFV fuel demand is met using E85. This is not surprising, considering



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that ethanol still sells at a higher price per unit energy in many locations, even after state and federal subsidies [3].

For drivers of ethanol capable vehicles, the choice of E85 will depend on two major factors: availability and attractiveness. The price and desirable qualities of the fuel contribute to the fuel “attractiveness”, while the number of fueling stations offering E85 can represent the “availability”. Utilization rates of any alternative fuel must be achieved through a combination of availability and attractiveness. The simplest way of measuring availability is as a percentage of existing fueling stations that offer E85, though there are many other considerations including geographic distribution and population density.

The national total number of retail fuel stations has been declining, but is currently around 160,000. The number of E85 pumps is rising, but is still less than 2,000 as of December 3, 2009 [4]. This means that the national average E85 station penetration is only a little over 1%. The geographic distribution of E85 stations also varies drastically between states. Even assuming a uniform distribution, station percentage is not a perfect representation of the effective availability. For example, diesel fuel is sold as a functioning alternative with only 40-50% of retail stations offering the fuel [5]. Diesel vehicles cannot use gasoline, yet experience full effective availability. While there are many differences between ethanol and diesel as fuel alternatives, the diesel station percentage value can be used as a benchmark for full availability of alternative fuels. Therefore, it is assumed that retail penetration of E85 would only need to reach about 50% in order to achieve full availability. An FFV could then run exclusively on E85 given appropriate geographic distribution of stations and FFVs in regions of appropriate population density.

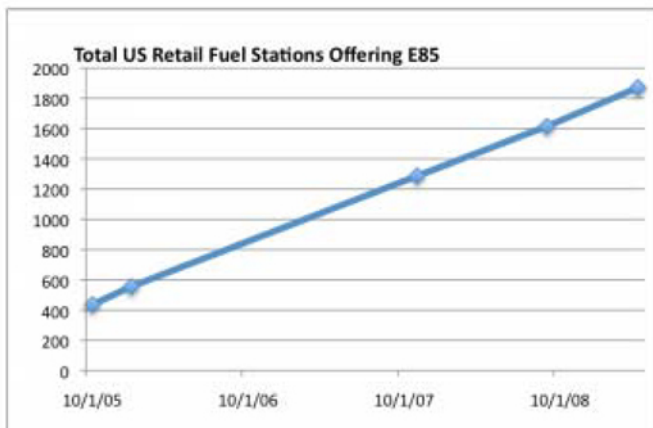


Figure 1. Trend of total retail fueling stations offering E85 [4]

Once E85 reaches a comparable level of availability to diesel, there is still the matter of fuel attractiveness. Theoretically, if

an energy equivalent alternative fuel were available to any FFV driver whenever they wanted to refuel, with equal economic utility to regular gasoline, then the result would only be 50% utilization of the alternative fuel by that FFV [6]. The attractiveness of a fuel may be affected by the relative price or other factors, such as environmental impact, anti-knock performance, or detergent additives as in the case of premium fuel.

The use of ethanol in a traditional flex fuel vehicle today typically results in a decrease in volumetric fuel economy (mpg), roughly equivalent to the loss in energy content of the ethanol fuel. On an energy basis, however, the efficiency is slightly improved in some existing models. Previous studies have shown an increase of up to 5% in gasoline equivalent fuel economy in current FFV models [7].

Ethanol has better antiknock properties than gasoline including higher heat of vaporization which is important in direct injection engines. Higher octane ratings provide the opportunity for higher compression ratios, higher boost pressures and more advanced spark timing. Optimizing engines to run on ethanol blends can provide improvement in energy equivalent fuel economy and/or better acceleration performance. Engine optimization for ethanol blends can in turn have a positive effect on the desirability of ethanol fuel. Several notable technologies, including variable compression ratio (VCR), ethanol boost direct injection (EBDI), and ethanol boosting systems (EBS), are being studied by major automotive companies (FEV, Ricardo, and Ford) [8,9,10].

Ultimately, the challenge of the blend wall is rooted in three core areas; the total biofuel target, the retail availability of biofuel, and the vehicles that can use biofuel. There are many intervening factors including the specific blend level, the specific types of vehicles, and different types of fuels. In the future, biofuel targets, fuel type, availability and attractiveness, apply to other alternative fuels as well. Regardless of whether the fuel is ethanol, butanol, biodiesel or any other alternative fuel, the same modeling approach can be taken.

METHODS

The core model used in this work is a fleet model developed in the Sloan Automotive Laboratory at MIT. Extensive details about the calibration and data sets used to generate this model are available through the recent publication *On the Road in 2035* [11].

The model uses historical sales data for cars and trucks, and recorded trends in vehicle scrappage to balance the fleet. Predictions of future vehicle sales and attributes are made based on sales growth and increasing fuel economy over time. The base model was modified to specifically account for LDVs categorized as FFVs, and non-FFVs. The fleet

model treats diesel vehicles separately and they are not included in this work.

The assumptions regarding the sales mix of vehicles, either cars or trucks, and their respective efficiency are shown in the [Appendix](#). Each model vehicle technology has a corresponding technology development trajectory which leads to improvements in fuel economy. The combination of sales mix and incremental improvements in fuel economy provides the basis for attributes of new vehicles sold. All fuel consumption values use a 22% increase relative to standard drive cycle certification to represent a more realistic on-road fuel consumption value. This corresponds to an 18% decrease in fuel economy as shown in [Figure 2](#). The 2016 CAFE proposal of 34.1 MPG [12] is graphed at the adjusted value of 28 MPG. The mechanics of the model use percentage based increases in fuel economy each year due to market penetration rates of new technology. The output is not determined based on a target fuel economy value and therefore shows a lag in reaching the CAFE targets.

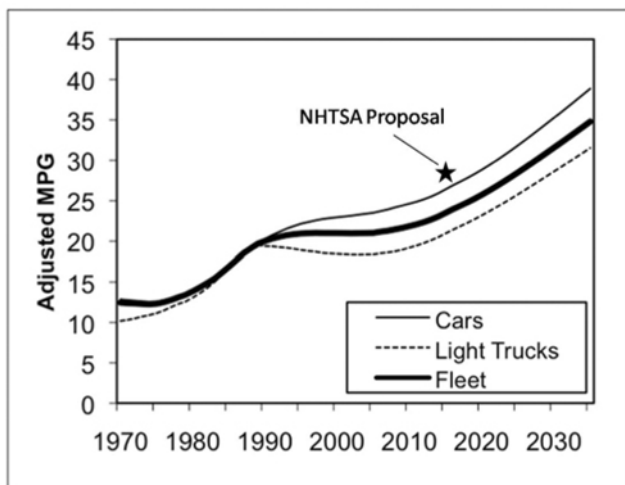


Figure 2. Adjusted fuel economy for new cars and light trucks sold each year in the fleet model used as a baseline input out to 2035. An 18% decrease in fuel economy is used for the adjustment factor to represent a more realistic on-road value. The National Highway Traffic Safety Administration (NHTSA) 2016 CAFE proposal of 34.1 mpg is shown plotted with the same adjustment factor as 28 mpg [12].

The vehicle miles travelled (VMT) are calculated as a function of vehicle age. The combined fuel economy of fleet vehicles, scrappage rate and VMT yields a total gasoline equivalent fuel demand per year shown in [Figure 3](#). This fuel demand can be apportioned to different types of vehicles, those using ethanol, gasoline and diesel. For the purpose of this modeling exercise, diesel biofuels are considered as fully miscible due to the lower immediacy of the biodiesel or

synthetic diesel blend walls. Diesel demand is substantial in the heavy-duty fleet, which is outside the scope of this model.

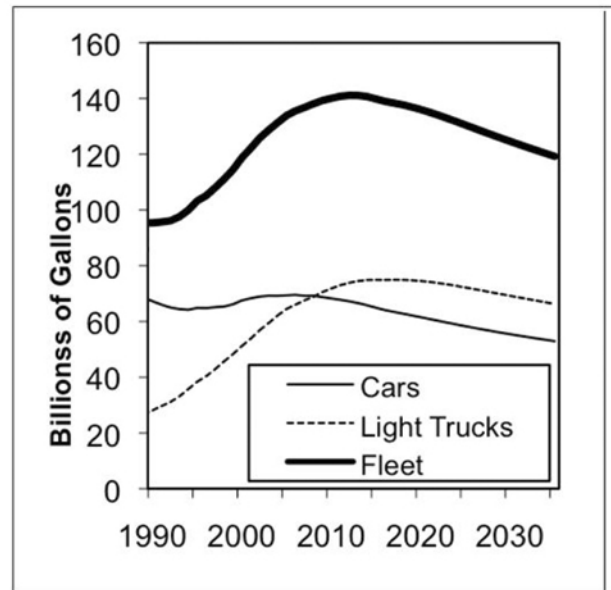


Figure 3. Fleet model values for gasoline equivalent fuel consumption in billions of gallons per year.

The total biofuel used in the United States can be understood as a summation of three major variables. In the case of ethanol the total volume of biofuel is equal to the volumetric blend of fuel multiplied by the number of vehicles that use a given blend and the frequency of utilization of each blend by each vehicle. The total ethanol volume is a sum of contributions from E10, E85 and any other ethanol blend. This relationship can be simplified to the following representative equation:

$$Total_Biofuel(t) \sim \sum Blend_i \% * Fleet_i \% * Utilization_i \% \quad (1)$$

Each of these four major variables can be affected by set of policy measures and technological developments. The following cases will illustrate the separate effect of each variable. Biofuels will be assumed to be ethanol unless otherwise stated.

TOTAL BIOFUEL

The total amount of ethanol blended per year depends on the Renewable Fuel Standard for a given year and the commercial availability of ethanol relative to other biofuels. Two representative scenarios were developed to represent a high and low availability of ethanol over time. The high target is an extrapolation of the current RFS from 2022 to 2035 assuming that 60 billion gallons of ethanol is feasible in 2030 [13]. The lower scenario is modeled after the current RFS 2022 target if it is delayed until 2035. All amounts are