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Cheaper Fuels for the Light-Duty Fleet

Opportunities and Barriers

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RESOURCES FOR THE FUTURE

Cheaper Fuels for the Light-Duty Fleet: Opportunities and Barriers

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Abstract

The shale gas revolution in the United States has dropped the price of natural gas (NG) significantly. Combined with new fuel and vehicle technologies, an opportunity exists to expand the use of NG throughout the economy, including in the light-duty fleet of cars and trucks. This expansion could involve the direct combustion of the gas in the form of compressed natural gas or liquid petroleum gas or, alternatively, the use of natural-gas-based liquid fuels such as ethanol or methanol. This paper examines the potential economic, environmental, and national security gains from replacing a portion of the domestic gasoline use in the light-duty fleet with these various NG-based fuels. Also examined are the regulatory barriers to the expanded use of the fuels. We find that these NG-based fuels could yield significant fuel cost savings relative to conventional gasoline in the light-duty fleet, along with gains to national security and, possibly, some environmental benefits.

Key Words: energy, natural gas, alternative fuels

JEL Classification Numbers: Q42, Q48, Q53, Q55

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Arthur G. Fraas, Winston Harrington, and Richard D. Morgenstern*

1. Introduction

Driven by the recent shale gas revolution, current US natural gas (NG) prices are hovering around $3.50/million British thermal units (Btu), half the decadal average. Meanwhile, oil prices have more than doubled over the past decade and are now about twice as high as NG on a Btu equivalency basis. Looking ahead, the Energy Information Administration (EIA) projects that NG will continue to retain a substantial price advantage, at least out to 2035 (US Department of Energy [DOE] 2012). Combined with significant advances in both fuel and vehicle technologies, the change in the relative prices of these two fuels creates an opportunity to expand the use of NG throughout the economy, including in the light-duty fleet of cars and trucks. This expansion could involve the direct combustion of the gas in the form of compressed NG (CNG) or liquid petroleum gas (LPG). Expansion also could occur via the use of liquid fuels derived from NG, such as ethanol or methanol, mixed with small amounts of gasoline to avoid cold-start problems; examples include E85 (85% ethanol, 15% gasoline) and M85 (85% methanol, 15% gasoline). Note that ethanol derived from NG is chemically identical to biogenic ethanol, although the costs, as estimated here, are substantially lower.

This paper examines the potential economic, environmental, and national security gains from replacing a portion of the domestic gasoline use in the light-duty fleet with NG and NG-derived liquid fuels. Also examined are the regulatory barriers to the expanded use of these fuels.

Although E85, M85, CNG, and LPG are all well known to automotive experts, they are not currently in wide commercial use. Thus, only limited on-the-road experience is available to support an economic analysis. The information presented in this paper is drawn from a variety of sources, including government data and academic and industry reports. At the same time, some of the critical data regarding the costs and emissions characteristics of the alternative fuels, as

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well as the cost of producing new vehicles or converting existing fleets to burn these fuels, are inherently difficult to verify. Thus, more than the usual dose of caution attends the estimates developed herein.

After accounting for differences in refining, energy density, in-use fuel economy, transport, and related costs—but assuming that the NG-based fuels pay the same road taxes as conventional gasoline rather than the lower taxes currently enjoyed by biofuels—we find that these NG-based fuels could yield significant fuel cost savings relative to conventional gasoline in the light-duty fleet. In particular, a new technology, recently patented by Celanese Corporation and expected to begin production in the United States sometime after mid-2015, offers the promise of a low-cost ethanol. For the most favorable case, we estimate that E85 could be produced and sold for \$0.31 to \$0.59/energy-equivalent gallon (gal) below the current price of regular E10 fuel (i.e., gasohol, 10% ethanol and 90% gasoline) in selected urban areas across the United States. These cost savings rise to \$0.52–\$0.83/energy-equivalent gal based on 2015 EIA fuel price projections. Other low-cost processes to convert NG to ethanol, methanol, or other liquid fuels are also quite possible.

Currently, the option of using E85 is limited to the 10 million flexible-fuel vehicles (FFVs) vehicles certified by the US Environmental Protection Agency (EPA). We estimate that with this new NG-based E85, drivers of these vehicles who drive 15,000 miles (mi)/year could save an average of \$157 to \$439/vehicle in annual fuel costs, depending on location and a range of assumptions about vehicle fuel economy. Those savings rise to \$261–\$617 in annual fuel costs based on 2015 EIA fuel price projections. The incremental production costs of these FFVs by the original equipment manufacturers (OEMs) are estimated to be \$100 to \$200/vehicle. Presumably as a result of the additional corporate average fuel economy (CAFE) credits available to the OEMs based on provisions of the Alternative Motor Fuels Act of 1988, FFVs generally sell for the same price as gasoline-fueled vehicles. Beginning with model year (MY) 2015, the allowable credits are scheduled to phase down, based on provisions of the Energy Independence and Security Act (EISA) of 2007.

CNG vehicles certified to use a compressed natural gas are the only other vehicles currently being sold in the United States by OEMs. Notwithstanding the high incremental costs and low sales volume of these vehicles, the owners of those that are on the road are already reaping the benefits of lower NG prices.

The use of alternative fuels in vehicles certified to use conventional gasoline requires vehicle modification, typically via purchase of a conversion kit. EPA-certified kits are currently available for E85, LPG, and CNG. For ethanol, the key challenge is to ensure that the converted FFV is compatible with the alternative fuels. In contrast, LPG- or CNG-capable vehicles are typically either mono-fuel vehicles, which are dedicated to a specific fuel, or bi-fuel vehicles, which include two independent fuel systems with separate tanks, fuel lines, and so on. The bi-fuel vehicles do not operate on a mixture of the two fuels and, because of the additional space requirements of the dual systems, typically have less storage or trunk space.

Combining estimates of vehicle conversion costs with actual or estimated information on the price of the four different alternative fuels, we see significant economic incentives for many vehicle owners to modify existing vehicles to burn NG-based fuels. For E85, where conversion costs are estimated to range from $320 to $1,300, we estimate a range of payback periods from nine months to eight years, depending on location and various assumptions about vehicle fuel efficiency and miles driven. Payback periods decline to six months to five years based on 2015 EIA fuel price projections. For M85, the information is less precise because methanol is not anticipated to be sold for road use in the United States in the near term, and no conversion kits are currently EPA certified. However, based on a range of assumptions, not least of which is the existence of a methanol fuel network, we find that the development and production of vehicles capable of burning methanol fuels could be an attractive economic proposition. Even with vehicle modification costs of several thousand dollars per vehicle, vehicle conversion could make economic sense for many owners. For both CNG and LPG, the conversion costs are considerably higher than for the alcohol fuels, on the order of $5,000 to $10,000/vehicle. Our calculations suggest that, for these fuels, conversion makes economic sense only for large, heavy vehicles with high usage rates.

Apart from the different market-based incentives across the four fuels for vehicle owners to purchase new vehicles or to convert existing ones to alternative-fuel capability, energy security and environmental benefits may be associated with the use of NG-based fuels. For example, substituting inexpensive alternative fuels from NG for gasoline made from crude oil would yield an estimated 20¢/gal saved in energy security/macroeconomic benefits. On the environmental side, current estimates indicate that (with a few exceptions) late-model light-duty vehicles (LDVs) manufactured over the past decade using conventional gasoline have direct conventional emissions that are comparable to those of similar vehicles converted to use alternative fuels. And although the shift to alternative fuels may decrease emissions of certain gasoline-related air toxics, such as benzene, these fuels are likely to increase aldehyde emissions. More research is needed on the potential trade-offs between these pollutants. At the same time, substantial reductions in both conventional and air toxics emissions are likely to be associated with the conversion of pre-MY 2004 vehicles. Despite the technical potential to reduce greenhouse gas (GHG) emissions, the situation remains murky as the net impact of NG-based fuels depends critically on the amount of leakage from the production and transport of the gas. Recognizing the considerable uncertainty in these estimates, we do not develop monetized benefit estimates for the possible difference in emissions between the use of conventional gasoline and the conversion of LDVs to alternative fuels.

In an examination of the barriers to converting existing vehicles to alternative-fuel capability, we find that, for CNG and LPG, no major regulatory barriers are apparent as several conversion kits have been approved by EPA and are currently available in the marketplace, although prices are higher in the United States than in other countries. However, largely because of the need to build in a duplicate fuel system, the kits are relatively expensive and thus attractive to only a small group of users. For methanol, no approved conversion kits are currently available.

E85 is quite a different story. Motivated by the available CAFE credits, OEMs produce substantial numbers of E85-capable vehicles, and at least one EPA-certified conversion kit is available in the marketplace, at a price of $1,300. Seemingly quite similar kits that are not EPA certified are available for $300 or less and apparently are sold in considerable volumes to US and foreign buyers. This raises the obvious question of why the prices of EPA-certified and noncertified kits differ so greatly. Accordingly, we explore the details of the EPA certification process, including the applicable waivers to the Clean Air Act (CAA) prohibition on the use of alternative fuels in noncertified vehicles. We also consider a number of possible pathways under the act for advancing the use of NG-based fuels in the light-duty fleet.

Finally, we note the effect of regulations on the incentives for the production of both FFVs and biogenic ethanol. Specifically, recently adopted rules will phase out any advantage auto manufacturers will receive for the production of E85-capable vehicles in MY 2016 and beyond. Ethanol producers benefit from a number of regulatory requirements and, in the case of cellulosic ethanol, from production tax credits. The combination of mandated blending requirements and declining demand for gasoline in the United States is likely to reduce the current market price of E85 from biogenic sources relative to E10. Further, EPA forecasts substantial production of cellulosic ethanol beginning in 2013. Recent studies project production costs of cellulosic ethanol to be competitive with the costs reported here for NG-based ethanol even without the regulatory and tax subsidies. If those projections are realized, the potential market for NG-based ethanol would be reduced, although the gains to consumers from E85 use would, if anything, be enhanced.

Following this introduction, Section 2 explores the costs of producing NG-based alternative fuels suitable for use in the light-duty fleet based on both current and projected NG prices. Section 3 focuses on the costs of converting existing vehicles or producing new ones to burn the various fuels. Section 4 considers other costs and benefits of expanded NG use in the light-duty fleet, including those related to conventional pollutants, GHGs, and national security. Section 5 integrates the various elements discussed in previous sections to develop an overall assessment of the payback period for the conversion of existing vehicles to use NG-based alternative fuels in the light-duty fleet. Section 6 identifies the key regulatory barriers, focusing on EPA's waiver process to allow the use of alternative fuels in conventional gasoline vehicles. This section also explores a limited number of possible pathways available under EPA's regulations to expand the use of such fuels. Section 7 considers the implications of recent regulatory changes for the manufacture of FFVs and for the production of both renewable and nonrenewable ethanol blended fuels. Section 8 offers overall conclusions.

2. Costs of Alternative NG-Derived Fuels

This section examines the cost of producing and distributing four alternative fuels: ethanol, specifically E85; methanol; LPG; and CNG. For each fuel, we present a description of the methodology used to develop the cost estimates, along with the results.

2.1 Energy Density and Fuel Performance

We first discuss the problems of comparing vehicle performance on different fuels. For example, fuel costs are usually presented on a per-gallon basis, but as shown in Table 2.1, fuels can vary substantially in energy content. Among the fuels considered here, gasoline and Indolene have by far the highest energy density. Indolene, a special type of gasoline manufactured to have the same characteristics (including energy content) in every batch, is used as a test fuel in the industry to ensure that test results are replicable and comparable from one vehicle to another. Pure alcohol fuels have the lowest energy density; for example, methanol and ethanol have volumetric energy densities of, respectively, about one-half and two-thirds that of gasoline. To compare the costs and other characteristics of these fuels on an apples-to-apples basis, one must express such characteristics in units of gasoline gallon equivalents (gge), which is the volume of fuel required to have the same energy content as gasoline.

In terms of pure combustion energy, a conversion to gge can be made simply by dividing the number of gallons of the fuel under consideration by the ratio of its energy content to that of gasoline. Thus, the gge of ethanol is 1.5 gal of fuel, and the gge of methanol is 2.0 gal. Again based purely on its energy content, the fuel economy of the vehicle burning the fuel in question relative to its gasoline fuel economy should be the reciprocal of its gge. Thus, a vehicle using E85 should have a fuel economy in miles per gallon (mpg) that is 71% of its gasoline fuel economy.

Table 2.1. Energy Density of Liquid Fuels

Fuel	Energy density (Btu/gal)	Mass density (lb/gal)
Gasoline fuels		
Gasoline (E0)	115,190[a]	6.0
Indolene	114,118[b]	6.0
Alcohols		
Pure ethanol (E100)	75,990[a]	6.6
Pure methanol (M100)	56,840[a]	6.6
Gasoline–alcohol blends		
E85	81,870	6.5
M85	65,590	6.5
E10	111,270	6.1

Notes: Gasoline and gasoline–alcohol blends can vary in energy content depending on crude and refining characteristics. The pure alcohols and Indolene are pure compounds and their energy content is fixed. Energy density values reported are lower heating values; in other words, they exclude the latent heat of vaporization of water in the combustion products, which in gasoline engines is unavailable to do useful work. Values for gasoline–alcohol blends are linear combinations of gasoline and pure alcohol values. lb, pounds.

[a] Listed values come from Unnasch (2006).

[b] Listed value comes from Central Weights and Measures Association (2013).

The official US government website for information on fuel economy is www.fueleconomy.gov. In its section on FFVs, the E85 fuel economy estimates, as a percentage of gasoline fuel economy, hover around 71%. However, in at least two fleet tests involving small numbers of police vehicles, the fuel economy actually experienced by E85-fueled vehicles in the real world was significantly better than what might be expected from the energy content of the fuel.

Unlike the government's tests to develop fuel economy ratings, these fleet tests were not run on dynamometers using a standard driving cycle (federal test procedure [FTP] or otherwise) and did not use Indolene. Instead, these were tests of flex-fuel police vehicles in actual use or in high-performance test procedures characteristic of police use. Both tests found a ratio of E85 fuel economy to conventional gasoline (E10) fuel economy of around 82% (see Table 2.2). The Los Angeles County Sheriff's Department (2012) compared the performance of three OEM FFVs to that of their gasoline-only counterparts on a test track using multiple drivers for each vehicle. The resulting fuel economy ratios were 76%, 83%, and 91%, far higher than the energy-content estimate. In Chicago, 25 Ford Crown Victorias were retrofitted with an EPA-certified E85 conversion kit supplied by Flex Fuel US (Disher and Sremac 2012). Each of these vehicles was driven in normal police work for a period of time using commercially available gasoline (E10) and E85; in total, these vehicles covered more than 1 million mi.[1] On average, the fuel economy using E85 was 82% of the E10 fuel economy.

Table 2.2. Test Results: Comparison of E85 and Gasoline (E10) Fuel Economy in Identical Vehicles

Description	Test type	Results
Chicago Police Department: test of 25 converted Ford Crown Victorias	On-road, typical police use	Average fuel loss on identical vehicles, gasoline to E85: 18%
Los Angeles Sheriff's Department	32 laps, 4 drivers, AutoClub Speedway, Fontana, CA	Fuel loss on identical vehicles, gasoline to E85
Chevrolet Impala		7%
Chevrolet Tahoe		17%
Chevrolet Caprice		24%

Further analysis of the 10-percentage-point discrepancy between the official fuel economy results and the results of the Chicago Police Department was carried out by the kit manufacturer, Flex Fuel US, and an independent vehicle testing contractor, Roush Industries. The analysis showed that about half the discrepancy (5%) was due to the greater difference in energy content between Indolene and true E85 used in the official EPA tests versus the energy difference between E10 and E75 in the real-world fuels. (Fuel marketed as E85 in Chicago varies in ethanol content over the year and averages about 75% ethanol.) The remaining 5% apparently was due to the greater combustion efficiency of the alcohol-based fuel in the real-world test. Much of that latter difference came from the higher octane of ethanol in the real-world test. In the EPA test, the efficiency boost of the ethanol was masked by the fact that Indolene is also a high-octane fuel, if not quite as high as ethanol in octane rating.

[1] Personal communication, Chris Disher, Flex Fuel US, June 26, 2013.

Moreover, in 2008, Flex Fuel US sent one certified vehicle from each of three classes[2] to Roush Laboratories for dynamometer testing on the FTP drive cycle (FTP 75). For the E85 test, these vehicles were retuned by advancing the timing in an effort to take full advantage of the combustion properties of E85. They were compared to the same vehicles on the same test using Indolene. Initial calculations showed that when burning E85, the fuel economy of each vehicle was at least 90% of the fuel economy when using Indolene. These results were derived using an algorithm for calculating fuel economy using gasoline test fuel. Later, EPA developed an algorithm for ethanol fuels, but the new algorithm was never applied to the above test results. However, based on similar results using other vehicles retrofitted with E85 conversion kits supplied by other manufacturers, Timothy Werner of Roush Industries estimated that the calculated fuel economy of vehicles using E85 on the FTP test would be 80%–85% of the fuel economy using Indolene—not as good as the originally reported 2008 results but still better than the on-road tests comparing E85 with conventional gasoline. Werner went on to say that a vehicle retrofitted with this particular conversion kit may well show a larger difference in fuel economy results vis-à-vis conventional gasoline than a vehicle retrofitted by other kit manufacturers or an FFV produced by an OEM. One reason is that, whereas other (perhaps newer) fuel system designs inject the fuel directly into the cylinder, the Flex Fuel US kit injects fuel into the throttle body, where evaporation cools and condenses the air, with a significant increase in combustion efficiency.[3]

These results suggest that the fuel economy benefits of using E85 could be considerably underestimated by the official fuel economy statistics published by EPA and the US Department of Energy (DOE) at www.fueleconomy.gov. The benefits may not, however, be as good as those indicated by the Roush FTP tests discussed above. In our cost estimates below, we do not use these most optimistic results; instead, we assume that the actual ethanol content of E85 is 75% and that the fuel economy of a vehicle using such E85 will be 82% of the fuel economy of a vehicle using conventional gasoline.

[2] Flex Fuel US offers EPA-certified conversion kits for three vehicle families: 2006 Ford F150/F250/F350 trucks; 2006 Ford Crown Vic/Lincoln Continental; and 2006 Chrysler models, including Dodge Charger and Chrysler 300. Each is covered by a reduced-fee certification allowing 50 conversions for the two Ford families and 100 conversions for the Chrysler-Dodge vehicles.

[3] Personal communication, Timothy Werner, engineering manager, Roush Industries, July 12, 2013.

2.2. Ethanol

A new process for producing ethanol from NG has been developed by Celanese Corp. (US Patent No. 8,222,466). The patent claims that, compared to existing processes for producing industrial ethanol, the new Celanese "TCX" process produces exceptionally pure ethanol along with a water stream pure enough to be reused or safely disposed of. The process, which uses NG as a feedstock, has the following steps:

NG→methanol and carbon monoxide (CO)→acetic acid + hydrogen→ethanol

Celanese is one of the world's largest producers of acetic acid but is not currently producing methanol. Celanese has announced plans to build a 1.3-million-metric-ton/year methanol production facility near Houston in Clear Lake, Texas, with an anticipated startup date sometime after mid-2015 (Celanese Corporation 2012a). The plant will be used to meet the growing worldwide demand for methanol and probably will support the manufacture of ethanol by the new TCX process. Celanese already has a pilot-scale TCX plant in Clear Lake, and the addition of methanol capacity there suggests that the production of TCX ethanol may soon increase as well. Moreover, Celanese has under construction a 0.2-million-metric-ton/year ethanol plant based on TCX technology using coal as a feedstock in Nanjing, China, and recently announced that it has received approval to expand this plant by 30%–40% (Celanese Corporation 2011, 2012b). The increased capacity is due to improvements in the efficiency of the TCX process, with no increase in capital expenditure required. This unit was constructed and started up in late June 2013. Celanese has also announced a joint venture with the Indonesian state-owned energy company Pertamina to produce ethanol from coal in that country (Katz 2012).

To begin, we focus on the possible opportunities to produce ethanol from NG at facilities suitably located around the country, an activity that may or may not reflect the company's actual intentions. Ethanol is a high-volume industrial chemical with multiple uses. Current federal policy requiring the use of biogenic ethanol effectively precludes the use of E10 made from NG in the United States. What follows, then, is an informal analysis of potential opportunities over the next few years for TCX ethanol in US fuel markets for LDVs. In our view, the most attractive of those opportunities lie in the production of E85 for that subset of vehicles in the light-duty fleet that can use it legally and without damage: FFVs. After discussing the costs of producing and transporting TCX ethanol, we describe what we believe is a plausible approach for introducing the fuel: find a few locations where TCX ethanol can be cheaply produced and look for opportunities to cheaply supply markets where the current or projected price of gasoline is high.

In the next section, we describe the data sources used to make the estimates; in subsequent sections, we describe the procedures for estimating the production cost of TCX ethanol and the cost of ethanol shipments. Then we turn to the task of finding attractive places to locate TCX E85 production facilities, based on NG prices and access to other markets.

2.2.1 Data

Historical data and future projections were collected for crude oil prices, retail gasoline prices, local NG prices for industrial users, state and federal fuel taxes, and the spatial distribution of FFVs. Current and implied prices of TCX ethanol and local E85 prices were estimated, including fuel taxes and service station markups, as described below.

Spatial Distribution of FFVs. To estimate the number of FFVs in various metropolitan areas, we obtained binned data on the number of FFVs by zip code from the National Renewable Energy Laboratory (NREL). Overall, FFVs appear to be spread widely across the country and are only mildly concentrated in areas with good E85 fuel availability. In 332 metro areas where data were available, only 6 have more than 10 FFVs per 100 people (comprising only about 30,000 vehicles in total), and only 43 have more than 6 FFVs per 100 people (about a million vehicles in total). The remaining metro areas have between 3 and 6 FFVs per 100people. Thus, areas with many FFVs are more or less those metro areas with large populations.

Retail Gasoline Prices. We relied on GasBuddy (2013), a website and mobile app that enables motorists to compare real-time gasoline prices at any locations in the United States. Much of the data made available by GasBuddy is reported in real time by users themselves. GasBuddy also makes available time series and cross-section datasets of local data. We obtained monthly average prices for the two years prior to March 2013 for all 159 US metropolitan areas in the GasBuddy database.

Energy Prices. EIA publishes historical and projected prices for crude oil and NG, as described further below, as well as historical data on average monthly NG prices for each state.

E85 Prices. We calculated an E85 price by taking a linear combination of TCX ethanol and the average reformulated blendstock for oxygenate blending (RBOB) prices. We used two more EIA data series to estimate the cost of RBOB, accounting for the fact that California RBOB is slightly different from the RBOB used elsewhere. For California RBOB, a dataset of daily spot prices is downloadable from the EIA website. The EIA website also has a daily record of NYMEX futures prices for New York Harbor RBOB, so we used this data series outside of

California. The average difference between the two series on the selected days was 4.8¢, and we used the average RBOB costs on those days to estimate the E85 price.

Taxes and Markup. Information on state and local taxes is taken from a report prepared for the Minnesota legislature (Michael 2012). Some states levy both excise and sales taxes, and some allow local as well as statewide taxation.[4] Further, to all estimates, we add the federal gasoline tax of 18.4¢/gal. When applying these taxes to ethanol, we assumed that TCX ethanol would be taxed at the same rate as gasoline on an energy-equivalent basis. (Although many states offer a break in fuel taxes for ethanol from biogenic sources, those tax breaks are unlikely to be available for ethanol made from NG.) The estimate of per-gallon service station markups comes from TIAX (2010), scaled up to account for the lower energy density of E85 compared to regular gasoline. This estimate was made for Southern California in 2008 and is used here in the absence of other estimates.

Transport Costs. We used the approximate rail and truck miles to each location and computed transport costs based primarily on information provided in a report from the National Academy of Sciences and described further below in Section 2.2.4. The rail cost calculation assumes the use of unit trains rather than individual railcars and assumes the construction of special handling facilities at sending and receiving terminals. The assumption that unit trains would be used reduces the cost of transport to most locations by about 8¢/gal.

2.2.2. Production Cost of Ethanol

Recently, Celanese provided an estimate of the cost of producing ethanol by the TCX process, as a function of the price (in dollars per thousand cubic feet (mcf). of the NG input:[5]

$$\text{TCX ethanol cost (\$/gal)} = 1.2691 + 0.1367 * \text{NG price (\$/mcf)}. \tag{2.1}$$

This cost function applies to a plant producing 380 million gal of ethanol per year,[6] or enough to supply E85 fuel to about 290,000 FFVs for a year, assuming 100% reliance on E85.

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4 The Michael (2012) report gives sales tax data in actual currency, without providing the associated retail price on which the calculated sales taxes are based. Because sales taxes are ad valorem taxes, the use of the sales tax information in cents introduces a small error into the calculation.

5 Personal communication, P. J. Houm, director of commercial and business development, Celanese Corporation, April 5, 2013. See also Celanese Corporation (n.d.).

6 Presentation to the Louisiana Oil and Gas Association (LOGA), P.J. Houm, Celanese Corporation, March 13, 2013.

In Table 2.3, we compare projected wholesale prices of TCX ethanol and conventional gasoline (US Gulf Coast unleaded regular [ULR or E0]) out to 2030, using EIA projections of NG and crude oil prices, shown in columns 1 and 2. The TCX ethanol cost (column 4) is estimated for 2012–2030 using equation 2.1. For comparison, column 3 contains estimates of average wholesale gasoline prices, computed by subtracting $0.52 for taxes, transport, and service station markup from projections of the average US retail gasoline prices during 2012–2030 in EIA's *Annual Energy Outlook* (AEO) for 2012. As shown in Table 2.3, the average difference between spot prices of gasoline (ULR; $2.78) and TCX ethanol ($2.31), in energy-equivalent units, is estimated to be 47¢/ gge in 2012, growing to $0.65/gge or more by 2020.

Table 2.3. Comparison of Projected Wholesale Prices of ULR Gasoline and TCX Ethanol

Year	(1) NG price[a] ($/million Btu)	(2) Average crude oil price[b] ($/bbl)	(3) Projection of gasoline wholesale prices[c] ($/gal)	(4) TCX ethanol cost ($/gge[d]	(5) Difference ($/gge)
2012	3.58	94.73	$2.78	$2.31	$0.47
2015	4.29	116.91	3.02	2.44	$0.58
2020	4.58	126.68	3.19	2.49	$0.70
2025	5.63	132.56	3.34	2.68	$0.66
2030	6.29	138.49	3.45	2.80	$0.65

Notes: All prices are in 2010 dollars per unit.
[a] DOE (2012b, 2010 Price series "Natural gas prices in $/million Btu at Henry Hub").
[b] DOE (2012b, 2010 Price series "Low-sulfur light crude oil prices in $/barrel").
[c] DOE (2012b, Petroleum product prices, Reference Case, "Motor gasoline") less $0.52 for average fuel taxes, transport, and service station markup.
[d] Derived from eqn (2.1) applied to column (1).

Considering that ethanol is more costly to ship and presents corrosion difficulties not applicable to conventional gasoline, the average gap between gasoline (E10) and E85 would be somewhat smaller than the estimates shown in Table 2.3. Of greater interest, however, is that the actual differentials would form a distribution around the mean, due to regional differences in prices of gasoline and NG. Over time, these differences might change—as a result of new investment decisions, changes in state tax policies, and so on—but they are likely to persist. What this means is that the differences between conventional E10 and TCX E85 are bound to be greater than $0.47–$0.65/gge in some regions, perhaps much greater. Places where the gap is largest may well be attractive locations in which to market E85 made from NG.

After a brief discussion of ethanol transportation costs, we return to the question of where to site ethanol production facilities and calculate the likely retail price gap between future E10 prices and TCX E85 prices.

2.2.3. Ethanol Transportation Costs

The cost of shipping transportation fuels depends primarily on four characteristics: the type of fuel, the quantity, the distance, and the mode of transport. Four modes are available for the shipment of ethanol or gasoline: truck, rail, barge, and pipeline. For each, transportation planners customarily divide costs into two categories: distance-fixed costs (DFC), which are the same per unit shipped for a given mode regardless of shipping distance, and distance-variable costs (DVC; Searcy et al. 2007). Examples of DFC include the cost of the vehicle itself, loading and unloading costs, and (perhaps) insurance. Examples of DVC include the cost of fuel and the wages of the crew or driver, and these are typically linear in distance. Thus, for a given type of load and a given capacity, total DFC and DVC are, respectively, the intercept and slope of the transportation cost function, that is,

$$\text{Cost}(d) = \text{DFC} + \text{DVC}*d, \qquad (2.2)$$

where d is distance. Average cost is then Cost(d)/d, and it is clear that the greater the distance, the less important are DFC.

Tables 2.4 and 2.5 show estimates of transportation costs by mode for gasoline and ethanol, respectively. The source of the gasoline estimates is Curley (2008). The ethanol estimates for truck, rail, and barge shipping costs are from a report on biofuels prepared by a team at UC Davis for the Western Governors Association (WGA 2008). Both sources were used by the National Research Council in the preparation of its 2009 report on transportation fuels from biomass. These cost estimates appear to be slightly higher than the ethanol shipping cost estimates produced by EPA for the RFS2 regulatory impact analysis (RIA) of about 15¢/gal (EPA 2009), although they are hard to compare because EPA's estimates are averaged for out-of-state and in-state shipments by state and are not given by distance.

The gasoline and ethanol estimates are not strictly comparable either because the gasoline costs are given as a range of unit costs per mile, without specifying the distance traveled, whereas the ethanol cost table breaks out the DFC and DVC separately. Also, the ethanol values are in terms of absolute gallons. To be comparable to gasoline, they must be adjusted for energy density[7] and for the higher combustion efficiency of ethanol, as discussed in Section 2.1. When these two elements are taken into account, comparable estimates are found in Table 2.6, where the data in Tables 2.4 and 2.5 are used to calculate the costs of shipping gasoline and ethanol 500 and 1,000 mi.

Table 2.4. Cost of Gasoline Shipment

Mode	Cost ¢/gal per 100 mi.
Truck	3.0–4.0
Rail	0.75–1.25
Barge	0.4–0.5
Pipeline	0.15–0.25

Source: Curley (2008).

Table 2.5. Cost of Ethanol Transport by Mode

Mode	Share[a] (%)	Capacity (gal)	Cost function[d]	
			DFC (¢/gal)	DVC (¢/100 gal*mi)
Truck	29	8,000[b]	2.0	2.35[e]
Railcar	66	33,000[b]	10.3	0.75
Unit train		3,300,000[b]	2.6	0.75
Barge	5	1,260,000[b]	2.9	1.5
Pipeline	< 1	300,000[c] (gal/day)	0	3.87[c]
Pipeline		1,000,000[c] (gal/day)	0	1.90[c]

[a] DOE (2010). [b] WGA (2008). [c] Searcy et al. (2007). [d] WGA (2008), except where indicated. [e] Average truck speed of 55 mph.

As shown, the cost of ethanol shipped by truck is toward the high end of the range of costs for gasoline. This is primarily due to the lower energy density of ethanol, which means that a greater quantity has to be shipped to have the same energy content. Ethanol is also more corrosive than gasoline, so the requirements for materials that come in contact with ethanol are generally more stringent. However, that may not necessarily be an issue. During the California

[7] Throughout, we use the following energy densities: gasoline (E0), 115,190 British thermal units (Btu)/gal; methanol, 56,840 Btu/gal; and ethanol, 75,990 Btu/gal. Mass densities are gasoline, 6.00 pounds [lb]/gal; methanol 6.61 lb/gal; and ethanol, 6.51 lb/gal (Unnasch et al. 2006).

methanol experiment in the 1980s, gasoline tank trucks were used to transport methanol—which is more corrosive than both ethanol and gasoline—from terminals to retail outlets, suggesting that shipment of ethanol or methanol by tank truck or railcar may be no more expensive on a per-gallon basis than gasoline.[8]

Table 2.6. Comparison of Gasoline and Ethanol Shipping Costs for 500- and 1,000-mi Trips ¢/gge

	500 mi		1,000 mi	
	Gasoline	Ethanol	Gasoline	Ethanol
Truck	15–20	19.7	30–40	36.4
Railcar	—	20		25.4
Unit train	4-6	9.1	7.5–12.5	15.7
Barge	2–2.5	14.9	4–5	17.9
Pipelines	0.8–1.2		1.5–2.5	
300 kgal/day		27.7		55.3
1,000 kgal/day		13.6		27.1
Ocean-going tanker	5	5	5	5

Notes: kgal, thousand gallons.

For rail and barge, the cost estimates of ethanol shipment are substantially higher than those for gasoline, differing by 5¢ to 10¢/gal for rail and 8¢ to 14¢/gal for barge shipment. However, this difference does not seem to be related to the physical and chemical characteristics of ethanol because the same estimates in the WGA report also apply to biodiesel, which is no more difficult to handle than gasoline. In fact, it is related to shipping volume. This is seen quite dramatically in the two cost estimates for rail—single cars versus unit trains. The main estimate made by WGA—and the estimate used in its cost modeling—was for single railcars. However, the report notes in passing that per-unit costs for a 100-car unit train are estimated to be only 15%–25% of the costs for individual railcars. In Table 2.6, those savings are applied to the DFC element, so that, as shown, a unit train is by far the least costly way to ship ethanol.[9]

[8] Personal communication, Michael D. Jackson, MDJ Research, San Jose, CA, February 24, 2013.

[9] The use of unit trains for bio-ethanol is substantial and growing fast. Kinder Morgan now has six unit-train terminals, capable of delivering ethanol from the Midwest to California, Texas, and the East Coast (Baltimore, Maryland, and Linden, New Jersey). Green Plains Renewable Energy Inc. recently opened a unit-train facility in Birmingham, Alabama, for shipment from western Iowa and Nebraska. These unit trains originate in the main corn-growing areas of the Midwest.

The largest difference between gasoline and ethanol is in pipeline shipping costs, which are estimated to be 10 to 20 times higher for ethanol than for gasoline. Our cost estimates for shipping ethanol by pipeline come from Searcy et al. (2007), who, based on consultations with ethanol and pipeline experts, present a cost function that gives the cost in dollars per tonne-km as an exponential function of pipeline capacity in tonnes per day:

$$\text{Cost} = 4.13{*}C^{-0.5885}. \tag{2.3}$$

Converted to capacity units in gallons per day and cost units in dollars per 100 gal*mi, this equation becomes

$$\text{Cost} = 0.6077{*}C^{-0.5885}. \tag{2.4}$$

Table 2.5 presents cost figures for two sizes of pipelines. The first, 300,000 gal/day, is the approximate size of the TCX ethanol plant that Celanese is now building in China. The second, 1 million gal/day, is the approximate size of the methanol plant that Celanese is building in Texas. Thus, for the foreseeable future, the volume of TCX ethanol available for pipeline shipment is not likely to be larger than the sizes presented in Table 2.6. By way of comparison, we used the formula in equation (2.4) to estimate the cost of a typical large liquid pipeline—the 150,000-barrel/day Seaway pipeline that ships crude oil from the Cushing, Oklahoma, pipeline terminal to refineries on the Gulf Coast—and arrived at an estimate of 0.6¢/100 gal-mi. That pipeline is currently undergoing expansion to 400,000 barrels/day, which will result in a cost estimate of 0.3¢/100 gal-mi, not much higher than the cost estimates provided by Curley (2008) and presented in Table 2.4. For pipelines as well as rail transport, then, the quantity shipped—rather than the distinctive properties of the fuel—is by far the most important determinant of the per-mile price of ethanol transport.

Still, even high volumes may not be enough to justify investment in large-capacity pipelines for ethanol. In 2010, POET, a large midwestern ethanol producer, and pipeline company Magellan Midstream Partners jointly proposed construction of a massive $4 billion pipeline that would carry ethanol from the Midwest to the Northeast. However, the developers wanted a federal loan guarantee, and though corn-state members of Congress introduced a bill to provide one, it wasn't acted upon (Whitford 2010). In response to a requirement in EISA,[10] DOE (2010) had just completed a feasibility study of a similar pipeline, and the findings were not

[10] http://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr/pdf/BILLS-110hr6enr.pdf, accessed August 5, 2013.

encouraging. DOE found that the planned capacity exceeded anticipated ethanol usage by almost 50%. Unless ethanol volume was substantially increased by the planned move from E10 to E15 and greater use of E85, the transportation cost would be 19¢/gal, well above existing transport costs of 11¢/gal for that corridor.[11] Until ethanol volumes expand substantially, a major ethanol pipeline is unlikely to be built without governmental subsidies.

Finally, Table 2.6 reports an estimate of 4¢/gal for ocean tanker shipment of ethanol, regardless of distance. This estimate, which is presented in a footnote in the National Research Council report, is far cheaper than other modes for ethanol shipment. However, neither ethanol nor E85 shipped by tanker can be delivered directly from ocean vessels to service stations; it would have to be loaded onto trucks. The fixed cost of truck shipment (from Table 2.6) would raise the cost of shipment to 6¢/gal.

2.2.4. Least-Cost Production of Ethanol

As a second approach, we zeroed in on locations with low industrial prices of NG and looked for marketing outlets for plants in those cities. For industrial gas prices, we used EIA data giving state average industrial NG prices for the last two years, as shown in Table 2.7. As displayed, NG was least expensive in Texas, Louisiana, and Alaska, so we located hypothetical plants on the Gulf Coast and in Anchorage, Alaska, with the idea that such plants would be able to supply all US coasts using inexpensive tanker shipment. We also located a third hypothetical plant in Charleston, West Virginia, a convenient location for supplying cities in the Midwest. Tables 2.8 and 2.9 put all of this information together to compare price estimates for TCX E85 and conventional E10. Two estimates are shown: an estimate based on current prices and the AEO projection of NG and gasoline prices for 2015 from Table 2.3. As shown, the projected gap between E85 and E10 prices ranges between 31 and 59¢/gge now, but grows to 52–83¢ by 2015, with the most attractive opportunities on the coasts. We emphasize that these assumed plant locations are for illustrative purposes only and may not be the optimum arrangement for getting TCX ethanol to major population centers.

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[11] As far as we know, only two ethanol pipelines are currently in use in the United States, both of which are owned and operated by Kinder Morgan. One runs for 75 miles (mi) from Tampa to Orlando, Florida, and was converted from a gasoline pipeline for an expenditure of $10 million (Galbraith 2008). The other runs for about 8 mi from Kinder Morgan's Linden, New Jersey, unit-train terminal to its New York Harbor terminal at Carteret, New Jersey. The unit-train service carries ethanol from the upper Midwest to the East Coast for domestic use and export (Lane 2012).

Table 2.7. Estimated Production Cost of TCX Ethanol, Ranked in Ascending Order (One Entry per State)

State	City	Average NG price, state, $/mcf	Calculated cost of TCX ethanol, $/gge
TX	Houston	3.528	2.304
LA	Shreveport-Bossier City	3.533	2.305
AK	Anchorage	3.584	2.314
KY	Lexington	4.376	2.457
WV	Charleston	4.688	2.513
AL	Mobile	4.821	2.537
SC	Columbia	4.851	2.542
KS	Topeka	4.914	2.554
GA	Macon	5.058	2.580
VT	Burlington	5.35	2.633
VA	Richmond-Petersburg	5.529	2.664

Notes: Each NG price is the average (March 2011–February 2013) for industrial users in the state indicated.
Source: EIA (2013b).

Finally, one should keep in mind that the price projections in Tables 2.8 and 2.9 are speculative, subject to uncertainties that could result in E85 prices that are considerably higher or lower than those projections. As noted above, for example, the use of individual railcars instead of unit-train transport could raise E85 costs—and presumably prices—by 8¢/gal, or 11.4¢/gge . More generally, shipment costs could be higher or lower than those projected. Costs of TCX ethanol production could vary from one location to another, but we have assumed that production costs depend only on local industrial NG prices. We believe these estimates are most reliable for the Houston site because Celanese has a TCX demonstration plant in operation there; costs in Anchorage or Charleston or other notional sites could differ. Uncertainties also surround the pricing of TCX ethanol by Celanese. These projections are based on the company's current pricing plans, as reflected on its web page on the TCX process, but its plans could change in the future. Although the company appears to be very confident that the product can be made in volume for the anticipated costs, those costs will not be known with certainty until a production-scale plant is actually in operation. Alternatively, Celanese could conclude (or perhaps already has concluded) that its total profits would be higher if the product were priced more attractively, so as to induce more motorists to invest in fuel conversions or new FFVs and, in turn, lead to greater demand at retail outlets.

Table 2.8. Conventional E10 and TCX Ethanol: Comparison of Current Pump Price Projections

						Current price		
City	Supply location	Shipping cost per gal	TCX ethanol delivered per gal	Taxes per gal	Markup per gal	E85 retail price $/gge	E10 retail price $/gge	Difference
Washington, DC	Charleston, WV	0.10	2.01	0.42	0.12	3.29	3.80	0.51
Boston	Houston	0.03	1.81	0.42	0.12	3.11	3.69	0.58
San Francisco-Oakland	Anchorage	0.03	1.82	0.82	0.12	3.53	4.10	0.57
Seattle	Anchorage	0.03	1.82	0.56	0.12	3.25	3.84	0.59
Los Angeles	Anchorage	0.03	1.82	0.82	0.12	3.53	4.07	0.54
Tampa	Houston	0.03	1.81	0.51	0.12	3.20	3.51	0.31
New York City	Houston	0.03	1.81	0.77	0.12	3.46	3.97	0.51
Pittsburgh	Charleston	0.07	1.98	0.51	0.12	3.35	3.70	0.35
Philadelphia	Houston	0.03	1.81	0.51	0.12	3.20	3.70	0.50

Table 2.9. Conventional E10 and TCX Ethanol: Comparison of Current and 2015 Pump Price Projections

						Projected price, 2015		
City	Supply location	Shipping cost per gal	TCX ethanol delivered per gal	Taxes per gal	Markup per gal	E85 retail price $/gge	E10 retail price $/gge	Difference
Washington, DC	Charleston, WV	0.10	2.01	0.42	0.12	3.39	4.13	0.74
Boston	Houston	0.03	1.81	0.42	0.12	3.20	4.01	0.81
San Francisco-Oakland	Anchorage	0.03	1.82	0.82	0.12	3.62	4.45	0.83
Seattle	Anchorage	0.03	1.82	0.56	0.12	3.35	4.17	0.82
Los Angeles	Anchorage	0.03	1.82	0.82	0.12	3.62	4.42	0.80
Tampa	Houston	0.03	1.81	0.51	0.12	3.29	3.81	0.52
New York City	Houston	0.03	1.81	0.77	0.12	3.55	4.31	0.76
Pittsburgh	Charleston	0.07	1.98	0.51	0.12	3.45	4.02	0.57
Philadelphia	Houston	0.03	1.81	0.51	0.12	3.29	4.02	0.73

A further source of uncertainty is the reaction of state and federal governments to the availability of a new transportation fuel that has the potential to disrupt existing markets and policies. In many states, renewable alternative fuels enjoy certain tax advantages over petroleum products. Whether NG-based fuels would enjoy these benefits is uncertain; throughout this report, we have assumed that fuel taxation would be the same as for standard gasoline on an energy-equivalent basis.

2.3. Methanol

In November 2012, the spot price of methanol climbed to a four-year high of $1.27/gal (Barry-Goodman 2012). However, the cost of producing methanol is less than this figure, probably much less. Currently, methanol production appears insufficient to meet worldwide demand, as several large chemical manufacturers have announced plans to build new methanol plants or reopen old plants. One could reasonably expect that the shortage has led to a price rise.

To estimate methanol production costs, we use the distance-fixed (DFC) and distance-variable cost (DVC) approaches of Searcy et al. (2007) and apply them to the NG feedstocks instead of distance. This approach fits in naturally with the relationships between NG prices and the price of TCX ethanol, developed in Section 2.2.1 above (equation [2.1]). The first term in equation (2.1) above represents the feedstock-fixed costs (FFC) of TCX ethanol; the second term represents the feedstock-variable costs (FVC) of TCX ethanol:

FFC($/gal)=1.2691

FVC($/gal)=0.1367*NG price ($/mcf).

This is a statistically derived, algebraic separation of costs into FFC and FVC, in contrast to the estimate based on physical principles an engineer would make.

At this point, recall that methanol is an intermediate product in the production of TCX ethanol. Thus, we can take the FFC and FVC directly from equation (2.1), dividing the FFC of TCX ethanol into one portion to produce methanol (FFCM) and the remainder to produce acetic acid and then producing TCX ethanol from the methanol input. Unfortunately, we don’t know what portion of the FFC is used in the methanol step. To get an idea of how much difference it makes, we estimate methanol costs per gallon for 25%, 50%, and 75% of the FFC. Results are shown in Table 2.10 for a range of NG prices. At current prices (about $3.50/mcf in 2012), the cost of methanol is between \$0.60 and \$1.07/gal.[12] If so, then the cost of producing methanol when NG is \$3.50/mcf is somewhere between 30¢ and 62¢/gal, and even at \$10/mcf, the per-gallon cost range for methanol is between 54¢ and 86¢. These estimates are well below the current market price of about \$1.30/gal as well as the maximum of \$1.16/gal implied by the TCX ethanol results.

Table 2.10. Estimated Production Costs of Methanol

NG price	Methanol FVCM	Methanol FFCM	Total cost
\$/mcf	\$/gal	\$/gal	\$/gal
Methanol FFCM = 25% of TCX ethanol FFC			
2	0.20	0.24	0.44
3.5	0.36	0.24	0.60
5	0.51	0.24	0.75
10	1.02	0.24	1.26
Methanol FFCM = 50%			
2	0.20	0.47	0.68
3.5	0.36	0.47	0.83
5	0.51	0.47	0.99
10	1.02	0.47	1.50
Methanol FFCM = 75%			
2	0.20	0.71	0.92
3.5	0.36	0.71	1.07
5	0.51	0.71	1.22
10	1.02	0.71	1.73

[12] These estimates are on the high end of an estimate found in a recent *Reuters* article (Mukhopadhyay and Krishnamurthy 2013).

Table 2.11 assumes that the methanol FFC is 50% of the TCX ethanol FFC to convert EIA's NG price projections in Table 2.3 into energy-equivalent price projections of methanol and gasoline out to 2030. These results suggest that, not only is methanol much cheaper than gasoline on an energy-equivalent basis, but it is much cheaper than ethanol as well. On a gasoline-equivalent basis, the estimated current wholesale prices of gasoline, E85, and M85 are \$2.78, \$2.31, and \$1.63/gge, respectively.

Table 2.11. Projected Wholesale Price Comparison, Methanol vs. Regular Gasoline

Year	NG price	E10 \$/gal	M85 \$/gge	M60 \$/gge
2012	3.58	\$2.78	1.63	2.59
2015	4.29	3.02	1.80	2.83
2020	4.58	3.19	1.89	2.98
2025	5.63	3.34	2.09	3.20
2030	6.29	3.45	2.22	3.35

2.2.1. Methanol Transport Costs

The physical and chemical properties of methanol are generally similar to those of ethanol, so we can draw on Section 2.2.2 above to estimate methanol transport costs. Despite the similarities, however, we would expect that methanol would be more costly to ship than ethanol on a per-mile basis, because the energy density of methanol is lower than that of ethanol. The cost of shipping a gge of methanol will thus be greater than the cost of shipping either gasoline or ethanol. Methanol is also more corrosive, although as noted in Section 2.2.2, that may not be an issue for tank truck or railcar.

Most methanol used in the United States is imported, and many US ports have extensive methanol-handling facilities, including New Orleans on the Gulf Coast; Wilmington, North Carolina, and New York on the East Coast; and Seattle, San Francisco, and Los Angeles on the West Coast. The same is true of internal ports on the Great Lakes and the Mississippi–Missouri–Ohio River system, with important methanol shipping centers at Chicago, St. Louis, Cincinnati, and Pittsburgh (Gebauer and Jordan 2002). And, as noted, methanol production is coming back to the United States, with at least two large production facilities set to come online in the next couple of years. Thus, shipment distances for methanol are likely to be lower than those for TCX ethanol for the next few years.

Table 2.12 shows a comparison of gasoline and methanol shipping costs. It is similar to Table 2.4; the only difference is the energy-equivalence adjustment factors for methanol and ethanol, but that difference raises methanol transport costs by quite a bit.

Table 2.12. Comparison of Gasoline and Methanol Shipping Costs for 500- and 1,000-mi Trips, ¢/gge

	500 mi		1,000 mi	
	Gasoline	Methanol	Gasoline	Methanol
Truck	15–20	30.3	30–40	56
Railcar	—	30.8		39
Unit train	4–6	14	7.5–12.5	24.2
Barge	2–2.5	22.9	4–5	27.5
Pipelines	0.8–1.2		1.5–2.5	
300 kgal/day		42.6		85.1
1,000 kgal/day		20.9		41.7
Ocean-going tanker	6	6	6	6

Note: kgal, thousand gallons.

2.2.2. Comparison of M85 and Gasoline at Retail

We now use the preceding results to make a rough comparison of the costs of M85, M60, and gasoline. We cannot be nearly as specific as we could in the case of E85, but we can make a pro forma calculation if we're willing to make a few assumptions, as follows.

- Methanol production costs are $0.60/gal.
- Methanol transport costs are 2¢/gge greater than ethanol (ocean) transport.
- The facility is located in California; therefore, total federal, state, and local fuel taxes come to $0.83/gge (estimated for 2012).
- M85 RBOB costs about the same as E85 RBOB ($2.95/gal).
- RBOB shipping costs can be ignored.

With these assumptions, the gasoline-equivalent price of M85 is $2.60. Comparing this price to the values presented in Table 2.7, our estimate of the pump price of M85 is right in the middle of the range of E85 prices in various cities. Although we estimate the production cost of methanol to be much less than that of TCX ethanol—less than half on a gasoline-equivalent basis—the cost difference is much smaller when comparing M85 and E85. Because methanol has a much lower energy density than ethanol, mixing it with RBOB or gasoline that has a much higher energy density has a larger effect on the energy density of the blended fuel.

2.4. CNG and LPG

CNG and LPG currently play small roles as motor vehicle fuels in the United States. In 2010, 140,000 LPG vehicles and nearly 116,000 CNG vehicles were registered in the United States (EIA 2012b). About half of the LPG vehicles and just under 60% of the CNG vehicles are LDVs, and most are fleet vehicles. However, they tend to be found mostly among the heavier LDVs, such as Chevy Suburbans and Ford F250s and F350s.

These two fuels have the potential to play a larger role, because they are low cost and noncorrosive. However, both are gases under ambient conditions, requiring pressurized tanks that are heavy, expensive to install, and can take up significant space in the vehicle. Such tanks have a smaller proportional effect on the volume and weight of a heavy-duty vehicle than an LDV. In addition, fueling station networks are sparse. Although 160,000 gasoline stations are available in the United States, only about 2,500 propane stations and 1,000 CNG stations are available, more than half of which are private.[13] Thus, LPG and CNG may be more suitable for heavy-duty and commercial fleet vehicles than for the private, light-duty fleet.

According to the *Clean Cities Alternative Fuel Price Report* (DOE 2012a) for October 2012, the average nationwide prices of LPG and CNG were $3.54 and $2.12/gge, respectively, at a time when the average pump price of gasoline was $3.82. Thus, CNG is the lowest-price alternative energy fuel. LPG is slightly less expensive than standard gasoline. However, propane industry analysts assert that the Clean Cities prices are more appropriate for backyard barbecues than for vehicles. They say that fleets with private stations or on-site storage can negotiate much more favorable prices. Werpy et al. (2010), citing data from industry sources, found that in 2009, monthly average propane prices at private stations were 35%–49% lower than comparable prices at public stations.

Table 2.13 shows retail price projections for LPG, CNG, and ULR gasoline, all taken from the AEO (DOE 2012b) Projected retail LPG prices track pretty closely with those of ULR, with both increasing by about 20% to 2030. During that same period, CNG prices increase by only 14%, compared to an increase in the projected wellhead price of NG of over 75% (see Table 2.3).

[13] Compressed natural gas (CNG) vehicle owners can also purchase a home fueling system for about $4,000 plus installation (Yacobucci 2011).

Table 2.13. Comparison of Retail Price Projections: LPG, CNG, and ULR Gasoline, $/ULR-Equivalent Gal

Year	LPG[a]	CNG[b]	Gasoline (ULR)[a]
2012	3.32	1.42	3.30
2015	3.74	1.46	3.54
2020	3.78	1.48	3.71
2025	3.92	1.57	3.86
2030	4.03	1.61	3.97
Pct chg, 2012–30	21%	14%	20%

[a] DOE (2012b, Petroleum product prices, Reference Case). As discussed in the text, substantial volumes are sold at private stations at lower prices.
[b] DOE (2012b, Natural gas supply, disposition and prices, Reference Case).

3. Vehicle Costs

This section examines the costs of converting existing vehicles—typically by purchase of a conversion kit—to be compatible with the various alternative fuels reviewed in this report: E85, M85, LPG, and CNG. The section also presents available information for new vehicles. The cost of new vehicles provides a lower bound on the conversion cost for vehicles in the existing fleet. The data presented here are derived from a range of sources, including reports from academic and government sources and national laboratories. We also provide information from the Internet on vendor prices. Although we have made some effort to assess the reliability of the reported information, in most cases we rely on the vendors' representations regarding both price and performance of the conversion kits.

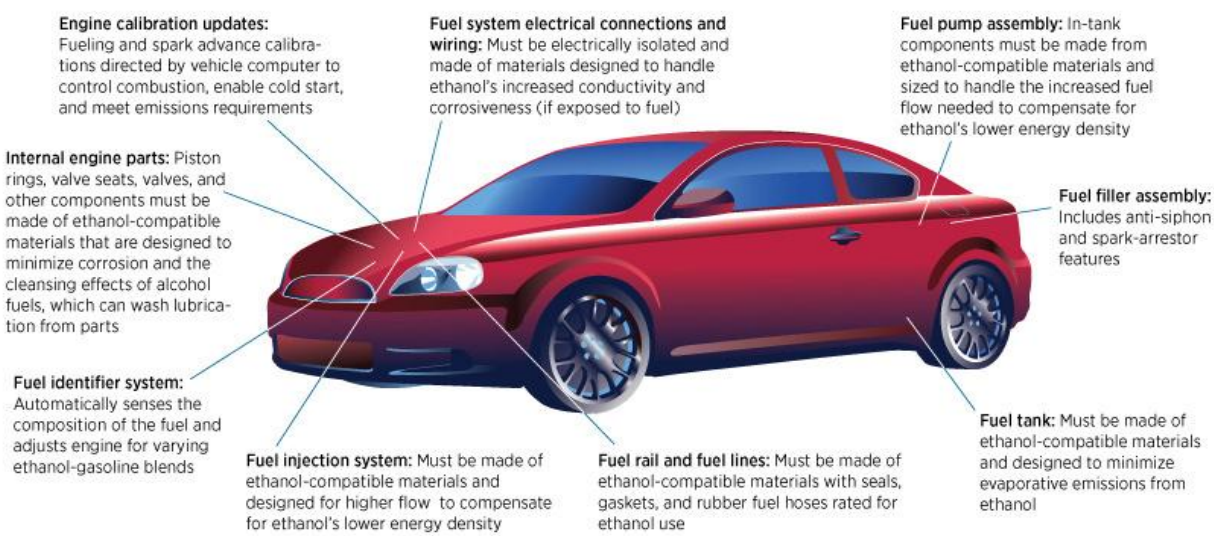
Apart from the direct vehicle conversion costs, other costs may affect consumer decisions. For example, the use of alternative fuels may affect vehicle performance or consumer convenience. We discuss some of these issues below, but we do not incorporate them in our payback calculations in Section 5.

3.1. Background

The approach to the conversion of vehicles to alcohol fuels differs from that for LPG and CNG. For ethanol and methanol, the general approach is to convert the vehicle to an FFV, which is designed to operate on conventional gasoline, an alternative fuel (ethanol or methanol), or a mixture of the two fuels. The alternative-fuel capability is incorporated directly into the existing fuel system. In contrast, LPG or CNG vehicles are typically either mono-fuel vehicles (that is, dedicated to a specific fuel) or bi-fuel vehicles with separate fuel tanks, fuel lines, dashboard instrumentation, and so on. Bi-fuel vehicles do not operate on a mixture of the two fuels.

For vehicles converted to FFVs using alcohol fuels, the changes in vehicle technology require a relatively simple upgrade in the gasoline-vehicle technology. The major issue in the conversion is to ensure that the fuel and engine components in the converted FFV are compatible with the alcohol fuel. TIAX (2012) identifies the following as components that may require modification of the fuel injection system and fuel pump because of the lower energy content of the alcohol fuels, hardening of engine valves and seats and piston rings to withstand the higher flow rates and the more corrosive environment associated with the use of alcohol fuels, and modification of the fuel tanks and lines to ensure their compatibility with the alcohol fuel and to avoid and higher evaporative emissions and deterioration in the materials (TIAX 2012). Figure 3.1 illustrates the changes that might be required to convert a conventional gasoline-fueled vehicle to an E85-capable FFV. (TIAX 2012, 33) Comparable changes would be required for an M85-capable FFV.

Figure 3.1. Components of an E-85 FFV Compared to Conventional Gasoline LDV



Source: DOE (2013h).

Although the conversion kit manufacturer needs to make an evaluation of these various components in converting a conventional gasoline-fueled vehicle, some analysts anticipate an increasing commonality between FFV and non-FFV vehicles. They suggest that, because they compete in global markets with a variety of different fuels in use, OEMs are likely to adopt common components compatible with alcohol fuels to reduce costs by condensing product lines and simplifying the supply chain for engine parts and fuel system components (TIAX 2012, 31). If this is the case, conversion of gasoline vehicles in the existing fleet might not require many of the modifications indicated above.

Although LPG and CNG vehicles can be designed as or converted to mono-fuel vehicles, the usual strategy in the United States and Europe is to convert the vehicles to bi-fuel capability. Maintaining gasoline capability means that the vehicle is not dependent on the limited refueling infrastructure for these alternative fuels. The gasoline capability may also help with ignition at cold start (Kramer and Anderson 2012). In addition, CNG vehicles use gasoline for engine starts to minimize cold-start methane emissions (Jackson 2012).

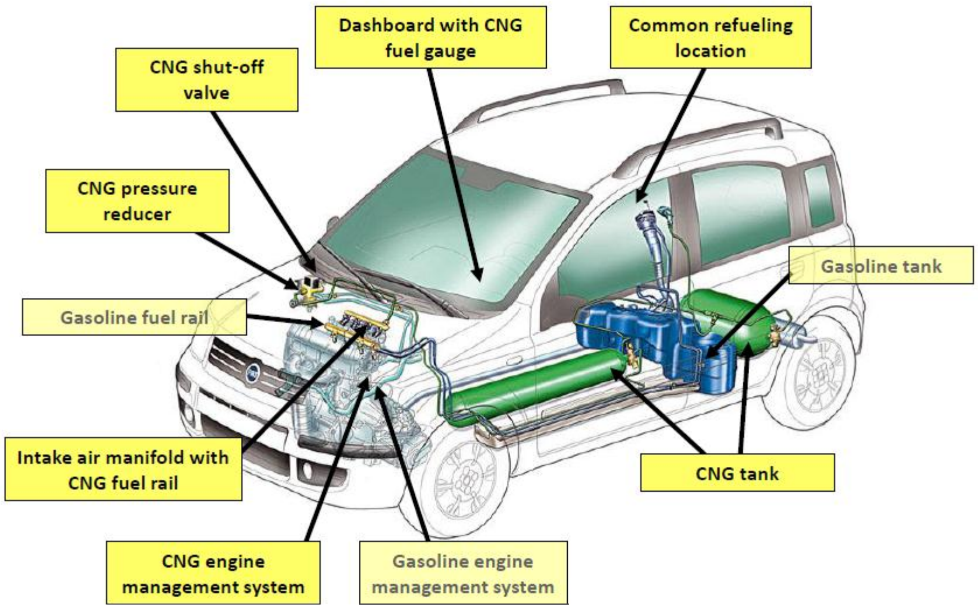
In terms of components, LPG and CNG vehicle conversions typically require separate fuel injectors (Kramer and Anderson 2012). Valve and valve seats may need to be hardened, and spark plug durability will need to be evaluated. The bi-fuel vehicles will also need to be optimized for operation with both fuels—but even with optimization, some reduction in performance with the alternative fuel may occur. For example, Edmunds (n.d. [a], 2013b) reports some reduction in power output for CNG bi-fuel pickups.[14] The separate fuel system in the bi-fuel vehicles also requires a separate fuel tank. The addition of a separate high-pressure fuel storage tank represents one of the most important and expensive changes with conversion of these vehicles to bi-fuel capability. Finally, after-treatment emissions control systems will need to be optimized for both gasoline and alternative-fuel use. In the case of CNG vehicles, European OEMs add a separate catalyst to control methane emissions.

Because of the complicated engine and after-treatment emissions controls of modern gasoline engines, the integration of these alternative fuels into the complex gasoline engine technologies requires close interaction with the OEMs to ensure effective performance and durability over the life of the vehicle (Jackson 2012).

Figure 3.2 illustrates the changes that might be required to convert a conventional gasoline-fueled vehicle to a bi-fuel CNG vehicle (Jackson 2012, 6).

[14] For CNG operation, the power output for the Chevrolet Silverado and GMC Sierra drop to 301 horsepower and 333 lb-feet of torque, from 360 horsepower and 380 lb-feet of torque with gasoline operation (Edmunds n.d.[a], n.d.[b]).

Figure 3.2. Example of European Natural Gas Vehicle



Source: Jackson (2012).

3.2. E85 FFVs

OEMs sell new E85 FFVs that can use conventional gasoline (E10), E85, or a mixture of the two fuels. In recent years, OEMs have sold hundreds of thousands of these FFVs; current DOE estimates suggest that more than 10 million E85 FFVs are in the existing US fleet. The design changes for an E85 FFV could include higher fuel pump delivery volume, wider bandwidth fuel injectors, engine emissions calibration, ethanol-compatible materials for all surfaces coming into contact with ethanol, and a fuel identifier system (TIAX 2012, 33). Although estimates of the incremental OEM production cost of an FFV are on the order of $100 to $200/vehicle (Anderson and Sallee 2011), EPA (2010a) reports that new FFVs are priced the same as gasoline-only vehicles.

One manufacturer, Flex Fuel US, offers an aftermarket conversion kit for $1,295 that has been certified for several MY 2006–2007 Ford and Chrysler vehicles.[15] EPA has reviewed this conversion kit and listed it with other alternative-fuel conversion kits. Anecdotal evidence from

[15] On its website, Fuel Flex US (n.d.) indicates that, with economies of scale, this conversion kit could potentially be installed for less than $500 per vehicle. See also Jonny Energy (n.d.).

two users suggests that no additional vehicle performance or maintenance issues are associated with the use of these conversion kits; one user reported some reduction in fuel economy consistent with the lower energy density of E85 (TIAX 2012, 39).

Aftermarket conversion kits are also offered on the Internet. These kits have not been certified by EPA and have not gone through the new notification process provided by EPA's 2011 rule revising its procedures for alternative-fuel conversions. Fuel Flex International (n.d.) is offering an E85 conversion kit for LDVs for $369 (with a $50 discount in November 2012). A website with international listings for E85 conversion kits lists prices ranging from $60 to $160 per conversion kit (Alibaba.com n.d.).

For the payback calculations presented in Section 5, we use a cost range of $320 to $1,300 for the conversion of vehicles in the existing fleet to E85 FFVs.

3.3. M85 FFVs

Because M85 is not an available fuel, no M85 vehicles are currently produced for the US market. California initiated an M85 pilot program in the late 1980s to take advantage of the superior emissions characteristics of M85 fuel vis-à-vis the gasoline-fueled vehicles of that period. At its peak in the mid-1990s, roughly 100 fueling stations and thousands of M85 FFVs were on California's highways (TIAX 2012, 27). However, the sharp drop in gasoline prices and improvements in the emissions characteristics of gasoline vehicles by the mid-1990s brought the California program to a close.

Methanol is more corrosive than ethanol. As a result, development of an M85 vehicle poses additional challenges. The design changes required for an M85 FFV could include higher fuel pump delivery volume, wider bandwidth fuel injectors, engine emissions calibration, methanol-compatible materials for all parts coming into contact with methanol, and a fuel identifier system. In addition, certain engine design changes were required for new Ford Taurus FFVs produced in the 1990s, including changes to the cylinder head to address pre-ignition with M85 and the use of cylinder piston rings, valve seats, and other parts that were more resistant to wear. Further work is required to evaluate the extent to which the use of methanol will require modification or replacement of specific vehicle components in converting the existing vehicle fleet to M85 (TIAX 2012, 41-43).

3.4. LPG (Propane) Vehicles

In the United States, OEMs do not directly provide new bi-fuel LPG vehicles; instead, outfitters convert the new OEM vehicles to use LPG as bi-fuel vehicles.[16] There are roughly 143,000 LPG-capable vehicles currently in use in the United States (EIA 2012b).[17] A conversion kit manufacturer, Icom North America, reports a price for a bi-fuel LPG conversion system of $6,500/vehicle (Beene 2010). Argonne National Laboratory (Werpy et al. 2010) reports costs of $7,800 for a conversion kit for a Ford F150 and $10,000 for a conversion kit for a Ford F250 or F350 based on prices from Roush. The conversion kit manufacturers have certified these kits with EPA.

For the payback calculations presented in Section 5, we use a cost range of $6,500 to $10,000 per conversion kit.

3.5. CNG Vehicles

Honda is the only OEM providing passenger LDVs using CNG; in recent years, Honda has been selling roughly 1,000 of these vehicles a year (Atiyeh 2012). Yacobucci (2011) reports a $5,000/vehicle incremental price for the Honda Civic GX dedicated CNG vehicle compared to a Honda Civic EX (using gasoline). NREL (2011, slide 5) reports a cost of $7,000/vehicle based on (a) bookmark cost estimates from Honda and (b) Business Case for CNG in Municipal Fleets. With the exception of the Honda Civic, most LDV conversions are carried out by certified conversion kit outfitters. NREL reports that there are eight conversion kit manufacturers (two of these make bi-fuel kits) and more than 100 outfitters (NREL 2011, slide 4). But these manufacturers are operating in niche markets mostly servicing government or private fleets. In 2009, DOE estimated that 100,000 CNG LDVs and trucks were in use on US highways (EIA 2012b; Davis et al. 2011).

Some Internet sources suggest that aftermarket CNG conversion kits—the more advanced sequential injection kits—start at $2,000 without the tanks (Cupler 2012). CNG tanks would increase the cost by $1,000 to $1,500. These kits may not be EPA certified. Government and

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16 In Germany, liquid petroleum gas (LPG) aftermarket conversion kits are available for roughly $2,600 to $3,300. In some eastern European countries, less expensive conversion kits are available for as little as $900; these “OEM uncontrolled” kits are considered to be of lower quality and durability (Kramer and Anderson 2012).

17 Note that a separate DOE website (2013a) reports 270,000 LPG vehicles; this figure includes school buses.

Internet sources suggest that the use of these aftermarket kits may cause issues with engine performance, emissions performance, and durability.

Regarding light-duty trucks (LDTs), General Motors began selling NG-fueled Chevrolet Silverado and GMC Sierra pickups in mid-2012 with an $11,000 premium over comparable gas-fueled models (Atiyeh 2012). In the latter part of 2012, Chrysler introduced a CNG-powered Ram pickup with a premium of $11,500 (Foley 2012).

For the payback calculations for LDVs, we adopt a cost premium of $5,000 to $7,000/vehicle over the cost of a gasoline vehicle.

3.6. Other Costs/Issues Affecting Consumer Conversion Decisions

For all of these alternative fuels, only a limited refueling infrastructure is in place. Roughly 2,500 stations have E85 pumps, half of which are located in six midwestern states, compared to more than 160,000 conventional gasoline stations across the United States (EIA 2012a, 7). There are also roughly 2,500 LPG stations, one-quarter of which are in Texas and California. Fewer than 1,200 CNG stations are available in the United States, and only 600 of these are public stations (DOE 2013f).[18] The inadequacy of the refueling infrastructure may impose "convenience" costs on consumers in terms of search costs in finding a refueling station and driving time required to get to an available station. The scarcity of refueling stations may also result in higher pump prices than would occur in a more competitive market. The lower energy content of these fuels (and with practical limits on tank capacity) may also require more visits for refueling than would be required with a conventional gasoline-fueled vehicle.

In terms of vehicle attributes, CNG may decrease engine performance and fuel economy (Cupler 2012). Efforts to optimize engine performance and fuel economy using CNG may degrade engine performance with the use of gasoline. Finally, CNG tanks add extra weight and take up space in the vehicles, reducing the carrying capacity of LDVs and LDTs (Jackson 2012; Kramer and Anderson 2012).

Similarly, LPG fuel may also adversely affect engine performance and fuel economy (Cupler 2012). In addition, LPG fuel can adversely affect the valves of vehicles that have not been properly retrofitted. Finally, LPG storage tanks will also add to vehicle weight and take up valuable space, reducing vehicle carrying capacity (Kramer and Anderson 2012).

[18] Also see Werpy et al. (2010, 4) and NREL (2011, slide 6).

4. Social Benefits

Two categories of social benefits are generally attributed to the use of alternative fuels in place of conventional gasoline: the environmental benefits of reducing vehicle emissions and the energy security benefits of reducing US consumption of oil.

4.1. Environmental Benefits of Using Alternative Fuels

Through the 1980s and 1990s, vehicles using alternative fuels had significantly lower tailpipe emissions of conventional pollutants—volatile organic compounds (VOCs), carbon monoxide (CO), and nitrogen oxide (NO_x)—than those using conventional gasoline or E10. However, at the end of the 1990s, EPA adopted more stringent fuel and emissions standards for gasoline-fueled vehicles. As a result, current LDVs using conventional gasoline have direct conventional emissions that (with a few exceptions) are comparable to the emissions of vehicles converted to use alternative fuels. And although the shift to alternative fuels may decrease emissions of certain gasoline-related air toxics, such as benzene, these fuels are likely to increase aldehyde emissions. More research is needed on the potential trade-offs among these pollutants. Despite the existing technical potential to reduce GHG emissions, especially by the control of methane leakage from NG production, recent estimates suggest that the well-to-wheel emissions of GHGs associated with currently available NG-based alternative fuels are roughly comparable to the well-to-wheel GHG emissions of conventional gasoline or E10. Given these comparabilities, and recognizing the considerable uncertainty in these estimates, we have chosen not to develop monetized benefit estimates for the possible difference in emissions between the use of conventional gasoline and the conversion of LDVs to NG-based alternative fuels.

In the sections below, we provide a more detailed discussion of the estimates of the direct vehicle emissions and the well-to-wheel emissions associated with the use of conventional gasoline and NG-based alternative fuels. Conventional pollutants and air toxics are both location-specific pollutants—damages associated with the emissions of these pollutants are greater in heavily populated areas with elevated ambient pollutant levels (at levels of concern). For this reason, reductions in direct vehicle emissions in heavily populated areas may be more important than reductions in the well-to-tank emissions associated with production of these fuels (particularly where the production facilities are located in remote, lightly populated areas). In contrast, for global pollutants like GHGs, damages are independent of the location of emissions. In this case, reductions of GHG emissions from fuel production and distribution are equally important as reductions in direct vehicle emissions.

4.1.1. LDV Emissions from Conventional and Alternative Fuels

Several rules developed by EPA in the late 1990s established substantially more stringent tailpipe emissions limits (e.g., EPA's Tier 2 rule requiring three-way catalysts) for light-duty cars and trucks and testing requirements that mandate more robust and durable control systems.[19] As a result, MY 2004 and later vehicles using alternative fuels and vehicles using conventional gasoline are likely to have comparable levels of tailpipe emissions of conventional pollutants, such as VOCs, CO, and NO_x.[20] This represents an important change from the substantial advantage alternative fuels had in terms of reducing these emissions compared to 1990s-vintage cars and trucks using conventional gasoline.[21]

Recent information published in DOE's (2012c) *Clean Cities 2012 Vehicle Buyer's Guide* indicates that virtually all of the EPA smog scores are the same for E85 and gasoline for the more than 50 listed 2012 E85 FFVs.[22] One listed vehicle—the Mercedes-Benz C300 4MATIC—had a better smog score of 5 using E85 compared to a score of 3 using gasoline. Under current regulations, manufacturers do not have a significant incentive to optimize FFV use of E85 to minimize emissions. Overall, only limited information is available on the potential to optimize alternative-fuel FFV conversions to reduce emissions of conventional pollutants. Certification data and limited testing on a small number of mid-2000–vintage vehicles for varying levels of ethanol blends show substantial variability across blends and FFVs. Some of the results suggest that FFVs operating on E85 may achieve small additional reductions in CO and NO_x emissions. However, the test results do not offer a consistent pattern of reduction for

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[19] This includes EPAs Tier 2 motor vehicle emission standards limiting the tailpipe emissions from LDVs, EPA's CAP2000 rule requiring OEMs to perform tests on the in-use fleet to confirm durability projections made at certification, and the Supplemental Federal Test Procedure (phased in over the MY 2001 to MY 2004 period), which added test cycles to the certification process to better represent actual driving habits.

[20] With the development of the three-way catalyst for spark ignition engines, the advantages of lower emissions and lower reactivity from methanol fuels have been eliminated (Bromberg and Cheng 2010). This is also probably the case for LPG, but without recent LDV testing, the exact benefits of LPG vehicles over their gasoline counterparts are unclear (Werpy et al. 2010).

[21] Methanol was originally pursued as part of an air quality strategy in California during the 1980s and 1990s to reduce tailpipe emissions of hydrocarbons and NO_x, which are precursors to photochemical ozone formation (TIAX 2010, 15).

[22] The smog scores are based on vehicle tailpipe emissions that contribute to local and regional air pollution.

these pollutants, and we found no discernible trend for other conventional pollutants.[23] The certification data also indicate that FFVs have somewhat lower emissions when using gasoline than do the same or similar non-FFVs. These results suggest that the calibration or design of FFVs provides a more effective control of emissions than the control systems for the same or similar non-FFVs (Yanowitz and McCormick 2009). (See the appendix for a further summary of these papers.)

Some literature suggests that engines could be optimized to achieve additional reductions in tailpipe emissions with the use of alternative fuels. TIAX (2012) reports some suggestive evidence that vehicles optimized (in a cost-effective way) to use alcohol fuels would yield reductions of conventional pollutants and gasoline-related pollutants (e.g., benzene, toluene, and xylene [BTX]) vis-à-vis conventional gasoline. However, substantial additional testing needs to be done to identify the potential reductions across a converted fleet of alternative-fueled vehicles relative to current gasoline vehicles. The story is more varied with respect to evaporative emissions from vehicles. The evaporative nonmethane hydrocarbon emissions from CNG vehicles are negligible and therefore much lower than the emissions from conventional vehicles. EPA regulations require that evaporative hydrocarbon emissions from E85 FFVs must be comparable to the evaporative emissions from conventionally fueled vehicles. Similarly, vehicles converted to E85 or to M85 will be required to meet the evaporative emissions limits for conventional vehicles. However, E85 may further reduce emissions of certain pollutants compared to conventional gasoline or lower-volume ethanol blends. For example, E85 is somewhat less volatile than conventional E10 gasoline, which may result in lower evaporative emissions.[24]

In the case of M85, high evaporative emissions issues can occur in FFVs when gasoline is introduced in a tank that contains small amounts of methanol. Because vehicle evaporative systems are sized for gasoline, adding methanol to gasoline that has not been modified to reduce its front-end volatility will almost certainly result in saturation of the canister and, consequently,

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[23] Tessum et al. (2010) combine the results for Tier 0 and Tier 1 flexible-fuel vehicles (FFVs) with the certification data for Tier 2 FFVs. However, there are good reasons to report the results for Tier 2 FFVs separately (the approach adopted by Yanowitz and McCormick [2009])—and Tessum et al. acknowledge as much. However, the Tessum et al. paper helps to inform our presentation of the certification data for Tier 2 vehicles because it provides additional information and detail on the certification data and on the Yanowitz and McCormick paper. Also see Coordinating Research Council (2011), Yassine and La Pan (2012), and Thomas et al. 2012.

[24] E85 is not eligible for the “1-lb” Reid vapor pressure waiver that E10 receives.

high evaporative emissions. Further research is required to investigate the possible effects of adding methanol to ethanol gasoline blends (Bromberg and Cheng 2010). Conversion could require modification of the vehicle's evaporative emissions control system to achieve EPA's evaporative emissions limits (TIAX 2012, 42).[25]

Cold-start emissions with methanol and ethanol blends require seasonal adjustment of the fuel formulation. Because these fuels have a high flash temperature (the temperature at which fuel vapors form an ignitable mixture in air), starts during cold weather are more challenging than with gasoline. In the case of methanol, cold-weather start is problematic because of the greater evaporative cooling of the methanol. More work needs to be done on cold-start emissions in cold-weather conditions (Bromberg and Cheng 2010).

With respect to toxic emissions, conventional gasoline vehicles may have higher emissions of aromatic air toxics like BTX, but the only emissions test data available seem to be for earlier Tier 0 and Tier 1 vehicles. E85- and M85-fueled vehicles will have higher aldehyde emissions—formaldehyde for methanol blends and acetaldehyde for ethanol blends.[26] Emissions test data for E85 FFVs indicate a substantial increase in aldehyde emissions with the use of E85. Acetaldehyde is the more prevalent aldehyde with increases (where reported) of a factor of two or more; formaldehyde emissions increase on the order of 50% or more (see appendix). In MY 2004 and later vehicles, Bromberg and Cheng (2010) suggest that both BTX and aldehyde tailpipe emissions would be well controlled by the three-way catalyst (Bromberg and Cheng 2010). Taken together, for MY 2004 and later vehicles, Yanowitz and McCormick do not see any substantial advantage in terms of air toxics emissions from the use of alternative fuels versus conventional gasoline blends because the reductions of the higher-toxicity gasoline-related air

[25] TIAX (2012) reports that, with the more corrosive nature of methanol on materials, additional costs may be required to ensure the materials compatibility of the evaporative control system.

[26] Testing has shown that neat methanol combustion produces a level of aldehydes about twice that of gasoline, with formaldehyde the predominant toxic emission from methanol combustion. Aldehyde emissions are effectively controlled by the use of a catalytic converter (Bromberg and Cheng 2010; EPA 2010a).

toxics are offset by the significant increases in aldehyde emissions (Yanowitz and McCormick 2009, 177).[27]

The conversion of older conventional vehicles (prior to MY 2004) would yield substantial reductions per vehicle (in grams per mile) in conventional and air toxic emissions. However, many of these vehicles are nearing the end of their useful lives and typically log substantially lower annual vehicle miles traveled compared to newer vehicles. Thus, the overall benefits (including the cost savings and the displacement of petroleum-based fuel) from the conversion of older conventional vehicles to alternative fuels are likely to be substantially smaller than those from the conversion of cars and trucks from more recent MYs (e.g., MY 2010 vehicles).

4.1.2. Well-to-Wheel GHG Emissions for Conventional and Alternative Fuels

California has developed well-to-wheel carbon intensity factors in implementing its Low Carbon Fuel Standard (or LCFS; California Air Resources Board [CARB] 2010; NREL 2011, slide 14). See Table 4.1. Table 4.1 presents the California-based estimates for these carbon intensity factors. The well-to-wheel carbon intensity factor for CNG produced in California is roughly 30% below that for gasoline. Most alternative fuels derived from renewable biomass also have well-to-wheel carbon intensity factors below that for gasoline. For example, the carbon intensity factor for California-produced corn ethanol and for Brazilian sugarcane-based ethanol are, respectively, 15% and 23% below that for gasoline. However, the carbon intensity factor for ethanol produced in the Midwest is greater than that for gasoline.[28] There is considerable uncertainty associated with these estimates because they involve estimates and assumptions regarding the energy required, the type of energy used to produce the alternative fuels (coal, NG, electricity, gasoline, diesel, and so on), and the emissions associated with the well-to-tank production and distribution of these fuels. These carbon intensity factors for NG-derived fuels

[27] We note as well that EPA's National-Scale Air Toxics Assessment (NATA) provides screening model estimates of the risks associated with exposure to air toxics, including benzene and formaldehyde. The 2011 NATA report (EPA 2011b) identifies formaldehyde as a national cancer driver (lifetime cancer risk > 10 in a million for a population > 25 million) and benzene as a regional cancer driver (lifetime cancer risk > 10 in a million for a population > 1 million). EPA (2011a) estimates that the national average lifetime cancer risk level is 50 in a million, or 210 cancers per year. Formaldehyde and benzene account for 60% of this national risk, with formaldehyde accounting for the greater share.

[28] This high estimate relative to California-produced corn-based ethanol reflects both the greater reliance on coal as an energy source in the Midwest and the substantial emissions associated with the transport of ethanol to California.

were based on estimates of the GHG emissions leakage associated with NG production available in 2009. Estimates for emissions associated with NG production in recent EPA emissions inventory reports were revised up in 2010 and were revised down in 2013. Because of the considerable uncertainty in these estimates, they are likely to be revised further.[29]

Table 4.1. Well-to-Wheel GHG Emissions Relative to Conventional Gasoline

	California LCFS[a]	Other sources
Ethanol	CA corn: 15% decrease Midwest corn: 10% increase Sugar: 23% decrease	Corn (average): 19% decrease[b] Corn (NG-fuel): 28% decrease[b] Sugarcane: 60% decrease
Methanol		9% decrease[c]
LPG	N/A	10% decrease[d]
CNG	21% decrease	6%–11% decrease[e]

[a] CARB (2010). [b] DOE (2013g).[c] TIAX (2010). [d] DOE (2013e). [e] DOE (2013c).

Other sources also provide lifetime well-to-wheel estimates. EPA estimates suggest that, relative to gasoline, the use of ethanol will result in lifecycle GHG reductions of 19% for corn-based ethanol (considering the current average across all production), 28% for ethanol production using NG as a fuel (but not as a feedstock), and 78% for ethanol produced from sugarcane (DOE 2013g; EPA 2010b, 471). TIAX (2010) calculated a 9% reduction in lifecycle GHG emissions for methanol relative to gasoline. Note also that the well-to-wheel GHG emissions for ethanol produced using the Celanese TCX process will be higher than the estimated emissions for methanol produced using NG as a feedstock because methanol is an intermediate product in the process. DOE reports that vehicles running on propane will reduce lifecycle GHG emissions by nearly 10% vis-à-vis gasoline (DOE 2013e). Argonne National

[29] In April 2013, EPA substantially reduced its estimate of the methane emissions from natural gas production compared to the 2010–2012 reports, which present estimates of GHG emissions in EPA's Inventory of Greenhouse Gas Emissions and Sinks (EPA 2013). The 2013 EPA estimate appears to be more consistent with estimates underlying the lifecycle emissions estimates presented in this report. Considerable uncertainty in these emissions estimates remains because they are based in large measure on emissions factors developed from a mid-1990s emissions inventory study. Several studies are underway to provide data on the emissions associated with current production practices, and EPA plans to revise these estimates to reflect the best information available.

Laboratory (Werpy et al. 2010) estimates that GHG emissions for CNG are approximately 6% to 11% lower than for gasoline throughout the fuel life cycle. CNG lifecycle GHG emissions are predominately the result of production-phase fuel leakage. Considerable uncertainty is also associated with these estimates for the reasons outlined above.

Recent information published in DOE's *Clean Cities 2012 Vehicle Buyer's Guide* indicates that 18 of 49 listed E85 FFVs have higher GHG scores (I.e., lower GHG emissions) using E85 compared to similar vehicles using conventional gasoline (DOE 2012c).[30] No comparable information is available for CNG and LPG vehicles.

4.2. Energy Security Benefits of Using Alternative Fuels

The literature generally identifies three separate energy security benefits associated with a reduction in US consumption of foreign oil: (a) a reduction in the macroeconomic effects of a world oil price shock or supply disruption, (b) a pecuniary benefit with the exercise of US market power (as a major consumer [monopsonist] in the world oil market) by curtailing its demand for foreign oil, and (c) a reduction in national security costs devoted to trying to preserve a dependable supply of oil. We address each of these below.

4.2.1. Macroeconomic Effect

The macroeconomic effects of sharp increases in world oil prices—with or without a specific disruption in oil supply—have been widely discussed and studied since the Arab oil embargo triggered by the 1973 Arab–Israeli (Yom Kippur) War. A disruption in oil supply reduces US economic production and, if sustained for long enough, could result in an economic downturn. Similarly, sharp increases in oil prices can reduce consumption and aggregate demand, potentially triggering a recession (Hamilton 2009, 2011).[31] An economic downturn imposes significant costs, with increased unemployment and the loss of economic output. Because changes in oil prices and supply occur relatively quickly, they may also impose additional transition costs as producers and consumers adjust to the new price structure. A

[30] One vehicle reported a lower GHG score relative to gasoline; no information was available for several vehicle types. EPA data for combined city and highway fuel economy testing indicate a drop in fuel economy (in mi per gallon [gal]) using E85 that is roughly commensurate with the lower energy content of test grade E85 (TIAX 2012, 36–37).

[31] Hamilton (2011) notes that if sharp energy price increases result in an increase in the share of income devoted to energy purchases, then these increases can affect consumption patterns and reduce the level of income and aggregate demand within the oil-importing country.

reduction in these macroeconomic costs associated with a cut in US dependence on oil imports and/or with a reduced role of petroleum products in the nation's macroeconomic health represents an important "external" benefit beyond the direct cost savings associated with a shift to alternative fuels.

In their most recent rulemaking for LDVs, EPA[32] and the National Highway Traffic Safety Administration (NHTSA 2012) have developed estimates of this macroeconomic benefit based on recent DOE-funded Oak Ridge National Laboratory (ORNL) studies (Leiby n.d., 2008, 2011, 2012). In their recent RIAs for the CAFE standards for MY 2017–2025 cars and light trucks, EPA/NHTSA estimate that each gallon of fuel saved that results in a reduction in petroleum imports would yield a benefit to the US economy of $0.197/gallon (in 2010$), with a range of $0.096 to $0.284/gallon.

4.2.2. The Monopsony Effect

Because the United States is a major consumer and purchaser in the world oil market, changes in the US demand for oil can affect world oil prices. In a manner similar to the way a coalition of suppliers like the Organization of the Petroleum Exporting Countries can exert monopoly power by restricting oil supply, the United States, through a concerted policy effort, can exert monopsony power by restricting its demand for oil. In its recent CAFE RIA, NHTSA reports that the available evidence suggests that US demand for imported petroleum continues to have some effect—albeit limited—on world oil prices. Based on recent ORNL studies, NHTSA (2012) reports that the monopsony effect would yield a benefit of $0.23/gallon saved, with a range of $0.077 to $0.397/gallon.

These "savings"—as realized in the form of lower gasoline prices at the pump—represent a transfer to US consumers, as well as consumers in other net-importing countries, from foreign producers of oil. Because it is purely a transfer, EPA and NHTSA do not include the monopsony effect in their RIA analysis of the benefits of more stringent CAFE standards.

4.2.3. National Security

Finally, some analysts argue that a national security effect is associated with US dependence on foreign oil imports. That is, US military force structure and expenditures are in part related to strategic concerns associated with maintaining a dependable supply of oil from

[32] 77 FR 62717

regions that are vital sources of supply, like the Middle East. However, in their analysis, EPA and NHTSA suggest that US military expenditures are governed by a broader set of security and foreign policy objectives and that military expenditures "are unlikely to vary significantly in response to changes in the level of oil imports" (NHTSA 2012, 900). EPA and NHTSA note that the costs of maintaining the Strategic Petroleum Reserve also have not been sensitive to changes in oil import levels. EPA and NHTSA do not include a national security benefit in their RIAs for the MY 2017–2025 CAFE standards.[33]

4.2.4. Converting Reductions in Domestic Consumption into a Change in Oil Imports

In their RIA for the MY 2017–2025 CAFE standards, EPA and NHTSA estimate that each gallon of petroleum fuel saved as a result of more stringent CAFE standards would reduce US oil imports by 0.95 gallons. The remaining 0.05 gallons would reduce domestic oil production. NHTSA explains that 50% of the reduction in fuel consumption would reduce the import of refined fuel. The remaining 50% reduction in consumption would reduce domestic refinery production of fuels, with 90% of this reduction coming from a reduction in US import of crude oil (and the remaining 10% from a reduction in US crude oil production).

5. When Do Vehicle Conversions Pay?

In Section 2, we showed that TCX ethanol, if produced, could offer motorists substantial savings over conventional gasoline (E10) in some areas of the country. Furthermore, one important class of vehicles—E85 FFVs—is currently capable of burning such fuel legally with no engine modifications required. Already, about 10 million such vehicles are on the road in the United States, so widespread availability of TCX ethanol at a price substantially below that of E10 would very likely make an immediate and substantial impact in the light-duty transportation market. Also, as noted, owners of CNG or LPG vehicles are already benefiting from the reduced prices of these fuels.

For all other vehicle–fuel combinations, including the pairing of TCX ethanol and non-FFVs, vehicle modifications would be required before the cheaper NG-based fuels could be used. In this section, we combine the conversion cost estimates of Section 3 with the fuel cost estimates of Section 2 to consider the circumstances under which such conversions might make

[33] NHTSA (2012) notes that the ORNL study also concludes that any federal budget savings would be unlikely to result from a reduction in oil use on the scale of the reductions projected for the MY 2017–2025 CAFE standards.

sense to the motorist. One should remember that methanol is not currently being used as a vehicle fuel, so these calculations assume the existence of a fuel distribution network.

In principle, the economic attractiveness of vehicle modifications to burn other fuels sets the cost of vehicle conversion against the average annual cost of fuel, which depends on (a) the difference in price between the old and new fuels and (b) annual fuel consumption. Fuel use, in turn, depends on annual mileage and fuel consumption rate.

5.1. E85 Conversions

Tables 5.1 and 5.2 show the annual savings and estimated payback period for the cities used in the E85 cost comparison of Table 2.9 for an LDV driven 15,000 mi/year at 20 mpg and 30 mpg, using the AEO 2012 projections of prices shown in 2012 and 2015, respectively. As shown, E85 FFVs require no vehicle conversion, and if E85 became available in these cities at these prices, owners of these vehicles would enjoy an immediate windfall of several hundred dollars per year. Other vehicles would need to be converted. For conversion costs, we used the upper and lower bounds of conversion costs reported in Section 3. Perusal of Tables 5.1 and 5.2 suggests that the economics of vehicle conversion to burn E85 are quite favorable for the low end of conversion costs. When the conversion cost is $320, the payback period is usually less than two years for both 2012 and 2015 projections. For conversion costs of $1,300/vehicle, the payback period is three to five years for each selected city except Tampa and Pittsburgh in 2012. In 2015, the payback period is less than five years for all cities.

Table 5.1. Payback Period and Annual Savings for E85 Conversions in Selected Cities, 2012

City	E85 price	E10 price	Annual savings (15,000 MPA[a])		Payback period (years)			
					$320	$1,300	$320	$1,300
	$/gge	$/gal	20 mpg	30 mpg	15,000 MPA, 20 mpg		15,000 MPA, 30 mpg	
Washington, DC	3.29	3.80	383.32	255.55	0.83	3.39	1.25	5.09
Boston	3.11	3.69	437.33	291.55	0.73	2.97	1.10	4.46
San Francisco-Oakland	3.53	4.10	427.91	285.27	0.75	3.04	1.12	4.56
Seattle-Portland	3.25	3.84	439.34	292.90	0.73	2.96	1.09	4.44
Los Angeles	3.53	4.07	405.41	270.27	0.79	3.21	1.18	4.81
Tampa	3.20	3.51	234.83	156.55	1.36	5.54	2.04	8.30
New York City	3.46	3.97	384.83	256.55	0.83	3.38	1.25	5.07
Pittsburgh	3.35	3.70	261.40	174.27	1.22	4.97	1.84	7.46
Philadelphia, PA-NJ	3.20	3.70	377.33	251.55	0.85	3.45	1.27	5.17

[a]Miles per year

Table 5.2. Payback Period and Annual Savings for E85 Conversions in Selected Cities, 2015

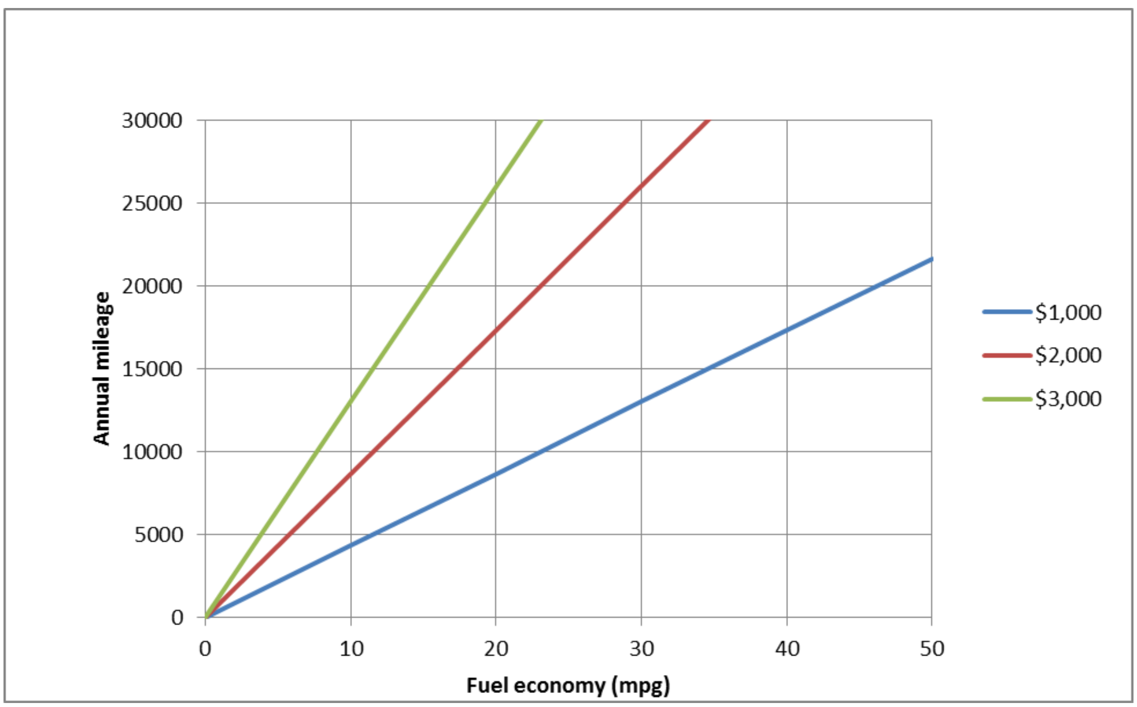
City	E85 price	E10 price	Annual savings (15,000 MPA)		Payback period (years)			
					$320	$1,300	$320	$1,300
	$/gge	$/gal	20 mpg	30 mpg	15,000 MPA, 20 mpg		15,000 MPA, 30 mpg	
Washington, DC	3.39	4.13	551.77	367.85	0.58	2.36	0.87	3.53
Boston	3.20	4.01	606.34	404.23	0.53	2.14	0.79	3.22
San Francisco-Oakland	3.62	4.45	623.16	415.44	0.51	2.09	0.77	3.13
Seattle-Portland	3.35	4.17	617.76	411.84	0.52	2.10	0.78	3.16
Los Angeles	3.62	4.42	598.71	399.14	0.53	2.17	0.80	3.26
Tampa	3.29	3.81	392.19	261.46	0.82	3.31	1.22	4.97
New York City	3.55	4.31	571.97	381.31	0.56	2.27	0.84	3.41
Pittsburgh	3.45	4.02	424.53	283.02	0.75	3.06	1.13	4.59
Philadelphia, PA-NJ	3.29	4.02	546.99	364.66	0.59	2.38	0.88	3.56

5.2. Methanol Conversions

Because we were unable to find any estimates of the cost of conversion to methanol, we approached the question in a different way. Given the estimated savings of methanol over conventional gasoline on an energy-equivalent basis, under what circumstances will a conversion cost of X be justified? Given X and the estimated per-equivalent gallon savings that methanol enjoys over gasoline, we calculate the combinations of vehicle use and fuel economy that justify conversion. In making these calculations, we assume a breakeven payback period of up to three years and use the methanol and gasoline pump prices estimated in Section 2.2, which, in turn, assume that the median state gasoline tax is 26¢/gge and that the fuels will be transported 500 mi from the refiner or port of entry.

The results are shown in Figure 5.1. For a given dollars-per-gallon margin, the breakeven conversion cost declines with gallons used, which, in turn, increases with annual vehicle use and decreases with fuel economy. Unsurprisingly, the vehicles most amenable for conversion are gas guzzlers with high annual mileage. The figure also suggests, however, that conversion may pay even for high-mpg vehicles; for example, a 20-mpg vehicle meets the conversion threshold at about 9,000 mi/year.

Figure 5.1. Minimum Annual Mileage To Justify Conversion Cost (Three-Year Payback)



5.3. LPG and CNG

In the late 1990s and shortly thereafter, OEMs produced several vehicle models powered by LPG and CNG. The number of LPG models reached five for all manufacturers by 2002, but after that year all production of LPG vehicles by OEMs ceased (Werpy et al. 2010). OEMs also produced a small number of CNG-powered vehicles, and a few of these are still being made, including the Honda Civic CNG, Chrysler RAM truck CNG, and several GM cargo vans. Although conversions by individuals still occur, both markets have been taken over by vehicle conversion manufacturers, who work with the Propane Education and Research Council and OEMs to enable Tier 2 OEM products to burn CNG or LPG, either exclusively or in an FFV with gasoline and sometimes E85 as other fuels. Concurrent with the fuel conversions, these vehicles are often customized to meet niche applications, such as taxis, police vehicles, paratransit buses, and school buses (Werpy et al. 2010).

The total number of alternative-fuel vehicles by type, shown annually for 1995 through 2010 in Table 5.3, indicates that the number of LPG vehicles grew slowly until 2003, then dropped much more rapidly, until by 2010 the LPG fleet was 17% smaller than it was in 1995. At the same time, the CNG fleet grew by 140% between 1995 and 2002, then stagnated or declined slightly, probably because of increases in the relative price of NG-derived alternative fuels relative to gasoline. In 2010, likely reflecting the drop in the relative price of NG, the fleet again started to increase.

The fact that CNG is a gas rather than a liquid, and that LPG, a liquid under pressure, turns gaseous at room temperature, drives the high cost of vehicle conversions. The estimates shown in Section 3 range from $6,500 to $10,000 for LPG conversions and $5,000 to 7,000 for CNG. CNG vehicles, at least, have the attraction of a very low fuel price, $2.12/energy-equivalent gal as well as a well-developed pipeline system that, if the demand were there, could probably deliver NG to fueling stations at low transportation costs, possibly even lower than that for gasoline. Comparing the average retail price of the two fuels, CNG enjoys a price advantage of $1.70/gge (Section 2.3), more than any other fuel examined. But given the estimated costs, the conversion to CNG of a 30-mpg gasoline vehicle that is driven 15,000 mi/year would have a payback period of 5.9 to 8.2 years. For a larger vehicle getting only 15 mpg, or a vehicle driven 30,000 mi/year, the payback period would be halved, at 2.9 to 4.1 years. This is more attractive, but it is hardly comparable to the payback periods for ethanol in favorable locations. It is only for large, heavy vehicles with high usage rates that fuel conversion makes economic sense. That is why most of the certified conversions among LDVs involve vehicles like Ford F250 or F350 trucks and vans and similar vehicles.

Table 5.3. Estimated Number of LPG and CNG Vehicles Registered in the United States

Year	LPG	CNG
1995	172,806	50,218
1996	175,585	60,144
1997	175,679	68,571
1998	177,183	78,782
1999	178,610	91,267
2000	181,994	100,750
2001	185,053	111,851
2002	187,680	120,839
2003	190,369	114,406
2004	182,864	118,532
2005	173,795	117,699
2006	164,846	116,131
2007	158,254	114,391
2008	151,049	113,973
2009	147,030	114,270
2010	143,037	115,863

Source: Davis et al. (2012, Table 6.1).

6. Regulatory Barriers/Pathways to Using Alternative Fuels in the Existing Fleet

6.1. Background

Title II of the CAA requires car and truck manufacturers to obtain a "certificate of conformity" prior to the production and sale of their vehicles and engines. This certificate of conformity assures that every vehicle and engine sold in the United States will conform over its useful life to EPA emissions standards. Under the certification process, EPA requires car and truck manufacturers to submit detailed information to show that their vehicles or engines meet all applicable emissions standards.[34] EPA (n.d. [a]) has also specified certification test procedures to measure vehicle or engine emissions, and manufacturers are required to use these emissions tests in demonstrating compliance with its emissions standards. EPA also has the authority to require

[34] EPA has established stringent tailpipe emissions limits for carbon monoxide, hydrocarbons, nitrogen oxides, particulate matter, and formaldehyde for MY 2004 and later LDVs. EPA has also set stringent evaporative hydrocarbon emissions standards for these vehicles. Beginning with MY 2012, LDVs and LDTs must also meet EPA emissions standards for GHGs.

further emissions testing of engines or vehicles, during production or after purchased vehicles have been in use for several years, to confirm that the manufacturer is producing compliant vehicles that will meet emissions standards over the vehicle's full useful life.[35]

Section 203(a)(3) of the CAA prohibits tampering with engines or vehicles.[36] The purpose of this antitampering provision is to maintain the integrity of the engine, fuel system, and emissions control system of the original vehicle or engine over the useful life of the vehicle. However, Section 203(a) also provides an exemption or waiver for the purpose of conversion of a motor vehicle to allow for the use of a clean alternative fuel as long as the vehicle or engine continues to meet applicable emissions standards. To implement this provision, EPA has developed a program—initially established through a 1994 rule—that allows manufacturers of alternative-fuel conversion kits to show that their systems warrant exemption from the CAA antitampering provision. The 1994 rule set out, as a key tenet of EPA's regulation of alternative-fuel conversions, the requirement that "an aftermarket conversion not degrade the emissions performance of the original vehicle as a condition of being exempt from prosecution for tampering."[37]

In 2011, EPA revised its regulation of alternative-fuel conversions by issuing its Clean Alternative Fuel Vehicle and Engine Conversions rule.[38] The rule represents EPA's effort to clarify and streamline its requirements for providing a waiver from the CAA antitampering provisions under Section 203(a). The rule creates some additional compliance options to reduce the economic and procedural impediments that clean alternative-fuel conversion manufacturers faced under EPA's earlier 1994 regulations.

LPG and CNG vehicles dominate the legitimate conversion market. Since 2003, EPA has accepted 532 vehicle conversion certifications (EPA 2012), of which all but 5 are concerned with either LPG (253) or CNG (274). (The others include kits for the conversion of gasoline vehicles to E85 FFVs and three kits for the conversion of hybrids to plug-in hybrids.)

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[35] EPA has defined "useful life" for recent model year light-duty cars and trucks as 10 years or 120,000 mi, whichever comes first (40 CFR 86.1805-04).

[36] EPA interprets the antitampering provision as applying to vehicles or engines regardless of age or mileage accumulation (76 FR 19833).

[37] 59 FR 48477.

[38] 76 FR 19830.

EPA makes available a list of all conversion kits it has certified since 2003. Table 6.1 summarizes this information, showing the number of conversion kits that have been certified by EPA each year between 2003 and 2012. Information on the number of vehicles converted for each approved conversion kit is unavailable, unfortunately. As shown, certification of LPG conversion kits dominated between 2003 and 2006, but then certification activity for conversion kits of all sorts nearly came to a halt in 2007–2008, perhaps as a reflection of the severe recession at the time. In 2009, the certification of LPG conversion kits resumed at levels enjoyed before 2007, while certification of CNG conversion kits grew so rapidly that they soon outnumbered LPG certifications by more than two to one, perhaps as a reflection of the drop in NG prices beginning in 2009. Throughout, EPA lists hardly any applications for certification of conversion kits of any other vehicle types. The much larger number of E85 FFVs on the road was almost entirely the result of OEM activity.

Table 6.1. Number of EPA-Certified Conversion Kits by Year

	LPG[a]	CNG[b]	Electric[c]	E85[d]
2003	43	0	0	0
2004	29	0	0	0
2005	16	4	0	0
2006	26	0	1	0
2007	7	0	1	1
2008	12	8	0	0
2009	21	20	1	0
2010	31	91	0	0
2011	35	77	0	0
2012	27	70		0

[a] Includes gasoline to LPG or to LPG–gasoline, and gasoline/E85 to LPG–gasoline/E85.
[b] Includes gasoline to CNG or to CNG–gasoline, and gasoline/E85 to CNG–gasoline/E85.
[c] Includes hybrid to plug-in hybrid.
[d] Includes gasoline to E85.
Source: EPA (2012).

6.2. EPA's Current Program for Clean Alternative-Fuel Vehicle Conversions for the Light-Duty Fleet

The 2011 rule established three conversion categories by vehicle vintage to facilitate age-appropriate testing and compliance procedures:[39]

[39] 76 FR 19832.

- new or nearly new (i.e., current or preceding MY;[40]
- no longer new, but within EPA's definition of useful life (i.e., less than 10 years old and less than 120,000 mi); and
- beyond useful life (i.e., more than 10 years old or greater than 120,000 mi).[41]

For both the "new" and "no longer new, but within useful life" categories, the current program for obtaining an exemption from the antitampering provisions maintains some key requirements—that is, a showing that kit conversions meet the same emissions standards as required for OEM certification. This includes emissions testing that satisfies EPA's required certification test cycles to demonstrate that the conversion kit meets intermediate and full useful life standards.

However, the addition of the "no longer new" and "beyond useful life" categories represents key changes to EPA's regulatory program for the conversion of alternative-fuel vehicles. For vehicles in these two categories, conversion kit manufacturers are required only to assemble a compliance notification, rather than go through the full certification process to recertify the vehicle with dual- or mixed-fuel capability. Manufacturers can also use an on-board diagnostics (OBD) scan test to show that the OBD system remains fully functional.

The revised program also includes some streamlining features that reduce the cost and burden of the program for "no longer new" and "beyond useful life" vehicles. The new compliance notification process allows conversion kit manufacturers to rely on good engineering judgment in preparing their compliance notifications for EPA. Good engineering judgment can include an engineering analysis showing that the conversion kits will meet acceptable emissions performance in the converted vehicles. Key elements in assessing good engineering judgment for a conversion kit include whether the conversion kit (a) uses technology that is at least equivalent to that of the OEM system and equally effective in design, materials, and overall sophistication; (b) uses components sized to match engine power requirements; (c) uses instantaneous feedback control; and (d) maintains proper OBD system functions.[42] A claim of good engineering

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40 76 FR 19842.

41 76 FR 19858–19859. EPA requires this demonstration even though a standard under Section 202 is no longer applicable. EPA argues that Section 203 contains a threshold criterion—that is, "conversion of a motor vehicle for use of a clean alternative fuel." EPA interprets this language to require a showing that a conversion will not degrade vehicle emissions (76 FR 19833).

42 76 FR 19834.

judgment will also probably include emissions test data to support the engineering analysis.[43] The use of good engineering judgment can reduce the amount of emissions testing required by allowing conversion kit manufacturers to apply one set of test data to represent a broader range of OEM vehicles in demonstrating that the conversion to alternative fuels will not adversely affect emissions control performance.[44] See Table 6.2 for a summary of EPA's requirements by vehicle vintage.

Key streamlining features:

- Although "no longer new but within useful life" vehicles must meet the same emissions standards as required for OEM certification, kit manufacturers are not required to meet full certification procedures. Relief for this category includes the following.[45]
    - A compliance notification process in place of certification, with reduced paperwork requirements and no certification fee.
    - Use of an OBD scan tool test to show that the OBD system remains fully functional for the converted vehicle (instead of the OBD demonstration tests required for OEM certification). This change alone reduces the testing cost by $26,000 per vehicle/engine family.
    - Elimination of OBD test group criterion.
- For "beyond useful life" vehicles, manufacturers can show that emissions will not increase with the alternative-fuel conversion by submitting detailed technical information describing the conversion system. EPA's evaluation will be based on good engineering judgment. EPA may require emissions test data if the technical description does not provide adequate assurance that the conversion kit will not degrade emissions performance or durability.[46] In addition, relief for this category includes the following.
    - A compliance notification process in place of certification, with reduced paperwork requirements and no certification fee.

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[43] Any testing or data must be generated at a quality laboratory capable of performing emissions tests that comply with EPA regulations (76 FR 19834–19835).

[44] 76 FR 19834–19835.

[45] 76 FR 19857–19858.

[46] 76 FR 19851.

- Use of an OBD scan tool test to show that the OBD system remains fully functional for the converted vehicle (instead of the OBD demonstration tests required for OEM certification). This change alone reduces the testing costs by $26,000 per vehicle/engine family.

Some additional cost-reducing elements of the current program are available to conversion kit manufacturers.

- Conversion kit manufacturers may carry over data from one MY to the next if the OEM did so in the original certification.[47]
- EPA allows conversion kit manufacturers to provide a statement of compliance in lieu of test data for the original fuel if the converted vehicle retains all of the OEM fuel system, engine calibration, and emissions control system functions when operating on the original fuel.[48]

Finally, small-volume conversion kit manufacturers (< 15,000 units/year) may use EPA default deterioration factors in lieu of long-term, high-mileage durability testing.[49]

In-use compliance. Clean alternative-fuel conversion manufacturers are subject to in-use requirements, including warranty, defect reporting, and recall requirements. EPA also has authority to conduct in-use testing.[50]

[47] 76 FR 19835.

[48] 76 FR 19836.

[49] 76 FR 19842. Note that in its recent rules establishing LDV GHG emissions and Corporate Average Fuel Economy Standards, EPA has adopted alternative definitions for small businesses and small-volume manufacturers. For small businesses, EPA uses the Small Business Administration definition, such that any firm with fewer than 1,000 employees (worldwide) is exempt from the GHG emissions standards. This definition applies beginning with the GHG emissions standards for MY 2013. EPA also provides that small-volume manufacturers—manufacturers with annual sales of fewer than 5,000 vehicles—can petition the agency for alternative emissions standards starting in MY 2017 (77 FR 62653–62654).

[50] 76 FR 19850.

Table 6.2. Key EPA Requirements for Manufacturers of Alternative-Fuel Conversion Kits

	New	Intermediate age	Beyond useful life
Certification	Yes; small-volume mfrs. eligible for fee adjustment	No; compliance notification; no certification fee	No; compliance notification; no certification fee
OBD tests	Full OBD demonstration	OBD scan test	OBD scan test
Emissions test requirements	Full set of EPA emissions tests	Full set of EPA emissions tests, but with flexibility to combine engine families (see below); small manufacturers may use EPA-specified deterioration factors in place of durability tests (see below)	Detailed technical information supported with test data
Engine group combination	Alternative-fuel kit mfrs. have some flexibility to combine engine families	Elimination of OBD grouping criterion	Good engineering judgment and test data may be sufficient to replace extensive testing
Emissions test baseline	Certification standards	Certification standards	Good engineering judgment and test data that support position that alternative fuel would not degrade emissions performance of vehicle
Durability test	Yes	Yes; but small-volume mfrs. can use EPA-assigned deterioration factors in place of durability tests	Good engineering judgment showing that alternative fuel will not degrade long-term vehicle emissions control performance

6.3. Case Study: EPA Grant of a Partial Waiver for E15

EPA's recent decisions providing a partial waiver for E15 for MY 2001 and later vehicles were made in the context of an evidentiary standard that is arguably similar to the standard that would apply for an alternative-fuel conversion kit. The waiver request was submitted under Section 211(f)(4) of the CAA by Growth Energy and 54 ethanol manufacturers. The E15 partial waiver was granted under a provision other than the antitampering language of Section 203(a), but the governing language is very similar.[51] EPA granted a partial waiver for E15 subject to the condition that summertime Reid vapor pressure not exceed 9.0 pounds/square inch. The waiver applies only to LDVs and LDTs for MY 2001 and later. EPA also requires that a fuel or fuel additive manufacturer deploying E15 must obtain EPA approval of a plan (and implement the plan) to prevent misfueling of vehicles and equipment for which E15 is not approved.[52] EPA reached its E15 decision based on potential effects in four areas: (a) exhaust emissions, immediate and long-term (durability); (b) evaporative emissions, immediate and long-term; (c) impact of materials compatibility on emissions; and (d) impact of drivability and operability on emissions (76 FR 4663).

In providing its partial waiver for E15, EPA relied heavily on "engineering judgment" in making its decision. For MY 2007 and later vehicles, EPA found that the emissions control systems for MY 2001 and later motor vehicles are more technologically advanced and robust than those of vehicles built in earlier years because of Tier 2 emissions standards and the additional testing programs adopted by EPA. Thus, based on its engineering assessment for these

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[51] Note that EPA views the Section 211 waiver process as entirely separate from the Section 203(a) exemption from the antitampering requirements of Section 203.

[52] 75 FR 68094 (November 4, 2010) and 76 FR 4662 (January 26, 2011). The DC Circuit recently dismissed the petitions for review for lack of standing, over a strong dissent. *Grocery Manufacturers Assoc. v. EPA*, 693 F.3d 169 (August 17, 2012). The court denied a petition for rehearing en banc, again over a dissent, on January 15, 2013. Some of the petitioners, including the American Petroleum Institute, recently petitioned the Supreme Court for writ of certiorari.

vehicles (supported by data from DOE's Catalyst Durability Study), EPA concluded that these vehicles would be capable of operating on gasoline–ethanol blends up to E15.[53]

EPA supported its engineering judgment with DOE test data for 19 vehicle models from MY 2007 and later and 8 vehicle models for the MY 2001–2006 period.[54] Durability testing was subcontracted to three laboratories: Southwest Research Institute, Transportation Research Center, and Environmental Testing Corporation.[55] The criteria used in selecting models for testing included coverage of major manufacturers, substantial sales volume for the vehicle, and characteristics of the vehicle design (i.e., whether the vehicle maintains an ideal air/fuel mix at wide-open throttle through an adaptive learning process).[56] For MY 2007 and later vehicles, the testing was restricted to Tier 2–compliant vehicles,[57] which were driven up to their full useful life (120,000 mi) using E15. Initial mileages for these vehicles ranged from near 0 to 50,000 mi; vehicles in the test program were driven approximately 70,000 to 120,000 mi.[58] To complete the

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[53] 75 FR 68105. Similarly, in setting out the basis for a partial waiver for MY 2001–2006 vehicles, EPA cited several regulatory programs in effect or phasing in for MY 2000: California Low-Emission Vehicle standards; EPA National Low-Emission Vehicle standards; CAP2000, requiring OEMs to perform tests on the in-use fleet to confirm durability projections made at certification; and the Supplemental Federal Test Procedure (phased in over the MY 2001–2004 period), which added test cycles to the certification process to better represent actual driving habits. EPA also cited the more stringent Tier 2 standards promulgated in 2000 (with phase-in beginning in MY 2004) as affecting OEM planning and design of vehicles over this period. Also, the early reduction credit provisions of Tier 2 provided an incentive for the early adoption of better control design and strategies. As a result of these regulatory changes, EPA argued that OEMs adopted more robust control for the MY 2001–2006 vehicles, similar to the technology used in Tier 2 vehicles, and that this technology would be durable with the long-term use of E15 (76 FR 4666–4670). As another factor, EPA also pointed to the substantial compliance margin OEMs designed into vehicles over the MY 2001–2006 period. With large compliance margins, vehicles using E15 would continue to meet emissions standards even with some emissions increase resulting from long-term use of E15 (76 FR 4670).

[54] DOE's Catalyst Durability Study initially involved 19 high sales volume car and LDT models (MY 2005–2009). The purpose of the study was to evaluate the long-term effects of E0, E10, E15, and E20 on the durability of the exhaust emissions control system. Analysis of the results at full useful life showed no significant difference between E0-fueled and E15-fueled vehicles (75 FR 68096).

[55] 75 FR 68105.

[56] The objective of this vehicle design is to adjust the amount of fuel injected to maintain the ideal stoichiometric air/fuel ratio. With learned fuel trim, the computer accumulates over time and stores in memory information on the air/fuel ratio. This information, combined with information on other measures of engine operation, allows the computer, through an adaptive learning process, to adjust the amount of fuel injection to maintain a long-term ideal air/fuel ratio.

[57] 75 FR 68106.

[58] 75 FR 68106.

test program, motor vehicles had to undergo anywhere from six to nine months of mileage accumulation and emissions testing.[59]

Through the use of engineering judgment, EPA was able to support its partial waiver decision for a large number of engine families across 10 MYs using emissions tests for a relatively small set of vehicle models (27 vehicle models; 83 vehicles).[60]

Two other features of EPA's waiver decision point to the potential for flexibility in the compliance notification process. In evaluating the DOE test data, EPA compared E15 vehicle emissions to EPA emissions standards for OEM certification—that is, EPA's emissions standards served as the baseline, not the much lower actual vehicle emissions reported by the OEMs for certification.[61] In addition, EPA accepted some increase above EPA standards for evaporative emissions for two vehicles, arguing that, on average across the whole fleet, E15-fueled cars would be better than E10-fueled vehicles (given the 1-pound Reid vapor pressure waiver for E10).[62]

6.4. Testing Costs for EPA's Revised Exemption Process for Alternative-Fuel Conversion Kit Manufacturers

6.4.1. EPA Cost Estimates for a Small Manufacturer

In its 2011 rule, EPA provided cost estimates for obtaining an exemption from the antitampering provision of the CAA for clean alternative-fuel conversions for small-volume conversion kit manufacturers (76 FR 19854). The cost estimates vary depending on the age of the vehicle. Vehicles in the "new, or nearly new" category must go through EPA's certification procedures; manufacturers can use EPA's new, lower-cost notification process for "no longer new" and "beyond useful life" vehicles.[63] The EPA testing cost estimates presented in Table 6.3

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[59] 75 FR 68107.

[60] Similarly, for the other factors relevant to waiver determinations (e.g., evaporative emissions and materials compatibility), EPA also employed engineering judgment based on and/or confirmed by available information, including data from DOE and other test programs (76 FR 4665).

[61] Exhaust emissions from vehicles certified by OEMs typically are roughly half the allowable emissions set by EPA rules (e.g., Tier 2 standards).

[62] 76 FR 4663.

[63] The actual cost of obtaining an exemption may vary from EPA's cost estimates, depending on such factors as conversion technology, fuel type, vehicle age, and the conversion manufacturer's sales volume (76 FR 19853).

represent the costs for a single aftermarket conversion for an OEM certification for a single engine family. These cost estimates do not include the cost of conducting durability tests.[64]

Table 6.3. EPA's Revised Exemption Process: Cost Estimates for Small-Volume Conversion Kit Manufacturers

	"New vehicle": testing cost for one aftermarket fuel conversion certificate[a]	"Intermediate-age vehicle": testing cost for one aftermarket fuel conversion kit
Total cost for exhaust tests	$6,258[b]	$6,258[b]
Total cost for evap tests	$6,369	$6,369
Total cost for OBD demo tests	$26,317	—
Total cost for OBD scan tool demo tests	—	$287
Total cost for travel, vehicle shipments, and data submission	$16,867	$12,916
Total cost for conversion	$55,811	$25,830

Notes: 2010$
[a] Does not include certification fees. [b] Does not include durability emissions tests.
Source: EPA, 76 FR 19857–19858

Much of the difference in cost between the "new" vehicle category and the two "no longer new" vehicle categories arises because the 2011 rule allows conversion kit manufacturers for vehicles that are of intermediate age and "beyond useful life" to use an OBD scan test in place of a full OBD demonstration test. This change reduces the testing costs for these vehicles by $26,000 for each engine group.

[64] 76 FR 19858. In supporting its partial waiver decisions for E15, EPA used DOE test data for 27 vehicles from MY 2001 and later. DOE's durability testing required driving/testing the vehicles up to the 120,000-mile useful life limit (these tests required six to nine months; 75 FR 68107).

EPA believes that, under the revised program, manufacturers of conversion kits will be able to combine engine test groups so that test data for a single engine family can be used over a broader set of vehicles. The use of test data for combined engine test groups would reduce the costs for each vehicle family, as defined by the OEM.[65] In addition, small-volume manufacturers would be able to use EPA-assigned deterioration factors in place of the durability testing required for large-volume manufacturers.

The cost estimate for the conversion of new vehicles does not include the certification fee. The certification fee for a 2010 LDV certificate was $35,000. Small manufacturers of conversion kits can use a reduced fee program for certification for the conversion of new vehicles. EPA used a certification fee estimate for new vehicles of $4,000 per engine family in developing its cost estimate for small-volume kit manufacturers.[66]

No certification fee is required under the revised rule for the compliance notification for conversion of “no longer new” and “beyond useful life” vehicles.[67]

6.4.2. Cost Estimates for Larger Manufacturers

The cost estimates presented above for a small manufacturer of conversion kits would also apply to larger manufacturers.

No certification fee is required under the revised rule for the compliance notification for the conversion of “no longer new” and “beyond useful life” vehicles.[68]

However, the EPA cost estimates above do not include the cost of conducting the durability emissions tests required of larger conversion kit manufacturers. As noted above, DOE conducted durability emissions tests in studying the effects of E15 on vehicles in the existing fleet. The DOE contract for the durability tests of 27 engine models (83 vehicles) over their full useful life cost $21 million, or a cost of $250,000/vehicle.[69] This estimate might be at the high end, given the specific circumstances surrounding the proposed waiver for the use of E15. At the same time, conversion kit manufacturers must provide other emissions test data in addition to the durability emissions tests.

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[65] 76 FR 19857.

[66] 76 FR 19856.

[67] 76 FR 19841.

[68] 76 FR 19841.

[69] Personal communication, Kevin Stork, DOE Energy Efficiency and Renewable Energy Office, October 11, 2012.

As a result, for a larger manufacturer of conversion kits, the cost of a compliance notification might fall in the range of $200,000 to $300,000 per test group, at least for the initial set of conversion test groups.[70]

6.5. EPA's Process: Pathways for Conversion of Existing Vehicles to Alternative Fuels

One should consider two key elements in converting existing vehicles to dual-fuel vehicles capable of using an alternative fuel: (a) the likely benefits and cost savings of converting existing vehicles and (b) the degree of difficulty in obtaining an EPA exemption from the antitampering provisions of the CAA. A targeted program would focus on high-mileage vehicles with lower miles per gallon performance—for example, light-duty pickup trucks and sport utility vehicles—because the conversion of these vehicles will yield the largest cost savings. Targeting a conversion initiative to specific vehicles also has important advantages because it reduces the cost and hassle of obtaining an EPA exemption and maximizes the actual gains from the program.[71] We identified the following conversion programs in terms of the degree of difficulty in obtaining an EPA exemption from the CAA antitampering provisions.

- *E85 for the existing fleet of FFVs*. More than 10 million FFVs currently on the road are capable of using E85. FFVs have EPA certification, and no additional regulatory hurdles hinder the use of E85 in these vehicles. DOE (2013b) reports that 2,270 E85 stations are available in the United States.[72]
- *Small-volume conversion kit manufacturers for "no longer new" vehicles*. The small-volume exemption applies to manufacturers with total annual sales less than 15,000 units. The use of EPA's small-volume exemption could be a particularly attractive approach in setting up a demonstration project. Conversion kit manufacturers falling into this category would be able—after appropriate consultation with EPA—to begin marketing conversion kits without having to carry out extensive durability testing of converted engines, substantially reducing the time and cost of securing an EPA exemption from the

[70] TIAX (2012b) reports a cost of $230,000 for one new vehicle retrofit certification.

[71] Any assessment of a conversion program by an alternative fuel conversion kit manufacturer should factor in the potential costs and business risks that would accompany adverse Inspection/Maintenance and in-use test results and the potential consequences of being targeted by EPA for a possible enforcement action.

[72] The bulk of the E85 stations are in the Midwest. There are 69 E85 stations in Texas, 56 stations in California, 17 stations in Nevada, and 4 stations in Utah.

CAA antitampering provision. Adopting this route for the deployment of alternative-fuel conversion kits would allow a manufacturer to obtain in-use experience with the kit, without the cost and potential regulatory delay of obtaining an EPA exemption for large-volume sales of a conversion kit. A developer of conversion kits might be able to take advantage of the small-manufacturer exemption from some testing requirements by licensing and supplying its kits to separate, independent entities (e.g., one company could do conversions of Ford trucks, and a separate, independent company could do conversions of GM sport utility vehicles). Under this approach, each of the independent entities would be required to file a compliance notification with EPA and be responsible for conversion kit performance, warranty, and so forth. The extent to which a developer might use this approach deserves a careful legal review.

- *Conversion kits for "beyond useful life" vehicles*. Manufacturers of conversion kits for "beyond useful life" vehicles will be able to use engineering judgment (coupled with some supporting test data) to minimize the amount of engine exhaust and evaporative emissions testing required to secure an EPA exemption. There is no need, for example, to conduct durability testing, because vehicles are beyond their useful life. But EPA expects a "good engineering judgment" presentation on the durability of the conversion kit and compatibility of the alternative fuel.[73] The disadvantage of focusing on this group of vehicles is that the gains per vehicle of conversion are likely to be lower. These are older vehicles with reduced remaining useful life and typically lower annual vehicle miles traveled.
- *Large-volume manufacturers of conversion kits for "no longer new" vehicles*. Large-volume manufacturers of conversion kits will be required to conduct durability tests for their conversion test groups for "no longer new" vehicles. Durability emissions testing is a potentially costly part of the compliance notification package. One particularly attractive target for large-volume manufacturers would be to develop conversion kits for vehicles for which there were corresponding production runs of E85 FFVs (e.g., the 2009 Chevrolet 1500 Suburban). Some observers have suggested that these vehicles are more likely to use designs and parts that are compatible with the use of alcohol fuels.

[73] EPA encourages conversion kit manufacturers to discuss their plans with the agency before assembling a compliance notification package.

Overall, we believe that several relatively low-cost pathways are available for addressing the recently revised EPA process for developers of alternative-fuel conversion kits. With respect to E85, roughly 10 million FFVs already in the existing fleet can use E85. In addition to these FFVs, another significant stock of vehicles that are similar to the FFVs can be converted to beE85 capable FFVs. A pilot project to convert these vehicles to E85 FFVs could be eligible for EPA's relatively streamlined small-volume kit outfitter process. EPA estimates that the testing costs would be on the order of $26,000 for a grouping of similar OEM vehicle models for a small-volume conversion kit outfitter.

For larger kit distributors and manufacturers, testing costs will be larger—perhaps $200,000 to $300,000—for a conversion test group because of EPA's requirements for durability testing. However, EPA allows manufacturers and distributors to group similar vehicle models to form a conversion test group.[74] The willingness of EPA to apply, to the alternative-fuel conversion kit notification process, grouping procedures similar to those used in approving the use of E15 under Section 211 of the CAA would reduce the uncertainty and the regulatory approval costs for kit developers.

Finally, for vehicles beyond their useful life, conversion kit manufacturers can submit a compliance notification, based on good engineering judgment, and limit the amount of emissions testing required to support their technical information package. The cost of EPA's process for these older vehicles would arguably be closer to $26,000 for a grouping of similar vehicle models than the $200,000 to $300,000 estimate for certification of a new or intermediate-age vehicle model. As noted above, the willingness of EPA to apply grouping procedures similar to those used in approving the use of E15 would reduce the uncertainty and the regulatory approval costs for kit developers.

6.6. EPA's Process: Manufacture and Distribution of Alternative Fuels

Section 211(f)(1)(A) of the CAA makes it unlawful for a fuel manufacturer to introduce into commerce a fuel or fuel additive that is not substantially similar to a fuel used in the certification of vehicles manufactured after MY 1974. All of the alternative fuels considered in this paper—E85, M85, LPG, and CNG—are being used, or have been used, in certified vehicles

[74] 76 FR 19857.

manufactured after MY 1974. However, this prohibition could apply to other fuel formulations, such as M60.

The only exception to the general prohibition lies in Section 211(f)(4), which authorizes EPA to issue waivers after a showing that the fuel will not cause or contribute to a failure of the vehicle to meet emissions standards. Thus, if a conversion manufacturer obtains certification for its conversion kit using a new alternative fuel such as M60, a fuel manufacturer that supplies the fuels for use in such vehicles would not be acting in violation of the Section 211(f)(1)(B) prohibition. But if the conversion kit manufacturer supplies EPA with only the notification package allowed by the Clean Fuel Conversion Rule—for instance, for an intermediate-age MY vehicle or family of vehicles—the fuel manufacturer would arguably violate the Section 211(f)(1)(B) prohibition if it were to distribute the fuel for use in the converted vehicles, unless the fuel manufacturer were first to secure a waiver under Section 211(f)(4). Alternatively, the conversion kit manufacturer could submit a certification package for one make/model of vehicle to satisfy the Section 211 certification requirements. As a result, the agency's willingness to find that its notification process for an alternative-fuel conversion kit under the 2011 rule also satisfies the waiver provision under Section 211(f)(4) for the manufacture and distribution of the alternative fuel would help reduce the barriers to the conversion of the existing fleet to alternative fuels.

6.7. Other Potential Barriers to the Use of Alternative Fuels in the Existing Fleet

6.7.1. State Standards

E85, LPG, and CNG are already deployed as alternative fuels, and an expansion in the use of these fuels should not face significant barriers. For high-level methanol blends (M70 to M85), converted vehicles are subject to California's Low-Emission Vehicle or Zero Emission Vehicle standards and would be required to meet these standards when using a methanol blend. Note that California would also require any methanol–gasoline blend to undergo a multimedia evaluation before it could be distributed for use within the state (TIAX 2010, 10.)

California also has a stringent certification process for conversion kit manufacturers. According to TIAX (2012, conversion kit manufacturers report that California standards are more stringent and costly than the corresponding EPA requirements. These manufacturers suggest changes in the California program similar to those adopted by EPA in its 2011 rule. In particular, they suggest that California could revise the OBD requirements and adopt a special allowance for small-volume manufacturers similar to those adopted in EPA's program for alternative-fuel conversions.

6.7.2. ASTM International

ASTM International has developed voluntary consensus standards to ensure product quality, enhance safety, and facilitate market activity. ASTM standards are available for the four alternative fuels considered in this report. The ASTM standard for E85 specifies an ethanol content of 51 to 83 volume percent; the standard for M85 specifies a methanol content of 70 to 85 volume percent.

Twenty-three states have incorporated ASTM standards for low-level ethanol blends in their regulations, and 17 have incorporated ASTM standards for E85 (TIAX 2010, 9). With an expansion in the distribution of E85 or M85, other states would probably move to adopt ASTM standards, with some attendant regulatory lag (especially for M85).

6.7.3. LCFS

California has adopted its LCFS with the goal of reducing the carbon intensity of transportation fuels. Some other states are also considering adoption of an LCFS. For the California LCFS, most alternative fuels derived from renewable biomass have carbon intensity factors below that for gasoline. However, ethanol produced in the Midwest has a carbon intensity factor that is greater than that for gasoline. The TIAX-calculated carbon intensity for methanol produced from NG is lower than that of gasoline, but the difference is less than 10%. Under the California LCFS, distributors or manufacturers of methanol fuel derived from NG would likely have to buy some LCFS credits if these estimates hold. California-derived CNG has a carbon intensity factor substantially below that for gasoline, and an increased use of CNG would generate LCFS credits. See Table 6.4 for California LCFS carbon intensity factors for various fuels.

Table 6.4. California LCFS Carbon Intensity Factors for Gasoline and Fuels That Substitute for Gasoline

Fuel type[a]	Carbon intensity	Carbon intensity including land use	Comments
California gasoline	95.86	95.86	Gasohol with 10% ethanol
CARB LCFS 2011	N/A	95.61	Maximum allowed in 2011 (initial); might be reviewed as more studies are available
Midwest ethanol (ETHC005)	75.1	105.1	Mainly made from corn; includes 40% of the plant's power from coal
California ethanol (ETHC003)	50.7	80.7	Considers plant's power comes from NG
Brazilian ethanol(ETHS001)	27.4	73.4	Made from sugarcane; transported by ship
CNG: via pipeline(CNG001)	67.7	67.7	North American NG compressed in California
CNG: landfill gas(CNG003)	11.26	11.26	Derived from landfills in California

Notes: Carbon intensity is measured as grams of carbon dioxide equivalent released per megajoule of energy produced.
[a] Parenthetical text indicates fuel identification codes.
Source: CARB (n.d.).

6.7.4. Manufacturer Warranties

With respect to ethanol, manufacturer warranties for E85 FFVs typically require these vehicles to use E85 that meets ASTM standards. For methanol, most manufacturers include in their owners' manuals the warning that use of methanol could cause fuel system and powertrain damage, which would not be covered by the warranties.

For LPG and CNG, EPA-certified conversion kits are often OEM certified, and manufacturer warranties are not affected by the conversion.

The most likely pathway for EPA certification of ethanol or methanol conversion kits would focus on vehicles that are two or more years old—that is, vehicles that are well into the life of their warranties at the time of conversion. As a result, the loss of manufacturer warranty coverage may present less of a barrier to conversion than might otherwise be the case.

In addition, under EPA's alternative-fuel conversion rule, the general requirement is that conversion kit manufacturers must accept in-use liability for warranty and recall as a condition for gaining an exemption from antitampering provisions. The applicable CAA and regulatory warranties continue to apply to the converted vehicle/engine according to the original OEM warranty period.

With respect to the conversion of vehicles to alternative-fuel capability, EPA (n.d. [b])offers the following advice to consumers:

> Warranty: Consumers considering conversion should investigate warranty implications in advance. Warranty liability for certain failed components in a converted vehicle or engine may transfer from the original equipment manufacturer to the conversion manufacturer. Generally, the conversion manufacturer maintains liability for problems that occur as a result of conversion, while the original manufacturer retains responsibility for the performance of any covered parts or systems that retain their original function following conversion and are unaffected by the conversion. Consumers should be aware that liability in a given conversion situation may not be clear, creating potential for confusion and even for dispute over which manufacturer is responsible for repair.

7. Recent CAFE and Carbon Dioxide Regulations: Implications for Alternative Fuels

One of the major issues confronting the deployment of alternative fuels is the problem of ensuring both an adequate fueling infrastructure (at competitive prices) and a commensurate stock of alternative fuel–capable vehicles. This problem has been characterized as the "chicken-and-egg" problem—denoting the difficulty of ensuring a coordinated deployment of both vehicles and fuel. This section considers the implications of recent regulatory changes for both renewable and nonrenewable ethanol-blended fuels.

7.1. Background

To promote the production of alternative-fuel vehicles, Congress adopted the Alternative Motor Fuels Act of 1988, which provides CAFE credit incentives to manufacturers of dedicated and dual-fueled alternative-fuel vehicles (US Department of Transportation, DOE, and EPA 2002). Although only a small number of alternative-fuel vehicles were manufactured in the first decade of the program, the program has been markedly successful in more recent years—more than 10 million light-duty FFVs capable of using E85 are in the current fleet. However, critics of this CAFE provision have argued that it is a "loophole" on CAFE requirements because E85 comprises only 1% of the fuel used by these vehicles. Because of this criticism, the 2007 EISA requires a phaseout of the FFV credit from MY 2015 to 2019.

Coincidentally, in 2007, the Supreme Court held in *Massachusetts v. EPA* that GHGs are pollutants within the definition of the CAA, opening the door to separate EPA regulation of the GHG emissions from vehicles.[75] A virtual one-for-one correspondence exists between carbon emissions from vehicles and the gallons of gasoline used per mile (the inverse of fuel economy as measured in miles per gallon). However, EPA sets GHG standards under the authority of Section 202(a) which does not provide a program for FFVs capable of using E85—thus, EPA is free to craft a program that best promotes the goals of the CAA. This effectively alters the focus of the program from the petroleum content of the fuel to a CO2-oriented program. In the joint NHTSA/EPA rulemaking that set CAFE standards (NHTSA) and GHG emissions limits (EPA) for MYs 2012–2015, EPA adopted GHG emissions incentives equivalent to the CAFE credits provided by NHTSA in recognition of the reliance by manufacturers on these credits in developing their compliance strategies.[76] However, beginning with MY 2016, EPA ended this emissions incentive for FFVs in favor of an approach based on demonstrated emissions performance for alternative-fuel vehicles. Thus, although EPA has provided manufacturers with some lead time to adjust their compliance strategies for MY 2016, this decision effectively closes the FFV credit "loophole" in MY 2016, several years ahead of the final phaseout mandated by the 2007 EISA.[77]

[75] 549 US 497 (2007).

[76] 77 FR 62829.

[77] Note that EPA's standards limit GHGs, not just CO_2, giving manufacturers some flexibility to make reductions in other GHG emissions—for example, a reduction in leaks from air conditioning equipment.

Despite significant growth in the stock of E85 FFVs in recent years, a commensurate increase in the use of E85 has not occurred. Only a small fraction of these FFVs actually use E85—mostly FFVs in government fleets (Davis et al. 2011, Table 6.1,). The high price of E85 relative to gasoline (especially on an energy-equivalent basis) and the limited availability of refueling stations continue to represent major barriers to the widespread use of E85. However, the requirements of the RFS adopted under the 2007 EISA may operate over the next few years to increase significantly the availability of E85 and reduce the price of E85 at the pump relative to conventional gasoline.

The first sections below outline the basic policy changes in the treatment of FFVs under the CAFE program and EPA's GHG emissions standards as well as the likely effect on the production of FFVs in future years. The final section discusses the likely effect of the RFS on the availability of E85.

7.2. FFV Credit under CAFE

As stipulated in the 1988 legislation, for purposes of calculating the fuel economy of a manufacturer's fleet, the CAFE program has treated FFVs as if they use the alternative fuel (e.g., E85) 50% of the time. In addition, the CAFE calculation for FFVs adjusts the measured E85 fuel economy (measured in miles per gallon) by a factor of 6.67, a factor reflecting the fact that the petroleum-based content of E85 is only 15%. That is, the calculated fuel economy for an FFV using E85 is given by:

$$adj\mathrm{FE}_{Alt} = \mathrm{FE}/0.15 = 6.67 \times \mathrm{FE},$$

where $adj\mathrm{FE}_{Alt}$ is the adjusted fuel economy for an FFV using E85 and FE is the measured fuel economy in miles per gallon for the vehicle using E85.

Thus, an FFV achieving 15 mpg when using E85 would be rated as having an adjusted fuel economy of 100 mpg. Given the assumed 50–50 split between the use of E85 and gasoline, the calculated CAFE value for an FFV is given by the following:[78]

$$\text{CAFE} = \frac{1}{\frac{0.5}{6.67 \times adj\text{FE}_{Alt}} + \frac{0.5}{\text{FE}_{Alt}}}.$$

Manufacturers are allowed to use the FFV credits up to a total credit of 1.2 mpg in calculating their corporate average fuel economy through MY 2014. However, beginning with MY 2015, the 2007 EISA requires a phaseout of the FFV credits for purposes of CAFE compliance on thefollowing schedule:[79]

Model Year	Credit Cap (mpg)
2015	1.0
2016	0.8
2017	0.6
2018	0.4
2019	0.2

The US Department of Transportation has updated its rules at 49 CFR 538 to reflect the 2007 EISA changes.

7.3 EPA Treatment of FFV Carbon Emissions

7.3.1. MY 2012–2015

The joint EPA/NHTSA rule establishing GHG emissions limits for MY 2012 to 2025 sets out separate EPA requirements for treating FFV GHG emissions. For MY 2012–2015, EPA provides a treatment of GHG emissions that corresponds to the CAFE approach.[80] That is, EPA

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[78] 75 FR 25665.

[79] CAFE credits are tradable and bankable (with some restriction on use) for MY 2012 and later vehicles.

[80] EPA sets GHG standards under the authority of Section 202(a) of the CAA. Section 202(a) does not specify a program for FFVs capable of using E85—thus, EPA is free to craft a program that best promotes the goals of this section of the CAA.

allows manufacturers to use a factor of 0.15 to reflect the fact that petroleum-based fuel comprises only 15% of E85 and to assume that FFVs use E85 50% of the time:[81]

$$\text{Carbon Emissions} = \frac{\text{FFV}_{Alt}\text{Emissions} \times 0.15 + \text{FFV}_{gas}\text{Emissions}}{2}.$$

This approach yields a calculated CO_2 emissions value that is substantially below actual CO_2 emissions for FFVs using gasoline. Thus, even if E85 comprises only 1% of FFV fuel use, FFVs will generate significant CO_2 emissions credits through MY 2015.

7.3.2. MY 2016 and Beyond

For MY 2016 and later, EPA substantially changed its treatment of the emissions calculation for FFVs. Manufacturers will no longer be able to use the 0.15 factor that adjusts for the fraction of petroleum-based fuel. Instead, they will be required to use actual tank-to-wheel CO_2 emissions for E85 and conventional gasoline, virtually eliminating the advantage E85 enjoyed in the CAFE calculation.[82]

In addition, manufacturers will no longer be allowed to assume that FFVs use E85 50% of the time; instead, they will be required to use a factor "F" representing actual FFV use of E85. Thus, the CO_2 emissions calculation becomes:[83]

$$\text{Carbon Emissions} = (\text{FFV}_{Alt}\text{Emissions}) \times \text{F} + (\text{FFV}_{gas}\text{Emissions}) \times (1\text{-F}),$$

where F represents the estimated actual use of E85.

In its GHG rules, EPA provides manufacturers with two pathways for developing the GHG emissions value for an FFV. First, manufacturers can use, as a default value, the GHG emissions estimate for FFVs using conventional gasoline. Second, EPA offers manufacturers two methods for demonstrating actual E85 fuel use. Manufacturers can submit to EPA data on actual E85 fuel use for its FFVs as a basis for its F value. Alternatively, EPA recently published draft guidance in response to requests from several manufacturers proposing to allow manufacturers to use a default value for F of 0.2 for MY 2016 FFVs, effectively reducing by 60% the prior

81 75 FR 25432.

82 An alternative approach, not adopted by EPA, would provide credit for renewable, as opposed to nonrenewable, sources of alternative fuel.

83 75 FR 25433–25434.

assumption of 0.5. EPA also proposed to allow manufacturers to use an F value of 0.2 for subsequent MYs (MY 2017–2019 vehicles) unless EPA makes further revisions to this weighting factor based on new information (78 FR 17660–17661).

This approach will virtually eliminate any advantage manufacturers would receive from the production of E85-capable FFVs in MY 2016 (and later years)—several years ahead of the final phaseout of the FFV CAFE credit required by the 2007 EISA.[84] To illustrate the effect of the change in the carbon emissions calculation, an FFV with measured carbon emissions of 330 grams (g)/mi using E85 and 350 g/mi using conventional gasoline would have substantially different calculated carbon emissions for MY 2012–2015 versus MY 2017–2019, as follows.

For MY 2012–2015:

$$\begin{array}{c}\text{Carbon}\\\text{Emissions}\end{array} = \frac{(330\ \text{g/mile})0.15 + 350\ \text{g/mile}}{2} = 199.8\ \text{g/mile}$$

For MY 2016–2019:

$$\begin{array}{c}\text{Carbon}\\\text{Emissions}\end{array} = (330\ \text{g/mile}) \times 0.2 + (350\ \text{g/mile}) \times 0.8 = 346\ \text{g/mile}$$

This is a significant increase of roughly 75% in rated carbon emissions with the change in calculation methodology for MY 2016 and later. In addition, for these later-MY FFVs, the rated carbon emissions for the FFV are virtually the same as the carbon emissions for this example vehicle when operating on conventional gasoline—346 g/mile versus 350 g/mile.

7.4. Effect of the Renewable Fuel Standard on E85

The 2007 EISA mandated a significant increase in the volume of renewable fuels blended in transportation fuel from a level of 9 billion gallons in 2008 to a total of 36 billion gallons in 2022. EISA also established an increasing cap for corn starch–based ethanol, starting at 9 billion gallons in 2008 and rising to 15 billion gallons in 2015 (Schnepf, R., and B.D. Yacobucci, 2013, see Table I. The 2013 cap is 13.8 billion gallons—a production level that the corn-based ethanol sector is likely to meet.

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[84] In its MY 2012 to 2016 CAFE rule, EPA projected that the fleetwide FFV CO_2 emissions credit for MY 2016—the first year of the new calculation for FFV credit—would be zero. Over MY 2012 to 2015, EPA projected a decline in the FFV credit from 6.5 grams/mi for MY 2012 to 3.7 grams/mile for MY 2015 (75 FR 25400).

Federal regulations and the structure of the excise tax exemption have operated to cap the amount of ethanol in conventional gasoline at 10%, and much of the light-duty fleet (with the exception of FFVs) has been designed to operate on E10. Given forecast ethanol production levels of 13.8 billion gallons and expected gasoline demand of 134 billion gallons for 2013, the United States will probably reach the "blend wall" in 2013—that is, the amount of ethanol required to be blended in gasoline under the RFS will be greater than 10% of total gasoline consumption.[85]

To ensure that refiners are meeting the mandated blend requirements under EISA, EPA requires refiners to show that they have blended the required number of gallons of alternative fuel in the gasoline (or other liquid fuels) delivered for sale. To implement this requirement, EPA has created a tracking system based on the RIN system (renewable identification numbers). The RIN system is basically an allowance system; 1 RIN is equal to 1 gal of alternative fuel blended into transportation fuel. Refiners are required to turn in the required number of RINs to cover their production of transportation fuel at the end of the year. RINs are transferrable and tradable. They can be used in the production year for the alternative fuel or in the following year—unused RINs expire if they have not been used during their two-year life. In addition, RINs from the previous year can be used to cover only up to 20% of a refiner's obligation in the following year.

In the initial years of the RFS, RINs have traded at a few cents per gallon. However, in March 2013, RIN prices surged to as high as $1.05/gal; they averaged around $0.70/gal in April 2013 (EIA 2013a). Market observers have suggested that concerns with the "blend wall" and the effects of last year's drought on corn production and prices underlie the substantial increase in RIN prices (Schnepf and Yacobucci 2013, 31). EIA (2013a) notes, in its most recent Short-

Term Energy Outlook, that the increase in RIN prices should reduce the market price of E85 relative to that of gasoline (E10). As an illustrative example, for a RIN price of $0.70/gallon, then:

[85] In an effort to address the "blend wall" issue, EPA recently approved the use of up to 15% ethanol in gasoline used by MY 2001 and later light-duty cars and trucks. However, only a small number of outlets dispense E15. The Congressional Research Service reports that, as of March 2012, only 13 stations were offering E15 for sale (Schnepf and Yacobucci 2013). Recent Congressional testimony indicated that fewer than 20 outlets were dispensing E15 in February 2013 (Dlouhy 2013). Also, resistance to the use of E15 continues because of concerns about the compatibility of E15 with the existing stock of vehicles. The AAA has issued a warning on the use of E15 in LDVs and has called on EPA to halt sales of E15 because of concerns about the potential damage to vehicle fuel systems and engines (Strauss 2012; Dlouhy 2013; Energy Information Administration 2013a).

Cost of Gasoline = 0.9 x ProdCostGasoline + 0.1x ProdCostEthanol – 0.1 x $0.70

and

Cost of E85 = 0.15 x ProdCostGasoline + 0.85 x ProdCostEthanol – 0.85 x $0.70.

If the production cost of ethanol is competitive with gasoline (on an energy-equivalent basis), then the higher current RIN prices give E85 a price advantage relative to conventional gasoline of roughly $0.50/gallon. A similar calculation suggests that the deployment of E85 would have a comparable advantage over E15 (as long as the cost of ethanol is below or roughly comparable to the cost of gasoline).[86]

Also, a number of tax incentives are currently available for the production of cellulosic ethanol—these incentives were extended through 2013 under the recently adopted “fiscal cliff” legislation. Cellulosic ethanol receives a $1.01/gal production tax credit. In addition, cellulosic biofuel plants placed in service before January 1, 2014, receive a special depreciation allowance. A tax credit for installing alternative-fuel infrastructure (including E85 fueling equipment) is also available for fueling station owners installing refueling equipment by December 31, 2013 (Renewable Fuels Association n.d.).

While there has been no commercial-scale production of cellulosic ethanol prior to this year, EPA projects that several plants will open this year with a projected production of 14 million gallons.[87] A recent NREL report projects a production cost for cellulosic ethanol of $0.60/liter, or $2.30/gal (Service 2013; Humbird et al. 2011). This production cost would make cellulosic ethanol competitive with the projected costs reported in Section 2 for an NG-derived ethanol—even without the subsidy provided by the RIN credit.

The projected increase in the production of cellulosic ethanol coupled with the substantial cross-subsidy and tax incentive increase the uncertainty facing the production of NG-based ethanol.

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[86] Considerable uncertainty, though, is associated with future RIN prices. RINs are generated for a variety of alternative fuels: 1.3 RINs for each gal of biobutanol, 1.5 for biodiesel (mono alkyl ester), and 1.7 for nonester renewable diesel. The quantity of RINs generated in any given year depends on EPA’s determination of the appropriate renewable fuel standard–mandated levels for ethanol, advanced ethanol, cellulosic ethanol, and biodiesel (72 FR 23909).

[87] 78 FR 9285.

8. Conclusions

In tandem with a series of technology advances in vehicles, the shale gas revolution has created new opportunities to substitute alternative fuels for conventional gasoline in the light-duty fleet. In this report, we have considered four such potential fuels: ethanol, methanol, CNG, and LPG. Importantly, the emergence of these alternative fuels can be driven by market forces and will not necessarily require government subsidies. They clearly advance the goal of energy security and will probably bring at least modest environmental benefits, especially for older vehicles.

Currently, the principal beneficiaries of these fuel and technology trends are the estimated quarter million owners of CNG- and LPG-capable vehicles, who are reaping substantial savings in fuel costs. Despite the estimated 10 million E85-capable FFVs on the road today, the only available gasoline substitute for these vehicles does not have a cost advantage at the pump over conventional gasoline. However, we see alternative pathways for bringing a lower-cost E85 to the pump. If and when ethanol produced by the newly patented, NG-driven Celanese process becomes available, owners of FFVs could realize substantial cost savings, up to \$0.83/gge in 2015.[88] If and when cellulosic ethanol becomes available at projected cost for full-scale production, owners of FFVs could realize similar cost savings.

Beyond the current fleet of EPA-certified alternative fuel–capable vehicles, significant opportunities exist to convert conventional gasoline vehicles to use such fuels, especially to FFVs using E85. Though attractive to automotive engineers and car enthusiasts, methanol has greater barriers to overcome than ethanol. Our projections suggest a small cost advantage for M85 but greater difficulties in fuel distribution and, especially, fleet conversion.

Although only one E85 conversion kit has been approved by EPA so far, there appears to be considerable potential to expand the number of approved kits to cover a wide range of vehicles and drive down kit prices substantially. Notwithstanding the many uncertainties associated with our calculations, we estimate that the payback for conversion could be as short as six months, depending on location, timing, and various assumptions about vehicle fuel economy and miles driven. Among the different categories of social benefits, the energy security/macroeconomic gains are the clearest. With respect to air pollution benefits, current

[88] Similarly, if and when cellulosic ethanol becomes available at projected cost for full-scale production, owners of FFVs could realize similar cost savings.

estimates indicate that (with a few exceptions) LDVs using conventional gasoline have direct conventional emissions that are comparable to the emissions of vehicles converted to use alternative fuels. And, although the shift to alternative fuels may decrease emissions of certain gasoline-related air toxics, such as benzene, it is likely to increase aldehyde emissions. More research is needed on the potential trade-offs between these pollutants. Despite the technical potential to reduce GHG emissions, the situation remains murky as the net impact of NG-based fuels depends on the amount of leakage from the production and transport of the gas. Recognizing the considerable uncertainty in these estimates, we have chosen not to develop monetized benefit estimates for the possible difference in emissions between the use of conventional gasoline and the conversion of LDVs to alternative fuels.

Despite our general optimism about the future for NG-based fuels in the light-duty fleet, there is clearly a chicken-and-egg issue of bringing the fuels to market and developing a sizable fleet of FFVs capable of using the fuels. We are at the beginning of a potentially long, complex, and highly uncertain process of market transformation. Here, we identify several key uncertainties:

- the ability and willingness of Celanese and/or other firms to produce and market E85 or other NG-based fuels at the forecast prices;
- the ability to produce biogenic ethanol, especially cellulosic ethanol, at forecast prices, could undermine the attractiveness of NG-based fuels;
- EPA’s willingness to adopt regulatory changes that reduce the costs of certifying conversion kits for the various NG-based fuels;
- the interest of conversion kit manufacturers in developing low-cost kits for these fuels;
- better understanding of the emissions implications of using NG-based fuels with respect to conventional air pollutants, air toxics, and especially GHGs;
- trends in NG prices, including the potential impacts of future state and/or federal regulation; and
- trends in global oil prices, including the impacts of future expansion of coal-based ethanol and methanol production in China and elsewhere.

How could the introduction of E85 actually occur? We sketch two possible paths for an NG-based fuel.

- One path would be highly localized, possibly starting near the Texas-based Celanese plant now under construction, where the company would supply the fuel to retailers for sale to FFV owners at prices significantly below those for E10. Retailers may include outlets owned or controlled by major oil companies, or they could be drawn from independents, such as Costco. Success in such a market could build demand for vehicle conversions as well as for new FFVs. It could also lead to expansion to other areas seeking to benefit from the lower-priced fuels.
- The other path would be larger in scale and regional, perhaps supported by an alliance among several neighboring states interested in introducing the new fuels. Such a path could rely on ethanol produced by the Texas plant or, perhaps, by a facility specially built to supply the regional alliance. The location of a specially built facility would probably be dictated by the availability of relatively low-cost NG and transportation options for shipping the product. To jump-start the effort, the states could offer an initial set of incentives or guarantees to the producers and/or consumers, the latter possibly in the form of exemptions from state road taxes similar to those enjoyed by users of biogenic fuels.

Implicitly, we've assumed that the regulatory landscape will remain unchanged for the foreseeable future. However, one can imagine regulatory changes that could either help or hinder the development and deployment of NG-based fuels. An example of the former would be an expedited, simplified process for obtaining EPA certification of conversion kits, which would probably drive down kit prices. An example of the latter would be an expanded mandate for the sale of biogenic ethanol, which would potentially shrink the market for the NG-based product. In this case, the "blend wall" could operate to bring cellulosic-based E85 into the market at an attractive pump price.

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Appendix. LDV Emissions from Conventional and Alternative Fuels

We have found only limited testing data for current-vintage FFVs (i.e., FFVs subject to EPA's Tier 2 emissions limits). Two survey papers present certification data for more than 70 different FFV models for MYs 2006 to 2009. In addition, a few papers report independent lab tests for a handful of MY 2006 and 2007 FFVs. Significant uncertainty is associated with these emissions data, with considerable variation in emissions across similar vehicles. Some of the results suggest that FFVs operating on E85 may achieve small additional reductions in CO and NO_x emissions. However, the test results do not offer a consistent pattern of reduction for these pollutants. The certification data also indicate that FFVs have somewhat lower emissions when using gasoline than the same or similar non-FFVs. These results suggest that the calibration or design of FFVs provides a more effective control of emissions than the control systems for the same or similar non-FFVs.

Studies of air toxics emissions from current-vintage FFVs are even more limited. We found only a few Tier 0 and Tier 1 vehicle tests for toxics like benzene and 1,3 butadiene. Most of the certification and emissions studies for current Tier 2 FFVs provide data on aldehyde emissions. These studies report a substantial increase in aldehyde emissions with the use of E85. Acetaldehyde is the more prevalent aldehyde, with increases (where reported) of a factor of two or more; formaldehyde emissions increase by around 50% or more.

Summary of Papers Reporting FFV Emissions Performance for E85 and Gasoline

Tier 2 Vehicles (Current Standards)

Yanowitz and McCormick (2009) compiled manufacturer certification data for 70 Tier 2 FFVs and similar non-FFV LDVs for MY 1999 to 2007. Overall, these results seem to be roughly consistent with the largely equivalent smog ranking for FFVs relative to non-FFVs reported above. Yanowitz and McCormick report a 15% reduction in CO for vehicles using E85, no significant change in Non-Methane Organic Gases (NMOG) emissions, and a 28% reduction in NO_x emissions (but the difference is not statistically significant). They also note that FFVs using gasoline (E10) have lower NMOG emissions than similar non-FFVs, suggesting that the calibration or design of FFVs provides a more effective control of emissions than that for similar non-FFVs (Yanowitz and McCormick 2009, 180; Tessum et al. 2010).[89]

Yanowitz and McCormick (2009) report that significant uncertainty surrounds the emissions from E85-powered vehicles, noting the considerable variation in emissions across vehicles, even for vehicles with the same engine type and with testing conducted by the same laboratory. They emphasize the need for more extensive testing of vehicles with a much wider range of test conditions (Yanowitz and McCormick 2009, 180)

The Coordinating Research Council, Inc. (CRC 2011) tested seven MY 2006–2007 FFVs and reports mixed results. CRC (2011) reports a 50% reduction in Non-Methane Hydrocarbon (NMHC) emissions with vehicles using E85 on one of three engine test cycles used in the study, but with no trend in emissions for the other two test cycles. For NO_x emissions, CRC reports a reduction that is almost statistically significant with increasing ethanol blends for one of the test cycles, but with no trend in emissions for the other two test cycles. For CO emissions, CRC reports no trend with ethanol blends for all three test cycles. Finally, CRC reports no trend in evaporative emissions with the higher ethanol blends for the running loss and hot soak tests, but the diurnal test yielded an increasing trend in emissions with the higher ethanol blends on the first day.

In a single-vehicle test of a 2006 Chrysler Town and Country, Yassine and La Pan (2012) found substantial reductions in hydrocarbon, CO, and NO_x tailpipe emissions and an increase in carbonyl emissions (e.g., aldehydes) at room temperatures with higher-blend ethanol fuels. E85 achieved the largest reductions in hydrocarbon, CO, and NO_x emissions and the largest increase in carbonyl emissions. At lower temperatures, they report that hydrocarbon and carbonyl emissions increased relative to emissions at room temperature (Yassine and La Pan 2012, 11–13).[90]

Thomas et. al. (2012) report the results of a test of the aftermarket Flex Fuel conversion kit installed on an MY 2006 Dodge Charger. They report that NO_x emissions appeared to

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89 Tessum et al. (2010) combine the results for Tier 0 and Tier 1 FFVs with the certification data for Tier 2 FFVs. However, there are good reasons to report the results for Tier 2 FFVs separately (the approach adopted by Yanowitz and McCormick [2009]), and Tessum et al. acknowledge as much. However, the Tessum et al. paper helps to inform our presentation of the certification data for Tier 2 vehicles because it provides additional information and detail on the certification data and on the Yanowitz and McCormick paper.

90 Whitney and Fernandez (2007) report significantly different emissions for E85 at low temperatures.

decrease with higher ethanol blends with two of the engine test cycles used, but appeared to increase with the other test cycle. CO and NMOG emissions were largely unchanged with the higher blends after installation of the conversion kit relative to the vehicle before conversion (Thomas et al. 2012, 13).

Emissions of Air Toxics

Even less attention has been given to toxic emissions from LDVs. We found only a few studies reporting Tier 0 and Tier 1 vehicle tests for toxics like benzene and 1,3 butadiene and no emissions testing data for these air toxics for current-vintage Tier 2 FFVs. For Tier 2 FFVs, several studies report a substantial increase in aldehyde (or, more broadly, carbonyl) emissions with the use of E85. Acetaldehyde is the more prevalent aldehyde, with an increase (where reported) of a factor of two or more; formaldehyde emissions increase by around 50%.

Older Vehicles

Yanowitz and McCormick (2009) also summarize results from eight earlier studies on the effect of ethanol blends on tailpipe emissions of Tier 0 and Tier 1 FFVs (most of these vehicles were manufactured in the 1990s). They report significant reductions in hydrocarbon, CO, and NO_x emissions for FFVs operating with E85 relative to emissions from these same FFVs and similar standard vehicles operating on gasoline (Yanowitz and McCormick 2009, 176). Tessum et al. (2010) report similar results for these older vehicles based on their own literature review of earlier studies. For earlier-vintage Tier 0 and Tier 1 FFV vehicles, Yanowitz and McCormick (2009) also report that the use of E85 will yield a roughly proportional reduction in benzene and 1,3 butadiene emissions relative to the use of conventional gasoline.