Future Scenarios for E85 in the U.S.

SwRI® Project No. 03.28491

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June 19, 2024

Benefiting government, industry and the public through innovative science and technology

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TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

1 INTRODUCTION

Concerns about greenhouse gas (GHG) emissions, and slower adoption of battery electric vehicles than previous forecasts, are leading to increased interest in renewable fuels. Analysis[1] by Argonne National Laboratory, in cooperation with industry experts, indicates that conventional or hybrid vehicles with renewable liquid fuels can achieve similar life cycle GHG emissions to battery electric vehicles.

The most widely used renewable fuel is ethanol. According to another study[2] by Argonne, "corn ethanol in the transportation fuel market resulted in a total GHG emission reduction benefit of 544 MMT CO_2e during the period 2005 to 2019." Currently, most ethanol is used as E10, a blend of 10% ethanol in gasoline. Some ethanol is also used as E85 (nominally 85% ethanol) in flex-fuel vehicles (FFVs).

But many FFV owners do not refuel with E85, and thus the potential GHG emissions benefits are not achieved. The purpose of this study is to identify scenarios for increased consumption of E85 in existing FFVs, and to quantify the GHG emissions benefits using life cycle analysis.

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[1] Kelly, Elgowainy, Isaac, et al., "Cradle-to-Grave Lifecycle Analysis of U.S. Light-Duty Vehicle-Fuel Pathways", report ANL-22/27, June 2022, https://doi.org/10.2172/1875764

[2] Lee, Kwon, Wu, and Wang, "Retrospective analysis of the U.S. corn ethanol industry for 2005–2019: implications for greenhouse gas emission reductions", 2021, https://doi.org/10.1002/bbb.2225

2 TRENDS IN CALIFORNIA

California provides an example of increasing E85 consumption. From 2016 to 2022, annual E85 sales volume[3] increased by more than a factor of five, while the number of FFVs[4] was approximately constant, as illustrated in Figure 1.

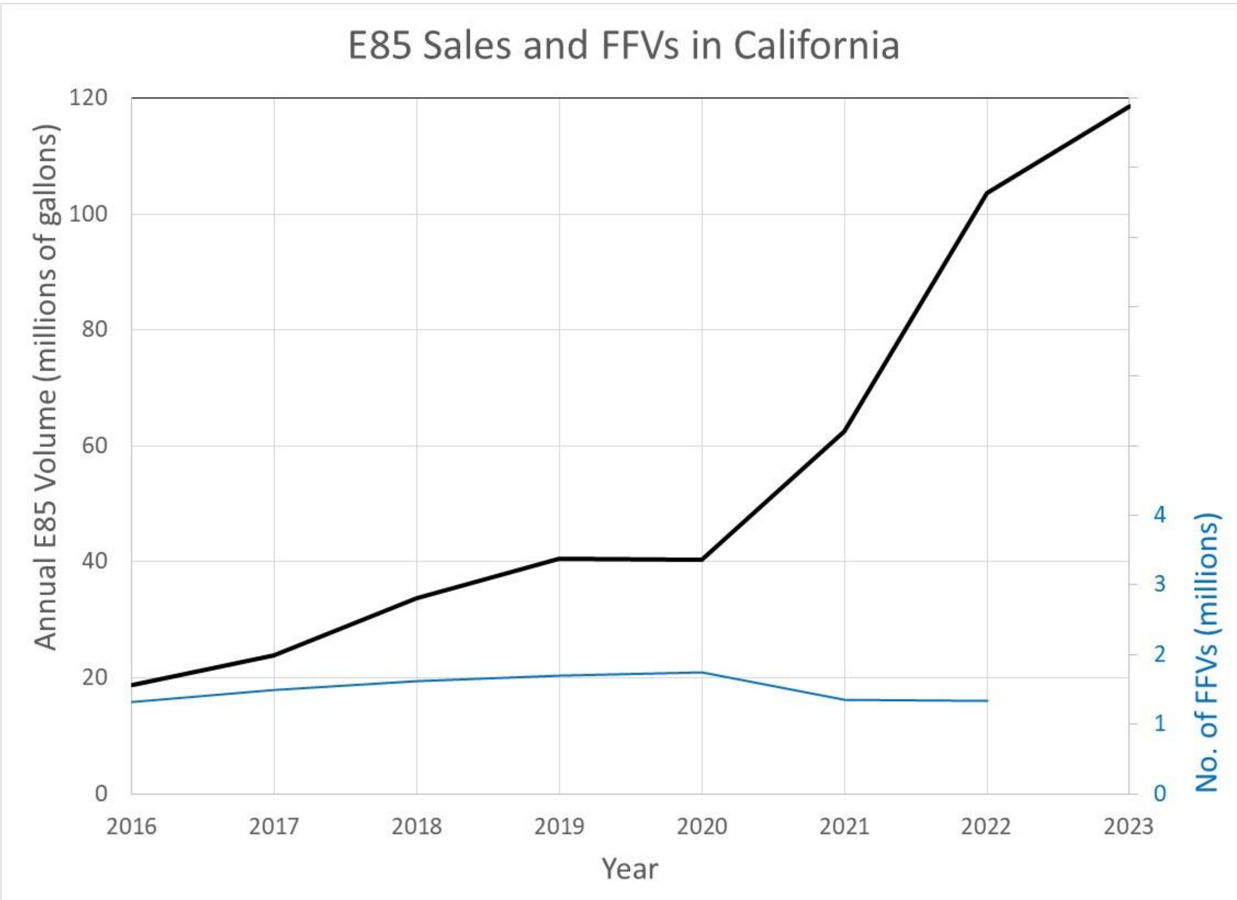

FIGURE 1: E85 SALES AND FFVS IN CALIFORNIA

[3] From CARB reported Test Program Exemption data, https://ww2.arb.ca.gov/resources/documents/alternative-fuels-annual-e85-volumes

[4] From U.S. Department of Energy, Alternative Fuels Data Center, https://afdc.energy.gov/transatlas#/?fuel=E85&state=CA

The California data was normalized[5] as annual E85 sales per registered FFV, as shown in Figure 2. Despite the recent significant increase in E85 sales, the average FFV consumed less than 90 gallons of E85 in 2023. Clearly, there is room for continued growth in E85 sales. Extrapolation of the recent trend indicates that California could reach 160 gallons of E85 per FFV in 2026.

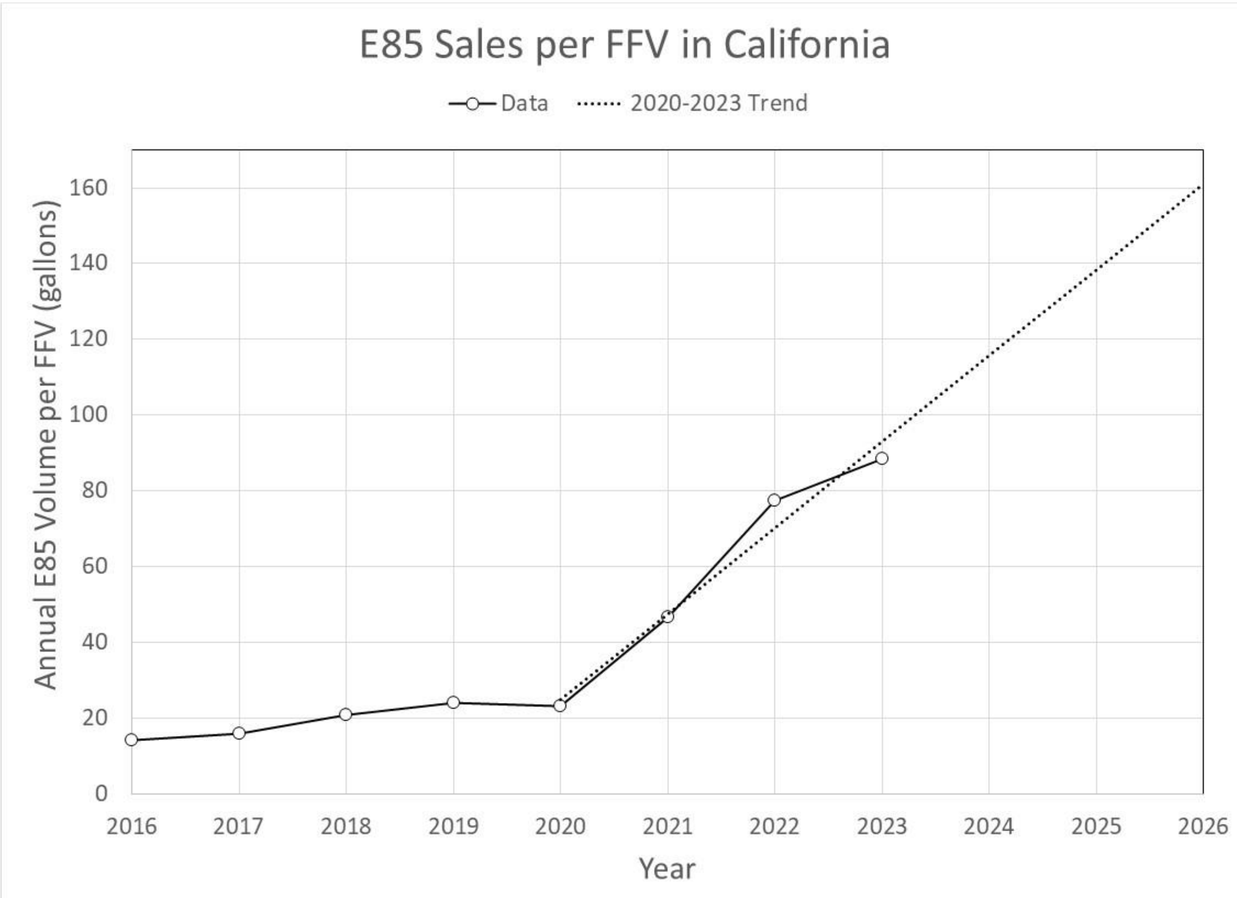

FIGURE 2: E85 SALES PER FFV IN CALIFORNIA

[5] Assuming the same number of FFVs in 2023 as in 2022

3 NATIONWIDE SCENARIOS FOR E85

There are 258.5 million light-duty vehicles[6] on the road in the U.S. Total gasoline consumption is 132.3 billion gallons per year[6], or 512 gallons per vehicle per year.

There are 20.9 million FFVs[7] on the road in the U.S., about 8.1% of all vehicles. If each FFV were fueled only with E85, it would consume 663 gallons per year (due to the lower volumetric energy density[8] of E85). This would result in total annual E85 sales of about 14 billion gallons, which would displace 11.1 billion gallons of E10 gasoline, as shown in Figure 3.

Recent California trends for E85 consumption per FFV are also shown in Figure 3. The 2022 value of 77 gallons E85 per FFV would result in 1.6 billion gallons of E85 nationwide. If recent trends in California are extrapolated only a few years to 2026, the result is 161 gallons of E85 per FFV, or 3.4 billion gallons of E85 nationwide. This would displace 2.7 billion gallons of E10 gasoline.

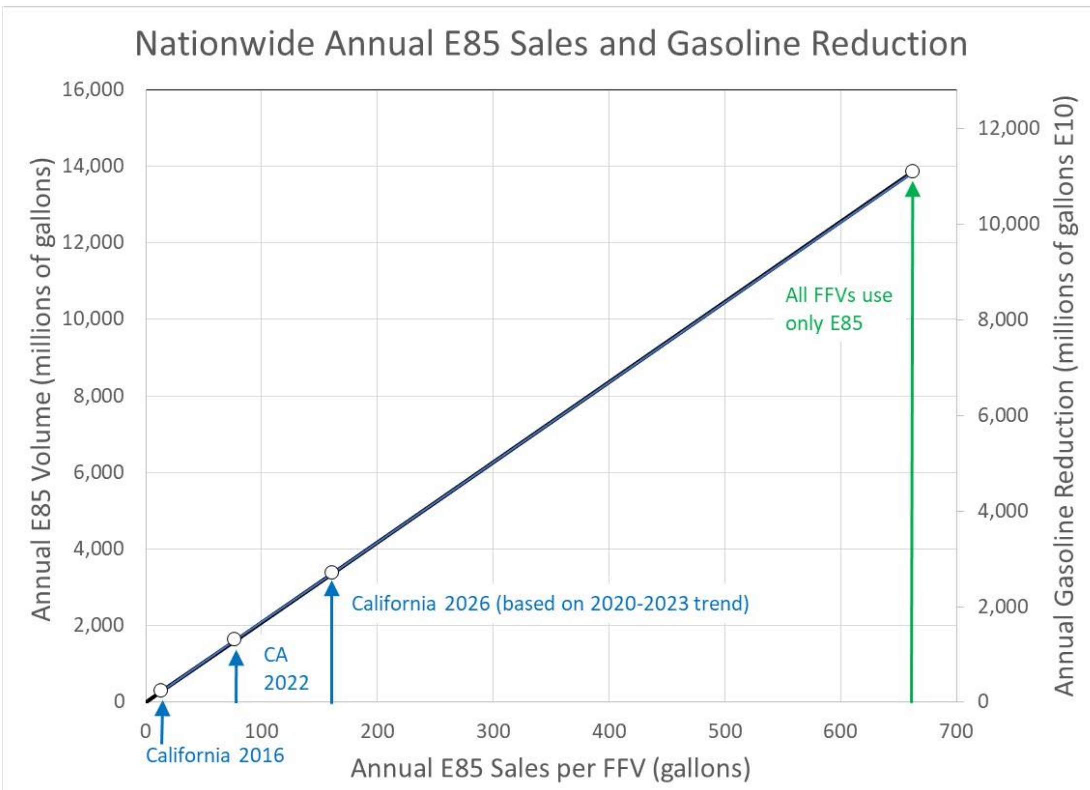

FIGURE 3: SCENARIOS FOR E85 SALES AND GASOLINE REDUCTION

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[6] From U.S. Energy Information Agency, Annual Energy Outlook 2023, https://www.eia.gov/outlooks/aeo/
[7] From U.S. Department of Energy, Alternative Fuels Data Center, https://afdc.energy.gov/states
[8] E85 has 23% lower energy per gallon than E10 (assuming 74% ethanol content), but improves engine efficiency by 3.7% (see next section of paper), so each gallon of E85 displaces 0.8 gallon of E10

4 ENGINE EFFICIENCY BENEFIT OF E85

When quantifying the effects of E85, it is important to account for changes in engine efficiency. Ford conducted back-to-back testing[9] of E85 and gasoline at three speed-load operating points and measured relative thermal efficiency benefits of 3.8% to 4.6% for E85, as shown in Figure 4. The testing was conducted at light loads where the engine was not knock-limited, so the benefit was not due to octane. Readers are encouraged to read the original SAE paper for further details.

The engine efficiency benefit of ethanol is now well accepted by experts. A literature review by authors from three major car companies[10] generalized the results from Ford and other studies as 0.5% engine efficiency improvement per 10% ethanol in the fuel (by volume). This value is used for the current study.

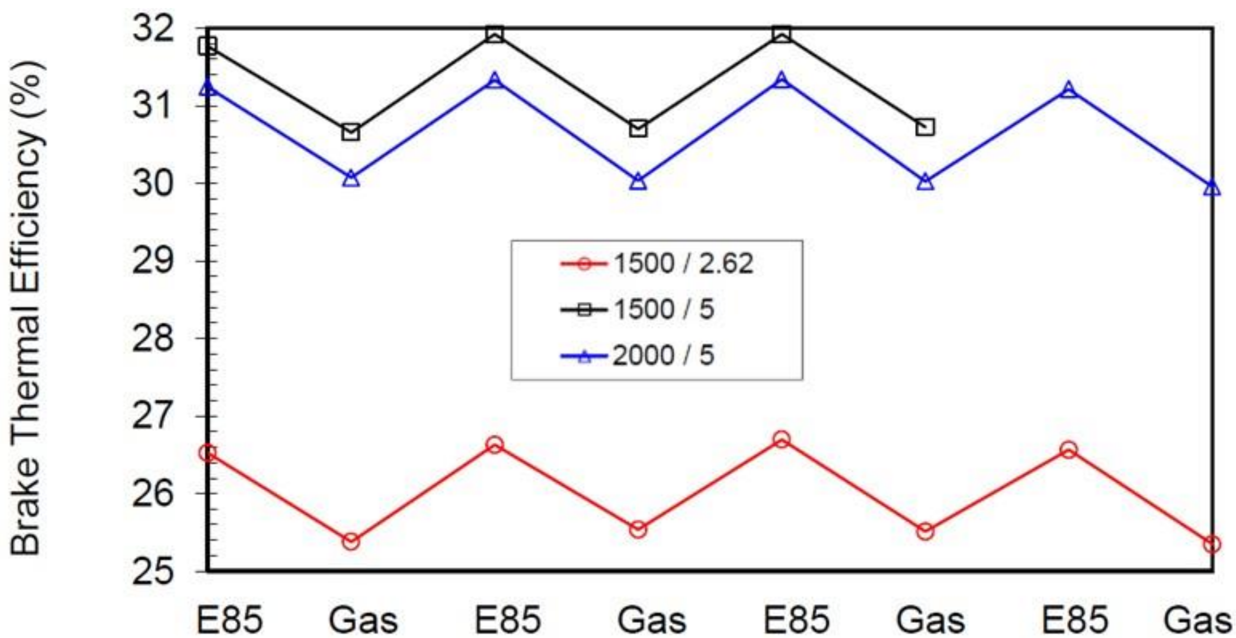

FIGURE 4: EFFECT OF E85 ON ENGINE EFFICIENCY

[9] Jung, Shelby, Stein, and Newman, "Effect of Ethanol on Part Load Thermal Efficiency and CO_2 Emissions of SI Engines," SAE Int. J. Engines 6(1):456-469, 2013, https://doi.org/10.4271/2013-01-1634

[10] Leone, Anderson, Davis, Iqbal, Reese, Shelby, and Studzinski, "The Effect of Compression Ratio, Fuel Octane Rating, and Ethanol Content on Spark-Ignition Engine Efficiency", Environmental Science & Technology paper 5b01420, 2015, https://doi.org/10.1021/acs.est.5b01420

5 LIFE CYCLE ANALYSIS

The life cycle greenhouse gas benefits of ethanol have been studied extensively. A critical review[11] of the literature by independent researchers from MIT, Tufts, and Harvard found a wide range of published values for the carbon intensity of ethanol, from 37.6 to 65.1 gCO_2e/MJ. The study noted a consistent decrease in the carbon intensity of farming and ethanol production over time, due to many factors including reduced use of nitrogen fertilizer and fossil fuel in farming and more efficient use of energy in ethanol production plants.

The most widely used and authoritative tool for life cycle analysis is the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model developed by Argonne National Laboratory. Key developers of this model studied[2] changes in the carbon intensity of corn ethanol, and found a 23% improvement from 2005 to 2019 (the black bars in Figure 5). The biggest contributor to the improvement was reduced natural gas consumption in ethanol production (the blue bars in Figure 5). The report states that "natural gas use in ethanol plants is subject to large variations, about ±40% of the median natural gas use in 2019, which means that there is the potential to further reduce GHG emissions if high natural gas consuming facilities can improve their efficiencies to levels closer to those of the low natural gas consuming ones" and that "renewable natural gas... can be an alternative option for... reduced CIs for ethanol".

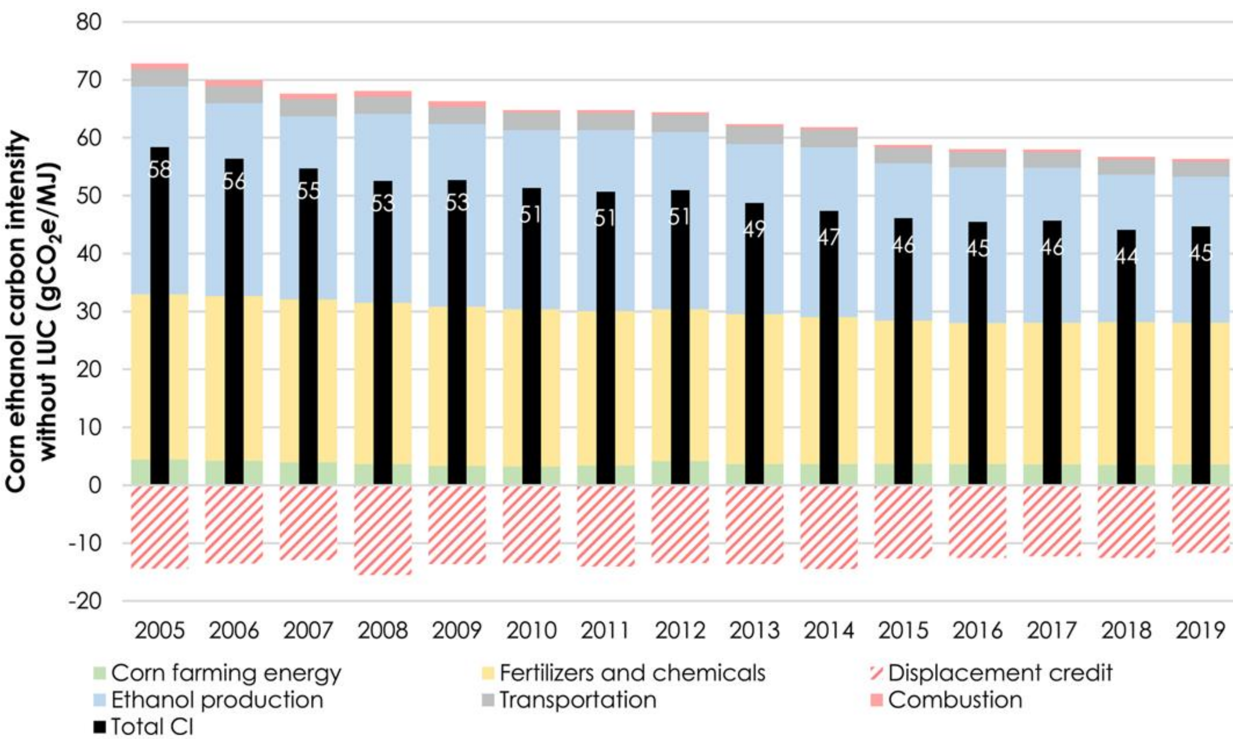

FIGURE 5: CARBON INTENSITY OF CORN ETHANOL, 2005 TO 2019

[11] Scully, Norris, Falconi and MacIntosh, "Carbon intensity of corn ethanol in the United States: state of the science", 2021, https://doi.org/10.1088/1748-9326/abde08

The second biggest factor for improved carbon intensity was reduced use of fertilizers and chemicals per bushel of corn (the yellow bars in Figure 5). The report states that "corn grain yield has increased continuously… while fertilizer inputs per acre have remained constant, resulting in decreased intensities of fertilizer inputs". It is important to note that corn yield[12] has been improving for many decades, as shown in Figure 6.

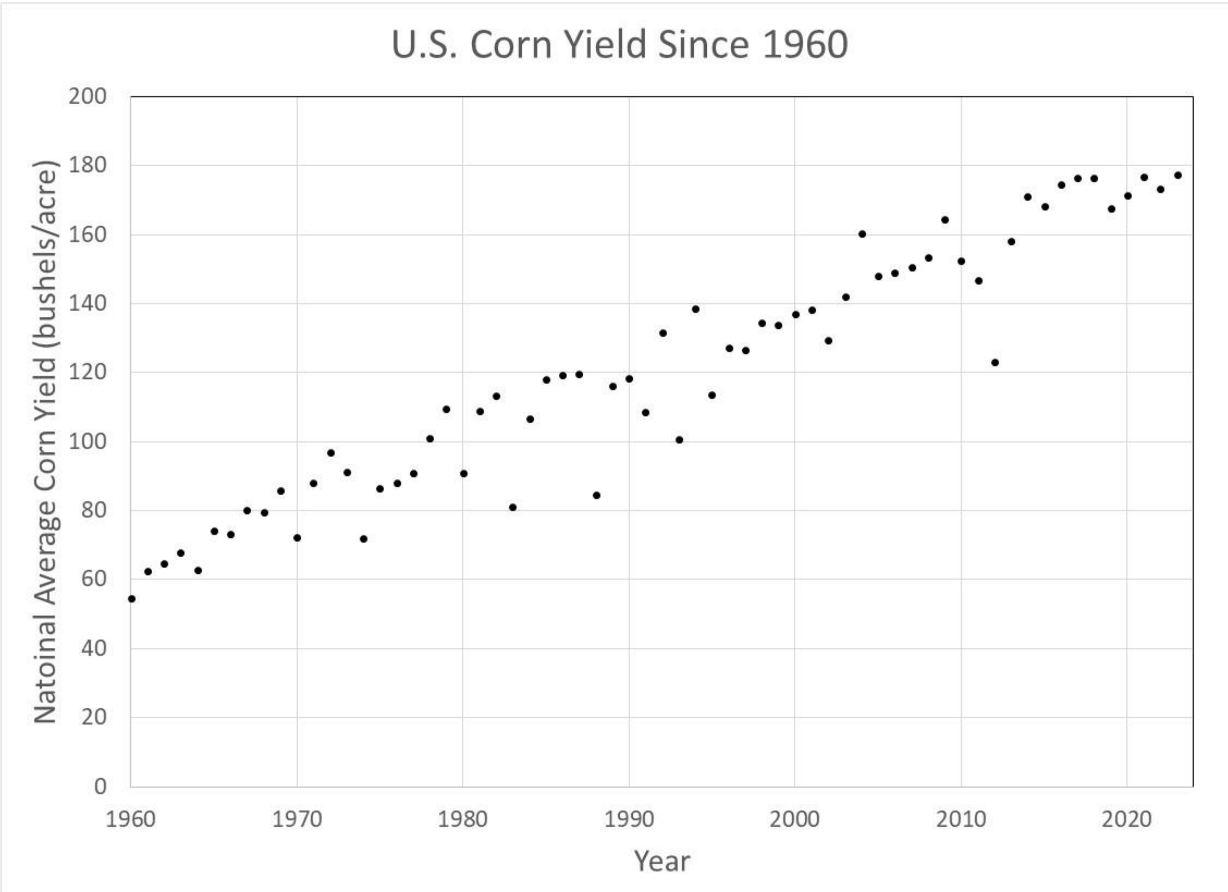

FIGURE 6: CORN YIELD SINCE 1960

[12] U.S. Department of Agriculture, National Agricultural Statistics Service, https://quickstats.nass.usda.gov/results/29260F67-A60C-3C6A-B323-8E5049510EBB

To quantify the potential future greenhouse gas benefits of E85, it is necessary to estimate the future carbon intensity of ethanol. It is reasonable to extrapolate recent trends into the near future, and this is common practice[13,14] for estimating the future carbon intensity of electricity production. According to documentation from the California Air Resources Board, ethanol used for credit under the Low Carbon Fuel Standard improved in carbon intensity[15] by 25% between 2011 and 2019. As described above, it is reasonable to expect that the two trends contributing to recent improvements in ethanol carbon intensity will continue in future years. For this study, the future carbon intensity of ethanol is assumed to continue the 2005-2019 trend, as shown in Figure 7.

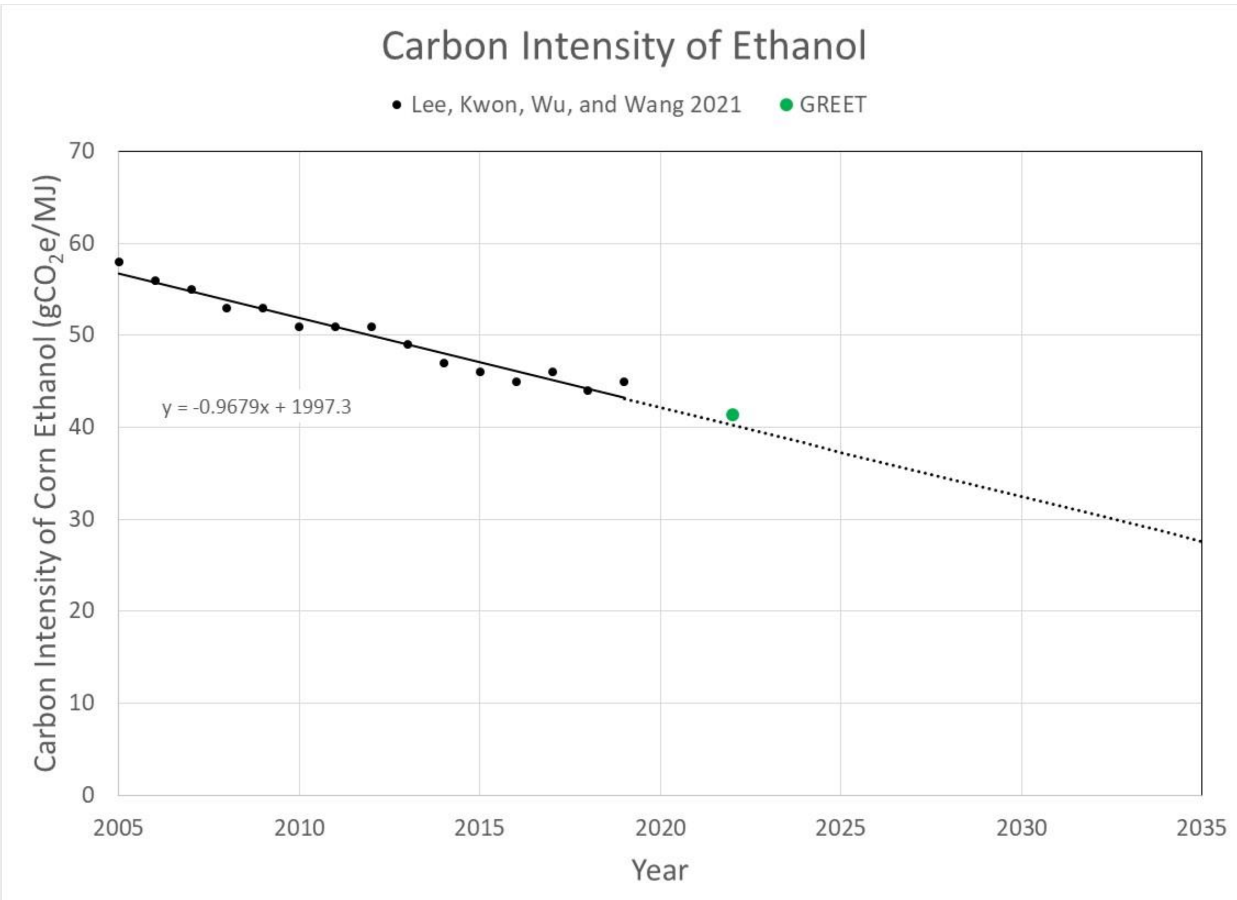

FIGURE 7: CARBON INTENSITY OF ETHANOL

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[13] Table 5-3 and Figure 8-12 of EPA Regulatory Impact Analysis, EPA-420-R-24-004, March 2024 https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-multi-pollutant-emissions-standards-model

[14] U.S. Energy Information Administration, Annual Energy Outlook, https://www.eia.gov/outlooks/aeo/

[15] Rosenfeld, Kaffel, Lewandrowski, and Pape, "The California Low Carbon Fuel Standard: Incentivizing Greenhouse Gas Mitigation in the Ethanol Industry," USDA Office of the Chief Economist, 2020, https://www.usda.gov/sites/default/files/documents/CA_LCFS_Incentivizing_Ethanol_Industry_GHG_Mitigation.pdf

Based on the carbon intensity of ethanol from Figure 7 and a few key values[16] from GREET, the carbon intensity of E10 and E85 can be calculated for future years. As shown in Figure 8, both E10 and E85 improve over time as the carbon intensity of ethanol improves. Due to the higher ethanol content[17] of E85, the CO_2 benefit of E85 vs. E10 improves from 35% in 2022 to 45% in 2035.

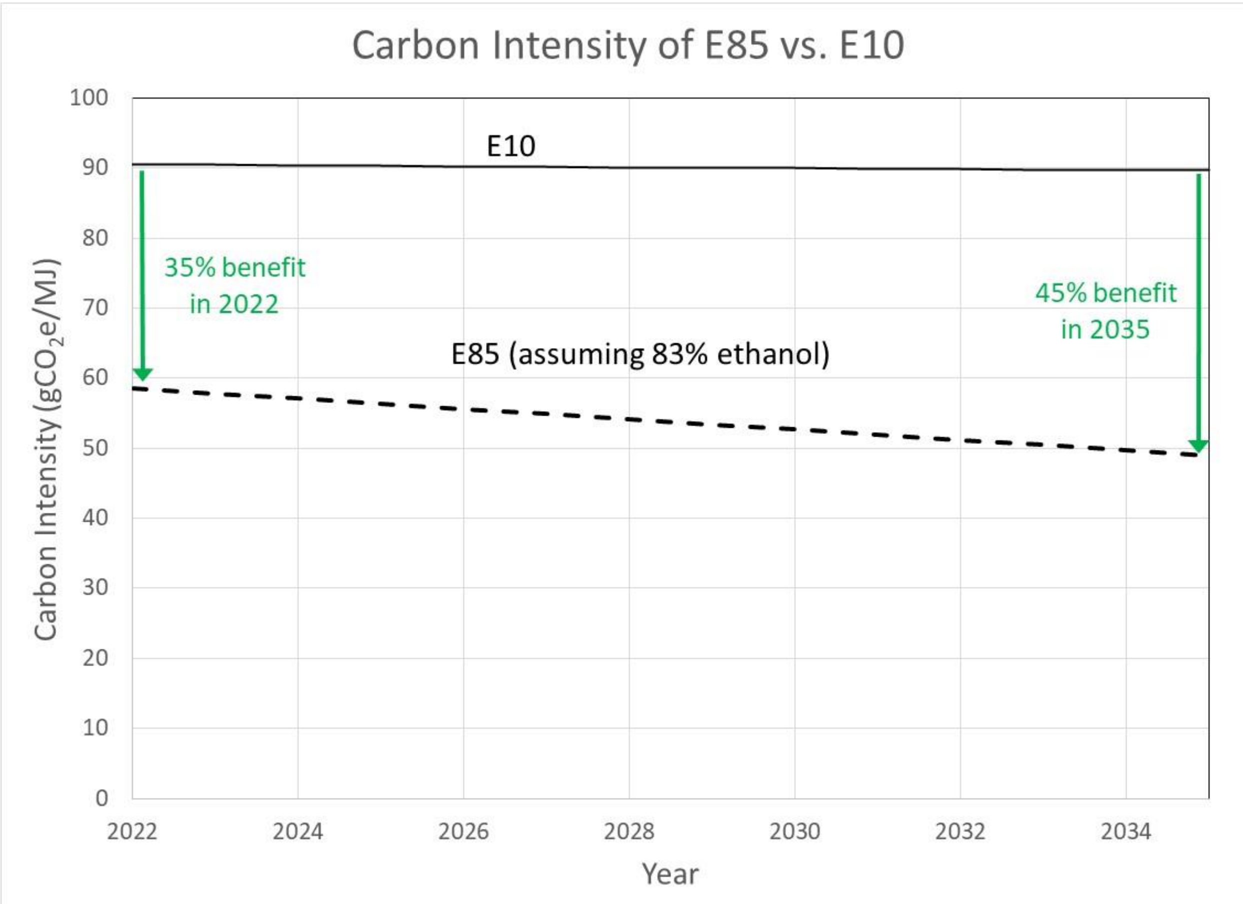

FIGURE 8: CARBON INTENSITY OF E85 VS. E10

[16] From GREET.NET 2023, simulation year 2022: ethanol LHV = 21,274 MJ/m3, gasoline blendstock LHV = 32,356 MJ/m3, E10 LHV = 31,270 MJ/m3, E10 CI = 90.1 gCO_2e/MJ

[17] In the U.S., ethanol content of E85 can vary from 51% to 83%. Unless indicated otherwise, the analysis in this paper assumes 83% ethanol content because it presumes that policies which recognize the greenhouse gas benefits of ethanol (e.g. low carbon fuel standards) would incentivize maximum ethanol content.

Using the conservative assumption of the 2022 carbon intensity benefit of E85 from Figure 8, greenhouse gas benefits can be calculated for each of the scenarios in Figure 3. As shown in Figure 9, if all FFVs used E85 the annual benefit would be 42 million metric tons CO_2e. If the projected 2026 E85 consumption per FFV in California were achieved nationwide, the annual benefit would be over 10 million metric tons CO_2e. And if the 2022 E85 consumption per FFV in California were achieved nationwide, the annual benefit would be almost 5 million metric tons CO_2e.

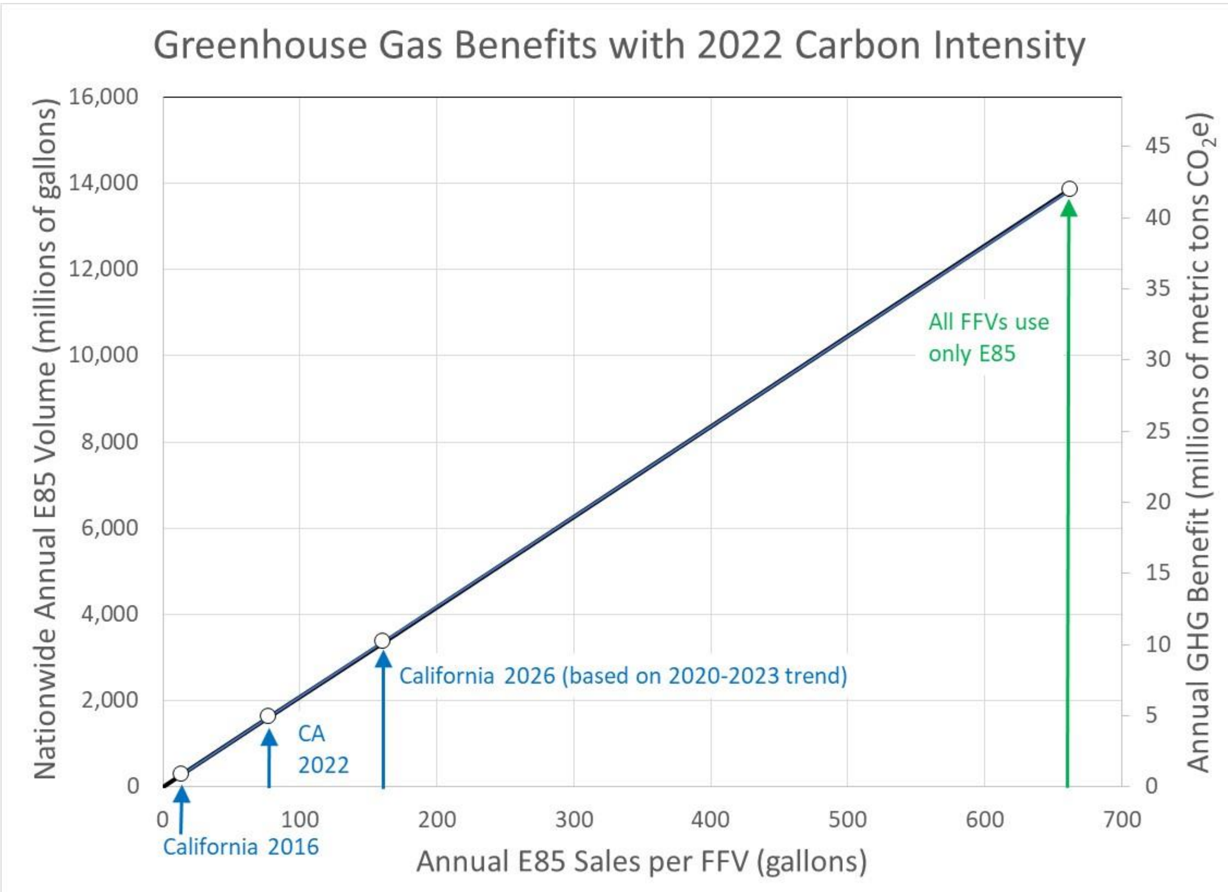

FIGURE 9: GREENHOUSE GAS BENEFITS WITH 2022 CARBON INTENSITY

But the benefits could be higher than indicated in Figure 9, as the carbon intensity benefit of E85 continues to improve over time (Figure 8). Using the assumption for the 2035 carbon intensity benefit of E85 from Figure 8, future greenhouse gas benefits can be calculated for each of the scenarios in Figure 3. As shown in Figure 10, if all FFVs used E85 the annual benefit would be over 54 million metric tons CO_2e. If the projected 2026 E85 consumption per FFV in California were achieved nationwide, the annual benefit would be over 13 million metric tons CO_2e. And if the 2022 E85 consumption per FFV in California were achieved nationwide, the annual benefit would be over 6 million metric tons CO_2e.

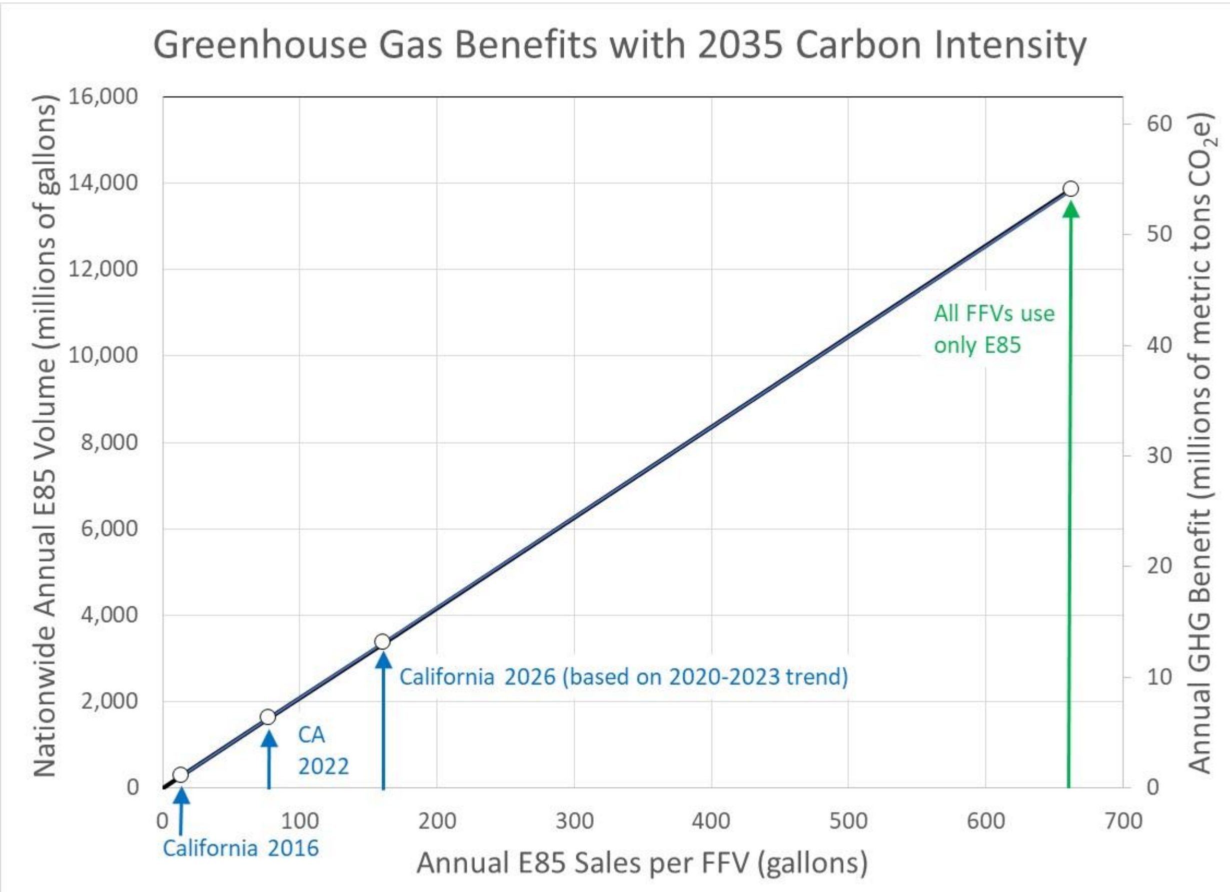

FIGURE 10: GREENHOUSE GAS BENEFITS WITH 2035 CARBON INTENSITY

6 RETAIL COST SAVINGS OF E85

The retail cost of E85 versus E10 was analyzed using data from E85prices.com, which is "crowdsourced" price information contributed by individuals nationwide. The analysis only used data where E85 and E10 prices were reported for the same station on the same date. The data was adjusted for the difference in volumetric energy content[18], and for the engine efficiency benefit described in section 4 of this paper.

The individual data points show significant scatter, but the monthly averages show a cost savings for every month from March 2022 to April 2024. There seems to be a general trend of increasing cost savings, although the trend is not statistically significant within the scatter of the raw data. As shown in Figure 11, the average cost saving of E85 was 6.0% over the last year, or 5.2% over the last two years. As shown in Figure 12, this translates to nationwide cost savings[19] up to $2.2 billion per year.

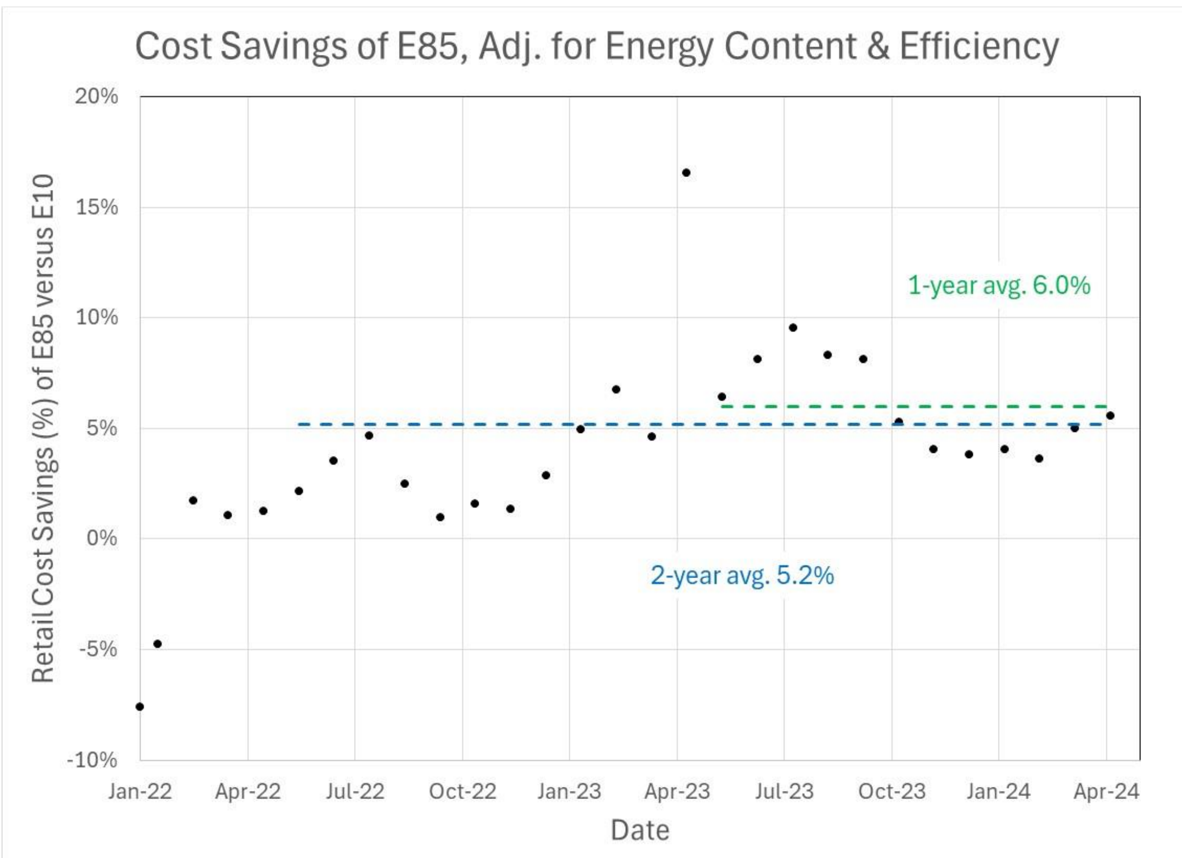

FIGURE 11: COST SAVINGS OF E85 VS. E10

[18] Assuming that the ethanol content of E85 was 83% in CA (where the Low Carbon Fuel Standard incentivizes maximum ethanol content), and 74% elsewhere.

[19] Based on 6.0% savings and 2023 average E10 gasoline cost of $3.32 per gallon https://www.eia.gov/energyexplained/gasoline/prices-and-outlook.php

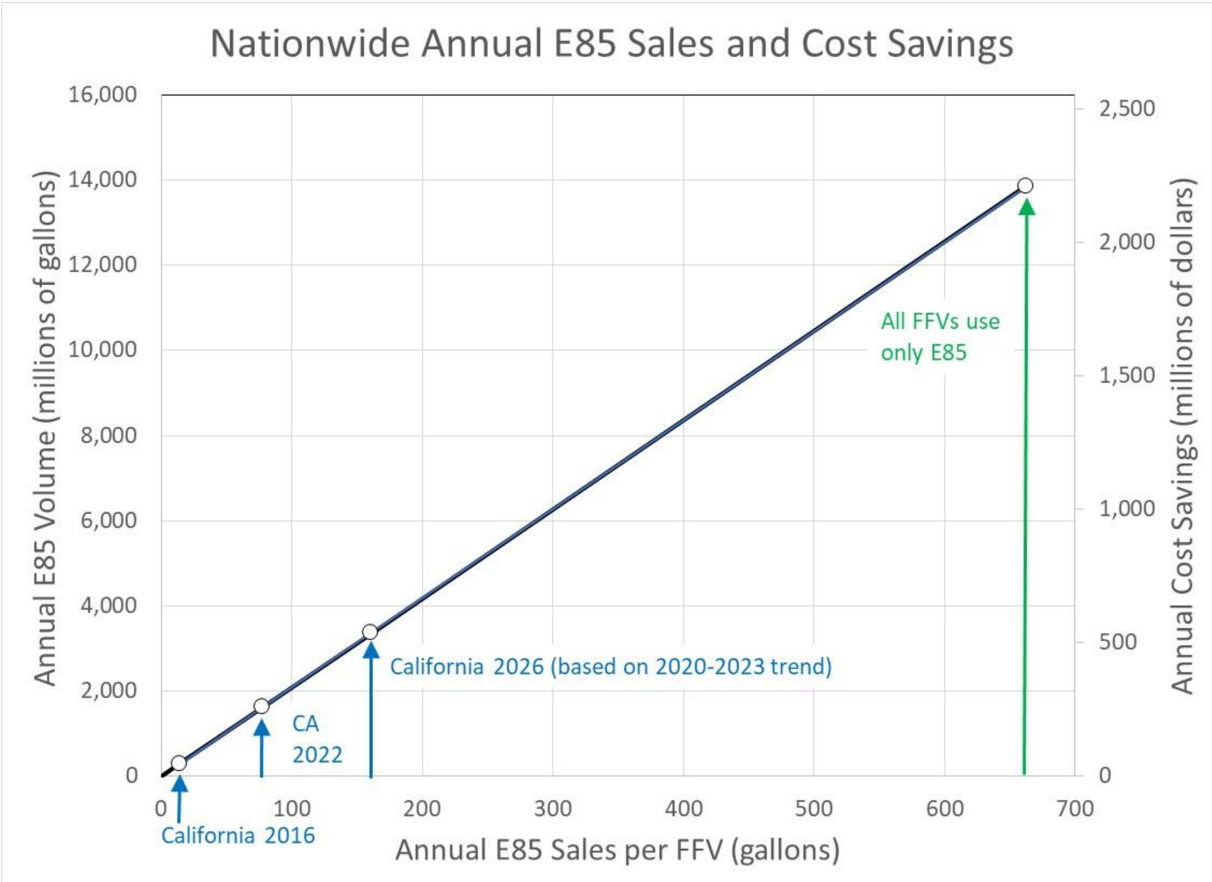

FIGURE 12: COST SAVINGS OF E85 SCENARIOS

7 DISCUSSION AND CONCLUSIONS

Widespread use of E85 (fuel with nominally 85% ethanol and 15% gasoline) would have significant greenhouse gas emissions benefits. This study identified possible scenarios for widespread adoption of E85 and quantified the greenhouse gas benefits using life cycle analysis.

E85 can only be used in flex-fuel vehicles (FFVs). About 8.1% of all vehicles on the road in the U.S. are FFVs. But many FFV owners do not refuel with E85, and thus the full potential emissions benefits are not currently achieved.

In recent years, E85 sales have increased dramatically in California. Annual E85 consumption per FFV increased from 14 gallons in 2016 to 77 gallons in 2022. If this trend continues, Californians will consume 161 gallons of E85 per FFV in 2026.

If all FFVs nationwide consumed 161 gallons of E85, it would result in annual greenhouse gas reductions of 10 to 13 million metric tons CO_2e. If all FFVs nationwide consumed only E85, it would result in annual greenhouse gas reductions of 42 to 54 million metric tons CO_2e.

In each case, the lower number is based on the 2022 value for carbon intensity of ethanol, and the larger number is based on the projected 2035 value. The carbon intensity of ethanol has been improving steadily for many years, and the projected 2035 value is based on a continuation of this trend.

To put these numbers in perspective, the EPA estimates[20] that its new standards will achieve benefits of 140 million metric tons CO_2e per year in 2035. These aggressive standards will require light-duty vehicles in MY2032 to produce about 54% lower average CO_2 emissions than in MY2026. But the standards are based on tailpipe emissions, not life cycle emissions. Because electric vehicles have zero tailpipe emissions, they are expected to play a dominant role; EPA estimates new vehicle sales to be about 56% battery electric vehicles by 2032. Fast growth of E85 could achieve a large fraction of this benefit, because E85 would improve life cycle CO_2 emissions for a large fleet of existing vehicles, not just new vehicles.

In addition to the greenhouse gas benefits, E85 generally offers a retail price advantage, which averaged 6.0% over the last year. If all FFVs nationwide consumed only E85, it would result in annual savings of over $2.2 billion.

[20] Table 204 of EPA final rule "Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles", 40 CFR Parts 85, 86, 600, 1036, 1037, 1066, and 1068, March 2024, https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-multi-pollutant-emissions-standards-model