Californias
Advanced Clean Cars
Midterm Review

Appendix F:
Scenario Planning: Evaluating impact of varying plug-in hybrid electric vehicle (PHEV) assumptions on emissions

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California Environmental Protection Agency
Air Resources Board

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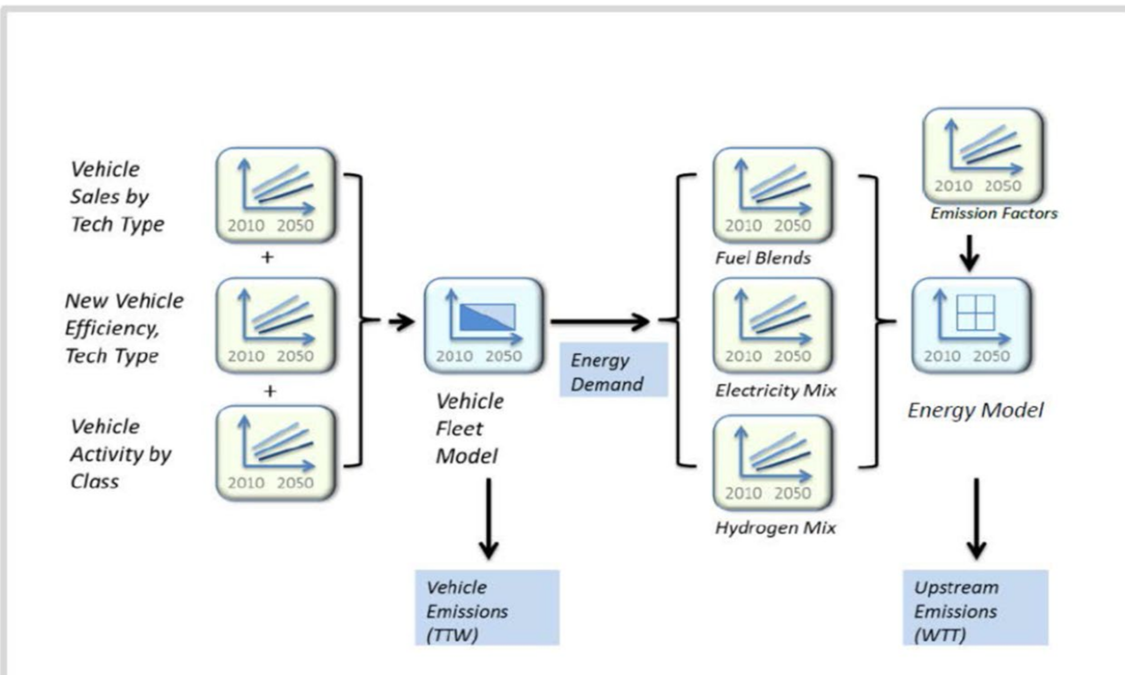
Introduction

The California Air Resources Board (ARB or the Board) previously explored the importance of zero-emission vehicle (ZEV) technologies in meeting California's long-term climate change and air quality goals using scenario planning in the Mobile Source Strategy[1] report released in May 2016. In that document, staff presented and discussed post 2025 scenarios incorporating various mobile source sector strategies to achieve long-term emissions reductions for both greenhouse gases (GHG) and criteria pollutants. The light-duty vehicle (LDV) advanced vehicle strategies build upon prior staff analysis in the Advanced Clean Cars (ACC) rulemaking staff reports from December 2011.[2] This report includes new LDV scenarios that represent sensitivity analyses relative to the Cleaner Technologies and Fuels scenario in the Mobile Source Strategy.

The ARB Vision model[3] was the primary modeling tool used to assess the emissions impacts of the various scenarios, accounting for both mobile source and upstream fuel production emissions. The structure of the Vision model is shown in Figure F-1 below.

Figure 1 - VISION Model Overview



In brief, the Vision model allows users to assess transportation well-to-wheel (WTW) emission impacts from changes in both downstream vehicle emissions and upstream fuel production

[1] ARB, 2016a. Air Resources Board. Mobile Source Strategy. May 26, 2016. https://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.htm
[2] ARB, 2011. Air Resources Board. ZEV Regulation staff report. December 7, 2011. https://www.arb.ca.gov/regact/2012/zev2012/zevisor.pdf
[3] ARB, 2016b. Air Resources Board. Vision Program. July 17, 2016. https://www.arb.ca.gov/planning/vision/vision.htm

variables in future year forecasts to 2050. In the downstream portion, users can modify variables such as vehicle technology sales fractions, fuel efficiencies, and vehicle activity. In the upstream portion, users can modify such variables as fuel blends and renewable fuel consumption. Most variables can be modified annually from 2010 to 2050. The model includes all mobile source sectors in ARB's inventory, and for light-duty and heavy-duty sectors, relies on ARB's EMFAC 2014 fleet inventory as a foundation.[4]

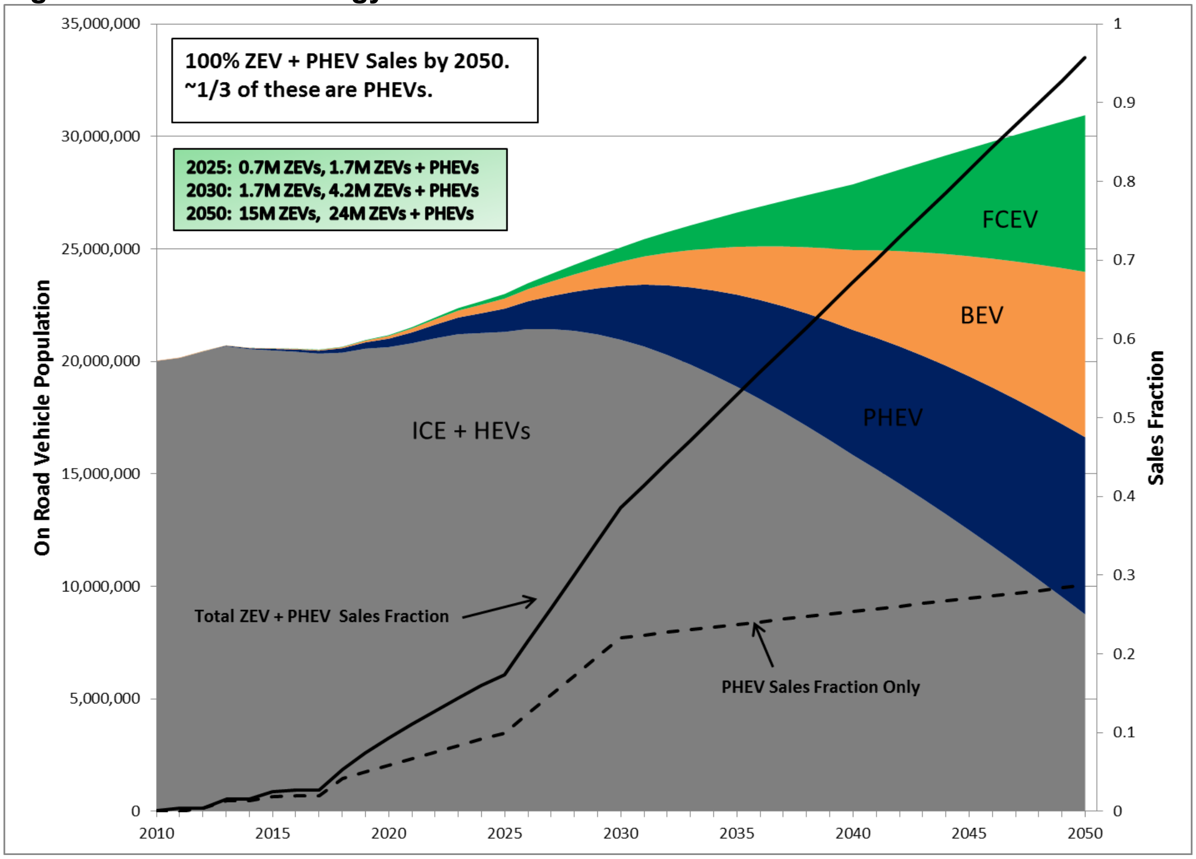
One of the primary scenarios presented in the Mobile Source Strategy, using the VISION 2 platform, was the Cleaner Technologies and Fuels (CTF) scenario. The objective of that scenario was to highlight a potential pathway for meeting the 2050 GHG emission reductions target (80% below 1990/2020 levels), as well as identifying strategies for meeting 2031 oxides of nitrogen (NOx) emission reductions in the South Coast Air Basin (SCAB) needed for attainment with national ambient air quality standards for ozone. The CTF scenario incorporated a number of strategies for the LDV sector including the following:

- Increased pure ZEV and plug-in hybrid electric vehicle (PHEV) sales (100% of new vehicle sales by 2050), beyond regulation minimum compliance in 2025.
- Progressive increase in fuel economy (all technology types), beyond 2025 CAFE compliance values.
- Progressive increase in PHEV electric vehicle miles travelled (eVMT) fractions (40% in 2025 to 60% in 2050 combined for passenger car and light truck classifications).
- Reduced growth in overall vehicle miles travelled (VMT) in future years (15% below baseline by 2050).
- Increased fractions of renewable sources for all fuel types.

Figure 2 and Figure 3 highlight the key assumptions in the CTF scenario regarding PHEV and ZEV sales and fuel economy increases in the LDV fleet, respectively. The figures also highlight the role PHEVs could play in the future years. Specifically, in the CTF scenario, PHEVs comprise approximately one third of total ZEV (which also includes battery electric vehicle or BEV and fuel cell electric vehicle or FCEV) new vehicle sales in 2050.

[4] ARB, 2016c. Air Resources Board. "EMFAC2014 Update" February 03, 2016. https://www.arb.ca.gov/msei/categories.htm#onroad_motor_vehicles

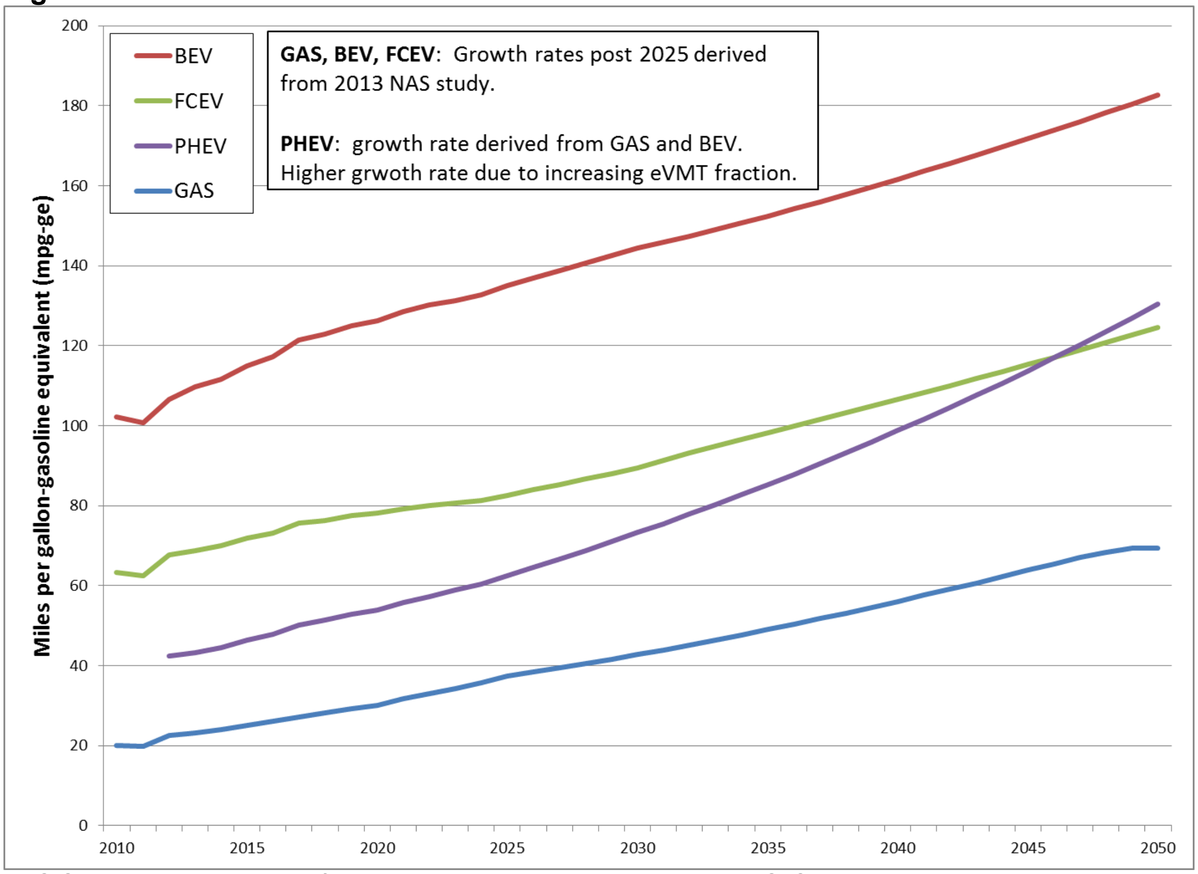
Figure 2 - Fleet Technology Profile in CTF Scenario



In regards to fuel economy (new vehicle, on-road performance), the CTF scenario assumes PHEVs will experience an increase in fuel economy from approximately 60 miles per gallon-gasoline equivalent (mpg-ge) in 2025 to approximately 125 mpgge in 2050. Compared to other technologies like gasoline, BEVs and FCEVs, the PHEVs experience a more aggressive growth in fuel economy. This is due to the assumption that the gasoline engine in the PHEV will increase in fuel economy in addition to the electric propulsion providing a higher eVMT fraction in future model years. As the eVMT fraction increases from 40% to 60%, PHEVs begin to achieve vehicle efficiencies that more closely resemble a BEV than a gasoline vehicle.

Regarding the eVMT fraction assumption, some current vehicles such as the 2017 Chevrolet Volt are likely to already exceed the near term and long term estimated eVMT fractions. However, this eVMT assumption is a weighted average for the entire passenger car and light truck combined fleet. Accordingly, it would account for some vehicles such as smaller passenger cars having a higher fraction of eVMT while other vehicles such as large SUVs or trucks that could have a lower fraction of eVMT.

Figure 3 - Fuel Economics in the CTF Scenario



MPG-GE represents new vehicle fuel economy in real-world on-road conditions. GAS is a category that includes both gasoline and non-plug-in hybrid vehicles combined. The 2013 NAS Study is the 2013 National Academy of Sciences "Transitions to Alternative Vehicles and Fuels" Report

Although the CTF scenario shows PHEVs play a significant role in all years through 2050, they are not a pure ZEV technology. PHEVs have internal combustion engines that emit GHGs and other criteria pollutants through tailpipe and evaporative emissions. The potential for these vehicles to emit such pollutants is highly dependent on parameters such as driving/charging behavior, fuel economy, and eVMT fractions as well as the onboard controls and durability of emission control systems. The impact of such parameters on GHG and criteria pollutant emissions would become even more prominent if PHEVs comprise a higher fraction of LDV fleet in the future. In order to assess the potential impacts of changes in PHEV parameters and higher PHEV sales fractions, staff developed several PHEV-focused VISION sensitivity scenarios to assess how the presence of PHEVs in the LDV fleet may affect California's ability to meet its statewide GHG and criteria pollutant emission targets in the future. The development of these scenarios and the inputs to the VISION model are described in the next section.

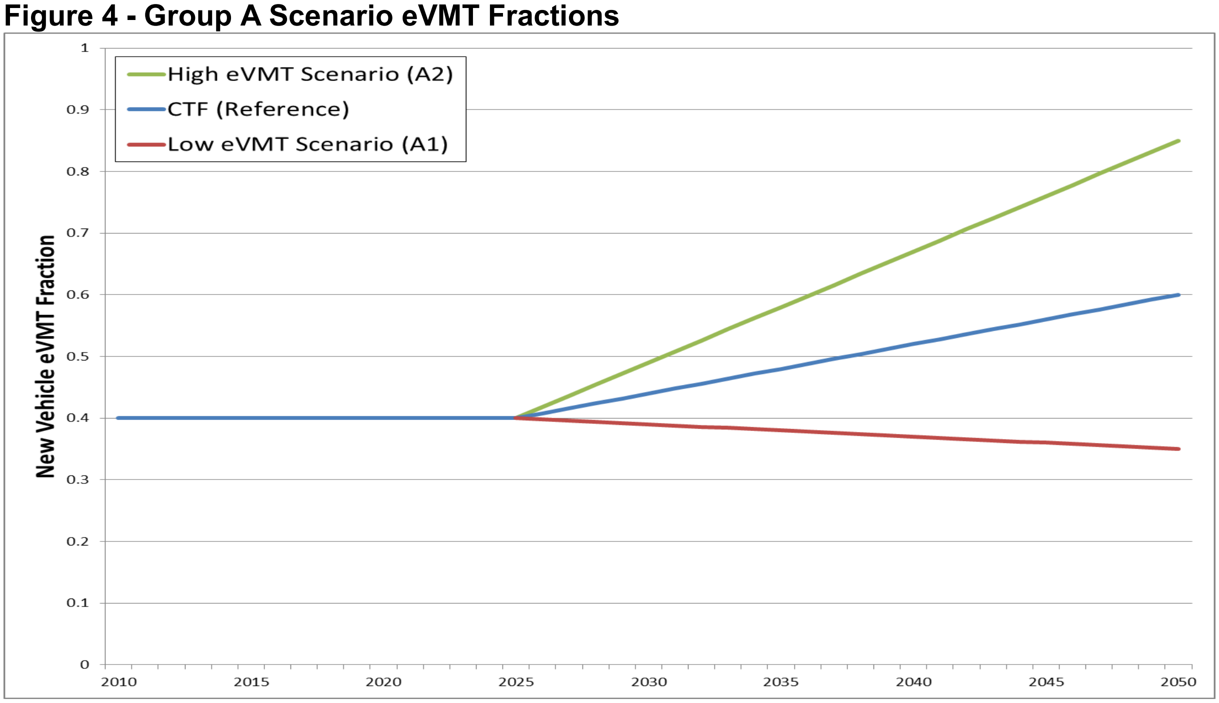
Development of scenarios and VISON model inputs

As previously described, the ability of PHEVs to control GHGs and criteria pollutants is dependent on vehicle parameters such as eVMT fractions and fuel economy, and on driving and charging behaviors. Such impacts become even more pronounced if PHEV sales fractions increase in the future. With that in mind, staff developed five sensitivity scenarios using the VISON model. These scenarios can be categorized into three basic groups and are described in detail below. Group A and B scenarios address a sensitivity study on PHEV variables, whereas the Group C scenario addresses sensitivity on fuel economy assumptions for all technology types. As such, Group C is placed at the end of the chapter.

I.A. Scenarios (A1 and A2)

These scenarios explore how changes in assumptions about PHEV eVMT fractions alone would impact statewide emissions in future years, while maintaining technology sales fractions from the CTF scenario. Specifically, staff developed a low eVMT fraction scenario (A1) where eVMT fractions would decrease from 40% eVMT (the baseline eVMT fraction in the CTF) to 35% in 2050. Staff also developed a high eVMT fraction scenario (A2) where eVMT fractions would increase from 40% eVMT in 2025 to 85% in 2050. These two scenarios equally bound the baseline CTF scenario (which assumes a growth to 60% eVMT by 2050) with alternative assumptions representing 25% higher and lower eVMT by 2050. The range of eVMT forecasts could be the result of numerous factors including faster/slower progress in vehicle technology, changes in consumer driving and charging behavior from influences such as energy and fuel costs, or availability of charging and refueling infrastructure. Figure 4 displays the change in eVMT fraction assumptions over time for the new scenarios as well as the CTF for comparison purposes.

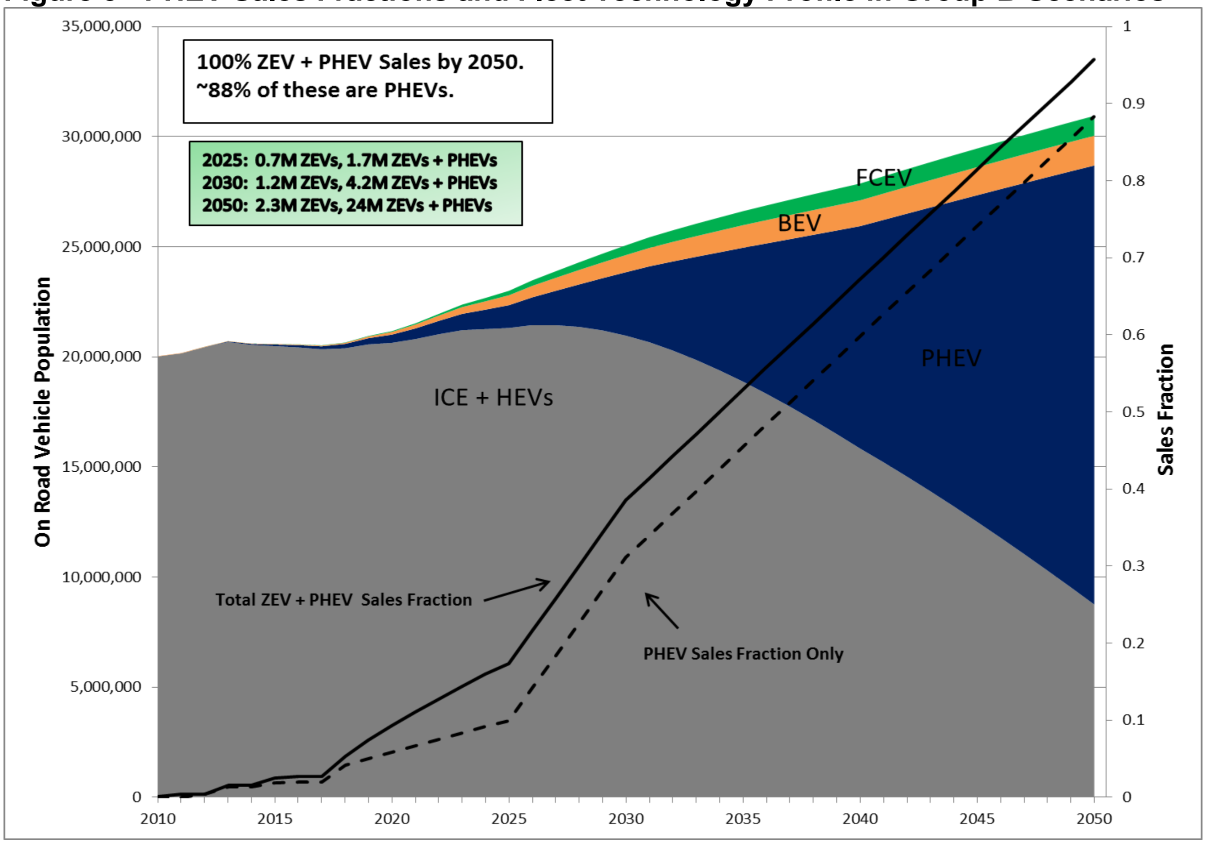
Figure 4 - Group A Scenario eVMT Fractions



I.B. Scenarios (B1 and B2)

These scenarios build upon the Group A scenarios by using the same eVMT fraction assumptions as in Group A, but simultaneously increasing the PHEV sales fraction to approximately 88% in 2050 instead of approximately 33% in the CTF scenario. This was done by keeping the same total ZEV sales fraction from 2025 to 2050 but allowing PHEVs to make up a larger portion of the total relative to the CTF scenario. In the B1 scenario, these higher PHEV sales were combined with the higher eVMT fractions used in Scenario A2. In the B2 scenario, higher PHEV sales were combined with the lower eVMT fractions used in A1. Figure 5 provides a graphical representation of the fleet technology profile and PHEV sales fractions for the Group B scenarios.

Figure 5 - PHEV Sales Fractions and Fleet Technology Profile in Group B Scenarios



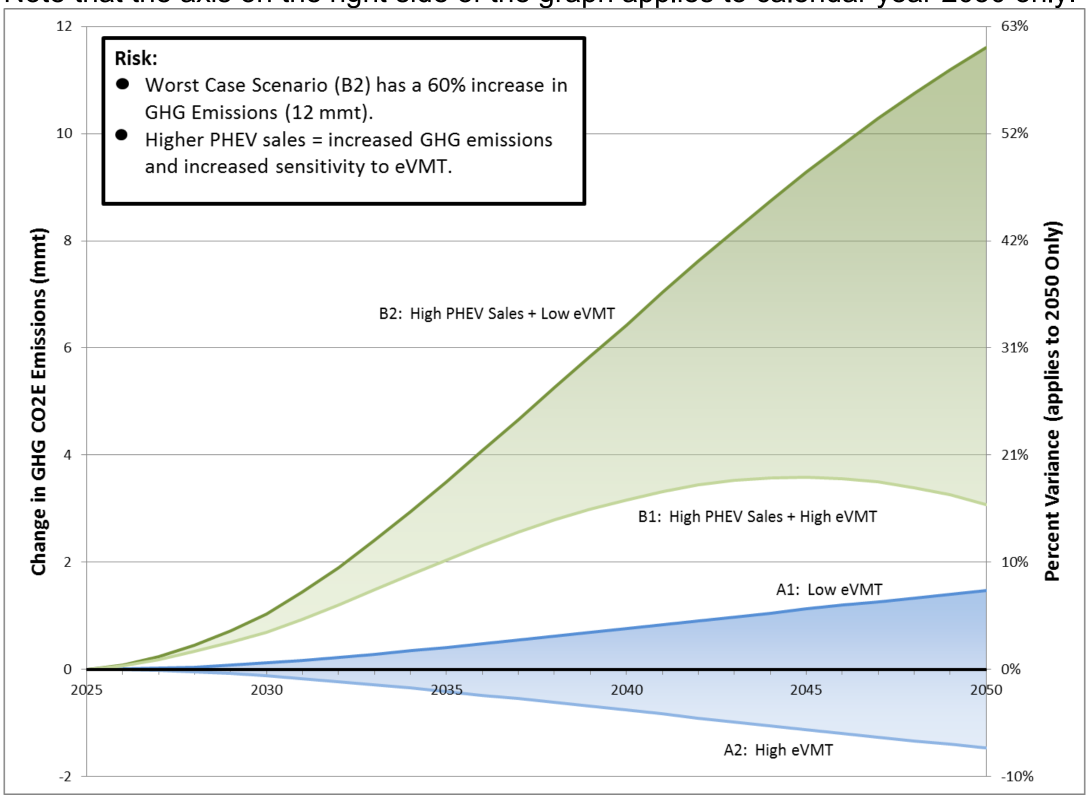
It should be noted that in all five of these scenarios, the total WTW biomass usage was kept constant to ensure LDV's portion of the limited feedstock (fuel source) did not change. Specifically, the total available biomass was fixed for use across all fuel types, including liquid biofuel consumption, as well as biomass used to produce electricity and hydrogen. For example, as hydrogen fuel consumption was decreased in scenarios A and B, more biomass was available for liquid biofuel use in PHEV vehicle consumption. If alternate scenarios were created where biomass is not used to produce hydrogen or electricity, then the biomass usage would be isolated to only the PHEV liquid biofuel consumption.

I.C. Summary of Results for Groups A and B

The relative impacts of the four A and B scenarios on WTW GHG emissions, tank to wheel (TTW) NOX and TTW volatile organic compounds (VOC) emissions are shown in Figure 6,

Figure 7, and Figure 8, respectively. Each of the pollutants followed the same trend for all four scenarios. Specifically, there were increased emissions under the B1 and B2 scenarios and the A1 scenario. Only under the A2 scenario (higher eVMT growth, no increase in PHEV sales fraction) did emissions decrease. When using the CTF scenario PHEV sales trajectories, higher and lower eVMT growth rates shows a modest sensitivity of less than ±7.5% change in projected GHG emissions by 2050. When combined with higher PHEV sales trajectory, however, the projected impact from the eVMT sensitivity ranged from a 16% to 60% increase in GHG emissions showing a much greater sensitivity to how the PHEVs are used in the fleet.

Figure 6 - WTW GHG Emissions for Group A and B Scenarios relative to CTF.
Note that the axis on the right side of the graph applies to calendar year 2050 only.



For the NOx and VOC results shown in Figure 7 and Figure 8 below, the results were directionally similar. Only scenario A2 (higher eVMT growth, no increase in PHEV sales fraction) showed lower emissions than the CTF scenario. Similar to the GHG results, the higher and lower eVMT growth combined with baseline PHEV sales fractions shows a very modest sensitivity of less than a ±7% change in projected NOx emissions by 2050 (0.8 tons per day (tpd) statewide). For VOC emissions statewide, the impact was ±3%. However, when combined with higher PHEV sales fractions, the projected impact ranged from an approximate 16% to 56% increase in NOx emissions and an approximate 20% to 33% increase in VOC emissions statewide by 2050 revealing a greater sensitivity to the eVMT growth assumptions. One note regarding the projected NOx and VOC emissions is that these projections utilized the EMFAC 2014 model. As noted in other appendices, ARB has been recently evaluating unique criteria pollutant emission impacts of PHEVs regarding the frequency of engine starts and the emissions from those starts and the findings of that testing have not yet been incorporated into the EMFAC model. Further, ARB's inventory staff are also updating many of the assumptions regarding emission rates that will impact these projections and are targeting a revised version for 2017.

Figure 7 - Vehicle Statewide NOx Emissions for Group A and B Scenarios relative to CTF. Note that the axis on the right side of the graph applies to calendar year 2050 only.

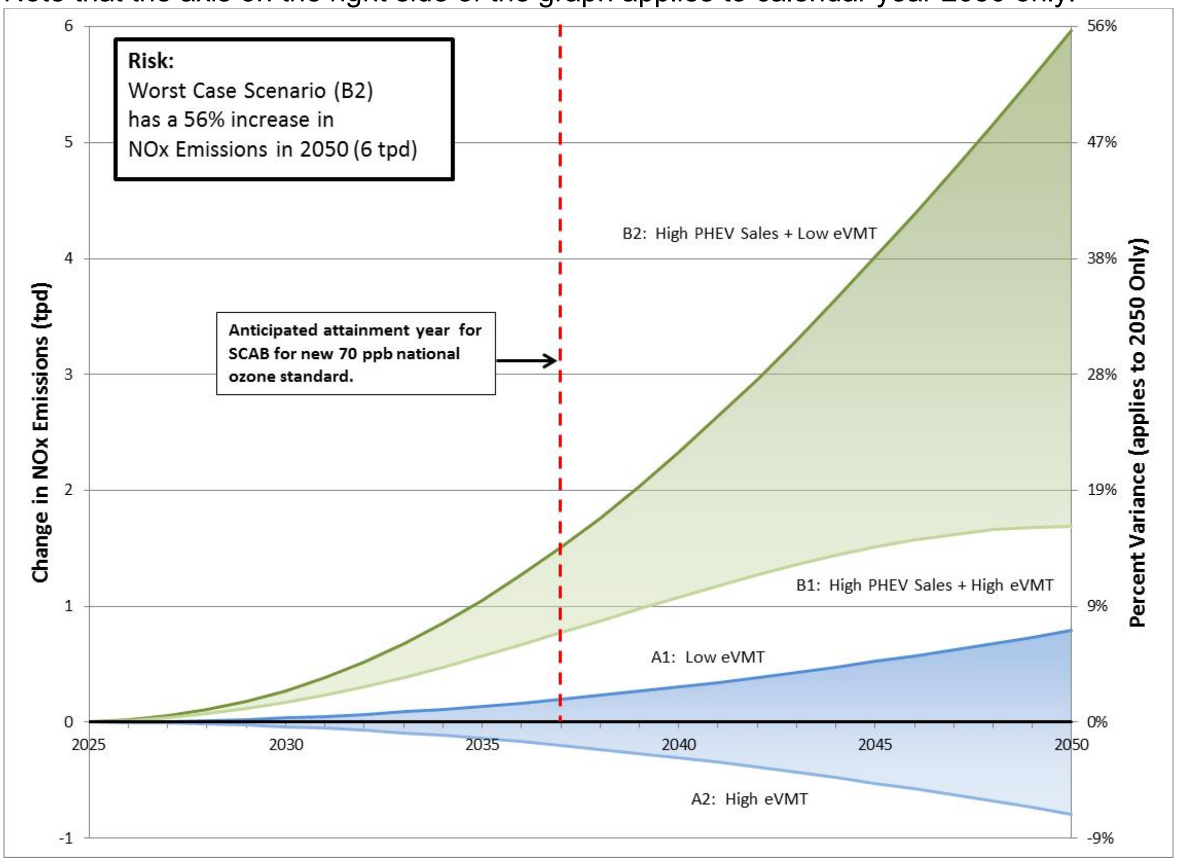
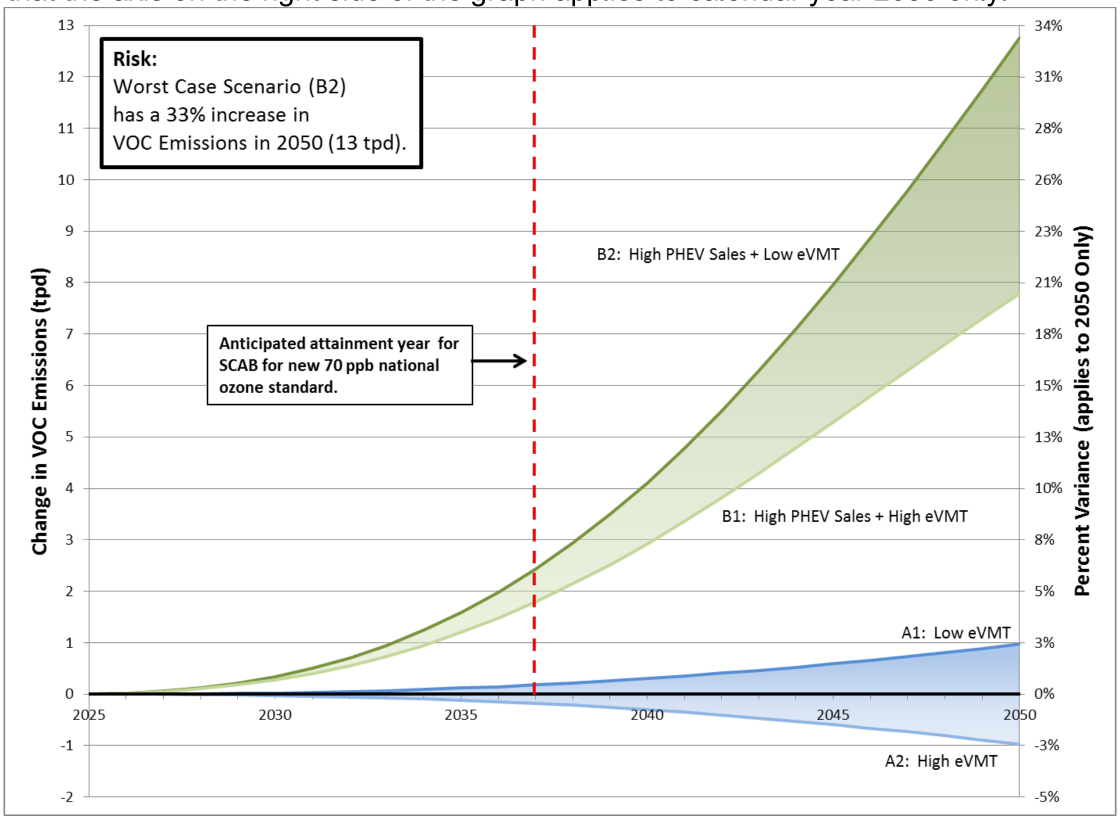


Figure 8 - Vehicle Statewide VOC Emissions for Group A & B Scenarios relative to CTF. Note that the axis on the right side of the graph applies to calendar year 2050 only.



An alternate “high PHEV fleet” scenario could be created (not done in VISION here) where total FCEV fleet vehicle volumes remain the same as the CTF scenario, and additionally PHEV fleet-wide electricity usage remains the same as the fleet-wide BEV VMT they replace (modeled as an increasing eVMT factor for new vehicle PHEVs). Specifically, it could assume PHEVs only displace BEVs and not any FCEVs compared to the CTF scenario. This combination of assumptions could result in a scenario with the exact same GHG emissions as the CTF scenario. However, to achieve the same electricity usage with PHEVs, the increasing eVMT assumption for new vehicle PHEVs would have to increase dramatically faster than ARB assumed in Figure F-4; an assumption ARB staff do not believe is possible.

Figures 9 and 10 below show the combined fuel demand results from Scenarios A and B. Fuel usage is a strong indicator for emissions impacts in the scenarios. Fuel types modeled in the LDV scenarios, and shown in Figures 9 and 10, include a gasoline blend, electricity and hydrogen. All three of these fuel types include varying blends of fossil based fuels as well as zero carbon and renewables. For the gasoline blend, the liquid fuel components include petroleum gasoline blendstock (CARBOB), ethanol from an increasingly more sustainable feedstock (moving away from corn), and renewable gasoline with a low carbon intensity. Hydrogen and electricity both include a large shift to renewable sources becoming mostly decarbonized by 2050.

In Figure 9, total fuel usage is shown. Fuel usage is reduced in A2-H (higher eVMT than CTF) as expected resulting in lower emissions shown earlier. In scenario B1-H where eVMT is higher than CTF but with more PHEVs in the fleet, total fuel usage is approximately the same as the CTF scenario, but there is more demand of gasoline blend fuel (and less hydrogen fuel demand). Because the gasoline blend fuel has a higher carbon intensity per unit consumed than hydrogen or electricity, the well-to-wheel emissions of B1-H are higher than CTF as shown in Figure 6.

Figure 9 - Total fuel usage (gasoline blend, electricity, and hydrogen) in CTF and Scenarios A and B (million gallons gasoline equivalent)

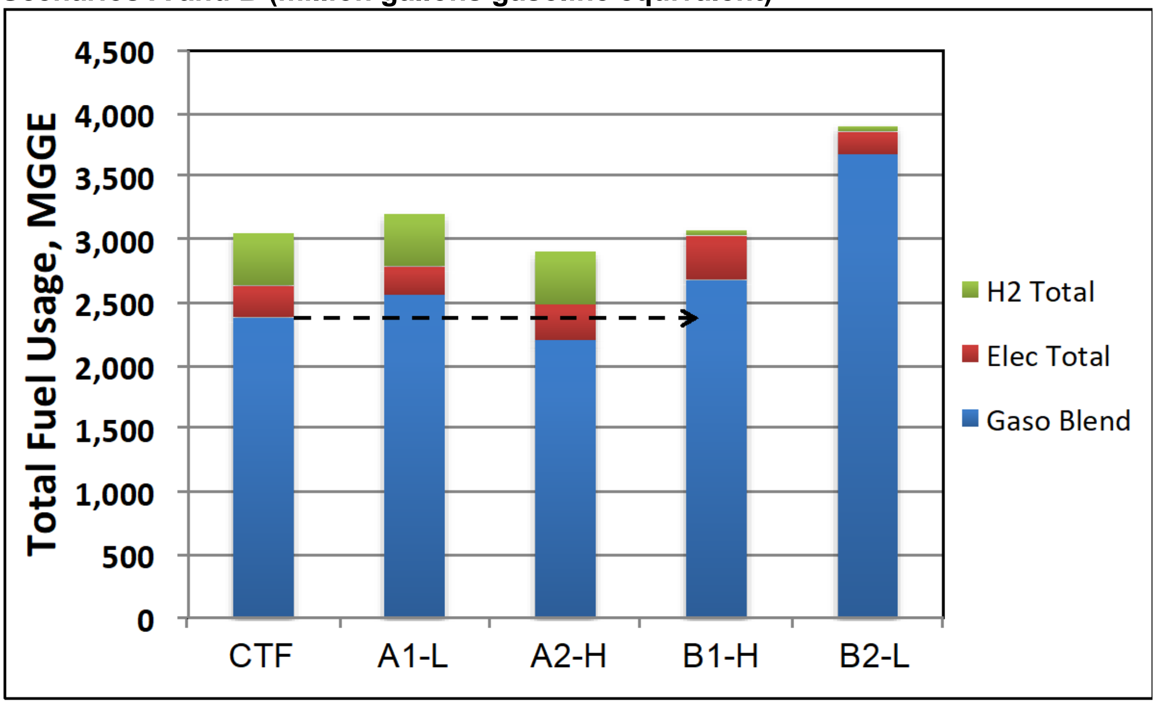
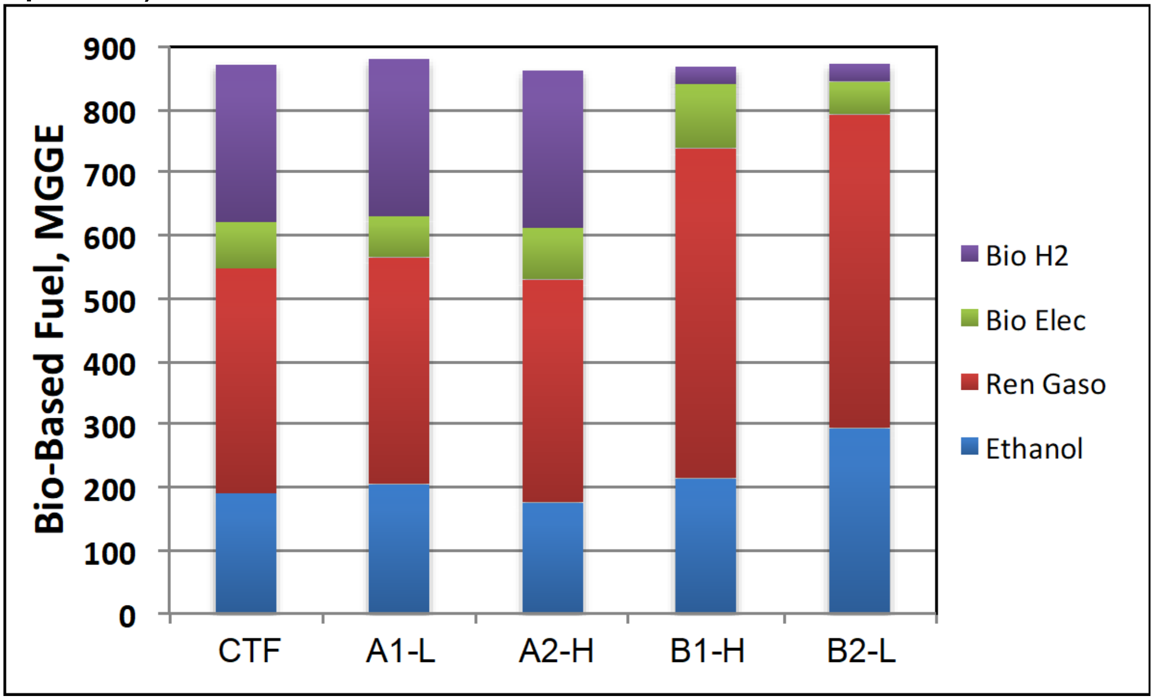


Figure 10 below shows a more specific portion of total fuel usage, the bio-based fuels from the gasoline blend, electricity and hydrogen. In the CTF scenario, bio-electricity and bio-hydrogen are part of the overall supply. For Scenarios A and B, the fraction of electricity and hydrogen supplied by bio-fuels was not changed, but as total electricity or hydrogen demand changes, so does the use of bio-based fuels. However, for the gasoline blend fuel, the renewable gasoline blend ratio was varied in Scenarios A and B such that the total bio-based fuel usage remained approximately the same as the CTF scenario (~900 million gallons gasoline equivalent, or MGGE). This was done to mimic a fixed supply constraint of bio-based fuels for LDVs in all scenarios. As a result of this, renewable gasoline usage increased substantially in Scenario B as bio-hydrogen was scaled back. Ethanol blends are fixed at 10% by fuel volume, but vary in the scenarios proportional to total gasoline blend usage.

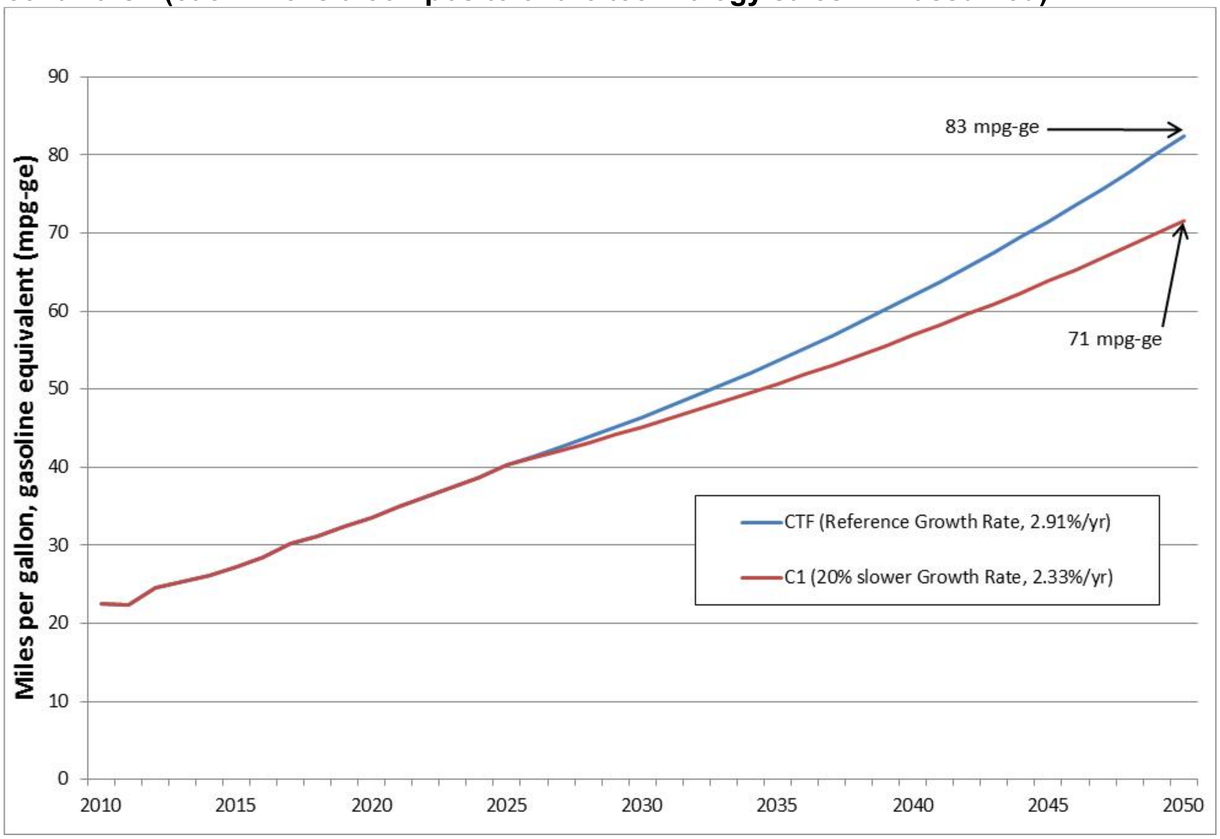
Figure 10 - Bio-based fuel usage in CTF and Scenarios A and B (million gallons gasoline equivalent)



I.D. Scenario (C1)

This scenario was developed to investigate the sensitivity of fuel economy improvement assumptions on future year GHG emissions. Specifically, the 2025 to 2050 annual fuel economy improvement rates for all technology types (i.e., gasoline, BEV, FCEV, and PHEVs) were lowered from 2.9% improvement per year to 2.3% improvement per year, which represents a 20% reduction in the annual improvement rate. Figure 9 provides a graphical comparison of the fuel economy growth rate of gasoline vehicles in the CTF scenario and Scenario C. The objective of this scenario was to quantify the magnitude of increased GHG emissions in 2050 and subsequently determine the required increase in ZEV sales rate from 2025 to 2050 in order to offset the increased GHG emissions in 2050.

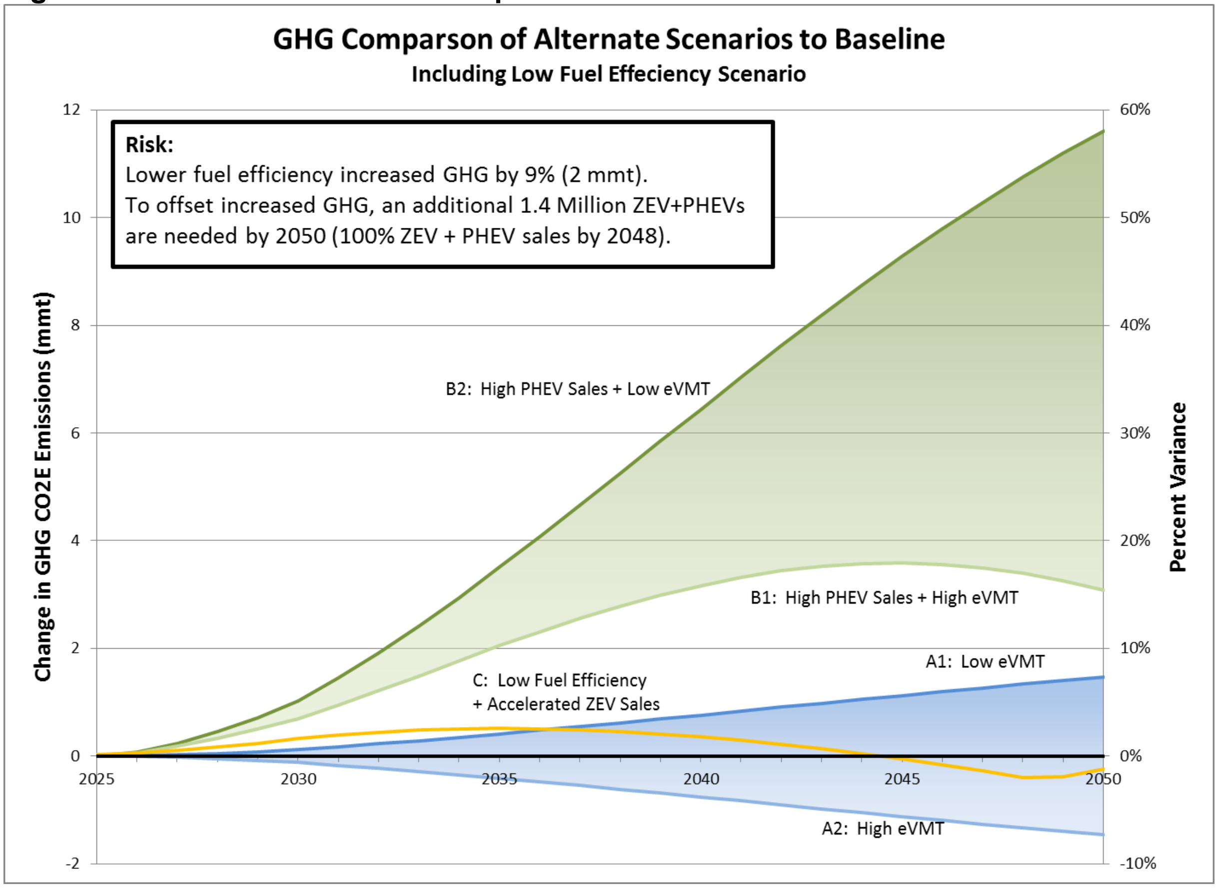
Figure 11 - Comparison of fuel economy growth rates for gasoline vehicles in CTF and Scenario C1 (each line is a composite of the technology sales mix assumed)



I.E. Summary of Results for Group C

In Scenario C, as the new vehicle fuel efficiency growth rates were slower for future years, fleet-wide GHG emission reductions are smaller (less GHG reduction benefits) compared to the CTF scenario. Specifically, the LDV 2050 GHG emissions went up by 2 MMT CO_2e, or approximately 9% of the LDV sector's 2050 GHG WTW inventory. To compensate for this impact, Scenario C modeled an increased rate of ZEV and PHEV sales to increase the overall efficiency of the fleet. The same technology sales mix used in CTF was assumed (approximately 1/3 each of BEVs, FCEVs, and PHEVs for the total ZEVs) and resulted in an increased sales rate needing to reach 100% ZEV sales by 2048 instead of 2050, adding an additional 1.4 million ZEVs and PHEVs to the fleet by the end year. The yellow line in Figure 10 represents the increase in CO_2 emissions over time in this scenario. As shown in the graph, the increased CO_2 emissions due to lower fuel economy are eventually offset to the original CTF levels in 2050 due to accelerated ZEV and PHEV sales.

Figure 12 - Scenario C Emission impacts



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ARB, 2016c. Air Resources Board. "EMFAC2014 Update" February 03, 2016. https://www.arb.ca.gov/msei/categories.htm#onroad_motor_vehicles