

Achieving an 80% GHG Reduction by 2050 in California's Passenger Vehicle Fleet: Implications for the ZEV Regulation

2010-01-2306

Published
10/19/2010

Joshua Cunningham
California Air Resources Board

ABSTRACT

In recognizing the potential for large, damaging impacts from climate change, California enacted Executive Order S-03-05, requiring a reduction in statewide greenhouse gas (GHG) emissions to 80% below 1990 levels by 2050. Given that the transportation light-duty vehicle (LDV) segment accounts for 28% of the state's GHG emissions today, it will be difficult to meet the 2050 goal unless a portfolio of near-zero carbon transportation solutions is pursued. Because it takes decades for a new propulsion system to capture a large fraction of the passenger vehicle market due to vehicle fleet turn-over rates, it is important to accelerate the introduction of these alternatives to ensure markets enter into early commercial volumes (10,000s) between 2015 and 2020.

This report summarizes the results and conclusions of a modeling exercise that simulated GHG emissions from the LDV sector to 2050 in California. Specifically, the analysis addressed two policy questions: (1) what fraction of the on-road fleet in 2050 needs to be zero-emission vehicles (ZEVs) ¹ in order for the LDV sector to achieve an 80% GHG reduction, and (2) what annual ZEV sales are necessary between 2015 and 2025 to initiate these fleet volumes?

Two scenarios were developed revealing how difficult it will be to achieve this goal. Scenario 1 achieves a 66% reduction in GHG emissions by 2050 using aggressive assumptions. This scenario assumes ZEV sales reach a quarter of a million units annually by 2025 and become 100% of new vehicle sales by 2050. Scenario 2 was developed to show what would

be required to achieve the full 80% GHG goal. To achieve this, two key parameters were modified with more aggressive and less certain assumptions. A steeper ZEV sales projection was simulated that achieves half a million ZEVs annually by 2025 and becomes 100% of new vehicle sales by 2040. Additionally, the availability of biofuels was increased to 1.7 billion gallons gasoline equivalent (BGGE), where it was limited to 1 BGGE in Scenario 1.

INTRODUCTION

In developing the policy for Assembly Bill (AB) 32, the California Air Resources Board (ARB) and other State agencies carefully studied the specific impacts of climate change on the State of California.² The AB 32 goal of reducing emissions to 1990 GHG levels by 2020 is the first step towards longer-term, deeper, reduction needed to stabilize the climate. The 2020 requirement is critical for two reasons. First, achieving deep GHG reductions in 2050 requires multiple decades of concerted effort, where interim actions are important.³ Secondly, climate change is a function of cumulative emissions in the atmosphere. Early reductions (2020) are therefore essential. In addition to the Governor's Executive Order and AB 32, the State Legislature and ARB have adopted a number of policies that address GHG emissions in the transportation sector specifically.⁴

Scenarios represent a projection of what could be possible - a "what if" story that can help provide context for decision makers. In the case of GHG policy development, scenarios help illuminate the bounds of how large emissions could

¹ In this analysis, ZEVs include fuel cell vehicles (FCVs) and battery electric vehicles (BEVs), not plug-in hybrid electric vehicles (PHEVs).

² This work is summarized in the Scoping Plan, <http://www.arb.ca.gov/cc/scopingplan/scopingplan.htm>

³ A number of studies have shown that multiple solutions will be required to achieve the GHG reductions [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]

⁴ These include the vehicle GHG regulation (Assembly Bill 1493 or "Pavley", 2004), the Low Carbon Fuel Standard (ARB, 2008), and the regional GHG target (Senate Bill 375, 2008).

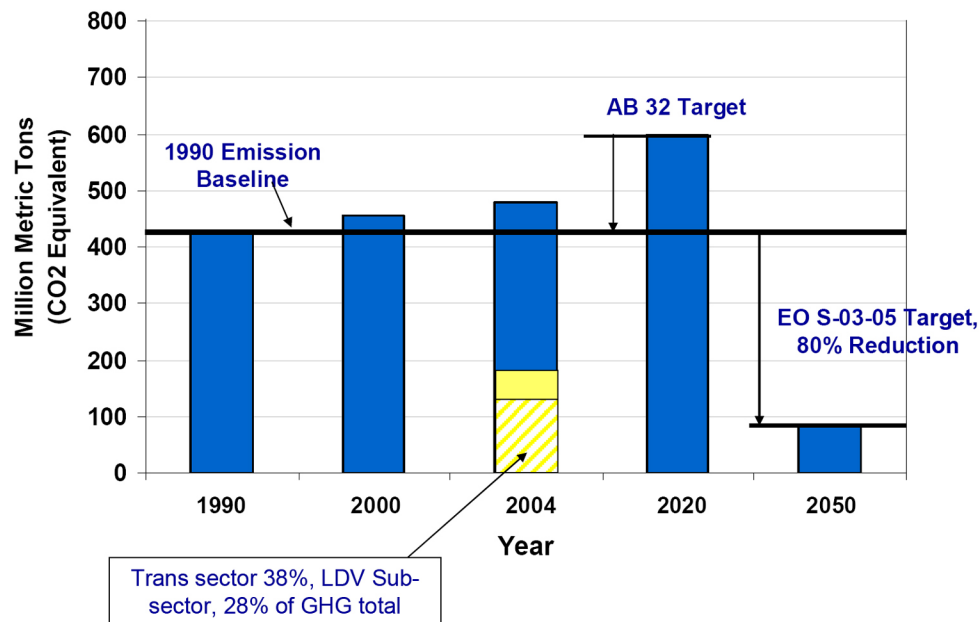


Figure 1. California GHG Projections and Policy Goals

grow, and what kinds of solutions could be employed to reduce them. Scenarios can reveal how large specific solutions would have to be, and over what timescales they need to be implemented. Scenarios are not, however, predictions of what the future will be, nor are they roadmaps for specific policies to 2050.

The scenarios in this analysis assumed a 2050 target of 80% below the passenger vehicle portion of 1990's GHG inventory, or 20% of 108.5 million metric tons (MMT) of carbon dioxide equivalent (CO₂e) emissions. This represents a "fair share" by the passenger vehicle sector. In reality, each sector will carry varying reduction levels to meet the statewide average of 80%. However, it is not likely that the target can be met unless passenger vehicles achieve large reductions in GHG emissions, given its 28% contribution to overall emissions today.

Figure 1 above shows California's actual GHG emissions through 2004 and projected emissions in 2020, along with the emissions reduction goals for all sectors. Meeting the 2020 goals will require over 170 MMT reductions of CO₂e emissions from projected 2020 levels (30%). For 2050, an additional reduction of 341 MMT is required to meet the 80% reduction goal. Compounding this challenge is a growing population which increases pressure on limited resources. According to the California Department of Finance (DOF), the State's population is projected to reach 60 million people by 2050⁵, double what it was in 1990.

This modeling exercise was conducted to support the development of the ZEV Regulation which is being considered for revision by ARB in late 2010. It does not represent ARB positions or assumptions in the other GHG policies such as LCFS, Pavley, SB 375, AB 32, etc.

METHODOLOGY

To develop an analysis of California's transportation sector GHG emissions over the next several decades, an energy and vehicle stock turn-over model was employed to simulate the vehicle fleet and its changing emission profile. The tool used was the United States Department of Energy's (U.S. DOE) Vision model, developed by the Argonne National Laboratory.⁶ ARB made changes to the model to simulate a California passenger vehicle fleet and energy system. The Vision model allows the user to specify new vehicle fleet market shares, vehicle technology and performance assumptions, fuel carbon intensity, and VMT per vehicle trends. The model then determines the on-road fleet composition, fuel usage, GHG emissions and total VMT. The Vision model is used by Federal policymakers and analysts in evaluating transportation energy policy questions.

In developing the scenarios for this analysis, assumptions were identified based on extensive review of the literature and stakeholder discussion. Key assumptions were identified for vehicle technology and performance, fuel supply, sales projections, and vehicle usage patterns. The primary factors that vary between scenarios are vehicle sales projections, the

⁵California Department of Finance (DOF), <http://www.dof.ca.gov/research/demographic/reports/projections/p-1/>

⁶U.S. DOE Vision Model 2008, http://www.transportation.anl.gov/modeling_simulation/VISION/.

vehicle technology mix in the market, biofuel supply levels, and vehicle miles traveled (VMT) per vehicle reductions.

California vehicle annual sales projections are based on ARB's Emission FACTors 2007 (EMFAC 2007) dataset, which includes historical data through 2008 and projections to 2040.⁷ Trends were extrapolated to 2050 to complete the dataset for this analysis. The fleet turnover rates are based on the national trends in the U.S. DOE's Vision model. Fleet turn-over rates determine how many vehicles remain on the road in any given year, and account for vehicle age, scrapage rates, declining VMT per vehicle based on age, etc. The average lifetime of a passenger vehicle in the United States is roughly 15 years. Generally, the market diffusion is slow, resulting in several decades for a new technology to substantially replace older vehicles.⁸

ASSUMPTIONS

This section outlines the primary input assumptions for the model along with how the varying advanced vehicle scenarios were chosen.

Achieving an 80% reduction in the transportation sector will require a broad mix of solutions. This includes reduced VMT per capita (partly through increased use of transit), increased vehicle fuel efficiency, reduced fuel carbon content, and implementation of advanced vehicle technologies. This analysis includes all of these solutions, but most carefully studies the vehicle technologies. Hydrogen fuel cell vehicles (FCV), battery-electric vehicles (BEV), and plug-in hybrid-electric vehicles (PHEV) with low carbon biofuels are the three most viable candidates for near-zero carbon transportation. This analysis shows all three vehicle technologies will be necessary in order to achieve an 80% reduction target, and to reduce the risk of technology or market failures.

The dataset assumes roughly 22 million vehicles are on the road in 2000, increasing to 40 million vehicles in 2050.⁹ Annual sales rates start from roughly 1.5 million vehicles sold per year in 2000 and grow to 2.7 million in 2050 (accounting for a sales decline in 2008-2009). Additionally, the analysis assumed a sales mix of cars and trucks shifted to a 70%/30% respectively by 2050.

Efficiency and VMT reductions

Fuel economy improvements are assumed and result from a number of factors, including vehicle down-sizing and vehicle weight reduction, in addition to powertrain efficiency improvements. Specifically, the analysis in MIT 2008 [5] was heavily leveraged for conventional vehicle fuel economy and the ratio of fuel economy between technology alternatives (although the exact projection of fuel consumption for each technology may vary from the MIT study). The MIT analysis was based on a mid-sized vehicle platform. This analysis assumes that by 2050, the average vehicle size has been reduced to a compact vehicle platform. This is represented as a steeper increase in fuel economy than would be expected if the platform size remained constant. Figure 2 below shows the assumed fuel economy values in the analysis for autos, separate fuel economy assumptions were developed for light trucks.

All technology alternatives are based on vehicle platforms with the same improvements relative to today's vehicle (weight reduction, down-sizing, aerodynamics, etc). Note that the PHEV fuel economy is not shown. The model accounts for the fuel economy of PHEVs on both grid-electricity and liquid fuels separately. For simplicity, this analysis assumes that when a PHEV is operating on grid supplied electricity, the fuel economy is the same as a BEV; when the PHEV is operating on liquid fuels, the fuel economy is the same as an HEV.¹⁰ In reality, this will depend on the specific vehicle design, weight, and control algorithms.

VMT reduction goals will target regional development and transportation planning, and will include solutions such as mass transit, compact urban design, carsharing, and more. The VMT per vehicle reductions in the scenarios were assumed to be 20% below the projected "business as usual" (BAU) per vehicle VMT in 2050. These projections for the BAU assume VMT per vehicle will stagnate at approximately 12,000 miles/yr, therefore the VMT in the scenarios are 9,600 miles per year per vehicle. Figure 3 shows the scenario trends for VMT where total VMT increases as State population grows.¹¹

Electricity and fuels carbon intensity

Electricity, hydrogen, and bio-hydrocarbon fuel carbon intensities were modeled with large reductions through 2050. The carbon intensity values from the LCFS were used in this model for each type of fuel production and feedstock, and

⁷ ARB EMFAC 2007, http://www.arb.ca.gov/msei/onroad/latest_version.htm

⁸ IEA 2008a, MIT 2008, Pew, NRC 2008c.

⁹ The vehicle population numbers are derived using both the vehicle sales projections from ARB's EMFAC model, and the national fleet turn-over rates used in the Vision model.

¹⁰ The scenarios all assume an increasing amount of all electric range for PHEVs over time.

¹¹ As noted above, DOF estimates California's population will grow to nearly 60 million people by 2050.

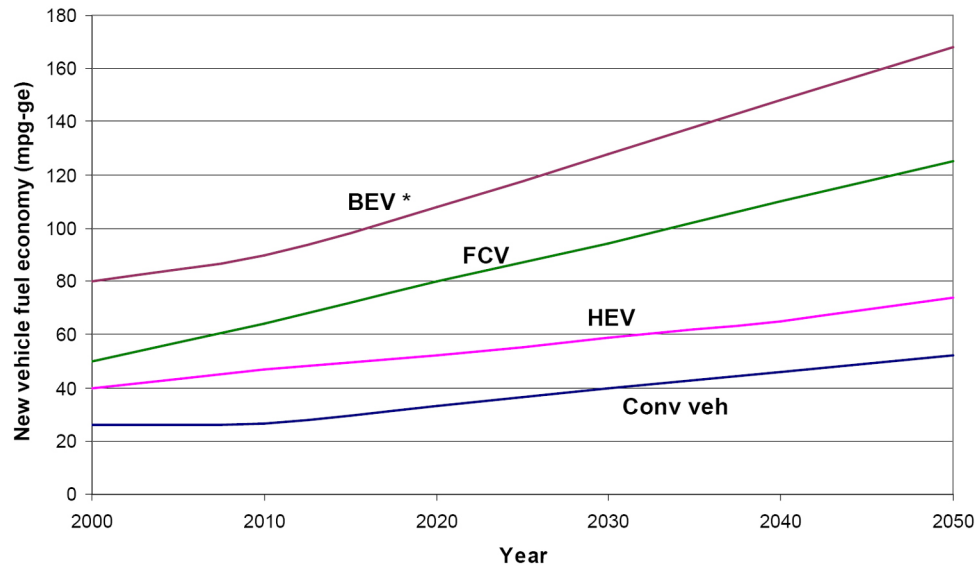


Figure 2. Fuel economy for the various powertrain technologies (cars) (Includes AC to DC energy loss from grid battery charging)

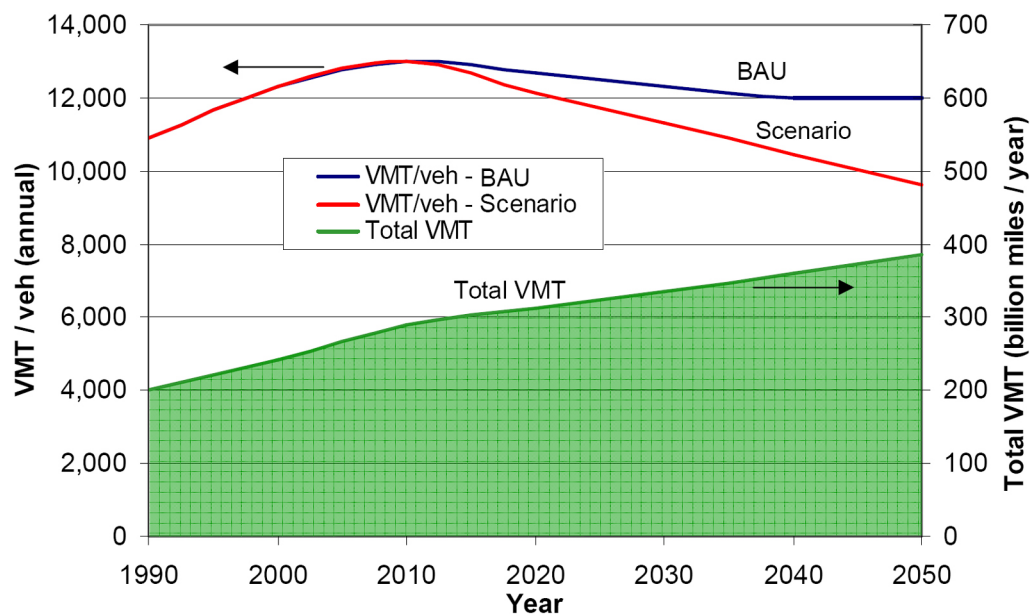


Figure 3. California VMT Trends

were assumed to be relevant out to 2050.¹² This is a change from the Vision model where the carbon intensity numbers were from Argonne National Laboratory's Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model. Specifically, the carbon intensity of hydrogen, electricity, and biofuels is largely reduced by 2050 (80%, 65%, and 90% respectively below today's levels), relying on sustainable feedstocks and carbon capture solutions. These changes will be challenging to achieve, and

will require expanded transmission lines, fuel distribution and large investments in sustainable power production facilities, along with technology innovation. Note that the scenarios ensured the 2020 policy goal was achieved for the LCFS, a 10% reduction in average carbon intensity by 2020. Additional details on the specific fuels and their feedstocks can be found in the [Appendix](#).

Over time, an increasing amount of low-carbon biofuels was assumed. Through 2020, a maximum of 10% ethanol in

¹²Low Carbon Fuel Standard Initial Statement of Reasons (ISOR) report, March 5, 2009 [11].

gasoline (E10) was modeled given the current national blend wall limit. To achieve the LCFS carbon reduction compliance in 2020, a large amount of E85 (85% ethanol fuel with 15% gasoline) fuel was assumed in addition to E10, but only for a limited timeframe between 2015 and 2025. After 2020, the model assumed a non-ethanol based bio-hydrocarbon fuel was commercialized. This is a long-term goal of the energy industry as it creates large flexibility in the levels of biofuel blends in gasoline and diesel, and allows them to transport biofuels blended with fossil fuels in pipelines.¹³

An important bounding parameter in the scenario was the projected biomass availability in 2050.¹⁴ If unlimited biomass supplies were available, theoretically conventional engines operating on very low-carbon biofuels could achieve the 2050 80% goal. In reviewing recent biomass assessments¹⁵, an upper limit of 1 BGGE was set for the passenger vehicle sector (including biomass for H2) for Scenario 1. This limitation considers that large quantities of biofuels will be needed in the aviation, heavy-duty vehicle, and marine sectors to reach their 2050 GHG reductions. Additionally, there will be increasing competition for sustainable biomass resources from other states and non-transport sectors. Although it was not modeled in this analysis, future commercialization of algae-based biofuels could significantly increase biofuel supplies. However, algae biofuel development is highly uncertain though is showing increasing potential. Refer to the [Appendix](#) for additional detail on the biofuel supply limitation.

Advanced vehicle sales projections

Several scenarios were developed to evaluate various advanced vehicle market and technology assumptions. The unique aspect of each scenario focuses on the different technology sales projections over time. Most of the sales projections are aggressive to achieve the deep GHG reductions. The projections were developed by studying external sources for long-term trajectories¹⁶ and using judgment of what is possible from the automotive industry for the near-term trajectories. Although this model does not simulate economic factors and consumer choice, the projections assume consumers will demand and purchase the advanced vehicles, either because of high gasoline and carbon prices or because the advanced vehicles offer new and attractive alternatives.

The following key trends are captured in Scenarios 1 and 2. [Figure 4](#) shows the assumed sales projections for the major vehicle technologies in the automobile (car) segment for Scenario 2 (additional figures are provided in the [Appendix](#)).

- The vehicle technology sales curves relied on the historical rate of hybrid electric vehicle (HEV) growth as a benchmark for the first 10 years, and realistic technology sales growth projections by 2020 based on known technical and infrastructure challenges.
- Both scenarios assume PHEV sales take off faster and decline long-term when FCVs & BEVs reach high volumes. It also assumes BEV sales take off faster than FCVs initially, but reach a saturation limit (30% of sales market by 2050); FCVs take off last but become the dominant low-carbon alternative by 2050.
- A progression of battery technology improvements was assumed. For PHEVs, the amount of all-electric range (AER) that the batteries can support grows over time from 10 miles (2020) to 50 miles (2050). For BEVs, it is assumed range increases and infrastructure grows to justify market shares projected.
- Although trends are similar for light trucks (not shown below), there is less reliance on BEVs in trucks and more reliance on PHEVs and diesel HEVs all the way to 2050.

RESULTS

[Figure 5](#) shows the GHG emissions between 1990 and 2050 for a “business as usual” (BAU) projection¹⁷ and two scenarios, both assuming all advanced vehicle technologies are fully commercialized. Scenario 1 in this analysis achieves a 66% reduction in GHG emissions by 2050 using aggressive but plausible assumptions. This scenario assumes ZEV sales reach a quarter of a million units annually by 2025 and become 100% of new vehicle sales by 2050. Scenario 2 was developed to show what would be required to achieve the full 80% GHG goal. A steeper ZEV sales projection was simulated where ZEV sales reach half a million units by 2025 and are 100% of new vehicle sales by 2040. Additionally, the availability of biofuels was increased to 1.7 billion gallons gasoline equivalent (BGGE), where it was limited to 1 BGGE in Scenario 1.¹⁸

The BAU projection assumes the Pavley 1 Regulation and LCFS are both fully implemented, followed by a straight-line projection that assumes the vehicle fuel economy and fuel

¹³ Ethanol is currently shipped separately by rail car and blended in gasoline close to regional markets. This creates additional infrastructure requirements and higher transport costs.

¹⁴ This biofuel limitation does not reflect any assumption from other ARB policies, such as the LCFS, it is simply a hypothetical value used for this analysis

¹⁵ [3](#), [12](#), [13](#), [14](#), [15](#), [16](#), [17](#)

¹⁶ [3](#), [5](#), [6](#), [9](#), [10](#)

¹⁷ The BAU projection does not reflect official ARB GHG inventory projections; it was developed solely for this modeling exercise and is purely hypothetical. Population data is from CA Dept of Finance (34 million people in 2000, 59 million in 2050). Total vehicle population grows from 20 million (2000) to 40 million vehicles (2050).

¹⁸ Both cases have reductions in VMT per vehicle (20% below the VMT/veh projections for 2050)

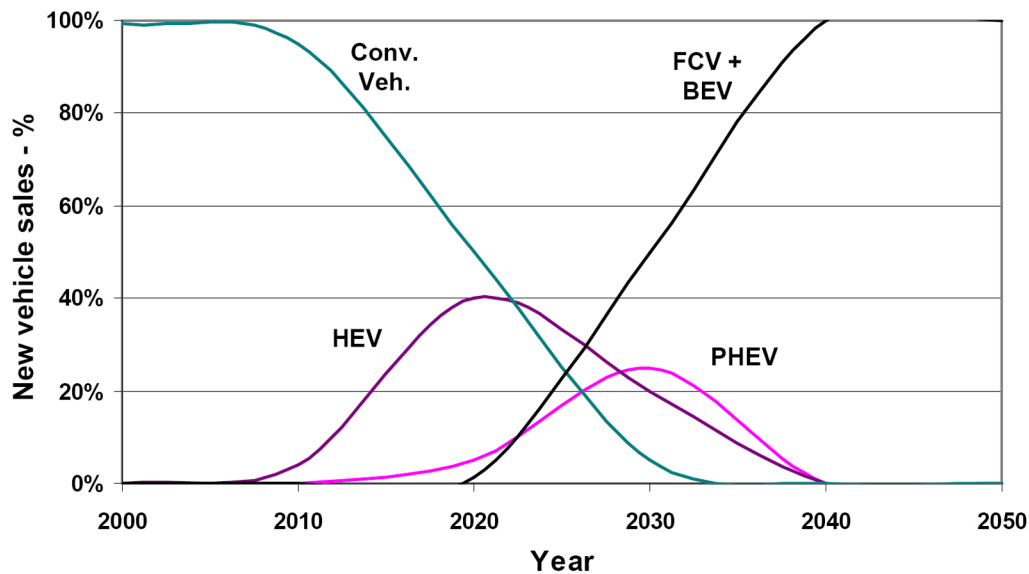
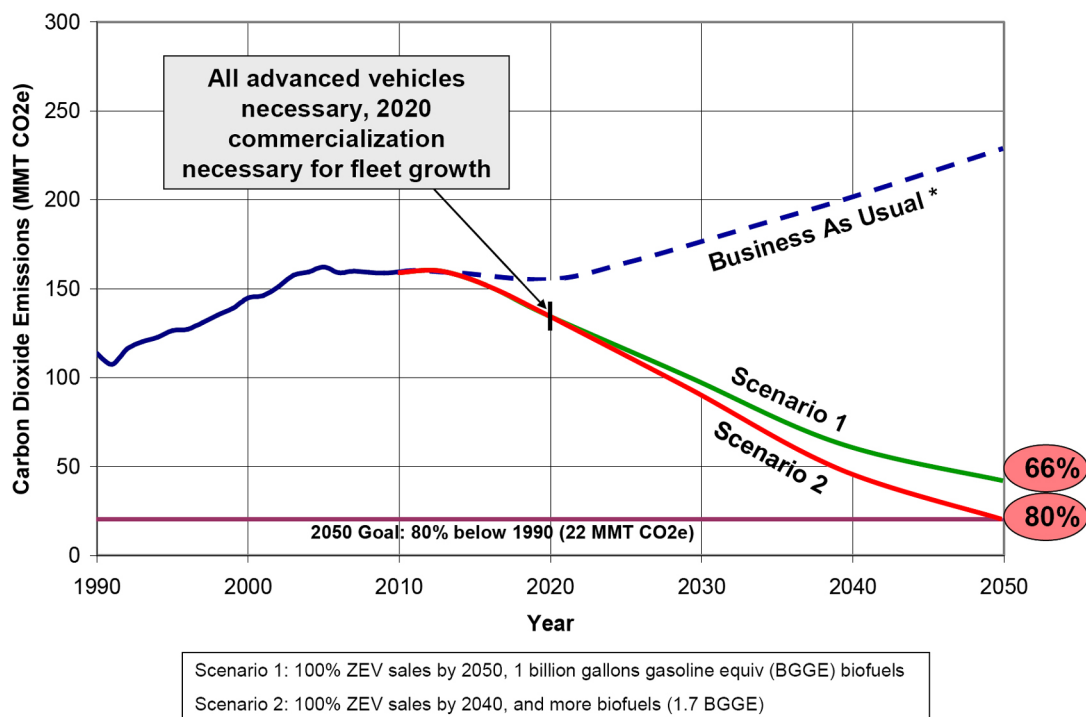


Figure 4. New vehicle sales, automobile (cars) segment - Scenario 2 (BEV = 30% of “FCV+BEV” in 2040)



* Hypothetical BAU for this analysis only, does not represent ARB projections. Assumes Pavley 1 and LCFS are implemented.

Figure 5. LDV fleet GHG emissions for two scenarios

carbon intensity values from 2020 are fixed to 2050 as vehicle population grows. It is important to note that the exact BAU projection does not affect the scenario results given the 80% GHG goal is referenced to the 1990 emission level.

Figure 6 shows that by increasing the 2020 ZEV annual sales six-fold (25,000 vs. 150,000), 2050 GHG reductions improve

from 66% to 73%. This is achieved by starting ZEV sales earlier but maintaining the same long-term sales slope as in Scenario 1. The scenario that achieves 75% assumes ZEV sales in later years are more rapid and reach the full new market share 10 years earlier (2040 rather than 2050). Using this “steeper” ZEV sales projection along with a larger amount of biofuels (1.7 BGGE vs. 1 BGGE), results in Scenario 2 in Figure 5.