# Assessment of Infrastructure Needs to Support Regulatory Requirements for Light-Duty Vehicles: Sensitivity to Technology Mix

## Introduction

This technical memorandum is an extension of the main report[1] named "Assess the Battery-Recharging and Hydrogen-Refueling Infrastructure Needs, Costs and Timelines Required to Support Regulatory Requirements for Light-, Medium-, and Heavy-Duty Zero-Emission Vehicles", which examined the cost and time required to install sufficient charging and hydrogen refueling hardware to support the number of zero-emission vehicles (ZEVs) required to fulfill existing and proposed vehicle regulations for light-duty (LD) and medium/heavy-duty (MDHD) vehicles[2]. The main report utilized technology mixes for new sales outlined by the state and federal regulatory agencies in the rulemaking process (see Appendix I from the main report for more details) and found that by 2035, the assumed sales and technology penetration scenarios will achieve a national average of 37% ZEV fleets in the LD sector and 19% ZEV fleets in the MDHD sector. In addition, a total of $294 billion investment will be needed to install approximately 6.6 million depot and public EVSE ports as well as 1,750 hydrogen fueling stations across the country. This study focuses on LD vehicles only and investigates how altering the technology mix affects the required supporting infrastructure and associated costs.

## Modeling Scenarios

While the regulatory requirements evaluated in the main report have included example fleet-wide ZEV penetration targets, none of the rules has explicitly prescribed how these targets need to be accomplished (e.g., the rules require fleetwide GHG and ZEV credits but there are few requirements on mix of ZEV technology)[3]. Similar to the main report, this study adopts the same classification of LD ZEV sales groups by states: California, Clean Car States, and Non-Clean Car States.[4]

This technical memorandum evaluates three different fleet mix scenarios in addition to the baseline (as presented in the main report), where the fractions of light-duty (LD) battery electric vehicle (BEV), plug-in hybrid electric vehicle (PHEV), and fuel cell electric vehicle (FCEV) have been adjusted to evaluate their impact on the overall energy demand and infrastructure needs. The detailed fleet mix scenarios are described below.

- High BEV Scenario: As shown in Figure 1 and Figure 2, 100% of LD passenger[5] ZEVs sold nationwide are assumed to be BEVs. This bookend, high electricity demand scenario was selected to understand the potential strain on the electricity grid if all the ZEV targets are fulfilled by full-electric vehicles only.

[1] Assess the Battery-Recharging and Hydrogen-Refueling Infrastructure Needs, Costs and Timelines Required to Support Regulatory Requirements for Light-, Medium-, and Heavy-Duty Zero-Emission Vehicles, available at https://crcao.org/wp-content/uploads/2023/09/CRC_Infrastructure_Assessment_Report_ICF_09282023_Final-Report.pdf

[2] During the development of this study (Fall -Winter 2023), the latest U.S. Environmental Protection Agency (EPA) emission standards had not been finalized.

[3] As mentioned later in the section, the Advanced Clean Cars II (ACCII) program limits the sales of PHEV.

[4] California: adopted ACCII and sells LD FCEVs; Clean Car States: states that have adopted (or are expected to adopt) ACCII rules and do not sell LD FCEVs; Non-Clean Car States: states that follow EPA's proposed LD Multi-Pollutant Emissions Standards. More details can be found in Figure 6 of the main report.

[5] Including passenger car and passenger truck from EPA MOVES output

- High PHEV Scenario: This scenario considers that 20% LD ZEVs sold nationwide are PHEVs[6]. FCEVs remain the same as assumed in the baseline scenario, and the rest are BEVs, as illustrated in Figure 3 and Figure 4. The PHEV sales fraction is capped at 20% because automakers are allowed to meet no more than 20% of their overall ZEV requirement with PHEVs, under the Advanced Clean Cars II (ACCII) program.[7]
- High FCEV Scenario: Under this scenario, the LD FCEV penetration in California increases from the baseline, consistent with the California Air Resources Board (CARB) 2020 Mobile Source Strategy modeling scenario.[8] Market share of FCEVs is projected to increase incrementally to 10% of total ZEV sales by 2030, and 25% by 2045, as shown in Figure 5. All other states remain the same as in the main report.

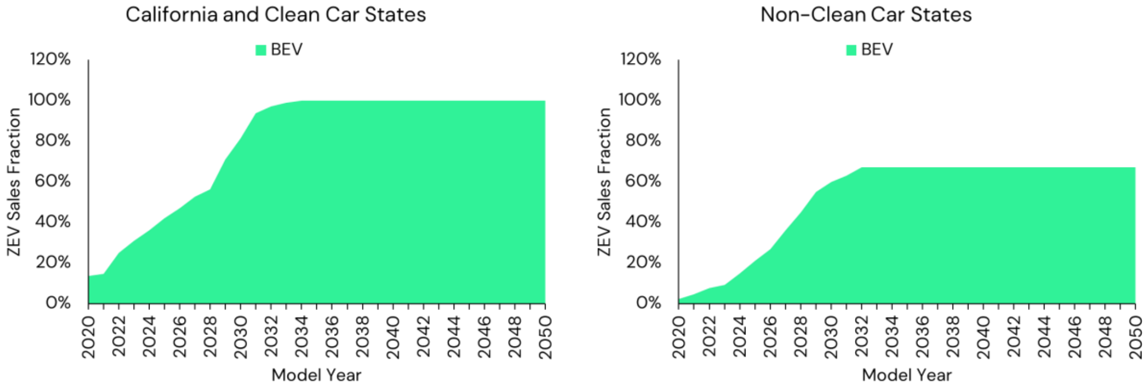


*Figure 1. ZEV technology mix for new sales[9] of passenger car under the high BEV scenario.*

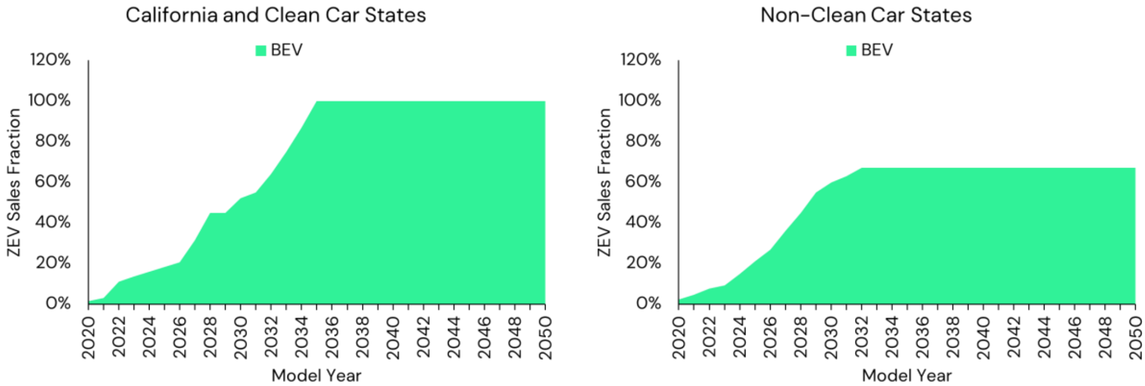


*Figure 2. ZEV technology mix for new sales of passenger trucks under the high BEV scenario.*

[6] Under the baseline scenario, PHEV fractions for passenger cars varied from 11% in 2025 to 5% in 2035 and for passenger trucks, 10% would be PHEV in 2025, and 15% in 2035.

[7] California moves to accelerate to 100% new zero-emission vehicle sales by 2035, available at: https://ww2.arb.ca.gov/news/california-moves-accelerate-100-new-zero-emission-vehicle-sales-2035

[8] 2020 Mobile Source Strategy, available at https://ww2.arb.ca.gov/sites/default/files/2021-12/2020_Mobile_Source_Strategy.pdf

[9] Note that in the main report, the y-axis of the adoption curves (Appendix I) was labeled as Fleet Mix. In this study, it has been updated to ZEV sales fractions to avoid confusion. They both signify the percentages of vehicle sales at a given model year that are ZEVs.

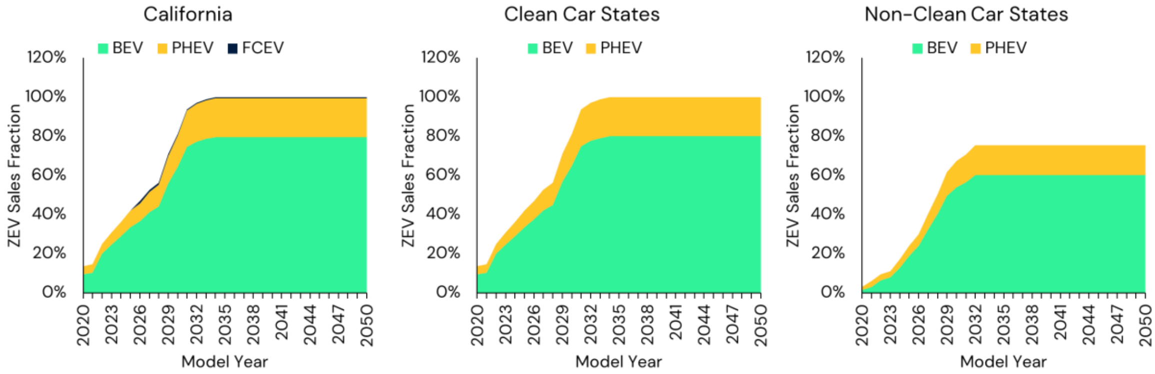


*Figure 3. ZEV technology mix for new sales of passenger cars under the high PHEV scenario.*

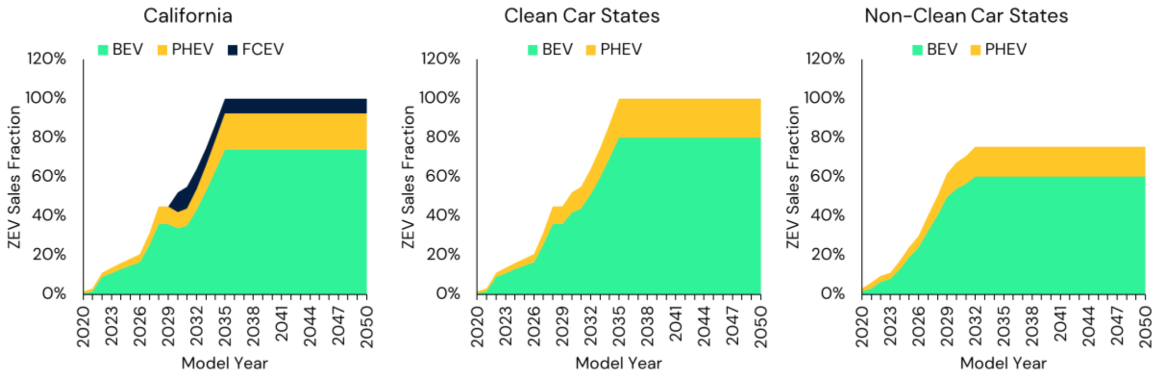


*Figure 4. ZEV technology mix for new sales of passenger trucks under the high PHEV scenario*

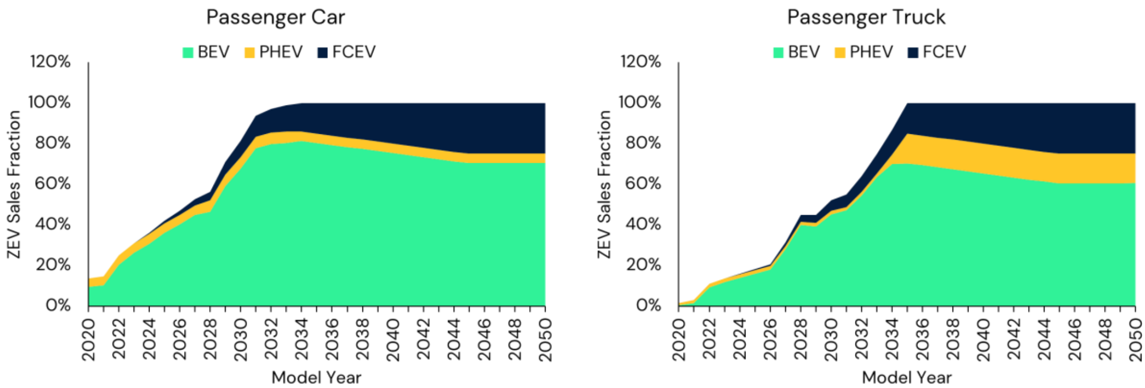


*Figure 5. ZEV technology mixes for new sales of passenger cars and passenger trucks under the high FCEV scenario in California.*

It is noteworthy that the high PHEV and high BEV scenarios will only affect the overall energy demand for states who have adopted the ACCII regulations (i.e., the Clean Car States). For Non-Clean Car States, ZEV penetration targets were established using all-electric miles fractions to align with the emission reduction requirements set by the U.S. EPA, regardless of technology mix. While total electric miles and energy demand for these states remain the same, ZEV populations alter between these scenarios. Because only a fraction of PHEV miles is projected to be electric, an increased number of PHEVs would be required to result in the same number of all-electric miles. An average fleet utility factor of 45% (FUF, fraction of total miles that are all-electric)[10] has been assumed for PHEV, which is the same as stated in the main report.

[10] Based on the finalized EPA Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles, a 45% of utility factor corresponds to a charge-depleting (CD) range of roughly 35 miles. More

## Fleet Modeling Results

Using the same methodology as described in the main report, the projected LD passenger vehicle stock and technology distribution under the three new scenarios were modeled. As shown in Figure 6 and

Table 1, if all the ZEV penetration targets evaluated in this study are fulfilled by BEVs (i.e., High BEV Scenario), by 2035, LD BEV population[11] will increase from 84 million as estimated in the baseline scenario to 91 million. The overall annual electricity demand will also see a 2% increase (10 TWh, from 473 TWh to 483 TWh) nationwide to power all the LD passenger vehicles in 2035. On the other hand, if PHEV sales fractions are maximized, BEV population may drop to 78 million while PHEV population increases from 11 million to 20 million. The overall electricity demand would also decrease by roughly 3% as compared to the baseline scenario to 460 TWh by 2035.

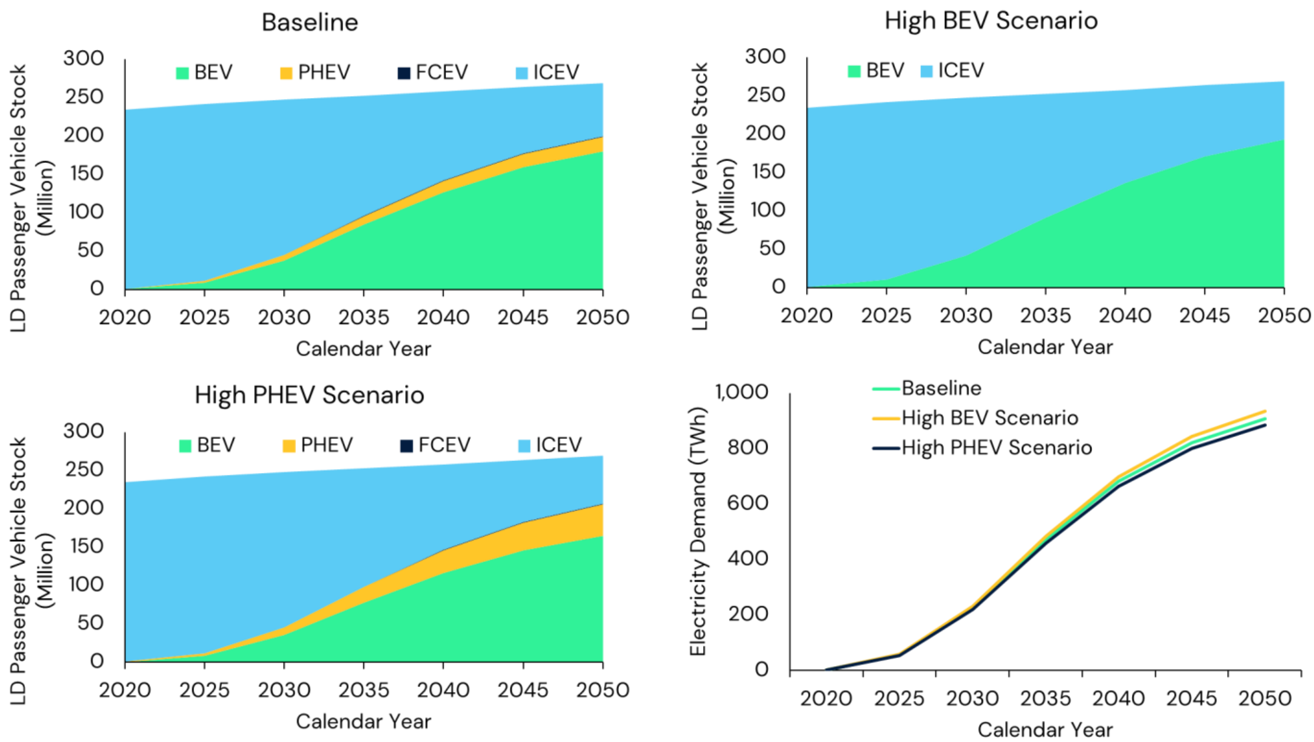


*Figure 6. Projected national LD passenger vehicle stock and electricity demand under baseline, high BEV, and high PHEV scenarios.*

*Table 1. Total on-road ZEV population (stock) in the U.S. by 2035 under baseline, high BEV, and high PHEV scenarios (in thousands).*

| Scenario | BEVs | PHEVs | FCEVs | Total ZEVs | % Change in Total ZEVs from Baseline |
|---|---|---|---|---|---|
| **Baseline** | 84,388 | 10,920 | 435 | 95,743 | N/A |
| **High BEV** | 91,190 | 0 | 0 | 91,900 | -4.8% |
| **High PHEV** | 77,696 | 20,056 | 435 | 98,187 | +2.6% |

Under the high FCEV scenario, plug-in electric vehicle (PEV, i.e., BEV and PHEV) population drops from 11.5 million to 10.7 million in California, while FCEV fleet expands to 1.2 million, as compared to 0.4 million in the

details can be found in Figure 11 of the Final Rule, available at: https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-multi-pollutant-emissions-standards-model

[11] Vehicle population and vehicle stock are used interchangeably in this report.

baseline by 2035, as shown in Figure 7 and Table 2. Accordingly, the annual electricity demand decreases from 55.6 TWh to 52.1 TWh while hydrogen demand escalates from 0.11 MMT to 0.27 MMT by 2035, and from 0.21 MMT to 1.15 MMT by 2050, as presented in Figure 8.

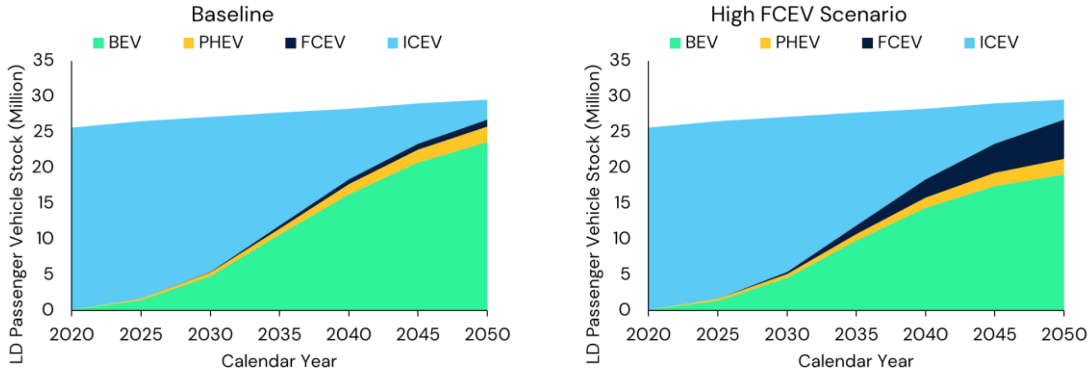


*Figure 7. Projected California LD passenger vehicle stock and technology distribution under baseline and high FCEV scenarios.*

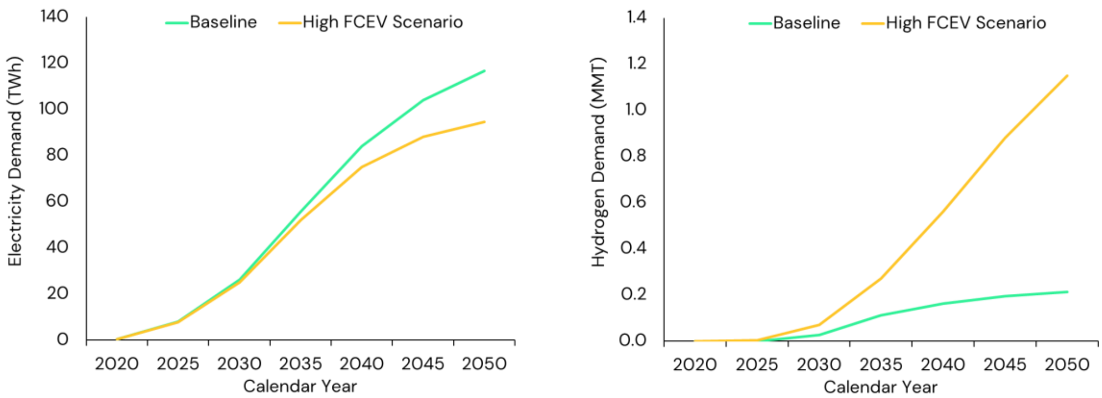


*Figure 8. Projected California LD passenger vehicle energy demands under baseline and high FCEV scenarios.*

*Table 2. Total on-road ZEV population (stock) by 2035 in California under baseline and high FCEV scenarios (in thousands).*

| Scenario | BEVs | PHEVs | FCEVs | Total ZEVs |
|---|---|---|---|---|
| **Baseline** | 10,616 | 876 | 435 | 11,927 |
| **High FCEV** | 9,844 | 876 | 1,207 | 11,927 |

In addition to vehicle stock, the project team has also compared how different scenarios may affect the total annual vehicle miles traveled (VMT) by fuel technology. As shown in Figure 9, by 2035, under the baseline scenario, around 42% of the total LD VMT are zero-emission, which includes all activities from BEV and FCEV, and 45% (FUF) of the total PHEV miles, and the rest 58% of VMT are from combustion technologies. The zero-emission VMT fraction increases to 43% under the high BEV scenario and drops to 41% under the high PHEV scenario. By 2050, the on-road zero-emission VMT fractions for the LD fleet are 73%, 74%, and 71% under the baseline, high BEV, and high PHEV scenarios, respectively.

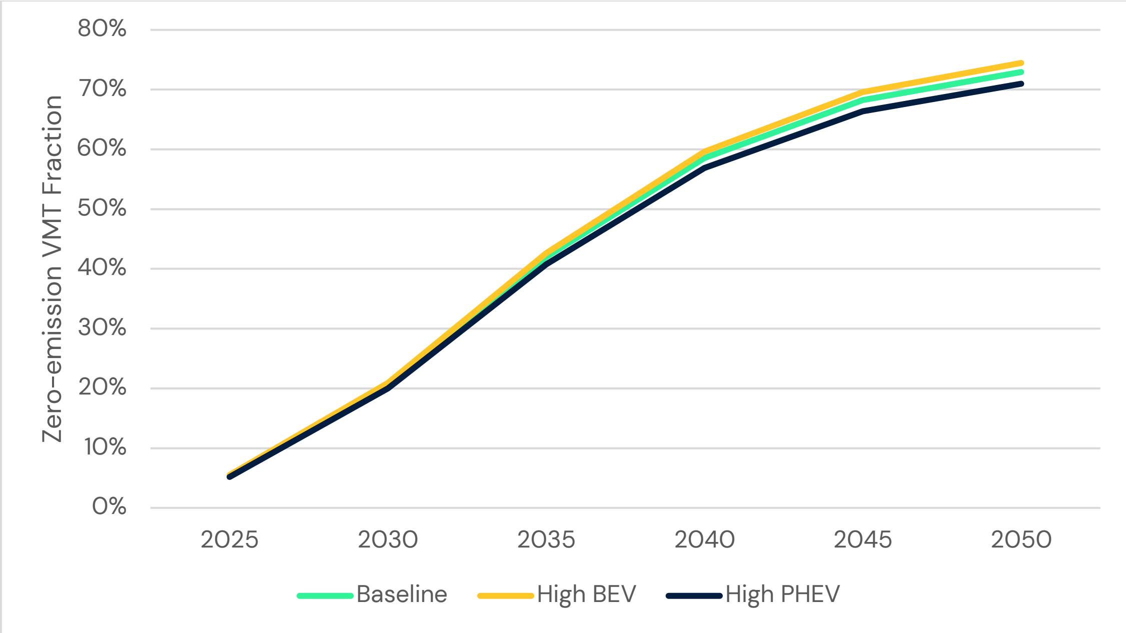


*Figure 9. Fraction of on-road LD VMT that are zero-emission (BEV, FCEV, and electric fraction of PHEV) under baseline[12], high BEV, and high PHEV scenarios.*

# Infrastructure Assessment Results

The LD infrastructure needs under the additional scenarios were also evaluated using the Electric Vehicle Infrastructure Projection Tool (EVI-Pro) and the hydrogen refueling infrastructure tool as described in the main report. As shown in Figure 10, as PHEV fraction increases, PEV drivers will correspondingly depend more on residential and private infrastructure to recharge their batteries. As PHEVs are often designed with all-electric ranges to cover daily commuting needs, charging at home or along commuting route (e.g., workplace, education facility, community center) with slow chargers (i.e., Level 1 or L1, and Level 2 or L2) are often sufficient to fulfill the typical needs while allowing drivers to maximize their electric driving without heavily relying on public or fast charging infrastructure. By 2035, roughly 64 million residential charging ports will be needed under the baseline scenario, and the needs go up to 65 million under the high PHEV scenario and drop to 62 million under the high BEV scenario. Similarly, the needs for private charging ports increase from 2.5 million in baseline to 2.6 million under the high PHEV scenario and reduce to 2.4 million under the high BEV scenario.

On the other hand, as illustrated in Figure 11, as BEV fraction increases, the demand for high-power, direct current fast charger (DCFC) will escalate. By 2035, under high PHEV scenario, the estimated number of DCFC 150 kW needed to support all the personal-use LD passenger PEVs on road in the U.S. is roughly 42.5 thousand, that of 250 kW ports is 68.5 thousand, and that of 350 kW is 108.3 thousand. Under the baseline scenario, the needed numbers of ports of the three power levels are 50.1 thousand, 74.3 thousand, and 115 thousand, respectively. These numbers surge to 59.7 thousand, 81.4 thousand, and 123.3 thousand, respectively, when every ZEV on road is a BEV. Detailed results can also be found in Appendix A.

[12] Since the high FCEV scenario only modifies the allocation of BEV and FCEV, it has the same zero-emission VMT fraction as the baseline scenario.

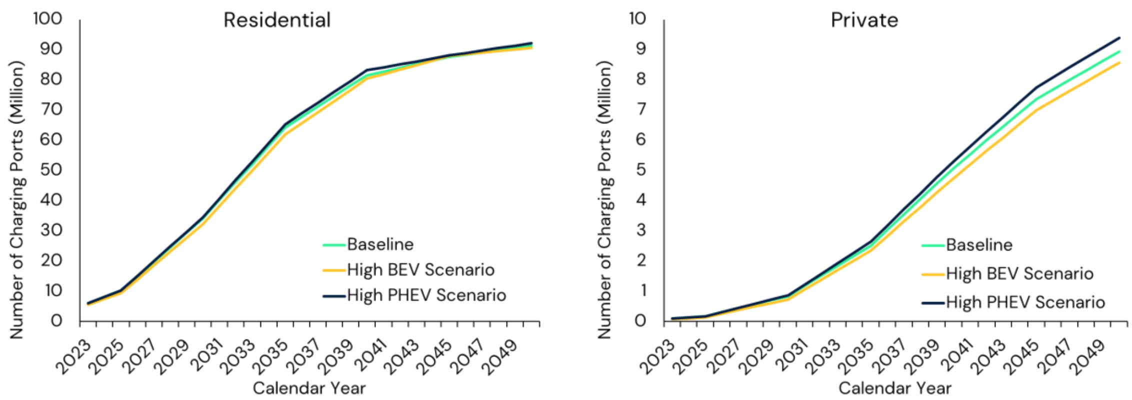


*Figure 10. Projected residential and private charger needs for passenger PEVs from EVI-Pro under baseline, high BEV, and high PHEV scenarios.*

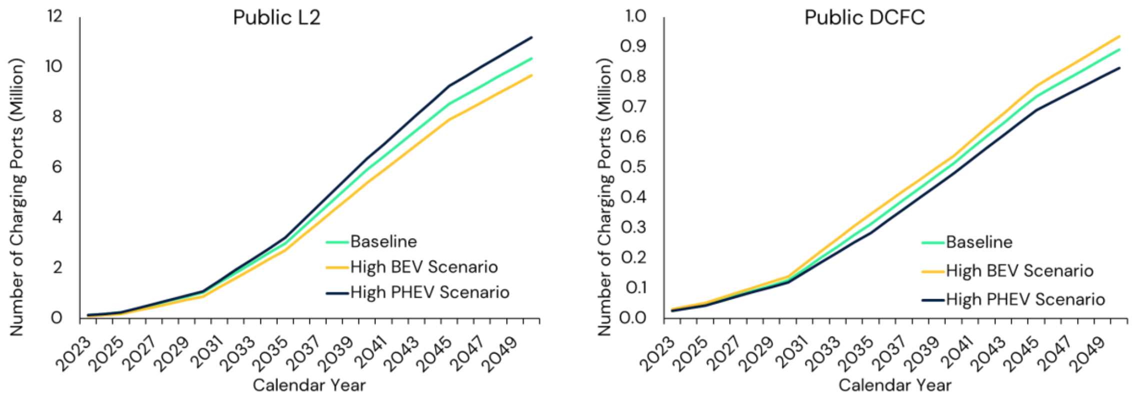


*Figure 11. Projected public charger needs for passenger PEVs from EVI-Pro under baseline, high BEV, and high PHEV scenarios.*

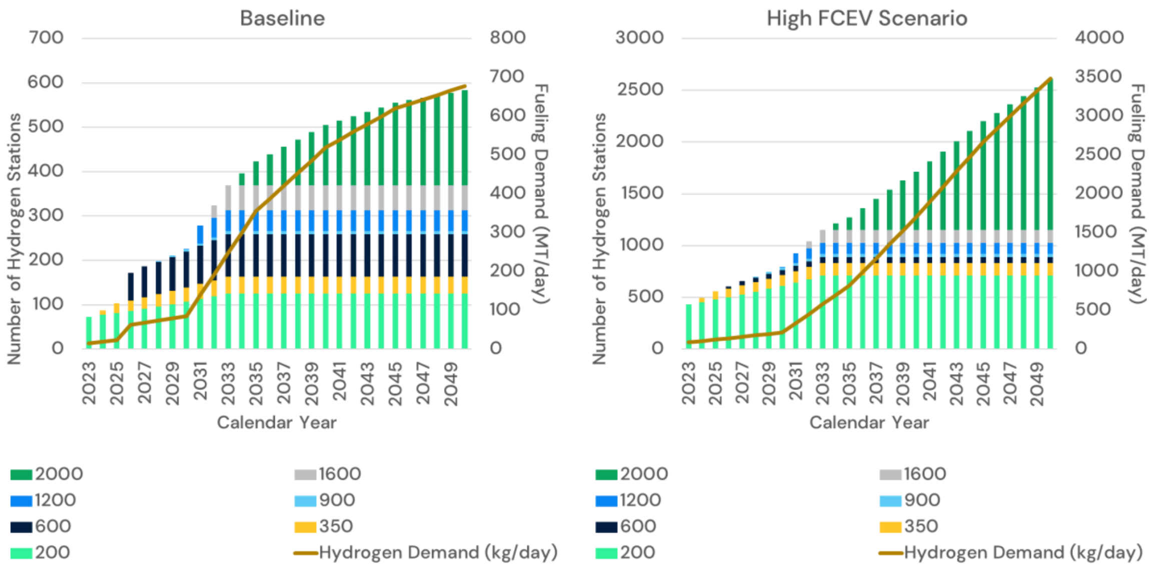


*Figure 12. LD hydrogen refueling station by capacity and fueling demand (MT/day) in California.*

As FCEV sales fraction ramps up under the high FCEV scenario, the demand for LD hydrogen refueling station in California would likely triple in 2035 as compared to the baseline, which requires almost 1,300 stations, with fueling capacities ranging from 200 kg/day to 2000 kg/day. By 2050, there will be roughly 2,600 LD fueling stations needed statewide under the high FCEV scenario, as compared to 580 stations estimated in the baseline. The resulted hydrogen refueling stations by capacity and total daily fueling demand under the two scenarios are presented in Figure 12. While the LD FCEV fleet expands in California, PEV population decreases, resulting in a reduction in charging infrastructure demand in the state, with 47,000 fewer public charging ports needed by 2035, and 394,000 fewer by 2050, as shown in Figure 13.

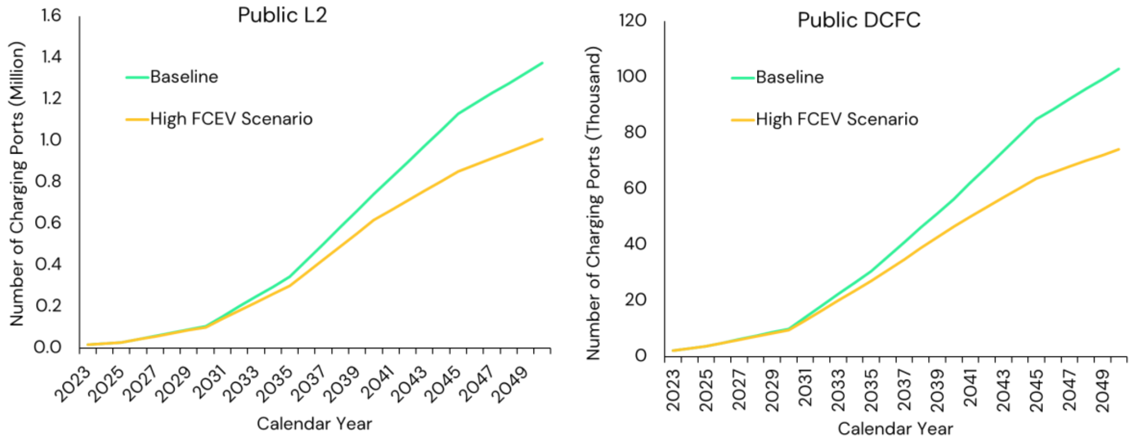


*Figure 13. Projected public charger needs for passenger PEVs in California from EVI-Pro under baseline and high FCEV scenarios.*

# Implication and Discussion

The impact of the different technology mixes under the three scenarios on infrastructure costs[13] were also evaluated and compared against the baseline and the results of net difference in investment are presented in Figure 14. Under the high BEV scenario, the total investment needed to install all the required public charging infrastructure is $5.3 billion more than the baseline scenario by 2035, and $8 billion more by 2050. However, as there is no FCEV penetration assumed in this scenario, the disparity is partially offset by the lack of LD hydrogen fueling infrastructure. As a result, the net difference of LD infrastructure investment needed is $4.4 billion more than the baseline by 2035 and $6.7 billion more by 2050.

For the high PHEV scenario, the net saving resulted from less demanding public charging infrastructure access as compared to the baseline scenario is $5.3 billion by 2035, and $11.6 billion by 2050. Hydrogen fueling demand and infrastructure are assumed to remain unchanged from the baseline scenario.

Since the high FCEV scenario leads to fewer PEVs on the road, it requires less charging infrastructure (home, private, and public) in general. Besides, as discussed in the main report, a lower PEV/LDV stock ratio also leads to higher percent of home charging access, which also results in less demand in public charging[14]. While initially the additional investment needed to install the extra LD hydrogen refueling stations under the high FCEV scenario exceeds the savings from building fewer charging stations, it may lead to long-term cost-saving opportunities in infrastructure equipment and installation. The net investment difference between the high FCEV scenario and baseline varies from a total of +$0.5 billion in 2035 to -$6.8 billion in 2050, primarily driven by the continuous capital cost reduction of hydrogen refueling infrastructure as assumed in the main report.

[13] Cost estimates for BEV charging infrastructure include electric vehicle supply equipment (EVSE) hardware and installations, while utility upgrades, land acquisition, and other soft costs are not quantified. Cost estimates for FCEV refueling infrastructure include refilling station compressors/boil off management and retail site distribution pumps, while costs associated with hydrogen production and distribution such as electrolysis unit, compression or liquefaction unit, distribution pipeline, compressed hydrogen delivery trucks or purification units are not quantified.
[14] Home charging access (fraction of PEV owners who have easy access to charge at home) increases from 75% in the baseline to 77% in the high FCEV scenario in California by 2035, and from 53% to 59% by 2050.

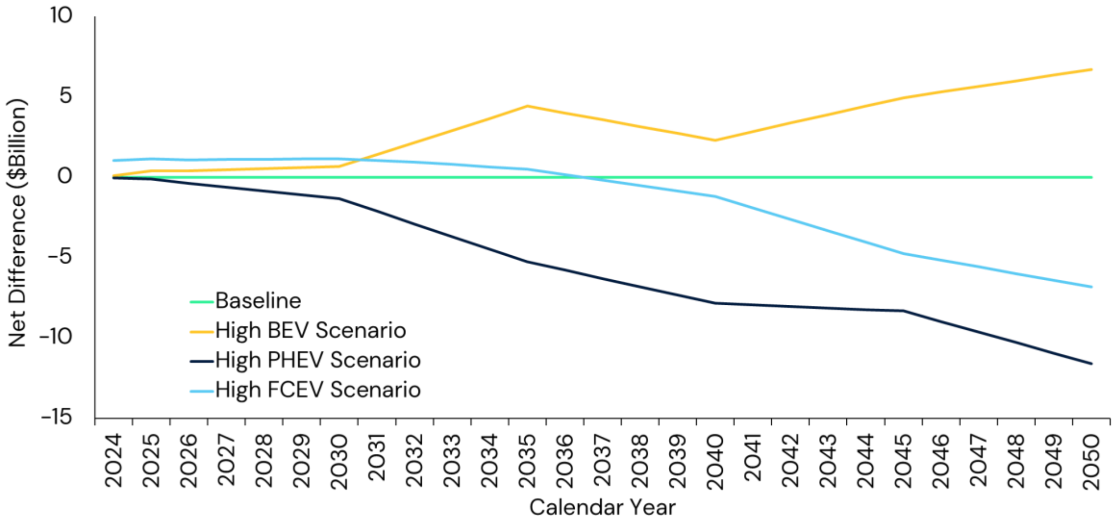


*Figure 14. Net difference in total investment needed to install all the required infrastructure (PEV charging and hydrogen fueling combined) under the baseline, high BEV, high PHEV, and high FCEV scenarios.*

In summary, this memorandum examines more closely how various ZEV technologies and penetration rates may affect the overall vehicle stock, energy demand, and investment needed to install the necessary charging and refueling infrastructure.

# Appendix I: Summary Table

*Table 3. Percent difference in nationwide residential, private, and public chargers under the high BEV and high PHEV scenarios as compared to the baseline scenario.*

| Year | High BEV | | | | High PHEV | | | |
|---|---|---|---|---|---|---|---|---|
| | Residential | Private | Public L2 | Public DCFC | Residential | Private | Public L2 | Public DCFC |
| 2024 | -8% | -21% | -24% | 17% | 0% | 1% | 1% | -2% |
| 2025 | -8% | -21% | -24% | 17% | 0% | 1% | 1% | -2% |
| 2026 | -7% | -16% | -20% | 14% | 0% | 2% | 3% | -3% |
| 2027 | -6% | -15% | -18% | 12% | 1% | 2% | 3% | -4% |
| 2028 | -6% | -14% | -17% | 11% | 1% | 2% | 4% | -5% |
| 2029 | -6% | -13% | -16% | 10% | 1% | 2% | 4% | -5% |
| 2030 | -6% | -13% | -16% | 9% | 1% | 3% | 4% | -5% |
| 2031 | -5% | -10% | -13% | 10% | 1% | 4% | 5% | -7% |
| 2032 | -5% | -9% | -12% | 10% | 1% | 4% | 6% | -8% |
| 2033 | -4% | -8% | -10% | 10% | 1% | 5% | 7% | -8% |
| 2034 | -4% | -7% | -10% | 11% | 2% | 5% | 7% | -9% |
| 2035 | -4% | -7% | -9% | 11% | 2% | 5% | 7% | -9% |
| 2036 | -3% | -7% | -9% | 9% | 2% | 5% | 7% | -9% |
| 2037 | -3% | -7% | -9% | 8% | 2% | 5% | 7% | -8% |
| 2038 | -2% | -7% | -9% | 6% | 2% | 5% | 7% | -7% |
| 2039 | -2% | -7% | -9% | 6% | 2% | 4% | 7% | -7% |
| 2040 | -1% | -7% | -9% | 5% | 2% | 4% | 7% | -7% |
| 2041 | -1% | -6% | -9% | 5% | 2% | 5% | 7% | -7% |
| 2042 | -1% | -6% | -8% | 5% | 1% | 5% | 8% | -6% |
| 2043 | 0% | -5% | -8% | 5% | 1% | 5% | 8% | -6% |
| 2044 | 0% | -5% | -8% | 5% | 1% | 5% | 8% | -6% |
| 2045 | 0% | -5% | -7% | 5% | 1% | 5% | 8% | -6% |
| 2046 | 0% | -5% | -7% | 5% | 1% | 5% | 8% | -6% |
| 2047 | 0% | -5% | -7% | 5% | 1% | 5% | 8% | -6% |
| 2048 | 0% | -4% | -7% | 5% | 1% | 5% | 8% | -7% |
| 2049 | -1% | -4% | -7% | 5% | 1% | 5% | 8% | -7% |
| 2050 | -1% | -4% | -7% | 5% | 1% | 5% | 8% | -7% |

*Table 4. Percent difference in California residential, private, and public chargers under the high FCEV scenario as compared to the baseline scenario.*

| Year | Residential | Private | Public L2 | Public DCFC |
|---|---|---|---|---|
| 2024 | -1% | -1% | -1% | -1% |
| 2025 | -1% | -1% | -1% | -1% |
| 2026 | -2% | -2% | -2% | -2% |
| 2027 | -3% | -3% | -3% | -3% |
| 2028 | -3% | -3% | -3% | -3% |
| 2029 | -4% | -4% | -4% | -4% |

| | | | | |
|---|---|---|---|---|
| 2030 | -4% | -4% | -4% | -4% |
| 2031 | -4% | -8% | -8% | -7% |
| 2032 | -4% | -10% | -10% | -9% |
| 2033 | -4% | -11% | -11% | -10% |
| 2034 | -4% | -12% | -12% | -11% |
| 2035 | -4% | -13% | -13% | -12% |
| 2036 | -5% | -14% | -14% | -14% |
| 2037 | -5% | -15% | -15% | -15% |
| 2038 | -6% | -16% | -16% | -16% |
| 2039 | -6% | -17% | -16% | -17% |
| 2040 | -6% | -17% | -17% | -17% |
| 2041 | -4% | -19% | -19% | -19% |
| 2042 | -3% | -21% | -21% | -21% |
| 2043 | -1% | -23% | -22% | -23% |
| 2044 | 1% | -24% | -24% | -24% |
| 2045 | 3% | -25% | -25% | -25% |
| 2046 | 1% | -25% | -25% | -26% |
| 2047 | -2% | -26% | -25% | -26% |
| 2048 | -4% | -26% | -26% | -27% |
| 2049 | -6% | -27% | -26% | -27% |
| 2050 | -8% | -27% | -27% | -28% |

*Table 5. Percent difference in total investment needed to install all the required infrastructure (PEV charging and hydrogen fueling combined) under the high BEV, high PHEV, and high FCEV scenarios as compared to the baseline scenario.*

| Year | High BEV Scenario | High PHEV Scenario | High FCEV Scenario |
|---|---|---|---|
| 2024 | 2% | -1% | 16% |
| 2025 | 3% | -1% | 9% |
| 2026 | 1% | -1% | 4% |
| 2027 | 1% | -1% | 2% |
| 2028 | 1% | -1% | 2% |
| 2029 | 1% | -2% | 2% |
| 2030 | 1% | -2% | 1% |
| 2031 | 1% | -2% | 1% |
| 2032 | 2% | -2% | 1% |
| 2033 | 2% | -2% | 1% |
| 2034 | 2% | -2% | 0.4% |
| 2035 | 2% | -3% | 0.2% |
| 2036 | 2% | -3% | 0.1% |
| 2037 | 1% | -2% | -0.1% |
| 2038 | 1% | -2% | -0.2% |
| 2039 | 1% | -2% | -0.3% |

| | | | |
|---|---|---|---|
| 2040 | 1% | -2% | -0.4% |
| 2041 | 1% | -2% | -1% |
| 2042 | 1% | -2% | -1% |
| 2043 | 1% | -2% | -1% |
| 2044 | 1% | -2% | -1% |
| 2045 | 1% | -2% | -1% |
| 2046 | 1% | -2% | -1% |
| 2047 | 1% | -2% | -1% |
| 2048 | 1% | -2% | -1% |
| 2049 | 1% | -2% | -1% |
| 2050 | 1% | -2% | -1% |

# List of Acronyms

| Acronym | Description |
|---|---|
| ACCII | Advanced Clean Cars II |
| BEV | Battery Electric Vehicle |
| CARB | California Air Resources Board |
| DCFC | Direct Current Fast Charger |
| EVI-Pro | Electric Vehicle Infrastructure Projection Tool |
| EVSE | Electric Vehicle Supply Equipment |
| FCEV | Fuel Cell Electric Vehicle |
| HD | Heavy Duty |
| ICEV | Internal Combustion Engine Vehicle |
| L1 | Level 1 [Charger] |
| L2 | Level 2 [Charger] |
| LD | Light-Duty |
| MD | Medium Duty |
| MDHD | Medium- and Heavy-Duty |
| MT/MMT | Metric Tons/Million Metric Tons |
| MOVES | Motor Vehicle Emission Simulator Tool |
| PEV | Plug-in Electric Vehicle |
| PHEV | Plug-in Hybrid Electric Vehicle |
| ZEV | Zero Emission Vehicle |

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