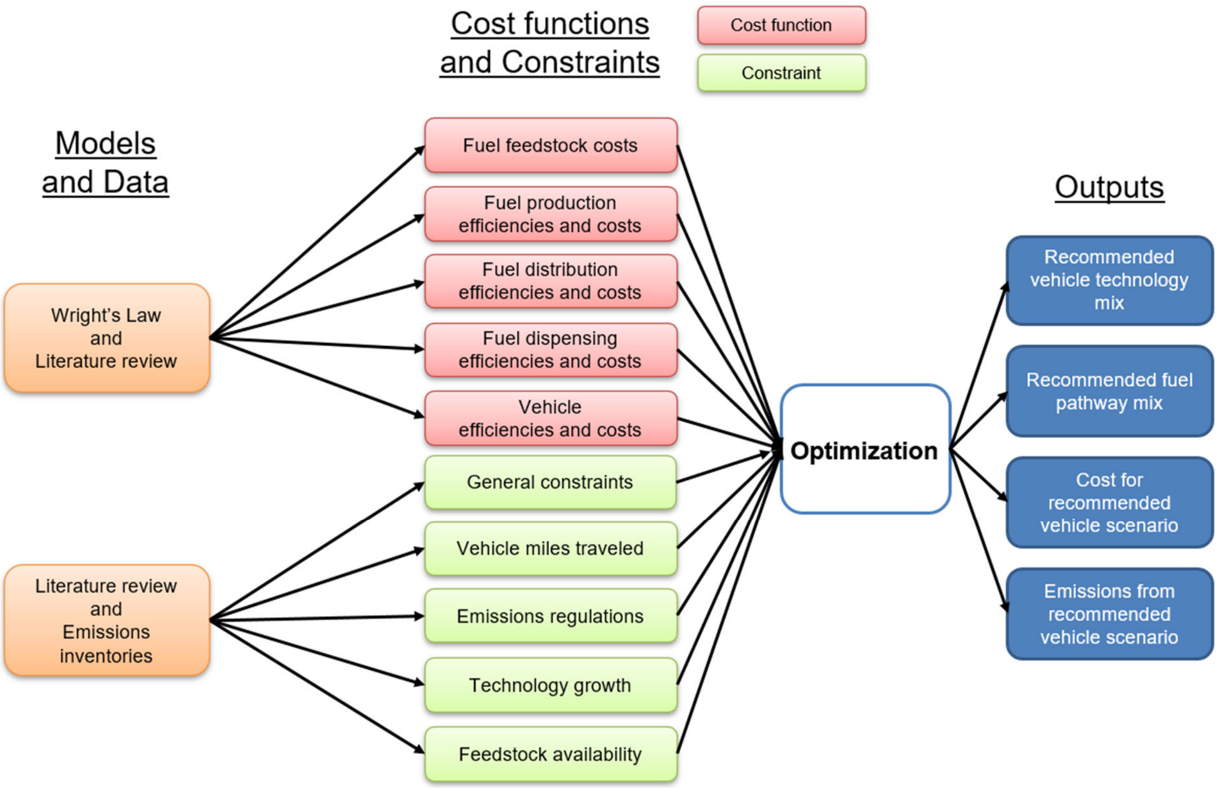
# HDV Optimal Deployment of Clean Vehicles and Fuels

To determine which heavy-duty vehicle (HDV) powertrains, fuels, and fuel pathways, an optimization program is used. This program, called Transportation Rollout Affecting Cost and Emissions (TRACE), selects viable deployments of possible technologies that satisfy constraints (e.g., feedstock availability) at the lowest cost. Further details on TRACE are given below.

## TRACE Model Description

TRACE is a vehicle powertrain and fuel deployment optimization model that projects fuel and vehicle use from 2020 through 2050 based on minimum cost while complying with various environmental and technological constraints. TRACE's model diagram is depicted in Figure 1.

*Figure 1. TRACE model diagram*



Fuel pathways are detailed from fuel feedstock (electricity and various biomass categories) to fuel dispensing infrastructure. Vehicles are analyzed by primary powertrain components and the glider. Wright's law is used to project the cost of fuel production equipment and vehicle components based on the adoption rate of each of the technologies; other cost projections (i.e., feedstock, distribution, and dispensing) are based on literature values. Efficiency for the fuel pathways and vehicles themselves are projected based on the literature. Emissions from both fuel pathway and vehicle tailpipe, as appropriate, are sourced from the literature.

Constraints are added to model the problem more accurately, including VMT constraints, fuel feedstock availability, powertrain availability, and both GHG and CAP emissions goals/legislation. VMT constraints use EMFAC data for vehicles of model year 2020 and beyond;

all prior vehicles are assumed to continue as EMFAC projects to 2050. These cost functions and constraints are added to a linear optimization algorithm to determine the lowest-cost method of meeting the constraints.

Modeled fuels include electricity, hydrogen (electrolytic and bio-derived), natural gas (electrolytic and bio-derived), renewable gasoline, and renewable diesel. Several pathways of producing each fuel are included. Modeled HDV vocations are linehaul, drayage, refuse, and construction.

Primary outputs of TRACE include the following: cost of fuels; cost of vehicles; fuel, feedstock, fuel production technology, and vehicle powertrain use for the various vocations; and resulting GHG and CAP emissions.

## ZEV Scenario

One approach to reducing the environmental impact of the transportation sector is increasing the use of ZEVs in parallel with the increase of renewable power generation that composes the electric grid. Such an approach is demonstrated by the California Air Resources Board's Advanced Clean Trucks Regulation and California Executive Order N-79-20.

Constraints imposed in this scenario include those previously except for emissions constraints. Specific to ZEV Scenario, the added constraint for increased ZEV technologies requires a linear increase from 0% at 2020 to 100% of post-2019 model year vehicles in 2050. This means nearly all vehicles are ZEVs in 2050, save for the small legacy fleet of internal combustion vehicles that EMFAC projects still be on the road in 2050.

The following are the results of the ZEV Scenario. Figure 2 shows the HDV fleet projections of the four vocations by powertrain technology. Note the heavy use of FCEVs in the linehaul and drayage vocations, and heavy use of BEVs in the drayage, refuse, and construction vocations. Additionally, construction has significant FCEV adoption at the last timestep as non-ZEV technologies are nearly completely phased out. CNG vehicles are used as a transitional technology with significant adoption in the mid-term. While there is no explicit constraint to reduce fossil fuel use in the ZEV Scenario, it is clear from Figure 3 that imposing ZEV requirements reduces the use of fossil diesel and natural gas over time.

With the lack of GHG constraints in the ZEV Scenario, negative carbon intensity biomass feedstocks are not highly prioritized. In fact, none of these feedstocks are projected. This is due to their relatively higher cost per unit energy.

Figure 4 shows the resulting GHG and CAP emissions of the ZEV Scenario. Recall that emission improvements are a result of transitioning to ZEV technologies in this scenario. Note that the removal of GHG constraints leads to the not meeting legislation requiring 1990 levels of GHG emissions by 2020 and 40% below by 2030. However, it is similarly important to note that the 2050 GHG emissions are far below the levels required by the California Executive Order S-03-05.

*Figure 2. ZEV Scenario: HDV fleet composition*

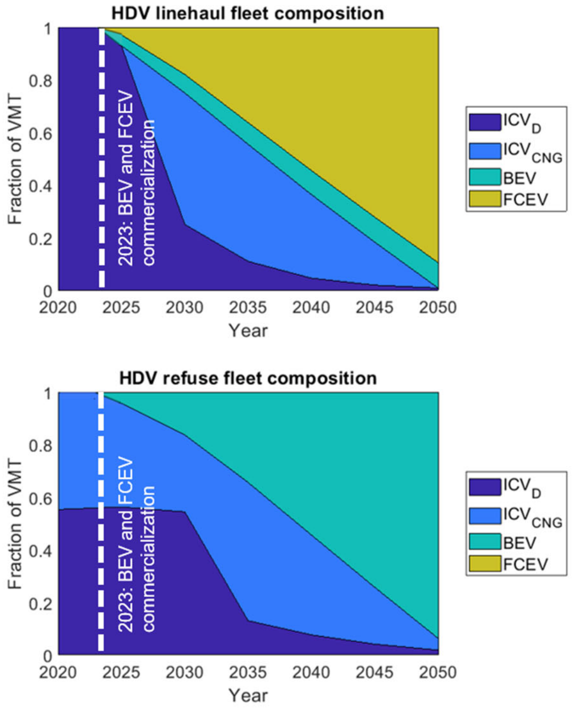


*Figure 3. ZEV Scenario: Fuel characteristics*

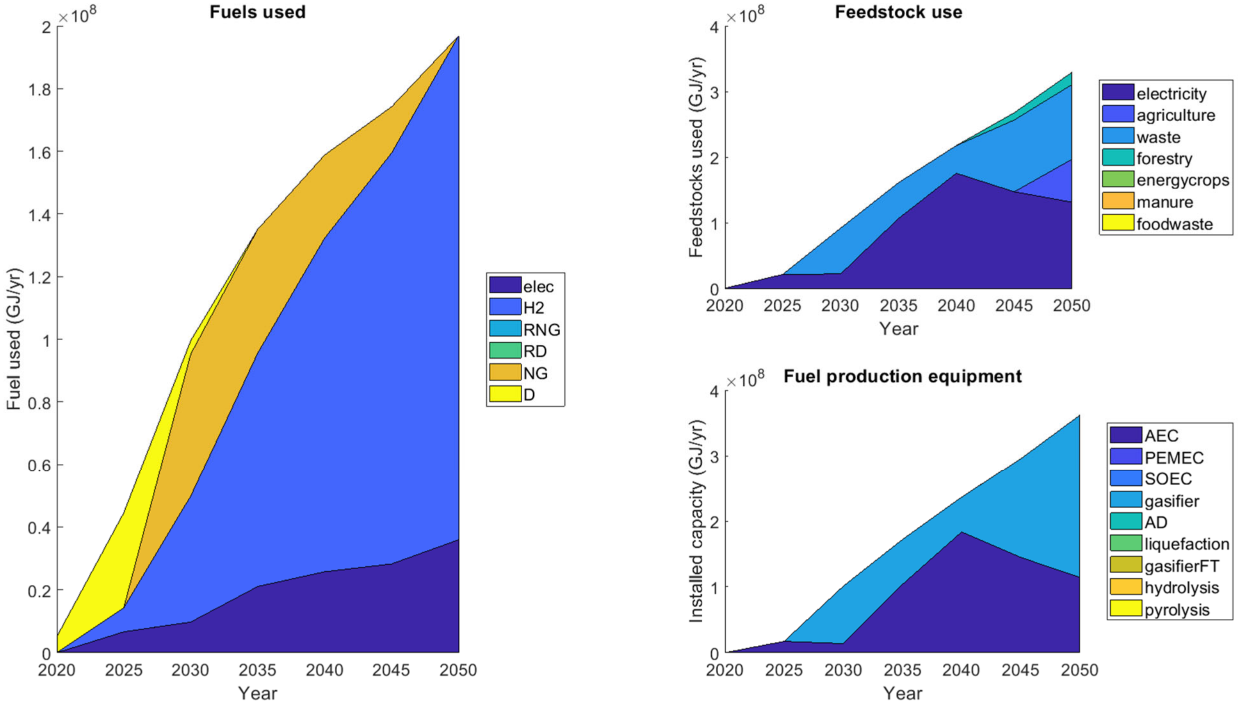


*Figure 4. ZEV Scenario: GHG and CAP emissions*

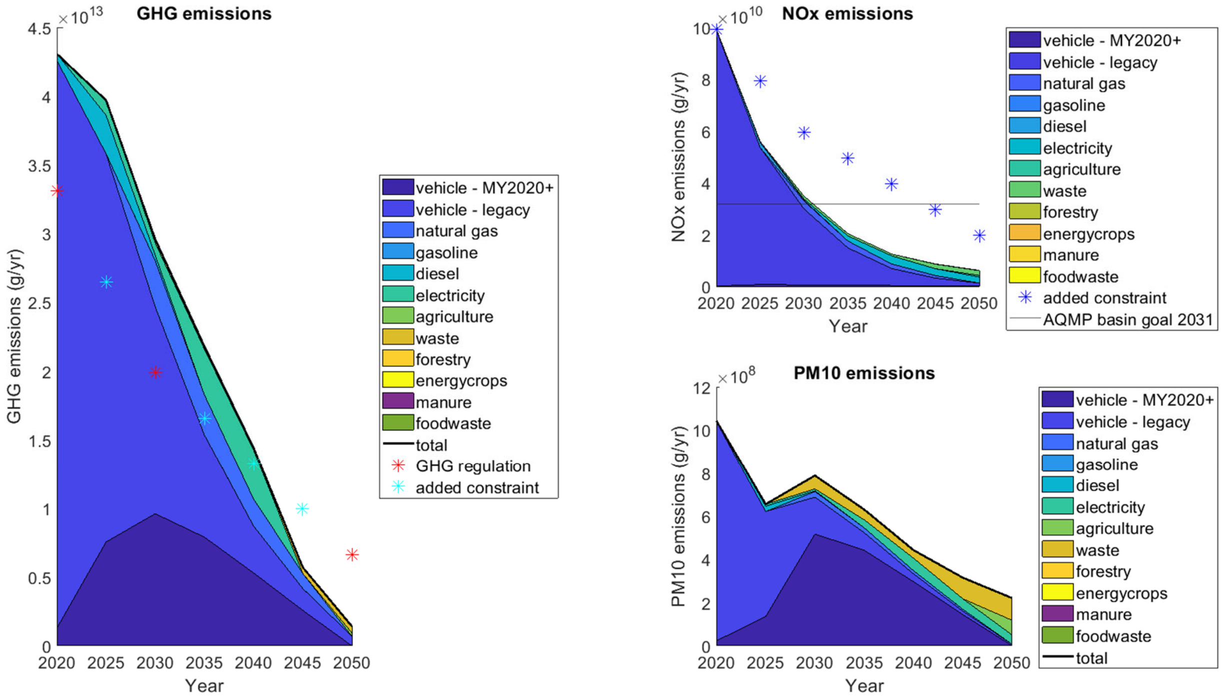


Table 1 shows both the annual cost for each of the years modeled as well as cumulative cost by the end of that year since 2020 for all vehicles of model year 2020 through 2050 and the fuel those vehicles use. The cumulative cost assumes the cost of each modeled year is carried through the rest of the proceeding four years up to the next modeled year.

*Table 1. ZEV Scenario: Cumulative cost*

| Year | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|
| **Annual cost (billions of $)** | 0.234 | 2.86 | 6.41 | 9.26 | 11.7 | 13.4 | 15.8 |
| **Cumulative cost (billions of $)** | 0.234 | 4.03 | 21.9 | 56.8 | 105 | 166 | 235 |

## Infrastructure Rollout

Parallel to HD ZEV deployment is the rollout of charging and fueling infrastructure to meet energy demands. Currently, there are about 64,000 level 2 chargers, 6,000 DC fast chargers, and less than 50 hydrogen fueling stations (with 45 more planned) in California [1]. Almost all this infrastructure is intended for light-duty vehicles.

In California current rollout of fueling and charging infrastructure for HDVs has been concentrated at fleet depots. These locations allow fleets to plan their stations to meet their current and future needs and that mean fleets have control of infrastructure and direct access during vehicle dwell times. This approach does have drawbacks, including higher investment and operating costs for the fleet to transition to zero-emission. As the population of HD ZEVs increases, there is greater opportunity for more centrally located stations with shared and/or public access to charging and fueling infrastructure.

Station sizing—number and power rate of chargers for BEV infrastructure and number of dispensers and hydrogen dispensing capacity for hydrogen infrastructure—is dependent on expected station demand. A fleet or other station operator may weigh current versus projected needs over the lifetime of the station to determine optimal sizing. Some stations may select to install greater hydrogen storage or invest in more significant electrical upgrades initially in anticipation of significant growth in demand in the future. Alternatively, station capacity can be increased over time, but by how much depends on the original design of the station. In the case that the expansion requires transformer upgrades, new trenching, and/or underground expansion of storage, it may be more costly to delay the upgrades rather than having a higher capacity but lower station utilization at the beginning.

Despite limited demand currently, the market is expected to grow sharply in the coming years in response to ZEV mandates, making it prudent to invest in the larger capacity from the start. For example, whereas the first generation of hydrogen fueling stations (focused on LDV) have daily dispensing capacities around 50-200 kg hydrogen, the newest stations, especially those planned for HDV fueling have considerably larger capacities, around 1,000 kg [2]. As demand for hydrogen grows and the market matures, average station capacities are expected to further increase. Individual station sizing will still be dependent on local demand and whether they are private or public.

For heavy-duty BEVs, infrastructure considerations include number of chargers and charging rate. For light-duty BEVs, which have charging options at home, work, and public areas, the average ratio of vehicles to chargers in the state is 1:1 [3]. There are limited data on current HDV to charger ratios, but modeling from Lawrence Berkeley National Laboratory suggests that an optimal combination of level 2 and DC fast charging could produce a ratio close to 1.7:1 [4]. HDVs are most likely of the on-road vehicle types to require DC fast charging due to their high energy demands. DC fast charging can significantly reduce charging time and enable vehicle electrification for fleets with high energy demands and low downtime. Alternatively, if a fleet is planning to rely on overnight charging, lower charging rates may be acceptable. The caveat to DC fast charging is that it is more expensive (~$60,000) than level 2 charging ($5,000-9,000), in terms of both installation and equipment costs as well as energy costs [5]. Fast charging may reduce the total number of chargers needed but allowing greater vehicle throughput, but the overall cost may still be more than relying on level 2 charging.

In terms of energy costs, investor-owned utilities in California have currently waived demand charges associated with HDV charging, but the future of electricity costs and demand charges is uncertain. Participation in grid services such as demand response or vehicle-to-grid could be a source of revenue for future fleets and help reduce total cost of ownership.

The following is the infrastructure rollout projected under the ZEV scenario. A range of potential infrastructure configurations are investigated to capture the uncertainty of station sizing and utilization. Figure 5 presents the number of chargers needed to meet heavy-duty BEV between the years 2020 and 2050, assuming a 1:1 ratio of vehicles to chargers and a 1.7:1 ratio. Figure 7 presents the number of hydrogen stations required assuming either an average fueling capacity of 1,000 kg or 4,000 kg. Utilization refers to the average dispensed hydrogen per day as a percentage of the station capacity. It is spanned here to capture the uncertainty over average demand per station. These results suggest a significant growth in ZEV charging and fueling infrastructure between now and 2050. Assuming HDVs require DC fast charging, this equates to a 10- to 20-fold increase in the number of DC chargers available today. Likewise, only a handful of station service HDVs today, but the number would need to grow to 1,000 to 12,000 by 2050 for the HDV categories modeled.

*Figure 5. Heavy-Duty Vehicle Chargers Assuming a 1-to-1 Ratio of Vehicles-to-Chargers*

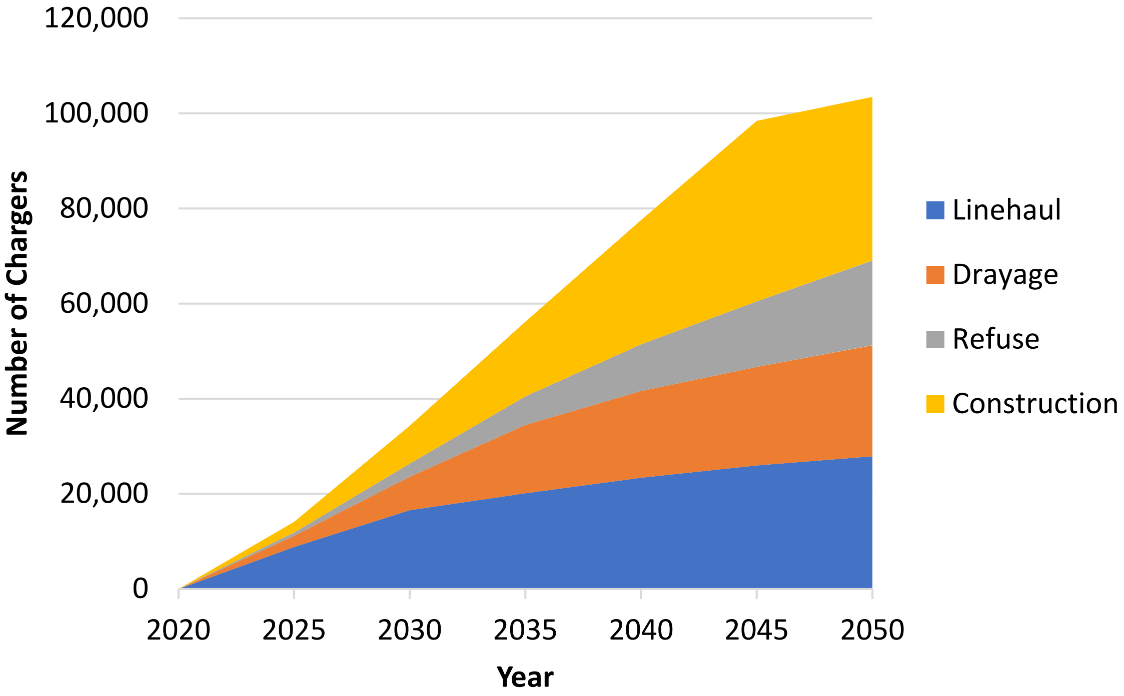


*Figure 6. Heavy-Duty Vehicle Chargers Assuming a 1.7-to-1 Ratio of Vehicles-to-Chargers*

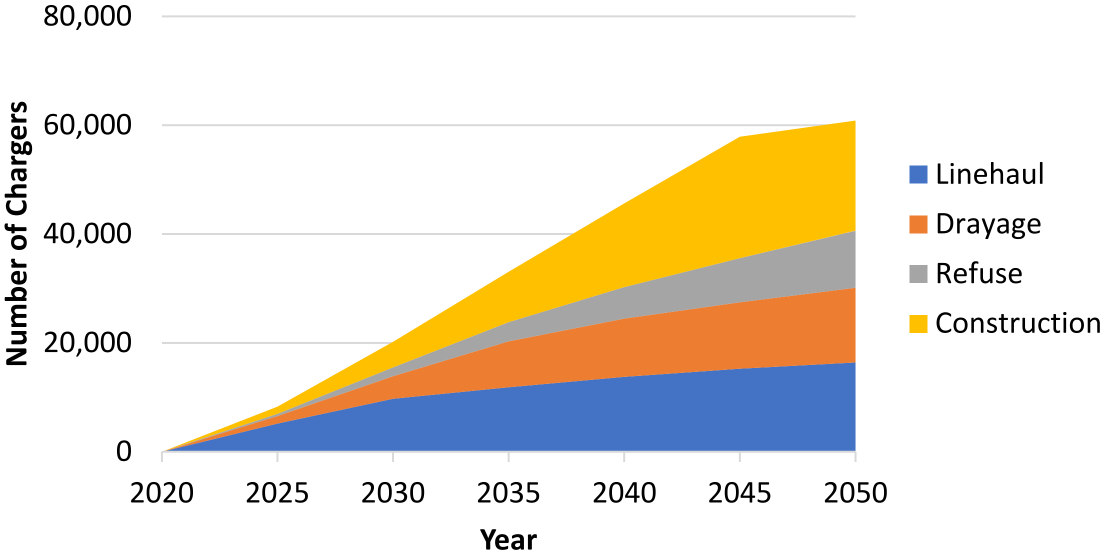
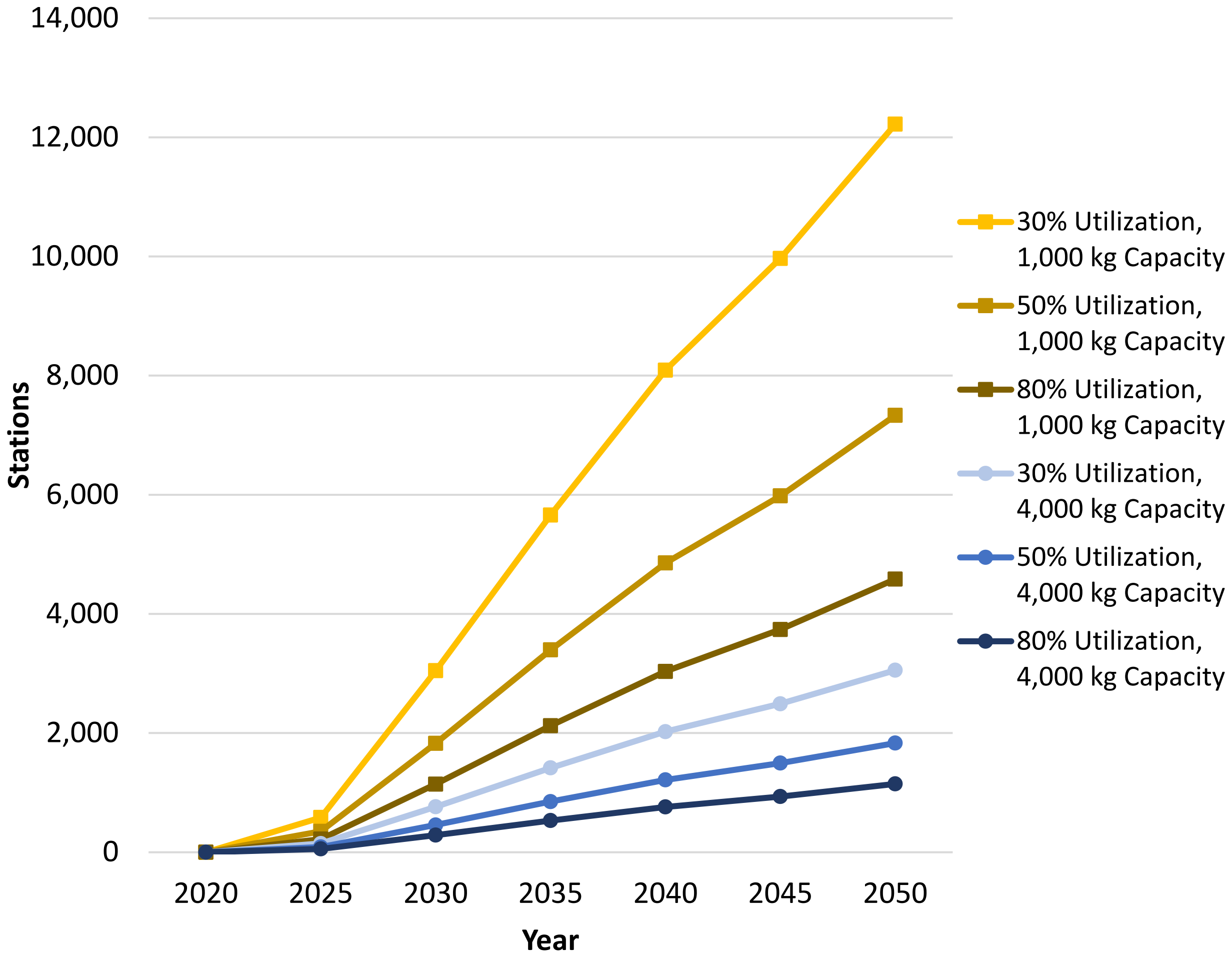


*Figure 7. Heavy-Duty Vehicle Hydrogen Fueling Stations Year 2020-2050, assuming an average station capacity of 1,000 kg or 4,000 kg at different utilization levels*



## References

[1] California Energy Commission, “ZEV and Infrastructure Stats Data,” 2021. https://www.energy.ca.gov/files/zev-and-infrastructure-stats-data (accessed Mar. 05, 2021).

[2] California Fuel Cell Partnership, “CaFCP H2 Station List,” 2020. .

[3] M. Melaina *et al.*, “National Economic Value Assessment of Plug-In Electric Vehicles: Volume I,” 2016. Accessed: Oct. 13, 2020. [Online]. Available: www.nrel.gov/publications.

[4] California Energy Commission, “Presentation - Medium-and Heavy-Duty Electric Vehicle Infrastructure Projections (HEVI-Pro) from Session 3: Modeling and Projecting Charging Infrastructure - Commissioner Workshop on Plug-in Electric Vehicle Charging Infrastructure,” 2020. https://www.energy.ca.gov/event/workshop/2020-08/session3-modeling-and-projecting-charging-infrastructure-commissioner (accessed Oct. 14, 2020).

[5] Argonne National Laboratory, “Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool,” 2019. https://greet.es.anl.gov/afleet_tool (accessed Nov. 03, 2020).