White Paper

Electric Highways:

Accelerating and Optimizing Fast-Charging Deployment for Carbon-Free Transportation

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List of Acronyms

Table 1. List of Acronyms

Acronym	Definition
BEV	Battery-Electric Vehicle
DCFC	Direct Current Fast-Charger
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCEV	Fuel Cell Electric Vehicle
HD	Heavy-Duty
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
kW	Kilowatts
LDV	Light-Duty Vehicle
MD	Medium-Duty
MHDV	Medium- and Heavy-Duty Vehicle
ML	Machine-Learning
MW	Megawatts
NEVI	National Electric Vehicle Infrastructure Program
SOC	State of Charge
ZEV	Zero-Emission Vehicle

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Executive Summary

Electric vehicle (EV) adoption has reached a tipping point. It is now accelerating toward mass market adoption, particularly in states taking proactive measures to encourage transportation electrification. New York and Massachusetts have made transportation decarbonization a priority: in 2021, New York adopted legislation targeting 100% zero-emission vehicle sales for passenger vehicles by 2035, and both states have adopted the Advanced Clean Trucks regulation, which mandates an increasing number of zero-emission medium- and heavy-duty vehicle (MHDV) sales starting in 2025.

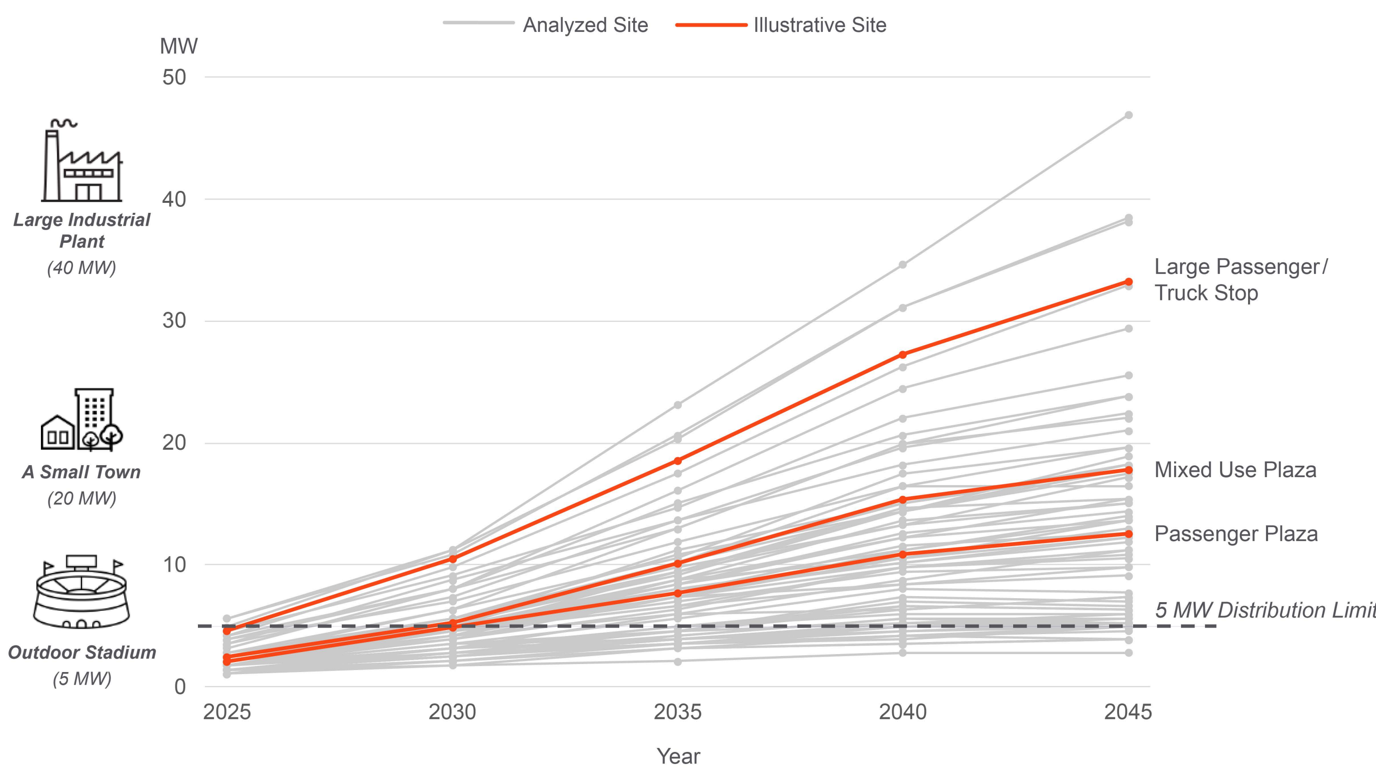
Meeting such targets will require a robust and accessible network of highway stations that provides on-route fast-charging to complement home, workplace, and depot charging. Paired with sales and manufacturing incentives such as those included in the Inflation Reduction Act of 2022, convenient access to fast-charging will further encourage EV market development and consumer adoption.

The electric grid will be critical to the rollout of fast-charging. Providing timely and sufficient electric service to energize this highway charging network will require data-driven and cross-sectoral planning. While other studies have investigated state, regional, and system-wide impacts of transportation electrification, electric infrastructure planning and development are driven by demand at specific locations throughout the grid. To that end, this study characterizes *site-specific* impacts at likely highway charging locations. These results will support utility long-term capital planning, planning for charging deployment by government agencies and private station operators, and thoughtful public policy to not only accommodate but accelerate EV adoption.

Conducted in partnership between National Grid and transportation data and analytics leaders CALSTART, RMI, Stable Auto, and Geotab, this study considers an electric highway future in which light-duty vehicles (LDVs) and MHDVs all electrify to meet state policy goals. We used observed charging station behavior and traffic data to model expected power demand growth between 2022 and 2045 across 71 sites in New York and Massachusetts, two northeastern states where National Grid is an electric distribution utility and transmission owner.

The results show that, by 2030, over a quarter of the 71 highway sites studied will require more than 5 megawatts (MW) in charging capacity to meet peak charging demand. As a reference, 5 MW of electric capacity is roughly equivalent to the electric demand of an outdoor professional sports stadium. Depending on local system voltages, this level of electric demand at a specific site may exceed the delivery limits of a typical distribution system interconnection and therefore require interconnection to the high-voltage transmission system.[1] Some high-demand charging sites could reach around 40 MW in peak charging capacity by 2045, which is equivalent to the electric load of a major industrial site (Figure ES-1). Note that the other large energy users' loads depicted in the figure below are approximate based on a range of loads.

Figure ES-1. Capacity Required to Meet Annual Peak Demand at Each Site Compared to Other Large Energy Users



The results of this study led to six main conclusions and recommendations, which are intended to inform and support policymakers, utilities, and site operators in planning for highway fast-charging deployment:

1. **A typical highway site will eventually need 20+ fast-chargers to meet drivers' needs.** As a result, these sites will see drastic increases in power demand compared to usage today. As shown in Figure ES-1, satisfying peak demand at some sites results in charging capacity comparable to that of major power users like large commercial or industrial sites. Delivering this amount of power to a single site requires long lead-time investments in utility infrastructure.
2. **While electric LDVs will drive load increases in the near term, MHDV electrification will magnify charging needs over the mid to long term.** Electric LDV registrations currently exceed MHDV registrations by a 1,425-1 ratio. As such, LDVs will play a larger role in providing demand certainty to site operators in the near term. As the electric MHDV population increases, its electric demand will ramp up considerably to surpass that of LDVs. By 2045, over 75% of average daily energy need across all sites is expected to come from MHDVs.
3. **Anticipated levels of demand will require transmission interconnection at many highway fast-charging sites.** While the potential benefits of managed charging and load management require further research, the study's results indicate a need for power well beyond the distribution system's typical limits. Fortunately, there is overlap between highway rights-of-way and those of the high-voltage transmission system. This overlap provides an opportunity to facilitate the interconnections required to meet these significant electric demands.
4. **Where feasible, we should bring chargers to the higher capacity wires that already overlap with the highway system.** Proximity to transmission lines should be considered in tandem with expected charger utilization during site selection. Today, charging developers site charging stations based on factors like traffic, expected utilization, and land availability. Access to electric infrastructure should play an equally critical role and can drastically impact development costs and timelines. By keeping both in mind, we can place charging demand in areas that make sense for drivers and make sense for the grid—accelerating the EV transition and reducing the cost of highway charging site development.

5. **Build the grid infrastructure once, and build it right.** At many sites, a transmission interconnection will likely be needed in the next decade to serve LDVs alone. Once any new electric infrastructure upgrade is required, it should be scalable and suitable for long-term needs. By implementing the right-sized interconnection upfront, rather than investing in a series of smaller distribution upgrades that will soon need to be replaced, we can avoid duplicative investments, reduce total costs, and future-proof high-traffic sites for accelerated charging deployment. Taking this long-term perspective will allow site operators and utilities to design for future demand, like growth in MHDV charging.

6. **The electric highway future is happening now.** The timelines required for grid infrastructure upgrades, particularly transmission, are much longer than those required for EV supply equipment installation. While charger installation can be completed in a matter of months, larger transmission interconnections and upgrades can take as long as 8 years to construct. This study suggests that some locations will need upgrades *before 2030*. Preparation of those no-regrets sites should begin immediately.

I. Introduction

Transportation is the largest source of greenhouse gas emissions in the United States, contributing over a quarter of all emissions in 2020.[2] Internal combustion engine vehicles also emit particulate matter, nitrogen oxides, carbon monoxide, and other pollutants that severely impact the health of residents around highways by contributing to asthma, lung cancer, cardiovascular diseases, neurological problems, and premature death.[3,4] In 2017, close to 20,000 U.S. deaths were attributed to air pollution from vehicle emissions.[5]

Furthermore, these impacts are not evenly distributed; they are felt more acutely in low-income communities and communities of color, which have been historically disadvantaged and burdened by transportation pollution.[6,7] The global and local impacts of transportation create an imperative to move quickly to electrify vehicles. Enabling electric vehicles (EVs) to travel on highways will have broad environmental and health benefits, particularly to heavily impacted communities who have been disproportionately subjected to transportation pollution.

Electrification of on-road passenger vehicles in the United States has recently eclipsed an important milestone: EVs surpassed 5% of new vehicle sales as of this writing.[8] Globally, this threshold is considered a tipping point for EVs to become mainstream options for consumers[9] and signals that much greater levels of EV market penetration will likely occur soon.

In New York and Massachusetts, legislation commits both states to fully zero-emission sales of passenger vehicles by 2035. New York has also committed to 100% zero-emission medium- and heavy-duty vehicle (MHDV) sales by 2045.[10,11] While deployment of zero-emission trucks remains limited, both states have also adopted California's Advanced Clean Trucks regulation,[12] which phases in progressively greater shares of zero-emission truck sales to as high as 75% for some truck segments by 2035. California's proposed Advanced Clean Fleets regulation, which could eventually be adopted by New York and Massachusetts, would require MHDV fleets to purchase more zero-emission vehicles (ZEVs) over time and could enable a 100% zero-emission MHDV sales mandate effective as soon as 2040.[13] These targets are expected to be more attainable as battery and powertrain technologies continue to mature and in the presence of supportive purchase assistance, advisory services, and infrastructure preparedness programs for fleets.

Meeting the aggressive EV targets and regulations established in leading states will require robust and easily accessible public charging networks. Highway corridor charging will serve as a key component for both passenger cars and trucks. For light-duty vehicles (LDVs), highway charging is crucial to provide seamless access along common passenger routes, alleviating range anxiety on longer trips. For medium-duty (MD) vehicles, highway charging provides an important complement to depot charging for local fleets with unpredictable duty cycles or, in some cases, may enable small business fleets to electrify without investing in depot charging. For heavy-duty (HD) vehicles, a comprehensive corridor charging network is critical to unlock cost-effective electrification in regional-haul and long-haul segments that have longer, more unpredictable daily duty cycles.

While other studies have investigated state, regional, and system-wide impacts of transportation electrification,[14] electric infrastructure needs are driven by demand at specific locations throughout the power grid. Accordingly, the objective of this study is to characterize *site-specific* impacts at likely highway charging locations. Currently, the electric grid does not have sufficient delivery headroom for highway charging at the scale identified by this study and required by policy targets. Sites with significant charging loads, as in multiple megawatts (MW), will necessitate considerable electric distribution system upgrades and, in many cases, high-voltage transmission-level interconnection. These interconnection upgrades can incur substantial cost and take 4-8 years to complete.

Utilities can provide the requisite levels of service to support highway fast-charging, but doing so cost-effectively requires planning for long-term loads rather than making reactive and iterative upgrades. While there are benefits to staging EV charger deployment (i.e., minimize upfront cost and increase relative utilization), grid capacity is not easily expanded in increments for new chargers. There are also benefits to rolling out new charging facilities, since studies have found that visible and readily available EV charging can encourage EV adoption.[15] Proactive investment to future-proof sites can reduce the need for duplicative investments, minimize grid infrastructure costs to site owners (and therefore reduce costs to drivers), and allow for faster and efficient charging installations.

This study, undertaken by National Grid and transportation data and analytics leaders CALSTART, RMI, Stable Auto, and Geotab, intends to inform public policy, long-term system planning, and site selection and development with forecasts of the power demands of passenger and commercial EVs at highway sites throughout New York and Massachusetts. To identify the magnitude of potential grid and interconnection capacity needs, the study considers a full electrification scenario for both LDVs and MHDVs, with multiple scenarios for the pace of EV adoption.

II. Study Design

Site Selection

We analyzed load impacts of EVs across 71 potential charging locations,[16] including service plazas, truck stops, and off-highway locations. As a whole, these sites create a network that would provide charging access across major highways in New York and Massachusetts (e.g., I-90, I-87, I-95, MA Route 24), including the entire segment of I-90 from Boston to Buffalo.

Sites were selected at locations approximately 30-50 miles apart and within one mile of a highway exit, in line with the Federal Highway Administration's National Electric Vehicle Infrastructure (NEVI) Formula Program Guidance.[17] We prioritized existing service plazas and established truck stops, followed by additional off-highway locations with commercial activity on site—amenities increase comfort for drivers during their charging sessions and entice more vehicles to stop. We also included sites located beyond National Grid's service territory to provide coverage across major roadways in these two states.

In anticipation of growing site loads, we factored in proximity to National Grid's transmission and substation infrastructure as a key selection criterion for the off-highway sites studied. The importance of this critical step in site selection cannot be overstated. We assumed that states and regions would leverage state-controlled sites that already host service plazas to constitute the backbone of a regional charging network. For routes without established on-highway service plazas, this study is the first (to our knowledge) in the United States to use proximity to major electric infrastructure as a site selection criterion. The addition of this screening criterion may be the most important step from an electric network and public policy perspective: proximity to this infrastructure can offer site developers additional charging capacity at the lowest costs over the long term while streamlining construction timelines.

Data Sources

We used two different approaches to simulate charging demand at the selected sites, one for LDVs and another for MHDVs. The two approaches differed due to data availability for the respective vehicle populations. A detailed explanation of these approaches is included in Appendix A: Methodology.

With EVs now becoming more widespread among the LDV segment, data already exist to characterize charging behavior. The LDV dataset, provided by Stable Auto, consisted of over 2.5 years of historical usage data for over 3,000 direct current fast-chargers (DCFCs) across the United States today. Stable Auto leveraged this existing data to train a machine-learning (ML) model that predicted charging demand at sites.

In contrast, because electric MHDVs are not yet widespread, the electric MHDV charging demand simulation required a different approach. The study assumed that electric MHDVs will operate similarly to existing internal combustion engine (ICE) MHDVs. The simulation took ICE MHDV data to project where and when these vehicles would charge if they were electrified. To do so, we obtained inputs from aggregated and anonymized telematics data via Geotab's ITS Altitude platform, which reflects observed distributions of MHDV stops at the selected sites drawn from millions of connected vehicles in operation today. Appendix A: Methodology describes each simulation approach in detail.

Key Assumptions and Considerations

The following simplifying assumptions directionally informed our conclusions from the study's results:

1. **All ZEVs have a battery-electric powertrain.**

   These projections assume that all ZEVs will be battery-electric vehicles (BEVs). Other zero-emission fuels, specifically green hydrogen, are expected to play a role in MHDV electrification over the long term, but there is currently no consensus on this technology's eventual market share. Several studies support the notion that the majority of MHDVs will be battery-electric, particularly for shorter and medium-haul needs. The National Renewable Energy Laboratory considers that, by 2050, the MD truck stock will include 66% BEVs and 16% fuel cell electric vehicles (FCEVs); the HD truck stock will consist of 56% BEVs and 16% FCEVs.[18] A report by the Mission Possible Partnership, and sponsored in part by RMI, shows that, by 2050, FCEVs make up almost no share of U.S. regional MHDV sales and 32% of long-haul MHDV sales, with the vast majority of other sales being battery-electric.[19]

This simplifying assumption of 100% battery-electric MHDVs could prove conservative when determining necessary electric capacity at certain sites. There are significant energy losses in the production and storage of hydrogen, and FCEVs have lower energy efficiency than BEVs.[20] Where hydrogen fueling relies on on-site electrolysis, analysis by National Grid in the United Kingdom suggests that site-level electric capacity needs could actually *increase*.[21] As such, the results presented in this paper for a fully-electric transportation sector are informative of the magnitude of MHDV charging needs, even considering the potential that a portion of MHDVs will utilize hydrogen fuel cell technology.

2. **Cold weather does not affect energy consumption or charging speed.**

   Cold weather is expected to affect vehicle efficiency and charging efficiency, although the long-term magnitude of this impact is still unclear. Today, EVs require more energy in cold temperatures (and in extreme heat) and may need 40%-60% more electricity to travel the same distance in cold weather as in warm weather.[22] Additional technology improvements, such as in-cabin heating and battery temperature management, could reduce this discrepancy in the future, which creates further uncertainties on cold weather's impact on charging behavior. To the extent that cold weather decreases vehicle efficiency and charging efficiency, expected loads will increase during winter months.

3. **Competitive charging will draw LDV traffic away from candidate site locations but less so for MHDV traffic.**

   As the number of LDVs on the road increases, the number of chargers will need to increase to meet demand and reduce range anxiety. The LDV assessment incorporated the reduction in demand driven by charger buildout based on the International Council on Clean Transportation (ICCT) EV charger forecast. The MHDV assessment did not account for competitive charging. An increase in MHDV competitive charging would reduce demand at candidate sites. However, this impact would likely be limited, since the MHDV charging network is not expected to grow at the rate of the LDV charging network, and candidate sites already provide coverage at 30- to 50-mile intervals across all major roadways. This analysis also assumed that traffic distribution among the 71 sites *remained constant*: failure to adequately deploy charging infrastructure at certain sites could increase the need for charging at other sites.

4. **Managed charging does not influence highway charging loads.**

   Managed charging is a critical strategy when groups of vehicles are connected to the grid for long periods of time and the delivery of power can be delayed to coincide with off-peak hours, such as at fleet depots. For the highway charging use case, where vehicles typically connect for shorter periods of time and drivers seek to charge as fast as possible within that window, managed charging offers more limited value. Overnight truck stops are an exception, in which case overnight power demand curves will be both off-peak and lower. For simplicity, this analysis assumed that vehicles charge at constant rates.

   The use of managed charging at highway service plazas and truck stops deserves more research. As states like New York and Massachusetts electrify heating, the grids in these states will become both winter-peaking and overnight-peaking in the coldest months, which may limit the value of managed charging for highway applications.[23]

5. **Each weekday/weekend day has an identical distribution of expected stop times, trip distances, and stop durations.**

   It is possible that highway traffic and electric demand will tend to be higher during certain weeks and days of the year, such as around holidays. This assessment did not explicitly account for these variations and considered average needs across all weekdays and weekend days of the year. As such, where the analysis considered annual peak demand, it did so for the peak of the model days and was not adjusted for holiday traffic.

Scenarios

We constructed scenarios to represent forecasted electric demands if both New York and Massachusetts achieve their policy goals while assuming that all ZEVs are battery-electric. These goals align the industry to achieve the greenhouse gas and criteria pollutant emissions reductions required by the world's climate and communities.

All results are presented assuming charging at a constant 350 kW, as detailed in Appendix A: Methodology. (A scenario for MW-level charging for MHDVs is also presented and discussed below.) Already, chargers capable of 350 kW are being installed on the New York State Thruway and in other locations. This capability is faster than most charging done today, but there are indications that technology is accelerating to faster charging at this rate.

Responses to a recent Request for Information from the Federal Highway Administration provide strong support that 350-kW charging will play a role, and perhaps become prevalent, for highway charging.[24] Comments from vehicle manufacturers, charging network providers, and state transportation officials highlight 350-kW charging as a future capability and even a necessary one to support highway travel.[25] The wide array of commenters from across the EV value chain indicates momentum toward faster charging over time. Since this study forecasts demand years into the future, it is reasonable to anticipate improvements in charging and battery technology to this standard and to plan for the grid infrastructure to support it.

Light-Duty Electric Vehicle Sales Scenario

For the LDV segment, the scenario used as the basis for all figures in the Results at Three Illustrative Sites section of this report envisions that 100% of new LDV sales are electric by 2035. This scenario is aligned with the Commonwealth of Massachusetts' Bill H.5060[26] and the Government of New York State's Bill A.4302/S.2758,[27] which require that all sales of new passenger cars and light-duty trucks be zero-emission by 2035 (Figure 1). The LDV forecast was based on the Goldman Sachs Investment Research EV sales forecast and scaled to meet the policy-driven targets.[28] EVs are assumed to have an 8-year life span in 2021, increasing to 12 years by 2025. The resulting vehicle populations are shown in Figure 2. Under the sales scenario, the total population of LDVs in operation remains the same.

Figure 1. National LDV Sales Percentages According to Sales Scenario (100% by 2035)

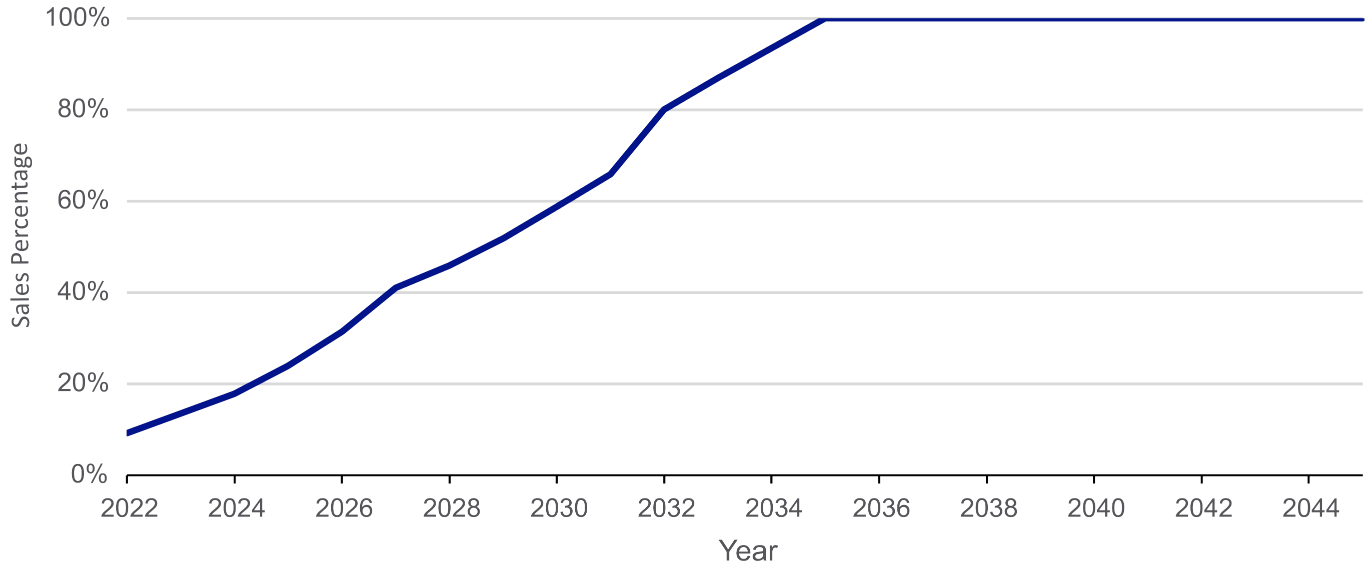
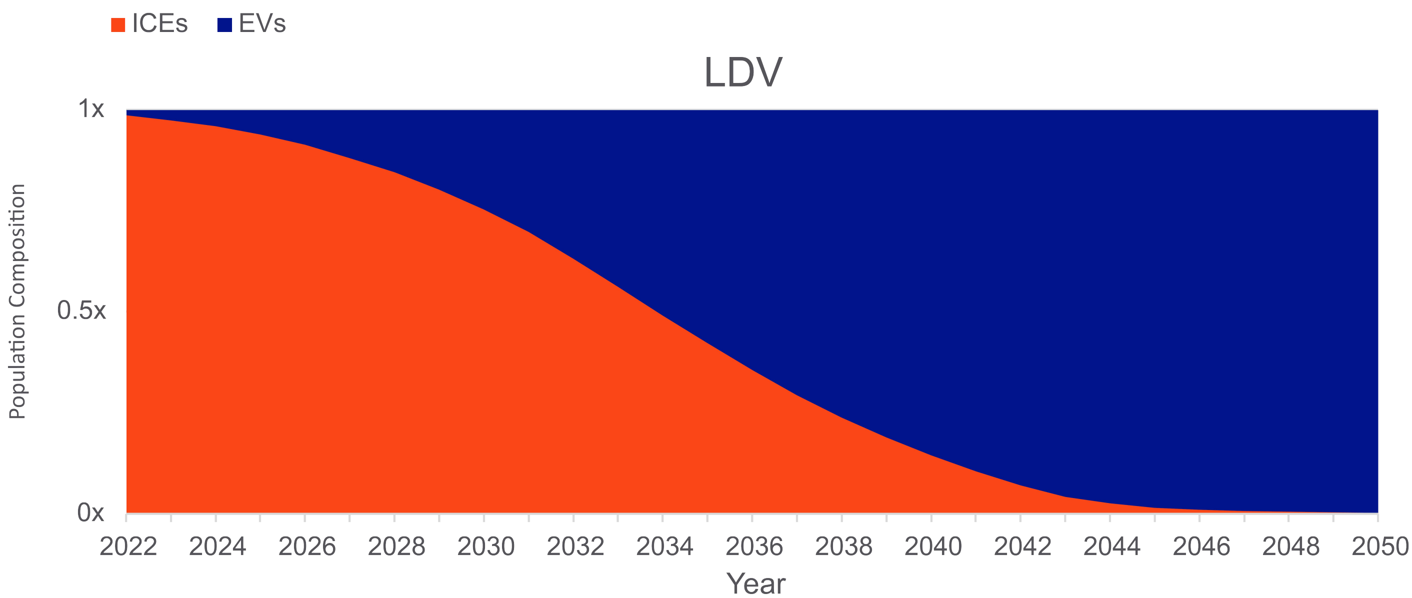


Figure 2. National LDV Population Composition Over Time Under Sales Scenario (100% by 2035)



Electric Medium- and Heavy-Duty Vehicle Sales Scenario

For the MHDV segment, the scenario used as the basis for all figures in the Results at Three Illustrative Sites section assumes that 100% of new MHDV sales are battery-electric by 2045 (Figure 3). As discussed above, all MHDVs are assumed to be battery-electric; there are no FCEVs in the analysis. The timeline for this scenario is aligned with the Government of New York State's goals to achieve 30% zero-emission MHDV sales by 2030 and 100% by 2045.[29] The target is also set in California's Executive Order N-79-20.[30] In the past, Massachusetts has followed California's ZEV regulations under Section 177 of the Clean Air Act, which indicates the 100% ZEV sales target is also likely to be adopted. To project EV population size over time, we assume a vehicle lifespan of 12 years.

Figure 4 shows the population growth and powertrain split expected under the sales scenario for MHDVs. For comparison, almost 60% of the starting MHDV stock is MD; however, most MHDV stops in the dataset come from HD. It is important to note that substantial growth in MHDV stock is expected over the next 30 years, as supported by MHDV fleet growth projections detailed in the U.S. Energy Information Administration's 2021 Annual Energy Outlook.[31] As such, we need to plan to support charging needs for trucks on the road today and for potentially many more on the road by 2045.

Figure 3. National MHDV Sales Percentages According to Sales Scenario (100% by 2045)

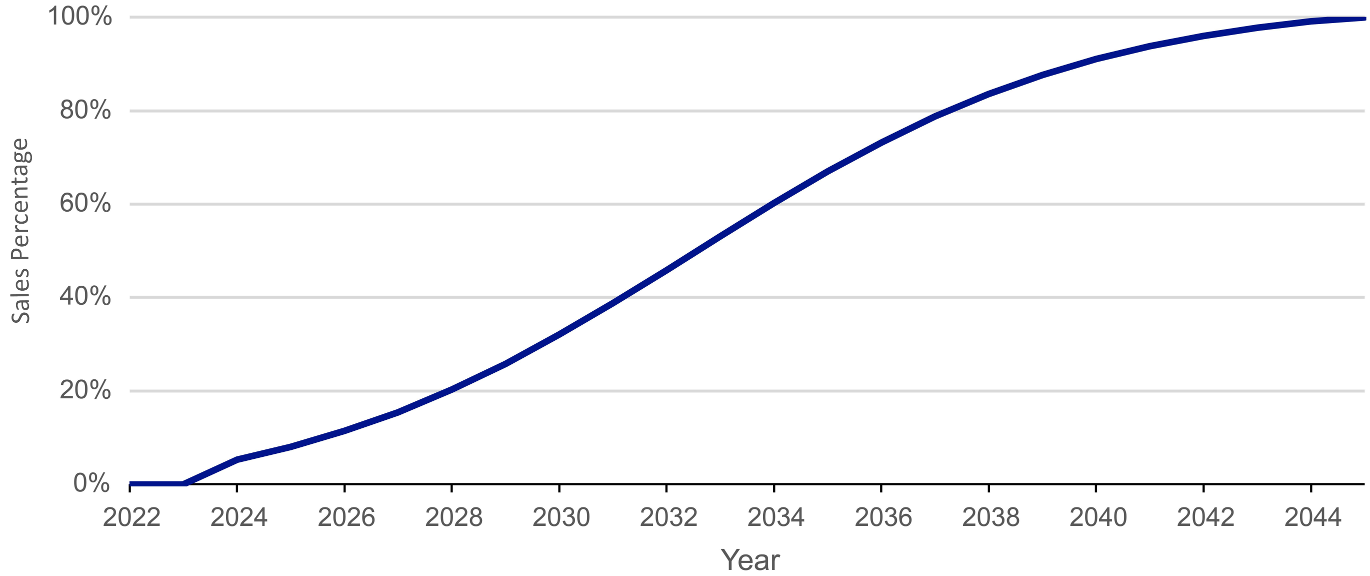
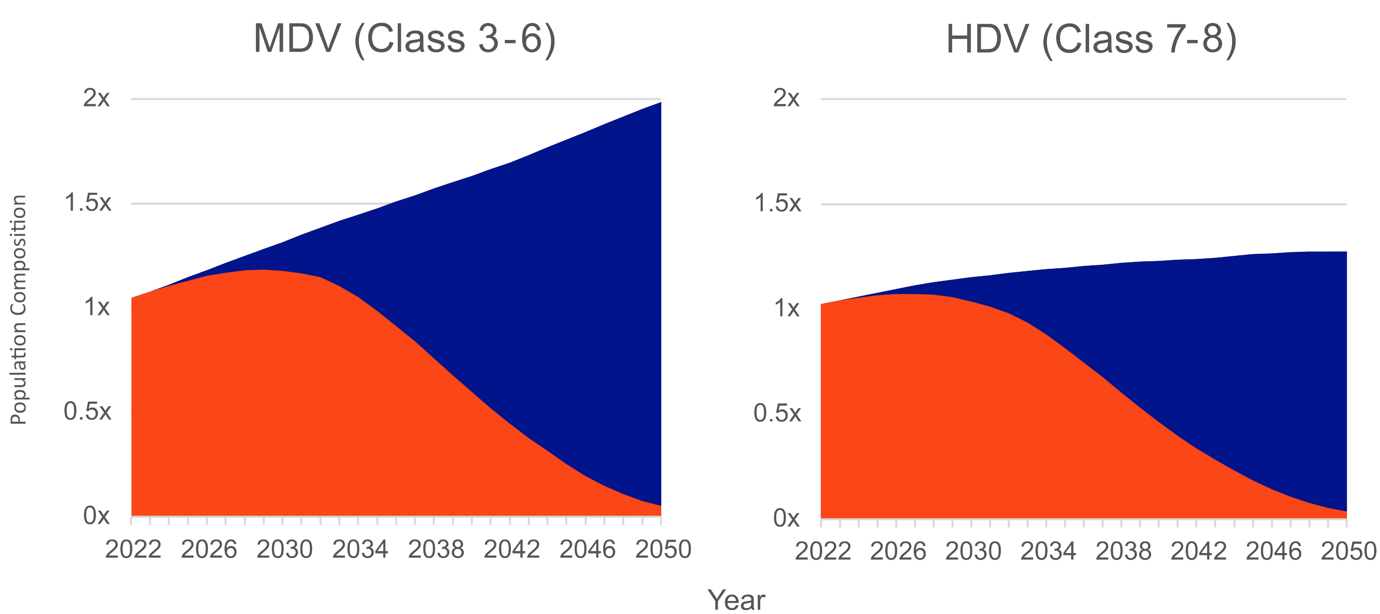


Figure 4. National MHDV Population Composition Over Time Under Sales Scenario (100% by 2045)



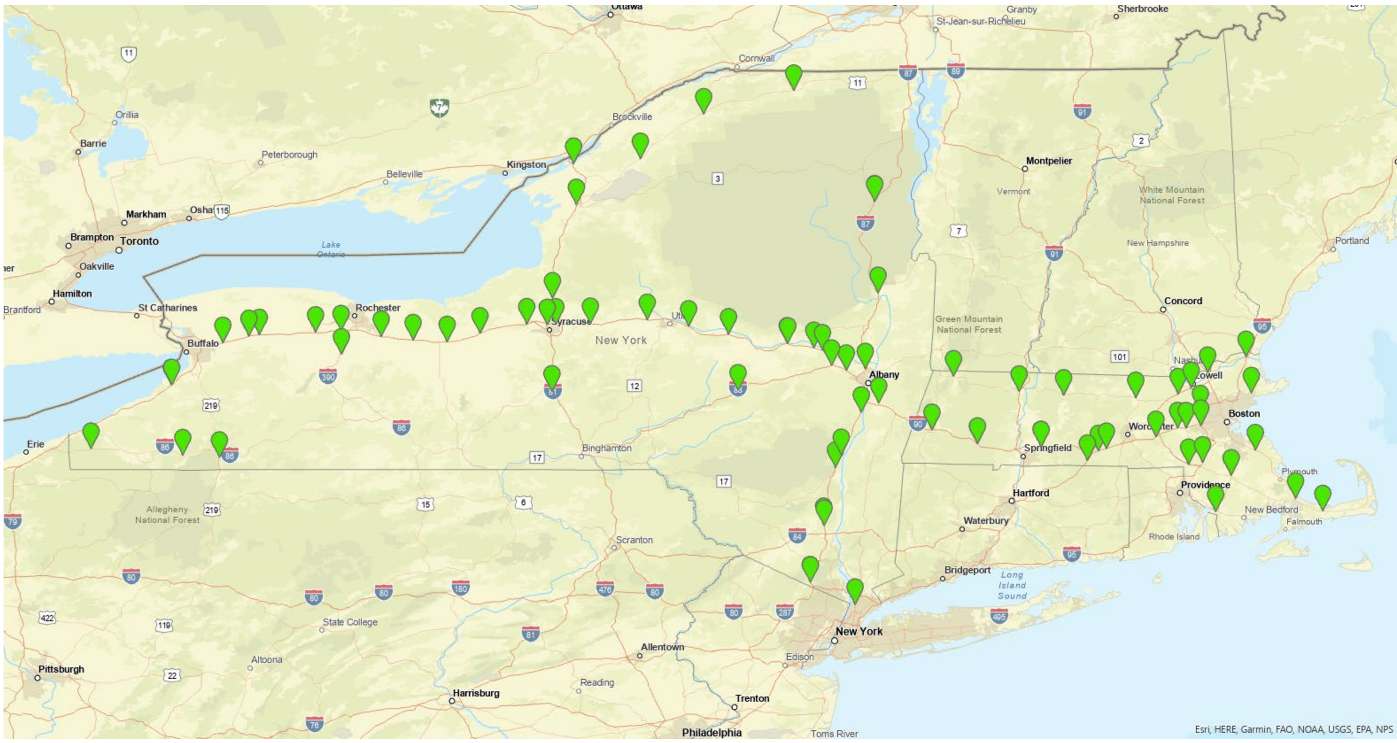
III. Results at Three Illustrative Sites

This section details the results for each assessment: first LDV, followed by MHDV, and then combined. Each assessment focuses on three sites that are representative of the variations seen across all sites surveyed:

1. **Large Passenger/Truck Stop:** represented by two neighboring sites in western New York, with about 10 megawatts (MW) of combined LDV and MHDV charging capacity required by 2030. These sites see a large amount of both LDV and MHDV charging capacity; MHDV capacity is over 70% of the sites' capacity in 2045.
2. **Mixed Use Plaza:** represented by a site in central Massachusetts, with about 5 MW of combined LDV and MHDV charging capacity required by 2030. This site sees a meaningful amount of both LDV and MHDV capacity, with growing share of MHDV needs over time (67% of capacity in 2045).
3. **Passenger Plaza:** represented by a service plaza in New York, with about 5 MW of combined LDV and MHDV charging capacity required by 2030. This site sees less of each LDV and MHDV capacity needed, and LDV is a larger proportion of capacity than other sites (40% LDV capacity in 2045).

In addition to the results for the three representative sites, this section includes overall capacity results across all 71 sites (Figure 5) for each assessment. For all assessments, it is important to remember that demand will vary across the day, relative to the times in which vehicles stop to charge.

Figure 5. Map of All 71 Sites Evaluated



Light-Duty Vehicle Results

Large Passenger/Truck Stop

The Large Passenger/Truck Stop site aggregates demand from two service plazas on opposite sides of a highway that could share the same interconnection. This site sees large demand from both LDVs and MHDVs. Figure 6 represents the distribution of projected demand over weekdays/weekends in 2035. Each line represents the percentile values for each 15-minute window across all weekdays/weekends. For example, the Weekday 100th percentile value for 3:00-3:15 p.m. represents the maximum demand observed for that time window across all weekdays in 2035. Similarly, the Weekend 95th percentile value indicates that the maximum demand observed in that window for 95% of weekend days. As seen in Figure 6, we project that, in 2035, the Large Passenger/Truck Stop site will see peak demand from LDVs in the afternoon.

Figure 6. Large Passenger/Truck Stop LDV Load Curve Variation in 2035

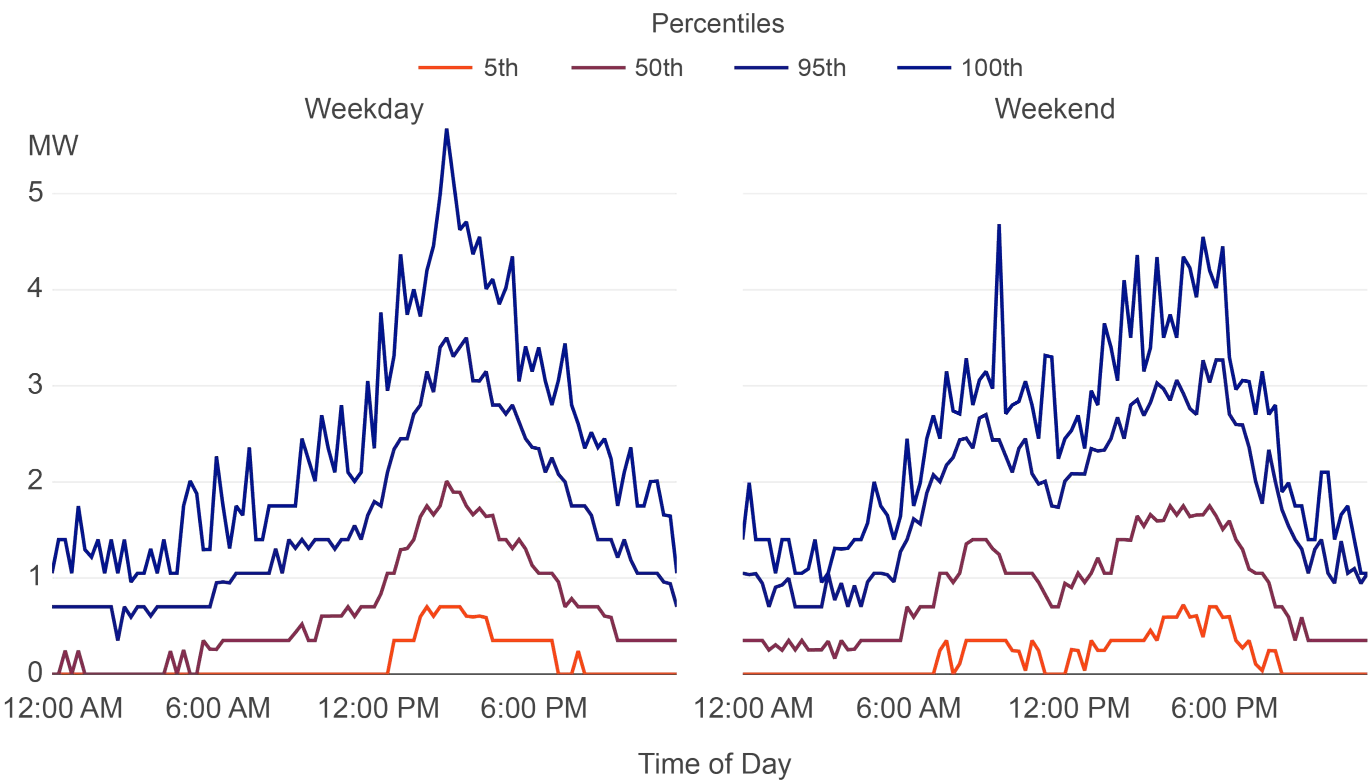
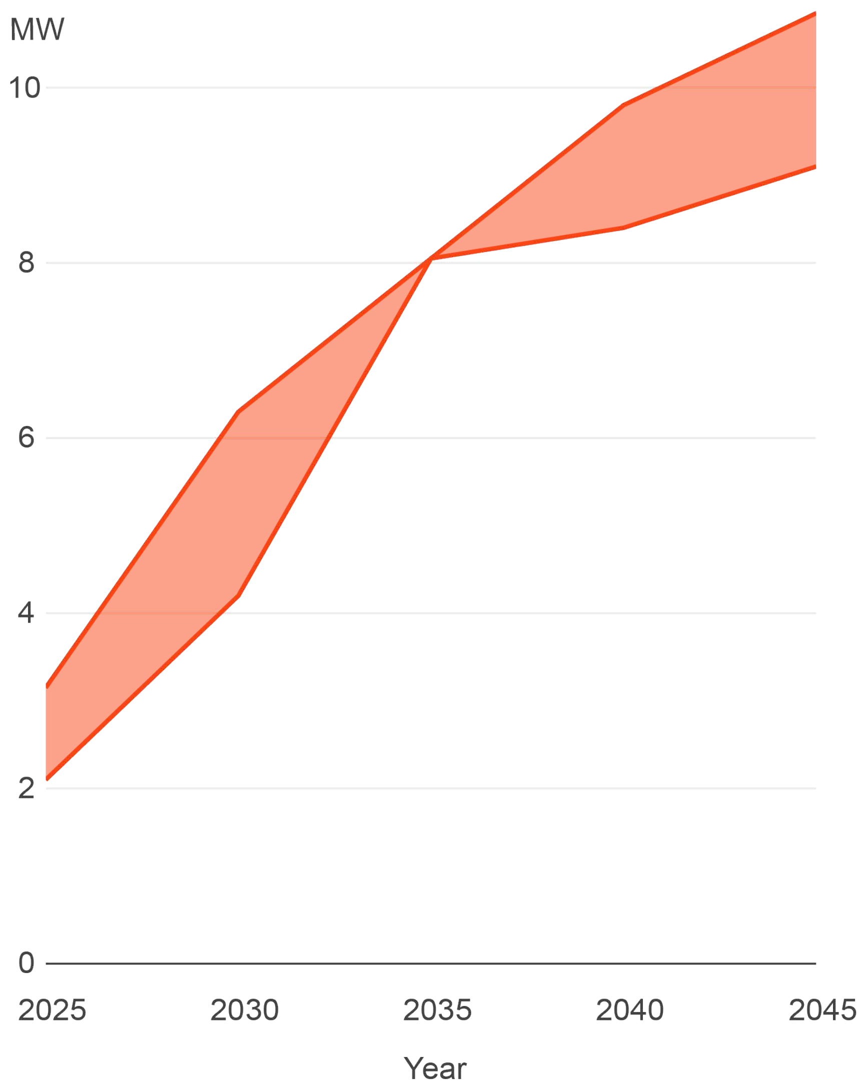


Figure 7 represents the capacity required at the Large Passenger/Truck Stop site to meet annual peak demand for LDVs. Capacity at each of the two truck stops is rounded up in 350-kilowatt (kW) increments since it is tied to the number of chargers required to satisfy demand. The lower bound represents the LDV expected charger utilization, while the higher bound represents the optimistic charger utilization scenario discussed in Appendix A: Methodology. In order to meet the 2035 demand from LDVs at the Large Passenger/Truck Stop site, the equivalent of 23 350-kW chargers, or 8.05 MW, would be required. By 2045, the equivalent of 26 350-kW chargers, or 9.1 MW, would be required.

Figure 7. Large Passenger/Truck Stop LDV Capacity Needed to Meet Annual LDV Peak Demand



Required capacity for LDV charging at this site is projected to increase by around 300% between 2025 and 2035. For this site, which comprises two plaza locations opposite each other on a highway, the charging capacities in Figure 7 are needed to meet peak demand at each location added together to reach the total capacity required (i.e., the total nameplate capacity of chargers summed across both sites). The hourly load curves appear slightly lower because they include the net peak of both locations.

Mixed Use Plaza

At the Mixed Use Plaza site, there is a larger peak during weekday afternoons, with two slightly smaller peaks over the weekend around 8:00 a.m. and 3:00-7:00 p.m. (Figure 8). To meet LDV annual peak demand in 2035, 13 350-kW chargers will be required, which results in 4.55 MW of site capacity. By 2045, servicing LDV demand would require 17 350-kW chargers resulting in 5.95 MW of site capacity (Figure 9).

Figure 8. Mixed Use Plaza LDV Load Curve Variation in 2035

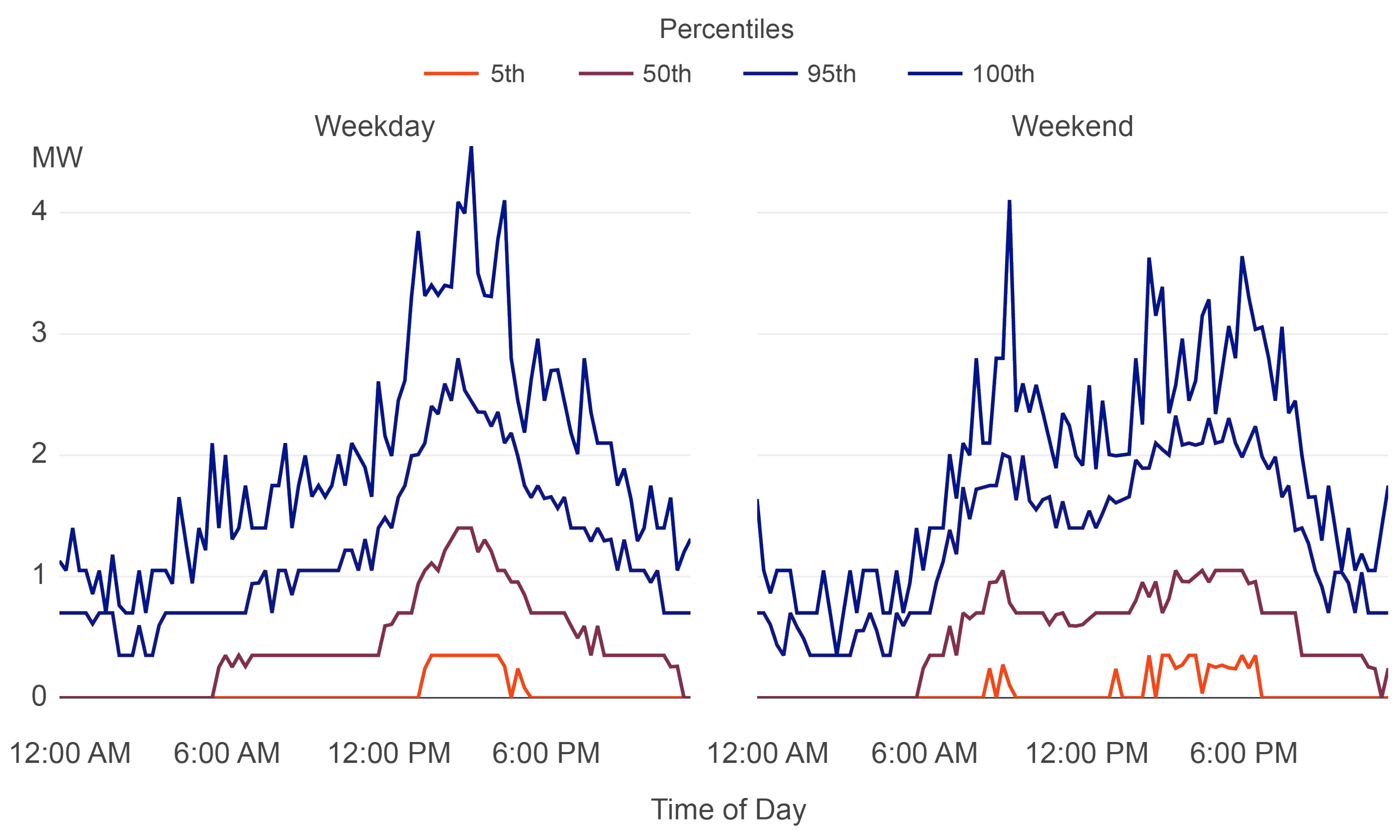
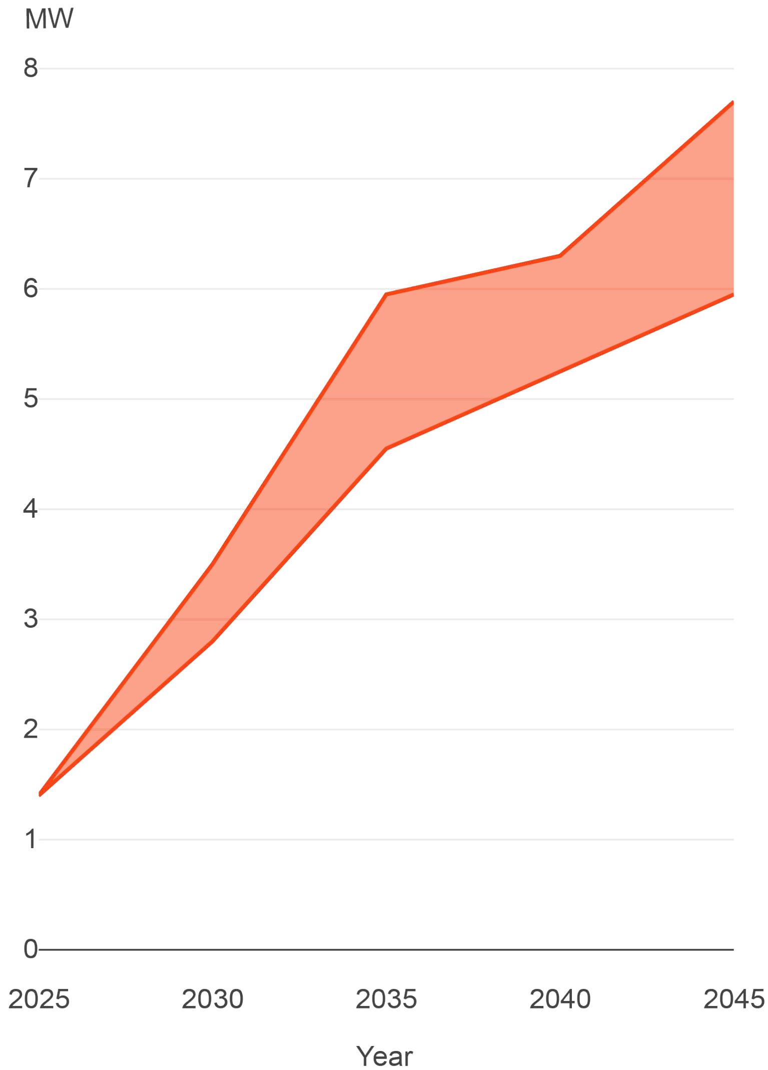


Figure 9. Mixed Use Plaza LDV Capacity Needed to Meet Annual LDV Peak Demand



Passenger Plaza

At the Passenger Plaza site, LDV demand is expected to peak during weekday afternoons, with a flatter peak demand curve over the weekends (Figure 10). To meet LDV peak demand in 2035, the equivalent of 10 350-kW chargers will be required, which results in 3.5 MW of site capacity. By 2045, servicing LDV demand at the Passenger Plaza would require 14 350-kW chargers resulting in 4.9 MW of site capacity (Figure 11).

Figure 10. Passenger Plaza LDV Load Curve Variation in 2035

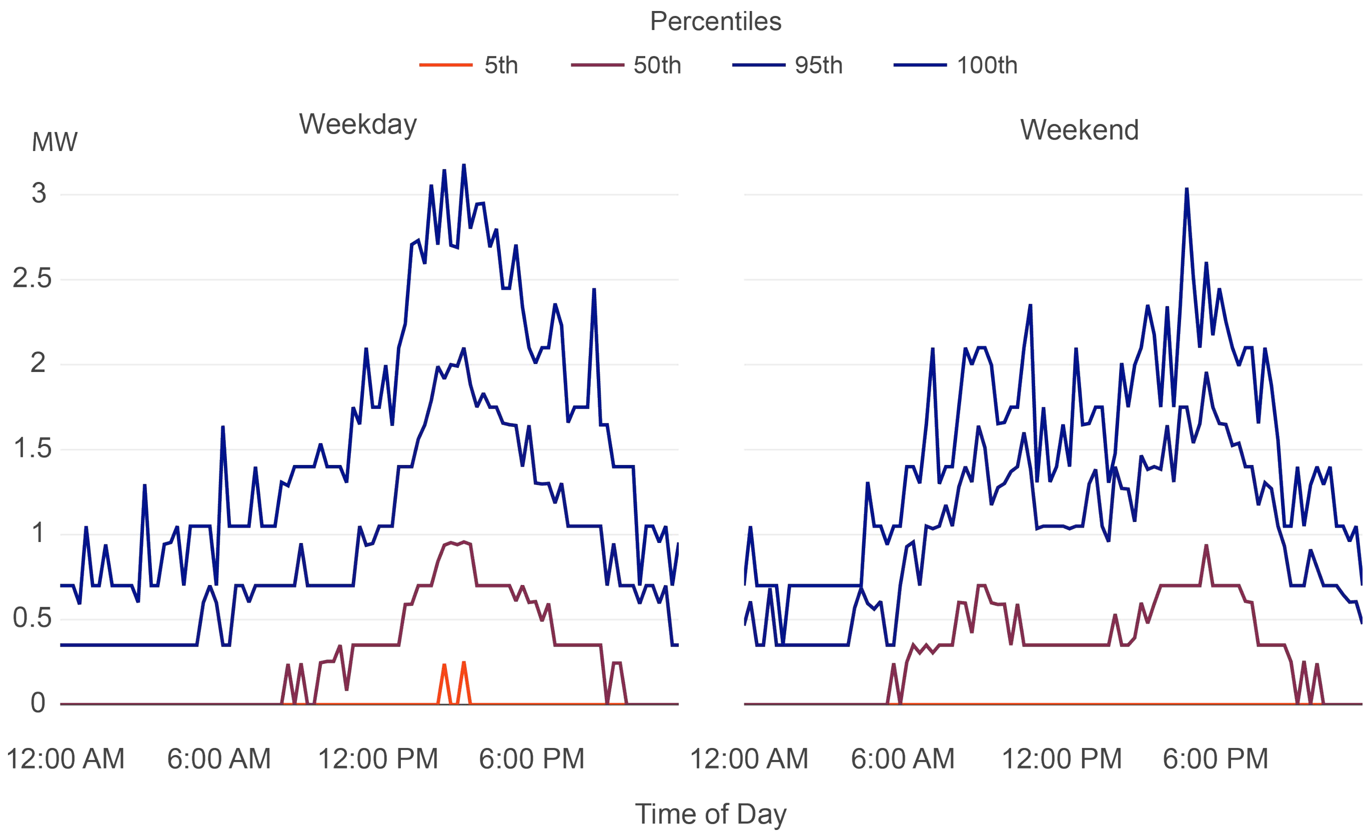
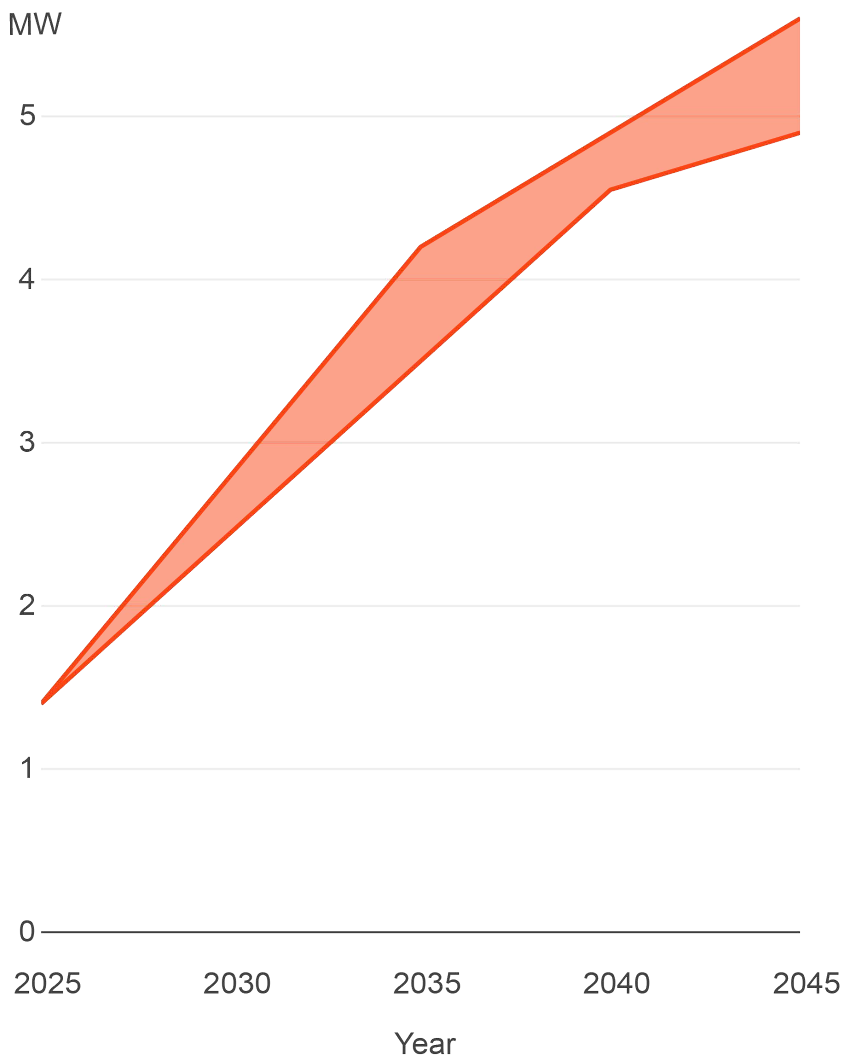


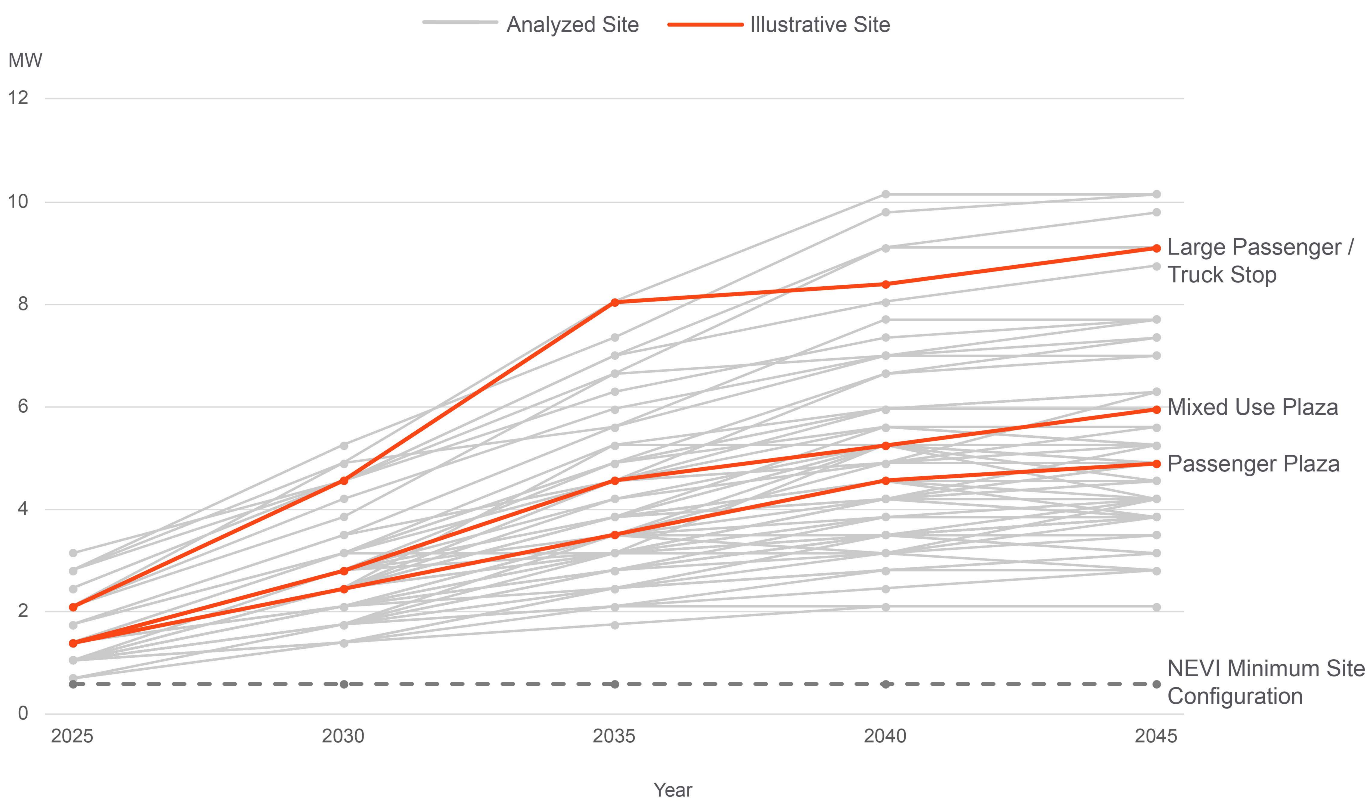
Figure 11. Passenger Plaza LDV Capacity Needed to Meet Annual LDV Peak Demand



Overall Light-Duty Capacity Results

Figure 12 shows the required capacities to satisfy peak LDV demand across all 71 sites. Overall, the LDV results show that, in 2025, sites will require the equivalent of two to nine 350-kW chargers (700 kW to 3.15 MW) to satisfy demand. By 2030, that range will increase to four to 15 350-kW chargers, reaching six to 29 chargers (2.1 MW to 10.15 MW) by 2040-2045—a threefold increase in required capacities over 15 to 20 years.

Figure 12. Capacity Required to Meet LDV Annual Peak Demand at Each Site



Additionally, these results show that the minimum site configuration required by the NEVI program formula funding guidance (four 150-kW chargers) will be surpassed by expected demand across many highway sites in the near future. Moreover, by 2030, sites begin to require LDV charging capacities in excess of 5 MW, which we consider as an indicator to explore interconnection solutions beyond low-voltage distribution. Transmission interconnection upgrades will likely be necessary at more highway sites in the next decade *to serve LDV demand alone*.

Medium- and Heavy-Duty Vehicle Results

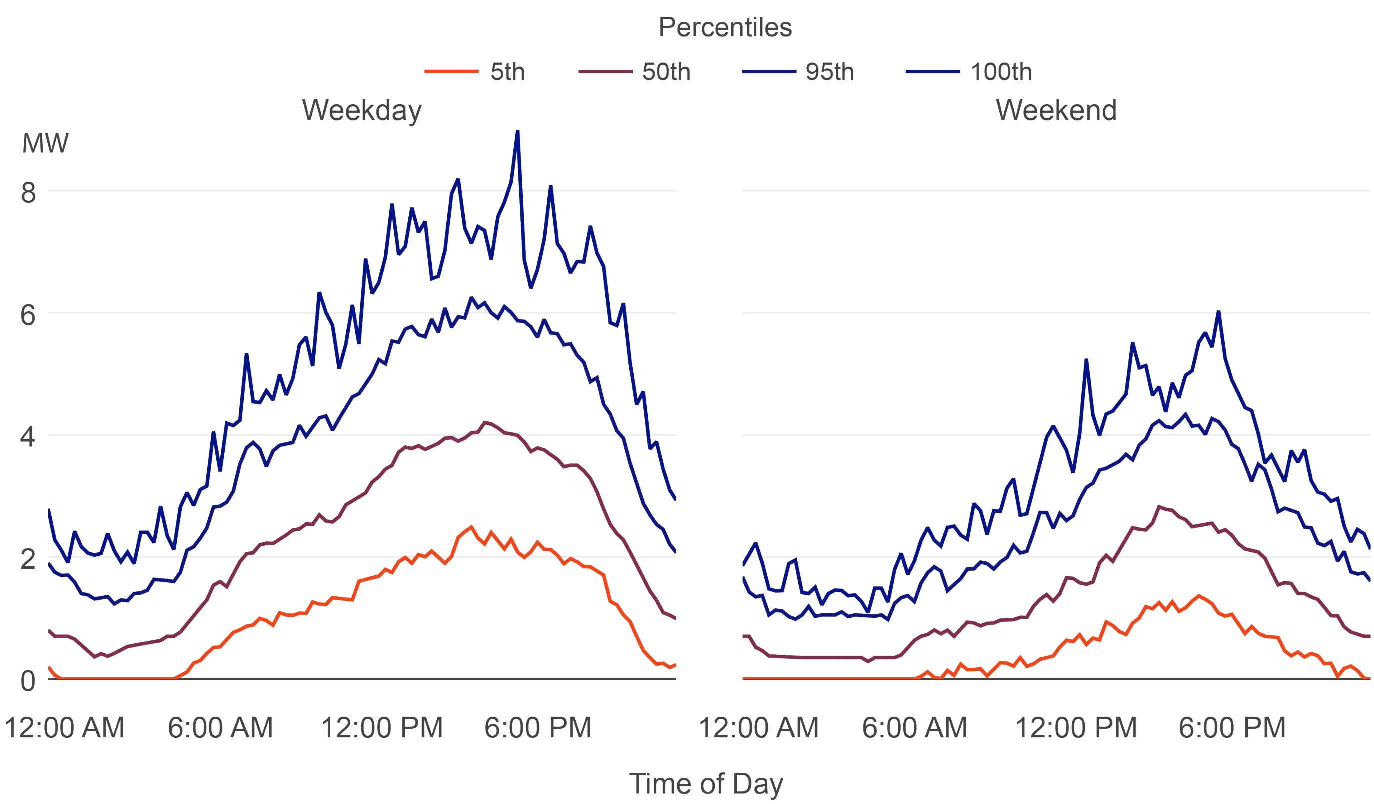
MHDV results are reported similarly, with expected load curves for 2035 and capacity required to meet annual peak demand over time. However, capacity is presented for two different charger configurations: 350 kW and 1 MW. MW-level charging is a newer technology that has the potential to better serve segments of MHDV drivers and has recently seen progress on technology and standards that indicate potential rollout in the future.[32] MHDV estimates are also provided to 2050, as opposed to 2045 for LDV.

Lower bounds of capacity graphs represent a constrained timing scenario (based on stop duration), while higher bounds represent an unconstrained scenario (based on energy depleted during the trip). The unconstrained scenario is the base case scenario used in all summary results.

Large Passenger/Truck Stop

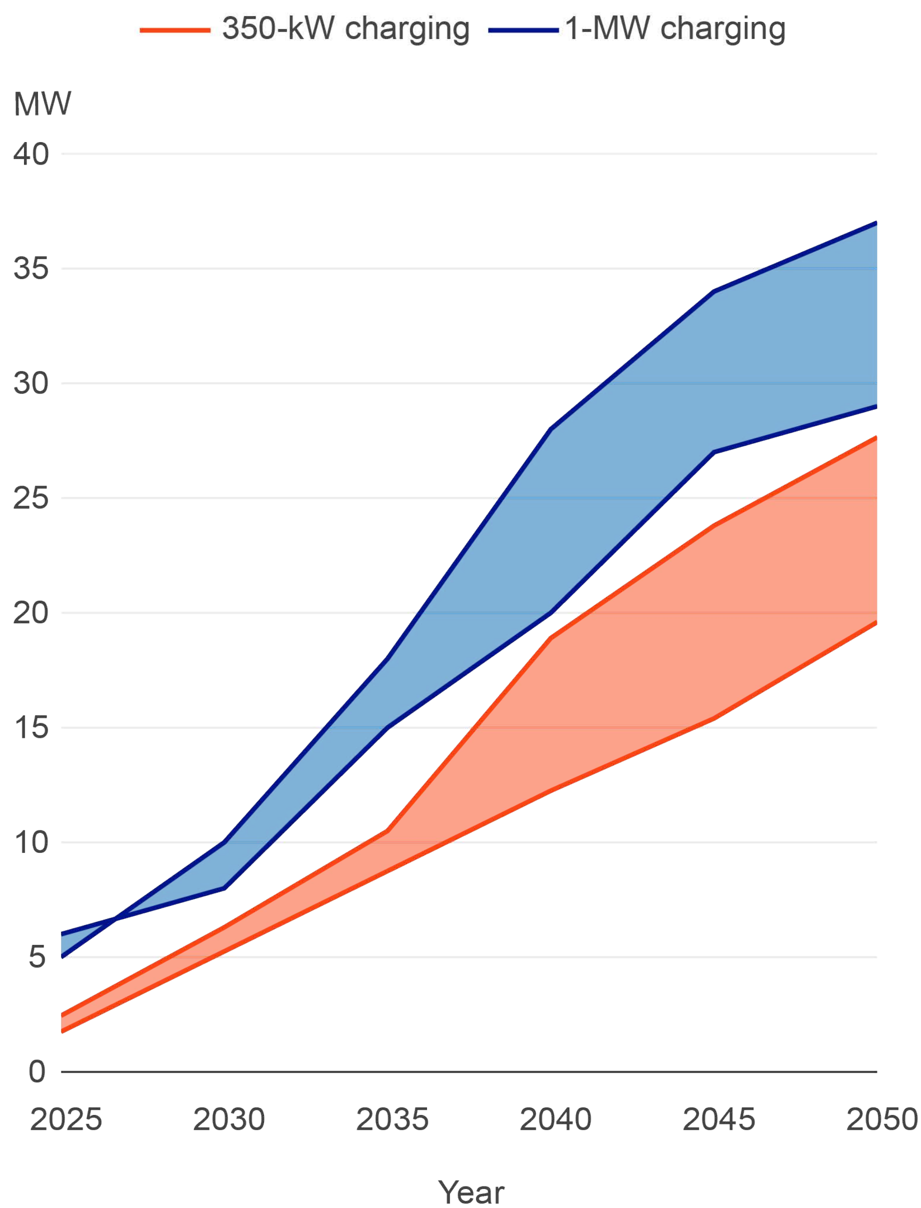
At the Large Passenger/Truck Stop site, MHDV demand will peak during the weekday afternoons, with high loads present from 1:00-9:00 p.m. MHDV demand is considerably lower over the weekend (Figure 13).

Figure 13. Large Passenger/Truck Stop MHDV Load Curve Variation in 2035



As soon as 2035, the two neighboring service plazas that comprise the Large Passenger/Truck Stop site will require 30 350-kW chargers to meet peak charging demand, resulting in 10.5 MW of charging capacity between the two service plazas. The base scenario is the upper bound of the area in orange in Figure 14, as opposed to the lower bound in the LDV analysis. MHDV charging capacity requirements continually increase for many sites as MHDV adoption ramps up later than LDV adoption.

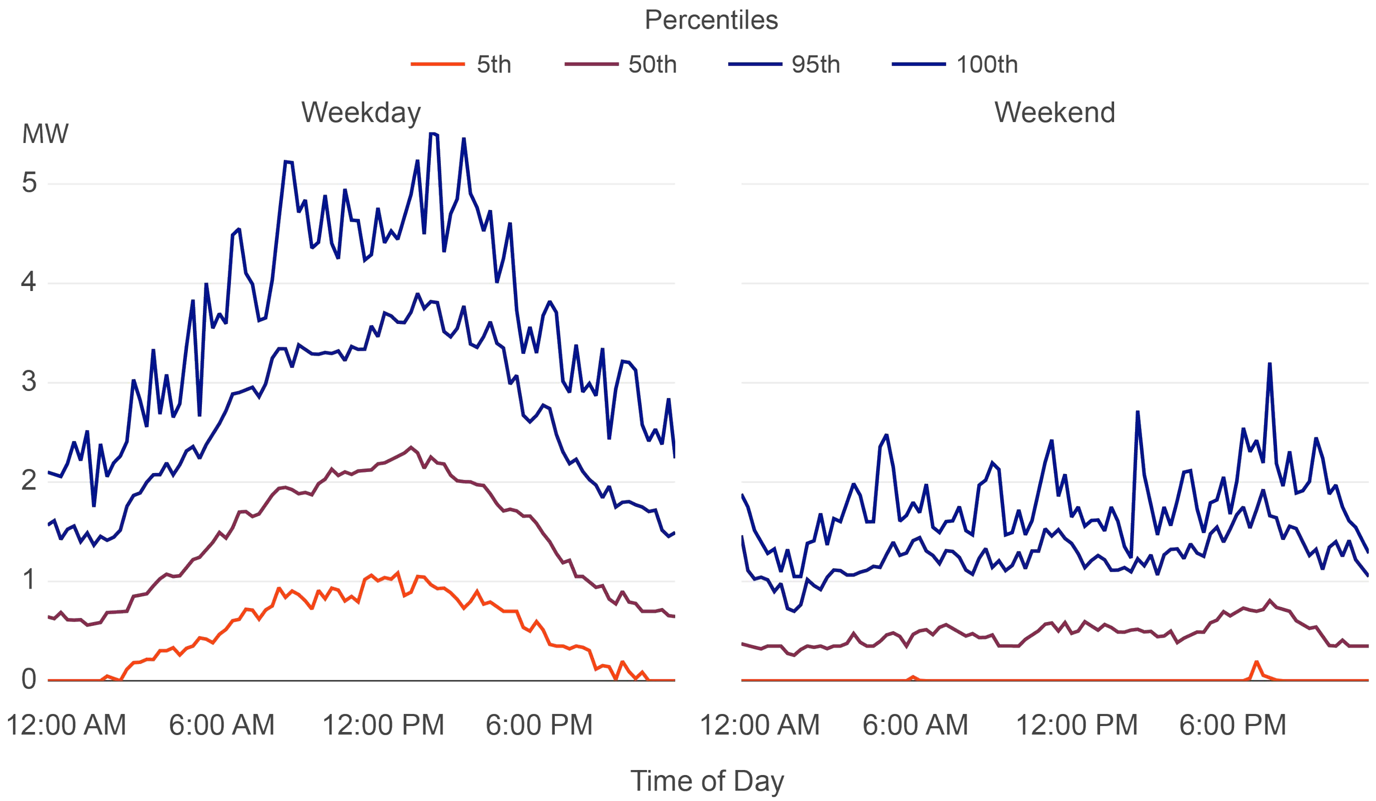
Figure 14. Large Passenger/Truck Stop MHDV Capacity Needed to Meet Annual MHDV Peak Demand



Mixed Use Plaza

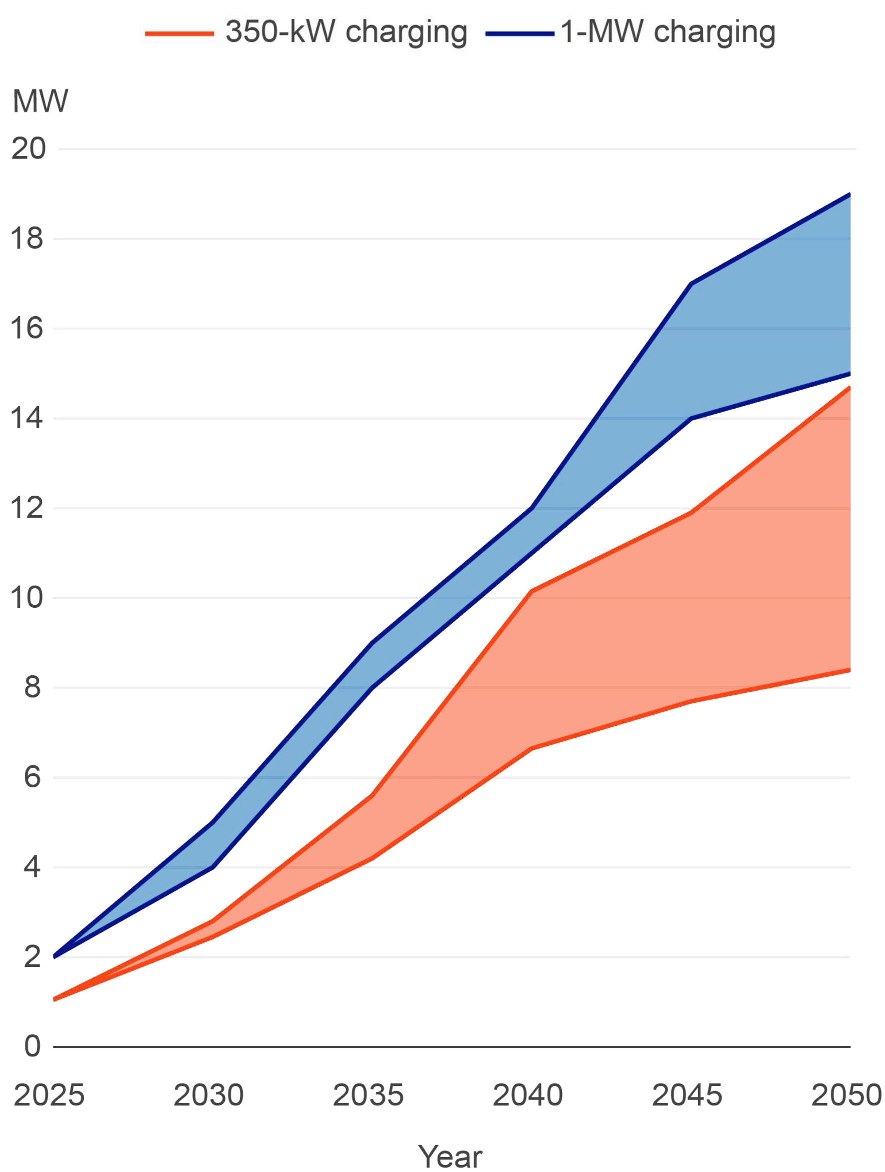
At the Mixed Use Plaza site, MHDV load curves are smoother throughout the day, with little variation between 8:00 a.m. and 4:00 p.m. MHDV charging demand is lower and fairly constant over the weekend (Figure 15).

Figure 15. Mixed Use Plaza MHDV Load Curve Variation in 2035



As soon as 2035, the Mixed Use Plaza site will require 5.6 MW of power, or 16 350-kW chargers, to meet MHDV charging demand (Figure 16).

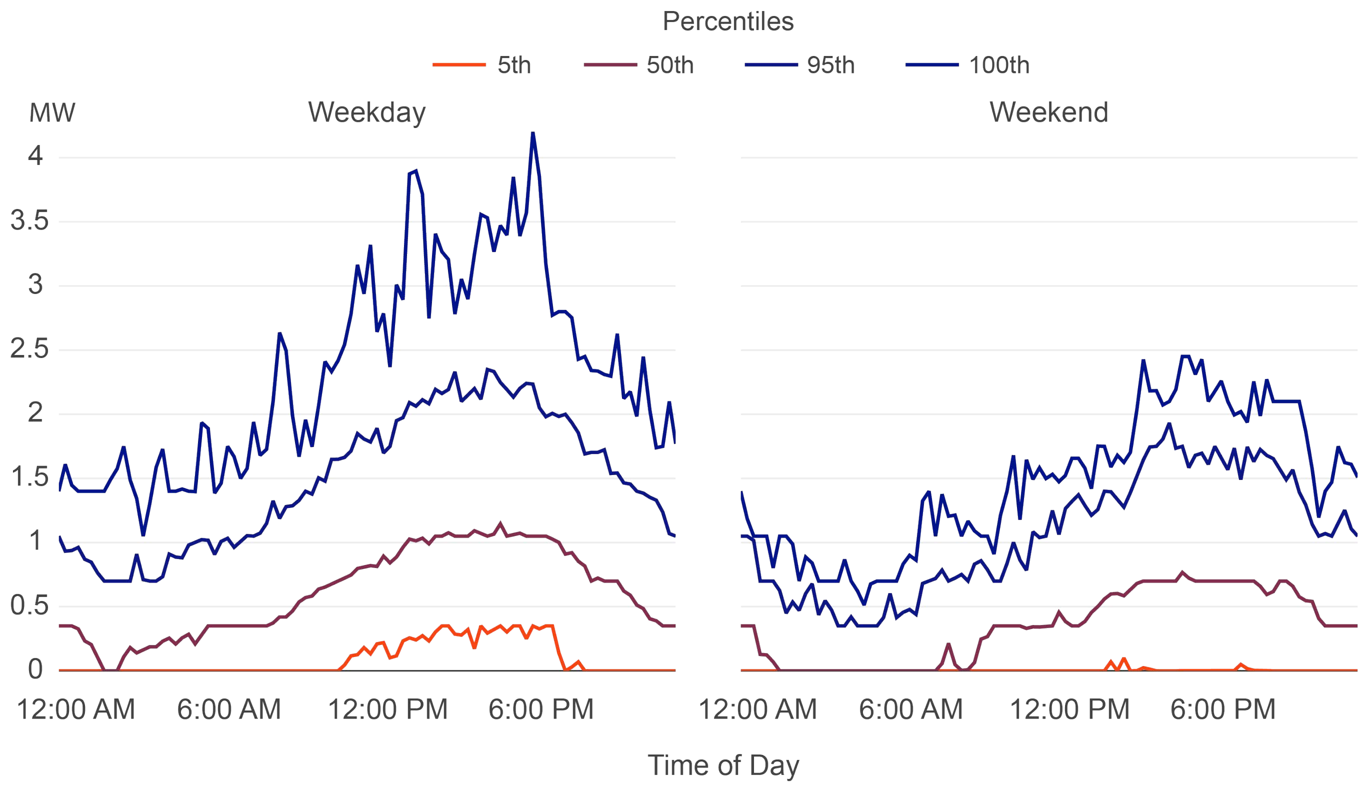
Figure 16. Mixed Use Plaza MHDV Capacity Needed to Meet Annual MHDV Peak Demand



Passenger Plaza

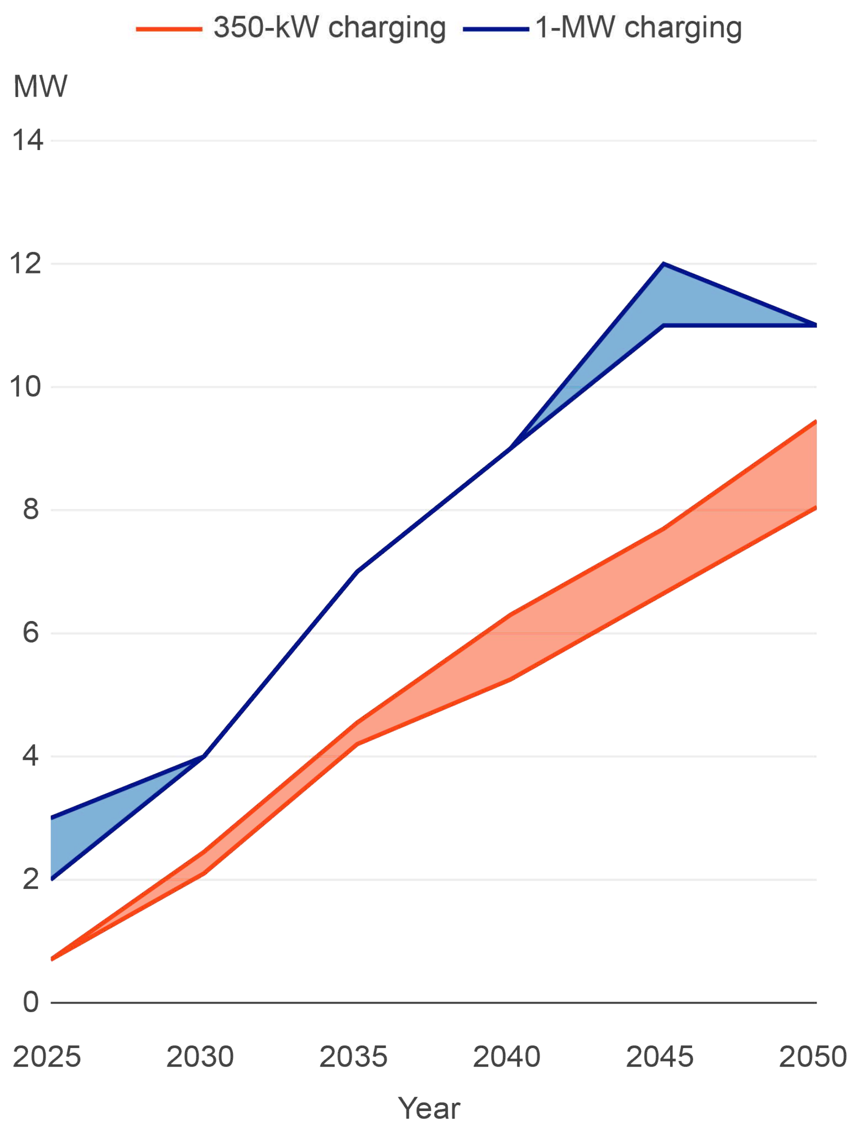
At the Passenger Plaza site, MHDV demand will peak on weekdays between 1:00-7:00 p.m. (Figure 17).

Figure 17. Passenger Plaza MHDV Load Curve Variation in 2035



As soon as 2035, the Passenger Plaza site will require over 4 MW of power to meet charging demand (Figure 18). This scenario would require installing at least 12 350-kW chargers for MHDVs by 2035.

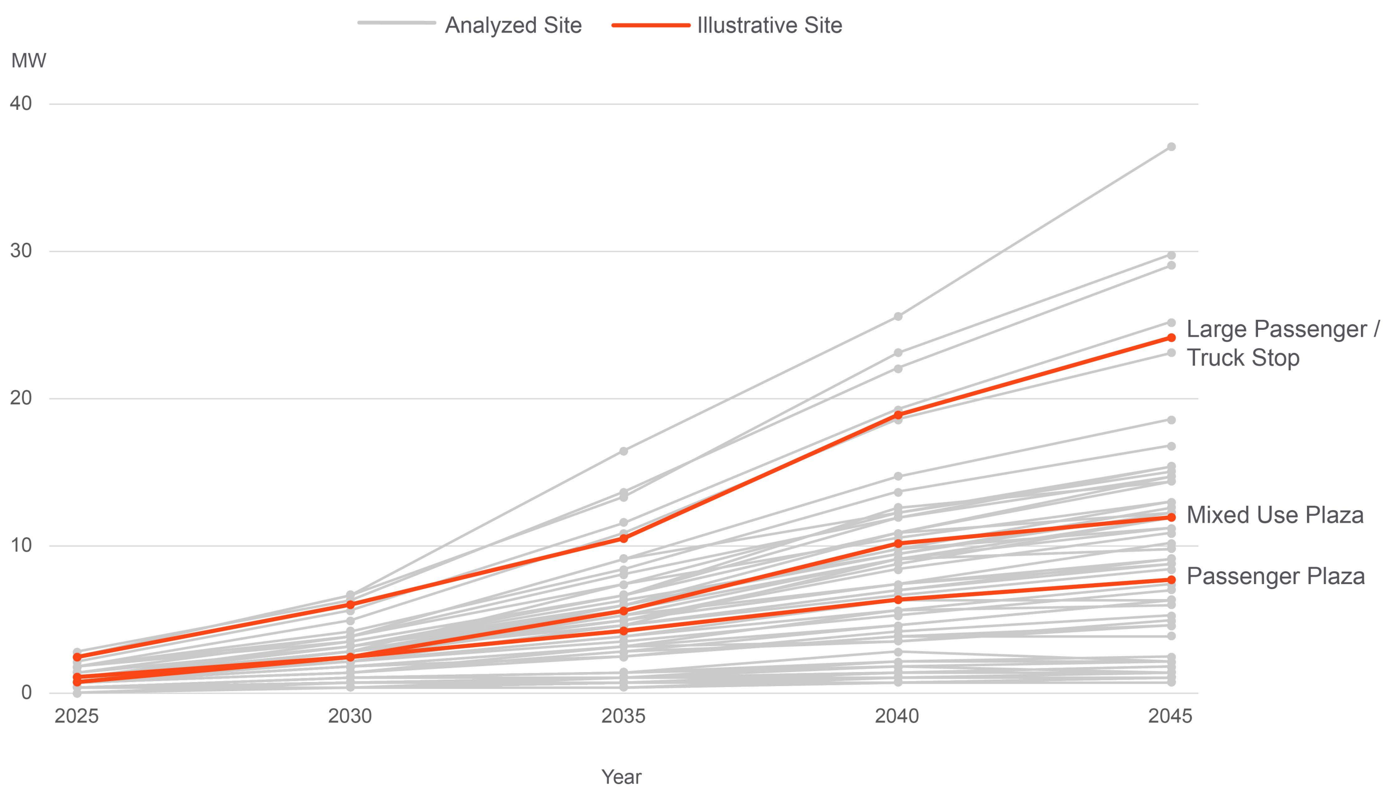
Figure 18. Passenger Plaza MHDV Capacity Needed to Meet Annual MHDV Peak Demand



Overall Medium- and Heavy-Duty Capacity Results

Across all 71 sites, MHDV results show that required capacity in 2025 will be comparatively low, with only a handful of sites requiring more than five 350-kW chargers to service MHDV demand. However, after 2030, steep increases in required capacity occur: at the Large Passenger/Truck Stop site, demand increases by roughly 10 MW a decade, requiring close to 70 chargers by 2045 (Figure 19).

Figure 19. Capacity Required to Meet Annual MHDV Peak Demand at Each Site

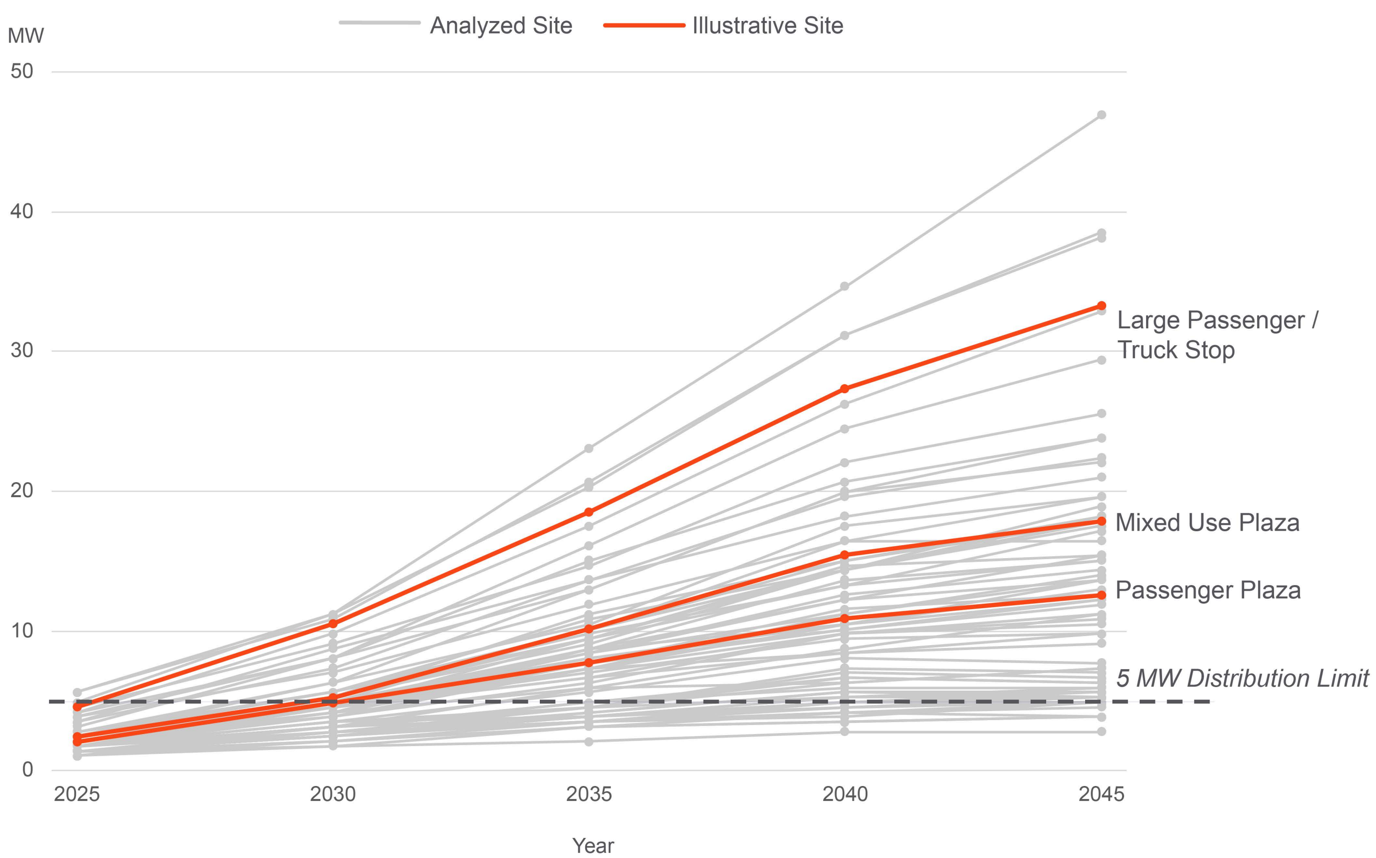


While LDV traffic will generate demand in the near term and could trigger initial interconnection upgrades, over the long term MHDVs will drastically increase the required capacity at many sites and much faster than may be expected—highlighting the importance of preparing for MHDV charging sooner rather than later.

Combined Results

Combining expected peak demands from LDVs and MHDVs helps to illustrate the total fast-charging capacity required at each site (Figure 20).[33] In New York, National Grid considers alternatives to distribution voltage connections for site-level demand exceeding 5 MW.[34] The results show that as soon as 2030, over a quarter of the 71 sites studied are expected to require charging capacity beyond this threshold—some sites could reach almost 40 MW of charging capacity by 2045, a level of power equivalent to that demanded by a major manufacturer. These results indicate that transmission interconnections will likely be needed to satisfy demand at many sites.

Figure 20. Capacity Required to Meet Annual LDV and MHDV Peak Demand at Each Site

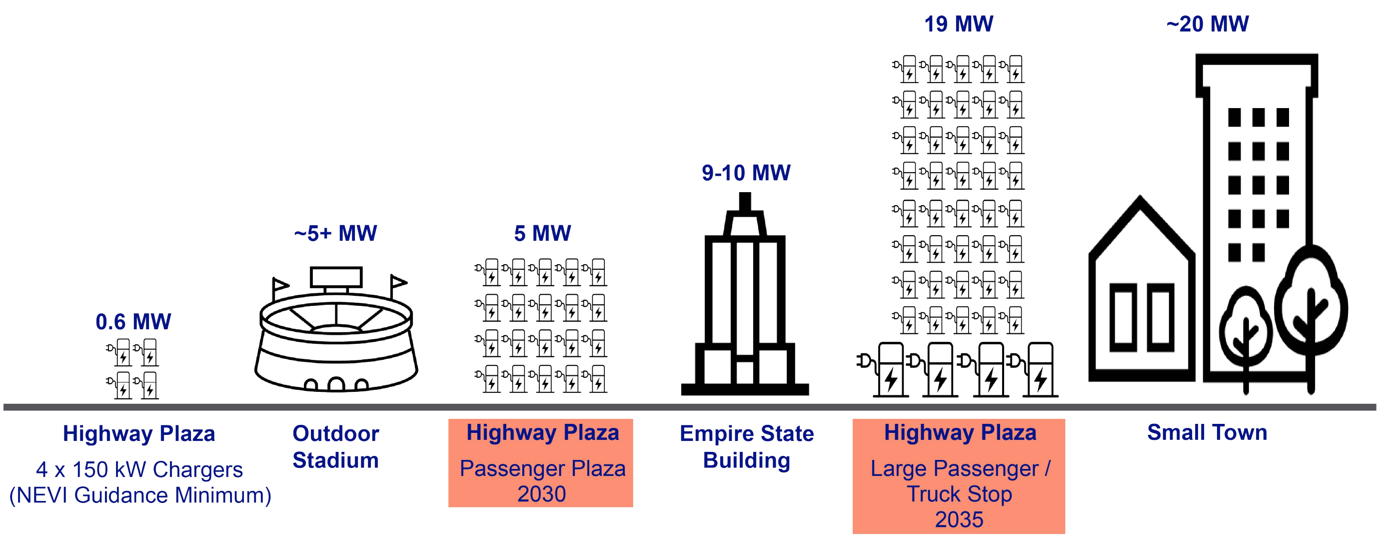


IV. Conclusion and Implications

A typical highway site will eventually need 20+ fast-chargers to serve expected traffic. As a result, these sites will see drastic increases in power demand compared to usage today. Highway charging sites will bring about significant electric loads. At many sites, these loads will begin to exceed distribution line capacity in the next 5-10 years.

For perspective, the Mixed Use Traffic Plaza and Passenger Plaza will each require about 5 MW of charging capacity by 2030—about the amount of power used by an outdoor professional sports stadium. By 2035, the nameplate charging capacity required at the Large Passenger/Truck Stop site will be roughly equivalent to the electric load of a small town (Figure 21). Note that the other large energy users' loads depicted in the figure below are approximate based on a range of loads.

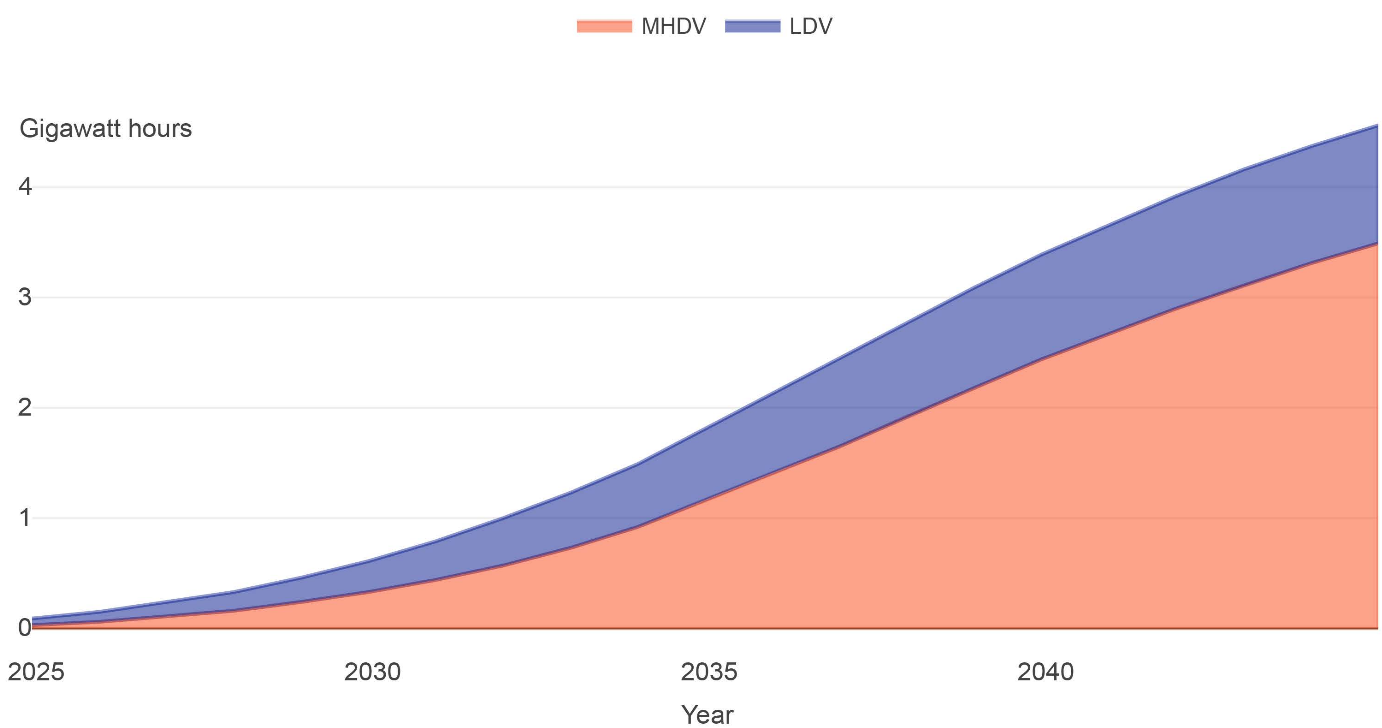
Figure 21. Comparative Peak Loads for Illustrative Sites and Other Major Users[35]



While LDVs will drive load increases in the near term, MHDV electrification will magnify charging needs over the mid to long term. As of June 2022, the United States had more than 2.7 million electric LDV registrations.[36] For comparison, as of June 2022, 1,895 electric trucks were registered in the country.[37] As a result, LDV charging demand will likely be a focus of site operators and policymakers in the near term, and LDVs will account for a large portion of total energy demand across highway sites.

However, it is important to plan for MHDV electrification today. Based on these results, MHDV electric demand will increase much quicker than may be expected. Some of the sites we analyzed required 5 MW of charging capacity for electric trucks *alone* by 2030. In fact, MHDV charging demands will exceed those of LDVs: by 2045, electric MHDVs will require over three-quarters of total energy demand at the 71 highway sites (Figure 22).

Figure 22. Average Daily Energy Demand Across All Sites



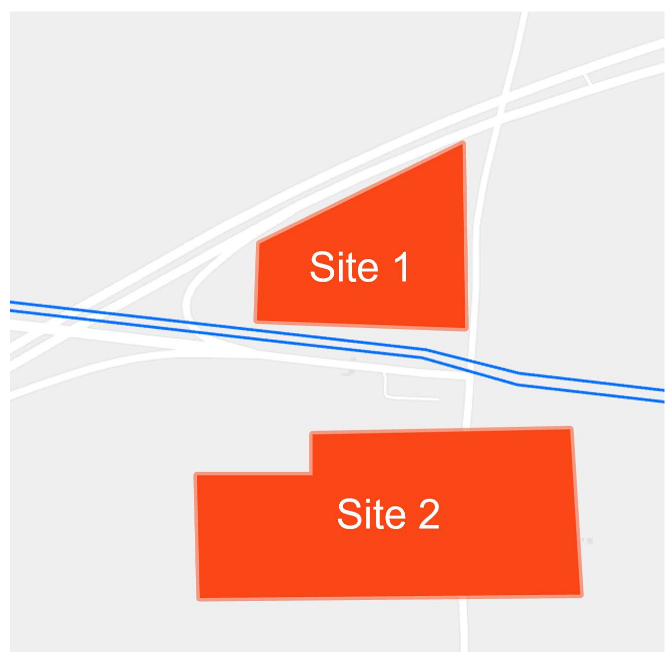
Through the NEVI program, the federal government is allocating funding to states to establish the beginnings of a national fast-charging network on major travel corridors. State policymakers should take the time today to plan charging infrastructure for both electric LDVs and MHDVs. Selecting sites that could host both LDVs and MHDVs will reduce the need for redundant interconnection infrastructure and create opportunities to future-proof infrastructure at high-demand sites. Considering MHDVs in highway fast-charging planning now will also allow policymakers to provide market certainty for MHDV manufacturers and businesses that are considering converting their fleets to EVs.

This study's results demonstrate the importance of involving electric utilities in state and federal planning for highway charging deployment. By doing so, utilities and site operators can implement electric infrastructure that serves not only the immediate load at a site but the ultimate charging needs, which could be more than 50 times the charging capacity (four 150-kW chargers) required under the NEVI formula funding guidance.

Anticipated levels of demand will require transmission interconnection at many highway fast-charging sites. As shown in Figure 20, over a quarter of the sites studied will cross the 5-MW charging capacity threshold as soon as 2030. Sites begin to resemble small towns or even industrial manufacturers in terms of their electric demand. At a certain threshold, highway fast-charging sites will require interconnection to the high-voltage transmission system.

Transmission interconnections are well-suited for highway charging applications, as they can provide sufficient electrical capacity to satisfy all charging needs for decades to come. The transmission system often overlaps with highways, providing an opportunity to efficiently facilitate this interconnection. The sites detailed in this report are all within about one-third of a mile from existing transmission lines. Figure 23 depicts an example of one location (not previously discussed) with two large charging sites adjacent to each other; two transmission lines run between them. It may not be feasible to extend the transmission network to every site, particularly in locations where there would be impacts to local residents and the environment, but there are opportunities for minimal extensions or taps of transmission lines to many highway charging locations.

Figure 23. Example Interconnection Location with Two Large Charging Sites



Additionally, connection to the transmission system offers resiliency benefits: transmission lines are the least likely to go out and the first to be restored after a power outage. Implementing these capacity-creating upgrades can allow utilities to address the needs of multiple nearby sites at once. For example, truck stops that are situated next to each other (on opposite sides of the highway), or highway service plazas and fleet depots located in the surrounding area, could share the benefits of newly created capacity.

Where feasible, we should bring chargers to the higher capacity wires that already overlap with the highway system. This analysis highlights that access to electric infrastructure is a critical factor—along with traffic, expected utilization, and access to suitable land—in the identification of high-priority fast-charging sites. Placing charging demand where the electric grid can easily accommodate it will provide significant cost savings to operators (and thus drivers) and minimize roadblocks to site development. Some existing service plazas and truck stops are very close to substations and transmission infrastructure; new plazas have an opportunity to guarantee proximity to high-capacity grid infrastructure.

Utilities have historically been in a reactive position, responding to customer requests wherever new demand may appear. Here, there is an opportunity to steer electric demand to the most intelligent locations for long-term growth. By strategically planning for highway charging, we can guide electric demand where it makes the most sense for commerce, communities, and our electric network.

Build the grid infrastructure once, and build it right. High-voltage infrastructure takes years to develop, which is why it is so important to take a long-term view when planning for expected charging demand. At high-traffic sites, a series of small, distribution-based upgrades will likely result in stranded costs, since that infrastructure would eventually need to be replaced with a transmission interconnection to meet driver needs. If we prioritize short-term needs over the long-term need, we risk a situation where site operators—and drivers—have to wait years for upgrades to grid infrastructure before new chargers can be installed, which could frustrate drivers and negatively impact confidence in EV charging.

At many sites, a transmission interconnection will likely be needed in the next 10 years to serve LDVs alone. By taking future charging growth from LDVs and MHDVs into account when implementing these solutions, we can future-proof sites to not only meet growing demand for charging but accelerate charging deployment at strategically selected no-regrets sites.

The electric highway future is happening now. As discussed, the timelines required for grid infrastructure upgrades, particularly transmission, are much longer than those required for EV supply equipment installation. If many sites will see transmission-level loads in the next 5-10 years, it is imperative to get ahead of the demand and begin planning for those upgrades now.

By deploying these no-regrets upgrades at no-regrets sites, we can ensure that the electric grid becomes an enabler—even an accelerator—to the EV transition.

Appendix A: Methodology

Light-Duty Vehicle Methodology

The LDV assessment for this study was led by Stable Auto. Based on the data sources and sales scenarios detailed above, we derived projected load curves for each site by simulating charging loads for each 15-minute window within the entire study period.

There were two primary parts to the simulation. First, the ML model predicted the average number of charging events expected to occur in any given 15-minute window in a day. Second, a simulated charging station took the number of charging events as an input to determine utilization, energy, and power requirements.

The ML model inferred the expected number of charging events by comparing 2.5 years of charging data from more than 3,000 DCFCs to location-specific attributes such as traffic, demographics, competition, time of day, and many more. Capacity constraints were considered to ensure that charging sessions could be accommodated by an available simulated charger.

We derived the duration and power of simulated charging events from a combination of vehicle specifications such as battery capacity and charging rate, driving characteristics such as expected state of charge (SOC) upon arrival, and charger specifications such as charging rate.

We sampled session power for each simulated charging event from a dataset of maximum charging rates for all BEV makes and models on the road today, further constrained by the maximum output power of chargers at each location.

We calculated session duration for each charging event by sampling from a dataset of battery capacities and maximum charging rates for all BEV makes and models on the road today, limited by the maximum output power of the chargers at the location, and assuming a constant SOC change during charging sessions. A constant SOC change adequately captured the behavior of charging events because there was no clear relationship in Stable Auto's dataset between session duration and charger power output. The average length of charging sessions today is observed to be approximately 30 minutes.

In the forecast, maximum charging rates and battery capacities grew year-over-year. The average maximum charging rate of BEVs was assumed to grow at 10% year-over-year, starting at 75 kW in Year 1. We calculated the forecasted length of charging sessions from the maximum session power and battery capacity in each year and assumed that drivers will seek to maintain a consistent SOC change, as noted previously.

All chargers in this analysis were assumed to have nameplate capacity of 350 kW. Maximum charge rate in the future was capped at 350 kW.

Site loads and needed charger deployments were calculated by simulating unconstrained charging events at each site. The number of chargers at each site was an input to the original ML model, so this value was fixed for the duration of the forecast. To obtain a projection of expected load unconstrained by the number of available chargers, each candidate site was assigned a number of chargers (20, 30, or 40) that was well in excess of the demand that would be expected today; not all chargers are expected to be used immediately. These resulting loads informed the number of chargers needed in each future time period to meet drivers' charging needs.

As the number of EVs on the road increases, the number of public chargers will also increase to meet demand. Stable Auto's models used the ICCT EV charger forecast to model how charger deployment will grow nationally. New demand for charging from increased EV adoption was assumed to be evenly distributed among National Grid's sites and third-party competitive networks. Third-party sites were considered to be competing for demand with a candidate site if they were located within a 1,000-meter radius.

For each LDV scenario, we provided two predictions to demonstrate the upper and lower bounds of predicted utilization. The primary source of uncertainty was the growth rate of EV sales. To take this uncertainty into account, we added a +30% confidence interval to the EV sales forecast. The optimistic utilization predictions were derived from the upper bound of the confidence interval (i.e., higher than expected EV sales). The expected utilization predictions were derived assuming no added confidence interval. The standard scenario was defined as 100% EV sales by 2035 with expected charger utilization.

Medium- and Heavy-Duty Vehicle Methodology

The MHDV assessment was led by RMI. Based on the data sources and scenarios detailed above, projected load curves were derived for each site by simulating charging loads for each 15-minute window within the entire study period. To do so, we randomly selected a number of charging events to occur in a 15-minute window. The number of stops was assumed to follow a Poisson distribution, with the expected number of stops set by the number of stops longer than 10 minutes in the Geotab ITS data for the hour containing the 15-minute window, scaled according to vehicle population projections detailed above. Similar to the light-duty analysis, results may have varied slightly between different runs of the model due to randomness built into the simulation. By focusing on actual ICE vehicle behavior, EVs were assumed to continue to operate identically to how ICEs operate today. This approach implicitly assumed that EV supply equipment (EVSE) will be deployed to meet charging demand at all sites that currently draw MHDV stops. If EVSE is deployed only at a subset of these locations, greater demand would be expected at each location with EVSE.

To first scale from the Geotab ITS data to the entire MHDV population in 2021, we used observed traffic counts conducted by the New York DOT at 14 locations along major roadways in New York, which we compared to MHDV traffic counts at the same locations in the Geotab ITS data.[38] On average, Geotab ITS data represented 6.86% of all MHDV traffic, so we multiplied stop counts in the Geotab ITS data by a factor of 14.6 to estimate total MHDV stop counts in 2021.

Each EV stop (longer than 10 minutes) was assumed to result in a charge. If drivers choose not to opportunistically charge during shorter stops or after short-distance trips, greater energy demand per charging event could be expected, as well as a shift of demand from periods of the day with shorter average stops (mid-day) to periods with longer average stops (evening).

For each stop that resulted in a charge, the study randomly assigned a distance value to the trip ending in the stop and a duration of the stop. The distribution of trip distances and stop durations was assumed to follow a lognormal distribution with parameters matching those in the Geotab ITS data for that time window. Based on these values, two charge time variations were explored: a time-constrained scenario and an unconstrained scenario. The time-constrained scenario limited the charge duration to the distribution of dwell times observed in the Geotab ITS data. The unconstrained scenario allowed vehicles to dwell as long as needed to recharge energy depleted in the trip leading to the stop at the candidate site.[39] Energy demand associated with each stop was calculated by assuming energy consumption rates of 2.5 kWh/mile for HD vehicles and 1.3 kWh/mile for MD vehicles.[40]

In addition to charge time variations, we examined two charger power variations: 350 kW and 1 MW. It is not yet clear which power rating will be most prevalent as MHDV electrification evolves. Early MHDVs have been limited to 350-kW charging, while 1-MW (or even greater) charging will likely be the norm for long-haul Class 8 truck charging in the future.[41] Regardless of vehicle capabilities, lower-cost 350-kW charging may still be preferable to 1 MW when higher power levels are not necessary.

For each power rating, we calculated the power demand per 15-minute window until the energy need was met or the stop ended. We then determined how many chargers of the specified power rating were required to satisfy demand. The number of required chargers was rounded up to the nearest whole number. Considering the two charge time scenarios and two charger power scenarios, the MHDV assessment included four permutations in total. The standard scenario was defined as 100% EV sales by 2045, time-unconstrained charging, and 350-kW charger power.

Endnotes

[1] Limits for distribution interconnection are system dependent. For example, in National Grid's New York territory, the typical load limit for a distribution interconnection is 5 MW. This limit could be higher in New England and other utility territories.

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