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Mind the gap

An assessment of 2030 and 2035 charging infrastructure needs for zero-emission medium- and heavy-duty vehicles in the United States

HAMILTON STEIMER, JAKOB SCHMIDT, YIHAO XIE, ARIJIT SEN, AND RAY MINJARES

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International Council on Clean Transportation
1500 K Street NW, Suite 650
Washington, DC 20005

communications@theicct.org | www.theicct.org | @TheICCT

EXECUTIVE SUMMARY

The zero-emission medium- and heavy-duty vehicle (ZE-MHDV) market in the United States continues to grow, with nearly 1,400 units sold during the first half of 2024. As this market develops, the charging network will have to expand to keep pace with the growing energy needs of ZE-MHDVs on the road. There has already been considerable investment in charging infrastructure for these vehicles: According to one estimate, as of early 2024, $30 billion in public, private, and utility financing had been announced or made available to build charging infrastructure for ZE-MHDVs (Lepre, 2024). Continued investment and supportive policies have contributed to the development of ZE-MHDV markets in first-mover states like California, and there are dozens of large-scale charging infrastructure projects currently underway or planned across the country.

Early market trends indicate a need for further investment in grid distribution capacity to support the growing network of high-powered chargers required for ZE-MHDVs, especially as other economic sectors also electrify. Experience from California shows that charging facility energization timelines can span multiple years due to lengthy upstream grid infrastructure upgrades. Modeling tools like the ICCT's HDV CHARGE model can be used to help electric utilities, charging infrastructure providers, and fleet operators plan by projecting where, when, and how much charging infrastructure will be needed to support ZE-MHDVs.

In May 2023, we published our first national near-term charging infrastructure needs study for Class 4–8 ZE-MHDVs, projecting charging needs for 2025 and 2030 at the state and county levels based on the near-term development of the zero-emission vehicle (ZEV) market. The analysis also included insights from industry stakeholders about existing challenges and potential solutions for deploying sufficient charging infrastructure to meet future ZE-MHDV demand.

This report updates our 2023 analysis. We apply revised technology and charging behavior assumptions to produce charging estimates at the state and county levels for 2030 and 2035 under three policy scenarios—Reference, Compliance, and Market Potential—that reflect low, moderate, and high levels of ZEV adoption. Our study identifies regional hotspots expected to experience the greatest infrastructure demand from ZE-MHDVs.

Table ES1 presents the modeling results at the national level under each policy scenario.

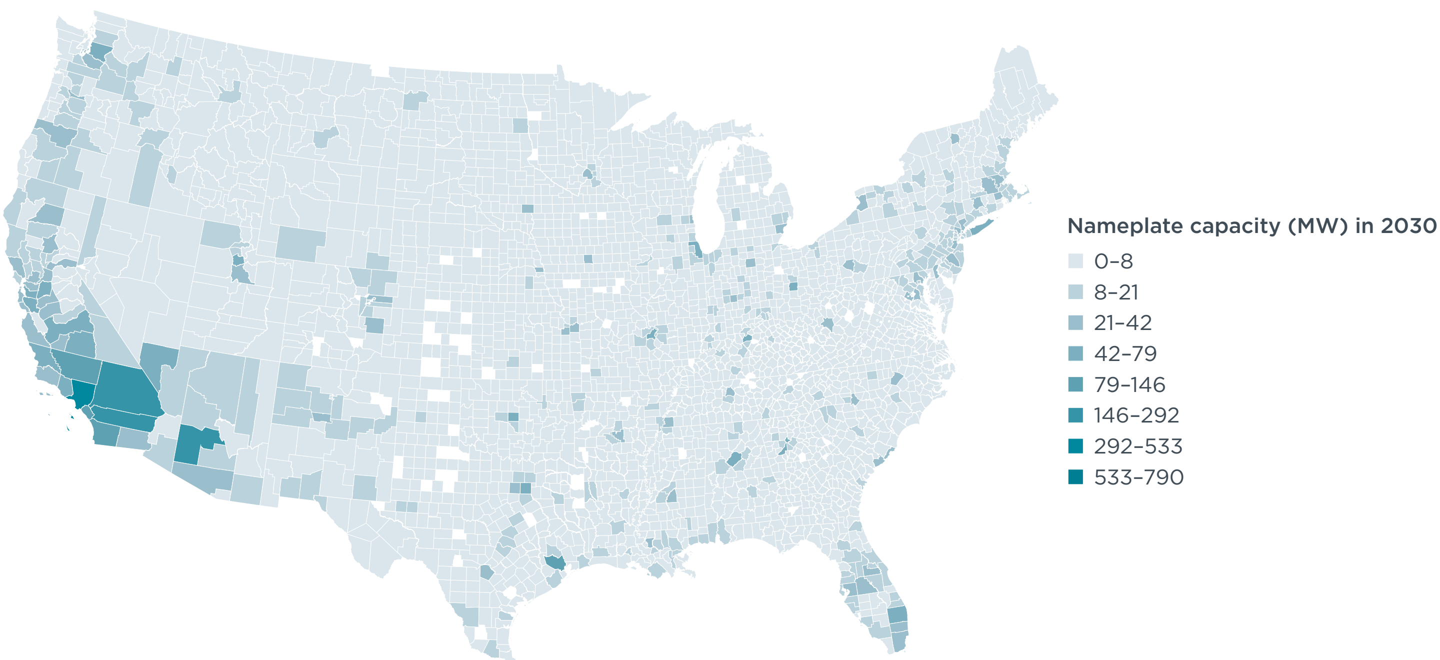
Table ES1
National-level charging infrastructure modeling results (2030 and 2035)

Output	2030			2035		
	Reference	Compliance	Market Potential	Reference	Compliance	Market Potential
Electric vehicle kilometers traveled (eVKT; thousands)	37,700	54,200	148,000	106,000	204,000	363,000
Daily energy consumption (MWh)	26,900	40,600	120,000	70,900	151,000	284,000
Nameplate capacity (MW)	9,500	13,200	33,900	20,900	40,600	70,500
Number of overnight chargers	128,000	171,000	410,000	332,000	565,000	929,000
Number of fast chargers	4,170	5,540	11,700	8,100	13,100	19,400
Number of ultrafast chargers	2,450	3,300	7,580	4,350	7,840	11,700
Total number of chargers	134,000	180,000	429,000	344,000	586,000	960,000

Note: Results rounded to three significant figures.

Intuitively, charging demands increase with higher ZEV adoption. By 2035, in the Compliance ZEV uptake scenario, an estimated 586,000 chargers are needed across the country, approximately 565,000 (96%) of which are overnight chargers. Based on our modeling assumptions, lower-powered overnight chargers are expected to be the dominant charger power level in all three scenarios, but fast and ultrafast charging will also be important, especially for public en route charging. Figure ES1 displays the expected county-level nameplate capacity under the Compliance scenario—that is, assuming a moderate level of electric truck adoption—in 2030.

Figure ES1
National charger nameplate capacity under the Compliance scenario (2030)



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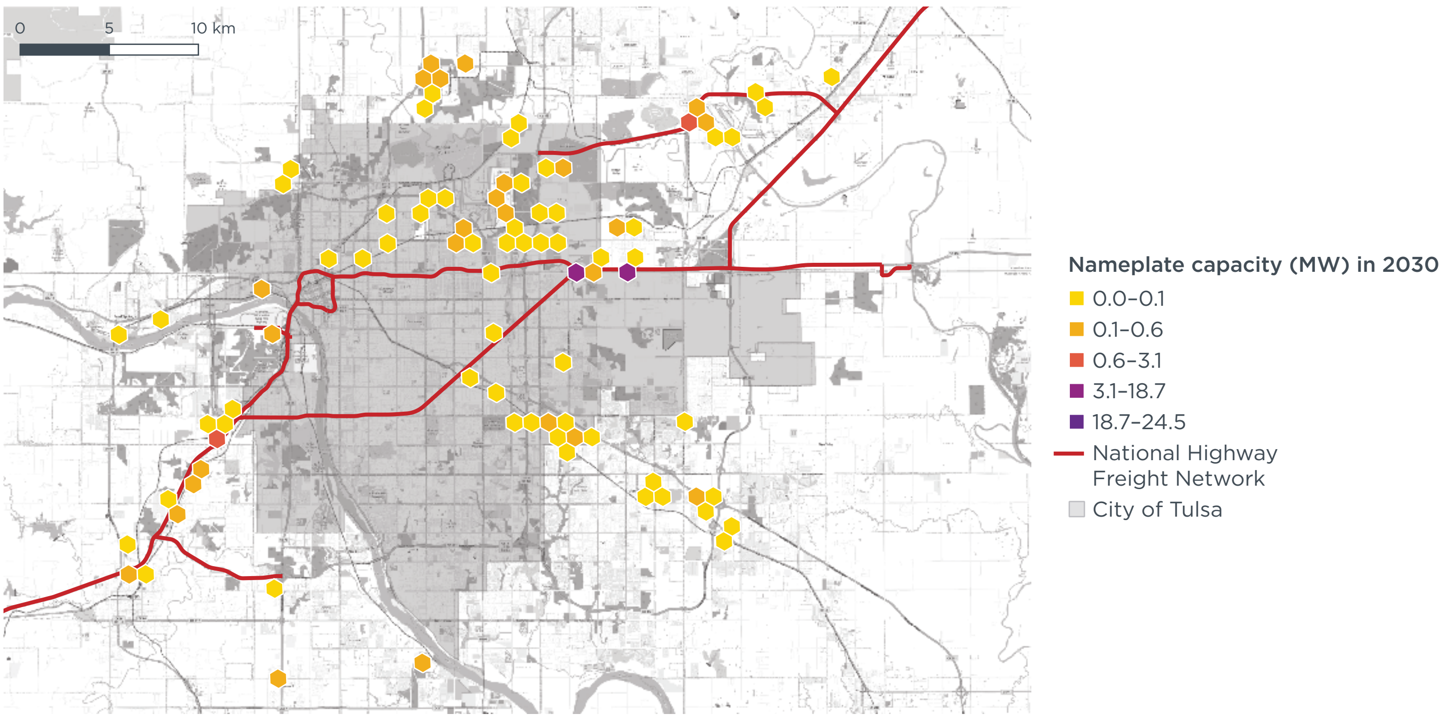
With information on commercial real estate properties and private truck stops, we determined proxy charging locations to estimate charging needs at the hex-8 (0.28 square mile) scale. This resolution is useful for system planners to assess the capacity and readiness of nearby distribution grid infrastructure. As an example, Figure ES2 displays our Compliance scenario results for Tulsa, Oklahoma, which is in a county ranking in the top 5% in terms of projected ZE-MHDV energy consumption. Without a national dataset of bus and refuse truck depots, we show results only for single-unit and combination trucks. For these two vehicle segments, we estimate a daily energy need of 70 MWh in 2030, increasing to 283 MWh by 2035. These trucks will thus require 278 total chargers with a nameplate capacity of 23 MW in 2030 and 1,034 chargers with a nameplate capacity of 80 MW in 2035.

Figure ES2

Charger nameplate capacity in Tulsa, Oklahoma, under the Compliance scenario (2030)



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As MHDV electrification accelerates after 2030, the growing ZE-MHDV population will contribute to increasing energy demands on the grid. Given long lead times for upstream grid infrastructure upgrades, electric utilities and regulators should anticipate future MHDV electrification and assess the preparedness of their local electrical grids. Modeling tools like HDV CHARGE can help electric utilities and regulators determine likely charging needs, assess where grid upgrades are needed, and identify cost-effective investments.

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INTRODUCTION

The zero-emission medium- and heavy-duty vehicle (ZE-MHDV) market in the United States is steadily gaining momentum. Over 1,600 new ZE-MHDVs were registered in 2023, an 8-fold increase compared with 2021, and around 1,400 units were sold in the first half of 2024 (Xie, 2024). As operators have shown increasing interest in electrifying their fleets, there has been substantial private and public investment in the ZE-MHDV charging infrastructure network. By the start of 2024, an estimated $30 billion in public, private, and utility financing had been announced or made available through funding programs to support the deployment of ZE-MHDV charging infrastructure, largely in California and other first-mover states; dozens of projects are currently under development, and several have already been launched (CALSTART, 2024; Lepre, 2024; Vehicle Technologies Office, 2024).

Policymakers and industry stakeholders have recognized that the continued growth of the ZE-MHDV market will require the electrical grid to rapidly expand to meet the energy needs of electrifying fleets and their high-powered chargers. Upstream grid infrastructure upgrades to support load growth from ZE-MHDV charging require advance planning and construction, resulting in multi-year energization timelines. As they plan for continued fleet electrification, electric utilities, charging infrastructure providers, and fleet owners and operators would benefit from modeling tools that can project where, when, and how much charging infrastructure will be needed in the future.

In May 2023, we published our first report on the projected near-term energy and charging needs of ZE-MHDVs nationwide (Ragon et al., 2023). Building on methods first developed in Minjares et al. (2021), the study used our in-house charging infrastructure model, HDV CHARGE (Schmidt et al., 2024), to identify the top states and counties where ZE-MHDV energy and charging needs will be concentrated. The analysis included insights from utility, government, and automotive industry stakeholders describing challenges and options for enabling charging infrastructure deployment.

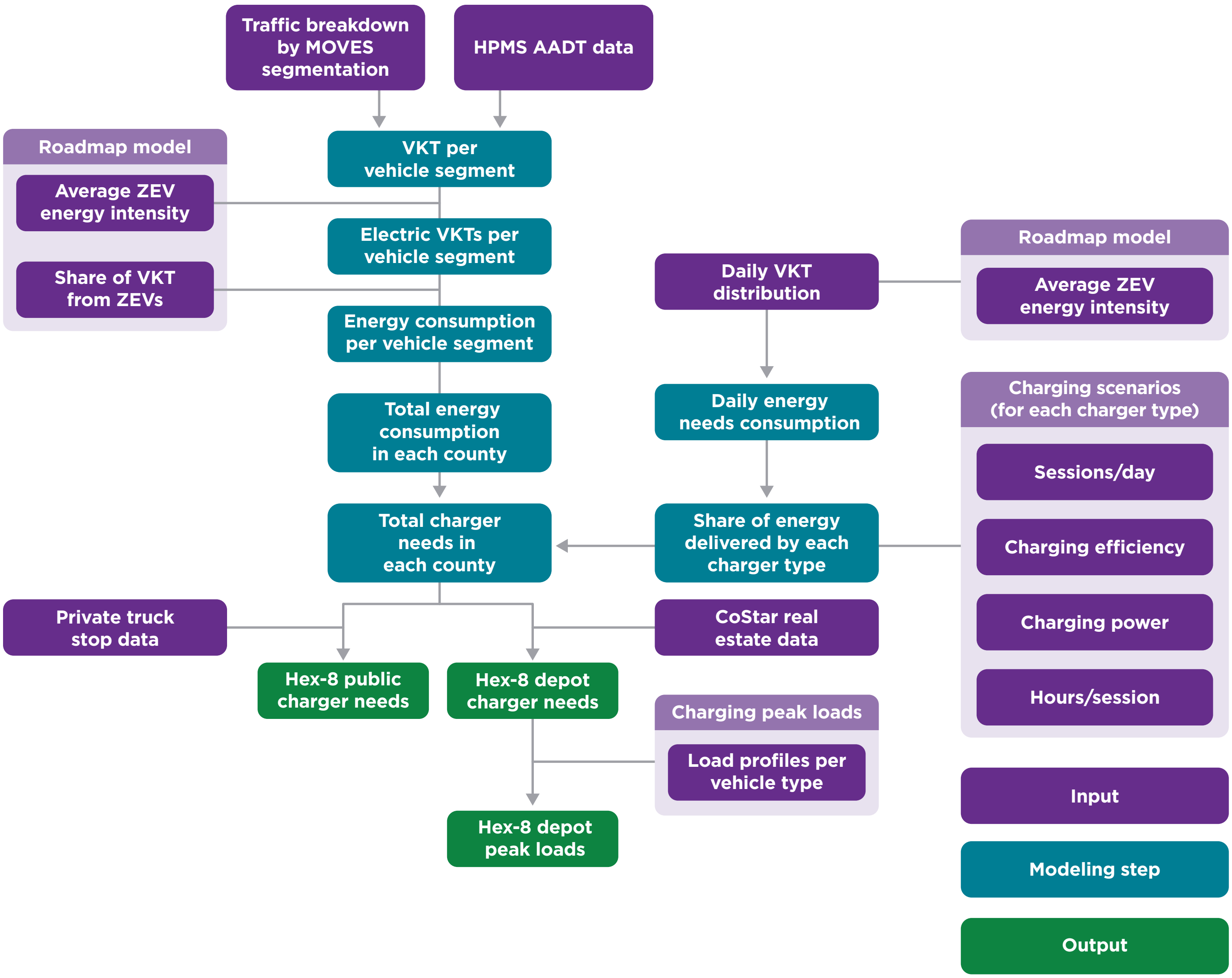
This report updates our May 2023 study, combining more recent public traffic data with refined vehicle and charging technology assumptions to identify where there will likely be significant demand for Class 4–8 ZE-MHDV charging infrastructure in 2030 and 2035. Our charging infrastructure projections are based on three ZE-MHDV policy scenarios—Reference, Compliance, and Market Potential—which reflect low, moderate, and high levels of ZEV adoption. With data on commercial real estate properties and private truck stops, we estimate where modeled charging infrastructure needs could be located at the hex-8 (0.28 square mile) level, a scale useful to help electric utilities identify where grid infrastructure investments may be needed.

The next section describes our modeling methods and presents our policy scenarios, traffic data sources, and technology and charging behavior assumptions. We also outline our process for mapping results at the hex-8 level and explain how we estimate potential peak loads in our analysis. We then share results at the national, state, and county levels under each scenario and highlight key findings such as projected energy consumption, nameplate capacity, and deployment of different charger types. Additionally, we illustrate our hex-8 mapping ability with results for Tulsa, Oklahoma, whose county is in the top 5% of all counties in terms of projected energy demand from ZE-MHDV traffic. Lastly, we discuss the limitations of this study and conclude with suggestions for further improvements to our modeling methods.

MODELING ASSUMPTIONS AND METHODOLOGY

Figure 1 shows a simplified diagram of our modeling approach. In the subsequent sections, we explain our methodology, including the use of HDV CHARGE, a customizable ZE-MHDV charging infrastructure model developed by ICCT in 2024 (Schmidt et al., 2024).

Figure 1
Diagram of our modeling approach



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POLICY SCENARIOS

We used the ICCT Roadmap model to project ZEV deployment and vehicle stock turnover for Class 4–8 ZE-MHDVs (Benoit & Alvarez, 2024). The Roadmap model estimates historical and projected vehicle population information and on-road emissions and can be used to model the impact of different policy scenarios on future vehicle technology adoption and emissions levels. Inputs to the Roadmap model, including energy intensities and vehicle sales, are harmonized with the U.S. Environmental Protection Agency (EPA)'s Motor Vehicle Emission Simulator (MOVES4) model and Heavy-Duty Technology Resource Use Case Scenario tool (EPA, 2023a, 2025).

We built three policy scenarios: Reference, Compliance, and Market Potential, which reflect low, moderate, and high levels of national ZE-MHDV deployment. The Reference and Compliance scenarios reflect two pathways for manufacturers to meet EPA's finalized Phase 3 greenhouse gas (GHG) emission standards for heavy-duty vehicles, which set increasingly stringent tailpipe carbon dioxide (CO_2) emission limits for Class 4–8 vehicles between model years 2027 and 2032 (EPA, 2024). In the Reference scenario, vehicle manufacturers can meet the emission standards through a mix of diesel vehicles, natural gas vehicles, hydrogen internal combustion engine vehicles, hybrid vehicles, and aerodynamic and tire-rolling-resistance improvements. In the Compliance scenario, which reflects the primary pathway toward meeting the final standards outlined in the regulation's accompanying *Regulatory Impact Analysis*, the emission standards can be met via moderate levels of ZE-MHDV adoption (EPA, 2024). The Market Potential scenario is an update to the sole ZE-MHDV deployment scenario modeled in Ragon et al. (2023) and reflects ambitious projections based on market developments and Inflation Reduction Act incentives.

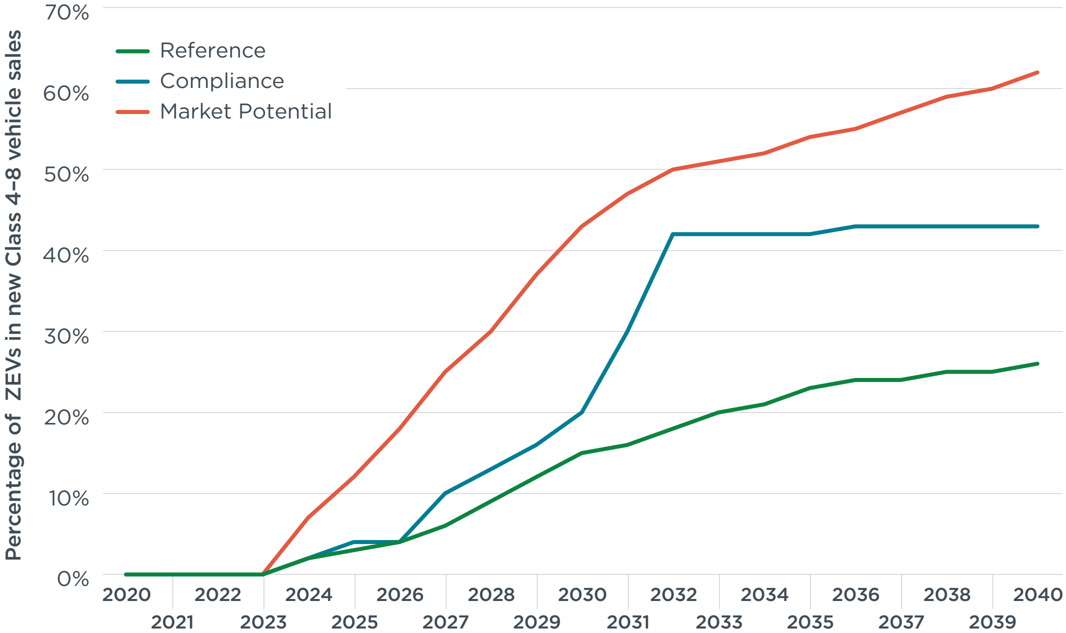
The Roadmap model aggregates the adoption rates from EPA's (2024) Phase 3 *Regulatory Impact Analysis* into the vehicle segments fed into HDV CHARGE. The Reference and Compliance scenarios assumed that states that have adopted California's Advanced Clean Trucks (ACT) rule are characterized by ACT-aligned ZEV adoption rates, which are higher than required by Phase 3 standards (Buysse & Sharpe, 2020).[1] The Market Potential scenario assumed more aggressive adoption rates fueled by ZEV tax incentives, which may supersede ACT market effects.

Figure 2 shows the sales-weighted average share of ZE-MHDVs in each scenario. ZEV sales shares directly shape the energy demand from the grid and charging infrastructure needs. We extend these policy scenarios to 2040 to model infrastructure needs across a longer time horizon.

1 States that have adopted ACT are California, Colorado, Maryland, Massachusetts, New Jersey, New Mexico, New York, Oregon, Rhode Island, Vermont, and Washington.

Figure 2

Sales-weighted share of ZE-MHDVs in the Reference, Compliance, and Market Potential scenarios



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The Market Potential scenario assumes an immediate and aggressive acceleration of ZE-MHDV sales, achieving approximately 1 million ZE-MHDVs on the road by 2030. The Compliance and Reference scenarios assume more gradual growth in the ZE-MHDV market; by 2030, the Compliance scenario projects over 400,000 electric trucks on the road nationwide, while the Reference scenario estimates almost 300,000. Table A1 in the appendix presents the ZE-MHDV population projections from the Roadmap model through 2035 for each scenario.

VEHICLE TRAFFIC DATA

We modeled energy consumption in HDV CHARGE based on segment-specific vehicle activity and technical assumptions such as daily vehicle kilometers traveled (VKT) and vehicle energy efficiency. We calculated total energy demand by analyzing annual average daily traffic (AADT) data acquired from the Federal Highway Administration's Highway Performance Monitoring System (HPMS). This publicly available traffic data can be converted into VKT for combination and single-unit vehicles and then apportioned to each vehicle segment, applying methods described in Appendix A of the ICCT's comments on EPA's proposed Heavy-Duty Engine and Vehicle Standards final rule (ICCT, 2022). Our VKT distribution was informed by data from the Federal Highway Administration (FHWA; FHWA, 2024a, 2024b).

This study used 2022 AADT data released in fall 2023 and determined the VKT performed by each vehicle segment on different road types to calculate vehicle energy demand in each state (U.S. Department of Transportation [DOT], 2021). Table A2 in the appendix displays how we determined each vehicle segment's VKT by road type, using New York state as an example.

CHARGING TECHNOLOGY AND BEHAVIOR ASSUMPTIONS

Table A3 in the appendix presents our assumptions on the charging power level and duration of overnight charging sessions used for this analysis. The duration of overnight charging sessions is based on the cumulative dwell time assumptions for each vehicle segment determined by Bruchon et al. (2024). Because these estimates reflect cumulative dwell times, they are likely upper-bound estimates of vehicle availability for lower-powered charging sessions. Bruchon et al. (2024) provides domicile dwell times for each 10th percentile, and we selected their 50th percentile estimate.

To determine overnight charging power levels, we first multiplied our battery capacity expectations for each vehicle segment (see Table A4 in the appendix) by an assumed power delivery of 85% of maximum power and a charging efficiency rate of 91.4%, which we held constant over time (Bruchon et al., 2024; Ragon et al., 2022). We then selected a power level capable of filling 100% of the vehicle battery during the dwell period, choosing between 19.2 kW, 50 kW, 100 kW, 150 kW, and 200 kW. We assumed a state of charge reserve of 20%, and these power levels were sufficient to meet fleet operators' assumed preference for vehicle battery levels at 100% at the start of their daily operations. Combination long-haul trucks were the one exception because their batteries are too large to be filled with an overnight charger under the assumed dwell time, which reflects their greater reliance on higher-powered chargers to meet their energy needs.

We limited fast and ultrafast charging sessions to 30 minutes each. Fast charging power levels were set at 350 kW, as this is usually considered the maximum power output of Combined Charging System chargers, although some of the newest models can achieve over 400 kW (DOT, 2023). For ultrafast charging, we assumed 1 MW of power based on conversations with vehicle manufacturers about charging power needs and vehicle technical specifications. We maintained our assumption of widespread commercial availability of megawatt charging in 2027 based on the expectation that the SAE J3271 standard will be finalized in 2025 (Bohn, 2023).

DISPLAYING RESULTS AT THE COUNTY AND STATE LEVELS

For our state- and county-level analysis, we used state-level AADT data from the Federal Highway Administration's HPMS. Sites of projected vehicle energy demand and charging needs from HDV CHARGE are based on patterns of vehicle traffic volumes on individual road segments. These anonymized traffic data do not contain information regarding vehicles' origins or destinations. We therefore projected county-level charging needs based on the vehicle activity within each county. Additional trip information such as origin and destination data would enable more precise predictions of charging locations at the sub-county level, particularly for vehicles passing through a county, but such data were not available for this study.

HDV CHARGE models charging needs optimally, calculating the precise number of chargers needed to meet the energy demand from ZE-MHDV activity. We rounded charger totals up to the next whole number to reflect realistic charger estimates. If HDV CHARGE projected a charger need of less than 0.1 for a particular county, we reallocated this need to the county in the same state with the largest charging needs. We assumed this approach would produce a higher number of chargers than needed to meet the energy needs of the fleet.

DISPLAYING RESULTS AT A HEX-8 LEVEL

We then translated the results from HDV CHARGE to the hex-8 resolution, which can be used to support distribution grid planning at the feeder level. This resolution has been used in other charging infrastructure modeling and vehicle data analyses (Brodsky, 2018; Electric Power Research Institute, 2024). We identified proxy locations where future depot and public chargers may be placed and allocated our county-level results to these locations to achieve the desired hex-8 display resolution. Charging results at this resolution can signal to distribution system planners where future charging hotspots may be located throughout their grid, allowing them to evaluate the available capacity on nearby feeder lines. We did not obtain national datasets on bus and refuse truck locations, so charger needs for these vehicles are included in our state- and county-level analysis but omitted from the hex-8 level analysis. Our hex-8 allocation approach is briefly summarized in Table 1.

Table 1

Summary of vehicle charging and energy needs allocation approach

Charger location	Charger type	Proxy locations	Allocation weight and order
Depot	Overnight / fast / ultrafast	Commercial real estate properties	Property size
Public	Overnight / fast / ultrafast	Private truck stops	Number of parking spots

Our modeling approach assumed that depot charging will be located at the vehicles' depot home base, where they have the longest dwell time. We approximated depot locations using commercial real estate data sourced from the CoStar real estate database (CoStar, 2024). Using this database, we identified commercial properties around the country likely to have Class 4–8 MHDVs based on detailed property information such as address, building type, and building and land area. Depot charging locations were weighted based on property size, with the assumption that larger properties have larger fleets and greater charging needs than smaller properties. More information about how we used the CoStar database to filter and identify properties with fleets is provided in Appendix B.

Presently, there are only a few public MHDV charging locations in the United States. As the electric truck market matures, a widespread public charging network will become necessary, especially for long-haul trucks. Assuming public charging will be located at convenient locations, we followed a similar approach used for depot charging and employed private truck stops as proxy locations for public charging. Data on over 6,000 private truck stops were collected by the U.S. Department of Transportation in 2015; Figure C1, in the appendix, maps private truck parking in Oklahoma based on these data (FHWA, 2025). We allocated public chargers to these locations with weights determined by the number of parking spots. While there is an extensive public truck stop network, as seen in Appendix C, these locations are not able to be commercialized with charging infrastructure due to a longstanding prohibition on commercializing the interstate right-of-way (Bureau of Transportation Statistics, 2024; 23 U.S. Code §111).

For counties in which there are no commercial properties or truck stops, we created a placeholder location at the center of the county representing the county's depot and public charging needs. This placeholder location was not suited for hex-8 mapping, as we did not attempt to estimate where a potential depot or public charging facility would be located. If these charging needs cannot be satisfied within the same county as the vehicle activity, they could be met at another location in a neighboring county.

There is an extensive system of commercial fueling locations throughout the country that could potentially support charging facilities in the future. To represent this alternative charging network structure, we modeled overnight public charging at private truck stops and fast and ultrafast charging at commercial fueling locations, assuming the smaller size and existing infrastructure of commercial fueling locations make them better suited to fast and ultrafast charging. For this analysis, we allocated charging stations based on state-level (rather than county-level) public charging needs, which resulted in no placeholder locations as all charging stations were allocated to a charging location.

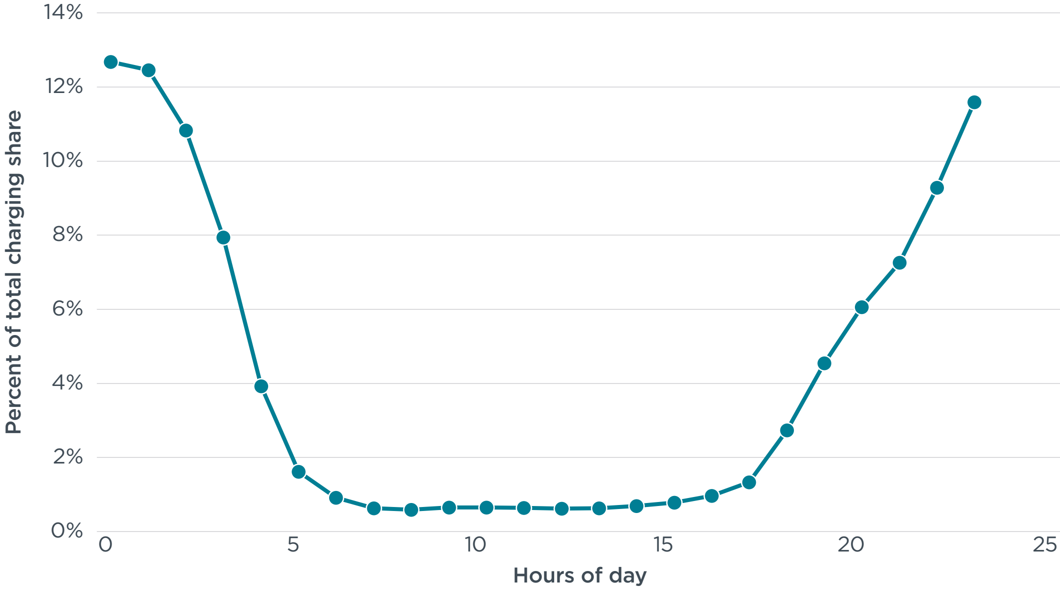
Data on commercial fueling locations were collected from the Commercial Fueling Network's Fleetwide database and the Pacific Pride database, which contain information on over 60,000 commercial fueling locations (Commercial Fueling Network, 2024; Pacific Pride, 2024). These databases were filtered for commercial fueling locations with 18-wheeler access and diesel pumps. We further narrowed this dataset to sites located within one-third of a mile of a transmission line, similar to distance assumptions made by National Grid in their *Electric Highways Study* (Katsh et al., 2023). Because these datasets did not contain information about each commercial fueling location's size or number of refueling pumps, we uniformly distributed public fast and ultrafast charging stations and assumed the colocation of fast and ultrafast chargers at these sites unless only one charger type was available. If there were more sites than chargers in a county, we randomly determined the remaining allocation order.

Estimating potential peak loads

HDV CHARGE calculates each vehicle segment's daily energy needs from the electric grid, but the model does not calculate the associated peak load from ZE-MHDV charging. We used load curves from Bruchon et al. (2024) to estimate potential peak loads from ZE-MHDV charging. Bruchon et al. (2024) calculated normalized average daily depot load curves for trucks, transit buses, and school buses, representing when vehicles are at their depot and available to charge. The researchers accessed truck data from Geotab's Altitude platform, transit bus data from the National Transit Database and the General Transit Feed Specification, and school bus data from the National Renewable Energy Laboratory's (2024) Fleet DNA database to produce operational profiles that informed the production of their load curves.

These load curves, as illustrated in Figure 3, represent one potential charging scenario that uses managed charging to distribute the load as evenly as possible over time instead of having vehicles charge immediately upon entering the depot. They thus reflect average daily vehicle operations, rather than a lower bound that could be attained through alternative load management strategies such as charging aggressively during off-peak periods (Bruchon et al., 2024). Moreover, our calculated peak loads do not reflect the total peak loads from ZE-MHDV charging, as the effects of public charging are not included. Public charging could result in higher peaks due to the more frequent use of higher-powered chargers, which may also not be operating under a managed charging system. Appendix B presents additional information about the data and load curve production in Bruchon et al. (2024) as it relates to this analysis.

Figure 3
Transit bus depot load curve



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We multiplied the daily energy consumption from the vehicle segments in HDV CHARGE with the corresponding normalized load curves from Bruchon et al. (2024) to calculate the charging load at each hour. We summed these hourly charging loads across all vehicle segments to determine the maximum summed hourly load, which represents the peak load. Like our HDV CHARGE outputs, the peak load is associated with a specific location, allowing us to present peak load estimates at the hex-8 and county levels.

Methodological differences with the 2023 study

In this analysis, we made certain methodological changes compared with our May 2023 study due to differences in data, analytical approach, and scope. Table 2 summarizes the main methodological differences between the two studies.

Table 2
Main differences between methodology in this study and Ragon et al. (2023)

Modeling component	Previous assumption	Current assumption
Roadmap	MOVES3	MOVES4
Policy scenario	Market	Reference / Compliance / Market Potential
Traffic data	2018 AADT	2022 AADT
VKT distribution	Nationwide	Per state
Overnight charging power levels	50–150 kW	19.2–200 kW
Charging session lengths	8 hours	Varies by vehicle segment
Charging efficiency	85%	91.4%
Peak load approach	Peak load ratio	Depot peak load curves
Result resolution	County level	Hex-8 level

As in the last study, we used the ICCT Roadmap model to generate projections of ZEV deployment and stock turnover for Class 4–8 MHDVs based on our designed policy scenarios. In this study, however, we estimated ZE-MHDV charging and energy needs for three policy scenarios—Reference, Compliance, and Market Potential—to demonstrate the role of policy in shaping ZE-MHDV market development and to reflect the potential future range of electric truck charging and energy needs. In our 2023 study, we projected future charging and energy needs for ZE-MHDVs based on only one policy scenario designed to model the potential maximum benefits from implemented Inflation Reduction Act incentives, which is the same as the Market Potential scenario in this study. Moreover, this study makes use of an updated Roadmap model, with outputs based on EPA's MOVES4 emission modeling system, which was released after the publication of our 2023 study.

In terms of traffic data, we used HPMS AADT data from 2022, which was the most recent reporting year available when we began this analysis. By determining VKT distribution by state rather than applying a national VKT distribution, we also incorporated changes to vehicle segment VKT and correlated energy consumption. Although our analysis identified similar priority freight regions for charging infrastructure as in the previous study, it ranked priority counties differently, owing to differences in the geographic distribution of these traffic data; while most freight traffic flows are consistent, they might change over time due to population changes, consumer preferences, and other factors. However, a comparison of 2018 and 2022 AADT data indicates that major freight corridors experienced the least variability in freight traffic flows, making them optimal locations for charging infrastructure development.

We also made several changes to our HDV CHARGE modeling. For example, in the May 2023 study, all vehicles were assumed to charge overnight for 8 hours. For this analysis, we updated overnight charging session lengths and power levels for each vehicle segment (see Table A3). For most vehicles, we assumed longer overnight charging times and more variability in overnight charging power levels. We also increased charger efficiency from 85% to 91.4% for this analysis. Additionally, for this study, we rounded HDV CHARGE's fractional charger outputs for each charger type and vehicle segment at the county level up to the nearest whole number, whereas in the previous study, depot and public charger outputs were summed at the county level before rounding. These changes affected the number of estimated chargers necessary to meet ZEV's energy needs and the chargers' nameplate capacity.

Lastly, we changed our peak load calculation approach. Previously, we applied a peak load ratio of 1.77, based on HEVI-LOAD data shared by Lawrence Berkeley National Laboratory (n.d.). For this study, we used data from Bruchon et al. (2024), because the data used for the previous method's peak load ratio were specific to California and limited to 2030. We estimated peak loads from depot charging based on load curves for each vehicle segment; this allowed for a more robust calculation than using our previous peak load ratio, which was applied universally to all vehicle segments. Our calculations assumed a managed charging approach, which could be as much as 30% lower than peak loads produced from unmanaged charging (Wood et al., 2024). Our modeling assumed depot-centric vehicles mostly rely on overnight chargers, which resulted in lower peak loads than the previous peak load ratio method because we did not attempt to estimate peak loads contributed by public charging, which usually results in a higher share of fast and ultrafast charging.

PROJECTED CHARGING AND INFRASTRUCTURE NEEDS

This section presents our modeling results. We focus on the Compliance scenario, which yields a moderate level of ZEV adoption relative to the more conservative Reference and more optimistic Market Potential scenarios.

Under the Compliance scenario, the Roadmap model projects that there will be 411,000 Class 4–8 ZE-MHDVs nationwide by 2030, with a network of almost 180,000 chargers. These vehicles will require nearly 40,600 MWh of energy from the grid daily, which is less than 1% of 2023 retail electricity sales (U.S. Energy Information Administration, 2024). After 2030, the MHDV population continues to grow, although the sales share of new electric MHDVs remains relatively constant after 2032. By 2035, the Roadmap model predicts that there will be an electric MHDV population of 1.49 million vehicles, requiring over 585,000 chargers. These vehicles will require 151,000 MWh of electricity from the grid every day, almost quadruple the daily energy needed in 2030. For comparison, by 2035, the Reference scenario results in 344,000 chargers for about 850,000 ZE-MHDVs, while the Market Potential scenario yields 960,000 chargers for nearly 2.47 million vehicles.

Table 3 displays the national-level results from HDV CHARGE for the three scenarios in 2030 and 2035.

Table 3
National-level charging infrastructure needs under all scenarios (2030 and 2035)

Output	2030			2035		
	Reference	Compliance	Market Potential	Reference	Compliance	Market Potential
Electric vehicle kilometers traveled (eVKT; thousands)	37,700	54,200	148,000	106,000	204,000	363,000
Daily energy consumption (MWh)	26,900	40,600	120,000	70,900	151,000	284,000
Nameplate capacity (MW)	9,500	13,200	33,900	20,900	40,600	70,500
Number of overnight chargers	128,000	171,000	410,000	332,000	565,000	929,000
Number of fast chargers	4,170	5,540	11,700	8,100	13,100	19,400
Number of ultrafast chargers	2,450	3,300	7,580	4,350	7,840	11,700
Total number of chargers	**134,000**	**180,000**	**429,000**	**344,000**	**586,000**	**960,000**

Note: Results rounded to three significant figures.

We next present our Compliance scenario results at the state, county, and hex-8 levels, highlighting regions and freight corridors expected to see the highest demand for ZE-MHDV charging in 2030 and 2035. We then demonstrate our improved mapping ability at the hex-8 level, sharing unrounded modeled results for Tulsa, Oklahoma. Finally, we examine how an alternative modeling approach would impact our public charging results, discuss how our modeling results differ between the three modeled scenarios, and compare with our May 2023 study.

STATE-LEVEL ENERGY NEEDS PROJECTIONS

ZEV market growth will vary between states, accelerating more quickly in states that have adopted California's Advanced Clean Trucks rule and other vehicle electrification policies. Table 4 displays the top 10 states by projected energy need in 2030 with comparative data for 2035. We present each state's share of daily VKT performed by electric vehicles (eVKT), daily energy needs, and charger nameplate capacity.

Table 4

Top 10 states by daily energy needs under the Compliance scenario (2030 and 2035)

State	2030			2035			% change in energy consumption from 2030 to 2035
	Daily eVKT (thousands)	Daily energy consumption (MWh)	Nameplate capacity (MW)	Daily eVKT (thousands)	Daily energy consumption (MWh)	Nameplate capacity (MW)	
CA	10,300	8,360	2,200	30,400	23,400	5,670	181%
TX	4,100	2,850	845	17,800	12,900	3,280	353%
FL	3,030	2,040	571	11,900	8,000	1,950	292%
NY	2,140	1,770	506	6,460	5,080	1,240	188%
IN	1,730	1,330	562	7,680	6,020	1,770	353%
GA	1,910	1,270	392	7,860	5,410	1,440	325%
WA	1,340	1,150	294	4,090	3,380	760	193%
AZ	1,600	1,070	302	6,260	4,200	1,020	293%
NJ	1,360	1,060	311	4,090	3,020	725	186%
OR	1,240	1,040	300	3,780	3,010	726	190%
U.S. total	**54,200**	**40,600**	**13,200**	**204,000**	**151,000**	**40,600**	

Note: Results rounded to three significant figures.

HDV CHARGE modeling projects that, by 2030, California will have the highest daily energy requirement for electric trucks, comprising 21% of total national energy needs. In 2030, the top 10 states make up 54% of expected energy needs, 53% of daily eVKT, and 48% of nameplate capacity nationally. The results do not change significantly by 2035, with the same 10 states making up 49% of total energy needs, 49% of total eVKT, and 46% of total nameplate capacity. The rate of increase in vehicle energy consumption differs between states, reflecting varying growth of ZE-MHDV populations across states. Table C1 in the appendix presents the results for all 50 states.

COUNTY-LEVEL RESULTS

As shown in Table 5, of 3,045 counties nationwide included in the HDV CHARGE results, the top 10 represent 15% of national energy consumption from ZE-MHDV charging in 2030 and 12% in 2035. As noted above, depot charging peak load estimates assume a managed charging approach.

Table 5
Top 10 counties by daily energy needs under the Compliance scenario (2030 and 2035)

County	State	2030		2035	
		Nameplate capacity (MW)	Depot charging peak load (MW)	Nameplate capacity (MW)	Depot charging peak load (MW)
Riverside	**CA**	273	18.7	746	48.3
Los Angeles	**CA**	303	24.5	790	64.6
San Bernardino	**CA**	198	15	533	39.3
Maricopa	**AZ**	148	23.4	503	77.6
San Diego	**CA**	145	12.7	382	33.8
Kern	**CA**	107	8.4	287	22.3
Orange	**CA**	95.4	8	252	21.3
Harris	**TX**	105	13.6	292	43.8
San Joaquin	**CA**	59	4.1	153	10.7
King	**WA**	61	6.3	145	17
U.S. total		**13,200**		**40,600**	

Note: Counties are ranked in descending order of energy consumption based on 2030 results. Results are rounded to three significant figures.

The top three counties—Riverside, Los Angeles, and San Bernardino—are within the Greater Los Angeles area, where large volumes of freight traffic flow between the Ports of Los Angeles and Long Beach and warehouses in the Inland Empire. Other leading counties are similarly along major freight corridors, such as the I-5, which runs from San Diego, California, to King County, Washington. Similar to the top states, these counties are expected to see rapid growth in ZE-MHDV activity from 2030 to 2035 and to require substantial charging infrastructure investment.

We categorized chargers into three types based on their power levels: overnight (19.2–200 kW), fast (350 kW), and ultrafast (1 MW). Fleets would likely use lower-power overnight chargers during their longest dwell times, usually at nighttime, to reduce energy costs. Fast and ultrafast chargers would likely be used between stops when charging times are limited or if overnight charging alone is insufficient.

Table 6 presents the top 10 counties' projected charger needs by power level; Table C2 in the appendix shows the results for the top 1% of counties. The assumptions of longer dwell periods for vehicle segments influence the modeling results, which indicate that most charging needs can be met with lower-powered overnight chargers if fleets maintain historical dwell times. Intuitively, fast and ultrafast charging would still be necessary for fleets that have to recharge their vehicles' batteries during the day to complete their routes.

Table 6

Top 10 counties' projected charger needs by power level under the Compliance scenario (2030 and 2035)

County	State	2030			2035		
		Overnight chargers	Fast chargers	Ultrafast chargers	Overnight chargers	Fast chargers	Ultrafast chargers
Riverside	**CA**	2,450	79	50	6,990	189	109
Los Angeles	**CA**	3,260	134	78	9,390	306	164
San Bernardino	**CA**	1,990	72	42	5,720	170	93
Maricopa	**AZ**	2,910	56	33	10,400	150	75
San Diego	**CA**	1,710	69	38	4,930	164	84
Kern	**CA**	1,130	44	24	3,250	105	55
Orange	**CA**	1,080	43	25	3,100	105	54
Harris	**TX**	1,550	51	35	5,640	79	48
San Joaquin	**CA**	547	22	13	1,560	47	26
King	**WA**	738	20	16	2,150	27	21
U.S. total		**171,000**	**5,540**	**3,300**	**565,000**	**13,100**	**7,840**

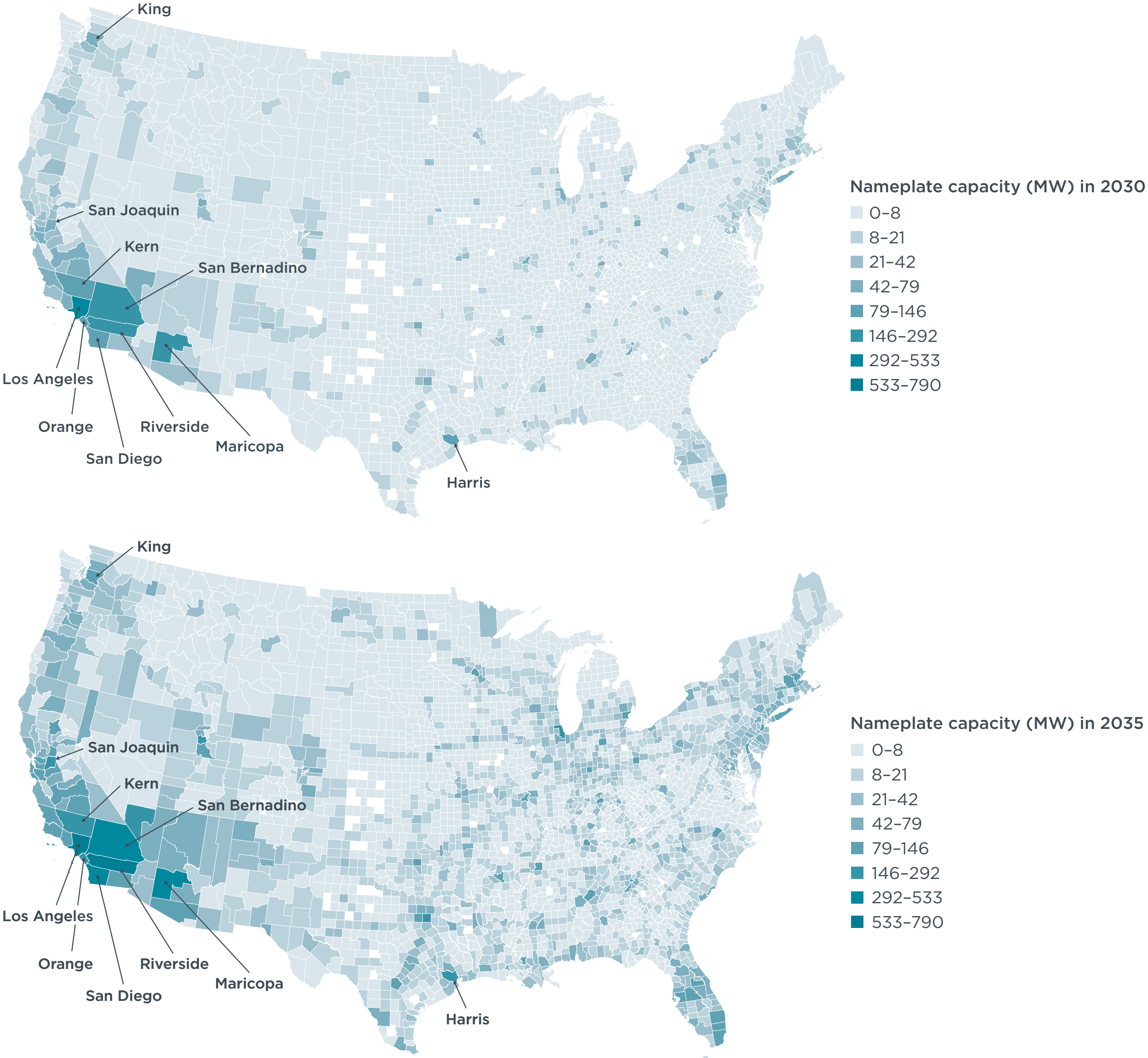
Note: Counties are ranked in descending order of energy consumption based on 2030 results. Results are rounded to three significant figures.

Focusing on absolute energy consumption alone can obscure other important trends, such as the concentration of ZE-MHDV energy needs. While some counties may not have the highest absolute energy consumption, they may rank highly in terms of energy consumption per unit area. For example, Bronx County, New York, ranks 157th in absolute energy consumption but 1st in energy consumption per unit area. Dense, urban environments with high levels of truck traffic may not be suitable for truck charging facilities due to space constraints or inflated infrastructure and land costs. Necessary charging infrastructure may have to be installed in neighboring counties.

Figure 4 shows the distribution of ZE-MHDV energy needs across the country. Counties along the I-5 and I-10 corridors, particularly those in California, are hot spots for projected ZE-MHDV energy consumption. Counties within eastern Texas, parts of southern Florida, and New England will likely need extensive MHDV charging networks due to high volumes of MHDV traffic along the National Highway Freight Network (NHFN). Charging infrastructure will also be necessary in the less densely populated South and Midwest to support major highway junctions with regional freight traffic flows.

Figure 4

County-level ZE-MHDV daily energy consumption under the Compliance scenario (2030 and 2035)



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CHARGING AND ENERGY NEEDS FOR TULSA COUNTY, OKLAHOMA, AND THE CITY OF TULSA

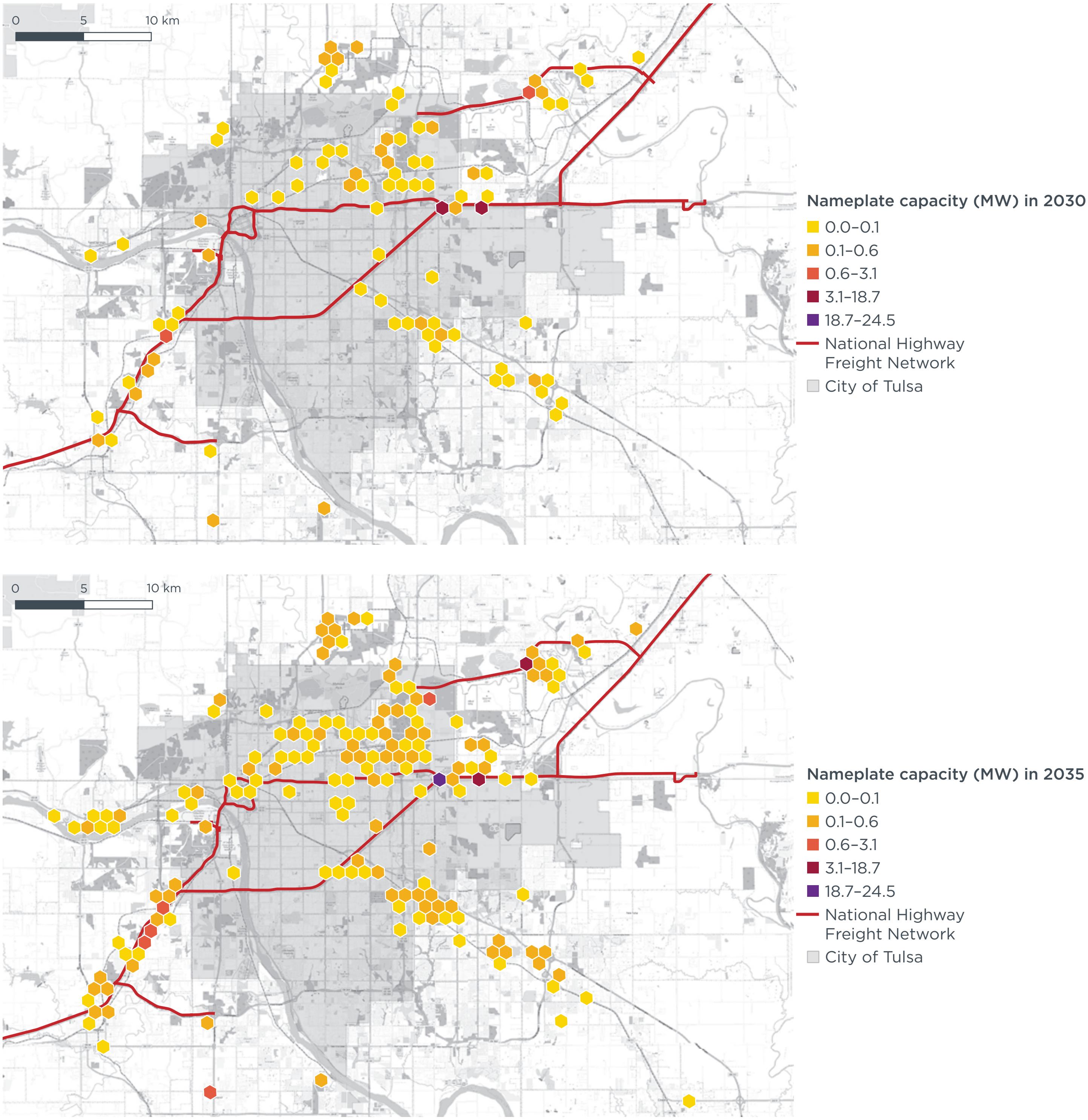
Oklahoma has several major trucking corridors that are part of the NHFN, as seen in Figure C1 in the appendix. An estimated 64% of the state's truck traffic travels through the state to transport goods elsewhere (Oklahoma Department of Transportation, 2016). Important routes include the I-35 connecting central Oklahoma and the Texas Triangle, the I-40 connecting the Eastern and Western United States, and the I-44 connecting St. Louis with Oklahoma City, where trucks can get on I-35 and I-40. According to a 2012 report, the highest volume truck corridor extends from central Oklahoma through Tulsa along the I-44 (Parsons Brinckerhoff, 2012).

Tulsa County, the second most populous county in Oklahoma (U.S. Census Bureau, 2022), ranked 112th in energy demand from ZE-MHDVs according to the HDV CHARGE modeling. For 2030, projected electric truck activity will require about 61 MWh from the grid daily and at least 219 overnight chargers, 13 fast chargers, and 6 ultrafast chargers. This totals about 21 MW in nameplate capacity. Daily grid energy needs are expected to increase to 236 MWh by 2035, requiring at least 791 overnight chargers, 32 fast chargers, and 16 ultrafast chargers, a total nameplate capacity of approximately 67 MW.

We next allocated the energy consumption and charging needs to specific locations throughout each county to present results at the hex-8 level, based on post-processing of the HDV CHARGE results. Charging and energy needs results at the hex-8 level are useful for grid distribution planners, who can use this information to identify the location and extent of necessary grid upgrades, like new feeders or expanded substations. The hex-8 results for Tulsa and surrounding areas are shown in Figure 5. This analysis only reflects single-unit and combination trucks, as more research is needed to determine the likely charging locations for bus and refuse truck fleets, which can generate concentrated power demands depending on their fleet size and depot locations. Potential charging locations for Tulsa can be seen in Figure C3 of the appendix.

Figure 5

Tulsa charger nameplate capacity under the Compliance scenario (2030 and 2035)



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Energy needs from combination and single-unit trucks are largely concentrated in a few main areas: in the southeast along the Highway 51/Broken Arrow Expressway, the industrial area around Tulsa International Airport along I-44, and the West Tulsa Industrial area. Because there are only five private truck stops within Tulsa County, modeled results for public charging are concentrated at a few facilities, resulting in higher nameplate capacity at each facility. If local truck stops are unable to host the necessary public charging infrastructure, Tulsa's public charging needs could be met at local commercial fueling locations or at other private truck stops in nearby counties, such as Wagoner, Rogers, and Creek counties.

Table 7 presents the 2030 and 2035 charger results for Tulsa in the Compliance scenario. Daily energy needs from single-unit and combination trucks are expected to total up to 70 MWh in 2030, requiring 278 chargers, mostly lower-powered and overnight. Demand is projected to increase to 283 MWh by 2035, requiring an estimated 1,034 chargers. Reference and Market Potential scenario results for Tulsa can be seen in Appendix C. There is a slight difference in charging and energy results between Tulsa County and the city of Tulsa because we include some of the surrounding area in our analysis for the city, which extends beyond the county's borders.

Table 7
Tulsa charging needs for single-unit and combination trucks under the Compliance scenario (2030 and 2035)

Charger Type	2030				2035			
	Overnight chargers	Fast chargers	Ultrafast chargers	Nameplate capacity (MW)	Overnight chargers	Fast Chargers	Ultrafast Chargers	Nameplate capacity (MW)
Depot	156	1	0	6.3	592	1	0	25.7
Public	102	13	6	16.6	390	34	17	54.5
Total	**258**	**14**	**6**	**22.9**	**982**	**35**	**17**	**80.2**

Note: Results are rounded to three significant figures.

PUBLIC CHARGING

The United States does not yet have a public charging network for ZE-MHDVs. Charging-as-a-service (CaaS) providers are constructing concentrated charging facilities around major ports and along freight corridors (CALSTART, 2024). Usually relying on higher-powered chargers, these charging facilities have the capacity to service hundreds of trucks a day with a nameplate capacity of several megawatts (Campbell, 2024).

We modeled a limited public charging network with all public charging, including overnight, fast, and ultrafast chargers, located exclusively at private truck stop locations. Within Oklahoma, we identified 175 private truck stops with over 7,500 truck parking spaces. County public charging needs were allocated to each location based on weights determined by the number of parking spots at each truck stop. We identified 20 counties without private truck stops, resulting in 20 placeholder locations.

Under the Compliance scenario, the HDV CHARGE model estimated that at least 1,320 public chargers—1,029 overnight chargers, 178 fast chargers, and 113 ultrafast chargers—would be necessary to meet the public charging needs of ZE-MHDVs in Oklahoma in 2030. Table 8 displays the public charging nameplate capacity results for Oklahoma under this scenario.

Table 8
Minimum public charging nameplate capacity in Oklahoma if concentrated at truck stops under the Compliance scenario (2030 and 2035)

Truck stops				
Percentile of number of chargers per site	2030 minimum nameplate capacity (MW)	2030 count of truck stops	2035 minimum nameplate capacity (MW)	2035 count of truck stops
0%–25%	0.05	40	0.05	39
25%–50%	0.15	34	0.60	38
50%–75%	0.70	34	1.95	37
>75%	1.05	32	4.0	36
Oklahoma average	**1.55**		**3.97**	
Placeholder locations				
Percentile of number of chargers per site	2030 minimum nameplate capacity (MW)	2030 count of placeholder locations	2035 minimum nameplate capacity (MW)	2030 count of placeholder locations
0%–25%	0.10	6	1.80	7
25%–50%	0.60	5	2.05	5
50%–75%	1.60	5	2.15	5
>75%	1.80	4	4.70	3
Oklahoma average	**1.33**		**3.65**	

The results from HDV CHARGE suggest that existing private truck stops, if they can be successfully converted for electrification, can meet the public charging needs of ZE-MHDVs in Oklahoma under the Compliance scenario: The projected 1,320 total public chargers needed in 2030 is less than 20% of truck parking spaces at existing private truck stops in the state. In 2030, the average nameplate capacity of this public charging network is below 2 MW, which might enable timely charger energization for fleets. However, there is variation within each quartile: The largest public charging facility, for instance, has a nameplate capacity of about 12 MW. By 2035, the projected average nameplate capacity increases to almost 4 MW, and the largest facility has a nameplate capacity near 25 MW, which may be difficult for some electric utilities to energize. More detailed telematics and additional information such as local distribution capacity can better inform utilities and regulators about which truck stops are capable of electrifying and the likely charger needs at each site.

In addition to private truck stops, diesel trucks also make use of an extensive network of commercial fueling facilities. Representing an alternative public charging scenario, we next modeled a case in which public charging needs are shared between truck stops and commercial fueling locations. We assumed that all overnight chargers were concentrated at private truck stops—which we posited have more amenities and thus may encourage longer parking periods—while all fast and ultrafast chargers were at commercial fueling sites. In Oklahoma, we identified about 100 commercial fueling sites located near transmission lines, potentially making them capable of a transmission interconnection. Table 9 displays the nameplate capacity results for Oklahoma under the Compliance scenario.

Table 9

Minimum public charging nameplate capacity in Oklahoma if shared between truck stops and commercial fueling locations under the Compliance scenario (2030 and 2035)

Truck stops only				
Percentile of number of chargers per site	2030 minimum nameplate capacity (MW)	2030 count of truck stops	2035 minimum nameplate capacity (MW)	2035 count of truck stops
0%–33%	0.05	55	0.15	67
33%–67%	0.15	58	0.85	44
>67%	0.40	41	1.9	40
Oklahoma average	**0.39**		**1.70**	
Commercial fueling locations				
Percentile of number of chargers per site	2030 minimum nameplate capacity (MW)	2030 count of commercial fueling locations	2035 minimum nameplate capacity (MW)	2035 count of commercial fueling locations
0%–50%	0.35	58	0.35	168
>50%	1.70	10	1.70	32
Oklahoma average	**1.18**		**1.18**	

Note: Results are rounded to three significant figures for display purposes.

Tables 8 and 9 illustrate how the design of the charging network can influence the demand on the local electrical grid. The primary analysis assumed a charging network concentrated at private truck stops. In Oklahoma, under this scenario, the required average nameplate capacity for public charging facilities is under 2 MW in 2030 and rises to near 4 MW by 2035, which would necessitate a greater number of electric utilities to invest in distribution grid capacity to ensure that fleets' energy demands are met in a timely manner. This proactive grid capacity investment may be most important for the largest public charging facilities, which our modeling projects could have nameplate capacity as high as 25 MW.

In an alternative scenario where public charging is divided between private truck stops and commercial fueling sites, the average nameplate capacity of the charging facilities is much lower, which might enable faster energization by avoiding the need for extensive grid upgrades, which are often required for charging infrastructure projects over 2 MW. However, the largest facilities in this case could still create challenges for electric utilities and warrant significant grid capacity upgrades. For 2035, for example, our modeling calculates the largest charging facility at a private truck stop could be almost 14 MW, and the largest facility at a commercial fueling site could be near 8 MW.

States have multiple available strategies to guide the development of a public charging network. Public charging sites could be equipped with fewer but higher-powered chargers, truck stops could be expanded to meet charging demand, or additional public charging facilities could be constructed at locations other than truck stops, among other options. State energy offices have a role to play in coordinating the development of a public charging strategy with electric utilities, truck stop operators, CaaS providers, and other actors to ensure that near-term investment needs are met.

COMPARISON BETWEEN SCENARIOS

Modeling results varied greatly between the Reference, Compliance, and Market Potential scenarios, illustrating how different regulations may shape the growth of ZE-MHDV adoption nationwide. While the scenarios assumed uniform ZEV deployment, meaning priority regions were similar across all models, the magnitude of potential energy consumption and charging needs differed as vehicle segments experienced varying rates of electrification.

For 2030, the total number of estimated chargers in the Market Potential and Compliance scenarios was about 3.2 times and 1.3 times higher than in the Reference scenario, respectively. In terms of total daily energy consumption, the Market Potential scenario projected about 3 times more than the Compliance scenario, which in turn projected about 1.5 times more than the Reference scenario. Table 10 shows the top 10 counties in terms of daily energy consumption in the Compliance scenario in 2030, with comparative results for the other modeled policy scenarios.

Table 10
Top 10 counties' eVKT and daily grid energy consumption for each policy scenario (2030)

County	State	Reference		Compliance		Market Potential	
		eVKT (thousands)	Energy consumption (MWh)	eVKT (thousands)	Energy consumption (MWh)	eVKT (thousands)	Energy consumption (MWh)
Riverside	CA	1020	866	1,320	1,200	2,360	2,040
Los Angeles	CA	1,320	987	1,490	1,180	2,780	2,090
San Bernardino	CA	811	641	973	825	1,790	1,440
Maricopa	AZ	562	357	871	569	2,380	1,730
San Diego	CA	677	491	737	556	1,400	1,010
Kern	CA	455	349	528	431	980	760
Orange	CA	428	315	475	367	895	660
Harris	TX	345	232	519	360	1,390	1,090
San Joaquin	CA	222	179	273	237	498	409
King	WA	220	167	277	234	458	355
U.S. total		**37,700**	**26,900**	**54,200**	**40,600**	**148,000**	**120,000**

Note: Counties are ranked in descending order of energy consumption based on 2030 results under the Compliance scenario. Results are rounded to three significant figures.

HDV CHARGE modeling suggests that even under the Reference scenario, which reflects the conservative pathway to meet EPA's Phase 3 emission standards, significant investments in ZE-MHDV charging infrastructure would still be necessary as fleets electrify. Even in this conservative scenario, we estimate that electric trucks will consume 26.9 GWh of electricity from the grid in 2030 through a charging network of about 9.5 GW. Charging infrastructure needs would be even larger if market trends are more closely aligned with the Compliance or Market Potential scenarios, which would require further charging and grid infrastructure investments to meet the energy needs of a more developed ZE-MHDV market. The results for all three scenarios suggest significant and rapid investments in charging infrastructure and grid upgrades may be warranted. Electric utilities and regulators would be best positioned to respond to the emerging market demand by planning for and investing in the enabling grid distribution infrastructure to support the range of possible scenarios modeled in this study.

LIMITATIONS

There are several limitations to this analysis that should be considered when interpreting the modeled results.

We used publicly available HPMS AADT traffic data from 2022. These data may potentially reflect some lingering impacts of the COVID-19 pandemic, which may influence reported traffic flows. Additionally, they are missing useful information that could be found in more detailed telematics data, such as vehicles' origin and destination, times when domiciled at depots or other locations, speeds, and road grade. Without origin and destination data, the analysis projects the energy and charging demands from vehicle activity projected to occur in each county, but it may not accurately model the charging needs from through traffic that may span multiple counties or states.

Lacking origin and destination information, our analysis incorporated other location data—on commercial properties, commercial fueling locations, and public truck stops—to estimate where charging may take place. However, it remains to be seen how the ZE-MHDV charging market will develop. For example, the analysis separated public charging between truck stops and commercial fueling locations, reflecting different patterns of vehicle behavior at these locations. However, it is possible that truck drivers' use of these locations may change in the future, which may require co-location of different charger types. Additionally, some sites may no longer remain useful as primary charging or refueling locations.

Additional information could help inform projections of where and when charging infrastructure would likely be needed. Hex-8 modeling currently only displays results for combination and single-unit trucks, omitting results for bus segments and refuse trucks, as depot location data for these segments were unavailable for this study. However, a more detailed regional analysis, like that performed in Steimer et al. (2024), could account for local fleet information and more accurately determine local charging needs at the hex-8 level for these additional vehicle segments. This may entail incorporating the location of specific fleet depots, amending the electrification adoption timeline to reflect the transition plans of local fleets, and adjusting charging assumptions to match fleet preferences. Further adjustment of results may be necessary if the geographic distribution of our traffic data does not capture all local truck activity or if our reallocation efforts do not reflect the local market's charging infrastructure development.

Our infrastructure modeling allocated chargers and determined the order of electrification at each location based on known features of the proxy charging locations: property size and number of parking spots. For sites without that information, our modeling assumed uniform distribution and allocated chargers at random when there were more locations than chargers. However, each fleet owner will have their own unique plan that determines the pace and scale of electrification independent of the information available for this study. For example, a small fleet might have the physical space required to install charging infrastructure, while a large fleet operating at capacity may not. Other unknowns include local grid conditions that may influence where and when charging infrastructure could be installed and energized.

These and other factors may cause a fleet to access charging at off-site, third-party charging facilities, which were not included in this analysis.

In the post-processing stage, the normalized charging load profiles from Bruchon et al. (2024) that represent managed charging curves for trucks, school buses, and transit buses informed this study's peak load calculations. Further research is necessary to calculate charging curves reflecting unmanaged charging and to better estimate the charging behavior of long-haul trucks, which will rely on a combination of depot and public charging facilities. Bruchon et al. (2024) also note that their month-long analysis period for truck data did not capture seasonal variation in operations that may influence charging needs. Additional data on public charging behavior could result in more accurate public charging load curve calculations.

HDV CHARGE models charging needs based on historical vehicle activity data and assumptions concerning technology and charging preferences, but the development of the ZE-MHDV charging network will be influenced by many parameters. For example, due to high vehicle and charging infrastructure costs, many first-mover fleets are using third-party charging services; these CaaS providers are leading the initial build-out of ZE-MHDV charging infrastructure at strategically located freight hotspots. As the market matures and costs improve, a more distributed charging network at locations like fleet depots, truck stops, and commercial fueling locations, similar to what this study models, may emerge. Grid capacity availability and energization timelines are other important factors that may determine where and when charging infrastructure can be installed, affecting ZE-MHDV fleets' electrification timelines.

CONCLUSION

This study projected ZE-MHDV charging demands in 2030 and 2035 based on three scenarios of future ZEV adoption. Building on our May 2023 report (Ragon et al., 2023), we used an updated version of our in-house ZE-MHDV charging infrastructure model, HDV CHARGE, and projected charging needs based on an expanded set of policy scenarios that reflect the EPA Phase 3 emission standards, more recent HPMS traffic data, and updated assumptions about charging times, power levels, and other variables.

Our modeling projects that under the Compliance scenario, which entails moderate ZEV adoption, ZE-MHDVs will require 40,600 MWh of energy from the grid daily by 2030, with a total charger nameplate capacity of almost 13,200 MW. Projected energy consumption and nameplate capacity increase dramatically by 2035, with total energy needs rising to 151,000 MWh and total charger nameplate capacity climbing to 40,600 MW. In our more conservative Reference scenario, ZE-MHDVs are predicted to need 26,900 MWh daily and will rely on 9,500 MW of charging infrastructure in 2030. In this scenario, by 2035, their energy needs are expected to increase to 70,900 MWh with a charging network of 20,900 MW. Meanwhile, in the more ambitious Market Potential scenario, daily vehicle energy needs will be 120,000 MWh in 2030, served by a charging network of 33,900 MW. By 2035, vehicles will need 287,000 MWh from the grid, and charging infrastructure nameplate capacity will increase to 70,500 MW.

ZE-MHDV charging needs will likely be clustered in port regions and along freight corridors where MHDV activity is concentrated, with most of the top counties in terms of projected ZE-MHDV energy consumption located in California and states along major NHFN corridors. Hex-8 modeling results for Tulsa, Oklahoma, illustrate how the local charging network may develop if charging infrastructure is installed at commercial properties and private truck stops. For our Compliance scenario, HDV CHARGE projects that single-unit and combination trucks in Tulsa will require 61 MWh from the grid daily in 2030, relying on a charging network of over 200 chargers. By 2035, energy needs are expected to increase to 236 MWh, with trucks relying on over 800 chargers. Hex-8 modeling can be improved with more detailed traffic data, data on grid capacity constraints, and information on local fleets' electrification plans and depot locations.

Based on historical vehicle behavior and other assumptions, HDV CHARGE projects that lower-powered overnight chargers can satisfy about 90% of energy needs in 2030 and 2035. However, multiple factors can determine the development of the local charging network and influence the charging preferences of fleets. Our results show how the concentration of public charging at private truck stops in Oklahoma results in higher average facility nameplate capacity than if public charging infrastructure is spread out further and installed at commercial fueling locations. While both approaches may result in manageable loads for electric utilities, if charging infrastructure is concentrated at only a handful of locations or if fast and ultrafast charging are the preferred charging power levels, electric utilities may need to further invest in grid capacity upgrades to meet ZE-MHDVs energy needs in time.

Modeling tools like HDV CHARGE can help electric utilities and their regulators to determine likely charging needs, assess where grid upgrades are needed, and identify cost-effective investments. Increased transparency from fleets about vehicle movements and from electric utilities about grid capacity can improve modeling tools' projections and usefulness. Fleets, charging providers, utilities, and other stakeholders will need to collaborate to efficiently build out the comprehensive charging network for ZE-MHDVs. Failing to do so will prolong the environmental and human health impacts from MHDVs, place upward pressure on electricity rates for ratepayers, and create logistical challenges for all stakeholders involved in this transition.

As part of a broader economy-wide shift toward electrification, MHDV electrification will add to the growing strain on local electrical grids, increasing energy demand at a pace not seen in decades. Given long lead times for new generation construction and infrastructure upgrades, electric utilities and regulators should strive to anticipate future MHDV electrification and assess the preparedness of their local electrical grids. This study illustrates the importance of utilities planning for both near- and long-term energy needs as the transition to ZE-MHDVs accelerates in the coming decades.

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APPENDIX A

Table A1

Roadmap projected zero-emission vehicle population per year per scenario

Scenario	Vehicle type	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Reference	Combination long-haul truck	1,262	1,725	2,235	3,132	4,770	6,221	8,956	12,401	15,914	19,500	23,152
	Combination short-haul truck	3,869	7,309	12,459	19,178	27,202	35,323	43,740	53,060	62,422	71,994	81,639
	Other bus	4,390	5,499	7,124	9,563	12,786	16,548	20,560	24,861	29,479	34,440	39,788
	Refuse truck	111	188	342	578	893	1,282	1,711	2,181	2,701	3,279	3,921
	School bus	4,078	5,676	7,670	10,677	14,644	19,533	24,814	30,564	36,964	43,990	51,745
	Single unit long-haul truck	885	1,534	2,582	4,190	6,333	8,987	11,875	15,045	18,563	22,462	26,770
	Single unit short-haul truck	20,120	34,842	58,616	95,052	143,631	203,771	269,281	341,095	420,871	509,232	606,918
	Transit bus	2,224	2,556	3,045	3,794	4,784	5,996	7,312	8,731	10,283	11,947	13,740
	Total	**36,939**	**59,329**	**94,073**	**146,164**	**215,043**	**297,661**	**388,249**	**487,938**	**597,197**	**716,844**	**847,673**
Compliance	Combination long-haul truck	3,036	5,271	8,187	11,762	15,910	20,500	29,386	47,756	66,116	84,490	102,836
	Combination short-haul truck	3,869	7,309	14,030	24,017	37,030	51,970	77,345	113,314	149,238	185,116	220,853
	Other bus	4,739	6,200	8,548	11,426	14,804	18,509	23,861	30,741	37,501	44,181	50,842
	Refuse truck	111	188	321	512	895	1,466	2,074	2,690	3,312	3,944	4,590
	School bus	5,338	8,220	12,032	16,778	22,406	28,842	37,827	49,440	61,147	72,890	84,726
	Single unit long-haul truck	885	1,534	3,314	5,666	8,564	11,949	16,791	23,144	29,557	36,046	42,616
	Single unit short-haul truck	20,120	34,842	75,216	128,515	194,191	270,912	380,712	524,697	670,142	817,204	966,225
	Transit bus	2,315	2,739	3,423	4,274	5,262	6,396	8,086	10,292	12,483	14,647	16,799
	Total	**40,413**	**66,303**	**125,071**	**202,950**	**299,062**	**410,544**	**576,082**	**802,074**	**1,029,496**	**1,258,518**	1,489,487
Market Potential	Combination long-haul truck	5,001	10,607	15,428	23,699	36,910	56,425	78,646	107,717	136,757	165,806	194,794
	Combination short-haul truck	23,965	47,135	76,913	119,257	164,398	210,605	259,309	308,514	354,594	401,930	450,342
	Other bus	7,312	10,947	16,429	22,407	28,601	34,613	41,199	48,644	56,109	63,611	71,191
	Refuse truck	974	1,962	3,257	4,955	7,032	9,430	11,922	14,523	17,231	20,061	23,030
	School bus	8,564	13,997	22,596	31,637	40,875	50,066	59,451	71,064	82,771	94,507	106,296
	Single unit long-haul truck	2,884	5,706	9,848	14,507	20,372	27,383	34,698	42,341	50,337	58,707	67,467
	Single unit short-haul truck	65,433	129,398	223,294	328,891	461,829	620,811	786,647	959,920	1,141,253	1,331,001	1,529,590
	Transit bus	3,312	4,655	6,606	8,712	11,185	13,924	16,811	19,922	23,015	26,089	29,135
	Total	**117,445**	**224,407**	**374,371**	**554,065**	**771,202**	**1,023,257**	**1,288,683**	**1,572,645**	**1,862,067**	**2,161,712**	**2,471,845**

Table A2

Fraction of vehicle activity assigned to each vehicle segment by road classification for the state of New York

Vehicle group	Vehicle segment	Rural restricted	Rural unrestricted	Urban restricted	Urban unrestricted
Buses and rigid trucks	Transit bus	2.4%	3.0%	3.0%	5.3%
	School bus	4.6%	5.8%	5.7%	10.3%
	Other buses	4.4%	5.5%	5.5%	9.8%
	Refuse truck	3.3%	3.2%	3.2%	2.8%
	Single unit short-haul truck (Class 4–5)	37.4%	36.2%	36.2%	31.4%
	Single unit short-haul truck (Class 6–8)	32.9%	31.8%	31.8%	27.7%
	Single unit long-haul truck (Class 4–5)	7.3%	7.1%	7.1%	6.1%
	Single unit long-haul truck (Class 6–8)	6.4%	6.2%	6.2%	5.4%
	Total	**100%**	**100%**	**100%**	**100%**
Tractor trucks	Combination long-haul truck	72.4%	72.4%	72.4%	72.4%
	Combination short-haul truck	27.6%	27.6%	27.6%	27.6%
	Total	**100%**	**100%**	**100%**	**100%**

Note: The above road classifications are based on EPA's MOVES model (EPA, 2023b, p. 93). Rural restricted roads are rural highways accessible only by an on-ramp. Rural unrestricted roads are all other rural roads such as rural arterials, connectors, and local streets. Urban restricted and urban unrestricted roads are similarly defined but pertain to urban highways and roads. Numbers have been rounded for display purposes and may not add up to 100%.

Table A3

Overnight charging session duration and power levels per vehicle segment

Vehicle segment	Charger type	Charging session duration (hours)	Charger power level (kw)
Combination long-haul truck	Overnight	5	200
Combination short-haul truck	Overnight	9	100
Single unit long-haul truck (Class 4–5)	Overnight	9.5	50
Single unit long-haul truck (Class 6–8)	Overnight	9.5	50
Single unit short-haul truck (Class 4–5)	Overnight	11	50
Single unit short-haul truck (Class 6–8)	Overnight	11	19.2
Refuse truck	Overnight	11	50
School bus	Overnight	17	19.2
Transit bus	Overnight	10.5	100
Other bus	Overnight	10.5	100

Table A4
Vehicle battery capacity projections

Vehicle segment	Battery capacity (kWh)		
	2025	2030	2035
Combination long-haul truck	1,101	990	927
Combination short-haul truck	440	411	394
Single unit long-haul truck (Class 4–5)	338	317	305
Single unit long-haul truck (Class 6–8)	157	146	140
Single unit short-haul truck (Class 4–5)	131	122	117
Single unit short-haul truck (Class 6–8)	282	264	254
Refuse truck	392	366	351
School bus	177	170	165
Transit bus	435	406	390
Other bus	677	670	660

APPENDIX B

Description of depot charging distribution process

HDV CHARGE allocates depot chargers based on the traffic patterns of vehicles, placing them where vehicle activity occurs. We identified proxy charging depot locations using information about warehouses and other commercial properties from the CoStar real estate database. The post-processing step isolated traffic activity within each county and assigned the associated chargers, energy demand, and peak loads to properties within the county.

The CoStar database includes detailed information on commercial properties such as their address, building type, building and land area, and number of loading docks. We focused on properties designated as distribution, manufacturing, refrigeration/cold storage, food processing, and warehouse facilities with a rentable building area greater than 50,000 square feet (CoStar, 2024). Properties between 10,000 and 50,000 square feet in rentable building area were included only if they had at least one loading dock. All properties designated as truck terminals were included.

Depot chargers were allocated based on warehouse area, defined as the rentable building area minus office and vacant space. The quantity of depot chargers allocated to a commercial property is reflective of that property's percentage of its county's total warehouse space. Therefore, commercial properties with more warehouse space than others were allocated more depot chargers for each vehicle segment, assuming larger properties have larger fleets.

The depot charging results allocation was ordered based on these weights, so the largest properties would be considered for a charger first. The location's charger total was calculated by multiplying the determined weight by the county charger total, rounding up to the nearest whole number, and subtracting it from the county total before calculating the number of chargers at the next location. For example, if there were 10 depot charging sites, 99 depot chargers, and a location with a weight of 10%, that location would be assigned 10 chargers after rounding. Before calculating the possible number of chargers at the next location, the total number of remaining charging stations for the county would be decreased by 10 chargers.

Description of peak load data

Bruchon et al. (2024) describe their methods for determining the normalized average daily depot load curves for their trucks, transit buses, and school bus vehicle segments. In this section, we provide a brief description of their data preparation and production of their vehicle load curves.

For trucks, the researchers first performed a clustering analysis to identify seven national representative regions based on trip distance and employment-weighted employment density. They then used Geotab's Altitude platform to analyze telematics data from vehicles operating in each of the zones, accessing descriptive statistics of 13,500 MHDVs. With these data and dwell times calculated in post-processing, they produced operation profiles that informed their charging load profiles, excluding long-distance vehicles as they are less likely to primarily rely on depot-based charging. Charging load profiles were based on total domicile dwell hours, which can occur at any time of day. Nationally scaling percentiles for each region were created to scale the load curves before they were normalized.

For transit buses, the researchers leveraged two major data sources: the National Transit Database and the General Transit Feed Specification (GTFS). Through a clustering analysis, they extrapolated bus operations, categorizing transit agencies into six clusters based on fleet size, weighted daily vehicle miles traveled, maximum bus utilization rate, and the minimum value of agency weekday vehicles operated during maximum service. With GTFS operations data (GTFS Schedule) and data on trips and vehicle positions (GTFS Realtime), the researchers produced transit bus operation profiles. Their charging load profiles reflect managed charging limited to vehicles' overnight dwell periods and were normalized to yield per-vehicle hourly load profiles.

For school buses, the researchers used school bus operating data from NREL Fleet DNA, filtering out trips shorter than two miles and depot dwell times shorter than one hour. Domicile dwell periods were at least 6 hours long and overnight. Charging load profiles were created using the EVI-Pro tool and the operating data from Fleet DNA. With managed charging, charging activity is spread across the buses' dwell time hours, including overnight and midday hours.

Table B1 maps the vehicle types in Bruchon et al. (2024) to our vehicle segments. This study used load curve data only for Class 4–8 trucks, taking an average of the combined load curves from Class 4–5, 6–7, and 8. We used load curve data from weekday operations, which produced higher load peaks than weekend data, except in the case of their door-to-door (refuse truck) segment, for which we used weekend data.

Table B1
Vehicle mapping between source types and Fleet DNA vehicle types

Vehicle segments	Bruchon et al. (2024) vehicle types
Combination long-haul truck	Regional
Combination short-haul truck	Regional
Single unit long-haul truck	Regional
Single unit short-haul truck	Local
Refuse truck	Door to door
School bus	School bus
Transit bus	Transit bus
Other bus	Transit bus

APPENDIX C

State-level results

Table C1

State-level charging and energy needs under the Compliance policy scenario (2030 and 2035)

State ranking	State	2030				2035			
		Total daily eVKT, Class 4–8 MHDVs (km)	Daily energy consumption (MWh)	Nameplate capacity (MW)	Share of national energy consumption	Total daily eVKT, Class 4–8 MHDVs (km)	Daily energy consumption (MWh)	Nameplate capacity (MW)	Share of national energy consumption
1	CA	10,250,274	8,357	2,204	20.6%	30,390,235	23,445	5,673	15.5%
2	TX	4,100,615	2,847	845	7.0%	17,806,950	12,906	3,279	8.5%
3	FL	3,029,474	2,043	571	5.0%	11,920,345	8,000	1,947	5.3%
4	NY	2,139,972	1,768	506	4.3%	6,458,901	5,082	1,243	3.4%
5	IN	1,726,903	1,328	562	3.3%	7,683,731	6,016	1,774	4.0%
6	GA	1,909,586	1,272	392	3.1%	7,858,404	5,407	1,440	3.6%
7	WA	1,335,837	1,154	294	2.8%	4,087,394	3,376	760	2.2%
8	AZ	1,595,538	1,070	302	2.6%	6,263,563	4,200	1,024	2.8%
9	NJ	1,360,200	1,058	311	2.6%	4,093,672	3,024	725	2.0%
10	OR	1,242,182	1,038	300	2.6%	3,775,889	3,011	726	2.0%
11	MO	1,400,834	1,002	452	2.5%	5,886,397	4,314	1,378	2.9%
12	IL	1,374,197	987	287	2.4%	6,000,323	4,494	1,107	3.0%
13	PA	1,471,501	962	281	2.4%	5,849,034	3,891	1,008	2.6%
14	NC	1,290,339	906	287	2.2%	5,195,714	3,659	1,001	2.4%
15	OH	1,213,282	871	292	2.1%	5,151,888	3,803	1,048	2.5%
16	CO	904,497	816	250	2.0%	2,774,629	2,396	620	1.6%
17	KY	1,074,500	793	364	2.0%	4,499,747	3,346	1,095	2.2%
18	LA	1,024,369	781	339	1.9%	4,401,374	3,375	1,045	2.2%
19	AL	992,602	740	314	1.8%	4,180,432	3,127	954	2.1%
20	MA	962,123	728	191	1.8%	2,873,665	2,061	476	1.4%
21	MD	861,294	701	188	1.7%	2,619,634	2,034	481	1.3%
22	NM	768,354	677	244	1.7%	2,310,964	1,942	524	1.3%
23	UT	1,046,852	676	189	1.7%	4,200,134	2,753	664	1.8%
24	OK	911,228	663	317	1.6%	3,735,395	2,715	909	1.8%
25	TN	847,094	641	194	1.6%	4,096,629	3,280	820	2.2%
26	WI	939,535	638	189	1.6%	3,873,647	2,708	727	1.8%
27	MN	835,267	576	175	1.4%	3,460,770	2,456	632	1.6%
28	AR	702,098	560	259	1.4%	3,149,160	2,533	798	1.7%
29	MS	711,990	543	276	1.3%	3,043,865	2,331	804	1.5%
30	MI	670,244	483	163	1.2%	2,968,155	2,229	595	1.5%
31	SC	686,533	462	149	1.1%	2,854,691	1,975	540	1.3%
32	VA	613,984	454	203	1.1%	2,696,698	2,091	682	1.4%
33	IA	524,237	398	187	1.0%	2,383,232	1,864	627	1.2%
34	KS	417,666	332	163	0.8%	1,965,849	1,599	557	1.1%
35	NV	377,343	277	88	0.7%	1,636,218	1,228	313	0.8%
36	CT	407,330	269	86	0.7%	1,589,627	1,050	257	0.7%
37	WV	304,492	216	131	0.5%	1,218,083	866	331	0.6%
38	ID	279,100	191	68	0.5%	1,183,337	836	237	0.6%
39	ND	239,467	176	106	0.4%	1,011,454	750	295	0.5%
40	NE	204,741	165	79	0.4%	1,005,209	839	279	0.6%
41	DE	248,857	159	51	0.4%	928,816	580	145	0.4%
42	ME	207,583	139	53	0.3%	834,184	570	164	0.4%
43	WY	170,919	134	63	0.3%	809,700	656	206	0.4%
44	MT	173,556	131	65	0.3%	765,110	590	200	0.4%
45	VT	151,136	117	57	0.3%	448,408	329	114	0.2%
46	SD	137,971	109	62	0.3%	657,307	536	195	0.4%
47	RI	131,316	100	37	0.2%	396,295	287	80	0.2%
48	NH	146,756	90	40	0.2%	549,180	334	97	0.2%
49	AK	57,517	37	26	0.1%	224,589	145	50	0.1%
U.S. total		54,173,284	40,634	13,249	100%	203,768,625	151,042	40,640	100%

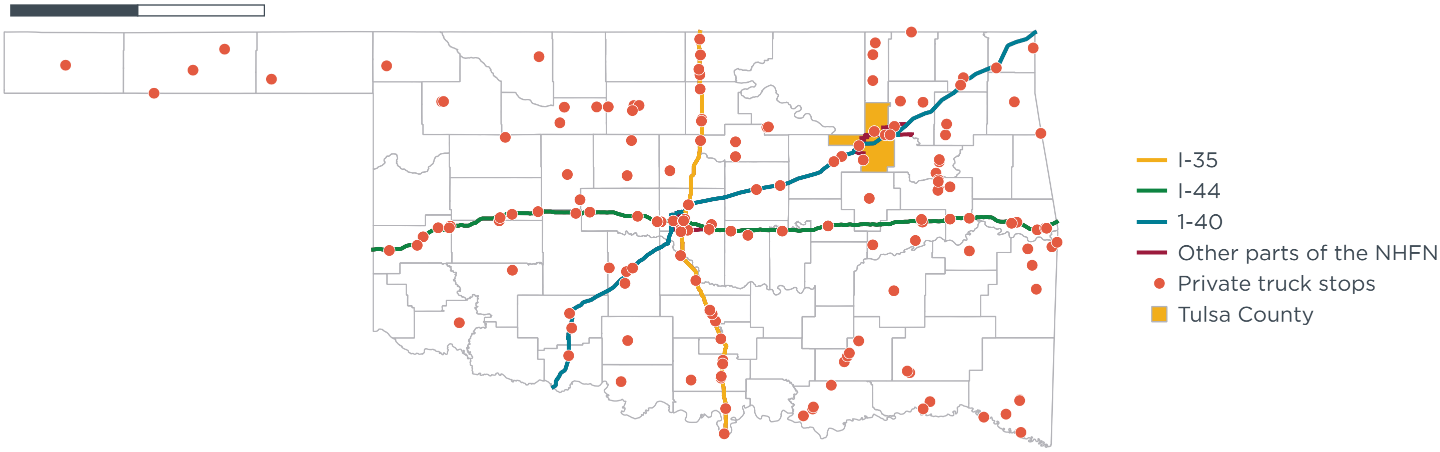
County-level results

Table C2
Charging and energy needs for top 1% of counties under the Compliance policy scenario (2030 and 2035)

County rank	County	2030 Daily energy consumption (MWh)	2030 Overnight chargers	2030 Fast chargers	2030 Ultrafast chargers	2035 Daily energy consumption (MWh)	2035 Overnight chargers	2035 Fast chargers	2035 Ultrafast chargers
1	Riverside, CA	1,204	2,446	79	50	3,405	6,992	189	109
2	Los Angeles, CA	1,177	3,257	134	78	3,280	9,390	306	164
3	San Bernardino, CA	825	1,993	72	42	2,326	5,724	170	93
4	Maricopa, AZ	569	2,906	56	33	2,111	10,393	150	75
5	San Diego, CA	556	1,707	69	38	1,547	4,926	164	84
6	Kern, CA	431	1,130	44	24	1,210	3,247	105	55
7	Orange, CA	367	1,075	43	25	1,023	3,098	105	54
8	Harris, TX	360	1,550	51	35	1,241	5,635	79	48
9	San Joaquin, CA	237	547	22	13	670	1,559	47	26
10	King, WA	234	738	20	16	658	2,146	27	21
11	Salt Lake, UT	209	1,274	20	15	768	4,595	31	19
12	Alameda, CA	205	592	26	14	572	1,699	57	30
13	Dallas, TX	189	1,015	12	6	809	3,774	32	13
14	Cook, IL	182	792	23	18	709	2,868	37	25
15	Santa Clara, CA	181	527	23	12	505	1,508	51	27
16	Fresno, CA	177	452	20	11	496	1,288	41	23
17	Tulare, CA	177	495	21	12	494	1,416	48	25
18	Ventura, CA	172	476	21	11	483	1,361	45	24
19	San Luis Obispo, CA	166	470	20	11	464	1,347	44	25
20	Clark, NV	160	700	18	15	691	2,662	36	24
21	Palm Beach, FL	159	748	20	15	531	2,698	31	19
22	Worcester, MA	156	593	7	5	439	1,716	14	8
23	St. Louis, MO	148	403	35	26	519	1,490	68	42
24	Suffolk, NY	145	571	20	17	388	1,647	30	19
25	Santa Barbara, CA	144	424	19	11	403	1,214	41	22
26	Middlesex, MA	143	616	13	12	401	1,787	18	14
27	Contra Costa, CA	141	400	18	10	396	1,144	39	20
28	Jefferson, KY	140	396	32	25	476	1,438	62	39
29	San Mateo, CA	140	467	23	12	387	1,342	48	24
30	Sacramento, CA	139	351	16	8	390	997	33	18
	U.S. total	40,634	170,999	5,539	3,297	151,042	564,893	13,062	7,837

Oklahoma and National Highway Freight Network

Figure C1
Oklahoma and components of the National Highway Freight Network (NHFN)



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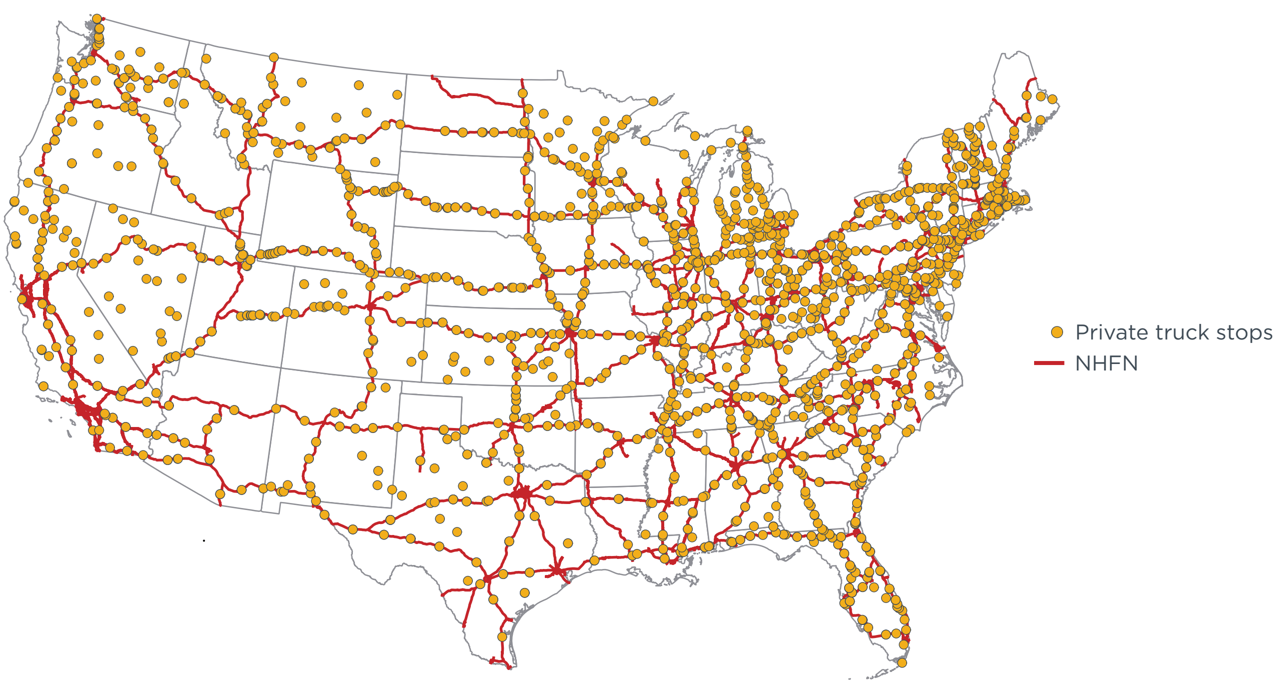
Public truck stop map

The U.S. DOT manages a nationwide database on public truck parking to track the availability of long-term parking where drivers can rest (Bureau of Transportation Statistics, 2024). Trucks operate under strict hours of service regulations that limit consecutive hours of driving and set minimum rest periods, so drivers often take their extended breaks at truck stops alongside highways (Federal Motor Carrier Safety Administration, 2022).

Figure C2
Public truck stop locations across the United States



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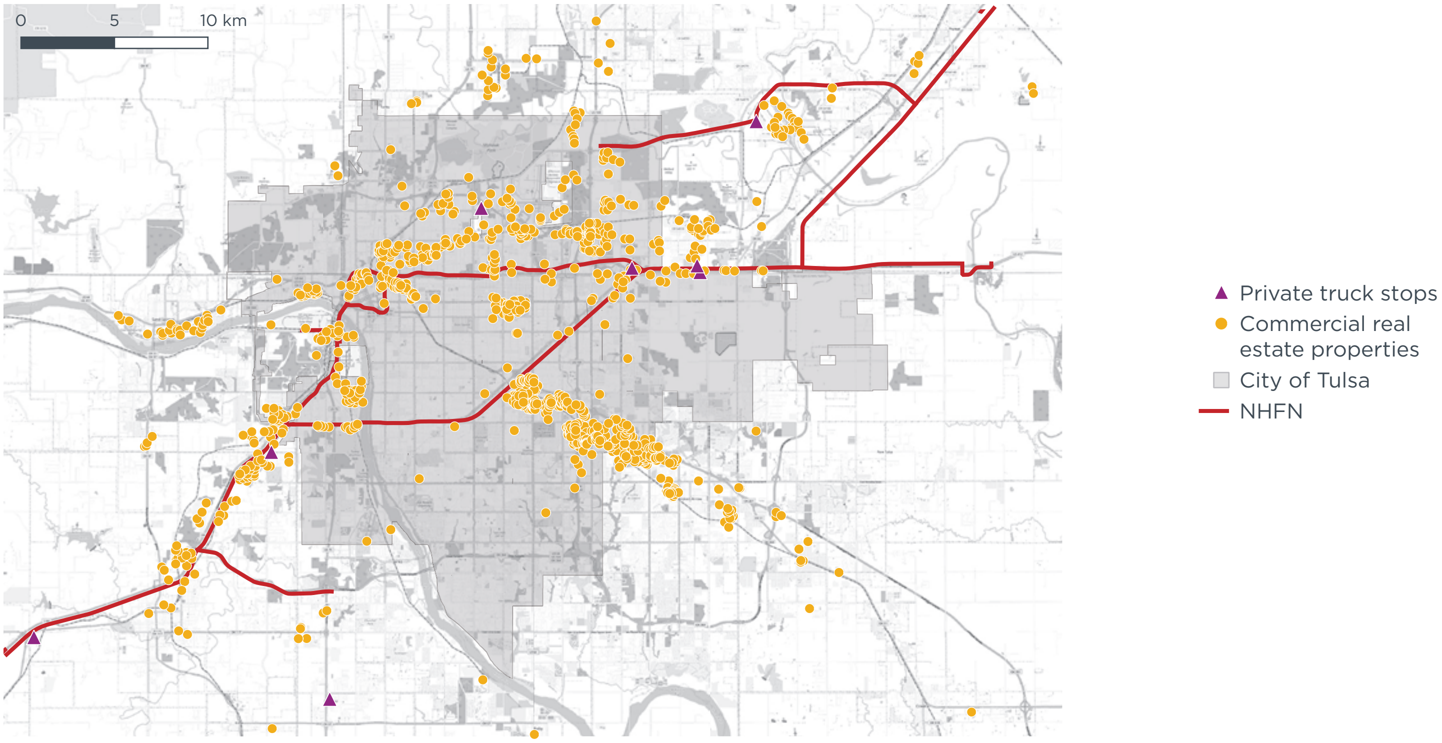
Potential charging locations for Tulsa

Figure C3

Commercial fueling and commercial real estate properties for Tulsa



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Comparison results

Figure C4

National charging nameplate capacity under the Reference scenario (2030)

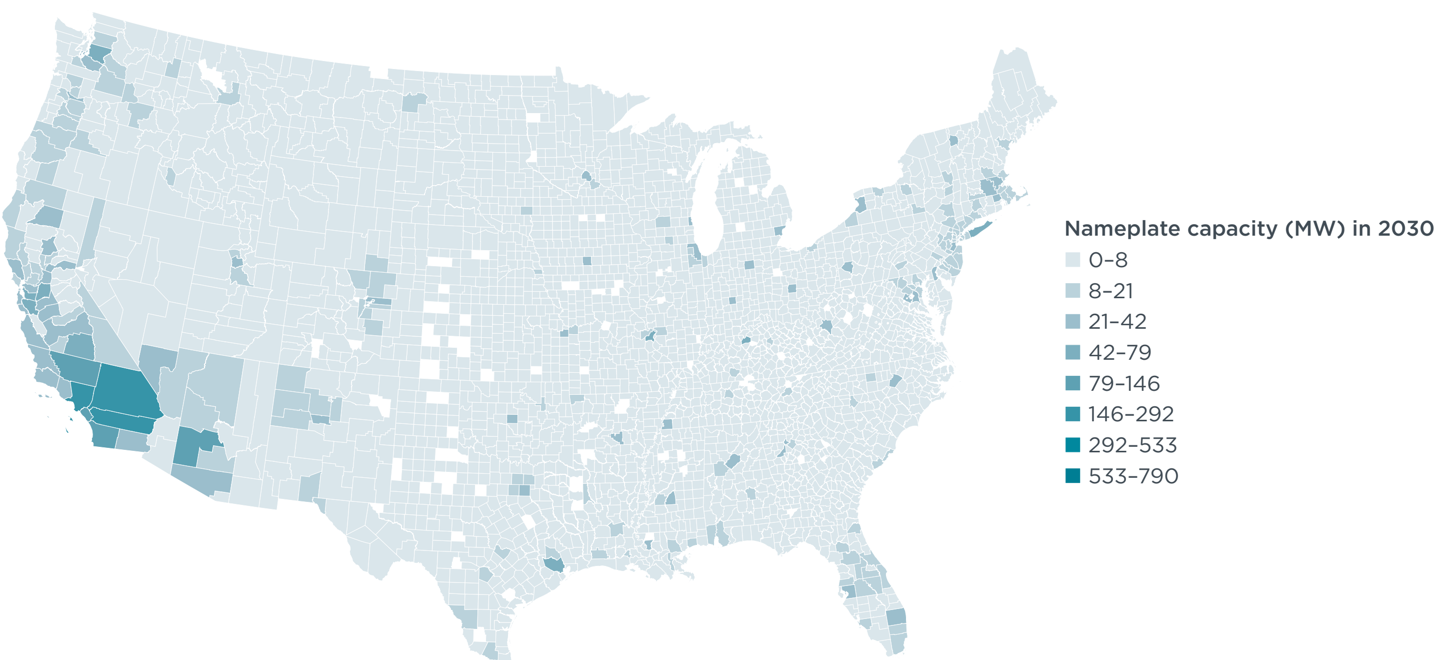

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Figure C5

National charging nameplate capacity under the Market Potential scenario (2030)

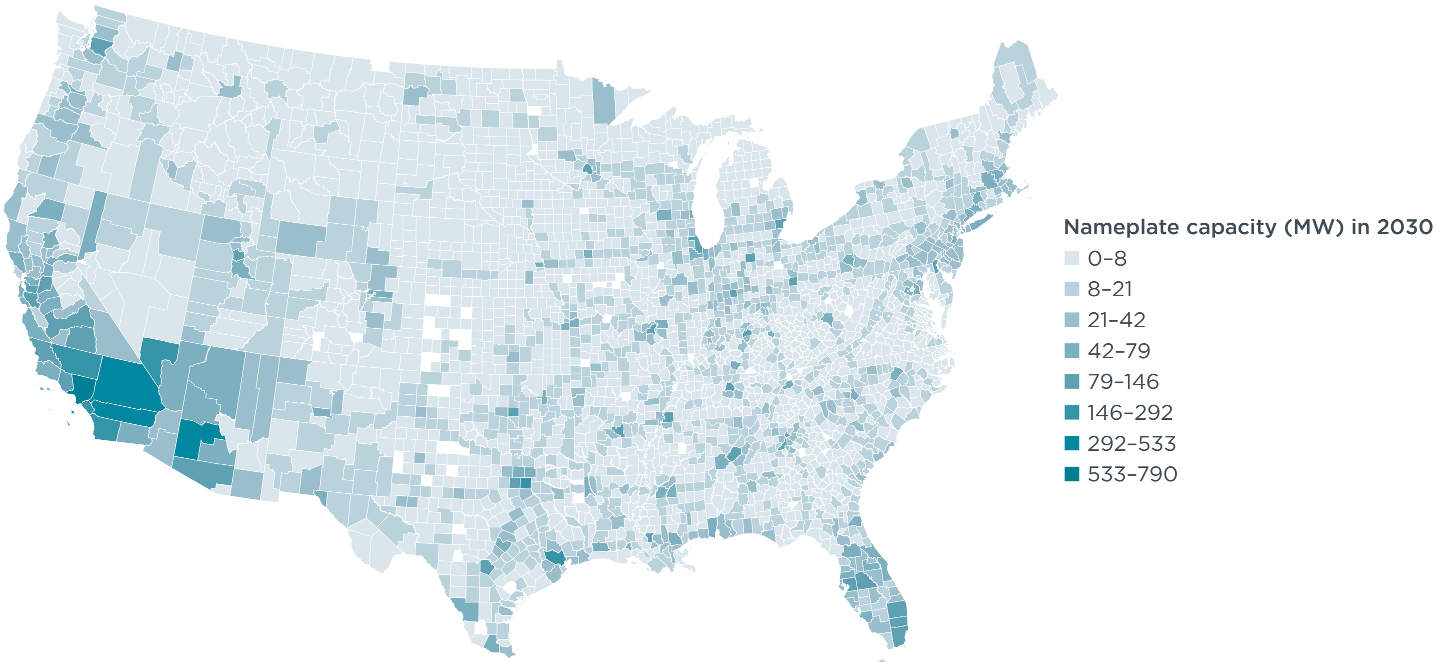

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Figure C6

National charging nameplate capacity under the Reference scenario (2035)

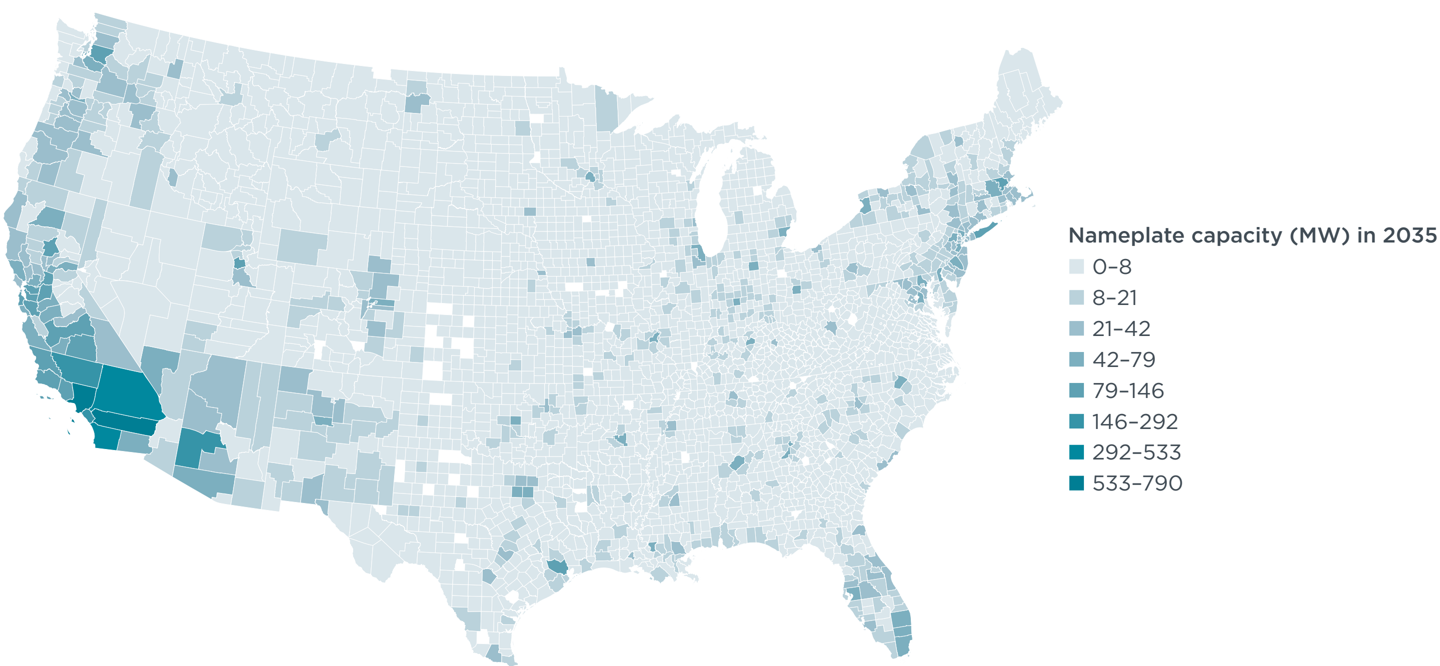

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Figure C7
National charging nameplate capacity under the Market Potential scenario (2035)

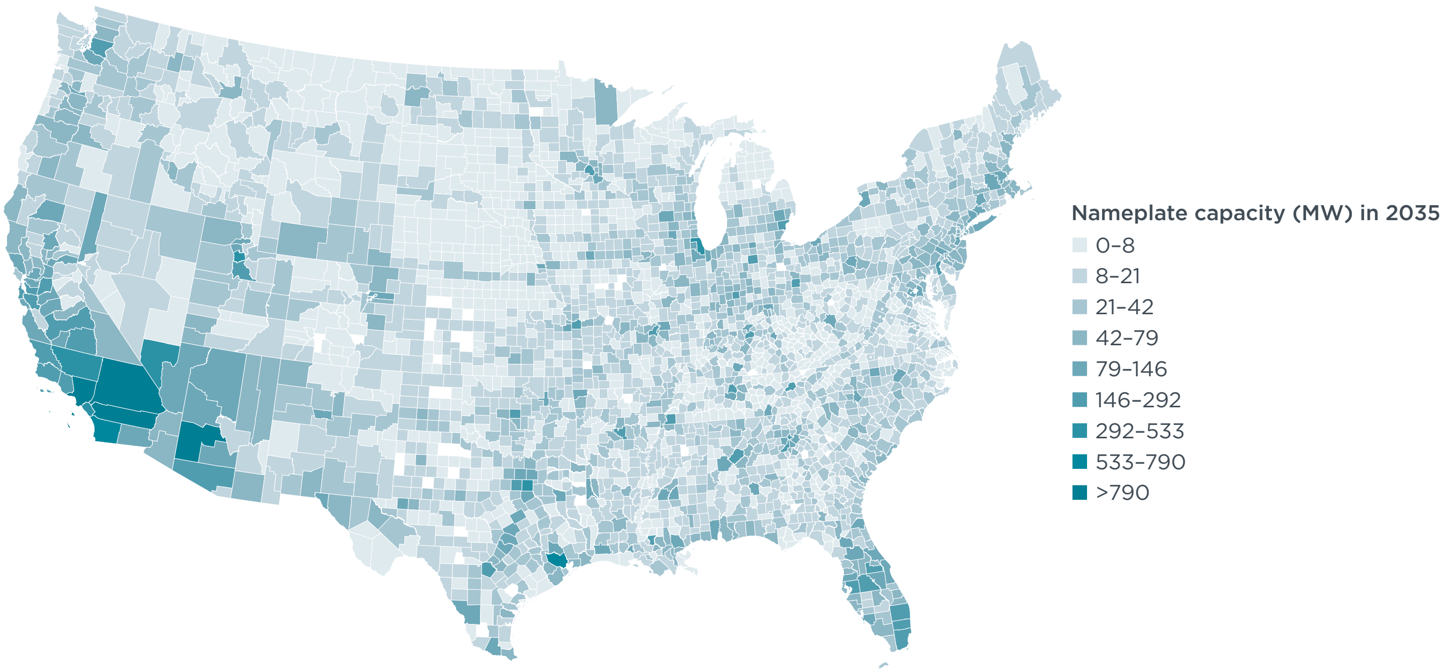

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Figure C8
Tulsa charging nameplate capacity under the Reference scenario (2030)

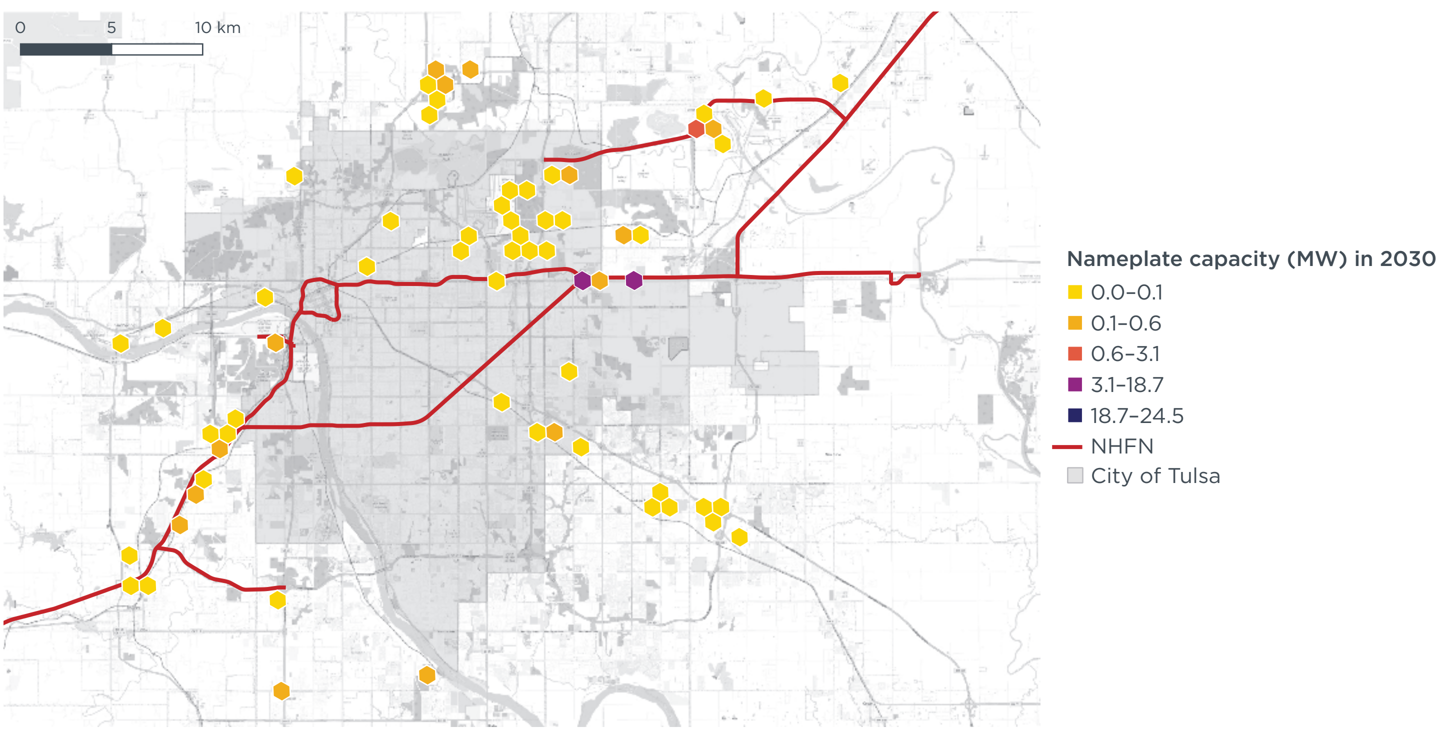

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Figure C9

Tulsa charging nameplate capacity under the Market Potential scenario (2030)

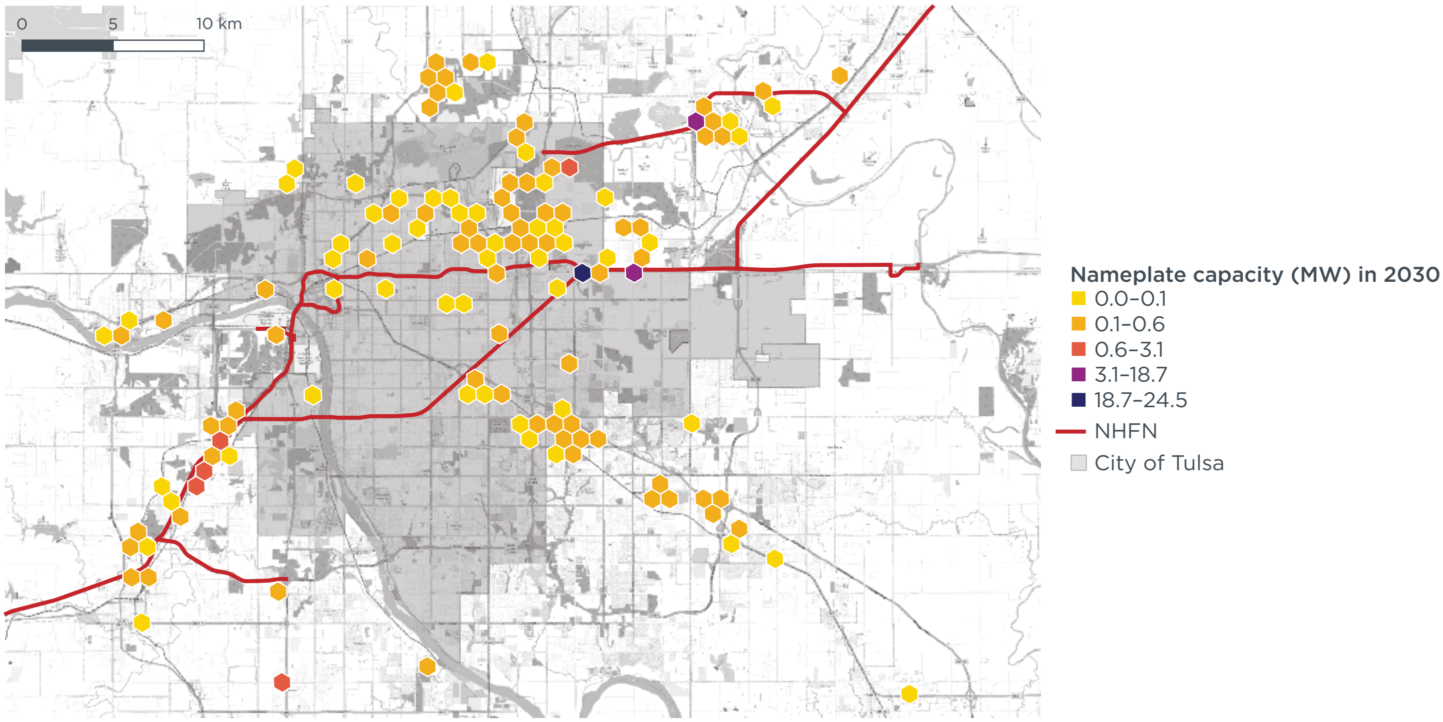

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Figure C10

Tulsa charging nameplate capacity under the Reference scenario (2035)

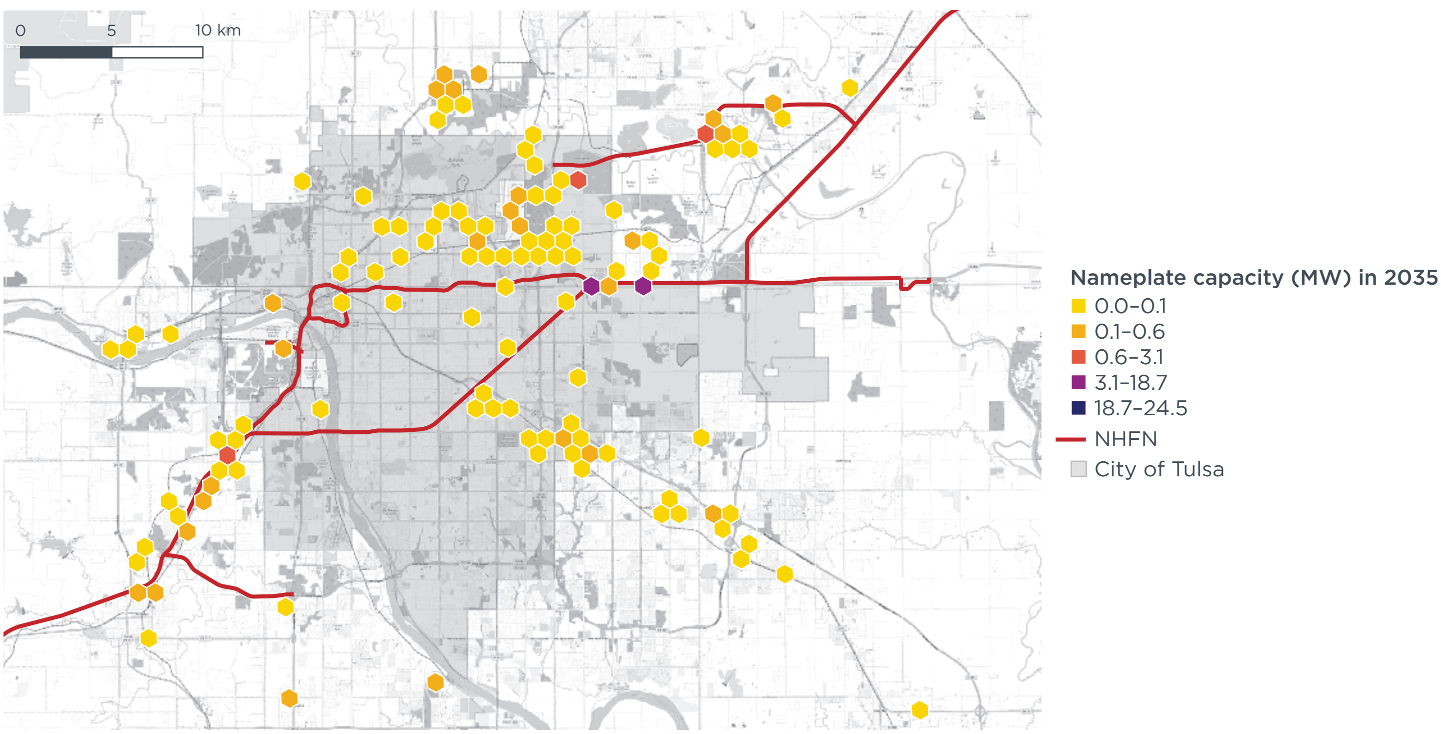

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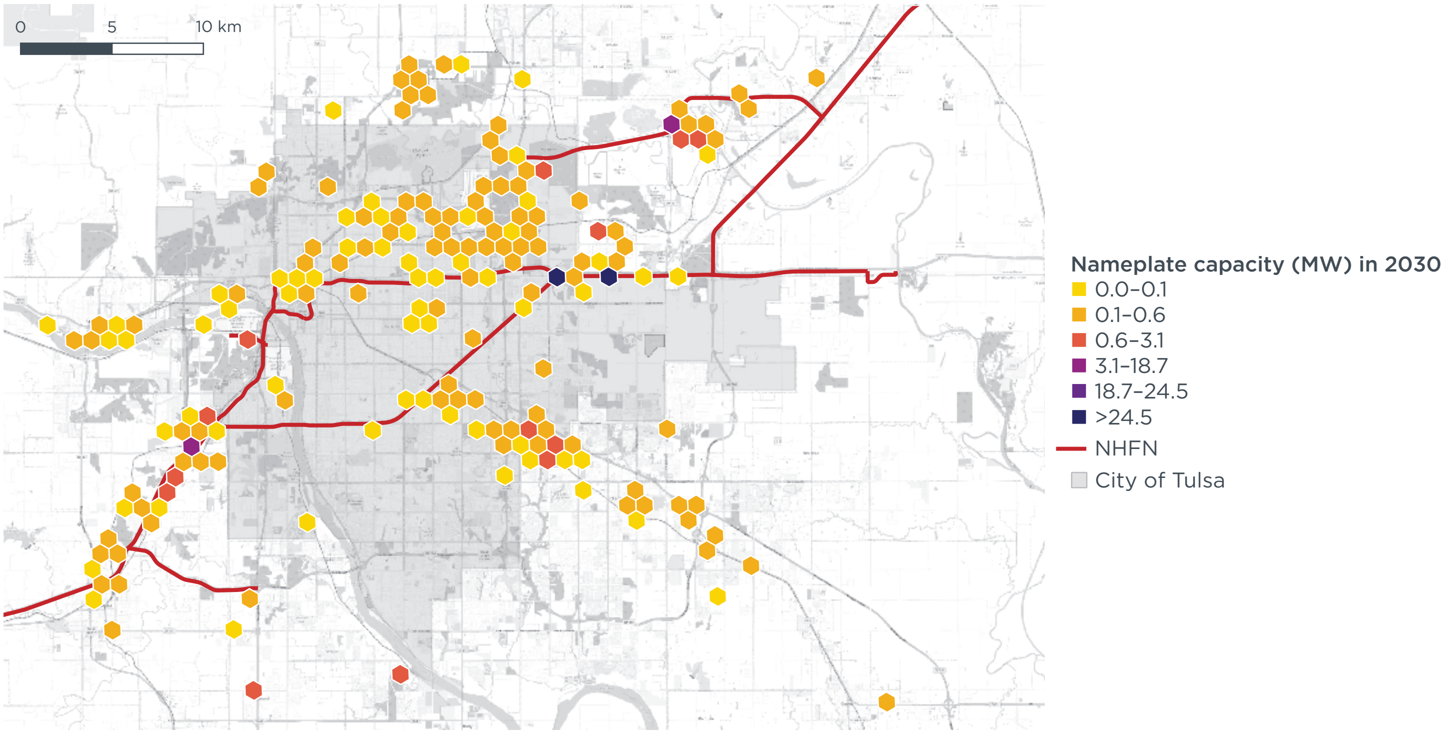
Figure C11

Tulsa charging nameplate capacity under the Market Potential scenario (2035)



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www.theicct.org

communications@theicct.org

@theicct.org

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