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International Zero-Emission Heavy-Duty Vehicle Infrastructure: Policy Playbook

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White Paper

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Executive Summary

This white paper summarizes recent efforts to incentivize and require the installation of charging infrastructure for battery electric medium and heavy-duty vehicles and identifies some key strategies for policy makers around the world. It reiterates recent findings such as by ICCT that regulatory actions, complemented by direct government funding for charging infrastructure, along with private sector incentives, are needed to rapidly ramp up this infrastructure to keep pace with the expected growth in battery electric trucks (BETs) and buses (BEBs) around the world, as covered in a companion document (*Zero-Emission Trucks: Benefits Analysis and Policy Synergy Recommendations*).

Based on this report and as reported in ICCT (2022 and 2023), here we highlight several key recommendations. Many others are contained in this report. These will likely continue to be refined as governments, OEMs, utilities, fleets and other stakeholders gain experience; as very few countries have as yet implemented these types of approaches, or even have much charging infrastructure in place yet for medium or heavy-duty vehicles. But these reflect our best understanding of approaches that can work, and that are needed, and are believed to be important considerations in developing policy. These points are supported by a range of examples in the document, including the last section that summarizes additional concepts.

Set installation targets for charging infrastructure to align with expected ZEV growth. Designing infrastructure targets that align with the pace of ZEV growth will help ensure broader geographical coverage of chargers. If possible, these targets are most effective in promoting ZEV transition when they carry binding obligations for public and private stakeholders to ensure that infrastructure deployment matches the needs of different vehicle types and travel patterns. The recently enacted European Union "AFIR" regulation (described below) does this.

Ensure sufficient charging and system power output is available ahead of demand. A range of efforts in California are directed at planning ahead, as described below. As California's approach also shows, coordination between energy, transportation, and environment agencies and electricity utility regulators is needed to streamline policy implementation and help ensure smooth and adequate charging infrastructure rollout.

Use regulatory tools and incentives to address charging gaps and improve the business case for private investment. Governments that seek to limit the role of public funding in the long-term need policy mechanisms that encourage efficient and faster deployment of private capital. Targeted regulations and allocation of public grants to the most challenging applications will improve the business case and promote equitable access. This will ultimately achieve scale more quickly and help ensure that more of the cost of infrastructure is shifted to the private sector over time.

Empower utilities to support ZEVs by designing electric vehicle-friendly rate structures and encouraging smart charging, where this makes sense. When utilities have a long-term view of grid requirements for the future vehicle fleet, they can plan for and invest in upgrading the grid effectively, if proper regulations are in place. Regulators can enable public and investor-owned utilities to pay for grid upgrades through phased introduction of new rate structures for electric vehicle charging. This can support new utility business models while limiting the impact on low-

income electricity consumers. Promoting smart charging capability increases the utilization of existing capacity and can potentially defer unnecessary grid upgrades.

Reduce lead times for infrastructure projects. Many charging infrastructure projects require extensive permitting, along with investments by the utility to provide "make ready" infrastructure such as upgraded power systems to serve charging locations. This can take many months to several years for all steps to be completed and initiate charging operations. Governments can help speed this process through permitting reform, directives to upgrade equipment in anticipation of expected charging infrastructure investments and ensuring good communication between different key stakeholder groups.

Consider promoting alternative business models that provide charging services. Alternative business models like "Charging as a Service", i.e. outside sourcing of charging management may be needed to help some fleet owners manage the high upfront costs and technology risks associated with installing and operating charging systems, and reduce the need for them to develop their own expertise. Governments can encourage these and foster private-sector involvement by designing flexible subsidy schemes and de-risking investments by transferring a portion of the risk to third parties or providing financial guarantees themselves."

1 Introduction

As countries adopt targets and policies for the uptake of zero-emission trucks and buses (as described in the companion document, *Zero-Emission Trucks: Benefits Analysis and Policy Synergy Recommendations*), there is a strong need to concurrently develop plans for, and installation of, appropriate infrastructure for those vehicles. This short report focuses on charging infrastructure, key actions needed, and what has been adopted so far by various countries to either promote or directly require (and/or fund) needed infrastructure.

This also draws on information provided in our companion report [title/link here], that provided details of policies to require or promote the adoption of the zero emission vehicles themselves. Recent reports by ICCT also provide important insights to this white paper. We look at recent reviews of (US) studies of the number of chargers that may be needed, and various policies that are in play now, mainly in the US and Europe, to provide those chargers.

The numbers needed will soon be quite large as the number of zero-emission trucks and buses rise, rapidly, in these markets. Getting the needed numbers of chargers deployed, both private and public, across different power levels for different situations, will be quite challenging.

2 A review of Charging Requirements for medium and heavy-duty vehicles in the US as a case study

For trucks and buses in the US, or anywhere, charging facilities will be needed in a certain ratio to the numbers of vehicles. If rapid growth in vehicle uptake is expected (or required), investments in infrastructure will need to happen concurrently or slightly ahead, and this will create a range of challenges. The exact number and types of chargers will depend on the types of charging that vehicles need; either at their own depot (private charging) or over the road, for example. The power level of chargers will also need to be tailored to particular needs for how rapid the charging must be (e.g. slower chargers for overnight charging and faster chargers for daytime, “real time” charging). To better understand the landscape of the current research on charging needs for electric medium and heavy-duty trucks in the United States in the near term, UC Davis has reviewed a range of studies of this type that have been published in the past 2 years. Here we present a simplified picture of some of the results, to provide an indication of the types of ratios that might be needed. Countries should undertake their own studies of this type as they develop infrastructure policy. Our findings are as follows:

- Across reviewed studies for the US, the charger-to-vehicle ratio ranges from 0.42 to 1.15 chargers per vehicle, with an average of 0.71 chargers/vehicle. Studies that have focused just on California have estimated a similar ratio, on average.
- Projections of the total number of battery electric trucks, for example in 2030, varies significantly across reviewed studies, which significantly affects the total number of chargers needed. This ranges from 486,000 to 2,950,000 for the US and 112,000 to 155,000 for California.

- Among reviewed studies that provide information on the percentage of electric trucks charging at different types of charging sites, the percentage of vehicles[1] charging at their own depot (also considered as private charging) ranges from 75% to 90%, while the percentage of on-road charging (typically considered as public charging) ranges from 10% to 25%. This percentage can significantly affect the numbers and types of chargers needed.

Figure 1 depicts the comparison of the charger-to-vehicle ratio in reviewed studies where available. (McKenzie, et al. 2021) and (Short, Shirk and Pupillo 2022) provide the range of charger-to-vehicle ratio in their studies because of different scenarios they developed. Thus, as shown in Figure 1, we separated the range into the low-end point and the high-end point.

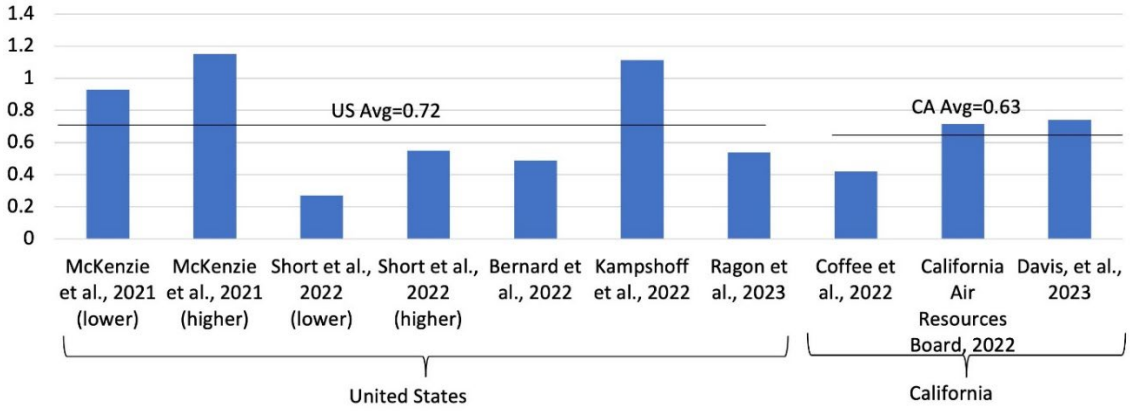

Figure 1. Charger-to-battery-electric-truck ratio to 2030 in reviewed studies (Source: UC Davis analysis for this report, 2024)

Again, there are many reasons for differences in the averages shown in the figure, and countries need to undertake their own research to derive detailed numbers that are suitable in their context. For example, one reason to explain the difference in charger-to-vehicle ratio is the difference in the assumption of charger composition. For example, three studies (i.e., (California Air Resources Board, Draft 2022 State Strategy for the State Implementation Plan 2022), (Coffee, et al. 2022), (Davis, et al. 2023)) have close estimations on medium- and heavy-duty electric truck stock in 2030; however, they have different visions for the charger composition in 2030. (Coffee, et al. 2022) estimate that more public level 2 charging will be needed to support the electrification of medium- and heavy-duty electric trucks in California while (Davis, et al. 2023) project that more chargers will be needed at depot charging rather than public charging. (Davis, et al. 2023) estimate that nearly 95% of the chargers will be for depot charging while estimation from (California Air Resources Board, Draft 2022 State Strategy for the State Implementation Plan 2022) is about 88% by 2030. Additionally, California Air Resources Board has a lower estimation of charging need with a smaller fleet size to support, compared to other estimations in (Davis, et al. 2023).

[1] Vehicles here usually refer to class 3 to 8, excluding long-haul; and personally owned class 4 to 8, along with long-haul trucks, are assumed to use on-road (also as public) charging in some studies.

The remainder of this report provides examples of important policies and regulatory systems to promote and require charging infrastructure to be developed in a manner that serves the growth in MHDVs. These policies may be appropriate for other countries though every location is different and rules will need to be tailored to local and national circumstances.

3 EV Infrastructure Policies – Examples and lessons from around the world

The following provide a range of examples and descriptions of programs to require or promote EV charging infrastructure installation and operation around the world, and in some cases alternatives to traditional business models to encourage charging, or to charging itself.

3.1 US National Policies – Developing the EV charging backbone with NEVI

The US government has adopted a range of funding programs to support the market development of both light-duty and medium/heavy duty ZEVs and ZEV infrastructure, but clearly the largest and most important is the $5 billion National Electric Vehicle Infrastructure (NEVI) Program (NEVI, 2023). This program provides dedicated funding to US states to strategically deploy EV charging infrastructure around the country along the nation's highway system, and even more specifically, the designated *Alternative Fuel Corridors* (AFC, 2023) within this system.

When the national network is fully built out, funding may be used on any public road or in other publicly accessible locations. Funding may not be used for private infrastructure and (until completed), only for the designated "alternative fuel corridor" routes. The funding can be used at state discretion (with a state plan submitted to DOT) on light-, medium- and heavy-duty infrastructure. States are expected to fund infrastructure for all vehicle types. Highway rest stops are often locations used by all types of vehicles, so it makes sense to include all types of infrastructure projects in such locations.

NEVI funding is available for up to 80% of eligible project costs, including:

- The acquisition, installation, and network connection of EV charging stations to facilitate data collection, access, and reliability,
- Proper operation and maintenance of EV charging stations; and,
- Long-term EV charging station data sharing.

To receive funding, states must submit plans to the FHWA and the Joint Office of Energy and Transportation (JOET, 2023) for review and public posting annually, describing how the state intends to distribute NEVI funds. The FHWA announced approval of all initial state plans on September 27, 2022 (NEVI, 2023). State NEVI plan updates are due annually, most recently on August 1, 2023 (NEVI, 2024).

3.2 Complementing NEVI: US DOT "Charging and Fueling Infrastructure" Charging Grants

Complementary to NEVI, the US Dept. of Transportation, Federal Highway Administration, has administered a Charging and Fueling Infrastructure (CFI) Discretionary Grant Program (DOT, 2023). Locations outside the alternative fuel corridors (such as urban locations) are eligible for grants in this program. During 2022-23 the program announced grants for 47 EV charging and alternative-fueling infrastructure projects in 22 states and Puerto Rico, including construction of approximately 7,500 EV charging ports.

While the vast majority of grants during 2023 were directed at public charging for LDVs, a few included infrastructure for medium/heavy duty vehicles. The most notable was for a major trucking hub in California. It included $56 million to construct two state-of-the-art truck charging sites in California to support two of the nation's busiest freight corridors. The sites will feature 90 DC fast chargers for passenger vehicles, 85 DC fast chargers for medium heavy duty electric vehicles, and 17 one-megawatt charging level chargers. The sites will also enhance grid stability with 63 acres of solar panels and battery electric storage systems. This type of grant will likely be replicated many times around the country in the coming years, in line with the expected roll out of heavy-duty electric trucks around the country.

3.3 European Union: Alternative Fuels Infrastructure Regulation (AFIR)

On March 28, 2023, representatives of the European Commission, the European Parliament, and the Council of the European Union (EU) agreed to a new EU Alternative Fuel Infrastructure Regulation (AFIR, 2023). For passenger cars and vans, the regulation will require EU Member States to ensure fast-charging stations at least every 60 km along the core corridors of the Trans-European Transport Network (TEN-T) by 2025. By 2030, this requirement extends to all smaller roads—the comprehensive TEN-T. For trucks and buses, 15% of the entire TEN-T (core and comprehensive) must be equipped with fast-charging stations at least every 120 km by 2025, increasing to 50% by 2027, and 100% by 2030. By 2030, the maximum distance between stations will be 60 km in the core TEN-T and 100 km in the comprehensive TEN-T. (ICCT, 2023)

Previously, the Alternative Fuels Infrastructure Directive (European Union, 2014), or AFID, required Member States to develop national policy frameworks for ensuring sufficient coverage of recharging and refueling infrastructure. The 'Fit for 55' package includes the new Regulation (AFIR) updating the earlier Directive and setting several mandatory requirements for the deployment of alternative fuels infrastructure in the EU. The legislation, recently finalized, does not only address needs of road vehicles, but also vessels and aircraft (European Union, 2023).

AFIR for the first time set legally binding national and EU-wide targets for the deployment of alternative fuels (electricity, hydrogen, and liquefied methane) infrastructure for road vehicles (including passenger cars, vans, trucks, and buses, but excluding 2- and 3-wheelers), vessels, and stationary aircraft.

AFIR not only requires European Member States to ensure the construction of a minimum network of charging and refueling stations along the TEN-T, but it also requires the development of a wide

range of technical standards. The choice of a regulation, rather than a directive, follows calls from both original equipment manufacturers (OEMs) and non-governmental organizations (NGOs) for greater political commitment (ACEA, BEUC and T&E, 2021).

The Regulation is also a better fit to integrate binding requirements on alternative energy infrastructure distribution facilities.2 The Regulation introduces minimum requirements for light and heavy-duty vehicles. It also covers electric road systems, but only in terms of technical standards.

For heavy-duty vehicle charging stations, or "pools", power requirements range from 1400 kW to 3600 kW per pool with individual chargers powered up to 350 kW charger), with increasing numbers of pools and charging levels required over time, to 2030. (European Union, 2023).

The Commission will report by end 2024 on the technology and market-readiness of different options, also regarding technical specifications for charging and refueling (European Union, 2023).

3.4 California: A suite of EV infrastructure policy innovations

3.4.1 Streamlined Permitting

Charging infrastructure typically requires installations of major, expensive equipment, generally involving permitting. This permitting can often be new to national and local authorities and be considered non-routine. The time for permitting can be as long as several years, in some cases.

In 2021, California enacted AB 1236 and AB 970 to ensure consistent state-wide permitting standards and timely and cost-effective installation of chargers. The goal was to make California "the most straightforward place in the country to install market enabling ZEV charging and fueling infrastructure" (CA GoBiz, 2021a).

These laws require cities and counties to adopt streamlined permitting procedures for electric vehicle charging stations (EVCS), including a streamlining ordinance and checklist. City and county streamlining status is reflected on the EVCS Streamlining Map and jurisdictions are graded based on the Permitting Electric Vehicle Charging Stations Scorecard.

Specifically, AB 1236 requires cities and counties to adopt an ordinance that creates an expedited, streamlined permitting process for EVCS. The Scorecard lists the AB 1236 criteria that must be included in a jurisdiction's ordinance (CA GoBiz, 2021b). Some best practice examples of ordinances for jurisdictions that meet all 7 scorecard criteria are linked below:

- City of Redlands Municipal Code Title 15, Section 15.58: Electric Vehicle Charging Systems
- City of Fresno Municipal Code Chapter 11, Article 1, Section 11-113: Electric Vehicle Charging Stations Review Process

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2 Derogations apply for portions of the network with low frequencies of use.

- San Luis Obispo County Municipal Code Title 19, Section 19.09.016: Expedited permitting for electric vehicle charging stations

Jurisdictions have flexibility to determine how to best develop a permitting checklist based on their permitting process. Once a city or county decides what information is required in an EVCS permit application, it is a best practice to combine those requirements and any helpful guidance into a single checklist document. The checklist should make the application process clear and straightforward for the applicant and must be available online. Some jurisdictions combine their checklist and application into one document for submission.

3.4.2 Encouraging Utilities to "pre-build" charging capacity

California Assembly Bill 2700, passed in 2022 (CA 2022) takes a first step in allowing utilities to "pre-build" capacity and calls for California utilities to incorporate fleet data to ensure the distribution grid is ready for medium- and heavy-duty vehicle charging. The bill sets out both a framework for data to be collected from fleets regarding EV planning, and guidance to utilities to use this data to plan for the demand growth implied therein.

The bill requires several California agencies to work together to collect data from medium and heavy-duty fleets on their plans, and share this data with electric utilities to help them prepare for coming increases in demand in specific locations. Utilities will need to act on this information and facilitate the readiness of their distribution systems to support the anticipated growth. The point is to avoid having utilities wait until vehicles are purchased or even depend on pre-purchase requests from fleets for charging related infrastructure, and plan ahead to anticipate such requests.

3.4.3 California Funding for infrastructure

ZEV charging and refueling infrastructure can be expensive, especially when new in an area or for small volume installations (or at least expensive on a per-unit basis when small). Direct funding of infrastructure installations, or tax credits or other incentives for private investments, can help spur both these installations and bigger commitments to the vehicles that use these.

The Clean Transportation Program, overseen by the CEC (CEC 2021a), sponsors programs that change California's fuel and vehicle types to assist the state to achieve its climate change policy goals. As part of the Clean Transportation Program, the California Electric Vehicle Infrastructure Project (CALeVIP) was created to stimulate breakthroughs in transportation and fuel technology in California. CALeVIP addresses regional needs for electric vehicle (EV) charging infrastructure across the state, while also supporting state aims to enhance air quality, battle climate change, and reduce petroleum consumption [CALeVIP 2021]. CALeVIP offers incentives for the installation of electric vehicle chargers and collaborates with local partners to develop and implement projects that meet current and future regional EV needs for Level 2 and DC fast charging up to 350kW. The statewide initiatives attempt to create a streamlined process to close substantial gaps in charging availability. The Energy Commission periodically adds funding for new CALeVIP programs. Notably, in 2021, the California Energy Commission approved a 3-year, $1.4 billion charging infrastructure plan with half the funds earmarked for disadvantaged communities (CEC, 2021b).

3.4.4 Public Utility supported infrastructure funding

Public utilities, such as electric utilities, can fund the construction of charging stations and add these costs to their rate base, if approved by the public utility commission. For example, three pilot schemes for the installation of charging infrastructure for light-duty vehicles were approved by the California Public Utilities Commission (CPUC) in 2014 [CPUC 2021]. PG&E, SCE, and SDG&E executed these initiatives, which included charging infrastructure at destination areas such as sports arenas, malls, and workplaces, as well as vehicle fleets such as municipal vehicles and multi-housing homes such as apartment buildings. A total of $202 million in electric rate-based funding was approved for the installation of up to 10,000 ports, with 8,563 already operational.

Pursuant to AB 1082 and AB 1083, the CPUC approved $54.5 million for PG&E, SCE, SDG&E, and Liberty Utilities to install about 940 charging ports at schools, parks, and beaches. Depending on the utility's program, anything from 25% to 100% of these installations will be in low-income areas. In early 2021, the four IOUs started the initial phase of implementing the pilots. This refers to PG&E's EV Schools and Parks Program, SDG&E's Power Your Drive Program[3], SCE's Charge Ready Schools and Charge Ready Parks Pilot Programs[4], and Liberty Utilities' School/State Park Charging Program[5].

The EV Fleet Program from Pacific Gas & Electric (PG&E) provides competitive incentives to help medium- and heavy-duty vehicle fleets install EVSE. PG&E provides specialized electrical infrastructure design and construction services, as well as lower electrical infrastructure construction prices [PG&E 2021b]. Schools, transportation agencies, and disadvantaged communities are all eligible for rebates on the purchase and installation of new EVSE. Transit or school buses, medium-duty vehicles, forklifts, truck stop electrification, transportation refrigeration units, port cargo trucks, airport ground support equipment, or other Class 8 vehicles are all eligible to receive this support. The rebate amounts vary by power level are ranging from $15,000 for equipment up to 50 kW to $42,000 for that over 150kW.

4 China's "Batteries as a Service" program and "as a service" programs generally

This section considers alternative business models that may particularly benefit fleets by reducing their risk and focus on solving difficult charging-related issues. These are typically termed "as a service" models. Charging as a Service (CaaS) is a subscription-based charging package that provides turnkey electric vehicle charging solutions that removes the burden of ownership and

[3] https://www.sdge.com/residential/electric-vehicles/power-your-drive/power-your-drive-for-schools-parks-and-beaches

[4] https://www.sce.com/evbusiness/pilot-programs

[5] https://california.libertyutilities.com/portola/residential/drive-electric/charging-program.html

maintenance and provides expertise. Battery as a Service (BaaS) does this in a vehicle "battery swapping" context, where fleets subscribe to a system that allows them to refresh their battery packs at swapping stations, and reduce or eliminate the need to worry about charging their own vehicles. The point in both cases is to minimize the risk undertaken by fleets, and shift this risk to service companies, which may be better prepared and better able to operate with such risk.

In the case of charging as a service, the CaaS provider deploys, installs, operates, and maintains the charging infrastructure (ICCT, 2023). Additionally, they can assist with planning for future system expansion, coordinate with the local utility, manage charging times to minimize the energy bill, and guarantee that the vehicles will be fully charged when they need to be operated. Fleet operators either pay a monthly fee for the service or can be charged based on their use of the infrastructure. CaaS can be provided by a truck manufacturer, utility provider, infrastructure operator, or a third-party organization, and there are examples of each (ICCT, 2023).

In the case of battery-swapping (BasS) services, there must be involvement and coordination between vehicle manufacturers (to create compatible vehicles), fleets (willing to buy such vehicles) and the service provider (who must ensure that both other group's needs and business models are met). There are some advantages built into this system; for example, fleets may be able to purchase only the truck bodies without any batteries, making the vehicle purchase cost much cheaper. Vehicle manufacturers may be able to join a system that has network benefits, and an ensured market for future sales (if other OEMs don't join the same program).

BaaS for trucks has so far been most successful in China, where tens of thousands of trucks are now part of battery swapping programs (ICCT, 2023c). The Chinese central government has expressed clear support for battery-swapping enabled heavy-duty trucks for short-haul applications at ports and mining sites, and as part of urban logistics solutions (NRDC, 2022). In October 2021, China launched a two-year pilot program to promote the application of battery-swapping technology in 11 cities.

5 Some Additional Strategies

There are many other actual or potential strategies for promoting the roll out of EV charging infrastructure, including important concepts coming out of recent experience. The following examples particularly draw from ICCT (2023), which outlined a range of strategies that help round out our presentation of existing policies and programs. These can help provide additional ideas and structure to thinking around accelerating infrastructure deployment and assisting fleets to electrify. Key points include:

1. **Help improve business models and conditions.** Governments can support charging infrastructure deployment and enable faster fleet transition when business opportunities for charge point operators are less evident. The goal is to incentivize planning from both the fleet and the electricity utility sides and ensure electric utilities are proactive and engage deeply in the process.
2. **Address electricity system constraints.** For large charging infrastructure deployment, there might be some grid constraints, mostly at the distribution stage (the generation and transmission stages are expected to be less of a bottleneck). While an already constrained grid can mean a significantly longer wait time before those interested get a functioning

charger, there are temporary mitigation measures and actions to increase the load factor of the existing grid that can be implemented so that companies can still electrify while the grid is being upgraded.

3. **Address the disconnect between the electricity and transportation sectors** by encouraging electric utilities to design fleet-friendly rate structures for EV charging, such as preferential night-time rates. This should also ensure collaboration between the groups via workshops and training programs to fleet operators. Fleet operators are historically more knowledgeable about transport than they are about the energy sector, and electricity utilities are historically less knowledgeable about the transport sector's needs regarding charging infrastructure; programs should bridge this gap.
4. **Ensure a base level of public charging infrastructure** by ensuring a holistic plan for network coverage, and providing subsidies and financing options for privately funded projects. Ensuring basic coverage for the public charging infrastructure network is important for small fleets that might not have the financial ability to install private chargers, for long-haul trucks that do not return to the same location every night, and to give confidence to fleet operators.
5. **Encourage private charging investments.** While public charging is critical, private charging is likely to be the dominant form, especially for "return-to-base" vehicles often owned by large commercial fleets that favor building and owning infrastructure dedicated to their fleet. Private charging investment subsidies can help kick-start the markets can ensure regulatory certainty to foster private investment.
6. **Address low utilization in financing systems.** Financing options that align repayment with the level of charger use can also be provided to address the uncertainty of ZEV adoption rates faced by developers and investors, so they can invest in charging and refueling infrastructure with confidence.

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