DOCKETED	
Docket Number:	19-IEPR-04
Project Title:	Transportation
TN #:	228787-46
Document Title:	NACFE - Amping Up - Charging Infrastructure for Electric Trucks 2019
Description:	N/A
Filer:	Wendell Krell
Organization:	California Energy Commission
Submitter Role:	Commission Staff
Submission Date:	6/19/2019 9:22:42 AM
Docketed Date:	6/19/2019

AMPING UP: CHARGING INFRASTRUCTURE FOR ELECTRIC TRUCKS

Widespread innovation and technological advances are producing technologies and practices that could affect decisive, revolutionary, and potentially disruptive opportunities across the transportation industry. As novel concepts, new applications, and original modes of behavior reach the market, fleets and manufacturers need information on the benefits, challenges, and risks so that everyone can profit in this evolving landscape. The North American Council for Freight Efficiency (NACFE) hopes that by fleet managers, manufacturers, and others using its Guidance Reports in the months and years leading to launch, the first generation of production technologies will perform much better and offer higher return on investments.

This report focuses on charging infrastructure considerations for North American commercial battery electric vehicles (CBEVs). In its previous Guidance Reports, *Electric Trucks—Where They Make Sense* and *Medium Duty Electric Trucks—Cost of Ownership*, NACFE found that while the benefits of electric vehicles can be huge, so are the power requirements for charging them. In fact, the previous reports identified charging infrastructure as one of the largest unknowns and sources of anxiety for fleets considering near-term adoption of this technology. NACFE created this Guidance Report to provide unbiased information detailing the multiple factors to consider in infrastructure planning for charging CBEVs. While there is no “one size fits all” solution to charging, there are common steps and considerations that any fleet considering deployment of electric trucks should undertake in order to ensure they have a complementary and cost-effective charging strategy in place.

This is the third in a series of NACFE guidance reports on electric trucks. It will be followed by Guidance Reports on Class 7 and 8 day cabs and Class 8 long-haul electric vehicles. The goals of this guidance report are to: a) give an overview of electric vehicle supply equipment (EVSE); b) provide information on procuring charging stations and the required electricity; and c) provide common steps and considerations to ensure a complementary and cost-effective charging strategy.

METHODOLOGIES

NACFE’s research for this report included interviewing key people with first-hand knowledge of electric vehicle charging infrastructure at fleets, manufacturers, suppliers, utilities, and industry groups. The report includes an extensive list of references to assist readers interested in pursuing more detail. Interviewees were specifically asked what they would want to see in this report and NACFE has taken care to include these wants in the final report. This report builds off the NACFE Guidance Reports: *Electric Trucks—Where They Make Sense*, published in May 2108, and *Medium Duty Electric Trucks—Cost of Ownership*, published October 2018.

SCOPE OF THIS REPORT

The report covers charging considerations for CBEVs currently in production for freight delivery. Because most CBEVs are currently being deployed in the goods movement sector in the medium-duty urban delivery and drayage sectors, much of the best practices and lessons learned come from these applications. And while we touch on considerations for long-haul CBEVs, much of this information is speculative at this point in time as electric trucks have yet to be deployed for this application in any meaningful way.

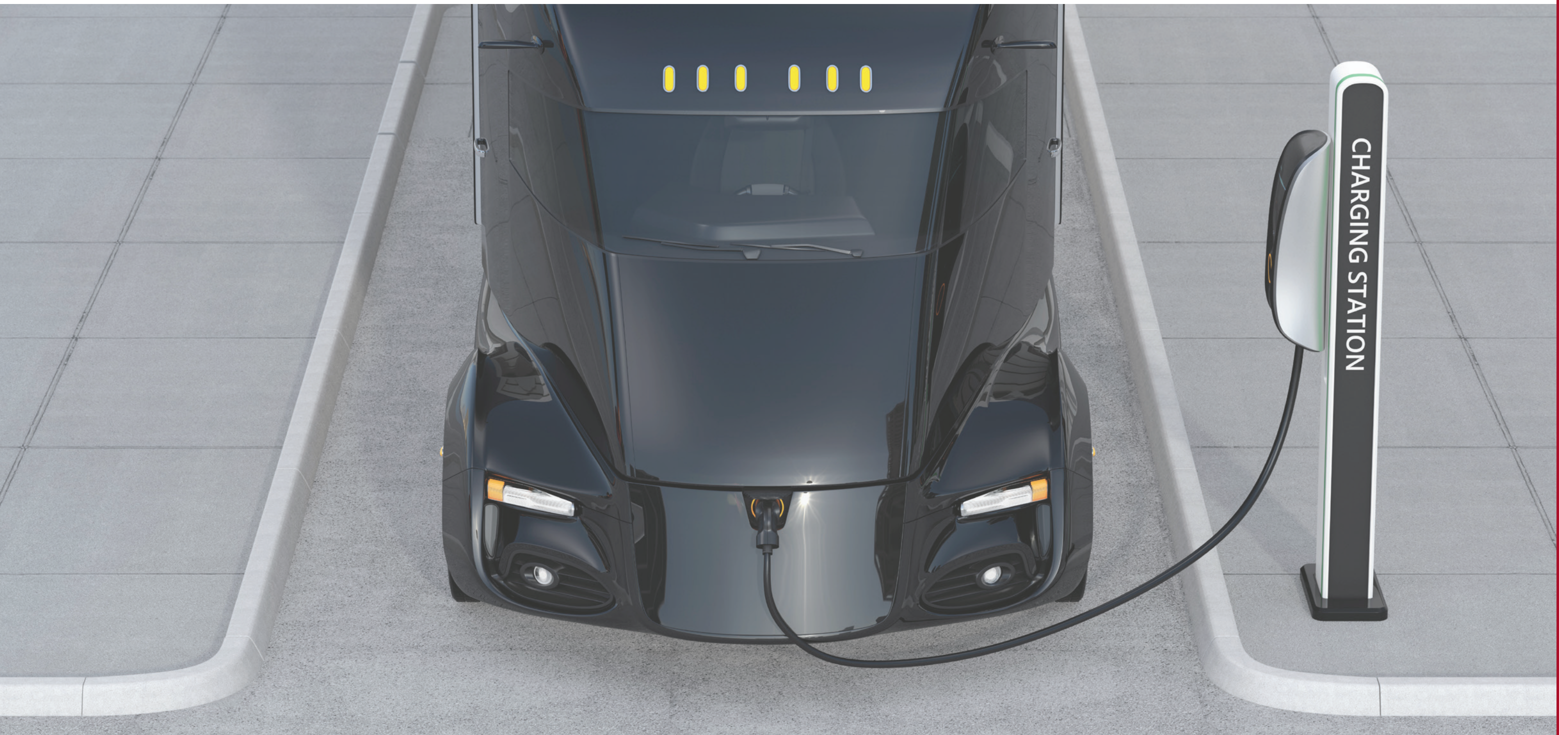


FIGURE ES1

ELECTRIC TRUCK CHARGING INFRASTRUCTURE COMPONENTS

HARDWARE

The physical charging stations, ports, panels, transformers, etc., including wiring/conduit, transformer upgrades, and installation

Does not vary dramatically from company to company. Main differentiators are connector types, speed, and price

Utility programs may cover some hardware costs

SOFTWARE/NETWORKING

Can be built-in to chargers or purchased from third-party vendors to complement chargers' built-in software

Enables cost-effective charging management, along with integration of distributed energy resources (DERs) and grid services

Provides data and analytics to fleet managers to inform charging decisions

Main differentiator between electric vehicle supply equipment (EVSE) provider companies

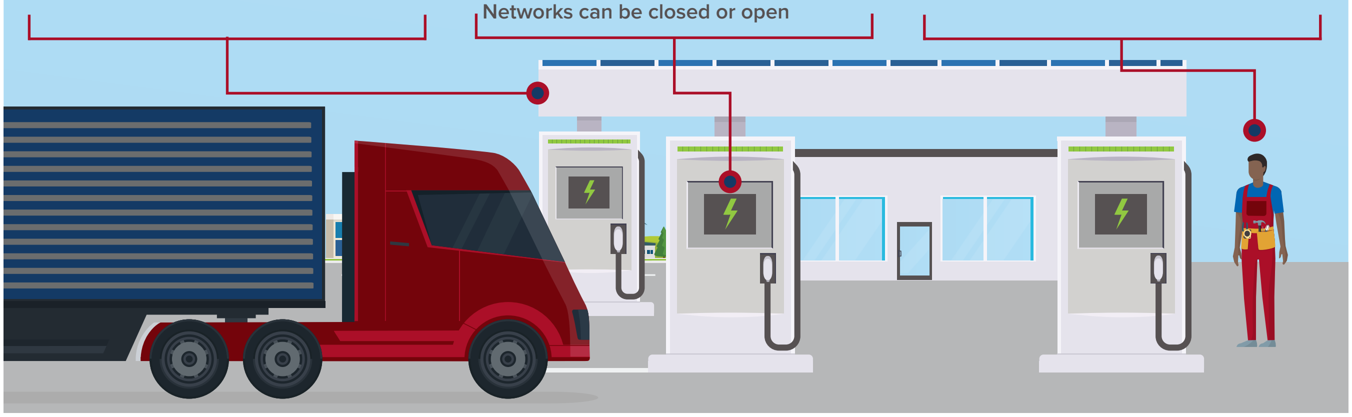
Networks can be closed or open

MAINTENANCE

Timely repair of charging equipment is essential for ensuring vehicle uptime

Service packages available to monitor and repair equipment

Necessary for proactively identifying and addressing issues



INFRASTRUCTURE BASICS

ELECTRIC VEHICLE SUPPLY EQUIPMENT

When planning for charging infrastructure, fleets must plan for three separate but related components: hardware, software/networking, and maintenance.

The hardware consists of the electric vehicle supply equipment (EVSE), also known as a charging station, which charges the batteries of electric vehicles. The most common type of EVSE is a plug-in charging station, which plugs into a port on the truck to recharge it. Unfortunately, charging station connecters are not yet standardized, and there are a number of competing charging station connector types throughout the world (e.g., SAE J1772, CCS, CHAdeMO, Tesla, etc.).

It is important to pair electric trucks with the appropriate type of connector. However, standardizing connectors may eventually occur for regional marketplaces as one configuration wins significant market share advantage over others. In the near term, commercial vehicles may be developed with several adapters to deal with various charging station constraints or forced to use proprietary connections and be limited to proprietary charging stations. Similarly, some charging stations offer multiple connector types to ensure usability across different vehicles. The connector choice may not be an issue for fleets with only one CBEV model and with dedicated A-B-A type routes where the vehicle only charges from its home base. However, if a fleet is using competing CBEV models from different manufacturers but wanting to use the same charging system, there may be need for adapters. Thus, for fleets that choose their vehicles first, they will need to know what type of port the truck has in order to plan which charger type(s) to purchase.

An alternative to charging through wires and plugs is termed wireless power transfer (WPT). Wireless charging protocols are in use with automobiles and some buses. Applicability of wireless charging to trucks is being investigated both in static situations where the vehicle is not moving, and in on-road methods were the vehicle is moving. Although static charging presents the least technical challenge for wireless, currently wireless charging technology appears too expensive for the trucking market, with a few exceptions for niche markets. For example, wireless charging may be an opportunity for heavy-duty trucks to charge while they're waiting to pick up loads from ports. It is also being considered as a solution in port applications where union contracts may prevent workers from physically plugging in charging cables. However, some see a bigger opportunity for wireless charging in the trucking sector.

Other charging options include overhead or in-ground conductive charging systems and battery swapping—rapidly charging vehicles by simply replacing the battery packs.

CHARGING SPEEDS

In regard to charging speed, there are three types of EVSEs: Level 1—a 120 Volt home wall outlet, typically only used for light-duty passenger vehicles; Level 2—a 240 Volt charger; and Level 3—DC Fast Chargers (DCFC).

Since a Level 1 charger is not appropriate for charging commercial fleets, fleets will need to decide between Level 2 or DCFC (or a mix of both) in order to keep their vehicles charged. Level 2 chargers can range from $2,000 to $7,000 and offer upwards of 7.2 kW of power, with some now offering over 19 kW. Depending on duty cycle, many fleets that employ "return to base" or "depot" charging find Level 2 EVSEs adequate for charging overnight or during their "dwell time" between shifts.

However, trucks with larger battery packs and/or shorter dwell times may need to consider DCFCs, which are much faster and also much more expensive. Not including installation or any grid/facility upgrades that may be required, current DCFC stations can cost upwards of $15,000 and as much as $90,000. Deciding which level of charging is right for your fleet depends on how many trucks need to be charged, the size of their batteries, and how long they each have to charge.

FIGURE ES2
TYPES OF EVSE (NACFE)

Type of EVSE	Voltage	Power (kW)	Price	Installation Requirements
Level 1	120 V	1.9 kW	Usually included with vehicle purchase (for passenger EVs)	Most plug-in electric light-duty vehicles come with a cord set capable of plugging into a standard home wall outlet, so no additional charging equipment is required
Level 2	208 - 240 V	7.2 - 19.2 kW	A few thousand dollars per charger	Requires installation of charging equipment and a dedicated circuit of 20 to 100 amps
DC Fast Charge (sometimes called Level 3)	Typically 480 V AC input	72 kW–1 MW (in discussion)	$15,000–$90,000 per charger	Requires installation of charging equipment and dedicated circuit

FIGURE ES3

POTENTIAL REAL-WORLD CHARGING SCENARIOS

Truck	Battery Size	Range	Charge Time with Level 2* **		Charging Time with DCFC* ***	
			To 80%	To 100%	To 80%	To 100%
Chanje V8100	100 kWh	150 miles	3–4 hours	4–6 hours	30–40 minutes	1–2 hours
Freightliner eCascadia	550 kWh	250 miles	17–18 hours	23–26 hours	2.5–3.5 hours	4–6 hours

* Assuming 20% state of charge
** Assuming 19.2 kW
*** Assuming 120 kW from charger and that vehicle capable of receiving 120 kW

For example, as shown in Figure ES3, an electric delivery van may be able to recharge its batteries in 4–6 hours using a Level 2 charger, whereas an electric Class 8 tractor may require the same amount of time to recharge using a DCFC.

Note: The estimates in Figure ES3 assume a 20% starting state of charge for the batteries, that the Level 2 charger delivers 19.2 kW, and that the DCFC delivers 120 kW. It also assumes that both vehicles are capable of receiving 120 kW.

“Fast charging is not really an issue for most medium-duty trucks in the US. Most are one-shift operations with lots of time to charge.”

–Don Francis, Clean Cities Georgia

CHARGER COMMUNICATION

In order to ensure proper charging, the charger must know how much power to provide and when. This is accomplished via the EVSE protocol, which, on a basic level, is a two-way communication between the charger and the vehicle. It detects the battery’s state of charge (SOC) and sets the correct charging current based on the maximum current the charger can provide as well as the maximum current the vehicle can receive. There’s also a safety feature that will prevent current from flowing when the charger is not connected to the vehicle or when there is not proper grounding. EVSE is also capable of detecting hardware faults and disconnecting the power in order to prevent battery damage, electrical shorts, or fire.

The EVSE protocol’s ability to understand battery SOC also creates opportunities for smart charging systems to prioritize the order of charging vehicles based on where power is most needed to optimize charging from the fleet’s perspective rather than by individual truck. For example, a truck with batteries that are 80% depleted will need more power and therefore more charging time than a truck with batteries that are only depleted 30%. Smartly managing these trade-offs and interactions requires appropriate software.

Image courtesy of Wikipedia Commons

CHARGER SOFTWARE AND NETWORKING

Charging software is key for easily and cost-effectively managing fleet charging operations and is now the main differentiator between EVSE provider companies. For example, software is what allows multiple chargers on-site to be able to communicate with one another to optimize sequencing, load management, and variable time of day electricity rates and what ensures that a fleet is charging smartly.

Sometimes, software comes built-in to chargers. Software can also be purchased from third-party vendors to complement the chargers' built-in software. In addition to real-time charging optimization, software is also capable of collecting data and providing analytics to help fleet managers make informed charging decisions.

Most software requires that a charger be connected to a network in order to achieve full functionality. Generally speaking, there are three types of charging station networks: non-networked—typically used in residential applications; closed—which communicate between the charging station and the network server; and open—which allow charging stations to connect to multiple open networks. Particularly when fleets are first dipping their toe into electrification and piloting charging solutions, they may want to opt for open, standards-based networks in case they want to test multiple chargers but manage them all together on one network or in case they want to switch or mix and match chargers in the future.

CHARGER MAINTENANCE

Similar to networking, charging companies may offer very different maintenance packages. These may include services such as proactive monitoring and repair of equipment if needed. Monitoring is important in order to spot and address issues before they snowball into crises. And timely repair of charging equipment is essential for ensuring mission-critical vehicle uptime. Therefore, maintenance packages should be carefully reviewed to ensure they meet fleet needs.

CHARGING LOCATIONS

Charging will roll out in stages, first at a fleets' home depot. Later, fleets may share charging, where a truck goes from its home depot to someone else's home depot, both equipped with chargers. Eventually, remote public charging is expected to emerge on high density freight corridors where distances demand a mid-trip boost or recharge. Charging will evolve as demand grows.

Similar to the personal vehicle market, most commercial vehicles currently charge at "home," or at private, "depot," or "return-to-base" charging stations. Due to the unpredictable "hub and spoke" nature of commercial trucking operations, most fleets currently adopting electric truck technology will want to place chargers at a central home base such as a warehouse, distribution center, or headquarters where trucks start from and return to each day. This type of "return-to-base charging" also makes sense because fleets have full control over site access, charger type, placement, and timing. This may mean redesigning the site, as the vehicles must be co-located with the chargers for some extended period of time to allow charging.

However, charging vehicles at the fleet's base during dwell times between shifts may not be sufficient for vehicles with larger battery packs and/or longer routes. One potential solution, at least for dedicated regional routes, might be to install charging stations not only at the fleet depot, but also at the customer's site(s). This could allow vehicles with relatively long A-B-A routes to charge at point B while unloading, giving them enough of a charge to make it back to their home base for further charging between shifts.

In addition to depot charging, fleets may also consider "opportunity charging" on the road. For example, vehicles may take advantage of the quickly developing public charging network if needed for range extension or in emergencies. However, because of the costs of using public chargers and the uncertainty of availability, vehicles will likely only want to rely on public charging in case of emergency. But knowing that this option exists should relieve some of the "range anxiety" that fleet managers and drivers may feel about potentially running out of power while away from their home base. Regardless of where charging takes place, fleets that invest in charging infrastructure will want to ensure that station utilization is maximized in order to justify the significant expense.

GRID INTEGRATION AND UTILITY BUSINESS MODELS

What is clear, as far as the overall charging system, is that electric trucks will increase demand on electricity. Because of this, grid capacity will need to be improved. New generation may need to be added if increased efficiency in other sectors (buildings, industry, etc.) is not enough to counterbalance the new load from the quickly electrifying transportation sector. Utilities may also need to develop new demand management and/or storage solutions to help balance timing concerns with electricity supply and demand. Similarly, new tariff structures may be necessary in order to encourage smart charging when electricity supply is available, clean, and economical.

Given constraints of the current grid, utilities would prefer that electric vehicles not charge during "peak" times when electricity demand is highest, typically in the late afternoon or early evening when people return home from work and begin doing energy-intensive chores. Rather, utilities are interested in encouraging charging (and other energy-intensive tasks) during "off-peak" hours when the grid has more excess capacity.

The growing demand for electric vehicles combined with state-level greenhouse gas reduction goals and mandates, are causing some utilities to rethink their tariff structures and even to design new tariffs specifically to support EV charging for commercial and industrial customers. This includes implementing time-of-use rates, in which utilities charge a different rate for on-peak versus off-peak times, or demand charges, which allow utilities to charge customers based on their individual peak demand or highest use in a given timeframe. Because of this dynamic, fleets with flexible operations or operations that allow for trucks to be charged at night will likely find charging to be more economical than fleets that may need to charge during the day or all at once to support mission critical operations. However, this dynamic will vary by region and by utility.

Because many utilities earn a profit based on a "cost-of-service" business model that guarantees a "rate of return" on the company's assets or "rate base," utilities are incentivized to build the necessary infrastructure to support transportation electrification, a trend which will likely require them to invest in new assets and therefore earn more profits. With this information in mind, fleets should not be shy in demanding reasonable support and accommodations from utilities to support vehicle charging.

PROCURING CHARGING INFRASTRUCTURE AND ELECTRICITY

There are two main business models for procuring charging stations and associated infrastructure. The most common is by buying the stations outright, often through a request for proposal process. In this scenario, fleets may hire a consultant to help make these decisions and set up the infrastructure (and potentially also help manage the relationship with the utility), but in the end, the fleet owns and manages the chargers, which are then considered a capital expense.

The other way is through leasing in which the supplier owns the stations and the fleet simply pays a fee for using them. This model allows the fleet to pay for the stations out of their operational expense budget. In both the lease and own options, fleets often pay charging suppliers not just for the physical stations but also for access to their fleet management networks, which again, are a recurring operational expense.

Other innovative business arrangements may be possible, including third parties that step in with capital to create turnkey systems, with various usage rates that could remove the site owner from the complexity of managing part or all of the charging system. Those third parties, similar to an energy service provider in the buildings sector, may specialize not just in infrastructure procurement and installation, but also in optimizing charging, which can have large financial implications. Especially for fleets with little experience or interest in optimizing charging, this sort of "charging-as-a-service" model can be a good option since these third-party companies specialize in this area and therefore may be better able to maximize efficiency and avoid load spikes and demand charges.

ELECTRICITY BUSINESS MODELS

Just as there are various ways to procure the charging infrastructure, there are also various ways to procure the electricity. Most fleets procure electricity the traditional way—through the local utility's electric grid. Depending on whether the region is a regulated or deregulated electricity market, fleets may have options with respect to which company they buy their energy from. In thinking through electricity pricing, fleets must be aware of their utility's rates and if and how demand charges are integrated into those rates.

Fleets can also get their electricity from on-site "behind the meter" solutions such as microgrids and renewables like solar PV. However, integrating systems like these into electric fleet charging systems is a very new concept and no data is yet available as far as best practices.

FINANCIAL ASSISTANCE

Fortunately for fleets, depending on the location and project, there are a myriad of financial assistance programs available to help make vehicle electrification more economically feasible. While some of these funding mechanisms are focused more on the vehicles themselves, some can also help cover the cost of charging infrastructure.

Utilities are typically aware of any financial incentives offered within their service territory, so speaking with a utility representative is usually a good place to start. There are also directories available online that allow fleets to search for funding support by location.

IMPLEMENTATION STEPS AND CONSIDERATIONS

Fleets planning for vehicle electrification must consider many variables for implementation. And while each project by necessity involves some bespoke engineering (since each site and project is different), there are some common factors to consider. A suggested chronological roadmap, including key considerations is outlined in Figure ES3.

The roadmap will have the same general steps regardless of number or size of trucks; however, as fleets scale the number of electric vehicles at each site, the charging procurement process will become exponentially more complex and time-consuming.

FIGURE ES4

CHARGING PROCUREMENT ROADMAP

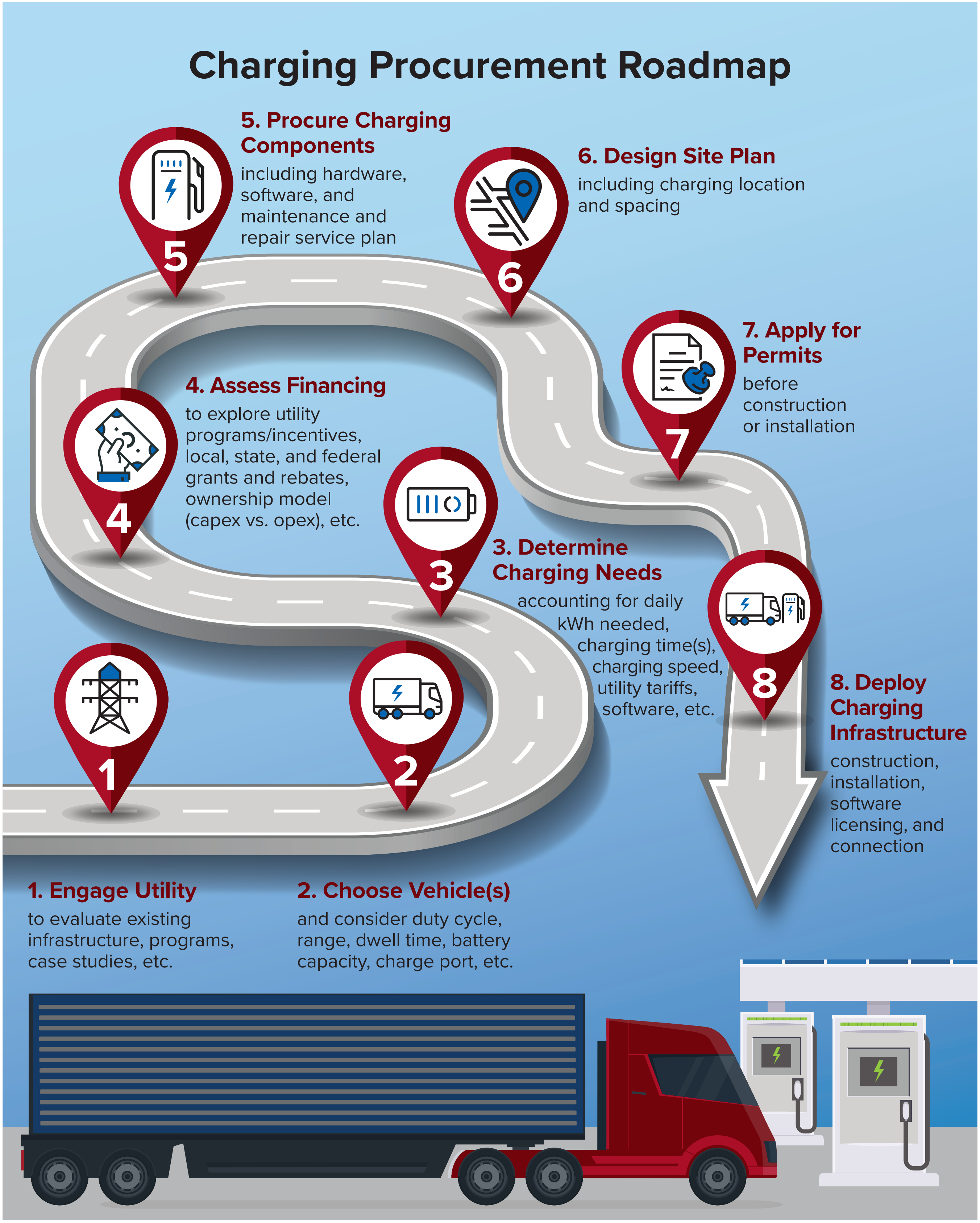
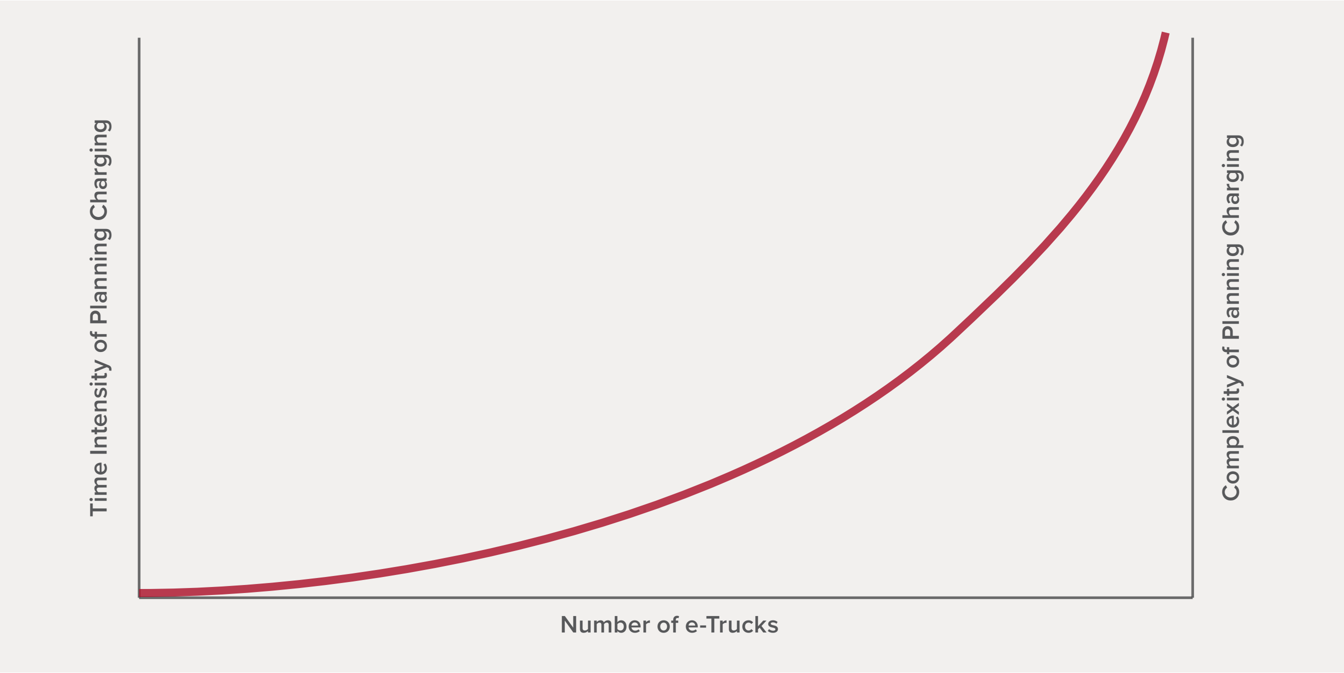


FIGURE ES5

CHARGING IMPLEMENTATION COMPLEXITY



This implementation process may be lengthy, but as more fleets and utilities gain more and more experience, this process will become more streamlined as a common "cookbook" approach evolves.

ADDITIONAL CONSIDERATIONS

In addition to the opportunities and challenges mentioned above, other considerations to take into account when planning for charging infrastructure include employee safety, fueling schedules and operator time requirements, scaling, grid services, integrating renewables, workforce dynamics, ratepayer benefits, and utility business model reform.

"Every charging installation faces a variety of variables—number of trucks to charge, local utility rate tariffs and power delivery structure, existing site and local grid details. There are no rules of thumb."

–Chris Nelder, RMI

Image courtesy of National Renewable Energy Laboratory

CONCLUSION AND RECOMMENDATIONS

NACFE's research into charging infrastructure for commercial battery electric vehicles to date has revealed the following:

- The focus for the foreseeable future of electric truck charging will be on private, "depot," or "return-to-base charging."
- Planning and permitting for charging infrastructure can be a time-intensive process, so fleets should appreciate lead times and start early.
- Fleets planning to electrify some or all of their vehicles should work closely with their local utility, regulators, cities, neighbors, OEMs, and charging system providers.
- Fleets should focus on differentiating products and companies based on their software, network, and maintenance offerings, and should ensure that they are comparing apples to apples during the procurement process.
- Fleets must develop a fairly sophisticated understanding of the existing electric infrastructure and demand, their electricity rates, and the types, number, duty cycles, and time available for charging of their vehicles—or contract a third party to do so for them.
- Fleets should plan on a site-by-site basis since charging infrastructure is not one size fits all.
- Fleet electrification will happen most where special programs are implemented to help mitigate hardware, installation, and electricity costs, at least in the initial stages of technology adoption.
- Fleets should consider investing in smart, networked charging software and services, particularly for deployments of multiple vehicles and/or vehicles with large battery capacities.
- Fleets should demand improvements from technology providers and utilities and inform them quickly of all dissatisfactions.
- As all new technologies go through learning curves, fleets should not make rash conclusions in the first months or year of operation, but realize that solutions will be iterative as experience amasses.

Fleets as well as utilities, regulators, and technology providers are constantly learning and developing in this rapidly evolving space. And innovative utility programs and rate structures are allowing commercial battery electric vehicles to charge successfully and economically in growing areas of the country. However, much broader and faster design and approval of these sorts of programs by utilities and regulators is needed in order to scale electric vehicle adoption across the nation. As much as possible, EV-friendly programs and rate structures should be standardized so that fleets with operations that span multiple utility service territories can scale their electrification efforts without having to reinvent the wheel in each new territory. It's important to remember that utilities are relatively new to the EV charging space, and that although it will require a significant departure from their historical rate structures and business models, it is in their financial interest to support the build-out of charging infrastructure because it offers additional rate-basing investments and load growth opportunities in an otherwise plateauing market.

It is also imperative that utilities understand the important differences between passenger EVs and commercial EVs. Not only is the charging capacity much higher for CBEVs, but they have unique needs and constraints due to their mission-focused operations, which are much less flexible than personal vehicle usage and charging times. As such, CBEVs need to be looked at as a distinct market rather than an extension of the passenger EV market.

"In order for electric trucks to scale, we need both the truck and the ability to charge it. The three keys to infrastructure deployment are standardization, collaboration for construction, and teaming with utility companies for the efficient delivery of electricity."

–Gary Horvat, VP of eMobility, Navistar, Inc.

While the charger itself is the most visible piece of the charging infrastructure ecosystem, fleets must focus more on the big picture than on simply comparing EVSEs. We expect more and more innovative networking and maintenance options to arise. Software will be invaluable as smart charging will be key to minimizing costs while also ensuring mission critical uptime of vehicles. Many business models exist to help manage charging, and fleets will need to decide what trade-offs they're comfortable making between risk management and price volatility. Fleets that develop expertise in smart charging will have a leg up on their peers, though innovative partnerships will allow even fleets new to the electrification space to be successful.

Smart charging and vehicle-to-grid capabilities may also enable new grid services that, if compensated for appropriately, may be a win-win-win for utilities, fleets, and ratepayers. That said, it is imperative that these services are piloted in the real world for further refinement, as they are mostly hypothetical today.

Last but certainly not least, charging infrastructure, though no doubt not sufficient today, should not be considered an insurmountable problem. Thomas Edison's first patent for the light bulb was filed in 1879 well before there was a North American power grid. Light bulb and electric motor technology ignited national development of new infrastructure to adapt society to the new technology rather than forcing the technology to fit poorly into the existing infrastructure. The power grid infrastructure was demand driven based on success of the electric devices that needed it. This lag between product introduction and infrastructure investment has been repeated many times, and there's no reason to think it won't be repeated for CBEV charging infrastructure as well.

THE FULL REPORT

The full report is available at www.nacfe.org and includes 160 references; a robust, current, relevant bibliography of charging infrastructure works; appendices that list charging infrastructure suppliers and utilities with electric truck charging programs; and 91 figures. See the Table of Contents below for more information on the full report:

NACFE

The North American Council for Freight Efficiency (NACFE) is a nonprofit organization dedicated to doubling the freight efficiency of North American goods movement. For the past 10 years, NACFE has operated as a nonprofit in order to provide an independent, unbiased research organization for the transformation of the transportation industry. Data is critical and NACFE is proving to help the industry with real-world information that fleets can use to take action. In 2014, NACFE collaborated with Carbon War Room, founded by Sir Richard Branson and now a part of Rocky Mountain Institute (RMI), to deliver tools and reports to improve trucking efficiency. These reports include a series of Confidence Reports that detail the solutions that exist, highlight the benefits and consequences of each, and deliver decision-making tools for fleets, manufacturers, and others. As of early 2019, NACFE and RMI have completed 18 such reports covering nearly all the 85 technologies available.

www.nacfe.org

ROCKY MOUNTAIN INSTITUTE

Rocky Mountain Institute (RMI)—an independent nonprofit founded in 1982—transforms global energy use to create a clean, prosperous, and secure low-carbon future. It engages businesses, communities, institutions, and entrepreneurs to accelerate the adoption of market-based solutions that cost-effectively shift from fossil fuels to efficiency and renewables. RMI has offices in Basalt and Boulder, Colorado; New York City; Washington, D.C.; and Beijing.

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Trucking Efficiency is an exciting opportunity for fleets, manufacturers, and other trucking industry stakeholders.

Learn more at: www.nacfe.org

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