Charging Down the Highway

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1. Introduction

My last post on this subject (on-road EV chargers) was similar to this one (to a degree) and had a similar name:

Charging Ahead: *It started out with an interesting article from Energy Central. It seemed to point towards a major EV Charger Project in the closest large city (Oakland, CA) to my hometown, Livermore. However, as I read this article, it described a much broader vision, and a consortium consisting of several major energy. real estate and mobility companies. It also promised to solve a major problem associated with EV Ownership. What if a potential owner cannot host an EV charger at his/her residence?*

The solution is obvious: more public fast-chargers. A Level 3 DC fast charger can fully replenish your EV in twenty to thirty minutes. Although this is more time than it takes to fill up an IC-powered car at a gas station, it's in the ballpark.

https://energycentral.com/c/ec/charging-ahead

When I named this post, I didn't realize the similarities, but these two posts are quite different. The above referenced post is mainly about conventional light EV chargers, and this one is about high-power charging for medium- and heavy-duty electric trucks. But before I start the main section of this paper, I need to add a clarifying subsection.

1.1. Large Truck Battery Charging

The largest and longest-distance trucks seem to be evolving to using hydrogen-fuel cells. Although the Tesla Semi (a battery-electric truck) claims a 500-mile range, like with many things that Elon claims, this doesn't seem to be quite true. Based on early customer experience, it seems to be 350- to 400-miles with a typical (full) load and a typical (California) route. For anyone that isn't familiar with my home-state highways, these have plenty of mountain passes.

A earlier-post on heavy trucks reviewed a Kenworth T680 Fuel Cell Electric Semi Tractor, and it claimed a 450-mile range and 20-30 minute (100%) refueling time.[1] But I would note that, outside of my home-state, hydrogen refueling stations are few and far between. As I recall, Elon also claimed an amazingly fast full recharging time, but that was using his specialized "Semi-Charger," and I don't know how many of those are out there.

2. High Power Charging

Just a few years ago, electric trucks seemed like a distant dream. Yet in 2024, American companies deployed more than 15,000 medium- and heavy-duty electric vehicles (EVs)—including battery-electric semitrucks, passenger buses, and delivery vans.[2]

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[1] https://energycentral.com/c/ec/really-big-electric-trucks

[2] Anna Squires, NREL, "The Dawn of Electric Trucking Calls for High-Power Charging," Jan 15, 2025, https://www.nrel.gov/news/features/2025/the-dawn-of-electric-trucking-calls-for-high-power-charging.html

Battery-electric trucks are not the only promising solution to reducing energy use in the transportation sector: Hydrogen fuel cell, biodiesel, and renewable diesel technologies will likely also play a role in helping slash the 20% of harmful transportation emissions produced by trucks. These vehicles are strong contenders to complete long-haul routes, which can often stretch for 1,000 miles or more.

But unlike other alternative fuel vehicles, electric trucks have hit American roads in force. As the e-commerce and freight industries boom, fleet orders for 2024 and beyond are picking up speed, spurred by increasing battery ranges and falling battery prices, lower operating and maintenance costs, and competitively low cost of ownership—in addition to duty cycle analysis showing many regional and local routes can easily be completed by today's EVs.

In other words: The dawn of electric trucks, buses, and delivery vans is here.

Still, heavy-duty electric trucks represent a paradigm shift away from conventional diesel-powered vehicles. Fleet owners, operators, and manufacturers have valid concerns about commercial EVs. Do electric trucks have enough range to complete their deliveries? Is there enough infrastructure available for them to recharge? How fast can they get back on the road? And when will operating commercial EVs cost the same, or less, than their diesel counterparts?

That is why U.S. Department of Energy (DOE) National Renewable Energy Laboratory (NREL) researchers are focused on meeting one of the trucking industry's greatest challenges: scaling up the fast, reliable charging infrastructure needed to power the tens of thousands more commercial EVs expected to hit the roads in coming years.

NREL's transportation researchers have been working on solutions to these questions for nearly two decades—from leading DOE's EVs@Scale Consortium[3] *to building a globally unique high-power EV charging emulation and evaluation facility.*

2.1. Designing Powerful, Reliable, Affordable Chargers

At the heart of the challenge of electrifying medium- and heavy-duty trucks is the nature of high-power charging. While many medium-duty trucks, buses, and delivery vans can charge overnight or during breaks in service using slower, lower-power chargers, the charging calculus changes when it comes to long-haul routes completed by heavy-duty trucks.

To charge a Class-8 semitruck in a matter of hours, for instance, a single charging connector may need to provide at least 350 kilowatts of power. To charge more than one heavy-duty truck at a time, and get them all back on the road quickly, a charging station may need to pump out 20 megawatts (MW) of power or more.

"Imagine plugging in 100 Tesla Model Ys and charging them simultaneously," said Andrew Meintz, NREL's chief engineer for EV charging and grid integration. "That's the same amount of electricity you'd need to fast-charge four or five electric trucks."

[3] The DOE's EVs at Scale Lab Consortium brings together national labs and key stakeholders to conduct infrastructure R&D to address challenges and barriers for high-power EV charging infrastructure. https://www.energy.gov/eere/vehicles/electric-vehicles-scale-consortium

Why do EV trucks need so much electricity? Because they need to be able to haul about 60,000 pounds of cargo over regional or long-haul routes that can span hundreds of miles. Trucks with overweight exemptions might need to haul 100,000 pounds or more. These enormous payloads and long-range requirements demand a powerful battery—not to mention ultra-robust charging hardware that can provide enough power to get EV trucks back on the road in a reasonable amount of time.

In response, NREL researchers have underpinned efforts to develop the Megawatt Charging System (MCS): a global set of standards that will allow EV chargers to provide, and EV trucks to accept, up to 3.75 MW of power at a time.[4]

The MCS addresses critical pain points in existing charging technology by ensuring that high-power EV chargers are reliable and universal. Through evaluation events hosted in NREL's world-class facilities, researchers ensure that high-power EV charging connectors from major manufacturers can provide up to 3.75 MW of electricity, can plug into commercially available EVs, and will not overheat or shock the user, even when misused. For years, after every round of hardware evaluations, NREL researchers have provided EV truck and charger manufacturers with detailed technical files to troubleshoot their equipment, allowing them to produce increasingly higher-quality technology.

"The MCS can provide so much more power than existing light-duty chargers that, rather than taking hours using a light-duty charger, commercial vehicle charge sessions can be completed in 30 minutes or less," said Isaac Tolbert, an NREL EV charging researcher. "The MCS really expands the capabilities and potential uses of commercial EVs for vehicle operators that need to get back on the road faster."

With the final MCS standard pending, NREL researchers have turned their attention to another critical barrier to widespread commercial EV adoption: designing the experimental, interoperable charging facility of the future.

Through the High-Power Electric Vehicle Charging Hub Integration Platform (eCHIP) project, NREL researchers are partnering with Argonne National Laboratory and Oak Ridge National Laboratory to design and demonstrate efficient, low-cost, high-power charging solutions that can function at both the kilowatt- and megawatt-scale.

The eCHIP project hinges on something called "DC distribution." Put simply, the electricity running through the walls of homes and buildings is typically available in the form of alternating current (AC) power. But EVs require direct current (DC) power to charge. Each time energy needs to be converted from AC to DC and back again, some of that energy is wasted. Instead, the eCHIP project aims to create a high-power charging system that distributes DC power directly from electrical sources into EVs—no conversion needed.

Even better, the charging system envisioned by eCHIP researchers will allow for seamless integration of on-site energy production from solar panels, backup power from energy storage systems, and "smart" software controls to optimize the flow of electricity from the grid to EVs.

Together, these strategies can help NREL researchers design the smart, high-power charging facility of the future—and break down critical barriers to fast, powerful, widespread commercial vehicle electrification.

[4] Isaac Tolbert, Namrata Kogalur, Jonathan Martin, and Andrew Meintz, "CharIN Megawatt Charging System: 4th Event Summary Report, May 2024, https://www.nrel.gov/docs/fy24osti/89238.pdf

2.2. The Infrastructure Challenge

EV charging hardware—ports, cables, and connectors—and their electrical distribution systems are not the only components that need to be reimagined for high-power charging. EV charging stations must be able to support multiple medium- and heavy-duty trucks, delivery vans, and passenger buses all charging at the same time.

The difficulty lies in the fact that each kind of EV requires a different power level to charge, Meintz said—and offering high-power charging at the megawatt scale in addition to kilowatt-level charging can require grid upgrades to be made ahead of time.

"The key challenge in EV site design is having a really good estimate of how much load the station is going to generate, where the site will be, and the size of the electrical load it needs to handle," Meintz said. "And then the really tricky part is knowing how all of that could change six years down the line, so you're not building a charging site that's sized to handle only the EVs of today but not future technologies."

For precisely this reason, NREL's transportation researchers specialize in end-to-end analysis of the energy needs for fleets of commercial EVs, their charging requirements, and their larger impacts on the grid.

***To pinpoint vehicle- and fleet-level energy needs:** The laboratory has spent decades building FleetDNA, DOE's largest body of real-world, in-use, high-resolution commercial vehicle data, and sophisticated drive cycle analysis tools. These research tools can provide the exact energy requirements for specific truck, bus, and delivery vans to complete their routes.*

***To design optimized commercial EV charging stations:** After pinpointing the energy needs of fleets of commercial vehicles, NREL researchers can identify optimal vehicle battery sizes, charging rates, and infrastructure placement using the laboratory's Heavy-Duty Electric Vehicle Integration and Implementation Tool, called HEVII. Then, using NREL's powerful Electric Vehicle Infrastructure – Energy Estimation and Site Optimization Tool (EVI-EnSite),[5] researchers can design, model, and optimize EV charging stations that are not only tailored to the needs of commercial fleets but also capable of providing the most cost-effective EV charging possible.*

***To forecast future commercial EV charging needs:** NREL researchers specialize in long-term load prediction analysis. Using a blend of real-world and simulated data, researchers can estimate the EV charging needs of a given region, facility, or charging site for years to come, so grid planners and policymakers can set grid upgrades and infrastructure installation into motion far in advance.*

These capabilities enhance the laboratory's expertise in smart charge management strategies—a critical element in providing cost-effective commercial EV charging.

Smart chargers can help fleets, governments, private businesses, and charging stations to offer cost-effective charging that never overloads the electrical grid. For instance, smart software controls can pull electricity from on-site solar panels or backup energy systems instead of the electrical grid to avoid surge pricing of electricity when multiple EVs are plugged in at once. They can even dynamically adjust the flow of electricity based on how long an EV driver can charge—directing less electricity to vehicles that can park for longer and more electricity to those that need to hit the road.

[5] NREL, "EVI-EnSite: Electric Vehicle Infrastructure – Energy Estimation and Site Optimization Tool," https://www.nrel.gov/transportation/evi-ensite.html

Through EVs@Scale projects such as eCHIP, FUSE, and others, NREL is leading efforts to advance high-power charging, smart charge management, and global charging codes and standards—in other words, lowering the barriers to commercial charging, one by one.

2.3. The Challenge of Scale

A final challenge to widespread commercial vehicle electrification may only become pressing many years down the line. But NREL researchers are addressing it today.

As commercial EV adoption accelerates and charging rates begin to climb toward 3.75 MW of power, demands on the nation's electric grids will increase, too. In the future, when EVs begin to make up the majority of medium- and heavy-duty vehicles on the road, single charging connectors will need to be able to provide thousands of kilowatts of power at a time, and charging sites will need to provide upwards of 20 MW.

Enter a globally unique facility, currently under construction at NREL's Flatirons Campus, called the Megawatt Charging Emulator (MCE).

Using real-world data, the MCE will enable researchers to emulate the charging profiles of several electric trucks, or even non-road vehicles like planes or trains, charging at a single site under different vehicle conditions.

Coupled with the Controllable Grid Interface (CGI), an electrical grid that can generate 20 MW of power—more than double the power of its predecessor—researchers can emulate conditions on both the vehicle and grid that are difficult to replicate in the field. Because it will be linked to several real-time emulators, the facilities will allow NREL's EV charging researchers to run enormous, complex grid emulations of how a grid and the EV charging infrastructure connected to it will function while handling up to 20 MW of electricity.

The CGI is part of NREL's Advanced Research on Integrated Energy Systems (ARIES), the nation's most advanced platform for energy system integration research at scale. Once complete, the MCE will supplement the ARIES platform portfolio, which also contains several resources to integrate energy storage, renewable power, flexible building loads, and other distributed energy resources. One day, it may even support research on electric aviation and electric charging for other transit modes. This globally distinct set of research tools and capabilities makes ARIES capable of addressing the challenges outlined in the U.S. Department of Energy's vision for a supercharged electric grid.

"What we're building at Flatirons is absolutely unique," Meintz said. "It will be the only facility in the world that can emulate both the electrical grid and vehicles. That capability will help us design EV charging hardware and infrastructure that not only operates at the 10 to 20 MW level but can boost the grid's performance rather than placing it under strain.

Final author's comment: I've highlighted some sections of the above text-excerpt from Reference 2. This is to point out an issue with the above concept. The first highlighted text in subsection 2.1 is: *"To charge more than one heavy-duty truck at a time, and get them all back on the road quickly, a charging station may need to pump out 20 megawatts (MW) of power or more."* Regardless of whether this charging station is added to an existing facility or built as a stand-alone facility, it is extremely unlikely that the current local distribution system will support an additional 20 MW.

The highlighted text at the bottom of page 4 recognizes possible solutions: "*For instance, smart software controls can pull electricity from on-site solar panels or backup energy systems instead of the electrical grid to avoid surge pricing of electricity when multiple EVs are plugged in at once.*" Thus, the only way this can exist is to either upgrade this local service (extremely expensive) and/or include a **high-capacity, expandible battery energy storage system (BESS)** in the charging station design. The latter will also have some other benefits for the charging station.

- Allow the charging station to store the least expensive (late night and early morning) energy for use during other hours.
- Allow support of a high-power DC charging circuit within the charging station (see highlighted text at the bottom of page 3).
- Store and distribute power from on-site renewables (like photovoltaic arrays).
- Buffer the high-power requirements of three or four trucks charging simultaneously (as they are likely to do during peak periods).

The good news is that as the batteries in large trucks become less expensive, and thus more viable, the same technologies might be used in BESS (or less expensive, but heavier variants, like using lithium-ion batteries in trucks and sodium-ion batteries for the BESS). Also demand for high-capacity BESS will increase dramatically for other large commercial & industrial facilities, especially those that have local renewable energy generation and/or need to host large electric vehicles (like logistic centers or warehouses).