Electric Transportation and Distribution Infrastructure: a Heavy-Duty Vehicle Deep Dive

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Commercial Vehicles: the Largest Slice after LDV

- Medium and heavy-duty vehicles second largest source of transportation GHG emissions (~21% of total)

- Current MHDVs are a major source of local air pollutants that negatively impact urban air quality and human health, disproportionately affecting disadvantaged communities located near freight corridors, ports and distribution centers

- Zero emissions (BEV and FCEV) offer a viable decarbonization pathway as technology has advanced greatly over the last decade (see Rise of EVs)

Source: EPA GHG Inventories
Medium- and Heavy-Duty Vehicle (MHDV) Breakdown

- **Commercial light trucks** (3%, <10,000 lbs.) aligned with light-duty vehicle efforts
- **Buses** (1%) are being targeted for rapid battery electrification
- **Medium** (5%) and **heavy-duty** (13%) are the largest pieces and while commercial deployment is still limited there are already cost-effective applications and growing opportunities for zero emissions vehicles
  - ~3.6M registered Class-8 trucks in the U.S., consuming ~27B gallons of diesel/year

➢ **Multiple solutions needed** for various MHDV applications
Not all Trucks are the Same, nor Used the Same Way!!

- ~10% of HD trucks have an operating range of 500 miles or more, whereas ~70% operate within 100 miles.
- Although the total energy consumption is skewed towards long-range operations, ~40% of energy is used by trucks that operate within 100 miles.
- Recent industry trends (e.g., the rise of e-commerce and low driver retention) produced a shift away from interregional and national hauls in favor of decentralized hub-and-spoke distribution models, which culminated in a 37% decrease in the average length of haul from 2000 to 2018 (not factored into Fig. 1).

Total Cost of Ownership: Cost-Parity in Sight

• Adoption driven by economics: Once tipping points are hit rapid scale-up expected

• BEVs, can be cost-competitive over the next decade, provide a solution for most buses and short-haul operations, ~ 60% of truck energy use

• But long-range, charging logistics, and extreme fast charging remain technological uncertainties: centrally-fueled H₂ FCEVs could support some use-cases

• Biofuels can also help address legacy vehicles, fleet turnover can take decades

Class 8 (300-mile) – Future
- Single-shift operations
- 60,000 mi/yr (230 mi/day)
- 16.7 year life (1M miles)

Class 8 (500-mile) – Future
- Multi-shift operations
- 150,000 mi/yr (580 mi/day)
- 6.7 year life (1M miles)

Source: Hunter et al. 2021. Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks. NREL/TP-5400-71796
Deep Dive: Charging Behavior & Grid Impacts of Short-Haul Electric Class 8 Semi Trucks

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Heavy-duty truck electrification and the impacts of depot charging on electricity distribution systems

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Considered 14 Class 7/8 tractor fleets from nine different companies in Fleet DNA database:

- 3,166 vehicle-days
- 2,105 operating-days (VMT > 10 mi.)

Selected fleets fit short-haul trucking segment:

- Fleet 1 and Fleet 2 vehicles travel 20,000 – 30,000 miles per year and operate within 50 mi. of depot – local delivery operations
- Fleet 3 vehicles travel 30,000 – 40,000 miles per year and typically operate within 100 mi. of depot – local/regional delivery operation
Insight 1: Limited VMT and Abundant Charging Opportunity

For Fleet 1 and Fleet 2, the max. daily driving distance is within 200 mi. while for Fleet 3, 89% of vehicle days are <300 VMT and 99% <500 VMT.

All fleets have ample opportunity for depot charging, averaging 14 hours of downtime per day.

- 74% of days have >12 hours and 96% have >8 hours of downtime.
Insight 2: Multiple Charging Options
Managed Charging Greatly Reduces Peak

- With **unmanaged charging** ("100 kW immediate"), peak demand coincides with the typical system-level peak period (5 pm – 9 pm)
- Through **scheduled charging** ("100 kW delayed"), peak demand may be shifted 8-12 hours throughout the course of the night
- With **intelligent modulation** ("Constant min. power"), peak demand can be greatly reduced.
- All charging loads (15-mins) freely available to download [LINK]
Insight 3: Charging Infrastructure Requirements

• **Financial benefit to low-power charging:**
  - For utilities, it produces lower peak demand and a smooth and predictable load profile
  - **Fleet managers** save on the capital costs of EVSE (purchase and installation of 50 kW 62–81% cheaper than 350kW).
  - In addition, fleets can save on electricity costs from **reduced demand charges**, if present.

• We found that **16, 23 and 103kW per vehicle** charging power levels were sufficient for electric trucks to fully recharge when off shift, all **much lower than is generally assumed**.
  - Depot-level peak < than sum of individual vehicles charging due to the asynchronous charging
Basic diagram of **secondary electrical distribution system**. Larger commercial customers may elect to own their own transformer and connect directly to the medium-voltage **primary network**, in which case the meter would be located on the opposite side of the distribution transformer.
Summarizing the Typical Cause, Cost, and Timeline for Distribution System Upgrades

Higher energy demands increase the likelihood for upgrades further upstream in the distribution system which are more expensive and take longer to complete.

**Approach:** Review of 10 public data and literature sources, supplemented by internal expert elicitation by industry co-authors.

| Table 1 | Summary of electricity distribution system upgrades for depot charging

<table>
<thead>
<tr>
<th>Component category</th>
<th>Upgrade</th>
<th>Typical cause for upgrade</th>
<th>Typical cost*</th>
<th>Typical timeline (month)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer on-site</td>
<td>50 kW DCFC EVSE</td>
<td>EVSE addition</td>
<td>Procurement, US$20,000-36,000 per plug; installation, US$10,000-46,000 per plug</td>
<td>3-10</td>
</tr>
<tr>
<td></td>
<td>150 kW DCFC EVSE</td>
<td></td>
<td>Procurement, US$75,000-100,000 per plug; installation, US$19,000-48,000 per plug</td>
<td></td>
</tr>
<tr>
<td></td>
<td>350 kW DCFC EVSE</td>
<td></td>
<td>Procurement, US$128,000-150,000 per plug; installation, US$26,000-66,000 per plug</td>
<td></td>
</tr>
<tr>
<td>Install separate meter</td>
<td>Decision to separately meter</td>
<td></td>
<td>US$1,200-5,000</td>
<td></td>
</tr>
<tr>
<td>Utility on-site</td>
<td>Install distribution transformer</td>
<td>200+ kW load</td>
<td>Procurement, US$12,000-175,000</td>
<td>3-8</td>
</tr>
<tr>
<td>Distribution feeder</td>
<td>Install/upgrade feeder circuit</td>
<td>5+ MW load¹</td>
<td>US$2-12 million¹</td>
<td>3-12*</td>
</tr>
<tr>
<td>Distribution substation</td>
<td>Add feeder breaker</td>
<td>5+ MW load²</td>
<td>-US$400,000</td>
<td>6-12¹</td>
</tr>
<tr>
<td></td>
<td>Substation upgrade</td>
<td>3-10+ MW load³</td>
<td>US$3-5 million</td>
<td>12-18</td>
</tr>
<tr>
<td></td>
<td>New substation installation</td>
<td>3-10+ MW load³</td>
<td>US$4-35 million</td>
<td>24-48⁴</td>
</tr>
</tbody>
</table>

*Cost and timeline ranges include procurement, engineering, design, scheduling, permitting and construction and installation; estimates are project-specific and vary greatly. *Costs reflective of 2019 and expected to continue to fall in future years; EVSE installation includes upgrading or installing service conductors and load centers; per-unit installation costs are reduced as the number of installed units increase. Feeder extensions or upgrades (including new feeder breakers) are typically required for new loads ≥5 MW, especially for voltages ≤20 kV; new loads >12 MW may require a dedicated feeder. *Feeder extensions or upgrades tend to be more expensive in urban areas than in rural areas. *Timeline for feeder extensions includes jurisdictional permitting for construction, obtaining easements and right-of-way, and procurement lead times. *Timeline for adding a new feeder breaker depends on substation layout and the time required to receive clearance for construction. *The decision to upgrade an existing substation versus to build a new one is largely dependent on the layout of the existing substation and whether there is sufficient room for expansion. *Additional time may be required for regulatory approval for the transmission line construction. DCFC, direct current fast charging.
Insight 4: Impact on Distribution Systems

- **Oncor conducted a substation load integration study**, for both average and peak demand days for 36 substations (close proximity to existing warehouse clusters).

- Magnitude of peak charging demand more predictive of substation upgrades than timing

- Majority (~80%) of substations could supply 100 EVs charging at 100 kW without upgrades; Nearly all (~90%) could supply 100 EVs charging at minimum power levels
Summary of Insights

- A lot of heavy trucks drive fairly low daily mileage and offer multiple charging options.
- Certain short-haul operations may be electrifiable with low-power depot-based EVSE (light-duty power levels).
- Depot charging provides load flexibility (from long predictable dwell times), enabling peak demand to be reduced through managed charging strategies.
- Distribution system upgrades (especially substations) are costly, and perhaps just as important, time consuming.
- Distribution substations may be more capable of handling near-term heavy-duty depot electrification than is generally assumed, especially with “right-sized” EVSE.
- Tons of variability - fleet operating schedules and charging requirements vary; available grid capacity depends on location and time of day. Fleet operators considering electrification should engage early with their local utility to establish a feasible power delivery schedule.
Emerging topic:

Vehicle electrification is rapidly transforming the transportation-energy landscape across multiple modes and with cross-sectoral impacts.

Need:

More nuanced demand-side modeling to assess **EV charging needs and flexibility**

EV integration opportunities: **solutions for synergistic improvement** of the efficiency and economics of electromobility and evolving electric systems

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*When and where EV charging occurs will be as important as *how much* electricity is needed*

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References


Questions?

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Supplemental
Recent policy momentum for heavy-duty truck electrification:

- In June 2020, CARB adopted Advanced Clean Trucks (ACT) regulation requiring the sale of zero-emission heavy-duty trucks starting in 2024 and requiring 40% ZEV truck tractor sales by 2035\(^6\).

- This year (2021), New Jersey announced plans to become the first state to adopt CA’s mandate.

- In June 2020, electric utilities in California, Washington, and Oregon provide a roadmap for freight and delivery EV charging infrastructure along I-5 and adjoining highways\(^7\).

- In July 2020, Governors from 15 states (+ Washington, D.C.) signed joint MOU committing to 100% of M/HDV sales be ZEVs by 2050 with an interim target of 30% ZEV sales by 2030\(^8\).


\(^7\) West Coast Clean Transit Corridor Initiative Study, June 17, 2020, [https://www.westcoastcleantransit.com/resources/WestCoastCleanTransitNewsRelease-Website.pdf](https://www.westcoastcleantransit.com/resources/WestCoastCleanTransitNewsRelease-Website.pdf)

Three Charging Strategies

a) **100 kW, Immediate**

*Unmanaged charging* case where 100 kW charging is performed “as soon as possible” (i.e., 15 min. after designated shift period) and continues until either (1) all depleted energy is recharged; or (2) the next shift starts.

b) **100 kW, Delayed**

100 kW charging is performed “as late as possible” beginning at either (1) the latest possible time to fully recharge all depleted energy prior to the next designated shift period; or (2) immediately in the case where there is not enough time to fully recharge depleted energy prior to the next shift.

c) **Constant, Min Power**

Charging is performed whenever a vehicle is available (to charge) at the lowest possible rate to fully recharge the day’s depleted energy. This strategy aims to reduce each individual vehicle’s peak demand (though not necessarily the fleet’s).

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*Veh. operating profile:*

- **Battery SOC (%):**
  - a) 100 kW Immediate
  - b) 100 kW Delayed
  - c) Constant Min. Power

*EV load profile:*

- **Charging power (kW):**
  - a) 100 kW Immediate
  - b) 100 kW Delayed
  - c) Constant Min. Power

- **Time of Day:**
  - a) 100 kW Immediate
  - b) 100 kW Delayed
  - c) Constant Min. Power

Legend:
- Green: off-shift/able to charge
- Red: on-shift/unable to charge
- Yellow: charging
Peak Depot Charging Loads

Note that per-vehicle contributions to the peak depot charging load are lower than the individual vehicle charging power levels due to the asynchronous charging behaviours from multiple vehicles.

Slower charging (constant minimum power strategy) led to much lower peak loads (<10 kW per vehicle for Fleets 1 and 2, and 20kW per vehicle for Fleet 3), which mitigates electricity demand charges and enables the use of less expensive EVSE.

In addition, the daily variance in peak load is reduced when vehicles are charged at slower rates, which results in an improved predictability for both utilities and fleet managers.

Fig. 6 | Peak depot charging load normalized per vehicle. Variation (bars) in per-vehicle contribution to peak depot charging load for each fleet and charging strategy with the average profile values overlayed (dots).
Energy Consumption Rate Sensitivity Analysis

Supplementary Table 2. Sensitivity of fleet load profile outcomes to variations in vehicle energy consumption rate

<table>
<thead>
<tr>
<th>Outcome</th>
<th>High Efficiency – 1.5 kWh/mile</th>
<th>Baseline – 1.8 kWh/mile</th>
<th>Low Efficiency – 2.8 kWh/mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum charging power</td>
<td>F1: 13 kW/vehicle</td>
<td>F1: 16 kW/vehicle</td>
<td>F1: 24 kW/vehicle</td>
</tr>
<tr>
<td></td>
<td>F2: 20 kW/vehicle</td>
<td>F2: 23 kW/vehicle</td>
<td>F2: 36 kW/vehicle</td>
</tr>
<tr>
<td></td>
<td>F3: 86 kW/vehicle</td>
<td>F3: 103 kW/vehicle</td>
<td>F3: 161 kW/vehicle</td>
</tr>
<tr>
<td>Average daily energy required</td>
<td>F1: 114 kWh/vehicle/day</td>
<td>F1: 137 kWh/vehicle/day</td>
<td>F1: 214 kWh/vehicle/day</td>
</tr>
<tr>
<td></td>
<td>F2: 124 kWh/vehicle/day</td>
<td>F2: 149 kWh/vehicle/day</td>
<td>F2: 231 kWh/vehicle/day</td>
</tr>
<tr>
<td></td>
<td>F3: 196 kWh/vehicle/day</td>
<td>F3: 235 kWh/vehicle/day</td>
<td>F3: 365 kWh/vehicle/day</td>
</tr>
<tr>
<td>Per-vehicle peak depot load contribution (constant minimum power)</td>
<td>F1: 8.1 kW/vehicle</td>
<td>F1: 9.7 kW/vehicle</td>
<td>F1: 15.1 kW/vehicle</td>
</tr>
<tr>
<td></td>
<td>F2: 8.0 kW/vehicle</td>
<td>F2: 9.6 kW/vehicle</td>
<td>F2: 15.0 kW/vehicle</td>
</tr>
<tr>
<td></td>
<td>F3: 16.7 kW/vehicle</td>
<td>F3: 20.0 kW/vehicle</td>
<td>F3: 31.2 kW/vehicle</td>
</tr>
</tbody>
</table>
Looking Forward

- More effort (and better data) is needed to **fully characterize the opportunity for heavy-duty truck electrification through depot charging**

- Extend analysis to consider both **operational and economic feasibility** of a broader share of operating segments:
  - First-Mile (**Drayage**)  
  - Regional  
  - Long-haul  

- Geospatial analysis of **fleet depot locations** could inform degree to which depots are located on shared electrical infrastructure (clustering) – Utilities want to know this in order to prepare
EVs can support the grid in multiple ways providing values for different stakeholders, including non-EV owners.