Perspectives on Charging Medium- and Heavy-Duty Electric Vehicles

Matteo Muratori and **Brennan Borlaug**

IEA Public Webinar on Public Charging Infrastructure Deployment Strategies and Business Models

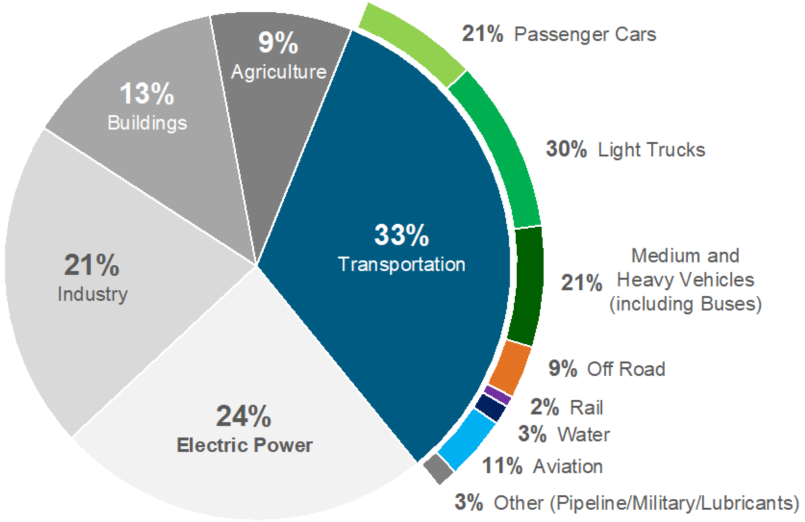
December 8th, 2021

U.S. DOE National Lab System

Commercial Vehicles: the Largest Slice after LDV

- Medium and heavy-duty vehicles (MHDVs) **second largest source of transportation GHG emissions** (21% in the US, 31% global)
- Current MHDVs are a **major source of local air pollutants** that negatively impact urban air quality and human health, and **disproportionally affecting disadvantaged communities** located near freight corridors, ports and distribution centers
- **Zero emissions vehicles** (BEV and FCEV) offer a viable decarbonization pathway.
  - While commercial deployment is still limited there are growing opportunities as technology has advanced greatly over the last decade (see *Rise of EVs*)

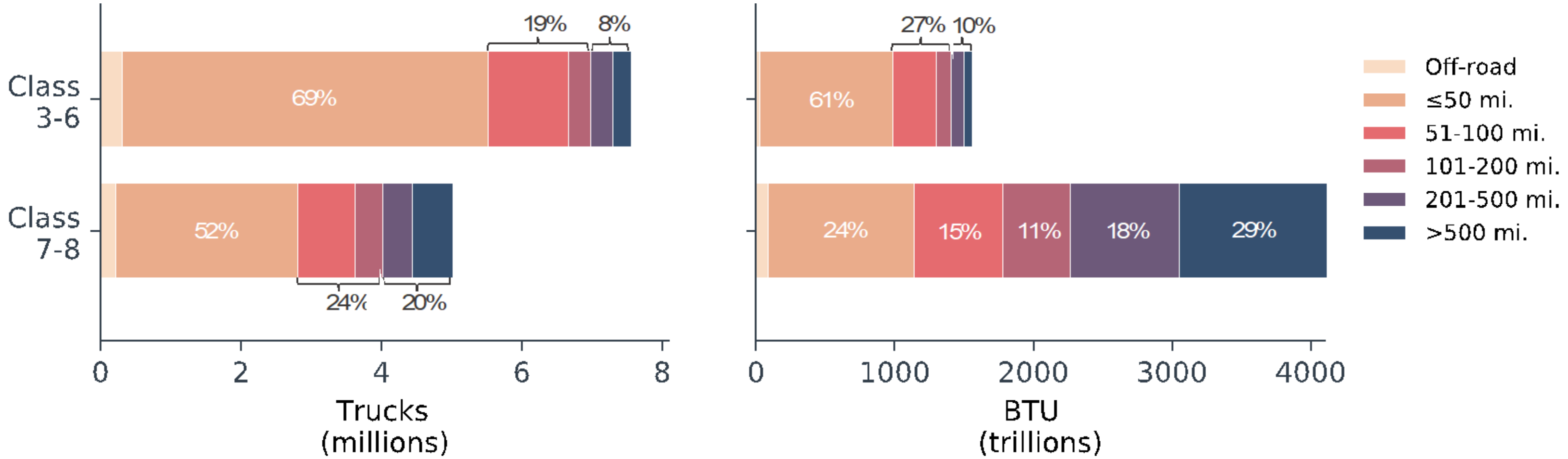
2019 U.S. GHG Emissions



Aviation and water include emissions from international bunker fuels. Fractions may not add up to 100% due to rounding.

Data Source: EPA GHG Inventories

A Lot of Heterogenies within MHDV: Not all Trucks are Driven the Same – Different Charging Solutions

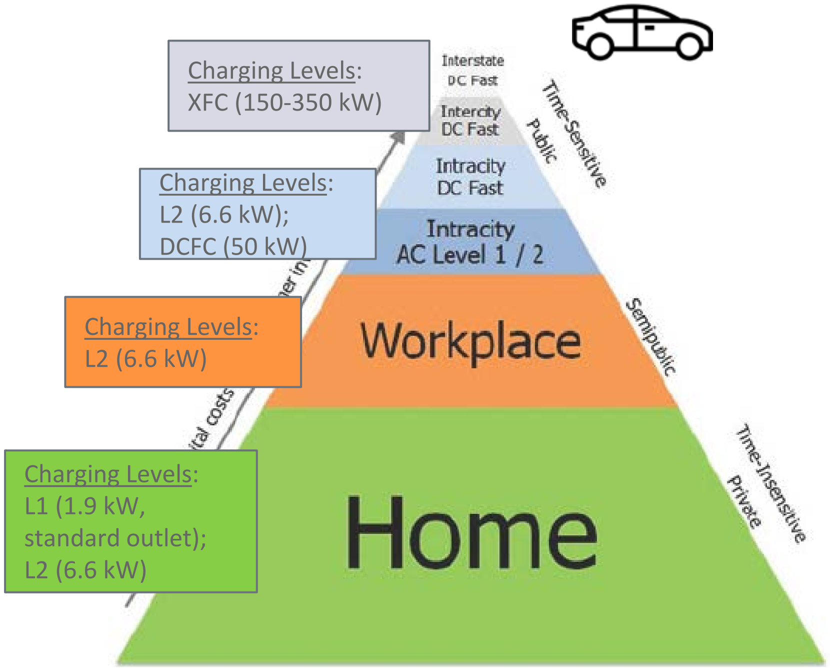


Source: Borlaug et al. 2021. Heavy-duty truck electrification and the impacts of depot charging on electricity distribution systems. Nature Energy.

- ~10% of HD trucks in the United States have a primary operating range of 500 miles or more, whereas **~70% operate primarily within 100 miles**.
- **~40% of energy is used by trucks that primarily operate within 100 miles**.
- Recent industry trends (e.g., the rise of e-commerce and low driver retention) produced a shift towards decentralized hub-and-spoke models: **37% decrease in the average length of haul from 2000 to 2018** (not factored into Figure above).

EV Charging Technology: a Variety of Solutions for LDV

LDV Paradigm:



Source: National Research Council. *Overcoming barriers to deployment of plug-in electric vehicles*. National Academies Press, 2015.

Charging EVs includes a lot **more options** than "gasoline stations"

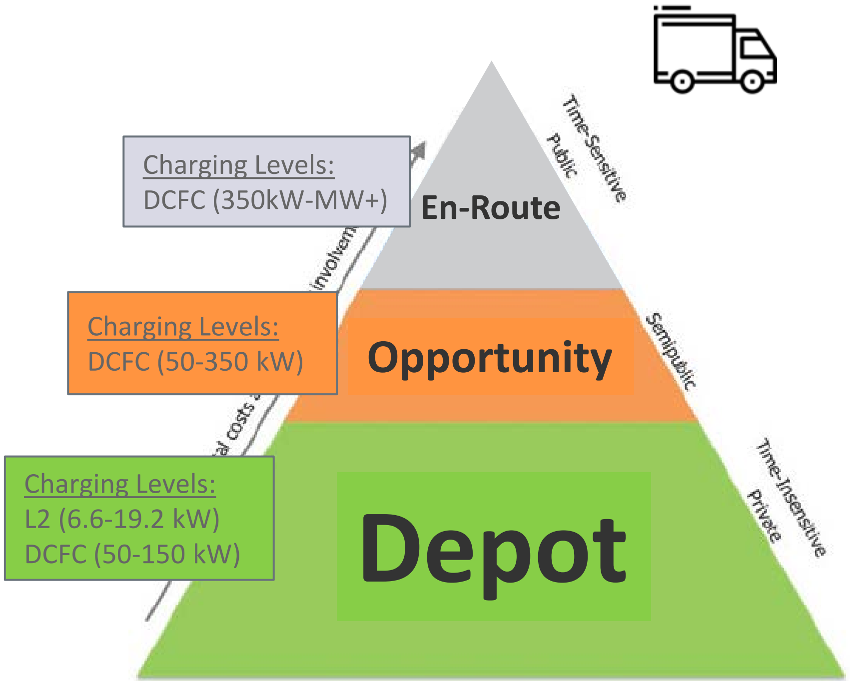
- **Home charging can cover most needs** (~95% of trips <30 miles) but not everyone has access
- **Workplace** next biggest opportunity
- **Public charging (L2 and DCFC) critical to build consumer confidence and enable long-distance**

Key gaps:

- Reliable and convenient intercity charging network (few trips but confidence issue)
- Solutions for people without home charging (no single answer)
- Providing convenient access to underserved communities
- Reducing costs and grid integration

EV Charging Technology: a Variety of Solutions for MHDV

MHDV Paradigm:



Charging EVs includes a lot **more options** than "gasoline stations"

- **Depot charging** can cover most needs **(~87% of U.S. MHDVs primary operating range <200 miles**) but requires on-site charging for all vehicles
- **Opportunity charging** (e.g., while loading/unloading or on break) could provide additional opportunity
- Public **en-route charging** (DCFC, MW+) as a safety net and for long-haul applications

Key gaps:

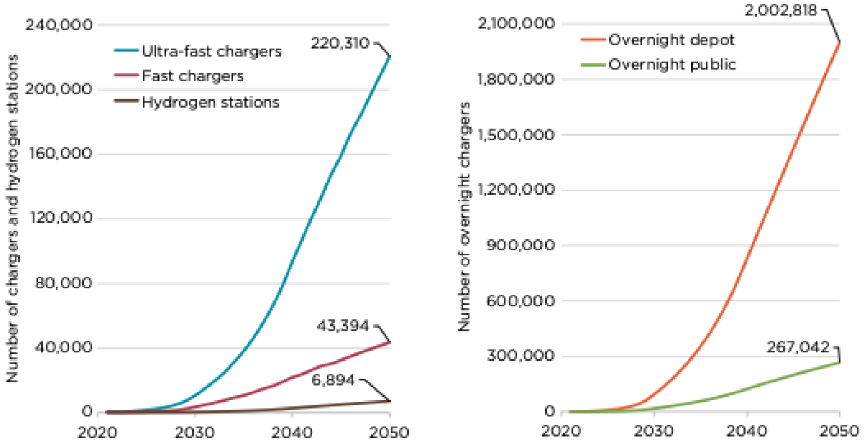
- Depot-charging solutions for all fleets/drivers (no single answer)
- Develop and demonstrate reliable opportunity charging solutions
- Intercity MW+ charging network (critical for some regional and most long-haul trucks)
- Reducing costs and grid integration

Depot Charging Critical for MHDV Electrification

ICCT, Sep. 2021

- Estimates **2 million overnight private chargers (e.g., depot) needed for 2.4 million U.S. ZEV tractors by 2050** (~77% of all chargers)

Infrastructure Needed for 100% U.S. ZEV tractor sales from 2040

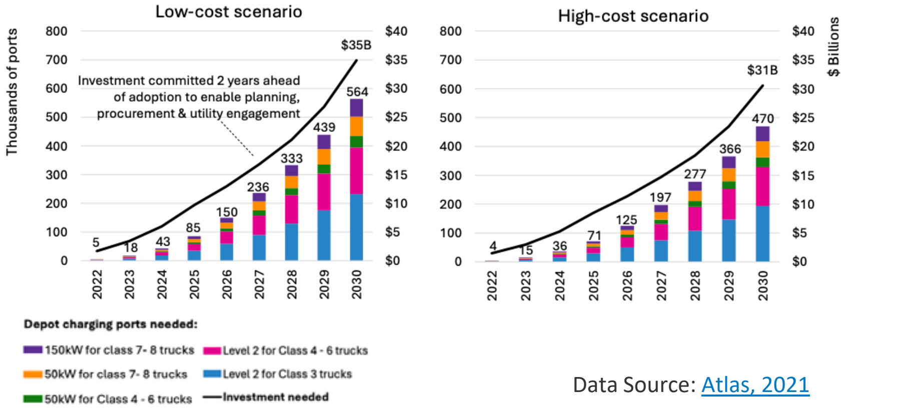


Data Source: ICCT, 2021

Atlas Public Policy, Nov. 2021

- Projects **most chargers will be needed at depots** – 500k by 2030, and that 75%-90% of MHDEV charging will be at depots.

Cumulative ports & committed investment needed to support electrification of depot-charging



Data Source: Atlas, 2021

nature energy

ARTICLES

https://doi.org/10.1038/s41560-021-00855-0

Check for updates

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

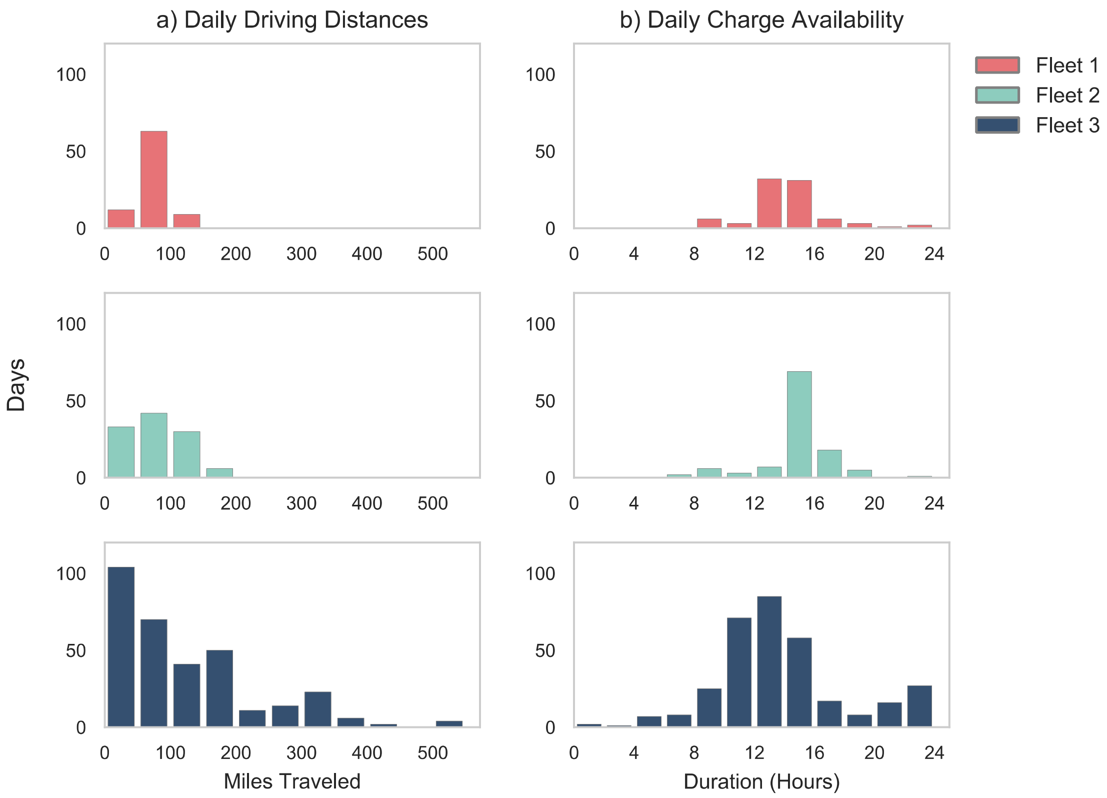
Brennan Borlaug[1], Matteo Muratori[1]✉, Madeline Gilleran[1], David Woody[2], William Muston[2], Thomas Canada[3], Andrew Ingram[3], Hal Gresham[3] and Charlie McQueen[3]

Paper:
https://doi.org/10.1038/s41560-021-00855-0

Data:
https://data.nrel.gov/submissions/162

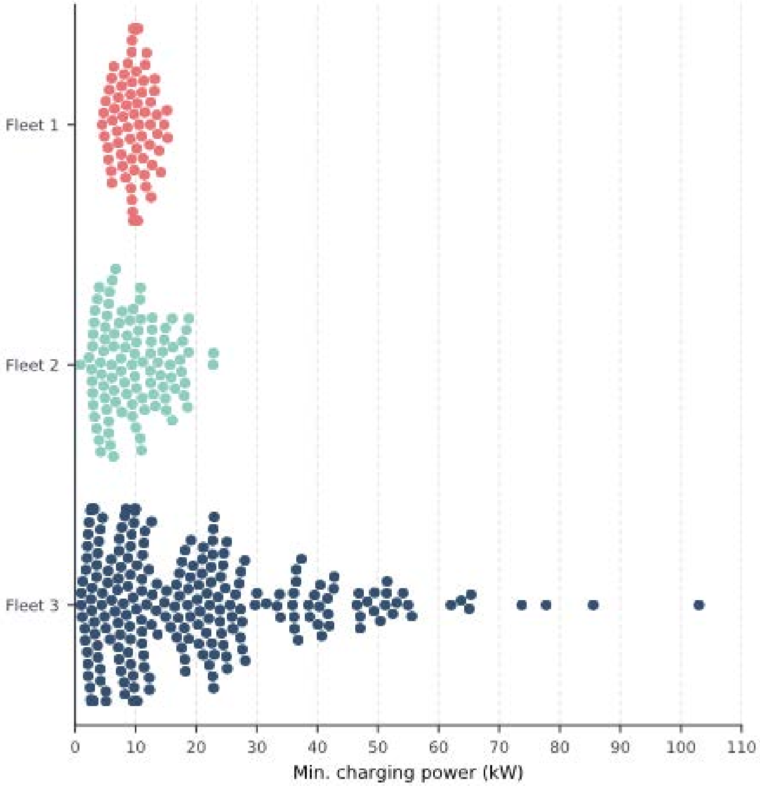
Code:
https://github.com/NREL/hdev-depot-charging-2021

Short-Haul Trucks: Limited Daily VMT and Abundant Charging Opportunity



- **Based on real-world data: a lot of heavy trucks drive fairly low daily mileage and offer multiple charging options.**
- These fleets have **ample opportunity for depot charging**, averaging 14 hours of downtime per day.
- **Depot charging provides load flexibility** (from long predictable dwell times), enabling peak demand to be reduced through **managed charging strategies**.

Depot Charging Requirements



- 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
- **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.

En-Route Corridor Charging

- Long-haul (and some regional) trucks will require **mid-shift en-route “fast” (e.g., MW+) charging** to remain on schedule.
- **En-route “truck stop” charging demand will be heterogenous** and dependent on:
  - **Vehicle design** (esp. battery cost and performance) and regional adoption
  - Possible **logistics** changes (how trucks are operated, shipping routes)
  - Size & **design** of en-route charging network (including distributed generation and storage)
  - **Regulation**: hours of service rules and role of ***automation***

Critical to Understand Charging Loads and Prepare for Effective Grid Integration (Distribution 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

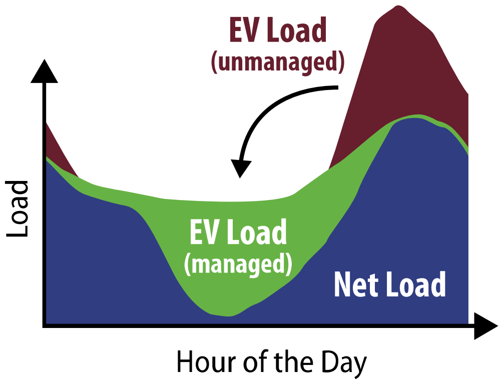
Component category	Upgrade	Typical cause for upgrade	Typical cost[a]	Typical timeline (month)[a]
Customer on-site	50 kW DCFC EVSE	EVSE addition	Procurement, U$20,000–36,000 per plug; installation, U$10,000–46,000 per plug[b]	3–10
	150 kW DCFC EVSE		Procurement, US$75,000–100,000 per plug; installation, US$19,000–48,000 per plug[b]	
	350 kW DCFC EVSE		Procurement, US$128,000–150,000 per plug; installation, US$26,000–66,000 per plug[b]	
	Install separate meter	Decision to separately meter	US$1,200–5,000	
Utility on-site	Install distribution transformer	200+ kW load	Procurement, US$12,000–175,000	3–8
Distribution feeder	Install/upgrade feeder circuit	5+ MW load[c]	US$2–12 million[d]	3–12[e]
Distribution substation	Add feeder breaker	5+ MW load[c]	~US$400,000	6–12[f]
	Substation upgrade	3–10+ MW load[g]	US$3–5 million	12–18
	New substation installation	3–10+ MW load[g]	US$4–35 million	24–48[h]

[a]Cost and timeline ranges include procurement, engineering, design, scheduling, permitting and construction and installation; estimates are project-specific and vary greatly. [b]Costs reflective of 2019 and expected to continue to fall in future years; EVSE installation includes upgrading or installing service conductors and load centres; per-unit installation costs are reduced as the number of installed units increase. [c]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. [d]Feeder extensions or upgrades tend to be more expensive in urban areas than in rural areas. [e]Timeline for feeder extensions includes jurisdictional permitting for construction, obtaining easements and right-of-way, and procurement lead times. [f]Timeline for adding a new feeder breaker depends on substation layout and the time required to receive clearance for construction. [g]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. [h]Additional time may be required for regulatory approval for the transmission line construction. DCFC, direct current fast charging.

Grid Integration is more than Impacts: Opportunity for Managed Charging

- Many MHDVs have duty cycles conducive to **managed charging** and/or bi-directional energy transfer (V2G)
- **Depot charging loads are more flexible** than en-route charging, providing opportunities for managed charging

Value of Electric Vehicle Managed Charging



Managed EV charging can support grid planning and operations

Reduce Bulk Power Systems Investment Costs
20–1350 $/EV/year

Reduce Bulk Power Systems Operating Costs
15–360 $/EV/year

Reduce Renewable Energy Curtailment
23–2400 kWh/EV/year

Reduce Distribution Systems Investment Costs
5–1090 $/EV/year

Increase Distribution Systems EV Hosting Capacity
30–450%

Source: Anwar et al. 2022. Assessing the value of electric vehicle managed charging: a review of methodologies and results. Energy & Env. Science.

Concluding Remarks

Emerging topic:

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

Electric Medium Heady-Duty Vehicles offer major emissions benefits (air quality) and if financial tipping point is reached adoption could scale up rapidly. The time to prepare is now!

Need:

Demonstration to assess transition obstacles and build knowledge on charging needs, costs, effective practices and grid integration (international transfer)

Nuanced demand-side modeling to assess **EV charging needs** (infrastructure) **and flexibility**: *when* and *where* EV charging occurs will be as important as *how much* electricity is needed

EV integration opportunities: **synergistic improvement** of the efficiency and economics of electromobility and evolving electric systems (lower charging costs and support the grid)

References

1) Muratori, M. *et al.* "The rise of electric vehicles—2020 status and future expectations." *Progress in Energy* 3, no. 2 (2021): 022002.

2) Borlaug, B., M. Muratori, M. Gilleran, D. Woody, W. Muston, T. Canada, A. Ingram, H. Gresham, and C. McQueen. "Heavy-duty truck electrification and the impacts of depot charging on electricity distribution systems." *Nature Energy* 6, no. 6 (2021): 673-682.

3) Hunter, C., M. Penev, E. Reznicek, J. Lustbader, A. Birky, and C. Zhang. "Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks" (No. NREL/TP-5400-71796). National Renewable Energy Lab.(NREL), Golden, CO (United States).

4) Minjares, R., Rodríguez, F., Sen, A., and Braun, C. "Infrastructure to Support a 100% Zero-Emission Tractor-Trailer Fleet in the United States by 2040" (Working Paper 2021-33). International Council on Clean Transportation (2021).

5) McKenzie, L., Di Filippo, J., Rosenberg, J., and Nigro, N. "U.S. Vehicle Electrification Infrastructure Assessment: Medium- and Heavy-Duty Truck Charging". Atlas Public Policy (2021).

6) Anwar, M.B. *et al.* "Assessing the value of electric vehicle managed charging: a review of methodologies and results" Energy & Env. Science, 2022.

7) Muratori, M. and T. Mai. "The Shape of Electrified Transportation". *Environmental Research Letters* 16, no. 1 (2020): 011003.

Questions?

Matteo.Muratori@NREL.gov

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Transforming ENERGY

Supplemental

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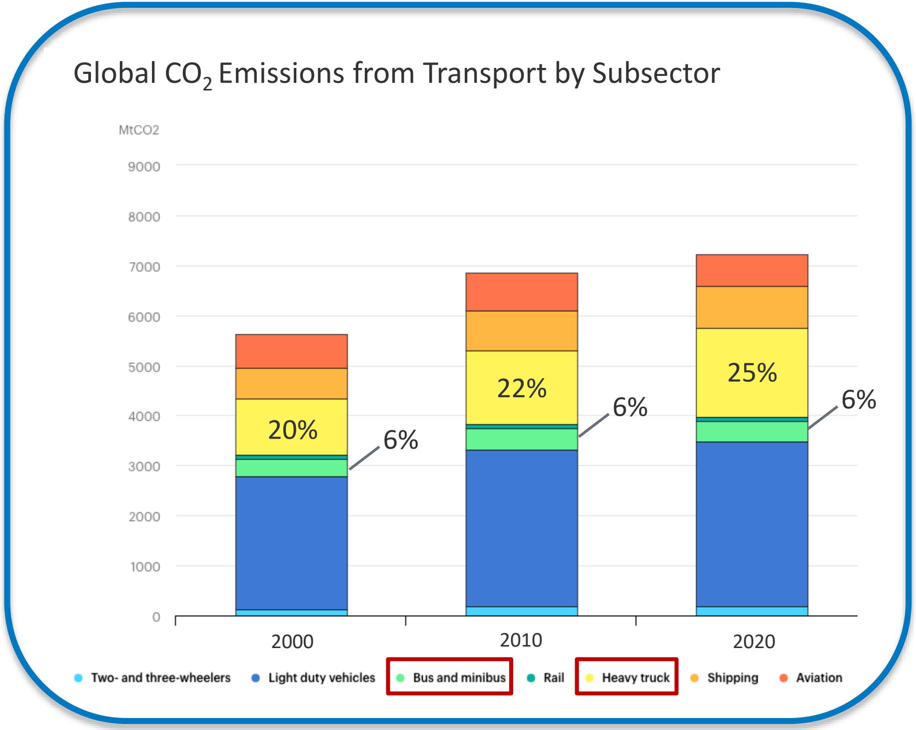
- Current MHDVs are a **major source of local air pollutants** that negatively impact urban air quality and human health, and **disproportionally affecting disadvantaged communities** located near freight corridors, ports and distribution centers
- **Zero emissions vehicles** (BEV and FCEV) offer a viable decarbonization pathway.
  - While commercial deployment is still limited there are growing opportunities as technology has advanced greatly over the last decade (see *Rise of EVs*)



Data Source: IEA, 2021

Current Momentum for Heavy-Duty Electrification

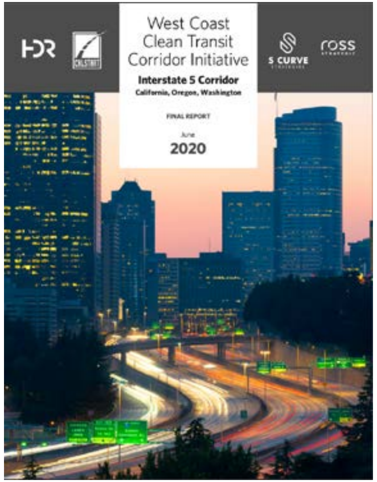
Recent policy momentum for heavy-duty truck electrification:

- 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].

CALIFORNIA AIR RESOURCES BOARD

California takes bold step to reduce truck pollution

First-of-its-kind requirement for electric trucks will help communities hardest hit by air pollution



MONEY

Tesla stock closes at record highs on electric Semi news

Dalvin Brown USA TODAY

Published 9:43 a.m. ET Jun. 11, 2020 | Updated 4:19 p.m. ET Jun. 16, 2020

RESEARCH SPOTLIGHT

WoodMac: 54,000 Electric Trucks on US Roads by 2025

That's a 27-fold increase over today's fleet, and the expansion of charging infrastructure will be nearly as dramatic.

KELLY MCCOY | AUGUST 11, 2020

2021: The Year the Rubber Meets the Road for Electric Trucks

January 13, 2021 | By Jessie Lund

HEAVY-DUTY

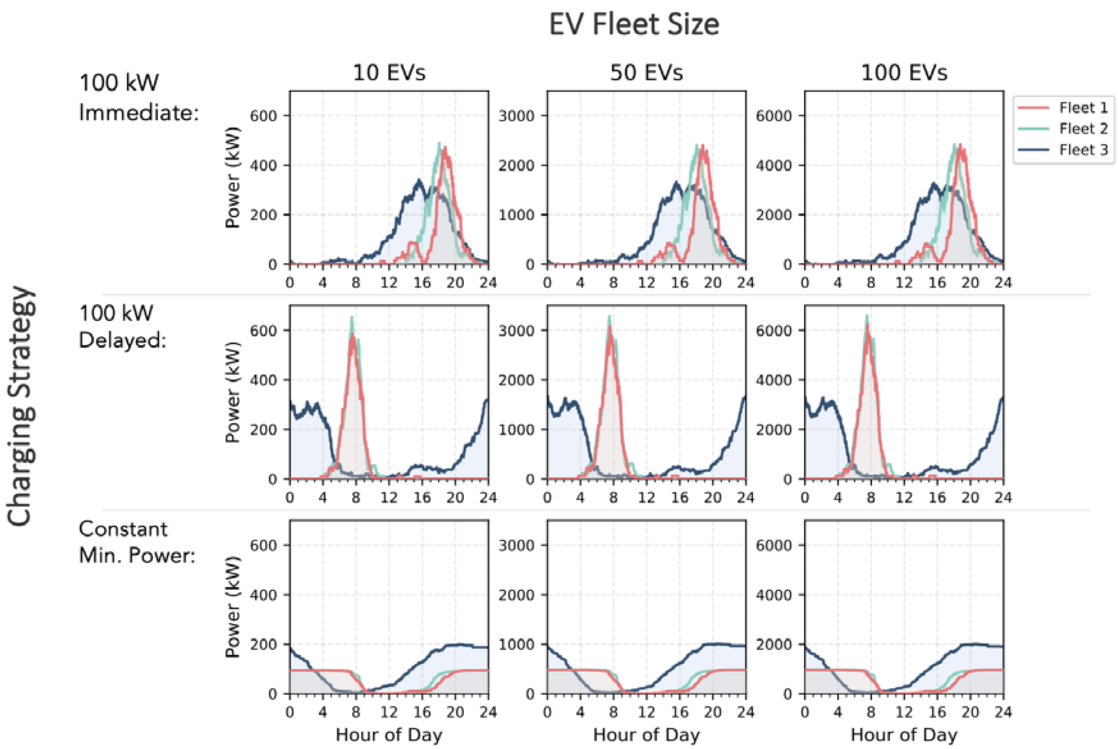
Daimler Trucks N.A. Opens Order Books For All-Electric Freightliner ECascadia, EM2

By Jason Morgan on Apr 6, 2021

[6] California Air Resources Board – CARB, June 25, 2020, https://ww2.arb.ca.gov/news/california-takes-bold-step-reduce-truck-pollution
[7] West Coast Clean Transit Corridor Initiative Study, June 17, 2020, https://www.westcoastcleantransit.com/resources/WestCoastCleanTransitNewsRelease-Website.pdf
[8] New York State, Gov. Cuomo, July 14, 2020, https://www.governor.ny.gov/news/governor-cuomo-announces-new-york-and-14-states-and-dc-ramp-electrification-buses-and-trucks

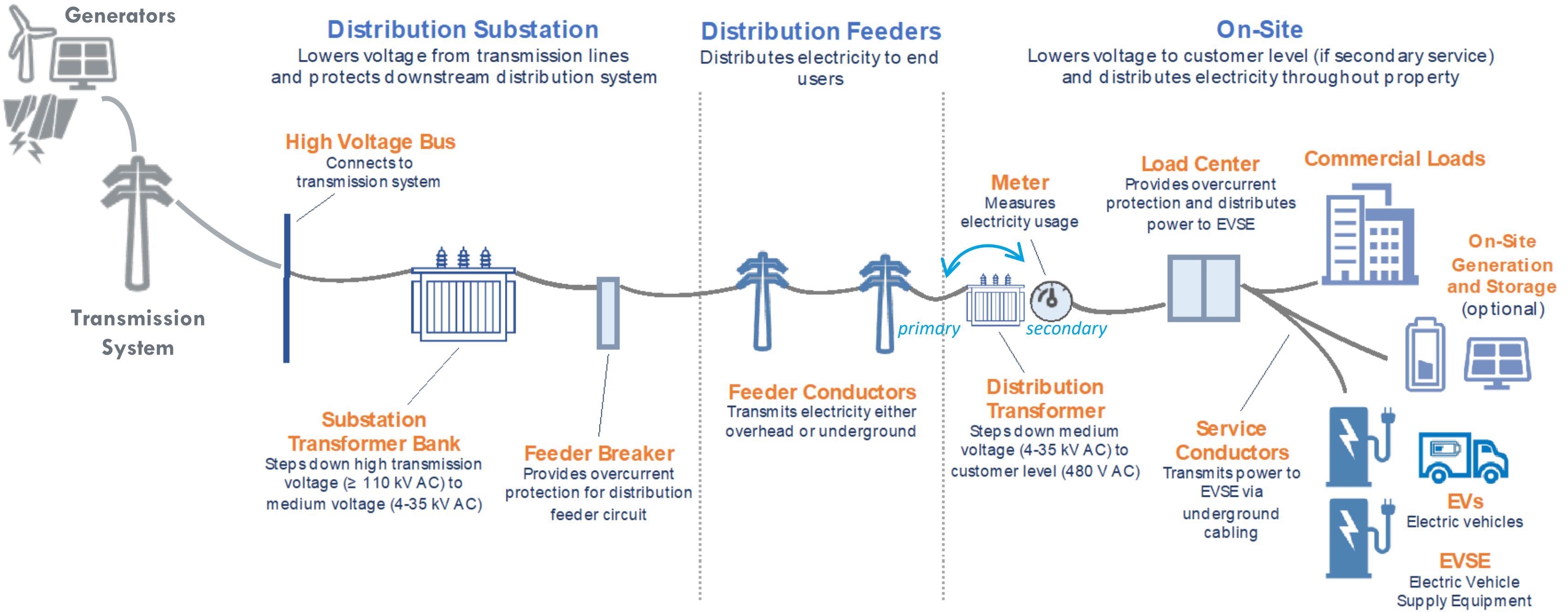
Insight 2: Multiple Charging Options

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]**

Distribution Network Scheme



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

Concluding Remarks

Emerging topic:

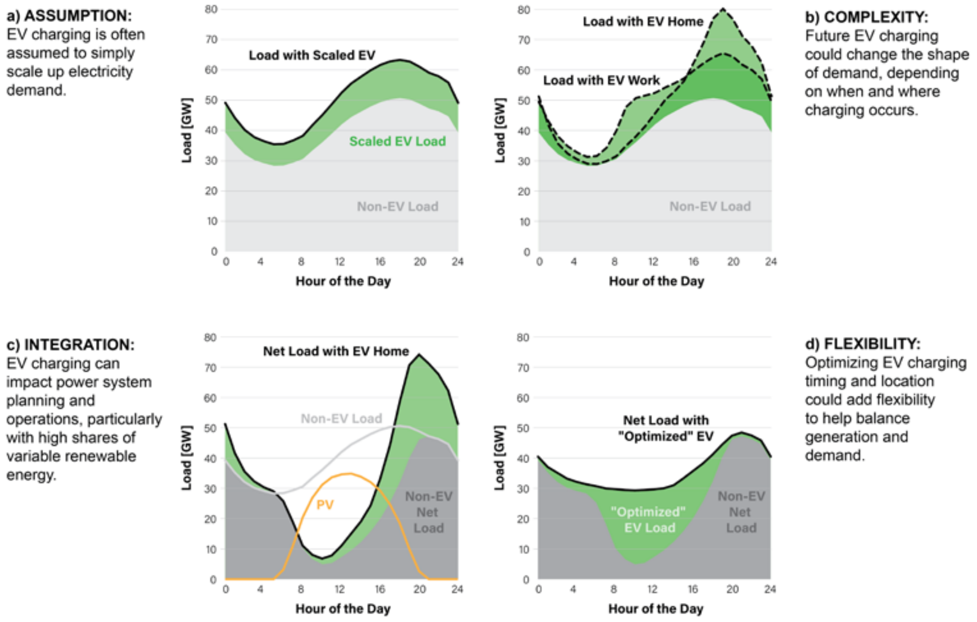
Vehicle electrification is rapidly transforming the transportation-energy landscape across multiple modes and with cross-sectoral impacts.

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

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

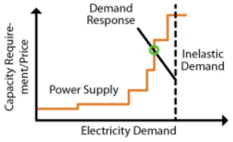


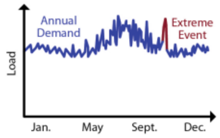
Source: Muratori and Mai, 2021. The Shape of Electrified Transportation. Env. Research Letter.

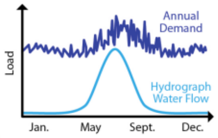
EVs can support the grid in multiple ways providing values for different stakeholders, including non-EV owners

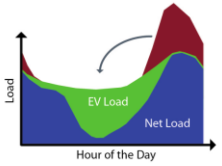
Smart electric vehicle-grid integration can provide flexibility – the ability of a power system to respond to change in demand and supply – by charging and discharging vehicle batteries to support grid planning and operations over multiple time-scales

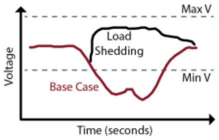
Power System Application	Generation Capacity and Transmission/ Distribution Planning	Resilience To Extreme Events	Seasonal Planning (Hydro/Long-Term Storage Dispatch)	Commitment and Dispatch Decisions	Balancing and Power Quality	Support End Consumers
Time scale	*Multi-year*	*Years (planning), hours (real-time response)*	*Months*	*Days to Hours and Sub-Hours*	*Seconds to sub-seconds*	*Years (planning), hours (real-time response)*
Vehicle-Grid Integration value	Ability to reduce peak load and capacity requirements and defer distribution systems upgrades if reliable EV charging flexibility is available	Load response to natural events (heat waves, tornados) or human-driven disasters, load postponement over days, and support microgrid management and grid restoration (V2G)	No role for EVs	Leverage EV charging flexibility to support supply dispatch and load-supply alignment (tariff management), variable renewables integration, operating reserves, energy arbitrage (V2G)	Provide voltage/frequency regulation and support distribution system operations	Tariff management (e.g., mitigate retail demand charges), complement other distributed energy resources (smart load, generation and storage), and minimize equipment aging/upgrades

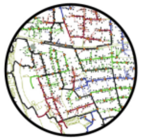












Source: Muratori *et al.* 2021. The rise of electric vehicles—2020 status and future expectations. Progress in Energy.