36th Electric Vehicle Symposium & Exposition
EVS36

Charging Needs for Battery Electric Semi-Trucks

Brennan Borlaug, Research Analyst – Electric Vehicles
National Renewable Energy Laboratory, Golden, CO, USA

Organized and Hosted by
EDTA
Electric Drive Transportation Association

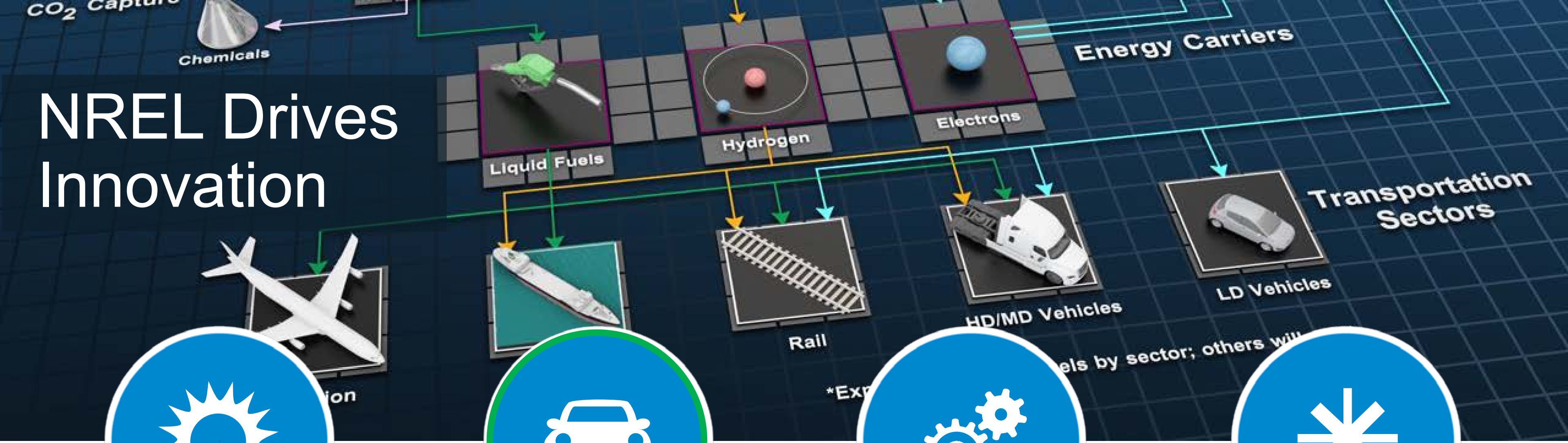
U.S. DOE National Lab System

Largest National Laboratories

NREL
Transforming ENERGY

accelerates the transition of clean energy technologies to the marketplace…

NREL Drives Innovation



Renewable Power

Solar

Wind

Water

Geothermal

Sustainable Transportation

Bioenergy

Electrification

Hydrogen

Energy Efficiency

Buildings

Advanced Manufacturing

Government Energy Management

Energy Systems Integration

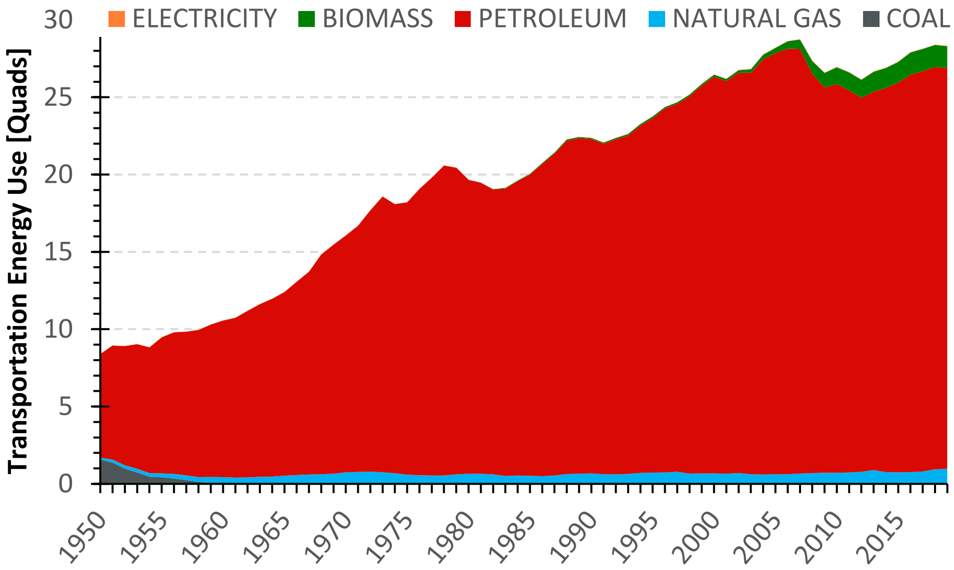
Grid Integration

Hybrid Systems

Security and Resilience

Transportation Systems are <u>Petroleum Dependent</u>

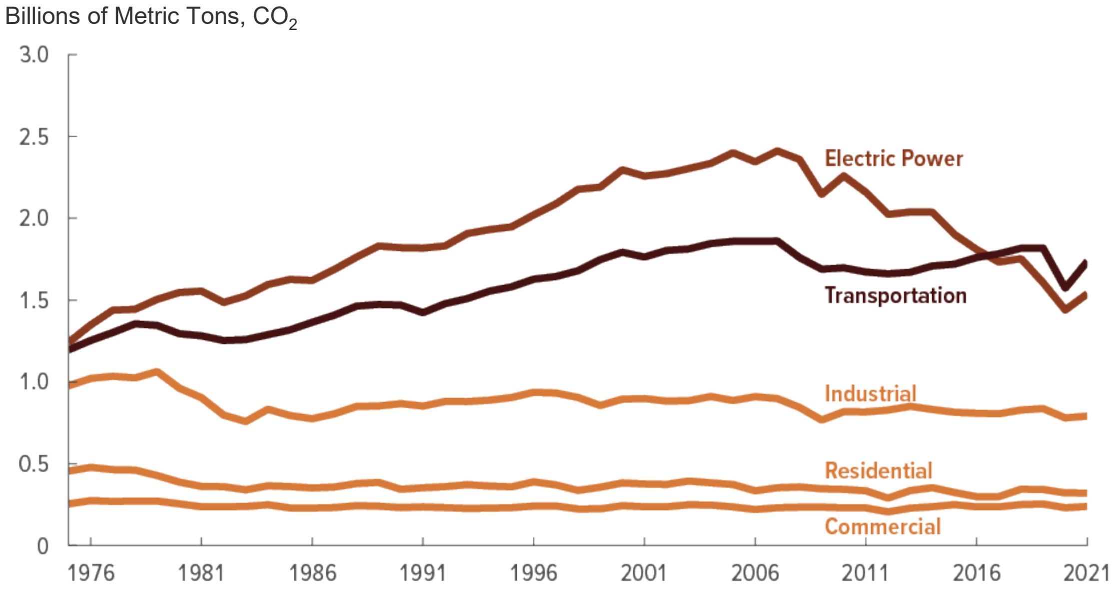
For >75 years, petroleum has been the dominant transportation energy source in the United States. **Today, petroleum products account for ~90% of the total U.S. transportation sector energy use**.



Source: NREL. Data: EIA (U.S.)

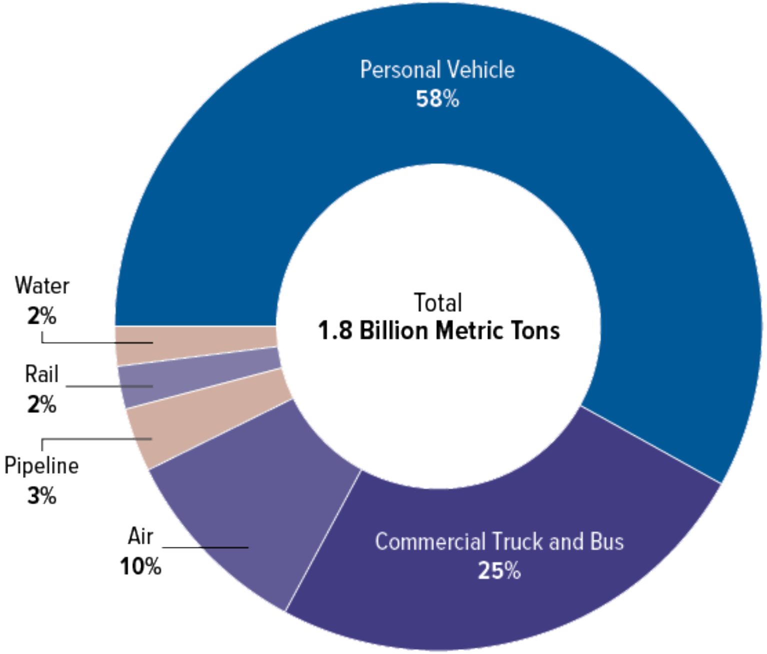
Transportation Systems are Carbon-Intensive

Transportation is now the **largest source of energy-related CO_2 emissions** in the United States and continues to rise while emissions from other major economic sectors are flat or declining.



Source: Congressional Budget Office; Data: EIA (U.S.)

MHDVs: Significant Source of CO_2 Emissions in U.S.



U.S. Transport-Related CO_2 Emissions by Mode, 2019

Source: Congressional Budget Office; Data: EPA

- **Medium and heavy-duty vehicles (MHDVs)** are the **2nd largest source of transport-related CO_2 emissions in the U.S.** (~25% of total).
- MHDVs are also a **major source of local air pollutants** that negatively impact urban air quality and human health.
- **Battery electric vehicles (EVs) offer a promising decarbonization pathway for MHDVs** as battery technologies continue to improve and costs decline.

Outlook for MHD EVs

2021:

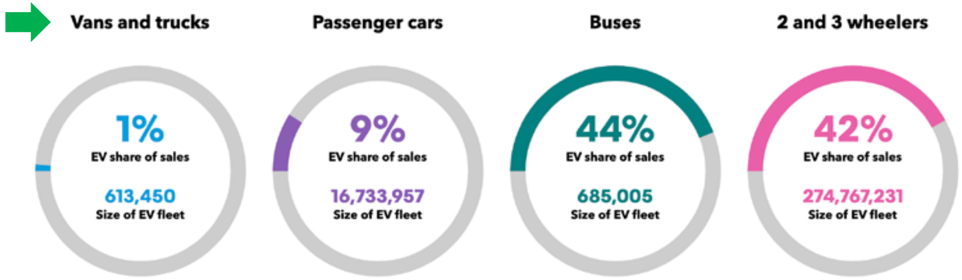
EVs ~1% of global M/HD market*

*not including buses

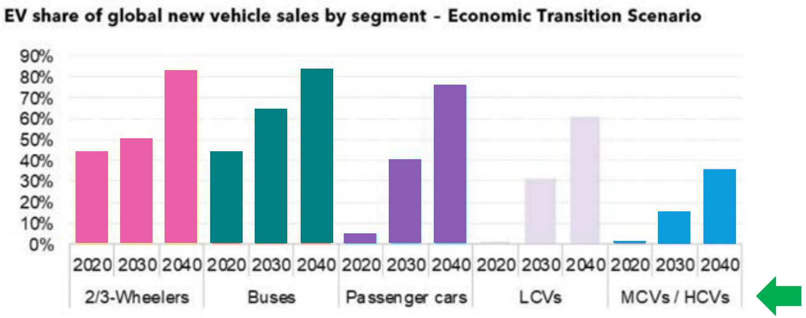
BNEF 2040:

EVs nearly 40% of global M/HD market*

*not including buses



global numbers as of 2021

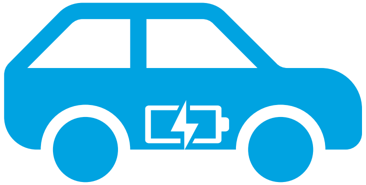


source: BloombergyNEF EVO 2022

For U.S. market, NREL projects EVs could make up 40% new M/HD sales by 2030!
(Ledna et al., 2022)

Preparing for MHD EVs

- **More vehicles** with **lower electricity demands**
- Charging is **geographically distributed**
- Power level: several kW to **hundreds of kW per vehicle**
- Spend **95% of the time parked** (opportunity for managed charging)



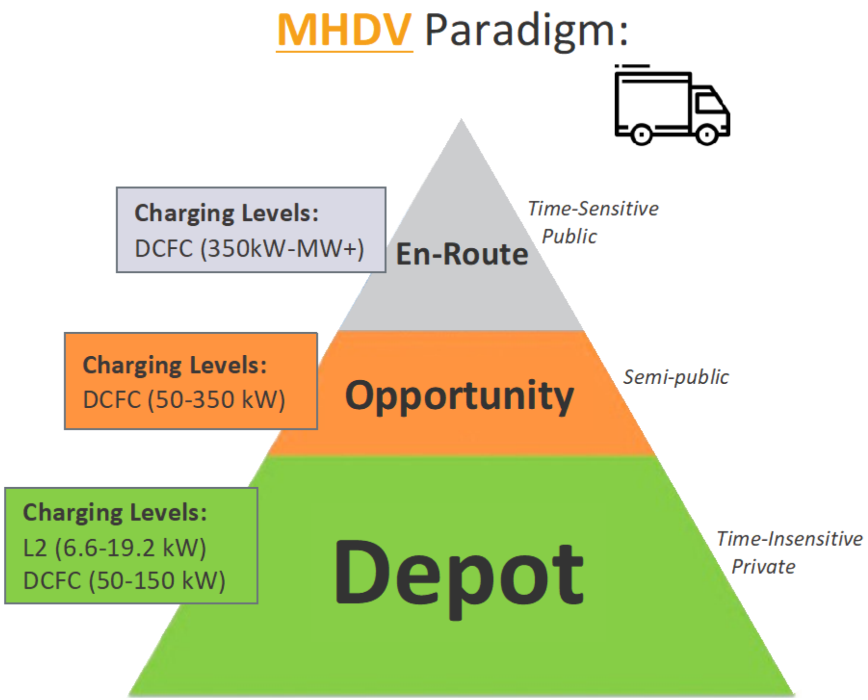
LDVs

VS

MHDVs

- **Fewer vehicles** with **higher electricity demands**
- Charging is more **geographically concentrated**
- Power level: tens of kW to **1+ MW per vehicle**
- Spend **less time parked**, but **more predictable operations** could enable managed charging

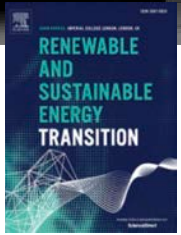
Charging MHD EVs



Source: Muratori, et al. (2023b)

Charging MHD EVs involves more options than traditional refueling paradigms.

- **Depot charging** can cover a significant share of total electricity demands for return-to-base operations.
- **Opportunity charging** (e.g., while loading/unload or on break) can maximize operational efficiency.
- **Public en-route charging** will be needed as a “safety net” and for long-haul operations.



ELSEVIER

Renewable and Sustainable Energy Transition
Volume 2, August 2022, 100038

Full-length article

Charging needs for electric semi-trailer trucks

Brennan Borlaug [a], Matthew Moniot [a], Alicia Birky [a], Marcus Alexander [b], Matteo Muratori [a]

Paper:
https://doi.org/10.1016/j.rset.2022.100038

Data:
https://data.nrel.gov/submissions/198

Study Overview

Motivation:

Significant uncertainty regarding the charging needs for heavy-duty battery electric trucks (HDBETs):

- *How might they charge?*
- *…at what power levels?*
- *…and where?*

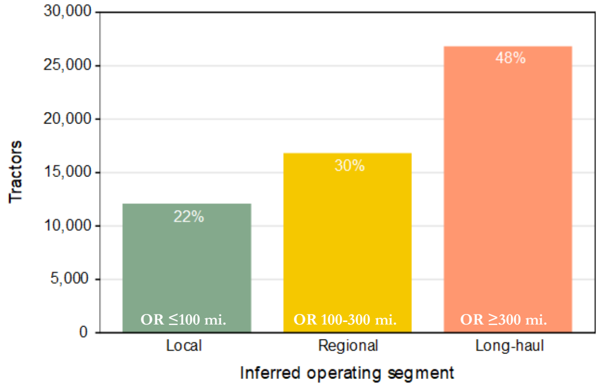
Objective:

Use **large-scale Class-8 telematics data** to **simulate heavy-duty battery electric truck (HDBET) charging** and empirically assess requirements for charging HDBETs with multiple battery ranges and across operating segments (local, regional, long-haul).

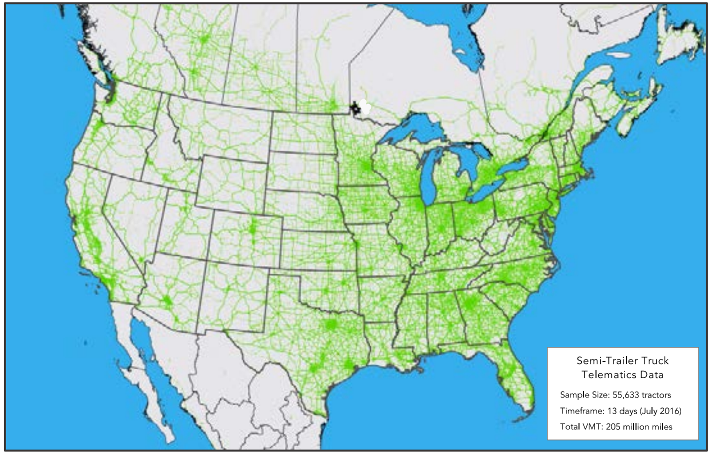
Data & Preprocessing

Data set contains hourly GPS traces from major truck manufacturer.

- **Geographic extent**: National (U.S. & Canada)
- **Collection period**: 07/01/16 – 07/14/16
- **Sample size**: 55,633 diesel trucks (~2% of U.S. truck population)
- Predominately **hourly data**, with recordings during truck movements and most dwells
- Contains **snapshot odometer readings**, used to determine vehicle miles traveled (VMT) and simulate battery state of charge (SOC).



Breakdown of truck operating segments in the data set (inferred from max operating radius over the collection period)



Map of truck activity

Approach: Charging Simulation

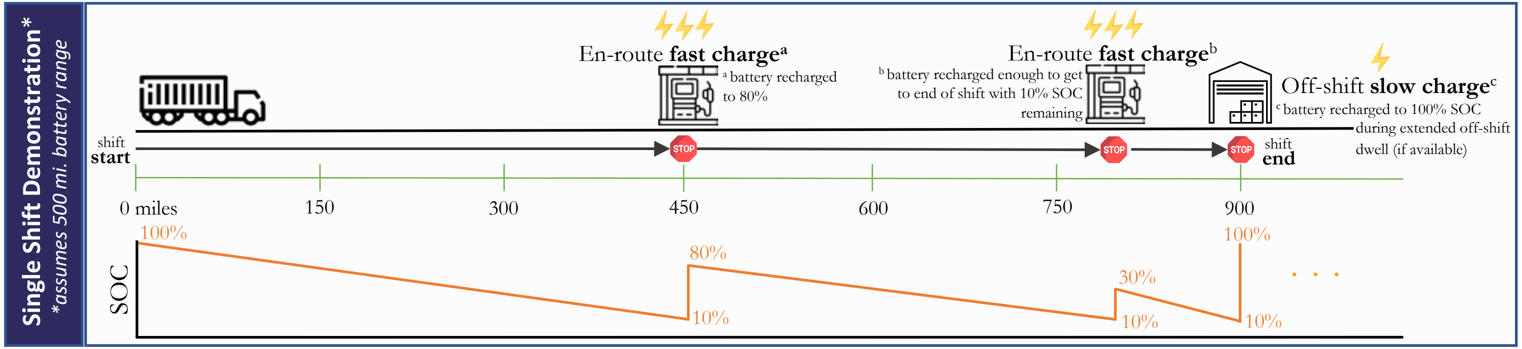
Simulate real-world diesel truck operations as if driven by a BEV to estimate the charging requirements for HDBETs.

Charging Types:

- **Off-shift slow** = opportunistic, occurring during extended dwells without disrupting operations (e.g., depot or overnight truck stop charging).
- **En-route fast** = shift-interrupting, occurs when an HDBET's battery SOC drops to 10% while on-shift.

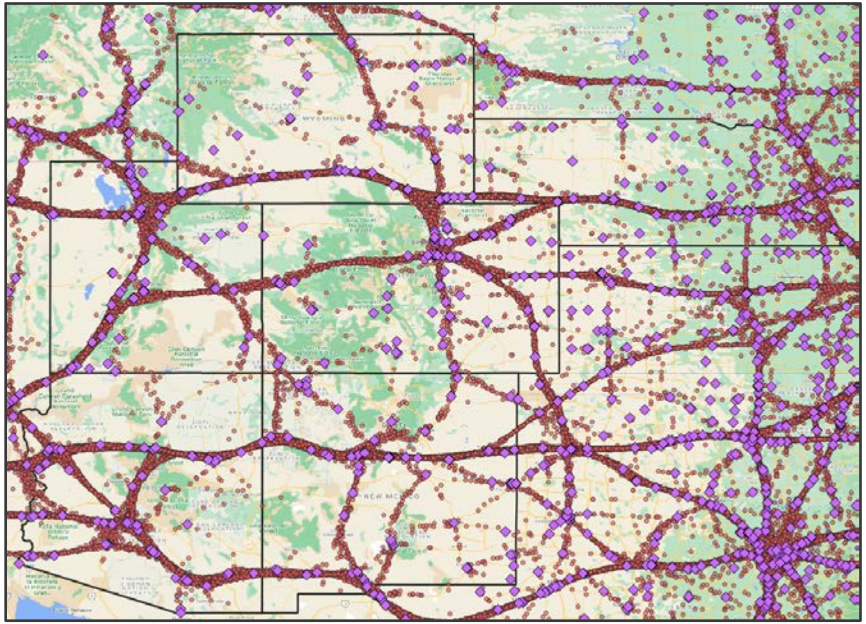
HDBET ranges considered:

- 150-mi. (currently available)
- 300-mi. (currently available)
- 500-mi. (currently available/coming soon)
- 750-mi. (future tech. improvement case)



Simulated Charging Demand

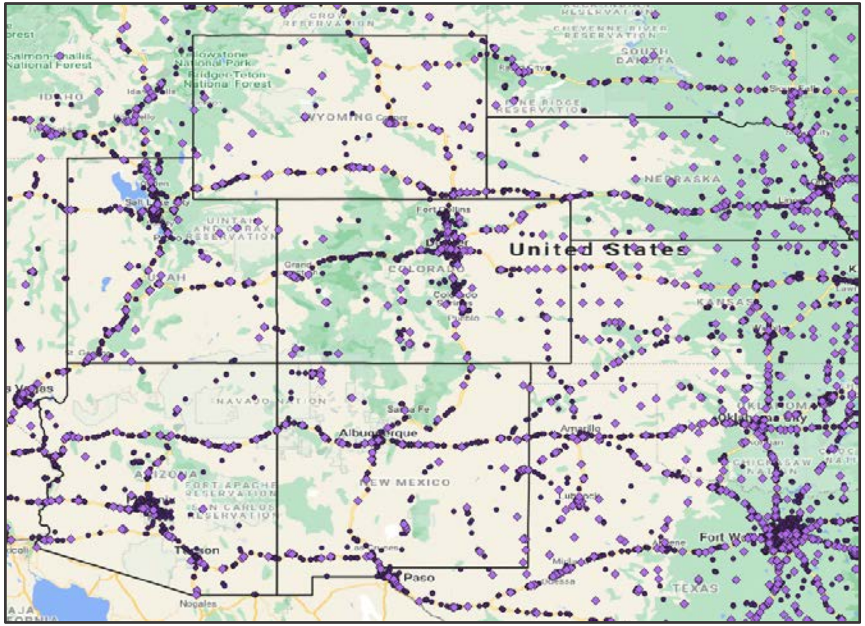
En-Route Fast Charging Demand



◆ = existing truck stop

● = fast charging demand (MW-scale)

Off-Shift Slow Charging Demand



◆ = existing truck stop

● = opportunity charging demand (kW-scale)

Finding: Current/Near-term BEVs suited for many heavy truck applications

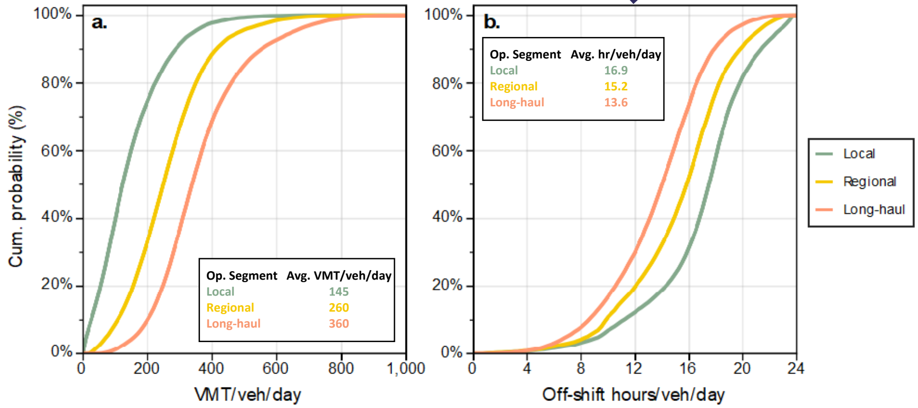
- Heavy trucks are driven much more than other vehicle segments (e.g., LDVs) but not as much as many believe:
  - **Local trucks**: 145 miles/day ; 17 off-shift hours/day
  - **Regional trucks**: 260 miles/day; 15 off-shift hours/day
  - **Long-haul trucks**: 360 miles/day; 14 off-shift hours/day

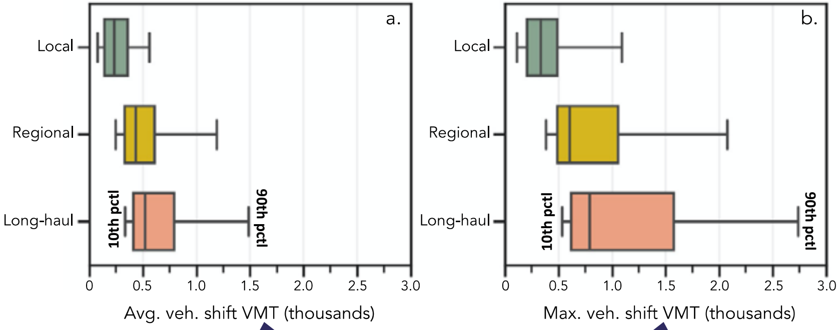
- **Average shifts** for all operating segments can be driven with current/near-term HDBETs (500-mi. range or less) and <u>no en-route charging</u>.

  however, …

- **Longest shifts** for most regional and long-haul trucks will <u>require en-route charging</u>, even for HDBETs with 500-mi. range.

Indicates max daily opportunity for HDBET charging w/o disrupting existing operations



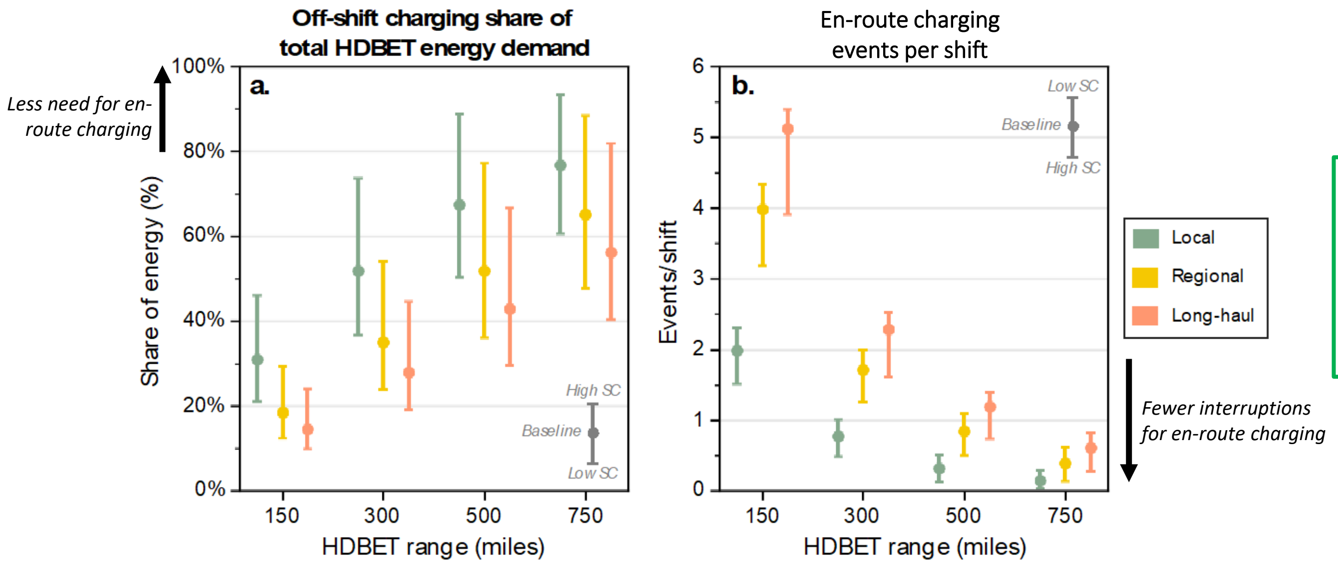


<u>Average</u> shift

<u>Longest</u> shift

Finding: Off-shift charging can serve much of an HDBET's electricity demands

Off-shift charging is **less disruptive** to existing operations and **less demanding** for the grid than en-route fast charging.



Observed Trends

Off-shift charging serves more HDBET electricity requirements as:

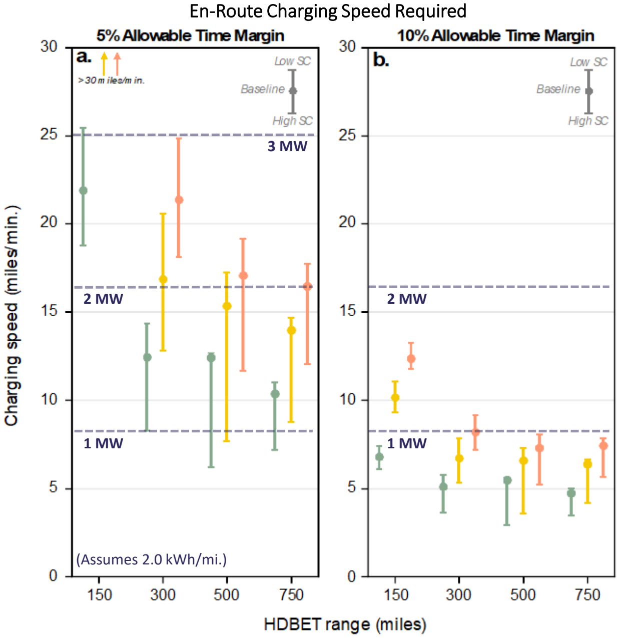
Operating distance ↓ (e.g., long-haul -> local)

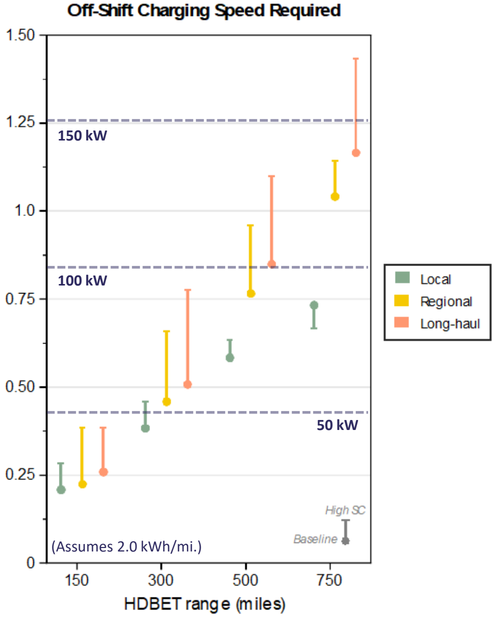
Battery range ↑

Access to off-shift charging ↑

Finding: MW speeds needed for en-route charging; kW speeds suitable for off-shift charging

Charging speed requirements are dependent on multiple factors including battery range, truck operating segment, availability of off-shift charging, and shipment time flexibility.





5% allowable time margin → 10% allowable time margin

Up to 5% longer shifts due to longer charging times

Observed Trends

Greater en-route charging speeds *required as:*

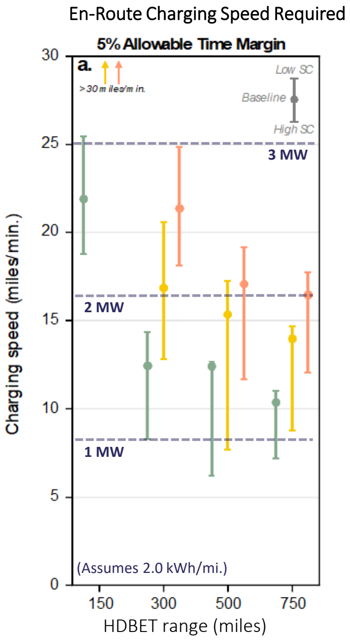
Operating distance ↑ (e.g., local -> long-haul)

Battery range ↓

Access to off-shift charging ↓

Time flexibility (allowable time margin) ↓

Finding: MW speeds needed for en-route charging; kW speeds suitable for off-shift charging



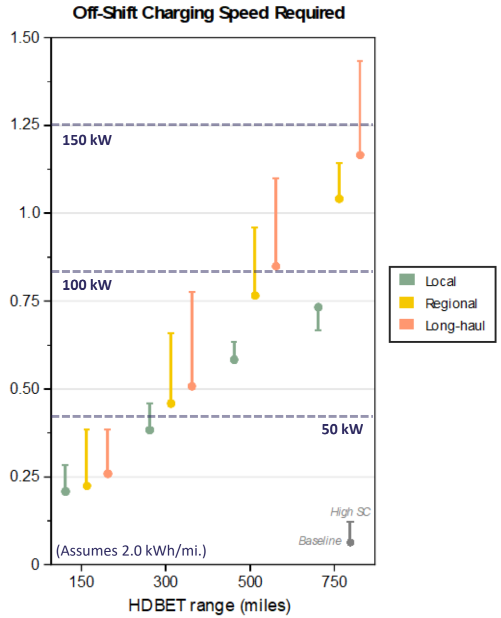
Example:

300-mi. HDBET

En-Route *Charging Speed Required:*	***Off-Shift*** *Charging Speed Required:*
– Local: 1 - 1.75 MW	– Local: ~50 kW
– Regional: 1.5 - 2.4 MW	– Regional: 50 - 80 kW
– Long-haul: 2.2 - 3 MW	– Long-haul: 60 - 90 kW

500-mi. HDBET

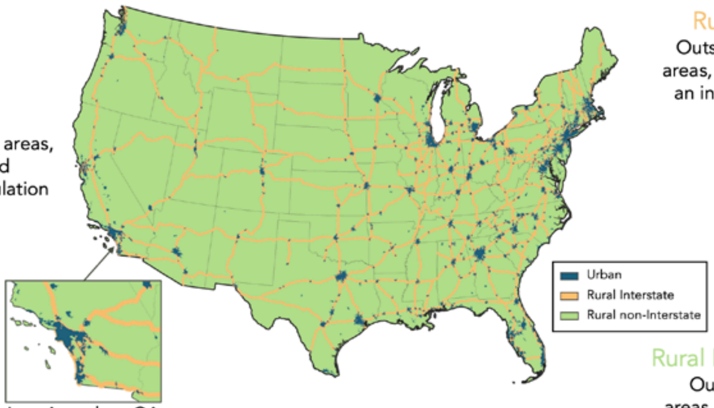
En-Route *Charging Speed Required:*	***Off-Shift*** *Charging Speed Required:*
– Local: 800 kW -1.5 MW	– Local: ~70 kW
– Regional: 1 - 2.1 MW	– Regional: 90 - 120 kW
– Long-haul: 1.4 – 2.3 MW	– Long-haul: 100 - 140 kW



Finding: Geographic Charging Trends

Simulated charging events are assigned as either urban, rural interstate, or rural non-interstate based on their location and proximity to the U.S. interstate highway system.

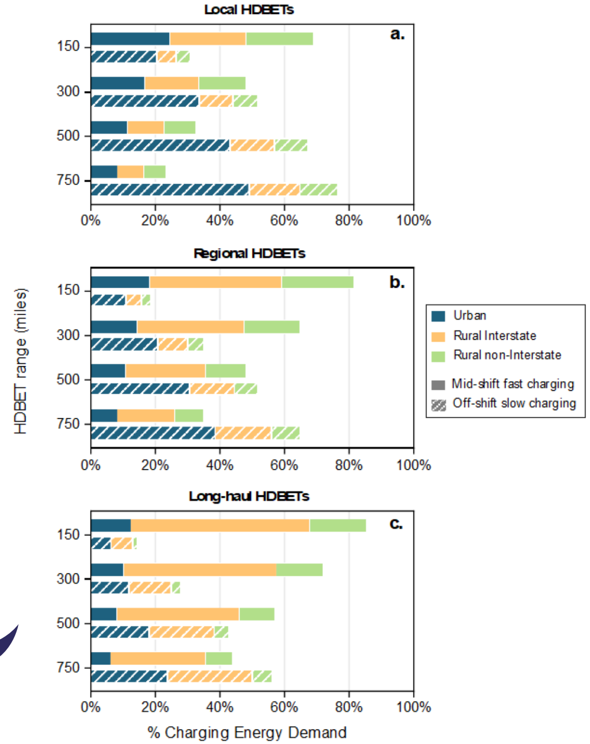
Urban
Census urbanized areas, densely developed regions with population ≥50,000.



Rural Interstate
Outside of urbanized areas, within 5 miles of an interstate highway

Rural Non-Interstate
Outside of urbanized areas, not within 5 miles of an interstate highway

Shares of Electricity Demand by HDBET Segment, Battery Range, and Location Type



Observed Trends

*as **battery range** increases, electricity demand shifts from..*

En-route → Off-shift charging;
Rural → Urban locations (dwells are frequently in urban areas)

*as **operating distance** increases (e.g., local -> long-haul) , electricity demand shifts from...*

Urban → Rural locations

Conclusions

HDBETs are coming...

This study finds that:

- Many **local applications** can be electrified with current/near-term HDBETs (500-mi battery range or less) and off-shift charging.
- Some **regional and long-haul applications** will require public MW-level charging which is not yet available in the United States.

Depot-based short-distance operations could be first to electrify due to limited near-term battery ranges and lack of public high-speed (i.e., MW+) charging infrastructure.

Deploying charging infrastructure for electric trucks involves **significant planning, coordination, & investment** (must start now to minimize delay!).

Thank You!

brennan.borlaug@nrel.gov

Ref: Borlaug, B. et al. (2022). Charging needs for electric semi-trailer trucks, *Renew. Sust. Energ. Transit.*, 2, https://doi.org/10.1016/j.rset.2022.100038.

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Vehicle Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL/PR-5400-86549

References

Borlaug, B. et al. (2022). Charging needs for electric semi-trailer trucks, *Renew. Sust. Energ. Transit.*, 2, https://doi.org/10.1016/j.rset.2022.100038.

Ledna, C. et al. (2022). Decarbonizing Medium- & Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis. NREL/TP-5400-82081, https://www.nrel.gov/docs/fy22osti/82081.pdf.

Muratori et al. (2023). Road to zero: Research and industry perspectives on zero-emission commercial vehicles, iScience, 26(5), https://doi.org/10.1016/j.isci.2023.106751.