Project ID# eems072
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U.S. DEPARTMENT OF ENERGY

SMARTMOBILITY

Systems and Modeling for Accelerated Research in Transportation

Charging Infrastructure for Freight

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2019 Vehicle Technologies Office Annual Merit Review
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Argonne NATIONAL LABORATORY | INL Idaho National Laboratory | BERKELEY LAB | OAK RIDGE National Laboratory | NREL NATIONAL RENEWABLE ENERGY LABORATORY

OVERVIEW

Timeline

- Project start date: Dec 2018
- Project end date: Sep 2019
- Percent complete: 30%

Budget

- Total project funding
  —DOE share: $350K
- Funding for FY 2019: $350K

Barriers and Technical Targets

- Refueling infrastructure is a major barrier to adopting alternative fuel freight trucks.
- Refueling infrastructure deployment for smart mobility applications has potential benefit but is dependent on cost-effective fueling infrastructure

Partners

- Idaho National Laboratory
- National Renewable Energy Laboratory
- Oak Ridge National Laboratory

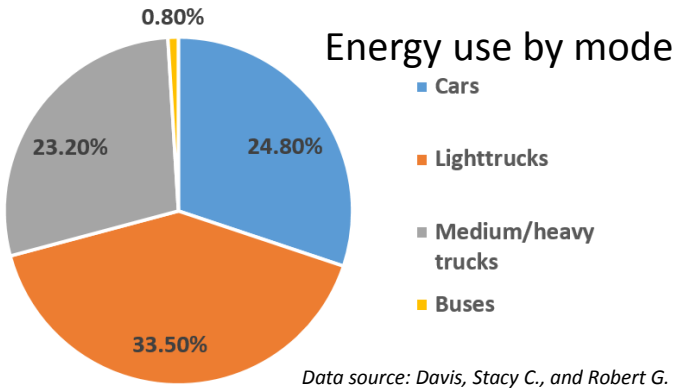
RELEVANCE

Impact:

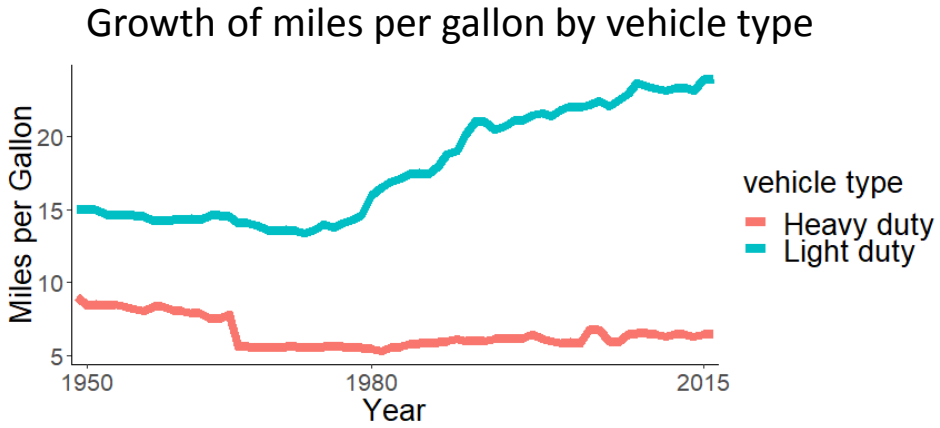
Trucks are by far the single most-used mode to move freight in the United States. Electrification of freight trucks, particularly class 7-8, is a key to improving the energy efficiency of the national transportation system.

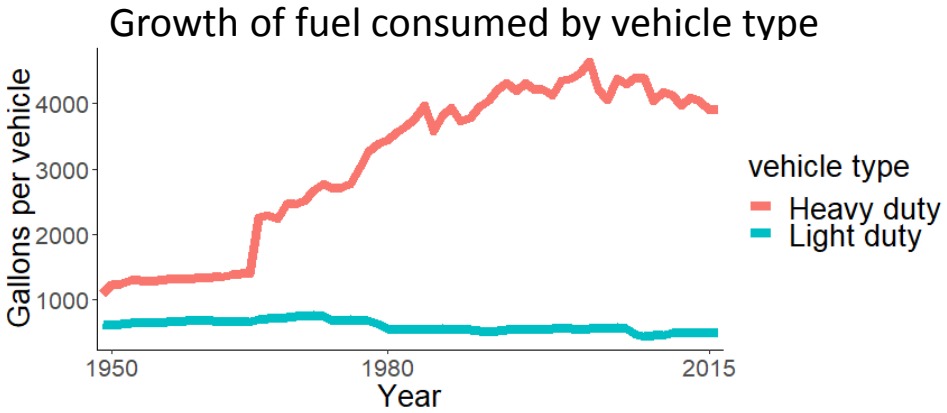
Objective:

Study which areas of motor carrier industry have electrification as a feasible solution to improve energy efficiency and explore options for charging infrastructure technology.



Data source: Davis, Stacy C., and Robert G. Boundy. Transportation Energy Data Book: Edition 37. Oak Ridge National Laboratory, 2019.





Data source: U.S. Energy Information Administration.
Light duty includes: passenger cars, light trucks, vans, and sport utility vehicles with a wheelbase equal to or less than 121 inches.
Heavy duty includes: single-unit trucks with 2 axles and 6 or more tires or a gross vehicle weight rating exceeding 10,000 pounds, and combination trucks.

APPROACH

1. Conduct industry segmentation and stakeholder analysis.
2. Estimate the performance (driving range, weight, and payload capacity) of electric trucks based on today's technology and future technology.
3. Estimate the performance (power and cost) of fast charger technology of today and future.
4. Create charging infrastructure scenario for class 7-8 trucks.

Milestone Name/Description	Criteria	End Date	Progress
Define freight use cases and perform market / stakeholder analysis for at least 3 cases. (INL)	Description of the use cases and market mechanisms .	3/31/2019	Complete
Create infrastructure scenario description for at least 2 use cases based on real-world data and create model to simulate change points (INL, NREL, ORNL)	Report on scenarios and description of model	6/30/2019	In progress
Report on charging infrastructure strategies to support class 7-8 truck and first/last-mile delivery vehicle electrification (INL, NREL, ORNL)	Submitted report	9/31/2019	In progress

TECHNICAL ACCOMPLISHMENTS

Analysis on national trucking data showed:

- More than 1.5 million motor carriers are registered to the U.S. Department of Transportation.
- 90% of the motor carriers in the U.S. own less than five power units.
- Miles traveled by a heavy truck is considerably higher than the miles traveled by a lighter truck.
- About 50% of the average haul lengths per trip of Class 7 and 8 trucks is longer than 200 miles.

Incentive analysis and trucking regulations showed:

- Truckers' incentive to drive consecutive hours (up to 11 hours) indicates the need for long-range trucks.
- Weight regulations would necessarily create a trade-off between a longer range (heavier battery pack) and a smaller payload.
- Charging stations can serve as range extenders; however, the driver's pay structure and hours of service limit will not be able to accommodate a long charging duration and likely necessitate extremely fast charging.

TECHNICAL ACCOMPLISHMENTS
SEGMENTATION OF MOTOR CARRIER INDUSTRY

Segmented the motor carrier industry into divisions for analysis:

By ownership:

- **Private motor carriers:** transport own cargo, usually as a part of a business that produces, uses, sells, and/or buys the cargo that is being hauled.
  ex. PepsiCo Inc, Coca-Cola Co., Halliburton Co.
- **For-hire carriers**: transport passengers, property, or goods owned by others for compensation. ex. FedEx, UPS, J.B. Hunt Transport.

By range of operation:

- **Long-haul**
- **Short-haul**

The majority of light trucks are used for short-range transport.

21 % of heavy trucks are used primarily for long-distance transport (range greater than 200 miles).

Number of trucks (thousands) by primary range of operation and vehicle size

	Light	Medium	Light-heavy	Heavy-heavy
50 miles or less	55,347 84%	1,086 70%	524 76%	1,117 54%
51 to 100 miles	6,707 10%	262 17%	89 13%	352 17%
101 to 200 miles	1,870 3%	72 5%	26 4%	167 8%
201 to 500 miles	863 1%	62 4%	34 5%	182 9%
501 miles or more	1,081 2%	65 4%	15 2%	248 12%
Total	65,871 100%	1,549 100%	689 100%	2,068 100%

Source: U.S. Department of Commerce, Bureau of the Census, 2002 Vehicle Inventory and Use Survey

TECHNICAL ACCOMPLISHMENTS
SEGMENTATION OF MOTOR CARRIER INDUSTRY

Within each interval of range of operation, the miles traveled by a heavy truck is considerably higher than miles traveled by lighter trucks.

Average miles traveled of a heavy truck is 4 times higher than that of a light truck.

Annual miles traveled (millions) per vehicle by range of operation and vehicle size.

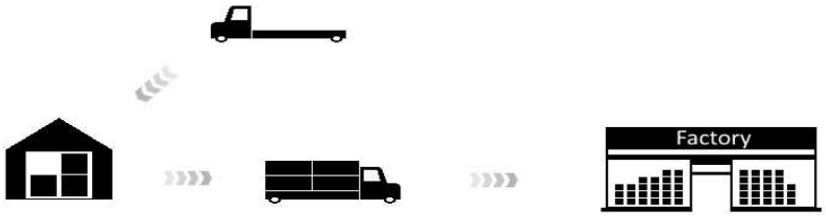
	Light	Medium	Light-heavy	Heavy-heavy
50 miles or less	12,014	12,507	11,423	**19,185**
51 to 100 miles	15,122	18,201	18,382	**37,114**
101 to 200 miles	16,233	19,676	29,736	**59,375**
201 to 500 miles	16,947	18,663	19,985	**87,556**
501 miles or more	13,814	13,187	27,196	**103,896**
Average	14,826	16,447	21,344	**61,425**

Source: U.S. Department of Commerce, Bureau of the Census, 2002 Vehicle Inventory and Use Survey

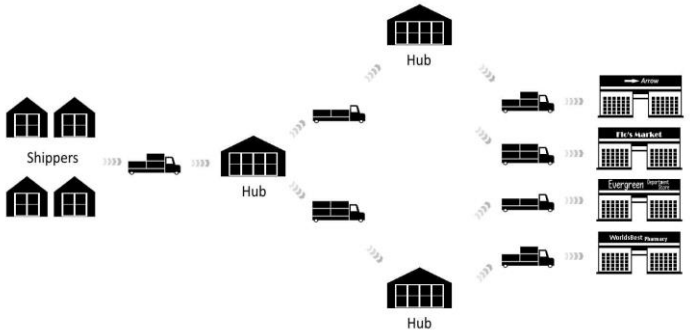
TECHNICAL ACCOMPLISHMENTS
SEGMENTATION OF MOTOR CARRIER INDUSTRY

By operation pattern:

Truckload carriers move a full truckload of shipment directly from origin to destination, typically long-haul service.



Less-than-truckload carriers collect shipments from local pick-up points and distribute goods through a network of terminals in less-than-truckload lots.



	Light	Medium	Light-heavy	Heavy-heavy	Total
Number of Trucks (thousands)	15.3 (1.9%)	45.9 (5.8%)	35.8 (4.5%)	**695.0 (87.8%)**	792.0 (100%)
Annual miles traveled (millions)	230 (0.4%)	938 (1.7%)	1,055 (1.9%)	**53,622 (96.0%)**	55,846 (100%)

	Light	Medium	Light-heavy	Heavy-heavy	Total
Number of Trucks (thousands)	20.4 (5.8%)	101.3 (28.9%)	53.5 (15.3%)	**175.0 (50.0%)**	350.2 (100%)
Annual miles traveled (millions)	419 (2.9%)	2,444 (17.1%)	1,157 (8.1%)	**10,267 (71.9%)**	14,288 (100%)

Source: U.S. Department of Commerce, Bureau of the Census, 2002 Vehicle Inventory and Use Survey

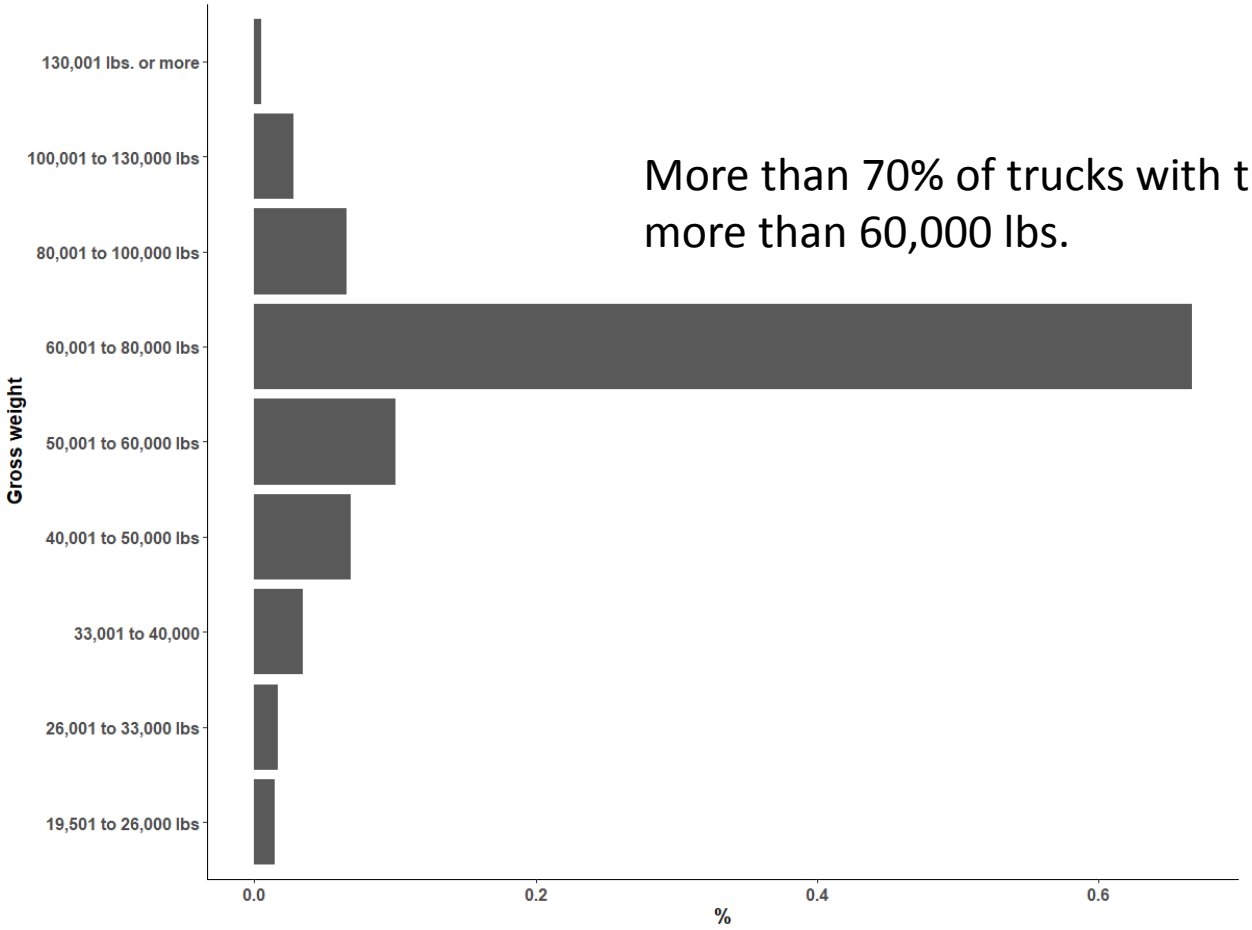
TECHNICAL ACCOMPLISHMENTS
ELECTRIC TRUCK RANGE AND PAYLOAD CAPACITY

- Estimated the performance (driving range, weight, and payload capacity) of a class-8 electric truck based on today's technology and future technology.
- The average payload carried by class 8 truck is about 14,500 kg, but can be up to 20,000 kg*.

	Today's Li-ion battery (240 Wh/kg)	Future Li-ion battery (500 Wh/kg)
250-mile range (550kWh)	 Battery weight : 2,300 kg (5,000 lbs) Maximum payload capacity: 26,700 kg (58,000 lbs)	 Battery weight: 1,100 kg (2,400 lbs) Maximum payload capacity: 28,000 kg (62,000 lbs)
500-mile range (1,100kWh)	 Battery weight: 4,600 kg (10,000 lbs) Maximum payload capacity: 14,400 kg (32,000 lbs)	 Battery weight: 2,200 kg (4,900 lbs) Maximum payload capacity: 26,800 kg (58,000 lbs)

*Transportation Research Board and National Research Council. 2010. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. Washington, DC: The National Academies Press

TECHNICAL ACCOMPLISHMENTS
Distribution of the gross weight of diesel trucks on road



More than 70% of trucks with trailers weigh more than 60,000 lbs.

Source: U.S. Department of Commerce, Bureau of the Census, 2002 Vehicle Inventory and Use Survey

TECHNICAL ACCOMPLISHMENTS
CHARGING OPTIONS

Charging Options

Conductive (Plug-in)

- Options:
  - 50-350 kW available (1000+ kW potential)
  - 50 kW (DC fast charger)
  - 120 kW (Tesla Super Fast Charger)
  - 350 kW (XFC eXtreme Fast Charger)

Pros: Mostly Standardized, Reliable, Lower infrastructure costs, can be done in parallel.

Cons: Interoperability issues, next gen would have heavy cables, cooling issues, and may have union issues.

TECHNICAL ACCOMPLISHMENTS
CHARGING OPTIONS

Charging Options

Catenary (Over-head or conductive in-motion)

- Options:
  - Overhead fixed routes
  - Conductive lines in road, median
  - Intermittent charging in zones.

Pros: Smaller battery needed, lower truck costs / weight, reliable sources of energy

Cons: High infrastructure costs, maintenance costs, visual nuisance, drag created from overhead connection.

TECHNICAL ACCOMPLISHMENTS
CHARGING OPTIONS

Charging Options

Wireless (Inductive)

- Options:
  - 50kW, 250 kW, (500 kW planned)
  - Placed in parking /stopping locations
  - Can place in road-ways

Pros: Hands free, no electrical shock hazards, not visible

Cons: High infrastructure costs, EM Field safety considerations, complexity, inter-operability and communications needs

TECHNICAL ACCOMPLISHMENTS
CHARGING OPTIONS

Placement Options

Depots:

Conductive chargers at end-of day for fixed routes.

Wireless at loading docks and parking.

On-Route

Catenary lines for fixed routes (dryage docks, movement zones).

Wireless in-road or at fixed stop locations.

Truck Stops

Conductive fast chargers at fueling locations (parallel charging possible).

Wireless charging at parking lots, night-time rest-areas.

TECHNICAL ACCOMPLISHMENTS
CHARGING OPTIONS

Theoretical Charging Times

	50 kW DC Charger	350 kW Charger	120 kW (x4 parallel)	250 kW Wireless	Catenary
150 Mile	6 Hours	50 minutes	37 minutes	1.2 hour	n/a
500 Mile	20 Hours	2.8 hours	2 hours	4 hours	n/a

Assumptions:

~2 kWH/mile

TECHNICAL ACCOMPLISHMENTS
STAKEHOLDER INCENTIVE AND REGULATIONS

Stakeholders' incentives and motor carrier regulations set the requirements for the vehicle and charger performance.

Truck driver incentives:

- 66% are paid by the mile*.
  - ➡ Downtime from charging is a loss to the driver.

Motor carrier regulations

- Gross Weight: The weight of a vehicle and load on the interstate highway system is 80,000 pounds.
  - ➡ Creates tradeoff between battery pack size and payload.

- Driver may not drive beyond the 14th consecutive hour after coming on duty, following 10 consecutive hours off duty.
  - ➡ Long hours of charging cannot be accommodated in a trip.

*Chen , Guang, W. Karl Sieber, Jennifer E. Lincoln, Jan Birdsey, Edward M. Hitchcock, Akinori Nakata, Cynthia F. Robinson., James W. Collins, Marie H. Sweeney, NIOSH national survey of long-haul truck drivers: Injury and safety, Accident Analysis & Prevention, Volume 85, 2015, Pages 66-72.

NEXT STEPS – SCENARIO DEVELOPMENT

- Analyze an example scenario for key segments:

(Segments)	Short-Haul	Long Haul
Truck Load (Point to Point)	Distributor Supply Business-to-Business	Long-Distance Delivery Business-to-Business
Less than Truck Load (Network)	Distribution Network Delivery from Hub	Distribution Network Chained Trips
Specialized	Busses / Dock-Work	

Long-Haul Point-To-Point

Longer than 500 miles
Charging during trip
Impacts Driver Route

Some Options:
Truck stops – Look at number and types needed, cost, time-impacts
Wireless charging at parking areas – Look at number and types needed, costs.

Short-Haul Distribution

Shorter than 250 miles/Day
Leave From and Return to Depot location
Specified route

Some Options:
Depot: Charging Infrastructure at Depot – Look at number and types of chargers, grid impact, costs
Wireless charging at Docking Locations – Look at time, ability to extend range

RESPONSES TO PREVIOUS YEARS REVIEWERS COMMENTS

- This is a new project started in FY19.

COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

INL

- Team members:

  Yutaka Motoaki, Victor Walker

- Focus:
  - Industry segmentation
  - Stakeholder analysis

NREL

- Team member:

  Alicia Birky

- Focus:
  - Freight Inter-City (Multi-Modal Freight 2.1)
  - Real-world data from FleetDNA
  - Truck Consortium

ORNL

- Team member:

  Amy Moore

- Focus:
  - Freight Intra-City (Multi-Modal Freight 3.1)
  - Freight Analysis Framework (ORNL)
  - Wireless charging for heavy-duty vehicles

REMAINING CHALLENGES AND BARRIERS

- Data on freight truck inventory are limited due to the discontinuation of the data collection by the Department of Transportation.
- Network operation of less-than-truckload carriers is complex and data acquisition is difficult.
- Uncertainty with regard to the cost of the advanced charging infrastructure.

PROPOSED FUTURE RESEARCH

FY19:

- Perform Additional Scenario Analysis
  - Analyze fleet operation patterns for long-haul, short-haul, and regional less-than-truckload operations.
  - Identify the charging and vehicle technology suitable for each scenario.

- Further investigate the complex trade-off relationships between driver's preference, technology performance of truck and charger, and regulations on trucking.

Future Work:

- Identify Future Research Gaps
  - Needs for infrastructure planning tools.
  - Business cost drivers
  - Grid Impact

Any proposed future work is subject to change based on funding levels

SUMMARY SLIDE

- The U.S. motor carrier industry has a complex business and operation structure with many firms with diverse interests.
- Industry segmentation is critical for infrastructure analysis.
- The requirements for vehicle and charging infrastructure are informed by stakeholder incentives and motor carrier regulations.
- Scenario analysis provides key insights into charging infrastructure needs for heavy-duty trucks.