EVs @ Scale
U.S. Department of Energy

TCO Analysis Approach and Regional Analysis of dWPT for Class 8 Tractors

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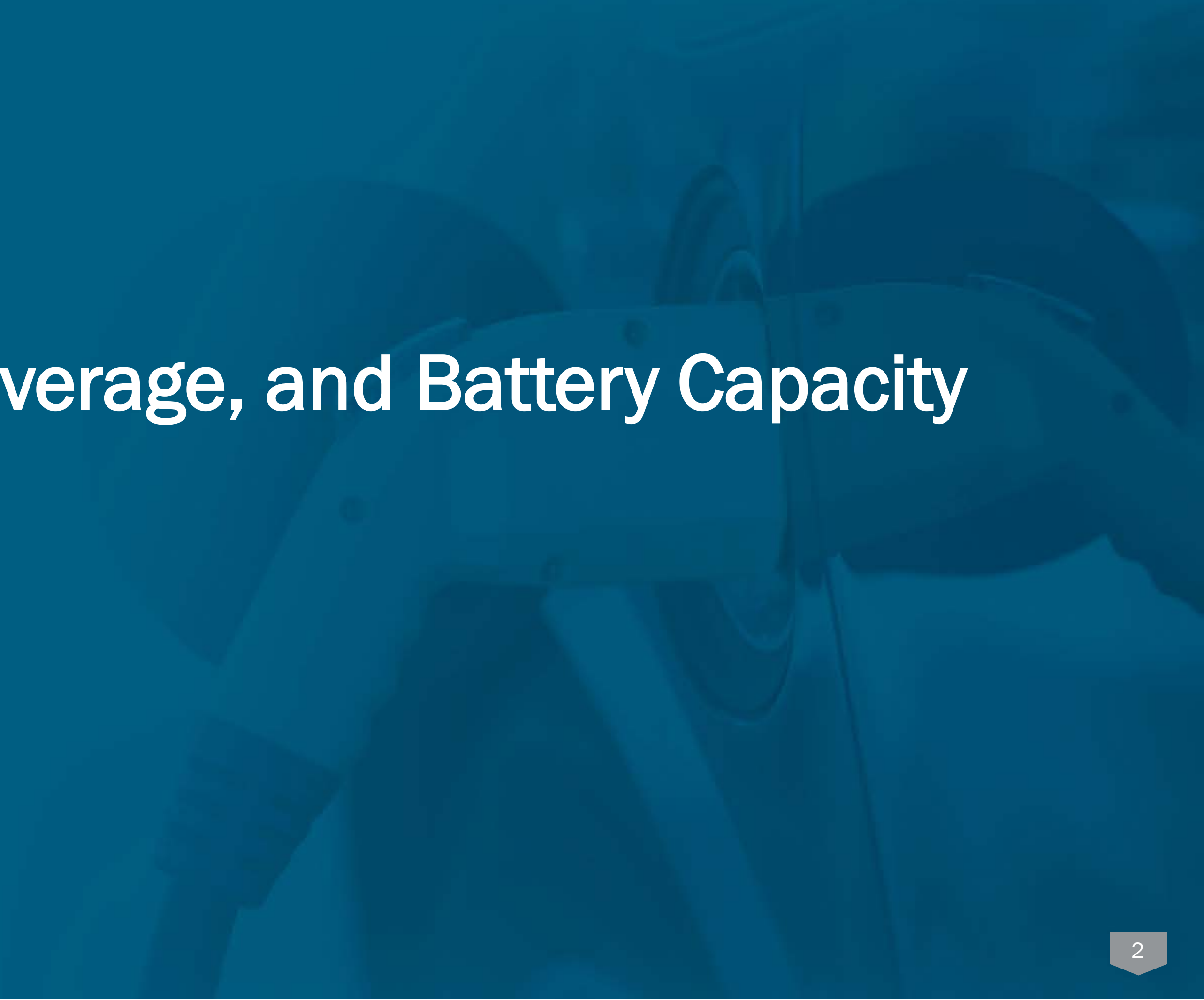
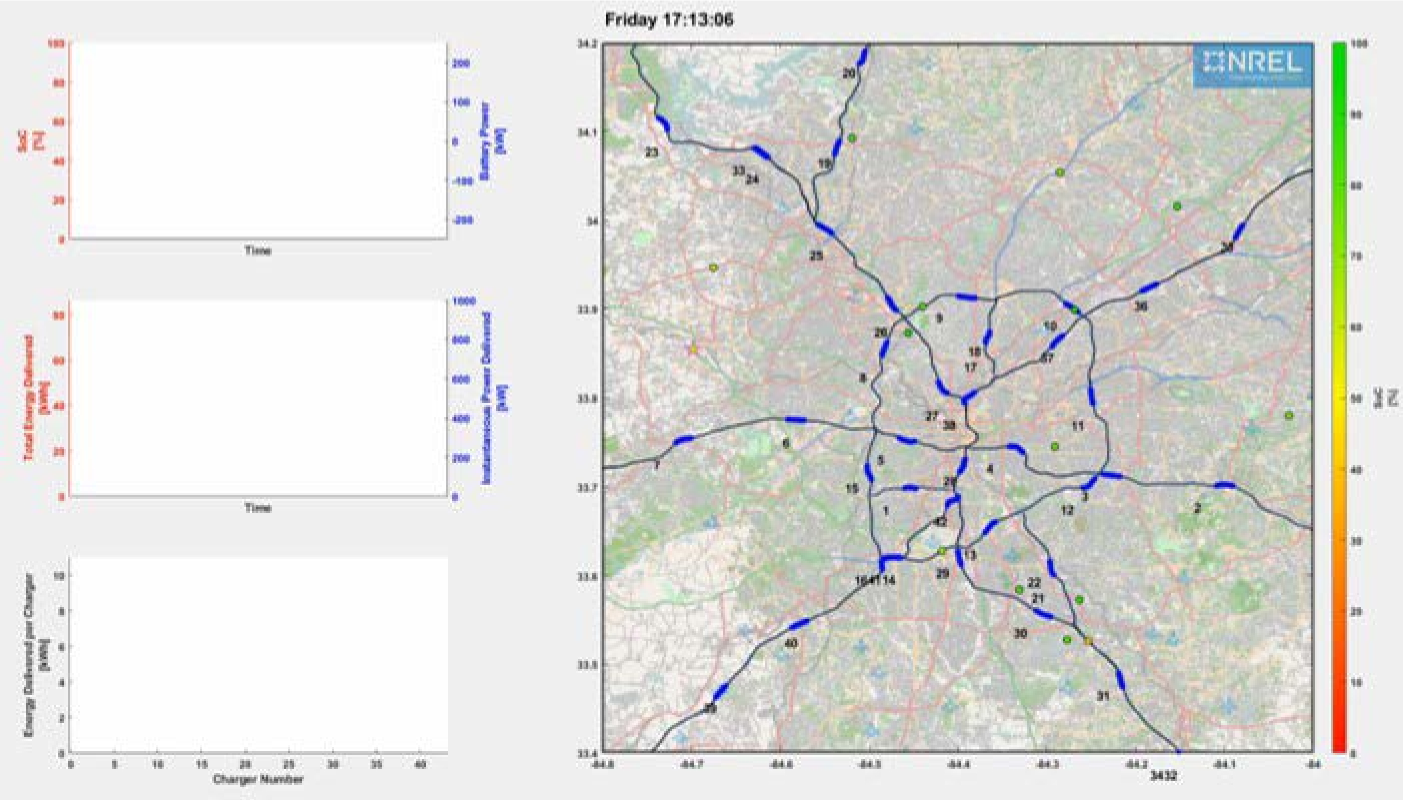
Identifying dWPT Power, Road Coverage, and Battery Capacity



Approach: EVI-InMotion

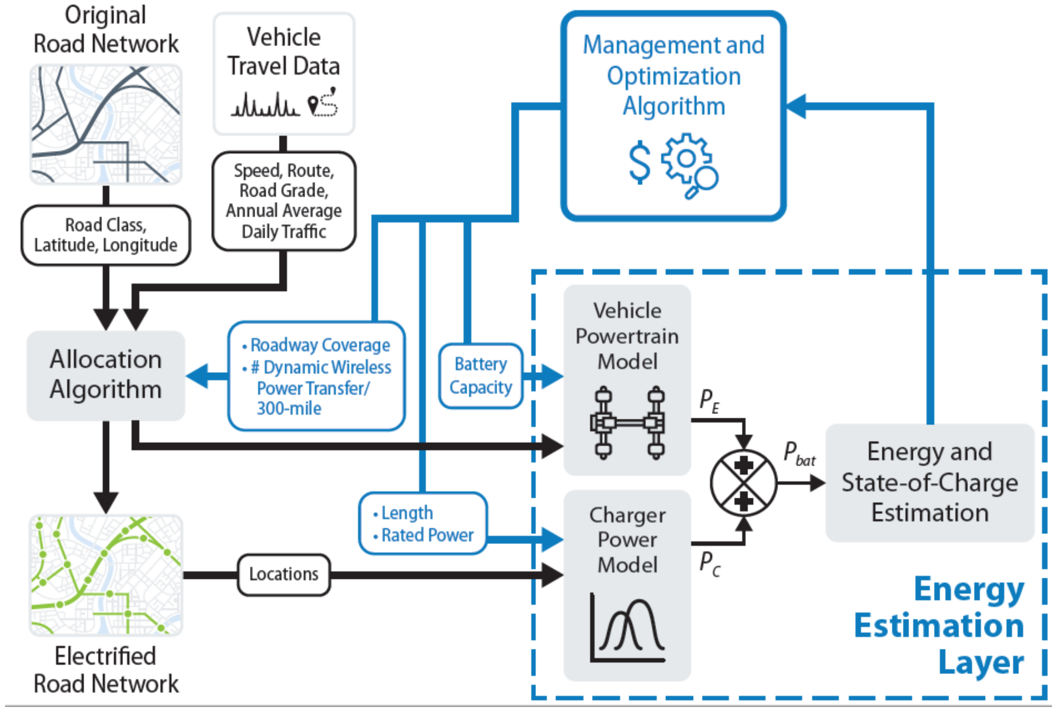
A case study dWPT System on Primary Roadways in Atlanta



- EVI-InMotion is a system planning/optimization tool for dynamic charging for EVs.

- It uses 1 Hz travel data and real road networks to explore the impact of dWPT system on EV travel.

- Estimate net kWh/mile per trip considering EV energy and energy from dWPT system.



Original Road Network

Road Class, Latitude, Longitude

Vehicle Travel Data

Speed, Route, Road Grade, Annual Average Daily Traffic

Management and Optimization Algorithm

Allocation Algorithm

- Roadway Coverage
- # Dynamic Wireless Power Transfer/300-mile

Battery Capacity

Vehicle Powertrain Model

P_E

P_{bat}

Energy and State-of-Charge Estimation

Charger Power Model

P_C

- Length
- Rated Power

Locations

Electrified Road Network

Energy Estimation Layer

EVI-InMotion

https://www.nrel.gov/transportation/evi-ensite.html

Performance Evaluation: Long-haul, Regional, and Local Trips

Trips classification:

- local (OR: < 100 mi.)
- regional (OR: 100-300 mi.)
- long-haul (OR: >300 mi.)

Performance metrics:

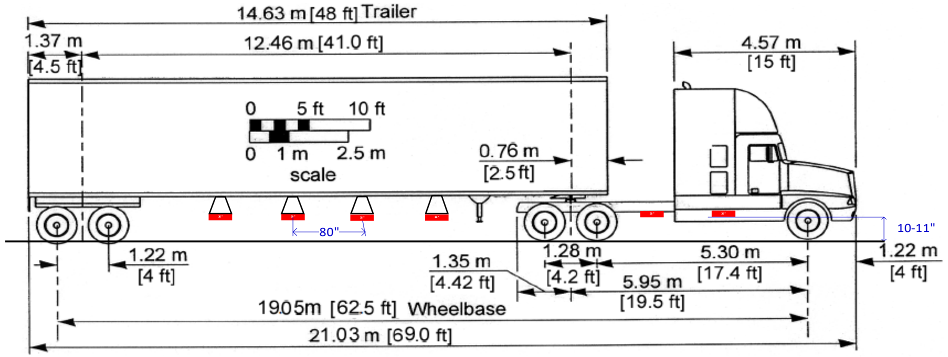
- dWPT kWh
- En route kWh
- Net kWh/mile

Class 8 EV Model and Parameters

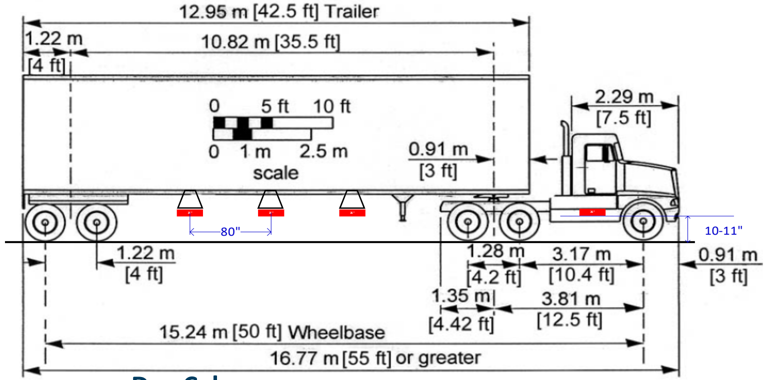
Goal: Identify representative class 8 EV models with the associated battery size and number of receivers

Class 8 EV Models:

- Two EV class powertrain models are considered:
    - **Sleeper Cab (1.3 MWh battery, 500 mi and 600 mi):** fits 6 receivers and used with regional and long-haul travel data.
    - **Day Cab (550 kWh battery, 250 mi):** fits 4 receivers and used and local travel data.
- Receivers can be installed at lower level in the trailers



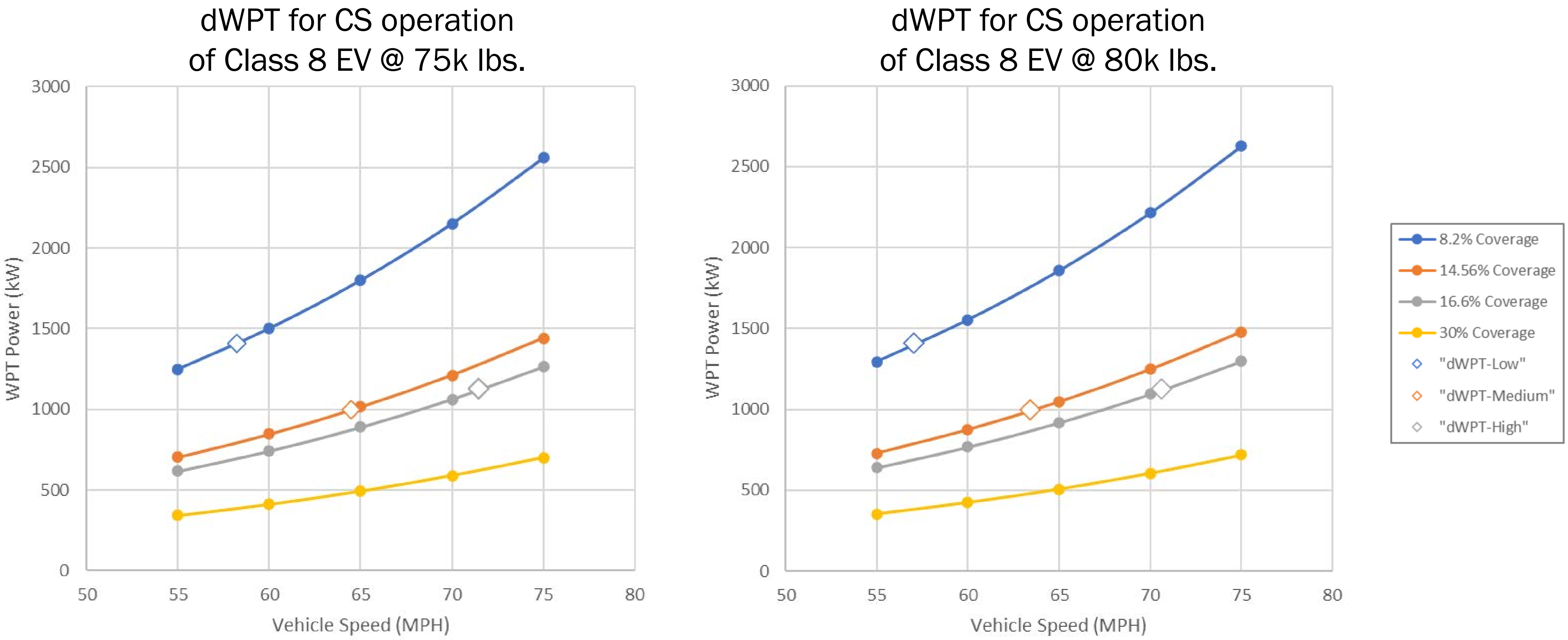
Sleeper Cab **Model A**



Day Cab **Model B**

		dWPT-Low	dWPT-Medium	dWPT-High
HD Sleeper Cab EV	Battery size (kWh)	200	200	200
	# receivers	6	5	5
	Received Power (kW)	~235 x 6 = 1,410	~200 x 5 = 1,000	~225 x 5 = 1,125
HD Day Cab EV	Battery size (kWh)	200	200	200
	# receivers	6→4	5→4	5→4
	Received Power (kW)	~235 x 6→4 = 1,410→940	~200 x 5→4 = 1,000→800	~225 x 5→4 = 1,125→900

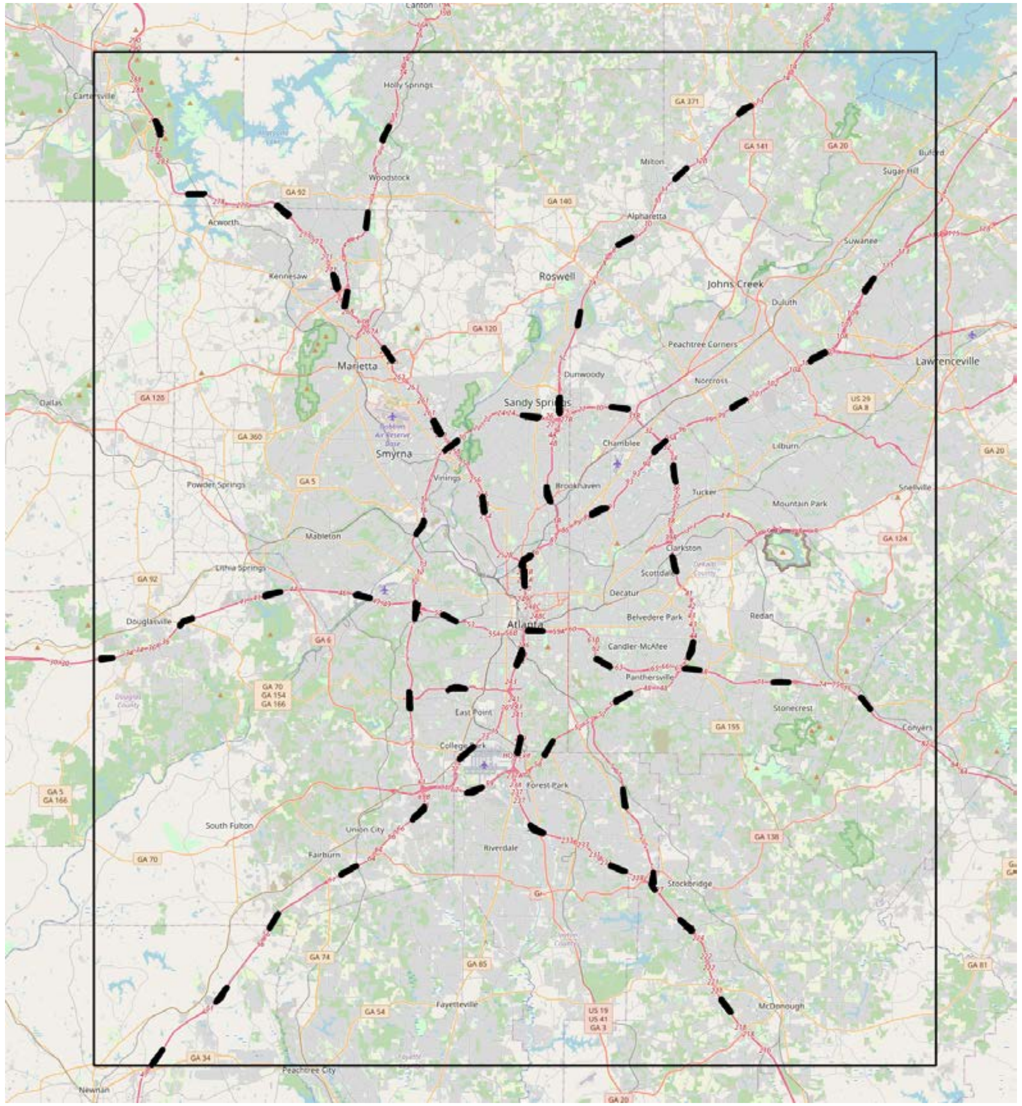
Design of dWPT System for Charge Sustaining



*Aerodynamic drag is based on day-cab model within FASTsim

Atlanta Wireless Charging System Metrics

Primary road network in Atlanta showing dWPT-Med system locations with 60 segment/300- mile



Atlanta Study Region

Total linear miles of roadway: 618.8 miles*

120 dWPT charging segments

Total lane-miles of roadway: 2,364.6 miles*

Linear-miles of electrified roadway:

Low: 48.6 miles (7.85% coverage)

Med: 87.0 miles (14.06% coverage)

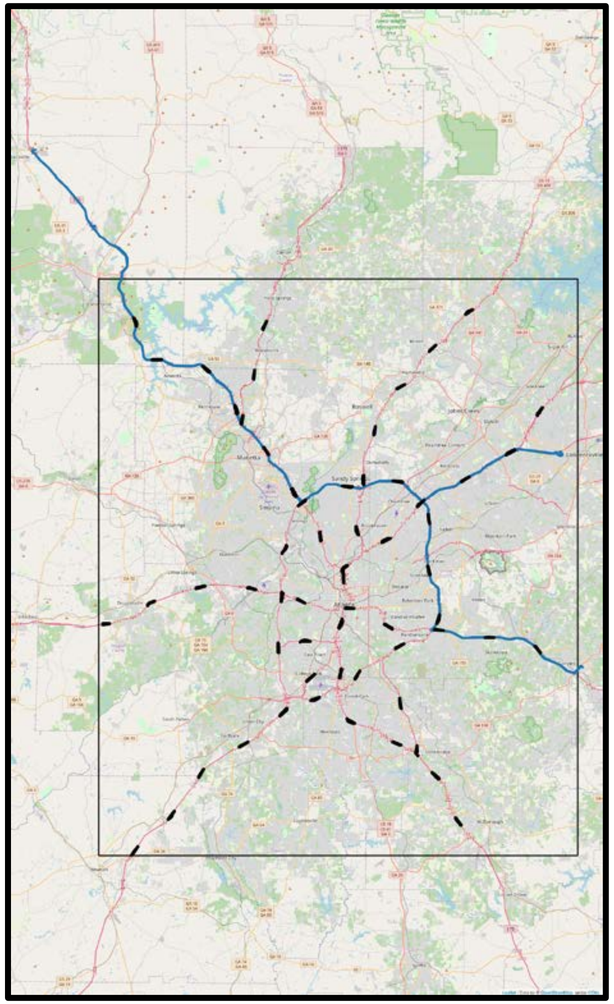
High: 99.0 miles (16.01% coverage)

There are roughly 45K linear miles of Interstate highway miles in the US. For simplification in this study, we assume electrification is only around Atlanta metro area and study vehicles in this region .

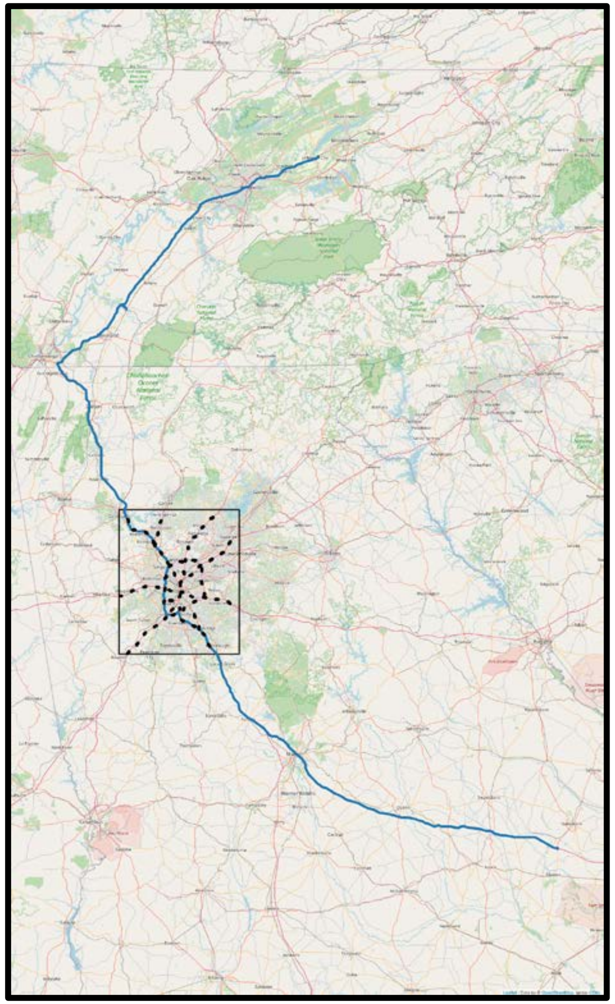
* = miles counted in each direction of travel

Vehicle Exemplar Routes

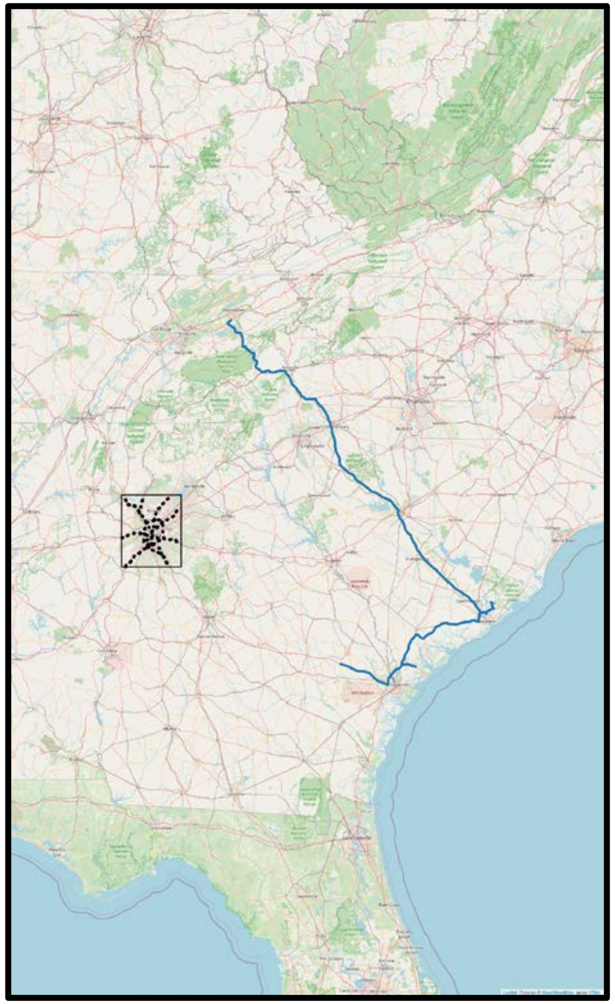
Local



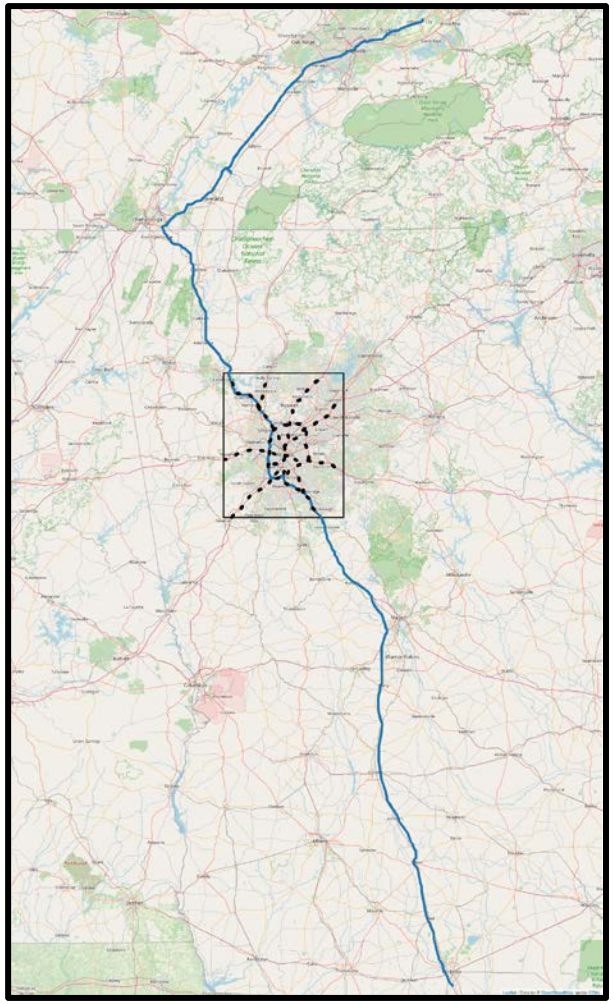
Regional, Day 1



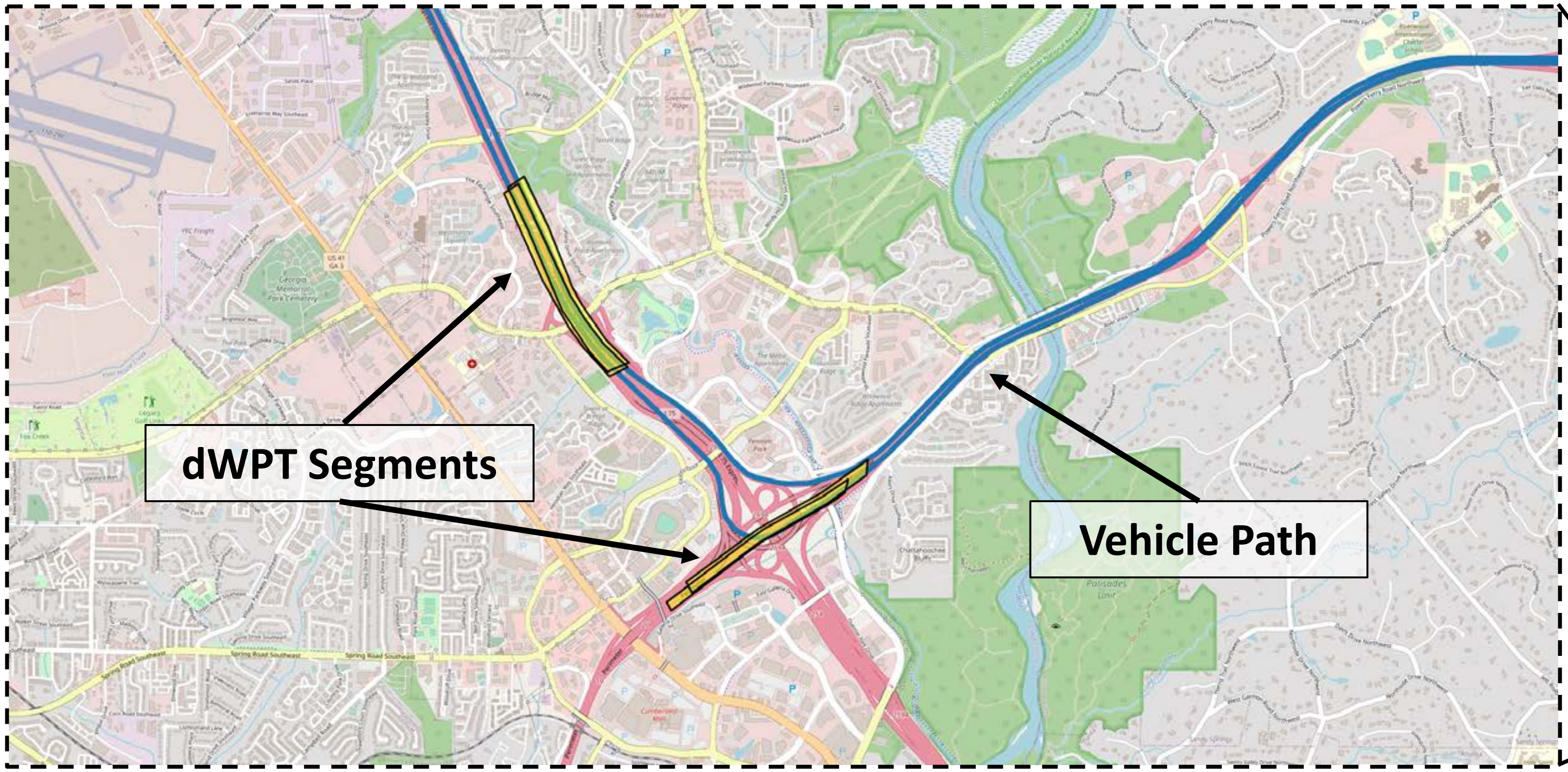
Regional, Day 2

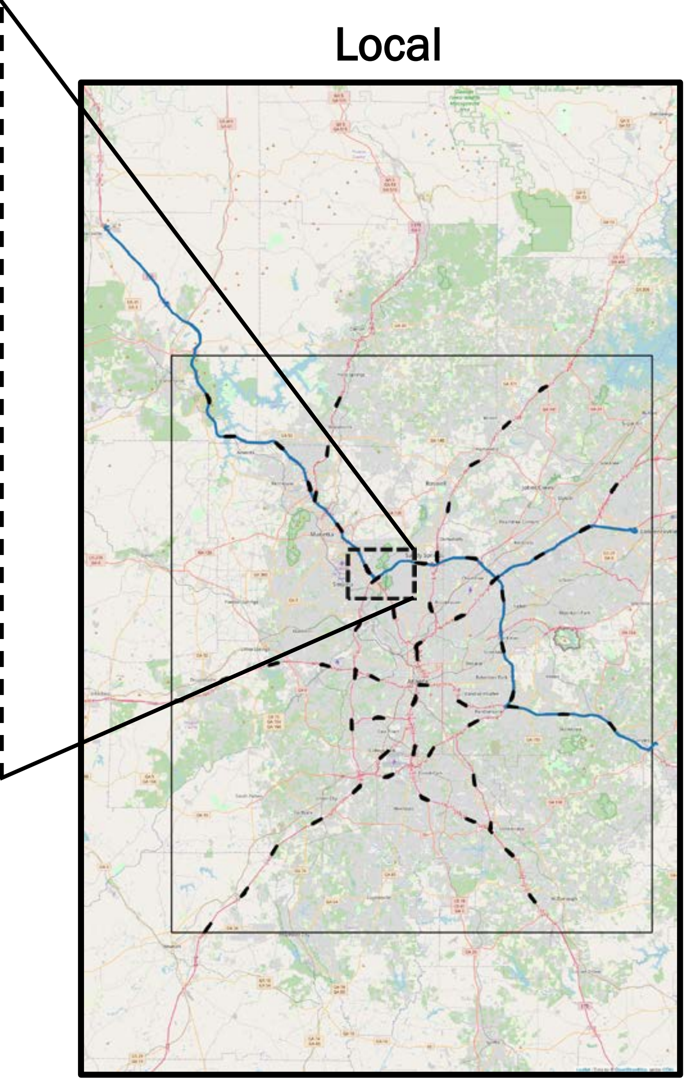


Long Haul



Local Exemplar





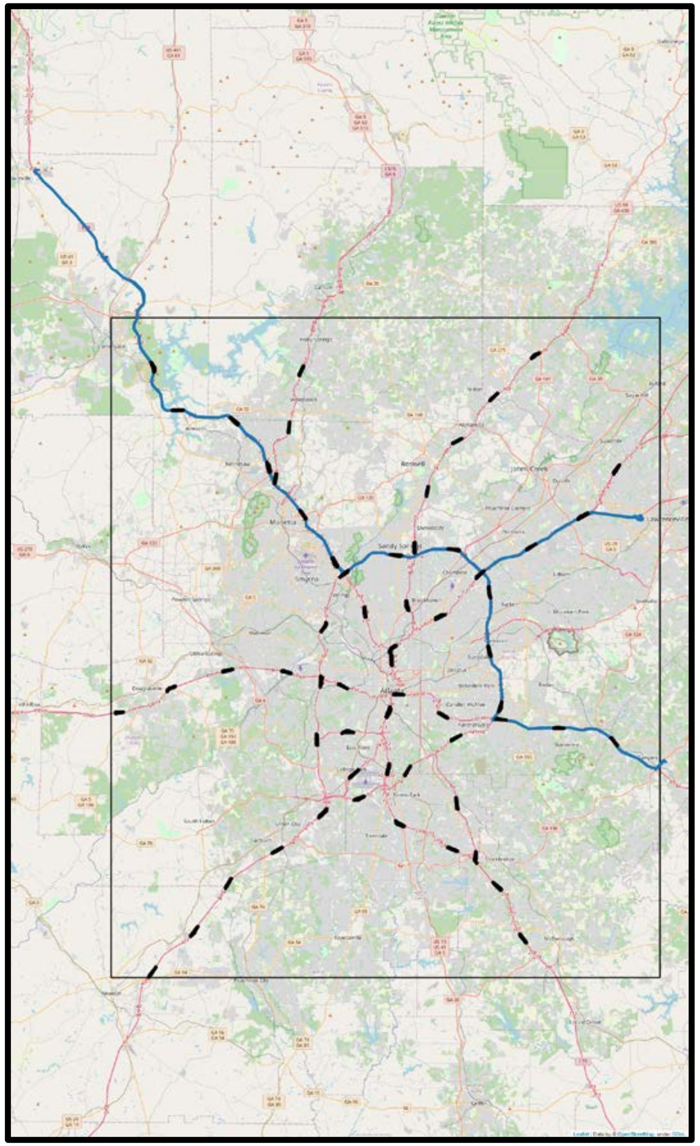
Vehicles receive charging from dWPT segments only if they are both within the charger perimeter and travelling on the road/direction associated with the charger

Local Exemplar

	Distance [mi]	dWPT Energy [kWh]	Fast-Charge Energy [kWh]	Depot Charging Energy [kWh]
Local	207	273	0	102
Regional Day 1	446	113	626	180
Regional Day 2	571	0	770	330
Long Haul	917	270	1232	521

- Vehicle travels 2x battery range without fast-charge stops
- Almost entire day spent in electrified region
- Local vehicle able to satisfy day's energy needs with only dWPT and end-of-day depot charging
- Majority of day's energy expenditure is replenished from dWPT charging

Local

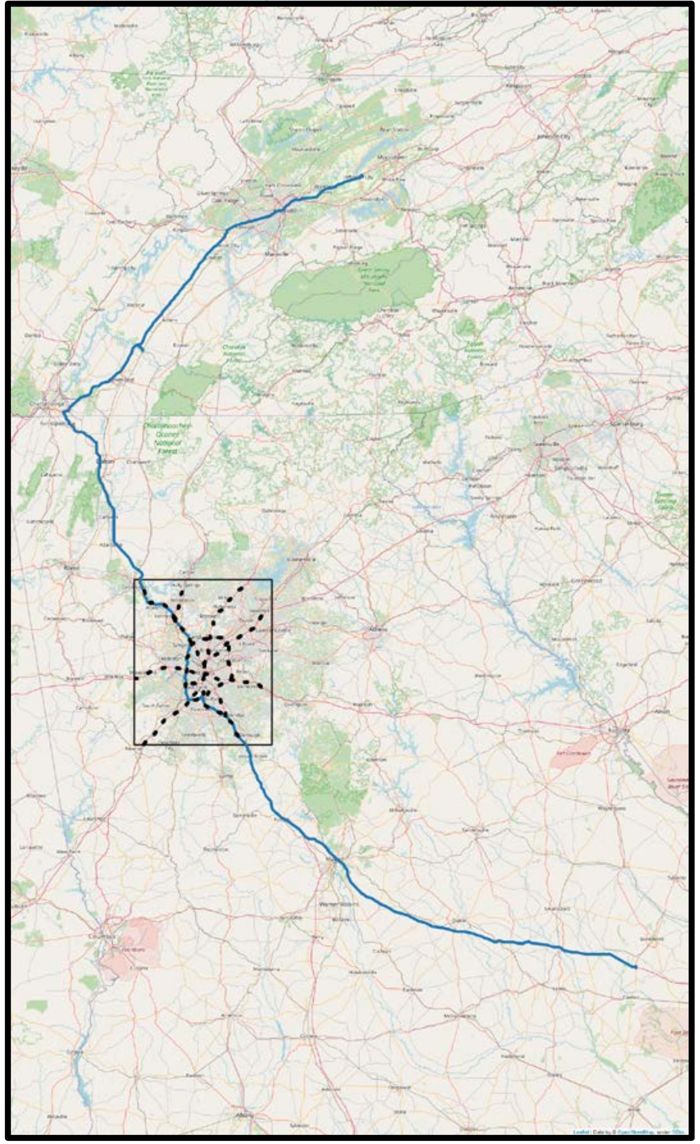


Regional-Haul Exemplar

	Distance [mi]	dWPT Energy [kWh]	Fast-Charge Energy [kWh]	Depot Charging Energy [kWh]
Local	207	273	0	102
Regional Day 1	446	113	626	180
Regional Day 2	571	0	770	330
Long Haul	917	270	1232	521

- First day of regional operation passes through electrified Atlanta region once (south-bound)
- Majority of day's driving occurs outside of electrified region
- Midday fast-charging required to satisfy day's energetic needs along with end-of-day depot charging and dWPT energy received on-road
- Majority of day's energy expenditure is replenished from midday fast-charging

Regional, Day 1

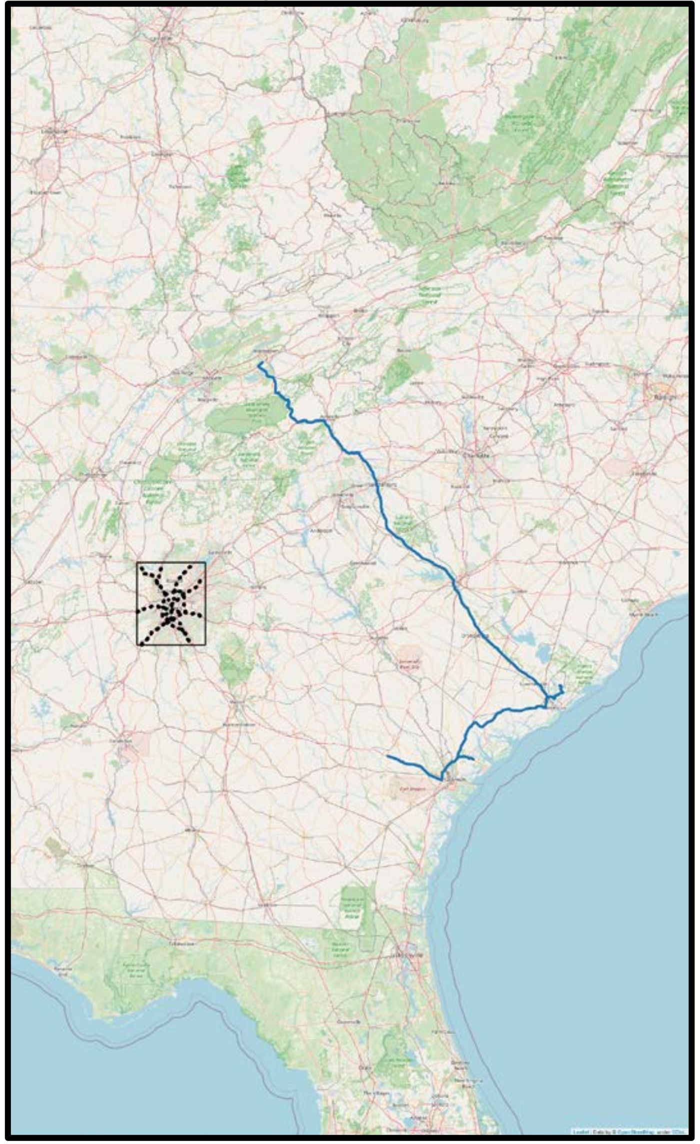


Regional-Haul Exemplar

	Distance [mi]	dWPT Energy [kWh]	Fast-Charge Energy [kWh]	Depot Charging Energy [kWh]
Local	207	273	0	102
Regional Day 1	446	113	626	180
Regional Day 2	571	0	770	330
Long Haul	917	270	1232	521

- Second day of regional operation did not pass through electrified Atlanta area
- Midday fast-charging required to supplement midday and end-of-day depot charging
- Majority of day's energy expenditure is replenished from midday fast-charging

Regional, Day 2

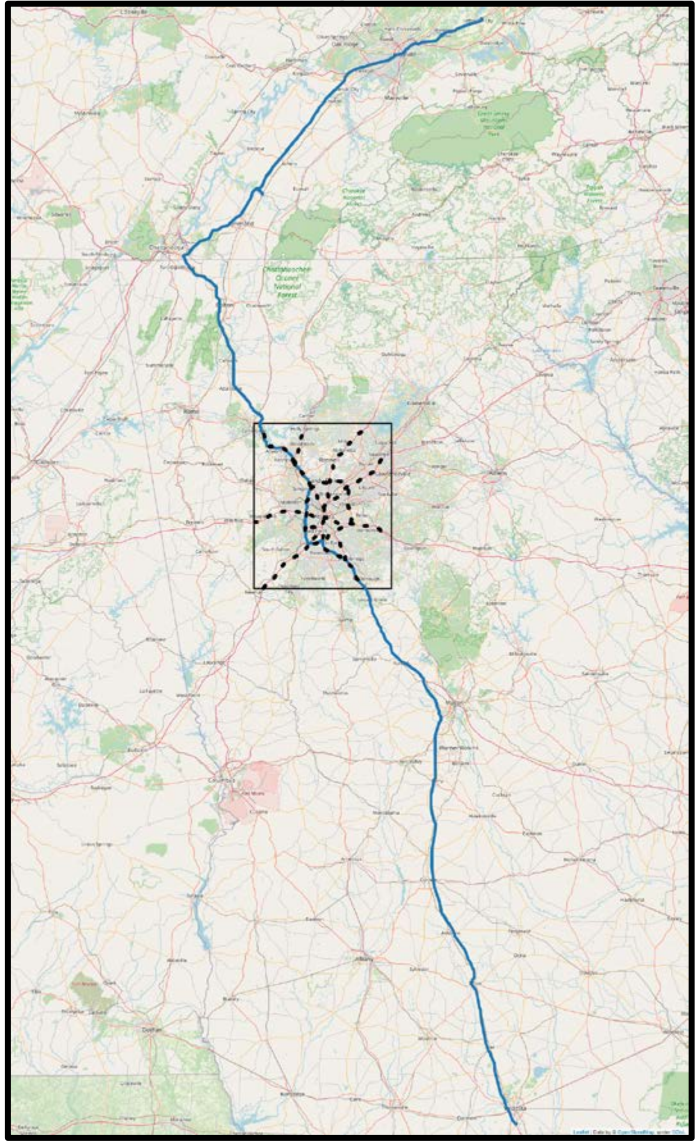


Long-Haul Exemplar

	Distance [mi]	dWPT Energy [kWh]	Fast-Charge Energy [kWh]	Depot Charging Energy [kWh]
Local	207	273	0	102
Regional Day 1	446	113	626	180
Regional Day 2	571	0	770	330
Long Haul	917	270	1232	521

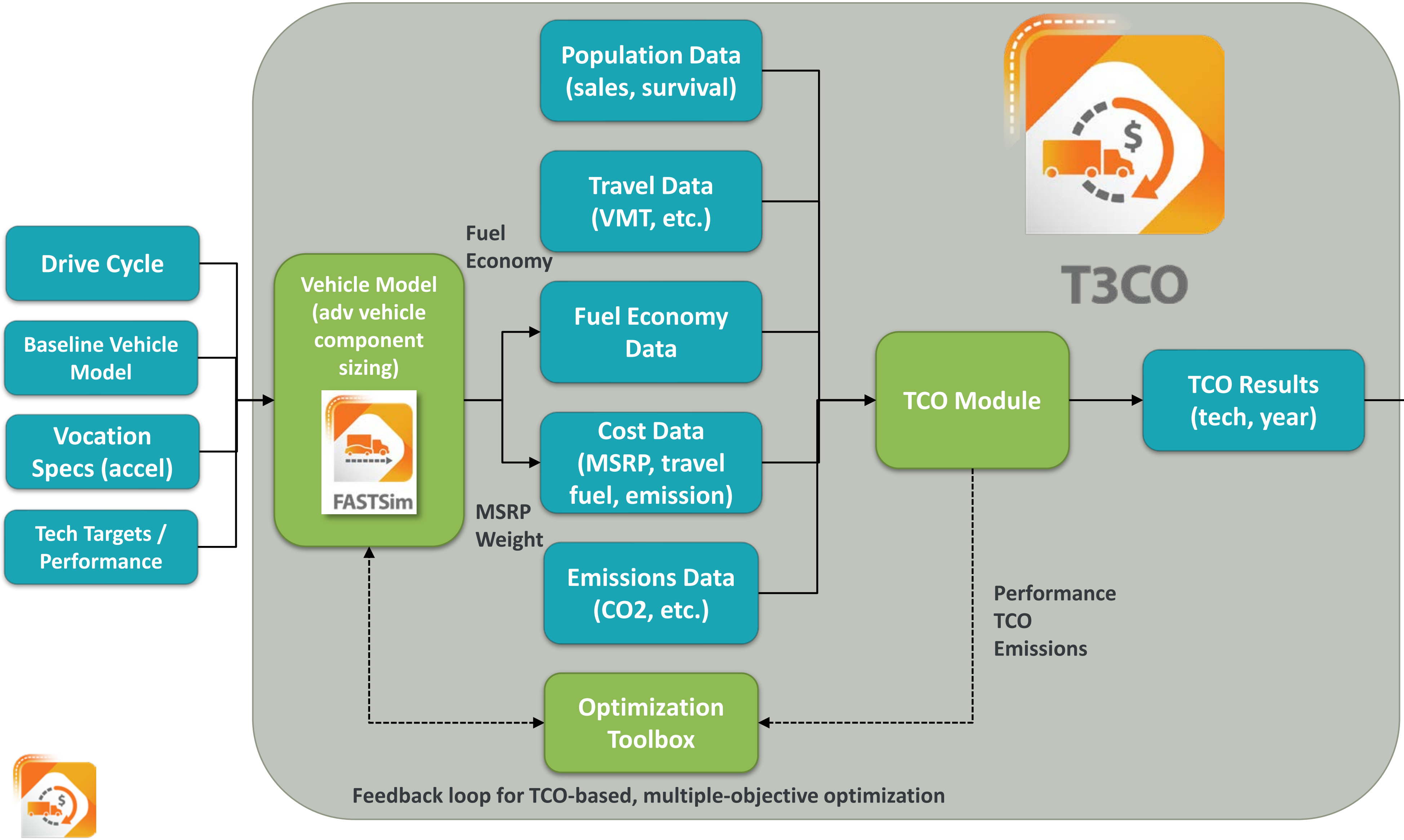
- Long haul operation passes through electrified Atlanta region twice (north-bound first, south-bound second)
- Majority of day's driving occurs outside of electrified region
- Midday fast-charging required to satisfy day's energy needs along with midday and end-of-day depot charging and dWPT energy received on-road, as travel is accomplished by two drivers
- Majority of day's energy expenditure is replenished from midday fast-charging

Long Haul



Total Cost of Ownership Modelling

Transportation Technology Total Cost of Ownership (T3CO) Modeling Flow Diagram



Drive Cycle

Baseline Vehicle Model

Vocation Specs (accel)

Tech Targets / Performance

Vehicle Model (adv vehicle component sizing)

FASTSim

Fuel Economy

MSRP Weight

Population Data (sales, survival)

Travel Data (VMT, etc.)

Fuel Economy Data

Cost Data (MSRP, travel fuel, emission)

Emissions Data (CO2, etc.)

Optimization Toolbox

TCO Module

TCO Results (tech, year)

T3CO

Performance
TCO
Emissions

Feedback loop for TCO-based, multiple-objective optimization

- **Modular for easy use**
- **Standard I/O for use with various vehicle models**
- **Spatial fidelity**
- **End-to-end vehicle simulations and TCO results**

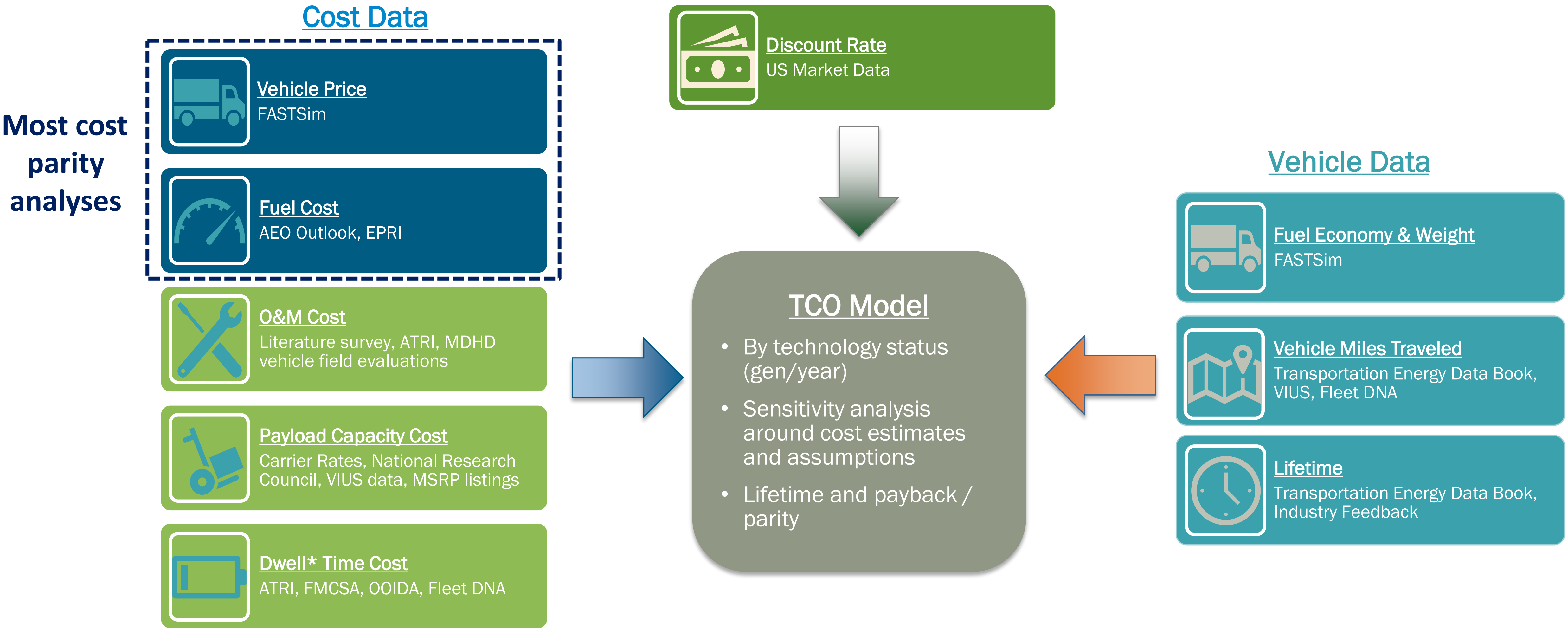
- **Help Set Technical Targets**
- **Focus Research Priorities**
- **Accelerate Technologies**
- **Evaluate Benefits**

Legend

- 🟩 Python module
- 🟦 Data File (tsv, csv)

T3CO https://www.nrel.gov/transportation/t3co.html

Total cost of ownership (TCO) modeling – Requires Diverse Data



Cost Data

Most cost parity analyses

Vehicle Price
FASTSim

Fuel Cost
AEO Outlook, EPRI

O&M Cost
Literature survey, ATRI, MDHD vehicle field evaluations

Payload Capacity Cost
Carrier Rates, National Research Council, VIUS data, MSRP listings

Dwell* Time Cost
ATRI, FMCSA, OOIDA, Fleet DNA

**Dwell time = down time for refueling/recharging*

Discount Rate
US Market Data

TCO Model

- By technology status (gen/year)
- Sensitivity analysis around cost estimates and assumptions
- Lifetime and payback / parity

Vehicle Data

Fuel Economy & Weight
FASTSim

Vehicle Miles Traveled
Transportation Energy Data Book, VIUS, Fleet DNA

Lifetime
Transportation Energy Data Book, Industry Feedback

T3CO Results Examples

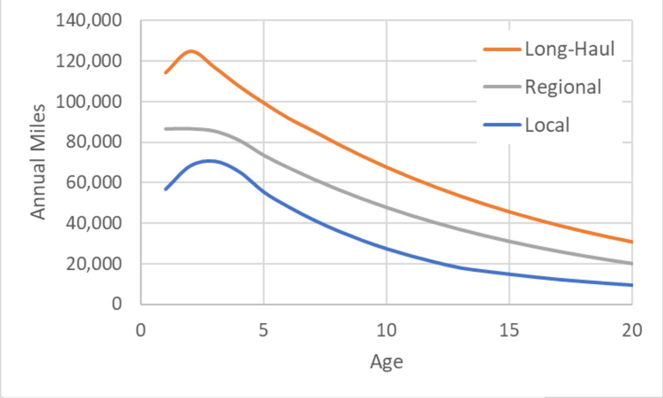
Key Inputs and Assumptions

- Analysis years: 2030, 2040
- Vehicle annual VMT from VIUS 2002
- Low and high technology trajectories - component-level assumptions over time, based on prior analysis for VTO
  - Battery & motor specific cost, energy/power density
  - Diesel engine efficiency and cost
  - Glider evolution (CdA and lightweighting) for diesel vs. electrified powertrains
  - Enroute charging power

- Fuel costs
  - Diesel – AEO 2023 without taxes
  - Electricity – AEO 2023 Commercial rate x2
  - Hydrogen – HFTO program targets - $5 by 2030, $4 in 2035-2050
- Duty cycle – Assume selected Atlanta region days are representative of average fuel economy and daily distance
- BEVs opportunity charge during stationary cycle time >30 min

Cost Element	Include?
Purchase cost (MSRP)	✓
Sales / Excise Tax	✓
Financing	✗
Depreciation	✗
Resale / Salvage	✓
Fuel	✓
Maintenance	✓
Energy Storage Replacement	✗
Fuel Converter Rebuild	✗
Insurance	✓
Labor	✗
Refueling Dwell Time	✓
Refueling Down Time Opportunity	✓
Maintenance Down Time Opportunity	✗
Payload Capacity	✓

General Assumptions			
Parameter	**value**	**units**	**notes**
TCO period	10	years	
discount rate	3%	na	annual discount rate for net present value calculations
RPE	1.2	na	retail price equivalent factor to convert manufacturer cost to price

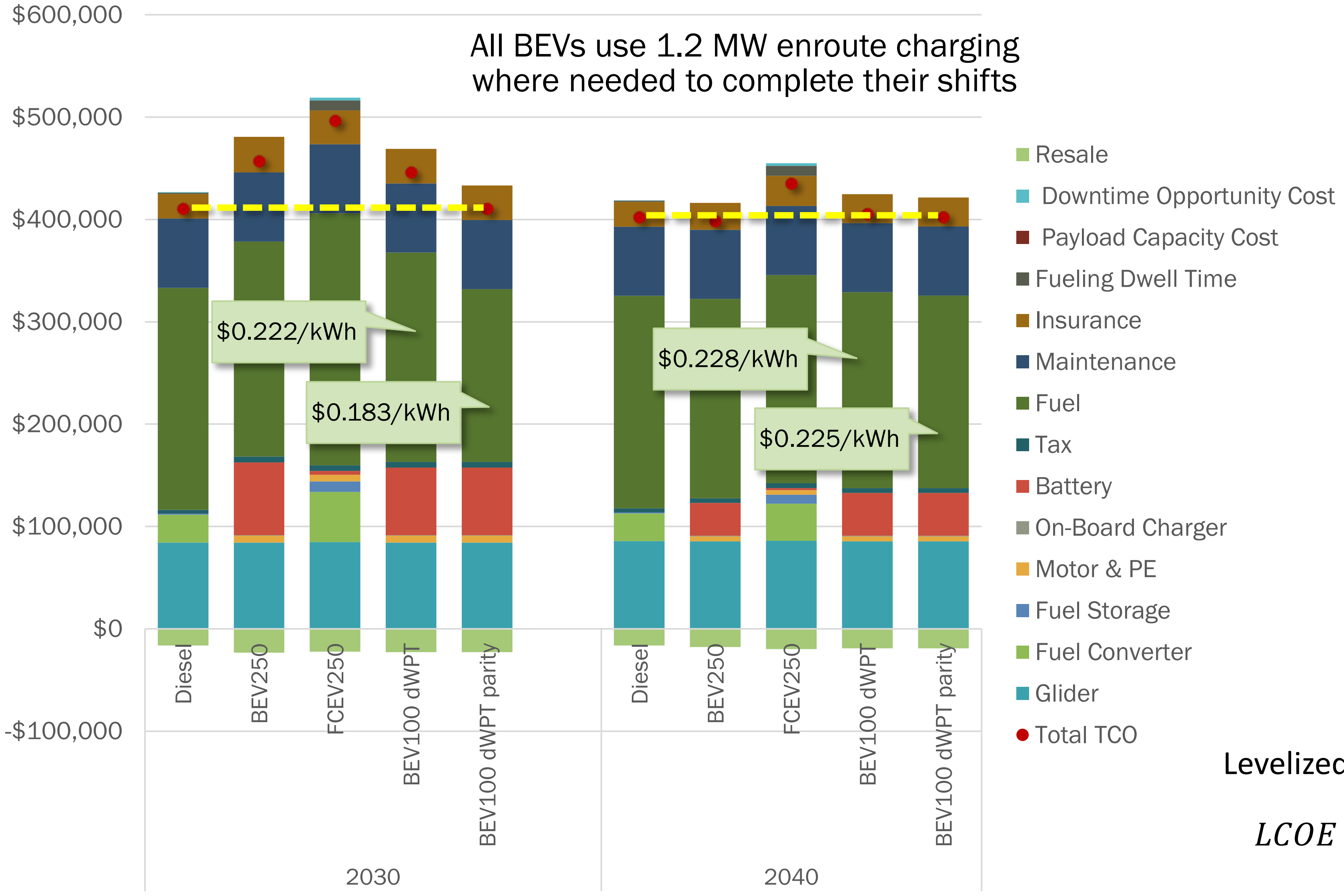


Source: Analysis of VIUS 2002 by NREL

	Battery Cost to Manufacturer ($/kWh)		
	Energy Battery (BEV)	Power Battery (dWPT) low tech	Power Battery (dWPT) high tech
2030	$100	$275	$187.5
2040	$50	$175	$112.5

Source: ICCT 2022, "A meta-study of purchase costs for zero-emission trucks" https://theicct.org/wp-content/uploads/2022/02/purchase-cost-ze-trucks-feb22.pdf

Local Haul 10-Year TCO, Low Tech Progress

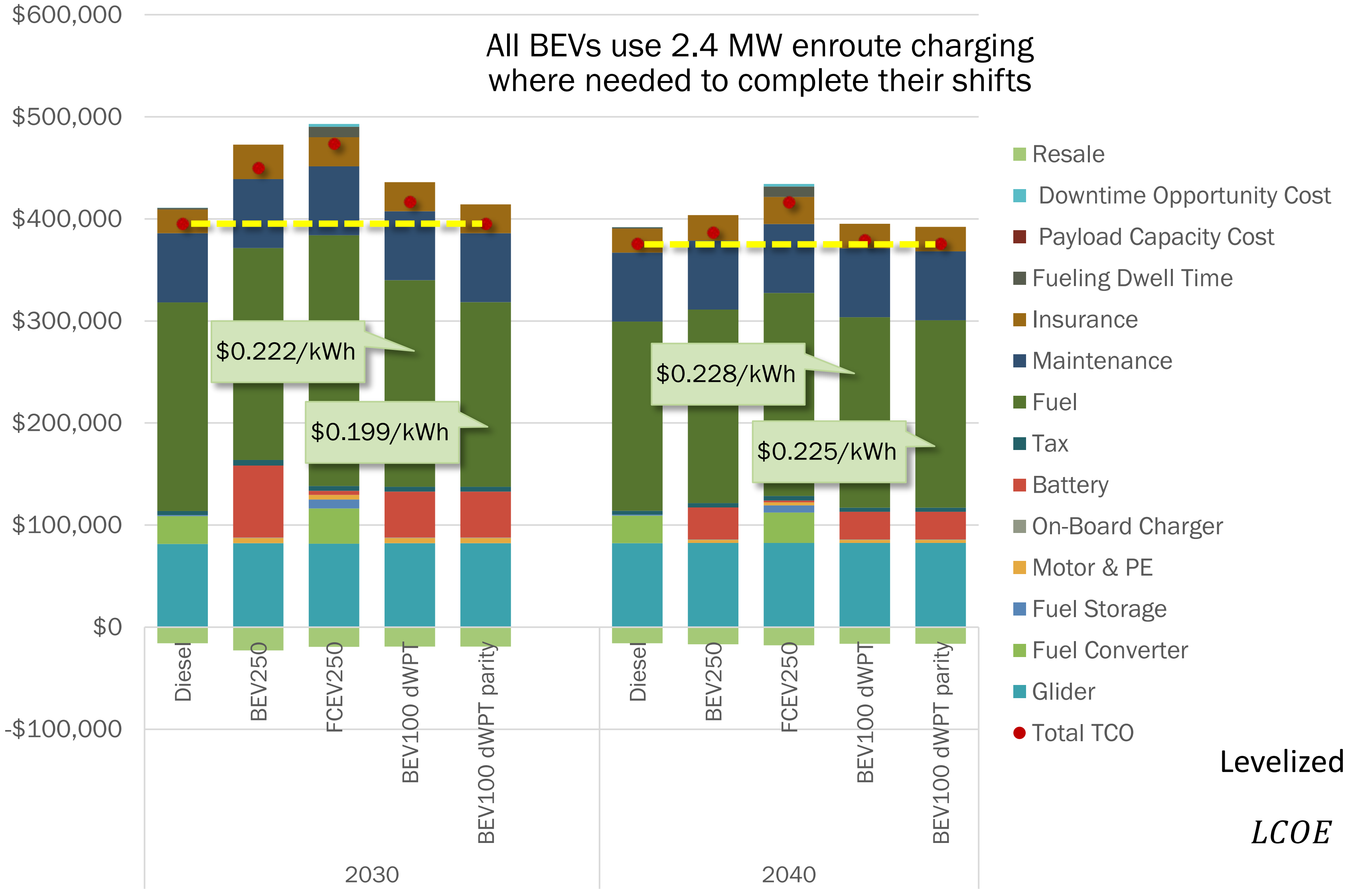

All BEVs use 1.2 MW enroute charging where needed to complete their shifts

- At assumed electricity cost, the dWPT option has the lowest TCO of ZEV options in 2030 but is higher in than BEV250 in 2040 due to battery cost
- Parity with diesel requires slightly lower levelized electricity cost than assumed average for stationary charging (including depot and truck stops)

Levelized electricity cost calculation:

$$LCOE = \frac{\sum_t (p_t * VMT_t * kWh\_per\_mi)}{\sum_t (VMT_t * kWh\_per\_mi)}$$

Local Haul 10-Year TCO, High Tech Progress



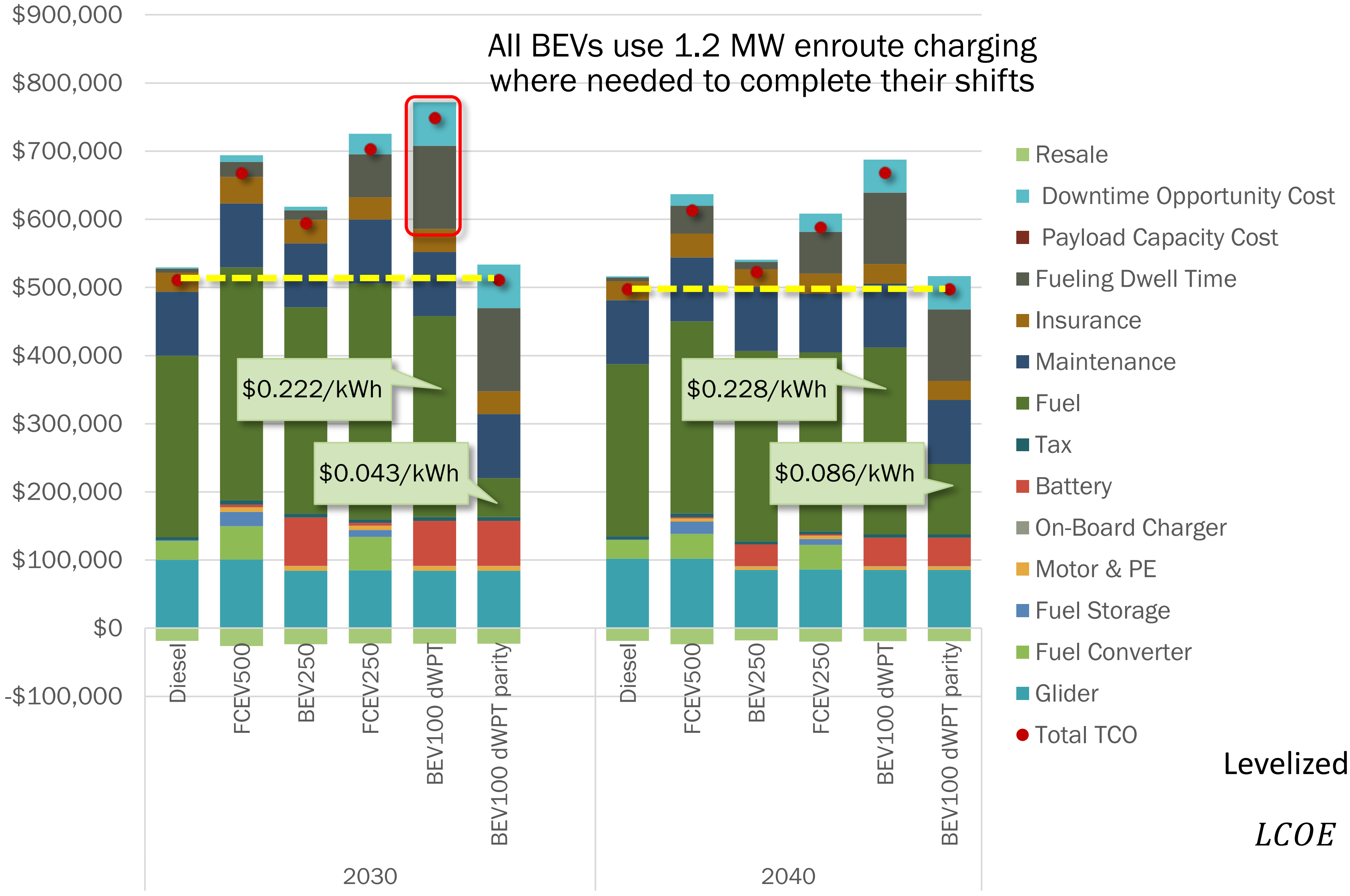
All BEVs use 2.4 MW enroute charging where needed to complete their shifts

- Results are very similar to the low tech progress case
- At assumed electricity cost, the dWPT option has the lowest TCO of ZEV options in both 2030 and 2040
- Parity with diesel requires slightly lower levelized electricity cost than assumed average for stationary charging (including depot and truck stops)

Levelized electricity cost calculation:

$$LCOE = \frac{\sum_t (p_t * VMT_t * kWh\_per\_mi)}{\sum_t (VMT_t * kWh\_per\_mi)}$$

Regional Haul 10-Year TCO, Low Tech Progress



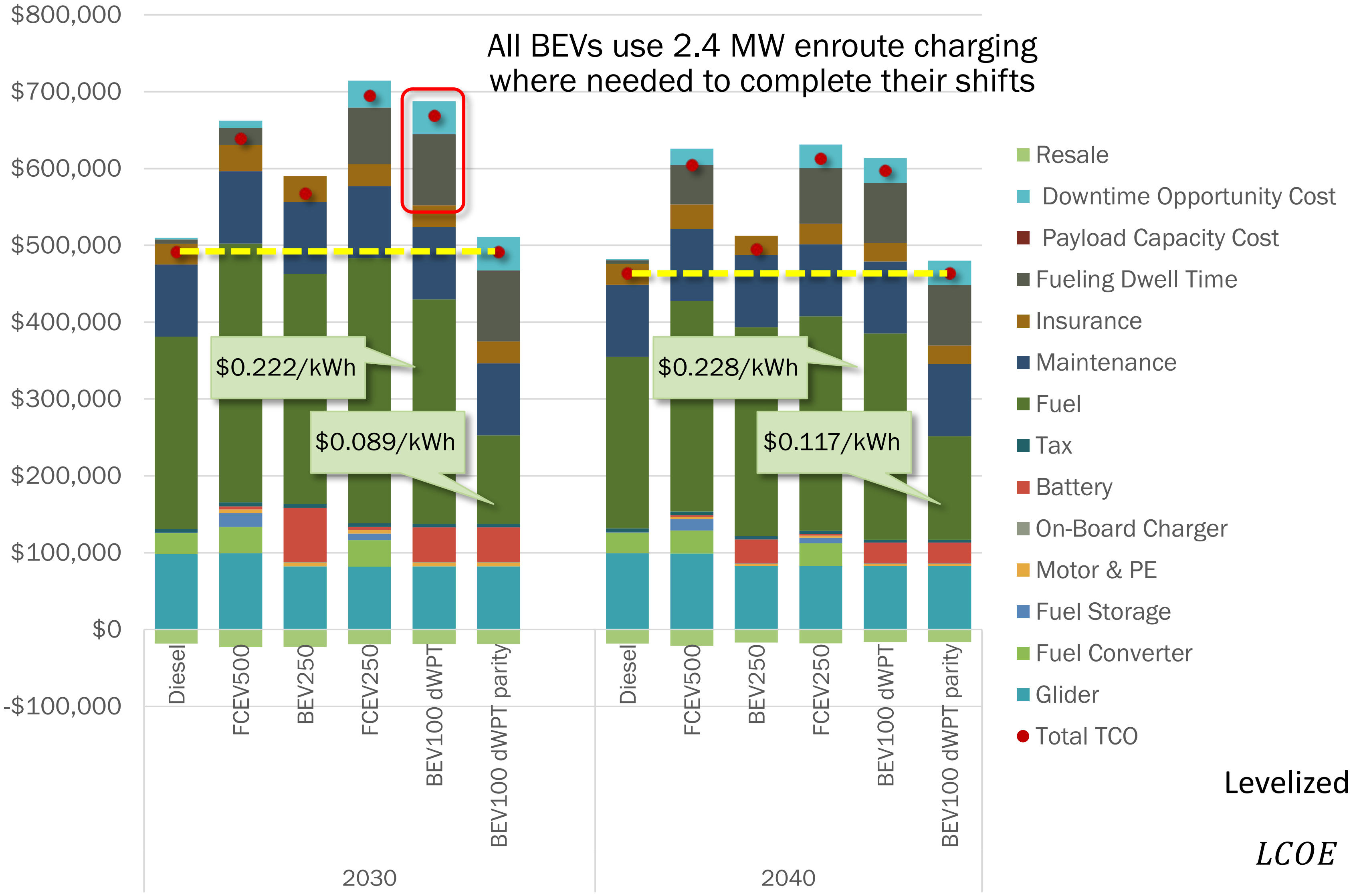
All BEVs use 1.2 MW enroute charging where needed to complete their shifts

- Parity with diesel requires very low electricity cost due to high frequency and duration of fueling stops
  - All BEVs opportunity charge when stopped for >30 min
  - All BEVs receive 1 charge between shifts free of fueling time penalties
  - Enroute charging at 1.2 MW
  - Minimal extent of dWPT network requires larger vehicle range
- BEV 250 without dWPT has lower TCO; larger capacity for dWPT would improve TCO

Levelized electricity cost calculation:

$$LCOE = \frac{\sum_t (p_t * VMT_t * kWh\_per\_mi)}{\sum_t (VMT_t * kWh\_per\_mi)}$$

Regional Haul 10-Year TCO, High Tech Progress

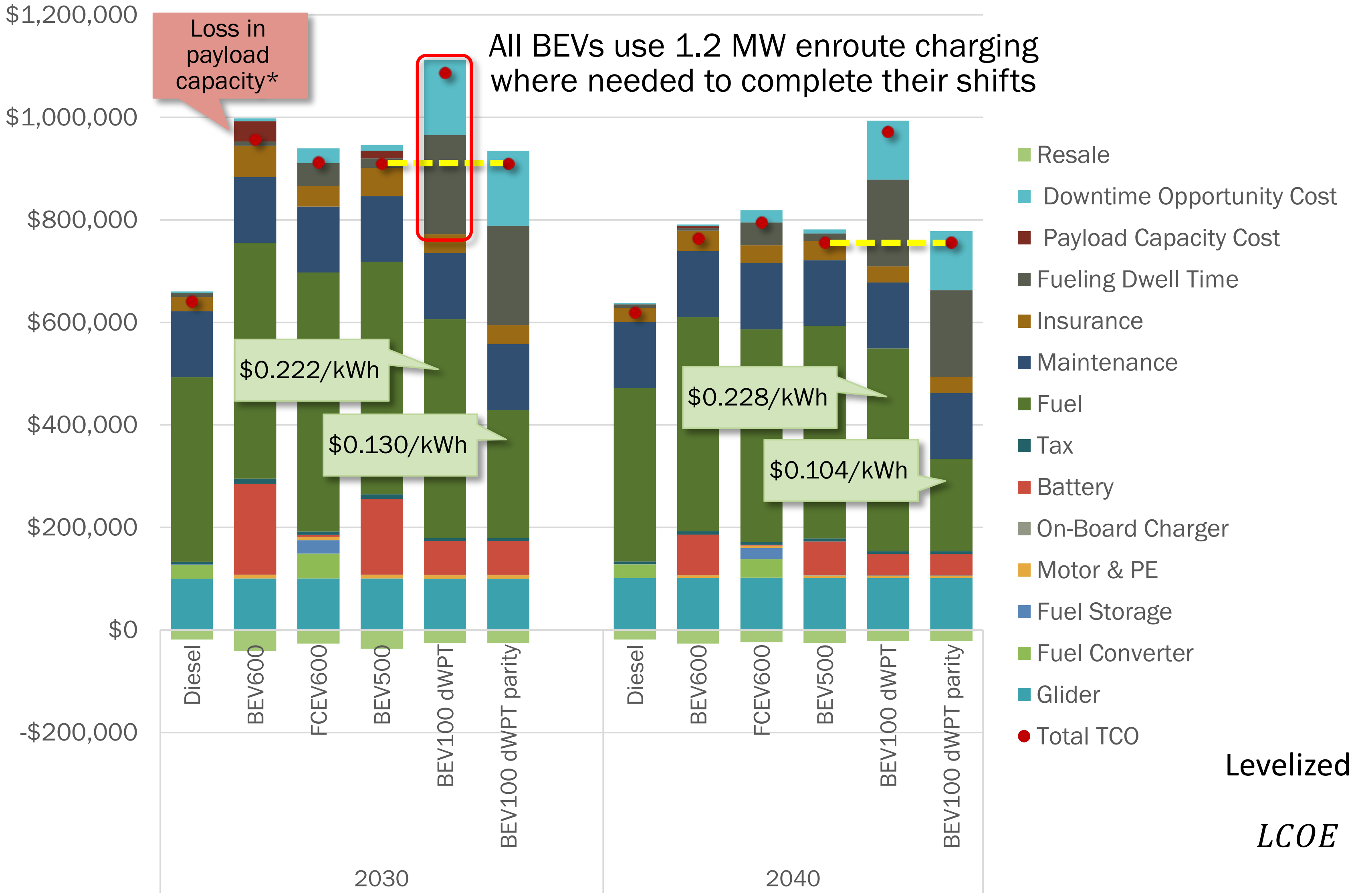

All BEVs use 2.4 MW enroute charging where needed to complete their shifts

- Results are very similar to low tech progress scenario
- Parity with diesel still requires low electricity cost due to high frequency and duration of fueling stops
  - All BEVs opportunity charge when stopped for >30 min
  - All BEVs receive 1 charge between shifts free of fueling time penalties
  - Enroute charging at 2.4 MW
  - Minimal extent of dWPT network requires larger vehicle range
- BEV250 without dWPT has lower TCO; larger capacity for dWPT would improve TCO

Levelized electricity cost calculation:

$$LCOE = \frac{\sum_t (p_t * VMT_t * kWh\_per\_mi)}{\sum_t (VMT_t * kWh\_per\_mi)}$$

Long Haul 10-Year TCO, Low Tech Progress



Loss in payload capacity*

All BEVs use 1.2 MW enroute charging where needed to complete their shifts

$0.222/kWh

$0.130/kWh

$0.228/kWh

$0.104/kWh

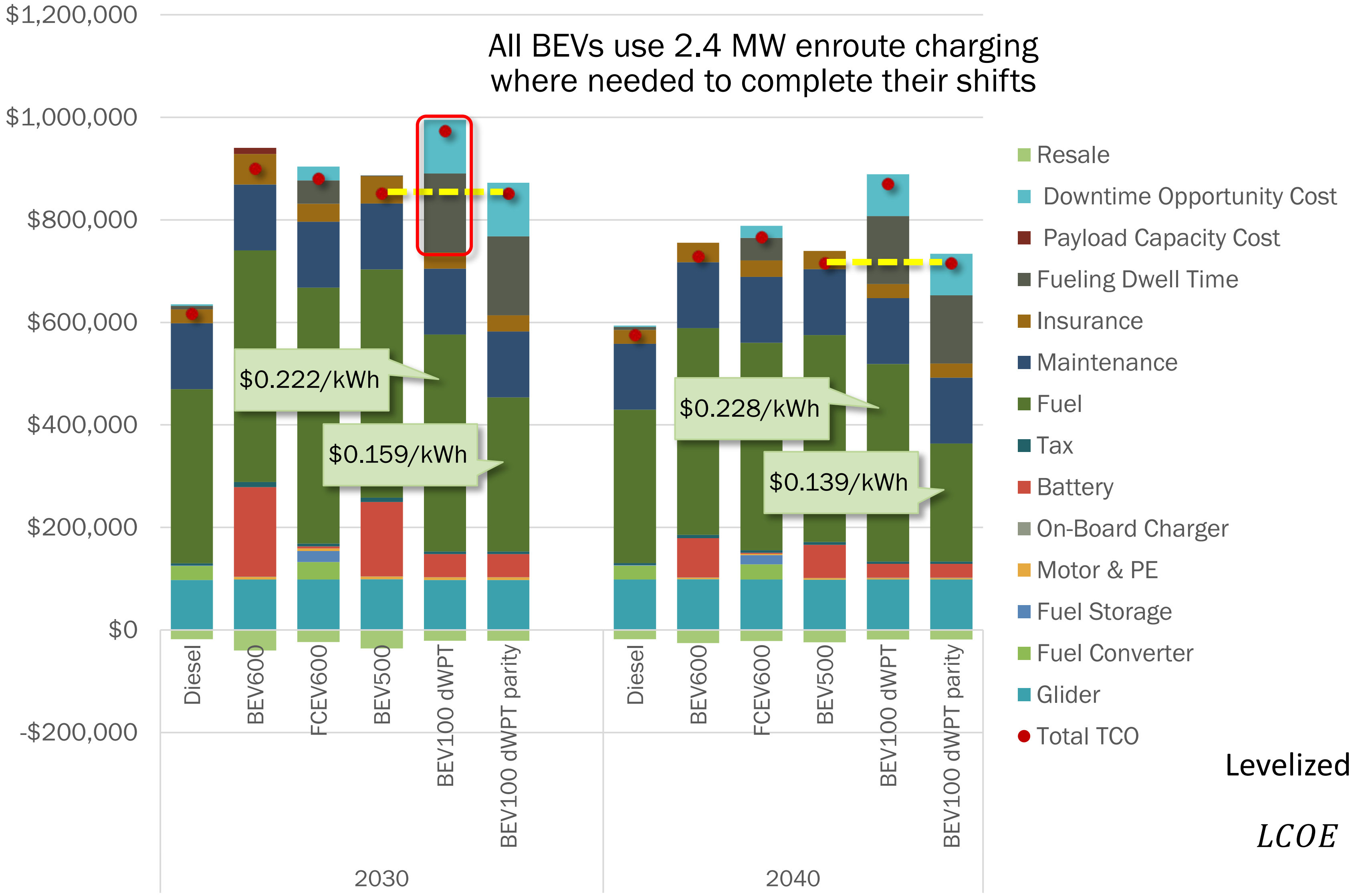
*ZEVs are allowed 2,000 lb GVWR exemption per current regulations

- BEV600 and BEV500 incur some payload capacity loss in 2030 but this is eliminated by 2040
- dWPT parity with diesel isn't possible in 2030 and requires $0.025/kWh in 2040 due to frequent stops to refuel enroute
  - $70/hr dwell (labor rate)
  - Downtime opportunity from efficiency calculation
- 2030 parity with FCEV600 or BEV500 can occur with lower electricity cost

Levelized electricity cost calculation:

$$LCOE = \frac{\sum_t (p_t * VMT_t * kWh\_per\_mi)}{\sum_t (VMT_t * kWh\_per\_mi)}$$

Long Haul 10-Year TCO, High Tech Progress


All BEVs use 2.4 MW enroute charging where needed to complete their shifts

*ZEVs are allowed 2,000 lb GVWR exemption per current regulations

- 2030 BEV600 payload capacity loss is much smaller than in low tech progress case and near zero for BEV500
- Parity with diesel requires very low electricity cost (~$0.04-$0.06) due to frequent stops to refuel enroute
- Parity with BEV500 can occur, but with lower electricity cost than assumed for stationary charging

Levelized electricity cost calculation:

$$LCOE = \frac{\sum_t (p_t * VMT_t * kWh\_per\_mi)}{\sum_t (VMT_t * kWh\_per\_mi)}$$

Results Summary / Key Takeaways

- Enroute charging frequency and time are key contributors to BEV TCO, especially for the 200 kWh dWPT
- In the local segment at assumed electricity cost, the dWPT truck is either the lowest ZEV option or very similar TCO to the other options; slightly lower electricity cost is required to achieve parity with diesel
- For the scenario assumptions used for this analysis, parity with diesel requires very low electricity cost in the regional and long haul segments due to frequency and duration of stationary charging when not on electrified roadways. Interim solutions may require increased vehicle range w/dWPT until network size is sufficient.
- Parity with FCEVs can occur with much less expensive electricity
- More extensive dWPT coverage, higher enroute charging power, less expensive power batteries, higher H2 and/or diesel cost, would change the parity potential

Segment	Parity to	Electricity Cost for Parity, Low Tech		Electricity Cost for Parity, High Tech	
		2030	2040	2030	2040
Reference Electricity Cost		$0.222	$0.228	$0.222	$0.228
Local	Diesel	$0.183	$0.225	$0.199	$0.225
Local	FCEV250	$0.277	$0.264	$0.285	$0.274
Regional	Diesel	$0.043	$0.086	$0.089	$0.117
Regional	FCEV500	$0.161	$0.182	$0.200	$0.234
Long Haul	Diesel	NA	$0.025	$0.037	$0.058
Long Haul	BEV500	$0.130	$0.104	$0.159	$0.139

Next Steps

- Corridor and roll-out analysis of electrified roadways to identify a proper transition across freight segments that allows for improved regional and long-haul cost parity.
- Sensitivity analysis on congestion and utilization of the electrified roadway network to optimize electrified lane miles and cost of charging along corridors.
- Broaden the drive cycle analysis to ensure better representation across segments
- Identification of the utilization impact on effective cost for charging infrastructure that considers lowest cost charging locations for each segment.

Thank You

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Back-up: Prior Analysis

System and Vehicle Performance

System Requirements (FY19)

- Identified dWPT system requirements: power level, roadway coverage, and placement
- Identified vehicle parameters: battery size and number of receivers

		Low requirements for LD EVs	**Medium requirements for LD EVs**	**High requirements for LD EVs**
Approach based on LD vehicles		- CS for intercity travels, - min road coverage, - low travel requirements (65 mph, 270 Wh/mile)	- CS for intercity travels, - min overall system cost, - medium travel requirements (74 mph, 310 Wh/mile)	- CS for intercity travels, - min overall system cost, - high travel requirements (86 mph, 350 Wh/mile)
Roadway coverage (%)		8.2	14.56	16.6
Transmitter power (kW)		235	200	225
LD EV	Battery size (kWh)	**59**	**30**	**30**
	# receivers	**1**	**1**	**1**
	Received Power (kW)	235	200	225
HD Sleeper Cab EV	Battery size (kWh)	452.9	202.1	178.6
	# receivers	6	5	5
	Received Power (kW)	~235 x 6 = 1,410	~200 x 5 = 1,000	~225 x 5 = 1,125
HD Day Cab EV	Battery size (kWh)	447.6	199.8	176.6
	# receivers	6	5	5
	Received Power (kW)	~235 x 6 = 1,410	~200 x 5 = 1,000	~225 x 5 = 1,125

Development of HD Vehicle Travel

Goal: Develop high-resolution (1 Hz) HD vehicle travel data (route and speed) for low-resolution waypoints (1 sample/hour).

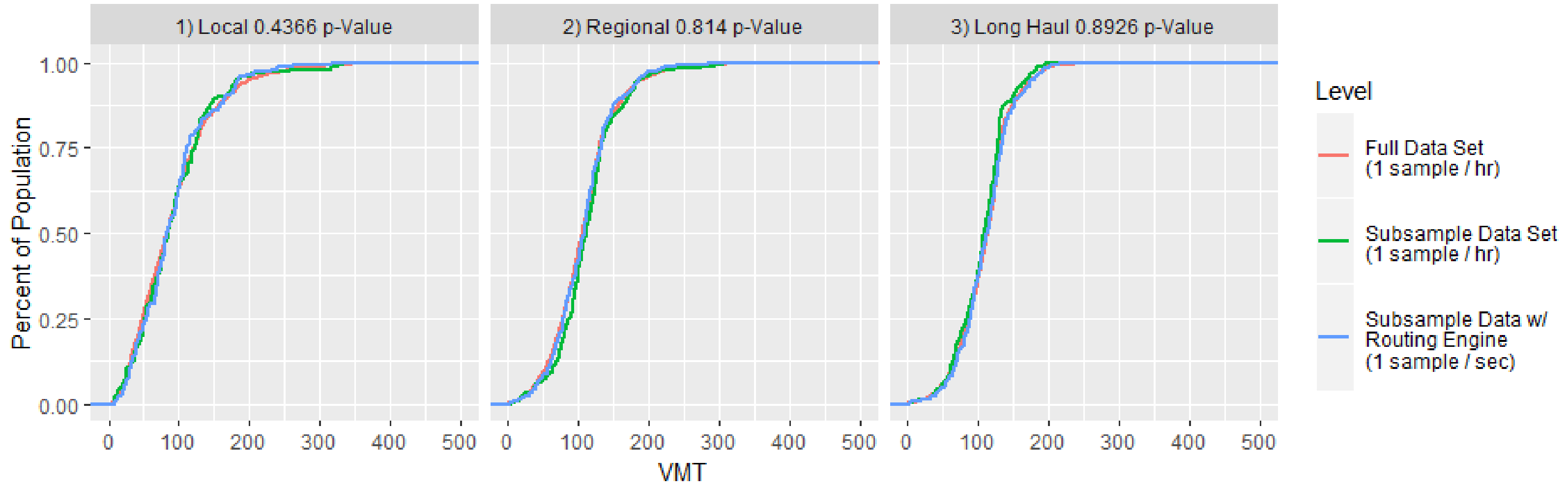
Data Methodology:

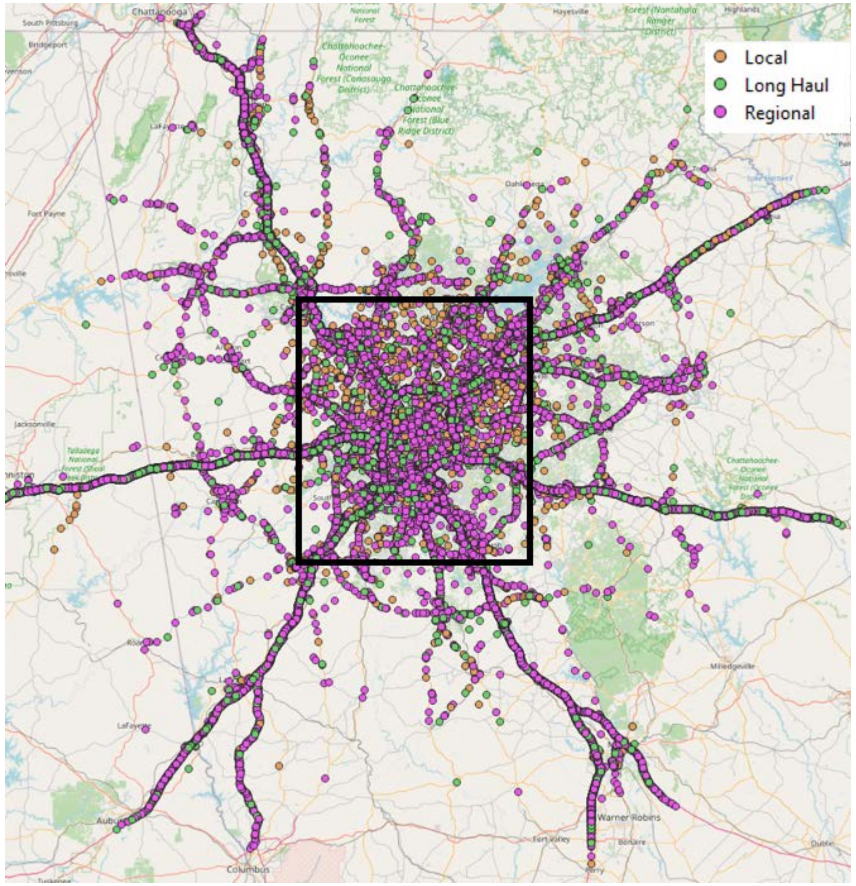
- *Classification*: local, regional, and long-haul based on the radius of operation

- *Subsampling*: select a representative subset of the total data set to reduce computational time.

- **Route generation**: generate and validate route data using 1 sample/h waypoints

- **Route discretization (1 Hz)**: develop 1 Hz route and speed profiles





- The HD data set makes up ~2% of all VMT for national freight.
- 7.6K unique HD vehicles within the Atlanta region.
- ~30K unique trips within the Atlanta region.
- Original data set 1 Sample per hour.

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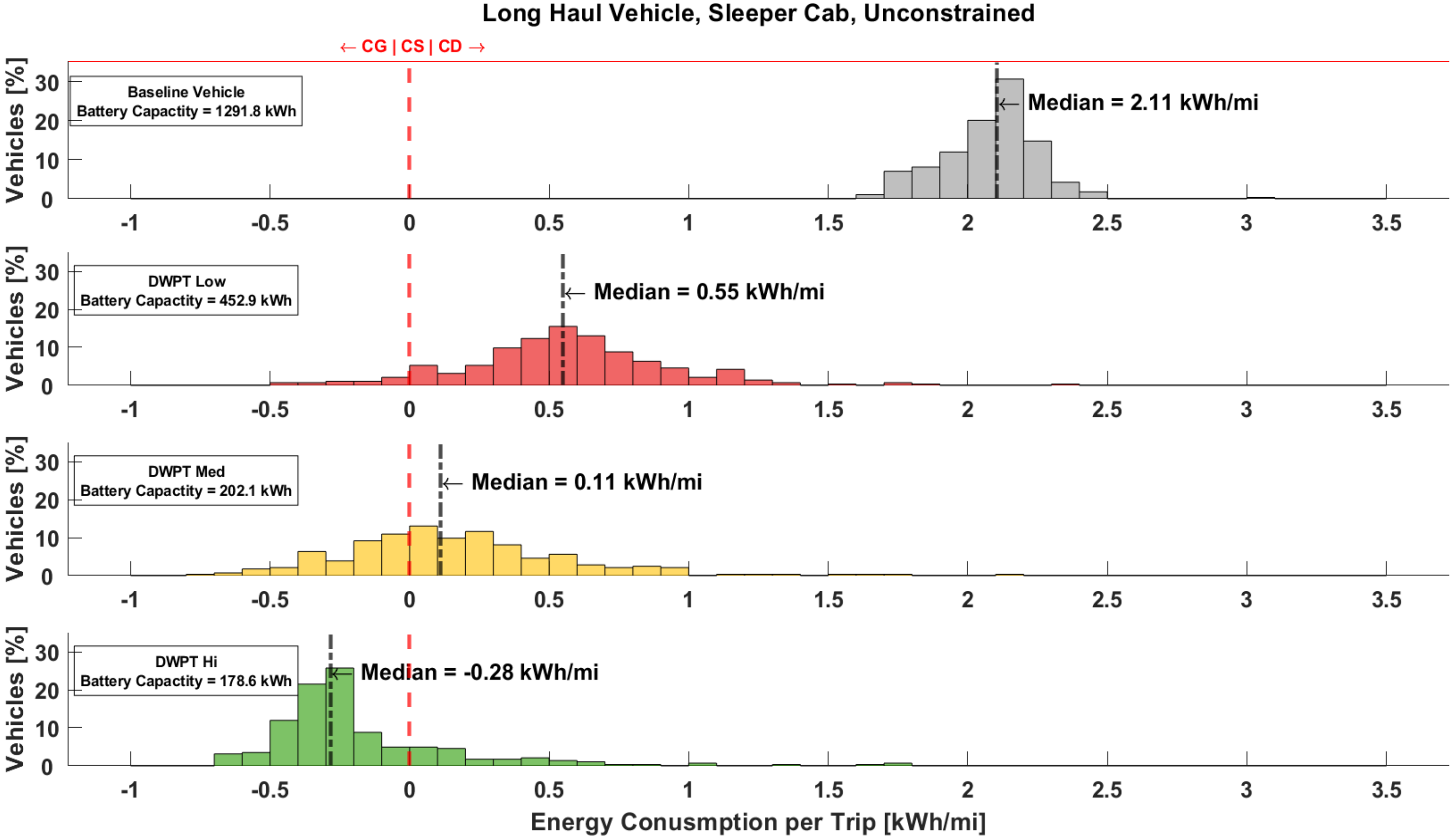
Long Haul Vehicles – kWh/mile

- Sleeper cab EV model with 5/6 receivers

Takeaway:

- Significant shift for kWh/mile distribution with dWPT system.
- dWPT-Hi shows negative kWh/mile in average.



Distribution of vehicle kWh/mile with and without dWPT system.

Results: Long Haul Vehicles – Performance Summary

EVs@Scale
U.S. Department of Energy

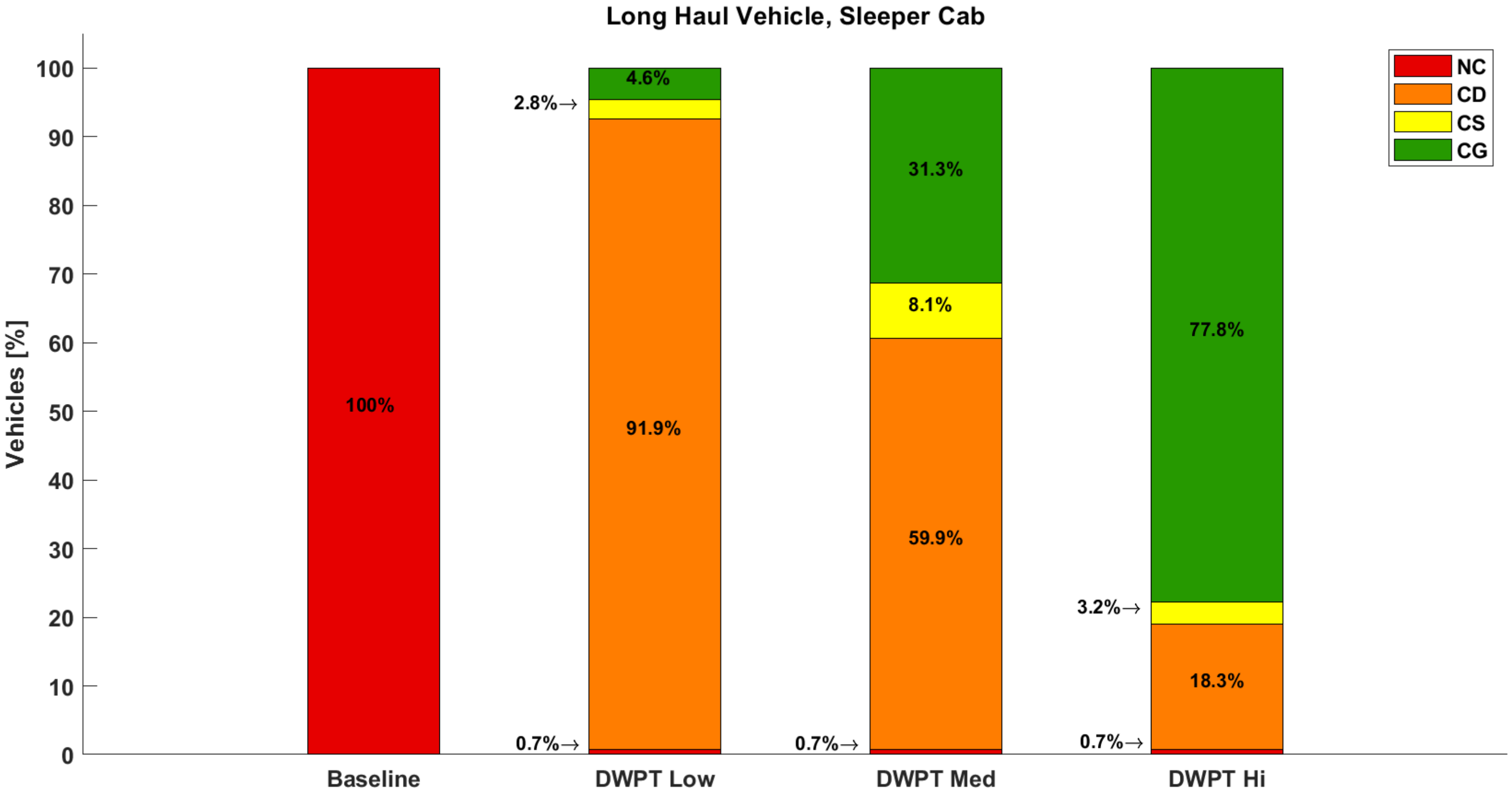
Modes of operation:

- NC: No charge encountered
- CD: Charge Depleting (kWh/mile > 0.05)
- CS: Charge Sustaining (kWh/mile = ± 0.05)
- CG: Charge Gaining (kWh/mile < -0.05)

Takeaway:

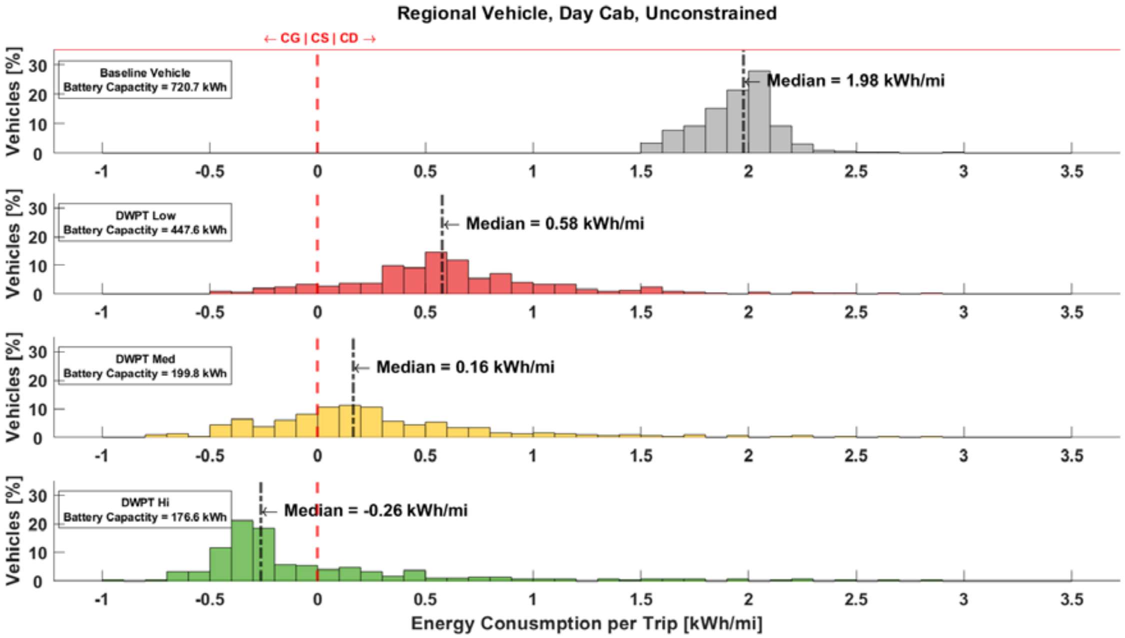
- < 1% of vehicles encountered NC.
- With dWPT-Hi: >80% of EV experience CG and CS.

% Vehicle at different modes of operation.



Results: Regional Vehicles – kWh/mile

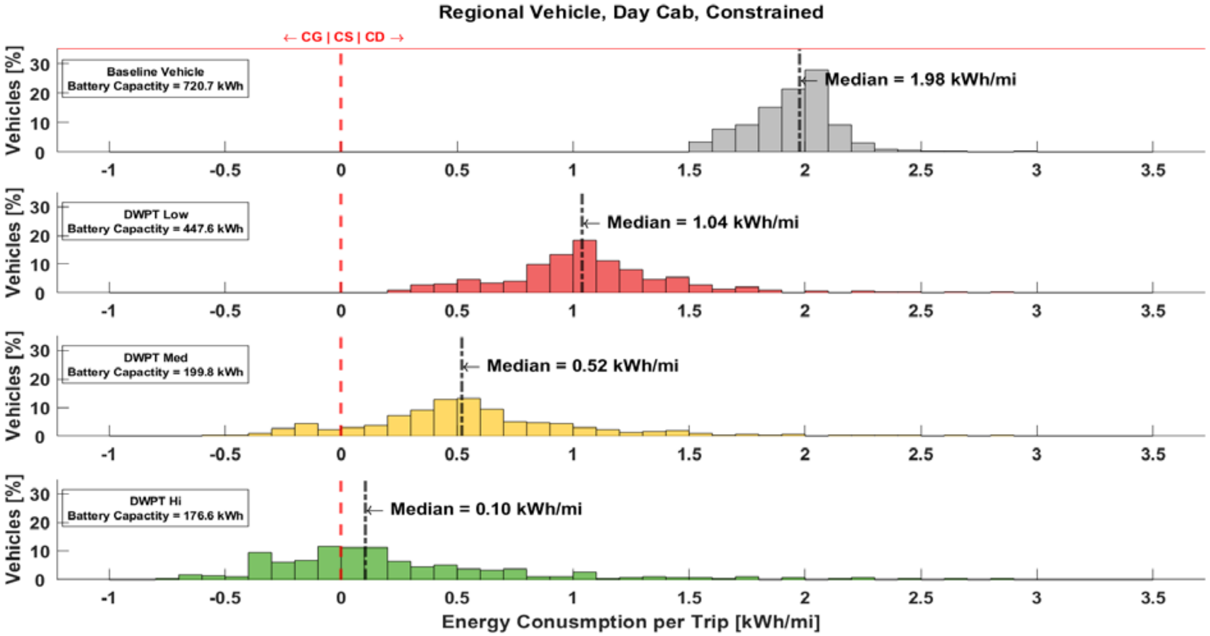
Distribution of kWh/mile with unconstrained vehicle



Day cab EV model:

- Unconstrained : 5/6 receivers
- Constrained: 4 receivers

Distribution of kWh/mile with constrained vehicle



Takeaway:

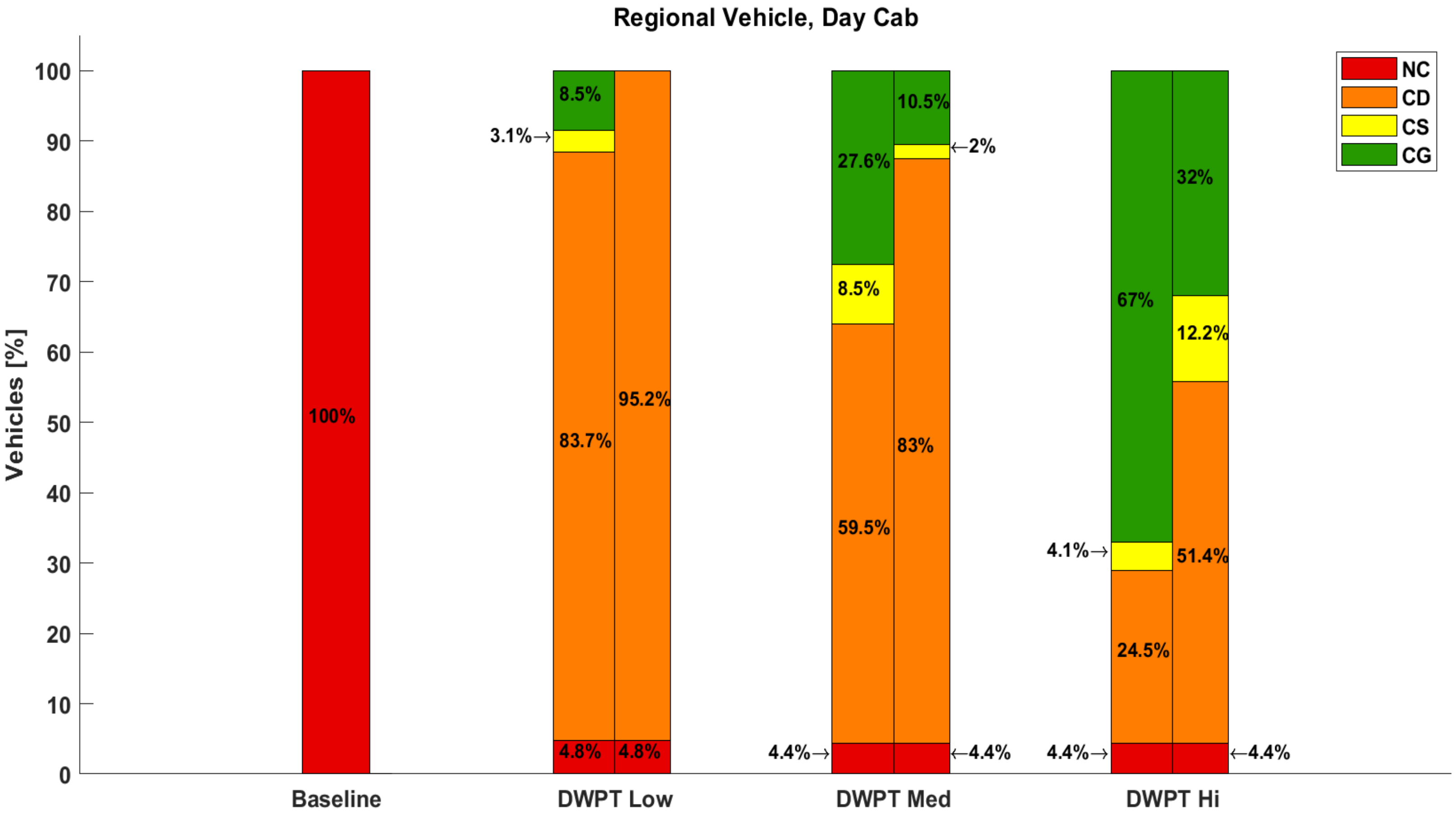
- Similar performance as Long-haul.
- Spatial constraint in day-cab leads to significant performance degradation.

Results: Regional Vehicles – Performance Summary

Takeaway:

- < 5% of vehicles encountered NC.
- With dWPT-Hi: >70% of EV experience CG and CS.
- Spatial constraint reduces CG & CS to 44%

% Vehicle at different modes of operation.



Left: unconstrained (5/6 receivers)
Right: constrained (4 receivers)

Atlanta Wireless Charging System Metrics

Total linear miles of roadway: 618.8 miles

Total lane-miles of roadway: 2,364.6 miles

Linear-miles of electrified roadway:

- Low: 48.6 miles (7.85% coverage)
- Med: 87.0 miles (14.06% coverage)
- High: 99.0 miles (16.01% coverage)

Lane-miles of electrified roadway:

- Low: 187.6 lane-miles (7.93% lane-mile coverage)
- Med: 332.9 lane-miles (14.08% lane-mile coverage)
- High: 379.6 lane-miles (16.05% lane-mile coverage)

Total Number of Chargers:

- 40 chargers/300-mi: 78 chargers
- *60 chargers/300-mi: 120 chargers*
- 80 chargers/300-mi: 158 chargers
- 100 chargers/300-mi: 200 chargers

Typical Charger Length:

- Low: 0.405 miles
- Med: 0.725 miles
- High: 0.825 miles

Typical Distance between chargers:

- Low: 4.59 miles
- Med: 4.27 miles
- High: 4.17 miles

NOTE: Spacing of 60 chargers/300-mi for all metrics

- dWPT System Parameters

Class 8 EV Model and Parameters

Goal: Identify representative class 8 EV models with the associated battery size and number of receivers

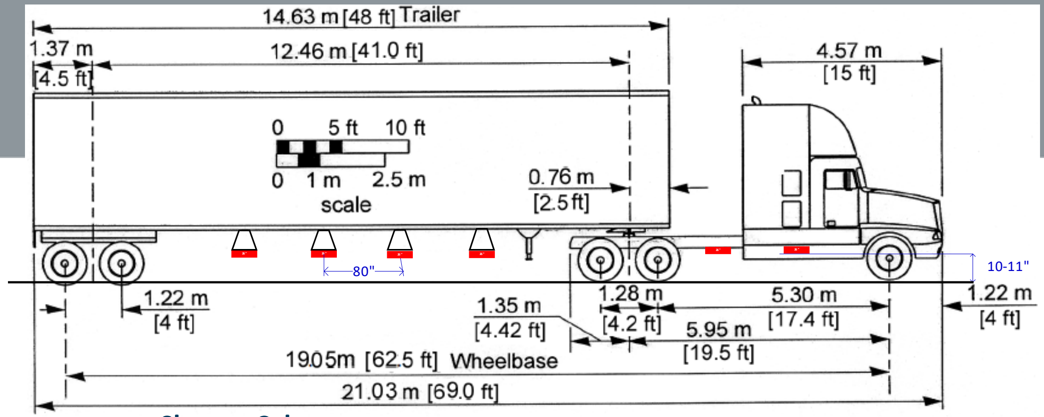
Class 8 EV Models:

- Two EV class powertrain models are considered:

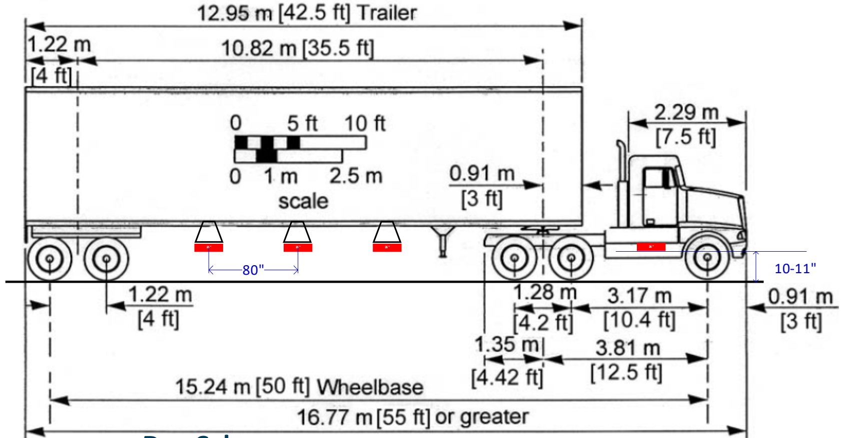
  - **Sleeper Cab (1.3 MWh battery, 500 mi, 2.31 kWh/mile):** fits 6 receivers and used with long-haul travel data.

  - **Day Cab (721 kWh battery, 300 mi, 2.17 kWh/mile):** fits 4 receivers and used with regional and local travel data.

- Receivers can be installed at lower level in the trailers



Sleeper Cab **Model A**



Day Cab **Model B**

		dWPT-Low	dWPT-Medium	dWPT-Hight
HD Sleeper Cab EV	Battery size (kWh)	452.9	202.1	178.6
	# receivers	6	5	5
	Received Power (kW)	~235 x 6 = 1,410	~200 x 5 = 1,000	~225 x 5 = 1,125
HD Day Cab EV	Battery size (kWh)	447.6	199.8	176.6
	# receivers	6→4	5→4	5→4
	Received Power (kW)	~235 x 6→4 = 1,410→940	~200 x 5→4 = 1,000→800	~225 x 5→4 = 1,125→900

Atlanta Wireless Charging System Metrics

Max Power at each charging site:

$$Site\ Power = Charger\ Power\ \times Number\ of\ Receivers\ per\ Vehicle \times Max\ Number\ of\ Vehicles\ on\ Charger$$

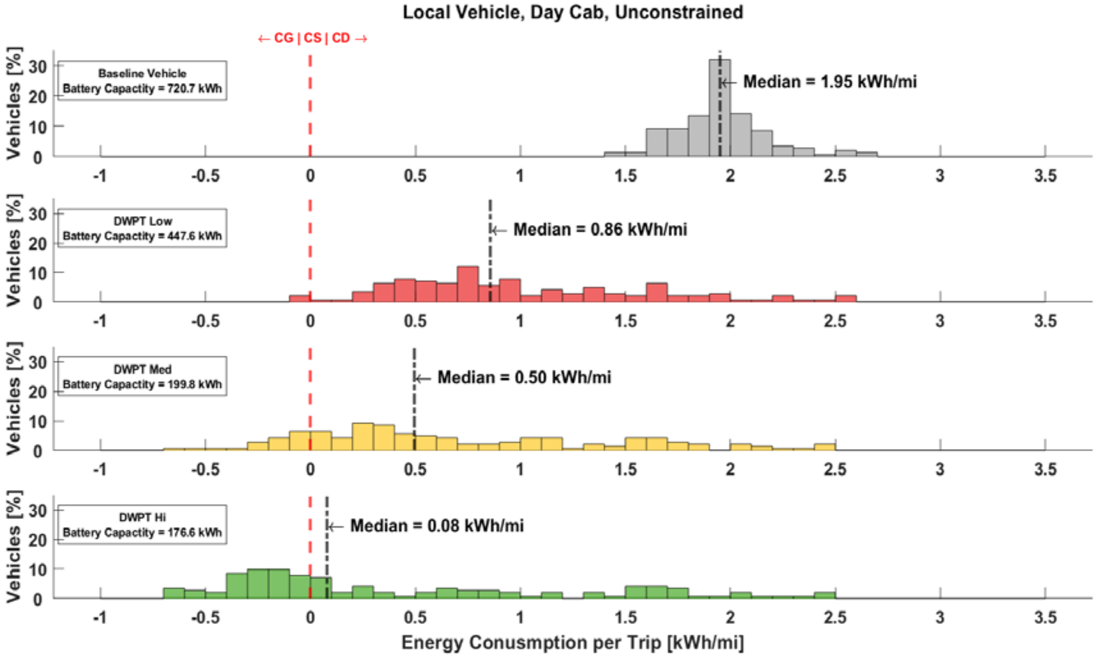
Coverage Scenario	Charger Power [kW]	Cab Type	Following Distance Assuming 2.2 sec Headway [ft]	Max Number of Vehicles on Charger	Max Power (single direction) [MW]	Max Power (both directions) [MW]
Low	235	Day Cab	209.7	8	7.5	15.0
		Sleeper Cab	209.7	7	9.9	19.7
Med	200	Day Cab	238.8	13	10.4	20.8
		Sleeper Cab	238.8	12	14.4	28.8
High	225	Day Cab	277.5	13	11.7	23.4
		Sleeper Cab	277.5	12	16.2	32.4

NOTE:

Spacing of 60 chargers/300-mi for all metrics

Results: Local Vehicles – kWh/mile

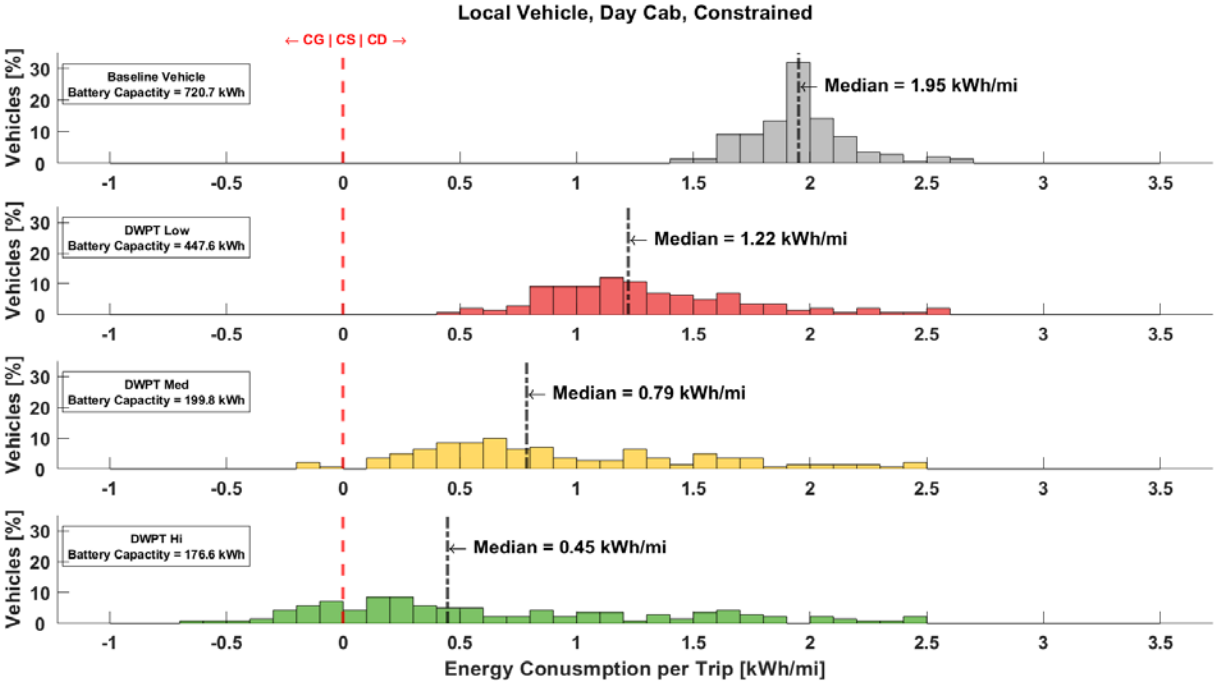
Distribution of kWh/mile with unconstrained vehicle



Day cab EV model:

- Unconstrained : 5/6 receivers
- Constrained: 4 receivers

Distribution of kWh/mile with constrained vehicle



<u>**Takeaway:**</u>

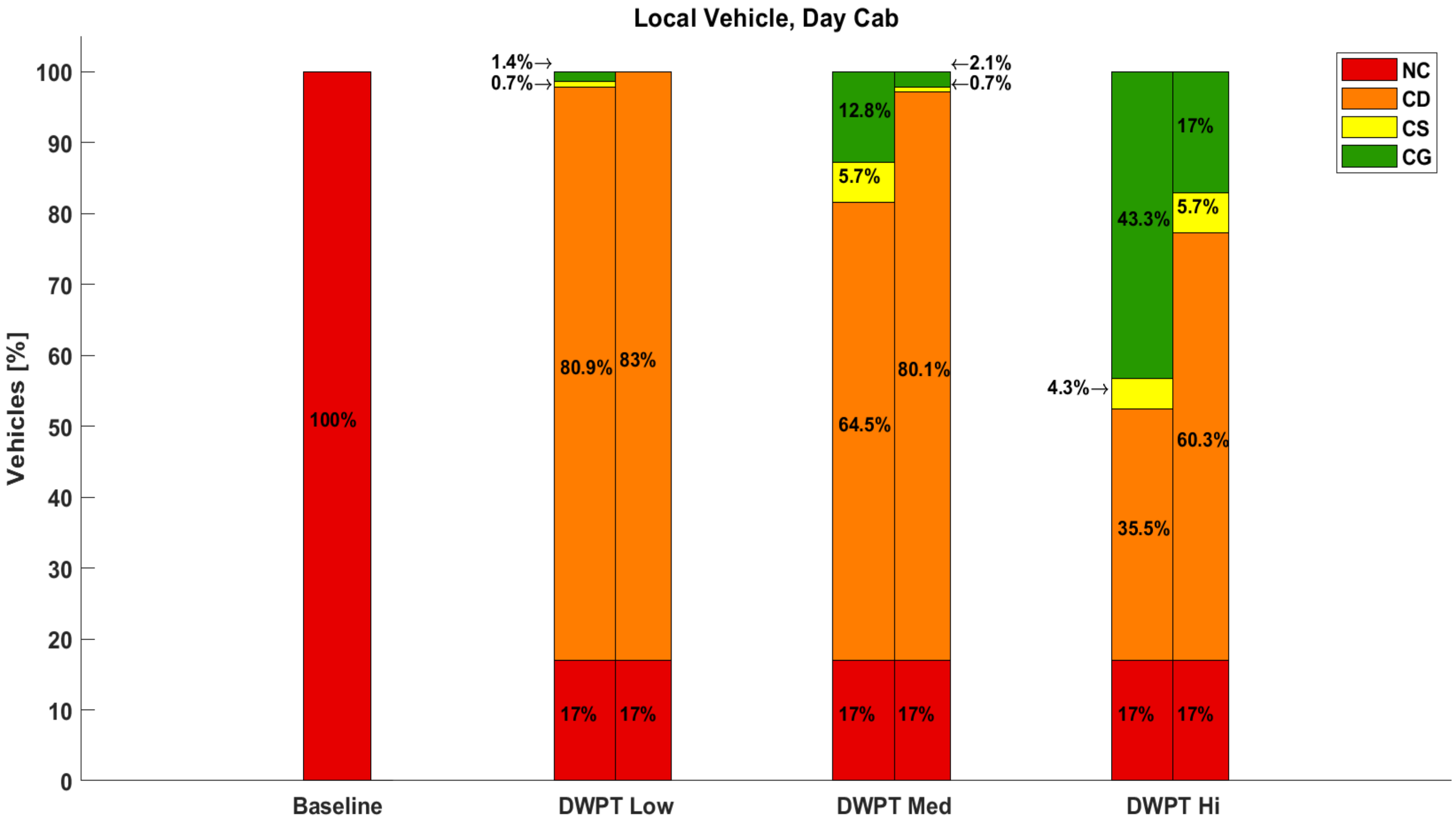
- Contribution of dWPT system is less with local vehicle than regional and long-haul.
- Spatial constraint in day-cab leads to significant performance degradation.

Results: Local Vehicles – Performance Summary

Takeaway:

- ~ 17% of vehicles encountered NC.
- With dWPT-Hi: ~47% of EV experience CG and CS.
- Spatial constraint reduces CG & CS to 22%

% Vehicle at different modes of operation.



Results: Overall Performance

Median kWh/mile with different dWPT System Parameters

Median [kWh/mi]		Baseline	dWPT Low	dWPT Med	dWPT Hi
Long-haul (sleeper cab)		2.11	0.55	0.11	**-0.28**
Regional (day cab)	unconstrained	1.98	0.58	0.16	**-0.27**
	constrained	1.98	1.04	0.52	**0.1**
% Increase in kWh/mile (constrained vs unconstrained)			44	69	370
Local (day cab)	unconstrained	1.95	0.86	0.5	**0.08**
	constrained	1.95	1.22	0.79	**0.45**
% Increase in kWh/mile (constrained vs unconstrained)			30	37	82

Takeaway:

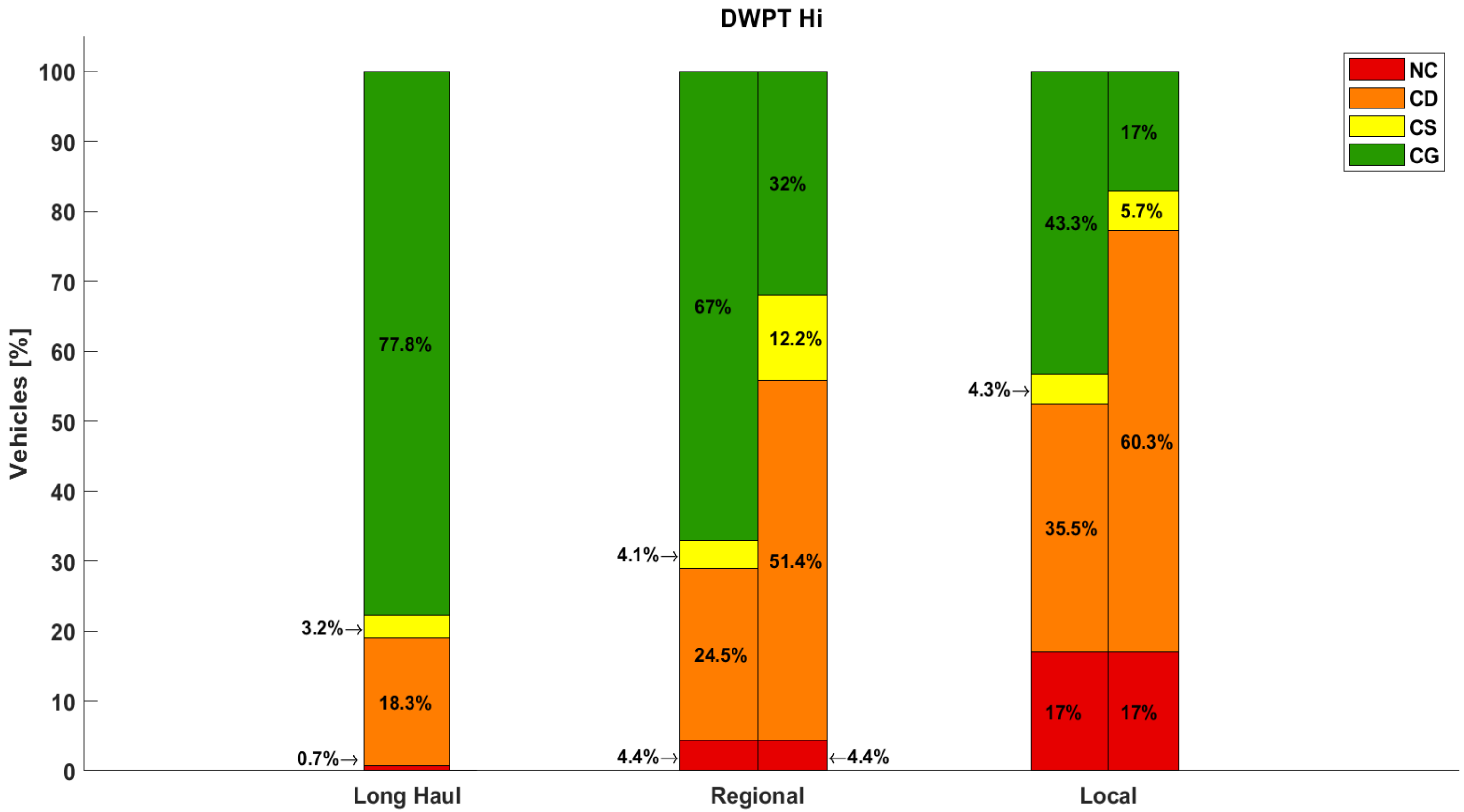
- dWPT-Hi shows consistent negative kWh/mile in average with all travels.
- Spatial constraints in day-cab leads to significant performance degradation.

Results: Overall Performance of dWPT-Hi

Takeaway:

- dWPT system is more effective for **long-haul (CG/CS: 80%)** and **regional (CG/CS: 70%)** than **local (CG/CS: 47%)** travel.
- **Spatial constraint** in day-cab leads to significant performance degradation (**82-370%** increase in kWh/mile)

% Vehicle at different modes of operation with dWPT-Hi



Left: unconstrained (5/6 receivers)
Right: constrained (4 receivers)

Conclusion

- Class 8 EV requires **5-6 receivers** to use the dWPT system (200–240 kW power and 8-20% roadway coverage) and compensate for vehicle energy depleting.
- dWPT system has the potential to significantly reduce the battery size with up to **65-85% reduction** in the sleeper-cab EV and **38-72% reduction** in the day-cab EV.
- Class 8 EVs with small-battery (**180-450 kWh**) and dWPT system can balance vehicle consumption leading to **negative/near-zero kWh/mile**.
- dWPT system is more effective in this study for **long-haul (CG/CS: 80%) and regional (CG/CS: 70%)** than **local (CG/CS: 47%)** travel because of dWPT placement on primary roads.
- **225-kW dWPT** system with **16.6% roadway** coverage allows class 8 vehicles to realize **consistent CS/CG** operation with **5 receivers** and **177-kWh** battery:
  - **~%113** reduction in vehicle energy balance for long-haul and regional
  - **%96** reduction in vehicle energy balance for local
- **Spatial constraints** in day-cab leads to significant performance degradation:
  - **15-22%** reduction in dWPT energy