Designing Dynamic Wireless Power Transfer Corridors for Heavy Duty Battery Electric Commercial Freight Vehicles

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Abstract

The use of wireless power transfer systems, consisting of inductive electrical coils on the vehicle and the power source may be designed for dynamic operations where the vehicle will absorb energy at highway speeds from transmitting coils in the road. This has the potential to reduce the onboard energy storage requirements for vehicles while enabling significantly longer missions. This paper presents an approach to architecting a dynamic wireless power transfer corridor for heavy duty battery electric commercial freight vehicles. By considering the interplay of roadway power capacity, roadway and vehicle coil coverage, seasonal road traffic loading, freight vehicle class and weight, vehicle mobility energy requirements, on-board battery chemistry, non-electrified roadway vehicle range requirements, grid capacity, substation locations, and variations in electricity costs, we minimize the vehicle TCO by architecting the electrified roadway and the vehicle battery simultaneously. The idea optimizes battery size and chemistry so that the depth of discharge between recharge events and expected life are balanced, thus fully utilizing the energy available throughout the course of the battery system's life. The approach is illustrated by applying it to the I-75 freight corridor, where the framework developed may be expanded and applied to a larger interstate system, expanded regional corridor, or other transportation network.

Introduction

There are four major types of freight transportation available for shippers to use in the world of freight shipping. The primary ones are by ground (road), rail, ocean, and air. Although these are the main categories of freight transportation, each method has their own processes that differ from one another. According to the American Trucking Associations (ATA) Trucks move roughly 72.5% of the nation's freight by weight. There were 4.06 million Class 8 heavy duty (HD) trucks (including tractors and straight trucks) in operation in 2021, up 2.3% from 2020. All registered freight trucks combined for a total of 302.14 billion miles traveled in 2020. Out of these 177.26 billion miles were traveled by combination trucks in 2020 [1]. According to the U.S. Environment Protection Agency (EPA), in 2020 the transportation sector generated ~27% of the total Greenhouse gas (GHG) emissions, constituting the single largest share of GHG emissions in the U.S. GHG emissions from transportation primarily come from burning fossil fuel for our cars, trucks, ships, trains, and planes [2]. Medium and Heavy-Duty trucks constitute approximately 26% of the total transportation based GHG emissions in the U.S. or about 7% of the total U.S. GHG emissions [2].

Nations around the world are expected to continue to adopt more stringent emissions standards for heavy-duty vehicle markets for both oxides of nitrogen (NOx) and greenhouse gases [3,4,5,6,7]. California's Air Resource Board (CARB) Omnibus Low NOx rule, which goes into effect in 2024, requires the manufacturers of heavy-duty diesel engines to comply with vastly more stringent exhaust emission standards. In addition, it amends in-use test procedures, creates modifications to the durability demonstration, lengthens warranty and useful life periods, and increases emissions collection and reporting dates [8]. Additionally, 13 other states have policies mirroring CARB regulations [9]. In addition, CARB's Advanced Clean Trucks (ACT) regulation requires manufacturers to sell increasing percentages of zero-emission trucks and is expected to further reduce the lifecycle emission of greenhouse gases and eliminate tailpipe emissions of air pollutants [10].

The Bipartisan Infrastructure Law, passed by the Biden administration in late 2021, will focus on rebuilding America's roads, bridges and rails, expand access to clean drinking water, ensure every American has access to high-speed internet, tackle the climate crisis, advance environmental justice, and invest in communities that have too often been left behind [11]. This law has established a U.S. National Electric Vehicle Infrastructure Formula Program ("NEVI Formula") to provide funding to states to deploy battery electric vehicle (BEV) charging infrastructure and to establish an interconnected network to facilitate data collection, access, and reliability [11,12,13]. Initially, funding under this program is directed to designated Alternative Fuel Corridors for electric vehicles to build out this national network, particularly along the Interstate Highway System. This will support and accelerate equitable adoption of EVs, including for those who cannot reliably charge at home. It will reduce transportation-related greenhouse gas emissions and help put the U.S. on a path to net-zero emissions by no later than 2050. This effort will also position U.S. industries to lead global transportation electrification efforts and help create family-sustaining union jobs that cannot be outsourced. [12,13].

In alignment with the Bipartisan Infrastructure Law, the U.S. Department of Transportation's Federal Highway Administration (FHWA) has designated alternative fuel corridors, a national network of alternative fueling and charging infrastructure, along the National Highway System. Designation of the corridors began in 2016 and has expanded each year since then, for a total of more than 145,000 miles over 119 Interstates and 100 U.S. highways/state roads. The designated corridor fuels include electricity, compressed natural gas, liquefied natural gas, propane, and hydrogen. The FHWA has interactive maps showing corridors and pending corridors for each fuel (see Figure 1) [14]. These corridors will form the backbone of a future electrified transportation (including freight) network. Early deployment of a DC fast charging network is shown in Figure 2. This represents stations that have >50kW charging capabilities using Combined Charging System (CCS) connectors. This represents 5846 fast charging stations across the U.S. Most of these stations may only serve up to 4 vehicles at a single time and are largely designed and designated for passenger vehicles. Given this, there is still a significant challenge ahead to design and deploy an electrified charging solution that will not only support both electrified passenger and commercial vehicles (CV).

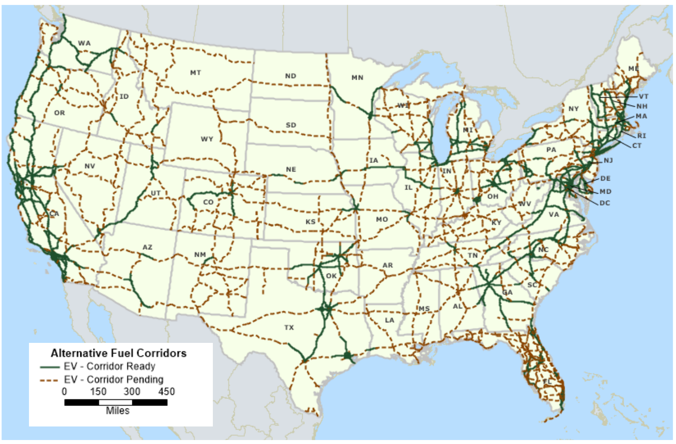


Figure 1. United States Alternative Fuel Corridors[15]

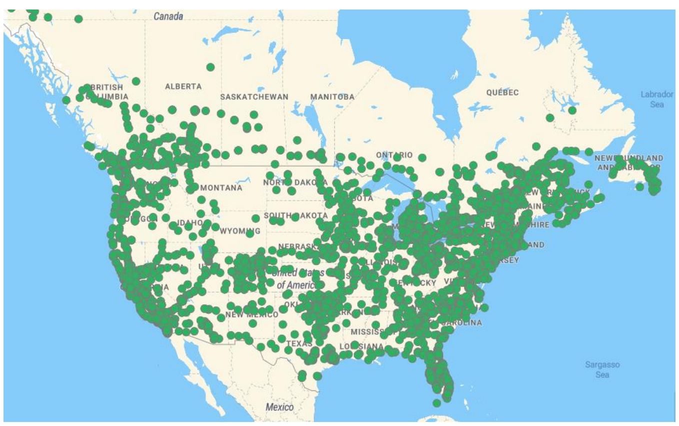


Figure 2. Map of DC fast charging stations with CCS plug type [16]

Currently near-zero/zero emission powertrains in CV are designed for specific mission use-cases (due to life, price, and weight), resulting in limitations on the operational diversity for the end-customer [17,18]. As we migrate from a carbon intensive fossil fuel-based freight transport system to a substantially/completely decarbonized freight transport system, several challenges need to be addressed. As compared to BEV or hydrogen powertrains, fossil fuel-based powertrains provide mission flexibility, and high uptime at a relatively low TCO. While the incumbent carbon intensive powertrains suffer from poor efficiency and are not sustainable to support Global Climate Change initiatives in transportation decarbonization, techno-economic challenges continue to create complex barriers to the large-scale displacement of these with highly electrified powertrains architectures [19,20,21]. Migration towards sustainable zero emission power in CV with steady long-term adoption rates is dependent on both vehicle and infrastructure solutions that are well aligned with CV end-user market needs. Their priorities are centered on: Availability (i.e., solutions are ready when it matters), Affordability (i.e., favorable economics), Efficiency (i.e., lower operational expenditure), Productivity (i.e., ability to get the job done), and Sustainability (i.e., emissions or CO2 footprint/TCO/system-of-system capabilities). At present, while research and development into zero emissions vehicle technologies is rapidly gaining momentum [22,23], based on the above priorities, challenges in the near term towards sustainable large scale customer adoption remains.

Adoption of BEV in HD commercial freight transportation is hampered by difficult technoeconomic obstacles. To enable widespread deployment of electrified powertrains, fleet and operational logistics need high uptime and parity with diesel system productivity/Total Cost of Ownership (TCO), while meeting safety compliance. Because of their comparatively high energy storage costs, greater weight, and recharging durations, BEV powertrains are currently only practical for shorter-range applications in HD truck transport. The use of dynamic wireless power transfer (DWPT) systems, consisting of inductive electrical coils on the vehicle and the power source may be designed for dynamic operations where the vehicle will absorb energy at highway speeds from transmitting coils in the road. This has the potential to reduce the onboard energy storage requirements for vehicles while enabling significantly longer missions. This paper presents an approach to architecting a DWPT corridor for HD battery electric commercial freight vehicles. By considering the interplay of roadway power capacity, roadway and vehicle coil coverage, seasonal road traffic loading, freight vehicle class and weight, vehicle mobility energy requirements, on-board battery chemistry, non-electrified roadway vehicle range requirements, grid capacity, substation locations, and variations in electricity costs, we minimize the vehicle CapEx and Fuel OpEx by architecting the electrified roadway and the vehicle battery simultaneously. The idea optimizes battery size and chemistry so that the depth of discharge between recharge events and expected life are balanced, thus fully utilizing the energy available throughout the course of the battery system's life. The approach is illustrated by applying it to the I-75 freight corridor, where the framework developed may be expanded and applied to a larger interstate system, expanded regional corridor, or other transportation network. While this analysis provides a pathway to architect the electrified roadway of a given freight corridor, it forms the backbone for a systematic approach that will be needed by infrastructure planners (both roadways and electric grid), fleets, and OEMs to sustainably deploy electrified heavy-duty vehicles for long haul freight transport leveraging DWPT technologies.

This paper is divided as follows. In the next section we will describe the overall methodology developed in this research. Following this we will delve into the results and analysis. Next, we will develop and discuss the technoeconomic solutions and identify conditions where the DWPT system provides a technology that has superior lifetime cost (CapEx and Fuel OpEx) than diesel powertrains from the perspective of the fleet. And lastly, we will provide concluding remarks.

Methodology

The fundamental assertion that will be explored in this paper is that the vehicle and infrastructure architecture for a DWPT system are correlated. Depending on the critical stakeholder, this correlation may vary. In this study the perspective developed is for the vehicle end-user and their lifetime cost of vehicle ownership while operating on roadways that support DWPT. Identifying the optimal balance of vehicle architecture (onboard battery characteristics) and the roadway infrastructure (DWPT coil power and coverage) will be critical in designing sustainable deployment pathways for these electrified freight transport systems.

ORNL has developed an advanced CV road and freight network, and energy systems architecture optimization and system-of-systems analytics using the OR-AGENT (Optimal Regional Architecture Generation for Electrified National Transport) modeling framework. This was introduced previously [24]. Through this framework, a parametric study is conducted using integrated sub-system data and models of the electrified vehicle powertrain architecture and dynamics, freight mobility (vehicle Origin-Destination (O-D), schedule, weight), traffic flow and roadway characteristics, weather (wind, precipitation, temperature, etc.), and energy flow pathways (grid capability, energy storage and dispensing, DER capability and siting). This unique approach to the system-of-systems analysis, combining vehicles, operations logistics, and energy pathways, provides a regional and seasonally specific constrained-optimal vehicle and infrastructure architecture solution based on technoeconomic measures for application operations. The architecture optimization is based on a defined system stakeholder (such as fleet, electrified equipment supplier, energy service provider, utilities, or planning agency) cost function. This will provide local government agencies, industry end users/energy suppliers, and equipment providers with a flexible planning tool to navigate the technology deployment of electrified freight transportation systems. The flexibility will allow regional characterization and accommodate constraints imposed by individual deployment efforts (arising from different stakeholder motivations in this eco-system). While more common analytical approaches to assesses infrastructure largely consider a piecewise systems approach without regional specificity, our approach systematically brings together a comprehensive assessment in developing clear and integrated vehicle and energy infrastructure roadmaps. The OR-AGENT framework has been applied in this paper to the task of developing both the vehicle and infrastructure architecture for the DWPT problem described above. The overall framework is shown in Figure 3. The following subsections will describe the details of each of the steps.

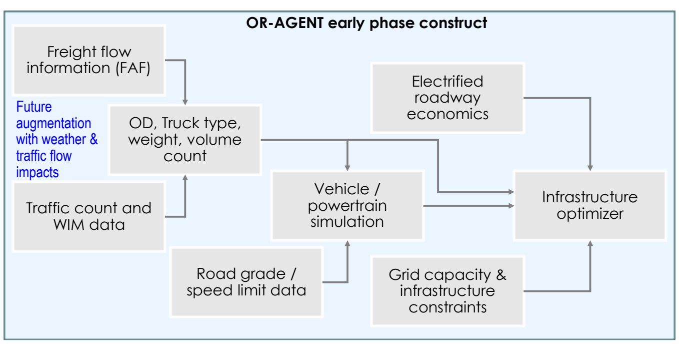


Figure 3. OR-AGENT early-stage workflow construct

A. Freight mobility network (O-D) data

In this study, freight mobility has been characterized using the Freight Analysis Framework Network (version 2021.05) [17]. The network contains state primary and secondary roads, National Highway System, Strategic Highway Network, National Highway Freight Network and several intermodal connectors as appropriate for the freight network modeling. The network attribute includes both traffic direction, function class, facility type, speed limit and adjusted speed to reflect unusual road characteristics, truck restrictions or permissions, and toll type. A summary of this is shown in Figure 4. Version 5 of the Freight Analysis Framework (FAF) integrates data from multiple sources to create a comprehensive picture of freight movement between states and major metropolitan areas via all modes of transportation. In the database, the areas are designated as FAF zones. FAF adopted these geographical areas from the Commodity Flow Survey (CFS). In the 2017 CFS, there are a total of 132 areas. The areas are classified into three types: metropolitan areas, the remainder of the state, and the entire state. These FAF zone points act as Origin and Destinations for this study. The initial dataset on freight tonnage moving from origin FAF zone to destination FAF zone included all FAF zones crossed by or near the I-75 corridor. Figure 5 shows the I-75 corridor, a selected FAF zone, and the zone centroids of all zones within 500 miles of the corridor. Using commercial truck routing software, combined with the FAF O-D pairs, freight route networks are identified. The freight network developed using this approach will closely represent most trucks that will use a part of the I-75 corridor to carry out their missions. Future work planned with OR-AGENT for electrification analysis will look at O-D more closely, down to the GPS coordinates of the origin and the destination. However, this limited resolution assessment was deemed appropriate for this study. Additional details of this data modeling on mobility have been described previously [25,26].

Figure 4. Estimated average FAF daily truck volumes on national highway system (2017) [27,28]

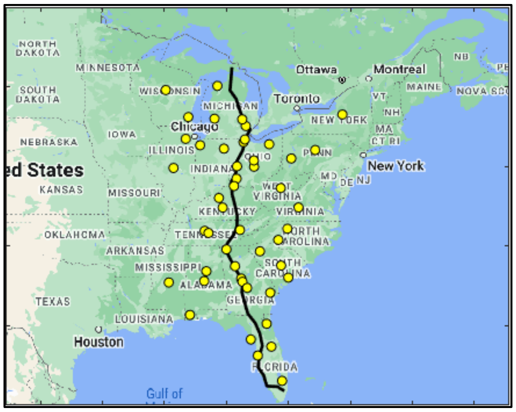


Figure 5. Location of Origin and Destinations considered for Heavy Truck travel along I-75 [24]

B. Freight weight data

State highway and transportation agencies construct, operate, and maintain a network of traffic count stations to monitor roadway usage by collecting data on vehicle volume, vehicle class, and vehicle weight. These station locations are shown in Figure 6 and Figure 7. These stations could be permanent or temporary (portable). Permanent traffic monitoring stations are operational on a year-round basis. Weigh-in-Motion (WIM) systems record the weight and axle configurations of vehicles traveling on the state highway system and provide valuable and necessary data for assessing the performance of our transportation infrastructure. WIM systems capture vehicle characteristics while the vehicle is moving at full highway speeds in the mainline highway lanes, as opposed to static scales, which require select trucks to exit the highway mainlines to be weighed. WIM sensors provide a means to estimate current and historical trends in truck volumes and weights because they operate continuously throughout the year and measure all passing trucks.

Figure 6. Traffic count and WIM station locations [29]

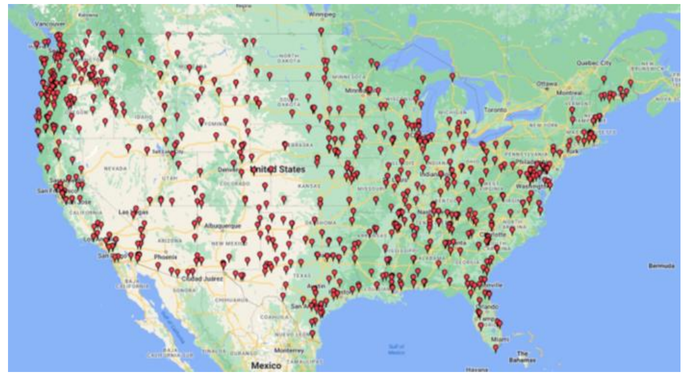


Figure 7. Stationary inspection and weigh station locations [30]

WIM systems record gross vehicle weight, dynamic axle loads and spacing, the number of axles, vehicle speed, lane and direction of travel, Federal Highway Administration (FHWA) vehicle classification, axle weights, date and time stamp, and so on. The WIM stations that are located on I-75 corridor were filtered and used as input in the modeling performed. HD vehicles were characterized per FHWA classifications into Class 9 – 13, with an example of this shown in Figure 8 with seasonality variation captured. Table 1 provides a summary of these aggregated weights and the percentiles of the population that will be used later in simulating the vehicle energy consumption along the I-75 corridor. Additional details of this weight have been described previously [25,26]. Using this data source, the HD freight vehicle weight and class seasonal statistical distributions may be established. This has been shown previously [25,26] and will be leveraged to determine the roadway energy and power requirements

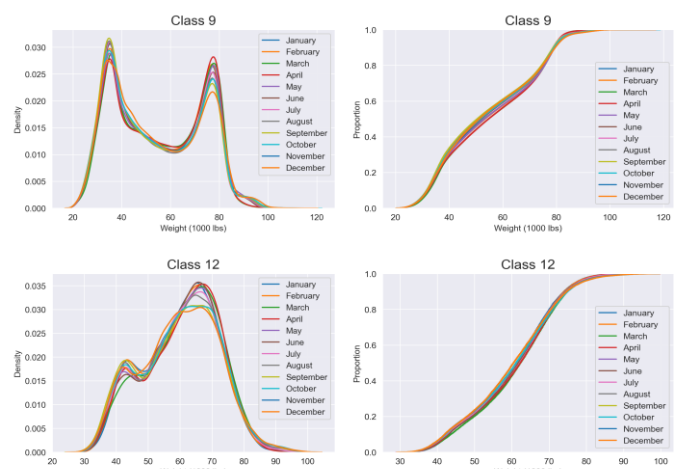


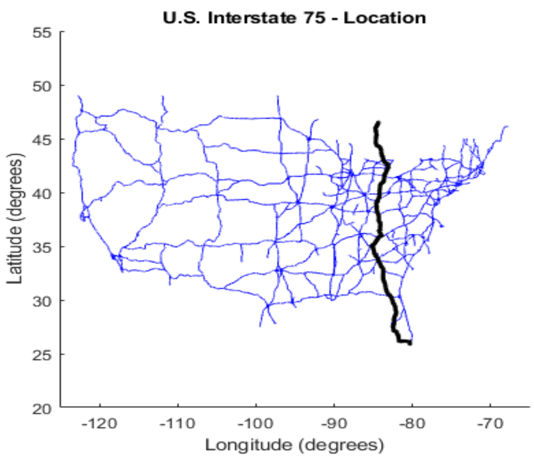
Figure 8. Aggregated weight statistics of Class 9 and Class 12 HD freight vehicles based on WIM and Weigh stations data along I-75

Table 1. Vehicle Weights for Fuel Economy Simulation

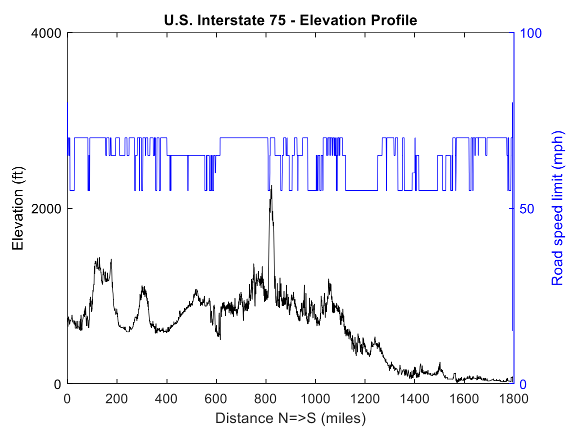
FHWA Class	Vehicle Weight (lbs)					
	5th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile
9	27,558	36,817	50,045	68,784	77,162	80,028
10	32,628	44,533	68,343	91,051	116,183	130,293
11	33,069	47,620	57,541	65,698	72,312	75,839
12	35,274	48,061	58,863	67,461	74,075	78,044
13	40,124	55,997	106,042	133,600	150,796	158,292

C. Road grade and speed data

To simulate the vehicles and characterize the energy consumption or needs, the I-75 roadway needs to be modeled. This includes assessing the road grade and vehicle admissible speed. For this study the latter will be treated as the road speed limit. In practice there are deviations to this [31] and more rigorous analysis is planned as mentioned above. To determine the roadway grade and speed limits the FAF databases [28] are refenced to identify the GPS coordinates associated with a given segment of the I-75 corridor.



(a) I-75 corridor (black) indicated among the entire U.S. interstate road system (blue)



(b) I-75 elevation and road speed limits

Figure 9. Characterizing the road grade and speed limits along I-75. Data extracted from ORNL FAF [28] and Nokia HERE [32] databases

These GPS coordinates are used with the Nokia HERE database to identify the elevation of the road at that point [32]. Due to the higher precision on elevation data in the Nokia HERE database this data may be differentiated to determine the road grade at each GPS coordinate. The summary of these results is shown in Figure 9.

D. Vehicle and powertrain modeling

Using the road-load dynamics developed previously [18] a 1-D HD BEV powertrain model is constructed (see Figure 10). While the traction drive (consisting of the MG and PE) feeds the final torque to the axles and wheels, the electrical power needed for this is produced through the onboard battery energy stored (with further discussions provided later). In addition, the battery efficiency is established given the internal resistance of a 620V nominal battery as a function of C-rate and State of Charge (SOC) (see Figure 10). Table 2 summarizes the key vehicle dynamic parameter set value based on application class and model year (MY) 2020, 2030 and 2040. Future vehicle dynamic characteristics have been derived from 21st Century Truck Partnership (21CTP) roadmaps [33,34].

The vehicle system architecture will be varied based on the battery size and chemistry. These will be explored to determine the lifetime cost (CapEx and Fuel OpEx) that a vehicle end-user will experience given various viable options for the DWPT vehicle and infrastructure architecture. Battery costs, weight and capacity will depend on the chemistry, the degradation period (or life), the roadway energy characteristics (propulsion and regeneration) the range of the vehicle without DWPT propulsion assistance, and the amount of energy required during DWPT propulsion assistance.

Estimating the battery life is complex, and depends on many factors including the chemistry, charge/discharge rates, fast charge frequency (based on C-rate), depth of discharge levels, operating temperatures, compounding throughput, micro-cycling, operational time (calendar life), cell balancing controls, etc. Detailed characterization of this requires extensive testing of specific cells and their module/pack configurations. For this study, we approach quantifying life by considering the total throughput in a generic Li-ion NMC (Nickel Manganese Cobalt oxide - representing high energy battery chemistries) and LTO (Lithium Titanate - representing high power battery chemistries) based battery. The total throughput is the cumulative energy flow in-to or out-of the battery during its life. The available throughput is characterized based on the total energy throughput during the admissible charge/discharge cycles. This is a simplified approach and captures the macroscopic behaviors well. In addition, the range expectations are met by sizing the battery based on mission type needs and limiting discharge to 80% capacity. The battery is finally sized to meet both the life and range expectations (while also meeting the C-rate constraints). The base characteristics for CV grade batteries used here are given in Table 3 [35]. In practice, the properties of Li-ion batteries, while generically classified into a few families, are quite sensitive to the specific cell compositions [35], but this variation is outside the scope of this paper.

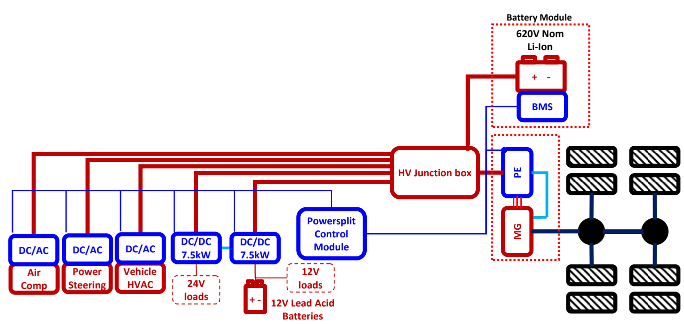


Figure 10. 1-D BEV powertrain vehicle model

Table 2: Vehicle dynamic parameters set point assumptions [36]

Class 8 truck	Units	2020	2030	2040
Vehicle GVW	klbs	65-80	65-80	65-80
Vehicle aero Cd – Class 9	-	0.5	0.42	0.39
Class 10	-	0.5	0.42	0.39
Class 11	-	0.59453	0.51453	0.48453
Class 12	-	0.62473	0.54473	0.51473
Class 13	-	0.65493	0.57493	0.54493
Vehicle tire Crr	-	0.006	0.00496	0.0048
Vehicle frontal area	m2	10.66	10.18	10.18
Vehicle tire radius	m	0.502	0.502	0.502
Vehicle RAR	-	2.47-2.93	2.47-2.93	2.47-2.93
Final Drive efficiency	%	97	97	97
Accessory loads	kW	3	2.6	2

Table 3: Battery chemistry properties assumptions [35]

		Value	
Parameter	Units	NMC	LTO
Throughput life charge/discharge cycles (80% DOD @ 1C)	Cycles	2500	12500
Cell specific energy density	Wh/kg	240	95
Pack specific energy density	Wh/kg	150	67
Cycle RMS C-rate limit	-	1	3
Max chare C-rate (continuous)	-	0.5-2	5
Pack cost	$/kWh	$200	$600

Results and Analysis

a. Workflow summary

The overall workflow here is summarized in Figure 11. The analysis consists of three primary stages as shown including:

- developing the road coil coverage given vehicle energy

Table 4 provides a summary of the energy consumption for the specific case of a MY2020 HD vehicle operating in the southbound

Table 4 for Class 9 vehicles. This data will provide the inputs to characterize the road energy and power demands along with the battery and DWPT road coil coverage requirements of the broader HD freight vehicle population present on the I-75 corridor.

demand, coil power levels, vehicle speeds, etc.
- developing the vehicle battery systems characteristics based on the vehicle energy demand, the battery chemistry, the amount of mission length spent on DWPT assist roadways
- developing the vehicle end-user TCO (limited to CapEx and Fuel OpEx) for the various viable architecture options including both vehicle and roadway architectures

This section will develop the first two stages in greater detail and explore the variations that have been called out in Figure 11. The third stage will be developed and discussed in the next section of the paper.

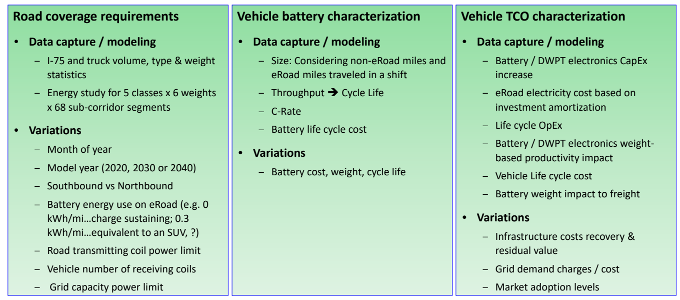


Figure 11. Analysis workflow considered in this study consisting of road coverage computation, vehicle battery characterization, and vehicle TCO (limited to CapEx and Fuel OpEx) assessment

b. Fuel economy results

In this study we have subdivided the I-75 corridor into 68 segments each of which will be used with the vehicle model to assess the energy consumption aggregated over each segment (see Figure 12). This approach has been previously discussed and applied for fuel cell electric vehicle and infrastructure analysis [24].

direction along the I-75 corridor. The results show the baseline diesel vehicle fuel economy, the BEV energy needs, and battery throughput. Other model year and direction variants have also been developed. Figure 13 illustrates a specific set of data from

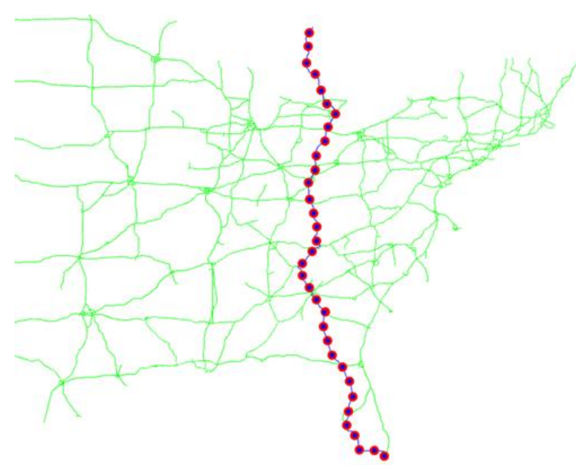


Figure 12. I-75 Segments for Fuel Economy Averages [24]

Table 4: Vehicle system energy consumption on I-75 roadway segments: MY2020 HD Line Haul vehicles operating North to South

(a) Diesel powertrain fuel economy (mpg)

Distance	Avg Speed	Class 9 - Weight (lbs)						Class 10 - Weight (lbs)					
		27,558	36,817	50,045	68,784	77,162	80,028	32,628	44,533	68,343	91,051	116,183	130,293
mi	mph	Energy (mpg)						Energy (mpg)					
12.27111104	65.25	9.273375	8.588716	7.773141	6.874324	6.514875	6.398444	8.889288	8.097048	6.889925	5.995777	5.357961	5.146282
22.59888882	55.00	10.59823	9.890724	8.998712	7.965151	7.569872	7.440928	10.20037	9.354543	7.98653	6.987844	6.143548	5.758282
47.54324566	66.47	9.330329	8.803778	8.129592	7.318596	6.997623	6.893073	9.035839	8.399847	7.336719	6.519926	5.840642	5.520703
73.81269011	70.00	8.514711	7.882541	7.065941	6.195519	5.903784	5.82136	8.163428	7.388843	6.21206	5.559655	5.005301	4.766459
102.1097295	66.11	8.750221	8.03752	7.196402	6.320293	6.01208	5.909532	8.338878	7.52366	6.337124	5.581968	5.23955	4.950032
132.0930628	70.00	8.489049	7.900099	7.239885	6.545048	6.27173	6.177869	8.148995	7.498787	6.558626	5.869697	5.398103	5.182588
158.4606373	69.24	9.20059	8.687814	8.047304	7.315221	7.045063	6.95846	8.914914	8.302238	7.330703	6.649537	6.121219	5.866287
184.1030186	67.33	9.661173	9.107576	8.336171	7.382926	7.023267	6.917743	9.35642	8.650508	7.403262	6.554601	5.923879	5.640984
216.2838308	67.32	9.941152	9.47348	8.857774	8.089218	7.781796	7.681571	9.679897	9.107973	8.106113	7.319565	6.620088	6.274505
247.963211	66.27	9.689193	9.099891	8.363818	7.515959	7.192584	7.089087	9.359243	8.655041	7.53347	6.715346	5.996956	5.660712
273.0163297	67.97	8.889691	8.290537	7.556468	6.700404	6.383101	6.285839	8.552686	7.84463	6.717786	5.941674	5.262519	4.945898
297.9989394	67.77	8.628102	7.9689	7.177688	6.296006	5.976614	5.878804	8.255317	7.486322	6.313711	5.555838	4.987224	4.725136
324.3718586	65.80	9.430441	8.852957	8.104189	7.249997	6.917595	6.814325	9.108311	8.401656	7.268265	6.461335	5.791242	5.513352
351.4393931	67.57	9.715661	9.241269	8.600846	7.78677	7.456012	7.347653	9.452245	8.865137	7.805106	6.959472	6.219715	5.889079
375.7863841	62.61	9.760282	9.005684	8.101883	7.135443	6.804655	6.657127	9.33221	8.459495	7.155233	6.272411	5.615935	5.303249
402.8438212	69.58	8.980936	8.456132	7.799806	7.027466	6.730107	6.634163	8.685717	8.059616	7.043593	6.288451	5.633739	5.330188
430.0027277	64.54	9.664841	8.967795	8.103686	7.112325	6.745316	6.63075	9.272546	8.445489	7.132576	6.228178	5.488767	5.174627
457.3749499	65.00	9.653596	8.969641	8.12354	7.152762	6.79093	6.675844	9.268303	8.457123	7.172686	6.266742	5.515164	5.188425
488.5239521	64.11	9.811556	9.119951	8.282811	7.327407	6.96796	6.851877	9.420537	8.61273	7.347056	6.443057	5.68519	5.341963
520.0850632	65.00	9.623971	8.945816	8.123413	7.182661	6.834179	6.724674	9.239275	8.447259	7.202391	6.332979	5.595469	5.26276
545.9767298	65.00	10.09989	9.509114	8.738987	7.791044	7.424467	7.304878	9.769259	9.04943	7.811325	6.880722	6.104925	5.762373
570.5656911	61.73	10.20847	9.471281	8.565428	7.528977	7.132682	7.007425	9.791415	8.921974	7.550412	6.566362	5.76088	5.408695
594.9824277	60.04	11.20083	10.43683	9.385057	8.166086	7.736896	7.586181	10.78326	9.809119	8.190524	7.126432	6.245382	5.980862
621.7126711	65.73	8.943297	8.316213	7.566922	6.657992	6.346418	6.252363	8.581726	7.898128	6.674375	5.865295	5.248801	5.000018
651.0932266	70.00	8.96447	8.435555	7.716881	6.828766	6.495093	6.397691	8.671343	8.006558	6.847929	6.055889	5.428327	5.159958
680.4932266	70.00	8.861626	8.317161	7.576603	6.741499	6.419999	6.31582	8.560377	7.879969	6.759683	5.955772	5.403244	5.222313
705.8487822	70.00	8.582242	7.98524	7.204071	6.31971	6.005822	5.912652	8.248095	7.518187	6.338354	5.579484	4.940709	4.686004
731.2043377	70.00	8.690418	8.082977	7.307586	6.486208	6.205028	6.118463	8.354391	7.612241	6.502135	5.849507	5.461855	5.167641
757.4348933	70.00	8.445595	7.729018	7.019051	6.278872	6.066919	6.006755	8.028796	7.27576	6.29248	5.831321	5.374106	5.221173
783.6848933	70.00	8.59832	7.979857	7.331891	6.597501	6.304885	6.211731	8.245762	7.586363	6.615241	5.895515	5.378105	5.169749
812.4837147	67.19	8.390539	7.567851	6.556584	5.972318	5.66904	5.580196	7.940138	6.958587	5.987718	5.348005	4.971311	4.918625
841.2001212	67.00	10.3675	9.446589	8.477675	7.481888	7.185624	7.095256	9.854491	8.82342	7.504059	6.81743	6.338375	6.219065
869.1723347	62.59	9.748679	8.731624	7.643459	6.825282	6.571025	6.497848	9.219401	8.030147	6.832194	6.204032	5.649954	5.458676
898.0704541	64.66	9.531451	8.778756	7.8167	6.83004	6.495561	6.400986	9.112082	8.193604	6.849041	5.99935	5.508825	5.272997
923.6041342	63.53	9.785158	9.153433	8.312004	7.290634	6.912764	6.791201	9.434203	8.654264	7.311738	6.376482	5.644549	5.325348
949.7349231	65.01	9.358108	8.589565	7.636952	6.589884	6.253952	6.15658	8.928197	8.006839	6.608574	5.847729	5.287807	5.071784
979.2124109	63.58	9.768655	8.91424	7.951968	6.944126	6.63547	6.539993	9.281721	8.300523	7.037981	6.216575	5.673836	5.459379
1005.062658	55.79	11.28974	10.54381	9.490144	8.194224	7.706838	7.559325	10.88419	9.923145	8.221437	7.033011	6.069455	5.651576
1029.441933	60.86	9.96569	9.117558	8.102178	6.95288	6.565241	6.449134	9.484161	8.495183	6.976146	6.071506	5.42106	5.14394
1057.023291	68.86	8.426602	7.761718	6.942605	6.132807	5.881015	5.794403	8.057517	7.245122	6.14796	5.516314	5.072017	4.883136
1083.151056	67.86	9.289998	8.576734	7.741271	6.823746	6.516963	6.430596	8.889221	8.06455	6.840013	6.112143	5.562921	5.335221
1108.775848	66.56	9.097976	8.438414	7.609511	6.642238	6.293141	6.188479	8.72567	7.938809	6.661517	5.840629	5.29042	5.070194
1135.642308	58.87	11.44247	10.57931	9.408287	8.057485	7.467208	7.321327	10.96745	9.882873	8.084088	6.828486	6.001084	5.637717
1160.728419	55.00	11.59434	10.80591	9.648386	8.259824	7.763059	7.608871	11.17203	10.12137	8.287959	7.092042	6.222184	5.854196
1184.760364	55.00	10.88522	10.04851	8.979936	7.759823	7.336509	7.205415	10.42085	9.404287	7.784024	6.766698	6.035331	5.682751
1208.792308	55.00	11.0161	10.24518	9.283992	8.181641	7.770435	7.638752	10.58629	9.662861	8.204478	7.169832	6.284419	5.904162
1233.782586	55.00	10.85568	10.08279	9.122301	7.992108	7.561952	7.423871	10.42239	9.504304	8.015559	6.933159	6.017876	5.607064
1259.235521	58.25	10.73081	10.04553	9.177064	8.149044	7.755489	7.628968	10.34834	9.523191	8.17085	7.173658	6.325405	5.93597
1284.635405	68.14	9.42547	8.912421	8.267805	7.505646	7.209731	7.114432	9.137754	8.522434	7.521194	6.767215	6.088954	5.763194
1310.25843	68.74	9.008805	8.490392	7.836034	7.057947	6.760255	6.665554	8.717665	8.09678	7.07433	6.325545	5.668698	5.361043
1338.623251	64.51	9.792895	9.177142	8.404049	7.506762	7.164144	7.054659	9.445828	8.710593	7.525267	6.661424	5.895697	5.549147
1364.314296	58.46	10.53918	9.822254	8.924414	7.87262	7.479016	7.351358	10.13543	9.282662	7.89432	6.897714	6.048688	5.677118
1389.794157	55.19	11.23341	10.49879	9.569583	8.471645	8.048798	7.914824	10.82279	9.940182	8.494866	7.434932	6.532168	6.120906
1417.991646	61.08	10.29598	9.48844	8.437382	7.285209	6.87517	6.74917	9.845478	8.851634	7.307891	6.311703	5.55823	5.28479
1445.201368	55.00	11.09815	10.36693	9.449264	8.342125	7.918951	7.785432	10.68852	9.816795	8.365782	7.314389	6.417206	6.023355
1472.395812	55.00	11.22771	10.53544	9.655265	8.59502	8.182066	8.049083	10.83929	10.00859	8.617686	7.571849	6.65797	6.230385
1499.473761	57.78	10.40439	9.659052	8.713816	7.629255	7.230788	7.104148	9.987807	9.090923	7.651667	6.658332	5.837068	5.483356
1527.581452	59.95	11.01576	10.31215	9.434555	8.425036	8.040541	7.917116	10.62207	9.773497	8.445571	7.481707	6.682898	6.288021
1552.034736	62.13	10.34532	9.650345	8.778249	7.784787	7.409252	7.289521	9.957146	9.121879	7.805291	6.864504	6.068131	5.702658
1578.928787	68.37	8.93605	8.358108	7.64472	6.811873	6.495161	6.396334	8.608836	7.92798	6.82897	6.046102	5.387185	5.084298
1606.423271	70.00	8.863651	8.341816	7.68579	6.912401	6.617775	6.523295	8.569914	7.946456	6.928407	6.184285	5.538633	5.247371
1631.795497	64.60	9.554545	8.925682	8.146346	7.246018	6.904706	6.794407	9.200073	8.455823	7.265435	6.404038	5.682367	5.366447
1658.205321	68.35	8.991209	8.442135	7.728291	6.923854	6.617446	6.526616	8.676867	8.003073	6.941179	6.174078	5.503895	5.194228
1685.232371	69.90	8.943362	8.429295	7.780977	7.012039	6.71599	6.619371	8.654243	8.040099	7.028043	6.27802	5.643361	5.358789
1712.495758	69.07	9.017309	8.480429	7.805832	7.018367	6.718189	6.621078	8.715561	8.073723	7.034681	6.272122	5.600268	5.288063
1740.127314	70.00	8.893537	8.378777	7.7312	6.970916	6.679386	6.585551	8.603765	7.988378	6.987319	6.245505	5.594269	5.291009
1767.526536	70.00	8.915056	8.403515	7.759092	7.004537	6.712481	6.61795	8.62774	8.015435	7.020959	6.275978	5.620633	5.313746
1792.175328	62.98	9.743282	9.060754	8.217269	7.259695	6.896638	6.782217	9.356418	8.548967	7.279614	6.388432	5.693074	5.35004

Distance	Class 11 - Weight (lbs)						Class 12 - Weight (lbs)						Class 13 - Weight (lbs)					
	33,069	47,620	57,541	65,698	72,312	75,839	35,274	48,061	58,863	67,461	74,075	78,044	40,124	55,997	106,042	133,600	150,796	158,292
mi	Energy (mpg)						Energy (mpg)						Energy (mpg)					
12.27111104	7.98827	7.214746	6.773684	6.454965	6.209342	6.083858	7.621272	6.99394	6.549171	6.232782	6.002249	5.872283	7.162349	6.490218	5.098231	4.868213	4.752857	4.549773
22.59888882	9.390992	8.510846	7.990531	7.604636	7.315331	7.170703	9.028241	8.299555	7.760305	7.376497	7.104474	6.94926	8.545468	7.733113	5.927066	5.270056	4.941296	4.812095
47.54324566	8.041974	7.430847	7.05956	6.775662	6.559281	6.449188	7.682818	7.186023	6.808724	6.529852	6.328531	6.215363	7.255376	6.706609	5.425742	4.926527	4.686093	4.595321
73.81269011	7.294128	6.57393	6.165902	5.87949	5.678287	5.592688	6.95312	6.376669	5.973478	5.701007	5.529611	5.444915	6.528145	5.929618	4.826647	4.471168	4.408218	4.384727
102.1097295	7.502078	6.72391	6.306979	6.019581	5.804698	5.707024	7.164641	6.529621	6.120442	5.838603	5.645673	5.530022	6.715784	6.079946	5.073723	4.680354	4.464191	4.401519
132.0930628	7.26906	6.668005	6.358966	6.137355	5.961002	5.864143	6.940382	6.46408	6.159119	5.955991	5.777036	5.685607	6.548734	6.077209	5.132942	4.906598	4.695682	4.641595
158.4606373	7.89762	7.327039	6.995196	6.760548	6.586974	6.496509	7.537019	7.079926	6.753598	6.531113	6.369332	6.276392	7.119864	6.638198	5.661318	5.258636	5.054884	4.974638
184.1030186	8.310071	7.662944	7.238483	6.913051	6.672904	6.5638	7.935802	7.415201	6.987302	6.673397	6.466622	6.354494	7.496927	6.904491	5.669553	5.311324	5.043741	4.979047
216.2838308	8.539285	7.998425	7.657314	7.398739	7.19728	7.093553	8.152186	7.715024	7.373355	7.120372	6.934434	6.826824	7.713236	7.228471	6.00541	5.478194	5.189878	5.077358
247.963211	8.297719	7.631244	7.238764	6.949443	6.730622	6.619138	7.914108	7.376893	6.980077	6.696504	6.494083	6.378384	7.459878	6.876994	5.537629	5.004933	4.722906	4.612241
273.0163297	7.618442	6.940469	6.5407	6.24186	6.025248	5.918475	7.264392	6.716155	6.30717	6.018818	5.820962	5.714579	6.833156	6.232832	4.926322	4.431581	4.210186	4.136131
297.9989394	7.385639	6.644756	6.218393	5.925732	5.712341	5.609324	7.035875	6.437829	6.011	5.727494	5.536301	5.432149	6.600113	5.95858	4.772277	4.360608	4.171384	4.114023
324.3718586	8.125379	7.462695	7.086187	6.794291	6.569954	6.463501	7.758792	7.227915	6.854113	6.5641	6.366433	6.255483	7.318153	6.767494	5.473581	5.015463	4.770834	4.6839
351.4393931	8.375937	7.819021	7.457851	7.179425	6.964436	6.85375	8.003485	7.549989	7.187481	6.916202	6.718504	6.60437	7.571393	7.062692	5.776011	5.274459	5.014438	4.911435
375.7863841	8.411043	7.553446	7.072335	6.742493	6.509931	6.354407	8.027026	7.329703	6.84559	6.525879	6.273272	6.148666	7.537713	6.792393	5.370812	4.863163	4.655968	4.591067
402.8438212	7.695774	7.101537	6.749728	6.487326	6.287982	6.186361	7.340298	6.861522	6.505289	6.248943	6.065863	5.961109	6.923371	6.402306	5.19406	4.716705	4.48394	4.395924
430.0027277	8.298316	7.506937	7.03471	6.687828	6.431424	6.305765	7.915221	7.275019	6.795574	6.457179	6.221631	6.088824	7.441503	6.738578	5.214045	4.687485	4.393354	4.298066
457.3749499	8.272315	7.495089	7.038828	6.702147	6.451749	6.325339	7.887024	7.258159	6.79477	6.465396	6.233969	6.102802	7.41252	6.727248	5.215573	4.694031	4.423207	4.322821
488.5239521	8.412563	7.633102	7.179118	6.844423	6.594445	6.467871	8.021505	7.389836	6.928648	6.600683	6.36824	6.235773	7.539019	6.85519	5.342662	4.792283	4.510021	4.404364
520.0850632	8.248668	7.485914	7.038843	6.710708	6.46934	6.347962	7.865069	7.246242	6.792378	6.473126	6.248696	6.123257	7.391281	6.720229	5.257403	4.741533	4.502996	4.415659
545.9767298	8.689314	8.001218	7.576963	7.249692	7.000509	6.874513	8.294665	7.736637	7.308294	6.988663	6.75876	6.626945	7.822675	7.207334	5.723824	5.190876	4.917779	4.81201
570.5656911	8.785153	7.935112	7.440412	7.076833	6.804355	6.667038	8.38307	7.689193	7.187233	6.831843	6.578371	6.43484	7.876242	7.123713	5.489288	4.92957	4.666375	4.569019
594.9824277	9.698358	8.792486	8.222863	7.795999	7.492178	7.324005	9.276411	8.541859	7.967643	7.555135	7.256839	7.125898	8.748828	7.929757	6.151391	5.558637	5.259088	5.199511
621.7126711	7.767928	7.099187	6.658006	6.342242	6.130505	6.034705	7.456417	6.90511	6.458697	6.161252	5.966901	5.863045	7.078787	6.42074	5.085835	4.688963	4.52262	4.460225
651.0932266	7.687275	7.065078	6.679383	6.381939	6.168464	6.069831	7.331751	6.829132	6.442435	6.159341	5.97718	5.876139	6.906658	6.357279	5.193956	4.774828	4.608377	4.554812
680.4932266	7.601794	7.000463	6.642171	6.375793	6.173268	6.069344	7.250032	6.783876	6.438771	6.183284	5.99686	5.891688	6.841699	6.365019	5.231234	4.92468	4.770218	4.682224
705.8487822	7.359584	6.670676	6.267854	5.966702	5.751156	5.646709	7.017338	6.464728	6.059876	5.769165	5.578319	5.472645	6.594086	6.005947	4.761859	4.377776	4.280825	4.261033
731.2043377	7.438079	6.771466	6.39682	6.143543	5.959037	5.871672	7.087237	6.565669	6.204556	5.963967	5.802732	5.715129	6.672478	6.142245	5.281407	4.848314	4.689257	4.64485
757.4348933	7.254154	6.658151	6.347937	6.051461	5.906211	5.850527	6.955134	6.508289	6.200347	5.918001	5.804057	5.753211	6.606921	6.165301	5.272404	5.066625	5.041967	4.945381
783.6848933	7.357504	6.801495	6.498858	6.260691	6.066699	5.969808	7.03176	6.605026	6.319931	6.07827	5.902402	5.798084	6.657618	6.240166	5.192563	4.859416	4.723992	4.685107
812.4837147	7.168624	6.264551	5.870799	5.786267	5.585435	5.463163	6.823204	6.104558	5.762714	5.694059	5.47153	5.330354	6.396065	5.72059	4.907237	4.723657	4.610734	4.568018
841.2001212	8.904928	8.020382	7.549268	7.219637	6.996197	6.898329	8.504707	7.8211	7.354232	7.041705	6.847262	6.748556	8.012872	7.326011	6.175872	5.871336	5.669283	5.574193
869.1723347	8.294401	7.284236	6.885909	6.610206	6.427682	6.345467	7.900346	7.115677	6.71901	6.481231	6.297855	6.205596	7.370345	6.711402	5.560695	5.243948	5.044787	4.982491
898.0704541	8.18053	7.330016	6.859442	6.54477	6.323844	6.21275	7.798167	7.122297	6.66187	6.362026	6.161988	6.048919	7.311249	6.627756	5.376279	5.000754	4.923962	4.880744
923.6041342	8.448032	7.69642	7.224131	6.866429	6.603659	6.474672	8.069516	7.457487	6.979722	6.630786	6.39143	6.25433	7.601494	6.91862	5.401172	4.908326	4.659059	4.570511
949.7349231	8.032304	7.15498	6.647461	6.297988	6.064679	5.952121	7.656673	6.946646	6.433936	6.111858	5.900303	5.797614	7.169791	6.411345	5.151166	4.768174	4.624962	4.570632
979.2124109	8.408301	7.527156	7.086298	6.679325	6.453171	6.344364	8.02877	7.335781	6.909428	6.495696	6.294283	6.195903	7.537959	6.884703	5.514352	5.135707	4.961686	4.908697
1005.062658	9.9113	8.965947	8.340297	7.864782	7.509478	7.336935	9.506128	8.727862	8.087836	7.617431	7.286937	7.107279	8.984011	8.078829	5.959751	5.254174	4.951617	4.843855
1029.441933	8.572216	7.621839	7.114379	6.661209	6.384699	6.24973	8.173445	7.413468	6.833854	6.454688	6.200644	6.064603	7.652278	6.875127	5.313551	4.803007	4.592416	4.511294
1057.023291	7.206036	6.479205	6.111651	5.860227	5.697073	5.613545	6.859161	6.29366	5.936388	5.709192	5.562303	5.474711	6.432281	5.890662	5.000232	4.687768	4.531417	4.494331
1083.151056	7.967859	7.234927	6.802986	6.505647	6.289429	6.194305	7.610324	7.03034	6.596239	6.311562	6.131664	6.0322	7.177531	6.557	5.395169	5.000625	4.842233	4.801995
1108.775848	7.808473	7.067976	6.644128	6.326797	6.08869	5.977239	7.446531	6.85567	6.43316	6.131915	5.920699	5.809124	6.999502	6.380638	5.144323	4.807386	4.627813	4.550649
1135.642308	9.882241	8.840125	8.191065	7.739395	7.297119	7.133183	9.434895	8.5848	7.938119	7.507907	7.08871	6.919244	8.857752	7.916007	5.902939	5.28621	5.017469	4.919427
1160.728419	10.20783	9.174149	8.488426	7.984825	7.621589	7.442039	9.798724	8.942107	8.239328	7.745281	7.406801	7.222788	9.254155	8.252388	6.147918	5.481406	5.168333	5.054608
1184.760364	9.564735	8.530422	7.914577	7.467826	7.156439	7.004283	9.173005	8.317158	7.682013	7.244299	6.958272	6.801803	8.638555	7.684854	5.910475	5.307478	4.994164	4.878211
1208.792308	9.700612	8.752382	8.198024	7.799253	7.504368	7.356043	9.310374	8.526737	7.954117	7.558731	7.283913	7.128287	8.789662	7.924367	6.118795	5.471643	5.15477	5.021883
1233.782586	9.560994	8.613411	8.053484	7.63652	7.32473	7.165931	9.17456	8.391527	7.814235	7.400182	7.104213	6.9362	8.657101	7.791543	5.840458	5.134687	4.773886	4.631218
1259.235521	9.373696	8.550833	8.053595	7.680889	7.400969	7.258551	8.981664	8.305584	7.795681	7.426241	7.163831	7.014108	8.484586	7.733048	6.007954	5.372586	5.050064	4.924633
1284.635405	8.092973	7.510832	7.164961	6.905713	6.709915	6.608858	7.723686	7.25436	6.905853	6.654136	6.472875	6.367732	7.294476	6.785467	5.577092	5.077016	4.805458	4.704585
1310.25843	7.731518	7.136113	6.776839	6.507409	6.307117	6.206406	7.377048	6.894251	6.529546	6.267317	6.084061	5.98001	6.957289	6.426869	5.219009	4.746183	4.510095	4.416063
1338.623251	8.415229	7.704299	7.283915	6.973302	6.740097	6.622574	8.027078	7.452457	7.027854	6.724092	6.507676	6.383568	7.559353	6.935858	5.498223	4.952588	4.663344	4.553766
1364.314296	9.163295	8.312951	7.806112	7.429019	7.146201	7.005142	8.766397	8.071035	7.553299	7.180047	6.916497	6.767834	8.259879	7.497351	5.771425	5.162402	4.779849	4.655127
1389.794157	9.903898	8.99893	8.457472	8.053541	7.749709	7.59887	9.51186	8.762562	8.202322	7.801123	7.518774	7.359382	8.993452	8.159177	6.279415	5.578649	5.214709	5.071144
1417.991646	8.856876	7.913111	7.342731	6.938524	6.645535	6.504542	8.447451	7.685806	7.109808	6.709303	6.444628	6.295776	7.928889	7.085526	5.395225	4.949794	4.683423	4.646436
1445.201368	9.78428	8.880959	8.341427	7.935779	7.629913	7.47447	9.395235	8.646906	8.089167	7.685701	7.398347	7.238055	8.880997	8.049103	6.188157	5.524669	5.163766	5.032918
1472.395812	9.927347	9.060925	8.539733	8.150636	7.8557	7.705029	9.537832	8.820009	8.282423	7.894583	7.617526	7.458984	9.02928	8.229347	6.37088	5.647489	5.281868	5.140359
1499.473761	9.088406	8.185447	7.653798	7.273005	6.988274	6.84477	8.7037	7.961182	7.421552	7.045379	6.78125	6.631143	8.196863	7.387173	5.659197	5.064519	4.773478	4.659011
1527.581452	9.514649	8.693565	8.228458	7.865558	7.59972	7.464974	9.086873	8.420102	7.946674	7.590934	7.345392	7.207112	8.558376	7.850587	6.250985	5.634775	5.316207	5.184171
1552.034736	8.888358	8.088186	7.61375	7.266189	7.00855	6.877673	8.480296	7.829883	7.349418	7.009838	6.770731	6.63443	7.980308	7.269592	5.698056	5.103944	4.789561	4.668035
1578.928787	7.659571	7.008841	6.620139	6.334008	6.117554	6.009317	7.30446	6.779451	6.385031	6.104345	5.906715	5.798388	6.878334	6.302313	5.037957	4.562448	4.366704	4.294794
1606.423271	7.594089	7.001865	6.647217	6.380504	6.181765	6.080931	7.242873	6.765087	6.405291	6.145998	5.962776	5.85941	6.830167	6.305877	5.110952	4.653153	4.41163	4.312671
1631.795497	8.220181	7.498692	7.073471	6.758875	6.525048	6.406972	7.845172	7.260818	6.827478	6.519622	6.304522	6.1814	7.387917	6.747476	5.347051	4.852016	4.60673	4.507613
1658.205321	7.727579	7.082384	6.720684	6.4323	6.227988	6.115454	7.374583	6.853026	6.482642	6.201385	6.006241	5.906448	6.944451	6.397402	5.130868	4.637151	4.387712	4.27748
1685.232371	7.665815	7.081956	6.731438	6.466366	6.267799	6.166917	7.312654	6.842344	6.486041	6.22779	6.045328	5.940862	6.899834	6.382362	5.201813	4.745974	4.504928	4.40891
1712.495758	7.719959	7.110999	6.748529	6.476942	6.271159	6.166797	7.363127	6.871115	6.50235	6.23597	6.046332	5.93831	6.94126	6.402103	5.156092	4.65803	4.404752	4.301358
1740.127314	7.617792	7.034728	6.687025	6.426375	6.228061	6.126973	7.267157	6.796524	6.443823	6.187175	6.004917	5.900697	6.855197	6.339212	5.139881	4.663067	4.426356	4.329641
1767.526536	7.636864	7.056596	6.711849	6.452462	6.253995	6.152728	7.285393	6.817376	6.468104	6.212187	6.028902	5.923614	6.873555	6.360979	5.158331	4.676426	4.439501	4.342923
1792.175328	8.399022	7.610678	7.145758	6.805996	6.554553	6.428977	8.017222	7.374497	6.901143	6.569238	6.336965	6.208928	7.541248	6.837862	5.40816	4.883325	4.608841	4.507939

(b) Battery electric powertrain energy needs (kWh/mi)

Distance	Avg Speed	Class 9 - Weight (lbs)						Class 10 - Weight (lbs)						Class 11 - Weight (lbs)						Class 12 - Weight (lbs)						Class 13 - Weight (lbs)					
		27,558	36,817	50,045	68,784	77,162	80,028	32,628	44,533	68,343	91,051	116,183	130,293	33,069	47,620	57,541	65,698	72,312	75,839	35,274	48,061	58,863	67,461	74,075	78,044	40,124	55,997	106,042	133,600	150,796	158,292
mi	mph	Energy (kWh/mi)						Energy (kWh/mi)						Energy (kWh/mi)						Energy (kWh/mi)						Energy (kWh/mi)					
12.27111104	65.25	2.106044	2.281695	2.534921	2.904355	3.069307	3.125715	2.2021	2.428338	2.895389	3.341144	3.806063	4.012268	2.484488	2.759137	2.950952	3.108971	3.23938	3.309733	2.614413	2.853706	3.061342	3.228015	3.35864	3.436986	2.792028	3.091898	4.024422	4.388531	4.565131	4.644186
22.59888882	55.00	1.670544	1.828469	2.057985	2.383327	2.528517	2.578187	1.757058	1.961919	2.375702	2.770379	3.202688	3.441568	1.960334	2.210592	2.382427	2.523304	2.637266	2.698092	2.060233	2.280441	2.467186	2.615403	2.729313	2.797507	2.205074	2.479764	3.337807	3.79743	4.075532	4.194078
47.54324566	66.47	2.089675	2.229707	2.431662	2.717914	2.845991	2.889735	2.166305	2.347303	2.711146	3.057462	3.426127	3.63105	2.471163	2.690539	2.840186	2.96301	3.062897	3.116083	2.5994	2.791749	2.953991	3.083073	3.182159	3.241547	2.766964	3.004973	3.732179	4.116252	4.339535	4.431614
73.81269011	70.00	2.330131	2.517399	2.787043	3.148745	3.300838	3.351382	2.432372	2.675148	3.140462	3.5263	3.92098	4.147723	2.753827	3.039871	3.225661	3.370851	3.48504	3.54458	2.896764	3.144443	3.341193	3.488871	3.599634	3.661852	3.08948	3.382274	4.147343	4.532749	4.708506	4.770427
102.1097295	66.11	2.250032	2.461506	2.760328	3.155055	3.312677	3.366296	2.366475	2.636937	3.146855	3.563097	3.942487	4.12345	2.663557	2.984535	3.196522	3.351667	3.4725	3.536692	2.803523	3.082862	3.307368	3.464487	3.583837	3.653856	3.00077	3.335431	4.130167	4.442975	4.630913	4.692695
132.0930628	70.00	2.347777	2.532023	2.775798	3.096979	3.233662	3.279927	2.449884	2.675245	3.089767	3.453387	3.805521	3.990113	2.777805	3.03932	3.202125	3.33053	3.433492	3.487996	2.919505	3.144749	3.315829	3.447898	3.548642	3.608378	3.105511	3.365117	4.062108	4.392689	4.550438	4.618167
158.4606373	69.24	2.148666	2.280628	2.469738	2.726037	2.834006	2.870462	2.220766	2.391348	2.720281	3.010187	3.29344	3.442553	2.539984	2.742371	2.876292	2.980249	3.061704	3.10492	2.670685	2.846309	2.98888	3.095344	3.175332	3.223135	2.836272	3.047927	3.614988	3.900187	4.080283	4.15276
184.1030186	67.33	2.022327	2.151942	2.344069	2.620424	2.742478	2.783456	2.092618	2.263372	2.613942	2.925325	3.20959	3.349166	2.389794	2.591761	2.732205	2.848511	2.94227	2.991372	2.512514	2.688678	2.839714	2.960769	3.052649	3.104089	2.67022	2.888526	3.480549	3.722545	3.872716	3.93192
216.2838308	67.32	1.979061	2.08571	2.242433	2.467257	2.56834	2.602988	2.037241	2.176636	2.461906	2.736978	3.038713	3.207583	2.341299	2.510176	2.627456	2.723843	2.802329	2.844326	2.461935	2.61026	2.737393	2.83851	2.916883	2.963998	2.612701	2.798174	3.388961	3.717114	3.923175	4.010918
247.963211	66.27	2.043767	2.188111	2.39538	2.687649	2.817483	2.861601	2.122725	2.308931	2.680792	3.031764	3.415979	3.629224	2.41895	2.645427	2.799336	2.925183	3.026966	3.081046	2.545408	2.744276	2.911251	3.043494	3.144838	3.205602	2.712784	2.958716	3.720839	4.131118	4.382224	4.490266
273.0163297	67.97	2.232972	2.407911	2.660476	3.016996	3.174457	3.227605	2.329103	2.554929	3.008553	3.4275	3.879168	4.126832	2.642787	2.916583	3.103391	3.257805	3.380567	3.445287	2.781663	3.021715	3.224772	3.385994	3.507242	3.579337	2.968947	3.267817	4.166656	4.633268	4.910886	5.021862
297.9989394	67.77	2.296676	2.497505	2.786255	3.194111	3.36961	3.429241	2.406614	2.665865	3.184852	3.650556	4.102376	4.34757	2.720159	3.033223	3.245289	3.414201	3.548592	3.619838	2.864843	3.138367	3.367294	3.540496	3.673017	3.75121	3.064691	3.401453	4.327102	4.783972	5.037677	5.134335
324.3718586	65.80	2.045746	2.188643	2.397988	2.68186	2.807761	2.850008	2.123607	2.310567	2.675182	3.003636	3.351237	3.526217	2.419981	2.640702	2.785404	2.903522	3.001276	3.050811	2.54582	2.737415	2.890226	3.015243	3.110168	3.163701	2.710352	2.937034	3.62094	3.952904	4.149255	4.233922
351.4393931	67.57	2.017383	2.125841	2.288103	2.526722	2.634328	2.671448	2.076618	2.219211	2.521079	2.814969	3.137012	3.312872	2.380011	2.551433	2.673681	2.775395	2.857665	2.901754	2.500503	2.650899	2.783092	2.889276	2.970827	3.019879	2.651593	2.84115	3.448698	3.773665	3.975404	4.060793
375.7863841	62.61	1.976093	2.143259	2.389349	2.735232	2.880281	2.932441	2.067502	2.28601	2.727937	3.121653	3.516052	3.731332	2.334117	2.596788	2.780127	2.926437	3.042129	3.100082	2.455563	2.685751	2.883084	3.033562	3.147067	3.21715	2.62363	2.911587	3.717857	4.127597	4.37465	4.47264
402.8438212	69.58	2.214491	2.363637	2.577241	2.879884	3.014211	3.059947	2.296207	2.488203	2.872754	3.235495	3.628349	3.843988	2.619944	2.852478	3.010462	3.140041	3.244698	3.300325	2.756242	2.959889	3.131006	3.266741	3.370747	3.432987	2.934267	3.18535	3.961198	4.371073	4.617446	4.719742
430.0027277	64.54	2.031339	2.200132	2.445817	2.79479	2.948781	3.001218	2.123435	2.343015	2.786665	3.201828	3.655005	3.903337	2.401997	2.66753	2.851017	3.000744	3.120443	3.184583	2.527994	2.761073	2.960066	3.116308	3.235775	3.307152	2.701674	2.992031	3.886778	4.357287	4.643835	4.769473
457.3749499	65.00	2.052894	2.221133	2.464263	2.808701	2.961115	3.012962	2.144985	2.362625	2.800643	3.211834	3.658243	3.904954	2.429058	2.693278	2.874306	3.022492	3.141746	3.205122	2.557037	2.788902	2.985136	3.140572	3.259098	3.329942	2.732499	3.020334	3.906467	4.368918	4.643405	4.76231
488.5239521	64.11	2.013195	2.180077	2.419863	2.758179	2.90887	2.959721	2.104499	2.319872	2.750222	3.156232	3.597807	3.837495	2.383642	2.64562	2.824232	2.97038	3.088589	3.151541	2.50973	2.739739	2.933717	3.087347	3.205289	3.275951	2.68321	2.968229	3.848027	4.30591	4.584332	4.703372
520.0850632	65.00	2.06086	2.230877	2.474025	2.819161	2.972425	3.024012	2.154128	2.37237	2.811073	3.218906	3.65304	3.889911	2.440022	2.705661	2.887484	3.036579	3.15681	3.219765	2.568861	2.801999	2.999586	3.156136	3.275014	3.345189	2.74545	3.035168	3.910948	4.359432	4.614947	4.721478
545.9767298	65.00	1.944054	2.075973	2.271868	2.550491	2.675014	2.717636	2.01591	2.18973	2.543941	2.880699	3.242814	3.43686	2.298755	2.508362	2.653893	2.773212	2.869806	2.921482	2.41826	2.602111	2.759699	2.884857	2.981002	3.038698	2.5755	2.804727	3.518908	3.878626	4.094675	4.188861
570.5656911	61.73	1.914587	2.079155	2.31892	2.657084	2.806644	2.857642	2.004471	2.21845	2.649197	3.053309	3.49107	3.729491	2.26451	2.524235	2.702293	2.846444	2.963588	3.025733	2.383874	2.612053	2.804845	2.955765	3.072281	3.141895	2.549919	2.832987	3.700429	4.151413	4.405967	4.511067
594.9824277	60.04	1.670742	1.795074	1.980946	2.241611	2.355254	2.393941	1.738506	1.902474	2.235582	2.541675	2.852515	2.996652	1.973435	2.16663	2.303714	2.41071	2.498274	2.54422	2.075211	2.243454	2.389653	2.50125	2.588218	2.639653	2.209984	2.421351	3.041171	3.309438	3.473293	3.53885
621.7126711	65.73	2.174984	2.356406	2.602516	2.948252	3.097703	3.14724	2.274266	2.501195	2.940124	3.336812	3.751395	3.968543	2.551308	2.811215	2.987067	3.131641	3.245969	3.30533	2.677676	2.899672	3.088824	3.238458	3.349452	3.415187	2.844599	3.1176	3.926032	4.325847	4.540724	4.616939
651.0932266	70.00	2.206143	2.351102	2.567545	2.877474	3.012585	3.05623	2.284932	2.476878	2.870232	3.211616	3.552366	3.728585	2.610788	2.838721	2.994979	3.123651	3.22605	3.277226	2.746697	2.945252	3.112748	3.24526	3.342942	3.395633	2.923349	3.166086	3.83156	4.134303	4.318613	4.398983
680.4932266	70.00	2.225557	2.376453	2.599428	2.888551	3.010059	3.051123	2.306306	2.507832	2.881999	3.206583	3.527512	3.679614	2.630277	2.855856	3.001245	3.11208	3.202772	3.251021	2.765634	2.956611	3.108223	3.221567	3.309555	3.362364	2.938056	3.160288	3.771845	4.036742	4.204487	4.274812
705.8487822	70.00	2.310367	2.487638	2.745992	3.104471	3.261599	3.312585	2.406928	2.637666	3.096211	3.506287	3.946386	4.181044	2.730112	3.00433	3.185752	3.335027	3.454873	3.516332	2.871797	3.110015	3.30364	3.458785	3.57524	3.641425	3.061656	3.346651	4.183962	4.585159	4.805626	4.882805
731.2043377	70.00	2.277436	2.450091	2.694857	3.005843	3.129366	3.170858	2.371123	2.595234	2.999207	3.325709	3.636904	3.804573	2.695689	2.951586	3.112089	3.229624	3.320792	3.368555	2.836485	3.054203	3.221147	3.33888	3.426544	3.478844	3.019849	3.269841	3.867856	4.159353	4.324891	4.398167
757.4348933	70.00	2.33107	2.524243	2.737062	2.97709	3.078085	3.111578	2.4402	2.655547	2.971734	3.221566	3.4995	3.672562	2.745987	2.962153	3.078691	3.171396	3.241124	3.277511	2.873683	3.049315	3.169732	3.262424	3.327338	3.363539	3.034479	3.214841	3.667165	3.928717	4.071264	4.119749
783.6848933	70.00	2.298562	2.473763	2.69584	2.980924	3.107262	3.14946	2.394568	2.605659	2.974122	3.314988	3.641395	3.808582	2.718834	2.943926	3.085374	3.198561	3.290635	3.339534	2.855135	3.041291	3.189655	3.305581	3.395211	3.450031	3.023842	3.237576	3.87608	4.16435	4.336904	4.407327
812.4837147	67.19	2.347007	2.595321	2.94941	3.25753	3.346487	3.37539	2.481365	2.803563	3.252585	3.487952	3.763245	3.917164	2.776951	3.155442	3.35121	3.447366	3.514201	3.548078	2.924983	3.251284	3.443231	3.535954	3.599574	3.635935	3.138624	3.480512	3.951144	4.1974	4.359449	4.424356
841.2001212	67.00	1.807657	1.892147	1.983753	2.064849	2.096993	2.108097	1.85469	1.952563	2.06306	2.171125	2.408949	2.546208	2.12838	2.219459	2.256066	2.280408	2.297977	2.305853	2.23056	2.299806	2.335012	2.355994	2.369901	2.379163	2.346451	2.40243	2.557475	2.798061	2.939414	3.000061
869.1723347	62.59	1.975027	2.16701	2.443528	2.737366	2.836181	2.868591	2.079777	2.329782	2.731625	2.990618	3.282542	3.456871	2.336224	2.631474	2.789896	2.89588	2.969202	3.005794	2.460231	2.71373	2.875341	2.979308	3.04744	3.086106	2.637275	2.904527	3.424849	3.730488	3.896143	3.966426
898.0704541	64.66	2.017433	2.187336	2.442074	2.778449	2.918175	2.964097	2.108659	2.335781	2.770886	3.133052	3.486045	3.63695	2.388263	2.654734	2.828047	2.962886	3.068028	3.122563	2.514087	2.745538	2.927998	3.066007	3.167512	3.224599	2.686409	2.959528	3.671957	3.921717	4.066356	4.130875
923.6041342	63.53	1.961967	2.110259	2.329525	2.644056	2.781697	2.827981	2.042781	2.237127	2.636725	3.004341	3.387426	3.596615	2.320731	2.554742	2.718345	2.852498	2.959273	3.015176	2.442283	2.647172	2.824071	2.964256	3.06913	3.131222	2.605461	2.861575	3.621629	3.998585	4.218315	4.316381
949.7349231	65.01	2.083809	2.271928	2.545809	2.928761	3.087659	3.138637	2.186114	2.43221	2.919768	3.316911	3.698595	3.912515	2.465466	2.758525	2.95489	3.114654	3.233057	3.294489	2.595936	2.851346	3.062577	3.224024	3.337625	3.405239	2.778622	3.088936	3.877299	4.255873	4.473435	4.561366
979.2124109	63.58	1.962781	2.118011	2.332299	2.599095	2.716662	2.757141	2.048675	2.245053	2.592974	2.909009	3.215271	3.368743	2.311095	2.534431	2.66878	2.774913	2.861244	2.906456	2.426405	2.616956	2.758498	2.866785	2.950153	3.000019	2.58	2.794371	3.391554	3.662901	3.827197	3.885742
1005.062658	55.79	1.554635	1.697429	1.907632	2.210011	2.345715	2.391041	1.632028	1.819161	2.202816	2.562074	2.955485	3.163136	1.837418	2.063051	2.221057	2.351682	2.458118	2.514837	1.934364	2.132408	2.304005	2.441316	2.54756	2.60931	2.071435	2.320929	3.097753	3.483557	3.698038	3.780986
1029.441933	60.86	1.93131	2.122104	2.400528	2.780247	2.935704	2.986772	2.03516	2.284097	2.771844	3.180213	3.571875	3.775429	2.286033	2.585152	2.786666	2.94536	3.066478	3.129783	2.407909	2.669769	2.886341	3.049334	3.168189	3.236636	2.582527	2.90384	3.740791	4.119235	4.341166	4.431208
1057.023291	68.86	2.35299	2.564968	2.865792	3.226696	3.366744	3.410744	2.468472	2.745235	3.21865	3.580898	3.910068	4.070518	2.78792	3.103521	3.290197	3.429752	3.532801	3.584925	2.936497	3.204015	3.398256	3.536367	3.635004	3.693356	3.141837	3.434973	4.104316	4.36733	4.527701	4.598094
1083.151056	67.86	2.065775	2.222879	2.436749	2.723727	2.839527	2.878847	2.151428	2.35137	2.717573	3.026193	3.335476	3.502194	2.445939	2.670344	2.814588	2.928257	3.01695	3.063274	2.572788	2.763066	2.916376	3.031843	3.117185	3.167616	2.737641	2.959416	3.548872	3.858832	4.060822	4.134544
1108.775848	66.56	2.122262	2.287689	2.535065	2.880549	3.027921	3.077656	2.213019	2.431187	2.87258	3.26087	3.629077	3.810266	2.513722	2.766899	2.940421	3.081522	3.193554	3.252903	2.645117	2.863879	3.047477	3.192228	3.301791	3.36588	2.820295	3.084185	3.83747	4.170755	4.363398	4.445453
1135.642308	58.87	1.643551	1.773678	1.97092	2.253869	2.377103	2.418846	1.713793	1.887596	2.247415	2.573033	2.909433	3.089126	1.942419	2.148009	2.294729	2.413724	2.508224	2.55835	2.043881	2.223359	2.381501	2.504555	2.597773	2.653412	2.181364	2.407231	3.073969	3.413688	3.609759	3.691707
1160.728419	55.00	1.491582	1.627392	1.827911	2.110843	2.229481	2.268681	1.5655	1.743767	2.10442	2.413768	2.723306	2.891959	1.760195	1.974653	2.123755	2.244104	2.337456	2.385852	1.852135	2.040284	2.201555	2.326085	2.417814	2.470773	1.982315	2.217521	2.866306	3.1809	3.37312	3.452592
1184.760364	55.00	1.614598	1.780586	2.021107	2.358731	2.498674	2.545193	1.705254	1.920317	2.351033	2.716788	3.065711	3.259779	1.907663	2.168868	2.347359	2.491453	2.602025	2.659008	2.009107	2.238267	2.431897	2.581274	2.689044	2.751973	2.157615	2.441859	3.198877	3.563224	3.784785	3.881234
1208.792308	55.00	1.587288	1.73908	1.957639	2.267646	2.404012	2.449845	1.6703	1.866446	2.260379	2.625291	3.005665	3.205968	1.874979	2.113257	2.275895	2.407226	2.5125	2.568405	1.974151	2.183259	2.359307	2.496635	2.600676	2.662535	2.116524	2.37525	3.144678	3.523546	3.751492	3.848663
1233.282586	55.00	1.629143	1.793823	2.032498	2.372019	2.524251	2.576272	1.719109	1.932757	2.364032	2.777117	3.231072	3.481036	1.924978	2.184874	2.363909	2.511216	2.630688	2.694444	2.027237	2.255605	2.450282	2.605444	2.724791	2.796531	2.176161	2.461202	3.361996	3.844517	4.142046	4.271137
1259.235521	58.25	1.709344	1.850725	2.055032	2.34539	2.475129	2.519612	1.786638	1.969657	2.338567	2.691281	3.079	3.294201	2.020136	2.243136	2.396267	2.52218	2.624159	2.678558	2.126071	2.322021	2.488573	2.621099	2.722942	2.784048	2.272091	2.516374	3.281062	3.688121	3.938946	4.046227
1284.635405	68.14	2.092213	2.222293	2.409662	2.671005	2.785763	2.824948	2.163241	2.331628	2.664914	2.976094	3.320632	3.512949	2.474498	2.67805	2.81561	2.927059	3.016389	3.063899	2.602746	2.780917	2.929763	3.046206	3.134884	3.1881	2.767617	2.986675	3.657255	4.021518	4.249693	4.348567
1310.25843	68.74	2.198632	2.34639	2.558638	2.858568	2.991827	3.036843	2.279593	2.470033	2.851539	3.209776	3.600465	3.815757	2.601674	2.83378	2.99205	3.121544	3.22546	3.280027	2.737259	2.941112	3.112987	3.248921	3.351262	3.412263	2.914601	3.16749	3.932479	4.337445	4.58039	4.681177
1338.623251	64.51	2.0048	2.153662	2.363573	2.665886	2.79913	2.844546	2.086294	2.276432	2.658782	3.022764	3.425811	3.649261	2.37226	2.602555	2.75951	2.889779	2.995177	3.050482	2.496424	2.698026	2.868487	3.005175	3.110122	3.171843	2.662476	2.910938	3.697659	4.123048	4.382614	4.493528
1364.314296	58.46	1.757973	1.911392	2.132517	2.450773	2.593334	2.642278	1.841831	2.040213	2.443233	2.830764	3.257469	3.492943	2.080263	2.321376	2.487416	2.625206	2.737157	2.796837	2.190349	2.402019	2.58271	2.727592	2.839274	2.906397	2.343912	2.60755	3.449638	3.904135	4.180973	4.297003
1389.794157	55.19	1.562962	1.703877	1.908157	2.19922	2.329222	2.373653	1.640088	1.822621	2.192369	2.545194	2.923487	3.131828	1.845925	2.068318	2.221564	2.347744	2.450056	2.50464	1.942964	2.138426	2.304897	2.437716	2.539991	2.60125	2.080151	2.32379	3.08699	3.489277	3.737656	3.845846
1417.991646	61.08	1.870646	2.046066	2.297422	2.652731	2.809376	2.861396	1.966407	2.19195	2.644516	3.059091	3.491413	3.724877	2.216374	2.488831	2.67554	2.826509	2.948864	3.011392	2.334738	2.573155	2.774948	2.933391	3.05251	3.122728	2.502415	2.796789	3.668386	4.092864	4.342148	4.446113
1445.201368	55.00	1.578419	1.727497	1.943528	2.254531	2.39445	2.442089	1.659825	1.853246	2.24718	2.621219	3.02073	3.237331	1.865476	2.101144	2.263555	2.397821	2.506928	2.565491	1.964221	2.171462	2.348231	2.489541	2.598315	2.663797	2.105403	2.364299	3.170736	3.586897	3.828596	3.930857
1472.395812	55.00	1.558754	1.700212	1.905235	2.197188	2.327786	2.372392	1.636231	1.819386	2.190302	2.544464	2.936266	3.155149	1.841731	2.065068	2.218995	2.345667	2.448417	2.503177	1.938832	2.135184	2.302496	2.435931	2.538548	2.600106	2.076237	2.321051	3.097512	3.52253	3.782795	3.894267
1499.473761	57.78	1.762988	1.931101	2.174723	2.51717	2.666763	2.717566	1.854754	2.072912	2.5093	2.912399	3.349174	3.585626	2.084756	2.349077	2.529686	2.674874	2.791157	2.852864	2.195347	2.427266	2.622597	2.773703	2.889259	2.958238	2.353341	2.640555	3.504178	3.950549	4.219647	4.334625
1527.581452	59.95	1.758437	1.894626	2.090454	2.355449	2.473002	2.513241	1.833014	2.009562	2.349271	2.668376	3.018479	3.213786	2.07863	2.291866	2.430671	2.54369	2.635332	2.684223	2.187156	2.373541	2.52353	2.641944	2.733248	2.788103	2.333975	2.558444	3.246521	3.62193	3.85439	3.956319
1552.034736	62.13	1.889761	2.042679	2.262259	2.573007	2.710579	2.757304	1.973045	2.170654	2.5657	2.937462	3.34622	3.573477	2.235417	2.475751	2.639161	2.77319	2.881956	2.939847	2.353228	2.56405	2.741445	2.88232	2.990797	3.055693	2.514419	2.77525	3.583726	4.020312	4.287481	4.402799
1578.928767	68.37	2.209092	2.372843	2.608466	2.94519	3.094717	3.146109	2.298495	2.509808	2.937479	3.339286	3.765051	3.997478	2.614935	2.870869	3.045179	3.18993	3.306045	3.367729	2.752029	2.976227	3.165317	3.316755	3.431526	3.500731	2.93506	3.211839	4.056985	4.494365	4.749851	4.85103
1606.423211	70.00	2.249362	2.402598	2.622278	2.93135	3.068542	3.115195	2.333329	2.530718	2.924129	3.294357	3.695962	3.915233	2.661164	2.900487	3.06313	3.195862	3.302552	3.359188	2.799677	3.009371	3.185751	3.324763	3.430681	3.493914	2.981176	3.240268	4.030526	4.443527	4.697481	4.805589
1631.795497	64.60	2.055373	2.213182	2.441977	2.765724	2.910049	2.959201	2.141594	2.346494	2.758067	3.147515	3.568662	3.798267	2.429017	2.676854	2.845878	2.9839	3.095919	3.155408	2.555554	2.772786	2.955741	3.100302	3.211428	3.277706	2.726398	2.995003	3.821188	4.251982	4.503554	4.612042
1658.205321	68.35	2.197643	2.355267	2.588452	2.9039	3.043766	3.088428	2.287082	2.491681	2.896254	3.272603	3.690263	3.92125	2.597245	2.848555	3.00947	3.148129	3.260743	3.31597	2.7306	2.952021	3.126953	3.273176	3.382271	3.442983	2.911744	3.17477	3.990154	4.434631	4.703402	4.817753
1685.232371	69.90	2.222604	2.369528	2.581428	2.881108	3.014563	3.06001	2.302832	2.493083	2.874077	3.23422	3.61815	3.823034	2.629077	2.859511	3.016416	3.144868	3.248385	3.303444	2.765644	2.967717	3.137832	3.272382	3.375042	3.436399	2.943729	3.193527	3.951394	4.341929	4.587089	4.691695
1712.496758	69.07	2.210713	2.364076	2.583977	2.894624	3.033012	3.080315	2.294731	2.492239	2.887338	3.262351	3.673633	3.900547	2.616302	2.856795	3.020758	3.155123	3.263734	3.321554	2.752954	2.964079	3.142231	3.2835	3.391821	3.456646	2.932916	3.194788	4.008621	4.445661	4.712377	4.827627
1740.127314	70.00	2.243222	2.394497	2.611049	2.916742	3.052568	3.098892	2.326113	2.520771	2.909582	3.276694	3.676971	3.897701	2.653906	2.890296	3.051084	3.182758	3.289141	3.345726	2.791965	2.999266	3.173774	3.311996	3.417926	3.481268	2.972491	3.229012	4.021548	4.441639	4.695814	4.802578
1767.524536	70.00	2.237193	2.386551	2.600658	2.901932	3.036856	3.08291	2.319041	2.511364	2.894841	3.259958	3.66023	3.881594	2.646759	2.880421	3.039082	3.168888	3.274505	3.330792	2.784394	2.989339	3.161397	3.298041	3.40339	3.466468	2.964002	3.217315	4.007441	4.429068	4.682775	4.789225
1792.175328	62.98	2.007201	2.176054	2.416519	2.761886	2.91653	2.96919	2.099978	2.316698	2.753749	3.170733	3.606377	3.845501	2.37139	2.633288	2.812677	2.961253	3.081126	3.145179	2.495	2.724344	2.918968	3.074734	3.193887	3.265336	2.665062	2.949406	3.820583	4.254339	4.491574	4.601718

(c) Battery electric powertrain energy throughput (kWh/mi)

Distance	Avg Speed	Class 9 - Weight (lbs)						Class 10 - Weight (lbs)						Class 11 - Weight (lbs)						Class 12 - Weight (lbs)						Class 13 - Weight (lbs)					
		27,558	36,817	50,045	68,784	77,162	80,028	32,628	44,533	68,343	91,051	116,183	130,293	33,069	47,620	57,541	65,698	72,312	75,839	35,274	48,061	58,863	67,461	74,075	78,044	40,124	55,997	106,042	133,600	150,796	158,292
mi	mph	Energy (kWh/mi)						Energy (kWh/mi)						Energy (kWh/mi)						Energy (kWh/mi)						Energy (kWh/mi)					
12.27111104	65.25	2.183077	2.381171	2.64608	3.003562	3.161963	3.220156	2.294329	2.539685	2.994371	3.450031	3.935525	4.151669	2.568023	2.865885	3.052797	3.201569	3.328323	3.398439	2.70004	2.956633	3.15785	3.317278	3.445965	3.525471	2.88229	3.190414	4.137421	4.519467	4.706882	4.765604
22.59888882	55.00	1.670587	1.828512	2.058029	2.38337	2.528563	2.578315	1.757101	1.961963	2.375745	2.771271	3.207006	3.449115	1.960378	2.210635	2.38247	2.523348	2.637309	2.698135	2.060276	2.280484	2.46723	2.615447	2.729356	2.797551	2.205117	2.479807	3.338096	3.800718	4.081414	4.201557
47.54324566	66.47	2.090278	2.234032	2.446014	2.754448	2.895821	2.944392	2.168689	2.3567	2.747022	3.130968	3.535874	3.754844	2.472019	2.698146	2.855612	2.986494	3.093543	3.151425	2.600465	2.798615	2.968854	3.106182	3.212316	3.27652	2.76916	3.015938	3.797681	4.21659	4.459119	4.558457
73.81269011	70.00	2.354032	2.586453	2.950026	3.462142	3.676162	3.744838	2.477968	2.796385	3.450535	3.973159	4.450554	4.689315	2.783931	3.148513	3.406358	3.615033	3.776015	3.858459	2.930598	3.245936	3.519196	3.731888	3.886987	3.971516	3.138558	3.527558	4.557586	4.985733	5.145443	5.199926
102.1097295	66.11	2.292041	2.52783	2.883584	3.376959	3.579634	3.648945	2.420534	2.732268	3.366832	3.902719	4.37772	4.567559	2.709747	3.072856	3.32855	3.52316	3.677552	3.760587	2.851959	3.167389	3.437155	3.634857	3.787786	3.878946	3.057723	3.445731	4.46891	4.811412	5.027488	5.106072
132.0930628	70.00	2.347826	2.533727	2.78507	3.145728	3.307674	3.36278	2.45059	2.680225	3.137195	3.57077	3.998575	4.200171	2.777885	3.042676	3.211615	3.350797	3.467745	3.531019	2.919621	3.147583	3.324519	3.466536	3.580668	3.649698	3.106122	3.370556	4.165143	4.542435	4.716389	4.787734
158.4606373	69.24	2.156904	2.296575	2.498459	2.784639	2.909144	2.950992	2.232942	2.414035	2.778016	3.110414	3.442521	3.613333	2.550055	2.763129	2.906441	3.020709	3.112003	3.160653	2.681691	2.866153	3.018279	3.135071	3.224545	3.27819	2.850253	3.072625	3.706512	4.022064	4.206412	4.278916
184.1030186	67.33	2.046308	2.208271	2.476967	2.891609	3.082264	3.147284	2.131037	2.361054	2.881561	3.383659	3.85767	4.079466	2.417205	2.676718	2.875569	3.047066	3.189458	3.265648	2.542014	2.767393	2.979771	3.157949	3.297741	3.379312	2.709302	3.001157	3.950373	4.368864	4.599419	4.690878
216.2838308	67.32	1.986822	2.096212	2.261426	2.50692	2.61969	2.659047	2.045961	2.191337	2.500955	2.810557	3.134766	3.31086	2.349711	2.522804	2.64698	2.750468	2.836084	2.882351	2.470626	2.622226	2.756206	2.864429	2.949843	3.001596	2.621921	2.813355	3.44843	3.795971	4.017661	4.108952
247.963211	66.27	2.052034	2.197454	2.404723	2.699352	2.830848	2.875148	2.131889	2.318275	2.692398	3.047438	3.43633	3.652627	2.427956	2.65477	2.808679	2.934802	3.037334	3.091672	2.554729	2.753619	2.920594	3.053025	3.154847	3.216078	2.722127	2.96806	3.73457	4.1505	4.405551	4.515409
273.0163297	67.97	2.254094	2.433471	2.691811	3.060302	3.223632	3.278801	2.351833	2.5834	3.05164	3.486714	3.955962	4.210839	2.664647	2.944083	3.131211	3.293625	3.420815	3.487744	2.80386	3.04881	3.252424	3.421953	3.546933	3.621488	2.99345	3.29323	4.22443	4.702789	4.978964	5.084115
297.9989394	67.77	2.320501	2.528374	2.828442	3.269095	3.466313	3.534281	2.434303	2.70288	3.258756	3.786955	4.263063	4.505194	2.746885	3.069098	3.289093	3.467011	3.611985	3.689808	2.892218	3.17358	3.410502	3.592441	3.734585	3.82005	3.094258	3.441008	4.418957	4.890604	5.150333	5.24623
324.3718586	65.80	2.074274	2.236041	2.492613	2.866551	3.030389	3.085562	2.160888	2.382807	2.85789	3.291796	3.739594	3.960568	2.452488	2.70661	2.885736	3.03536	3.160813	3.224979	2.580291	2.800131	2.988295	3.14291	3.265484	3.335628	2.751293	3.018673	3.877982	4.305313	4.547249	4.648829
351.4393931	67.57	2.029843	2.147998	2.33933	2.62635	2.759387	2.805591	2.092216	2.257544	2.619225	2.993966	3.425084	3.649116	2.393377	2.584888	2.725469	2.843879	2.941299	2.995008	2.51519	2.682285	2.832743	2.955386	3.051932	3.111595	2.669902	2.882494	3.617768	4.016496	4.250127	4.346061
375.7863841	62.61	2.064656	2.270595	2.567613	2.963618	3.132979	3.189997	2.177222	2.443626	2.954677	3.413375	3.853143	4.096657	2.43398	2.752835	2.967933	3.127283	3.258197	3.326413	2.561086	2.839516	3.066581	3.233356	3.364691	3.443011	2.745178	3.086966	3.993941	4.457109	4.72845	4.826808
402.8438212	69.58	2.222361	2.372808	2.58889	2.899175	3.039174	3.087004	2.30479	2.498507	2.891814	3.270574	3.677938	3.898459	2.628317	2.862895	3.021954	3.153355	3.260799	3.318207	2.764839	2.970281	3.142379	3.279689	3.386274	3.45041	2.943458	3.196289	3.991496	4.409283	4.659111	4.760157
430.0027277	64.54	2.063097	2.246913	2.518003	2.916941	3.095485	3.155873	2.16364	2.403573	2.907453	3.379813	3.882268	4.155216	2.437278	2.723818	2.927143	3.096215	3.233697	3.307111	2.564595	2.815118	3.035128	3.211685	3.348598	3.429403	2.742408	3.057757	4.055974	4.564185	4.853737	4.984098
457.3749499	65.00	2.054801	2.231008	2.491755	2.871085	3.041068	3.099036	2.150635	2.381834	2.862113	3.321979	3.82128	4.088646	2.431642	2.709475	2.904398	3.066308	3.197836	3.267988	2.560118	2.803712	3.01439	3.183967	3.314553	3.392984	2.738065	3.042828	4.019769	4.520644	4.794751	4.911424
488.5239521	64.11	2.026398	2.194323	2.435168	2.776745	2.929405	2.981124	2.118537	2.33452	2.768699	3.182539	3.636862	3.879519	2.397607	2.65995	2.839573	2.98695	3.106334	3.169935	2.523977	2.753986	2.948903	3.103797	3.222883	3.294275	2.697457	2.982801	3.87438	4.338775	4.617056	4.735858
520.0850632	65.00	2.060874	2.231193	2.47624	2.827758	2.984945	3.037856	2.154158	2.37356	2.819474	3.239261	3.690142	3.937371	2.440036	2.706414	2.889791	3.041021	3.163437	3.227734	2.568875	2.802642	3.001671	3.160412	3.281316	3.352978	2.745464	3.036483	3.930315	4.394801	4.651836	4.757216
545.9767298	65.00	1.94413	2.080187	2.296535	2.622033	2.771444	2.822847	2.0176	2.203711	2.6142	3.020682	3.465553	3.70679	2.298916	2.517517	2.680101	2.817557	2.930544	2.991397	2.418565	2.609601	2.784199	2.927901	3.040294	3.108054	2.576744	2.820064	3.660111	4.093214	4.343361	4.449029
570.5656911	61.73	1.939432	2.111959	2.361774	2.727932	2.893784	2.950438	2.033833	2.256183	2.719195	3.167567	3.649733	3.913031	2.292122	2.56042	2.746212	2.899193	3.027289	3.096027	2.412499	2.647622	2.848111	3.007986	3.135115	3.211923	2.580724	2.8728	3.816482	4.314505	4.584792	4.691704
594.9824277	60.04	1.762092	1.951113	2.259111	2.724645	2.928532	2.995786	1.861785	2.127131	2.713934	3.252926	3.806501	4.082193	2.075894	2.376472	2.605786	2.798366	2.954788	3.034976	2.183815	2.444832	2.688773	2.888246	3.042825	3.132431	2.341686	2.678846	3.780915	4.294772	4.579843	4.691149
621.7126711	65.73	2.264457	2.482803	2.79428	3.244415	3.437597	3.500486	2.383554	2.663956	3.233688	3.745854	4.272746	4.50986	2.651595	2.965457	3.18953	3.375032	3.521271	3.597126	2.781449	3.049634	3.289233	3.480279	3.621562	3.705391	2.95947	3.296021	4.337347	4.783619	4.987299	5.056408
651.0932266	70.00	2.207008	2.364445	2.625474	3.047864	3.244113	3.309448	2.290642	2.512312	3.037497	3.548105	4.055404	4.294648	2.612079	2.864633	3.056506	3.225414	3.367742	3.441847	2.748428	2.967353	3.171096	3.343919	3.480308	3.558107	2.927976	3.20615	4.150439	4.568031	4.781063	4.867386
680.4932266	70.00	2.228914	2.397058	2.708623	3.184889	3.396539	3.467231	2.315201	2.574163	3.173377	3.731974	4.243954	4.459055	2.634585	2.901887	3.117947	3.297666	3.449412	3.532613	2.770555	2.993883	3.218646	3.401577	3.548274	3.63808	2.946317	3.234717	4.246843	4.626768	4.821825	4.881677
705.8487822	70.00	2.329888	2.537466	2.867462	3.35139	3.565778	3.635636	2.440429	2.726185	3.340278	3.88278	4.411387	4.671688	2.754373	3.082837	3.318882	3.517883	3.679728	3.763772	2.898642	3.183088	3.433962	3.639878	3.797753	3.888007	3.098334	3.451955	4.534233	4.986491	5.222704	5.298695
731.2043377	70.00	2.284164	2.484598	2.803799	3.258441	3.452443	3.518055	2.390149	2.669506	3.248003	3.753176	4.179928	4.374869	2.704574	3.012025	3.230694	3.404656	3.54444	3.619025	2.846981	3.108048	3.336097	3.51203	3.646442	3.727096	3.038119	3.356212	4.239744	4.595235	4.778313	4.854899
757.4348933	70.00	2.385036	2.697033	3.123744	3.654337	3.856984	3.922711	2.553742	2.9487	3.643048	4.148904	4.505531	4.682271	2.815138	3.229362	3.501575	3.713233	3.863515	3.941147	2.952294	3.300834	3.585146	3.79741	3.940424	4.024415	3.15426	3.56258	4.5232	4.853106	4.97694	5.011101
783.6848933	70.00	2.314807	2.516069	2.813299	3.245658	3.429603	3.487207	2.423802	2.685149	3.234894	3.726103	4.200188	4.420614	2.738892	3.008235	3.20608	3.374337	3.509659	3.577226	2.877278	3.099258	3.303366	3.472601	3.601818	3.680702	3.05353	3.323036	4.250079	4.630407	4.83563	4.917737
812.4837147	67.19	2.389457	2.738919	3.293413	3.892947	4.107061	4.175521	2.571063	3.062412	3.88091	4.426411	4.855215	5.004227	2.827885	3.383858	3.729223	3.948443	4.113276	4.196428	2.98196	3.462742	3.81583	4.03702	4.195159	4.285001	3.226996	3.783941	4.848635	5.134207	5.243928	5.285931
841.2001212	67.00	1.998047	2.336097	2.80884	3.433909	3.687965	3.762492	2.18121	2.617757	3.419425	4.021345	4.401359	4.541171	2.367877	2.85799	3.175776	3.432398	3.630358	3.726255	2.497491	2.915412	3.251467	3.515451	3.703488	3.814009	2.711012	3.201459	4.40029	4.686971	4.817892	4.874523
869.1723347	62.59	2.065452	2.369851	2.827557	3.39074	3.601078	3.668128	2.228573	2.636062	3.378471	3.894836	4.336631	4.555973	2.449178	2.924308	3.218634	3.437076	3.595044	3.674111	2.585358	2.995586	3.303248	3.523797	3.673655	3.754649	2.805031	3.27499	4.299883	4.71453	4.906387	4.978026
898.0704541	64.66	2.098071	2.329495	2.709385	3.243242	3.471818	3.544725	2.219927	2.547236	3.230782	3.807015	4.328233	4.54086	2.482552	2.849167	3.114681	3.328964	3.499248	3.586903	2.614878	2.930561	3.209654	3.430421	3.593276	3.68545	2.807545	3.199843	4.326841	4.700146	4.879623	4.944698
923.6041342	63.53	1.969469	2.138033	2.408579	2.820683	3.008075	3.070242	2.05979	2.292178	2.810788	3.313118	3.837257	4.108387	2.330367	2.600419	2.804648	2.977808	3.118082	3.192122	2.453294	2.688622	2.908054	3.088639	3.225891	3.307324	2.622716	2.925989	3.926492	4.413649	4.666079	4.782543
949.7349231	65.01	2.139289	2.374667	2.737123	3.261366	3.484984	3.557783	2.265872	2.58522	3.248885	3.811636	4.322349	4.570124	2.529975	2.900612	3.158883	3.378961	3.544741	3.631481	2.665098	2.987399	3.265191	3.487923	3.648688	3.743837	2.864893	3.261825	4.358718	4.810625	5.015217	5.103048
979.2124109	63.58	2.086107	2.361825	2.77522	3.317509	3.521732	3.585128	2.235511	2.603	3.306303	3.81964	4.264414	4.483628	2.46119	2.880939	3.161616	3.385519	3.54835	3.626404	2.590497	2.952283	3.251072	3.476915	3.629576	3.717296	2.791104	3.22704	4.289312	4.689787	4.887219	4.940673
1005.062658	55.79	1.58524	1.774401	2.080536	2.538919	2.741067	2.809267	1.684535	1.950414	2.527957	3.069182	3.668415	3.984061	1.873879	2.180875	2.412978	2.608844	2.767431	2.851871	1.974327	2.242541	2.493965	2.698239	2.855793	2.948561	2.126496	2.476084	3.641797	4.239388	4.578991	4.715067
1029.441933	60.86	1.992374	2.210111	2.55247	3.04765	3.256817	3.3265	2.108202	2.407088	3.036423	3.5891	4.112796	4.370996	2.352891	2.700135	2.951509	3.156873	3.318486	3.40354	2.477503	2.780412	3.049569	3.26008	3.419553	3.512221	2.661756	3.044849	4.162338	4.648309	4.897666	5.002507
1057.023291	68.86	2.371098	2.602023	2.963368	3.449627	3.654281	3.72095	2.494262	2.812758	3.438317	3.976545	4.484902	4.699243	2.806799	3.159049	3.393726	3.579456	3.728109	3.804787	2.956011	3.25451	3.494023	3.683074	3.825469	3.9081	3.166111	3.508502	4.495688	4.892988	5.096283	5.18133
1083.151056	67.86	2.203985	2.451648	2.820986	3.329329	3.540937	3.610377	2.336664	2.66641	3.318745	3.858942	4.290116	4.483174	2.601577	2.969307	3.22514	3.426803	3.583913	3.666054	2.737391	3.051337	3.323479	3.529385	3.678495	3.768565	2.934438	3.317351	4.33214	4.700174	4.897613	4.979533
1108.775848	66.56	2.202881	2.405696	2.739022	3.246778	3.469375	3.54438	2.311103	2.593344	3.234907	3.826127	4.33328	4.5583	2.604236	2.917791	3.155673	3.360002	3.526108	3.613242	2.740369	3.009822	3.257613	3.467079	3.628754	3.724409	2.929409	3.263561	4.347362	4.762039	4.971064	5.050374
1135.642308	58.87	1.703567	1.905626	2.247711	2.782235	3.017793	3.097827	1.810088	2.099187	2.769924	3.393662	3.98582	4.2568	2.01531	2.343496	2.602543	2.824607	3.006897	3.103737	2.123751	2.409173	2.686565	2.915758	3.096389	3.200372	2.287325	2.661462	3.91778	4.455908	4.744997	4.85788
1160.728419	55.00	1.539293	1.755683	2.099075	2.609924	2.835218	2.911021	1.654078	1.952919	2.59791	3.193885	3.791491	4.095471	1.821403	2.170358	2.428509	2.644178	2.818074	2.910441	1.92113	2.226631	2.505008	2.729135	2.9009	3.002974	2.080738	2.473145	3.711634	4.296848	4.622269	4.750138
1184.760364	55.00	1.640336	1.842713	2.146059	2.589129	2.780468	2.844985	1.749984	2.01795	2.578819	3.086069	3.574421	3.849174	1.940423	2.261411	2.488105	2.675129	2.82276	2.90043	2.045706	2.327064	2.572246	2.766292	2.910622	2.99661	2.208044	2.561414	3.591892	4.109239	4.419312	4.546599
1208.792308	55.00	1.596308	1.761511	2.0032	2.361349	2.52822	2.585672	1.686367	1.901281	2.35264	2.808101	3.300342	3.561251	1.886556	2.146516	2.326817	2.476103	2.598085	2.663595	1.98716	2.215203	2.40994	2.565687	2.685879	2.7584	2.134717	2.417881	3.331558	3.818623	4.112294	4.238543
1233.282586	55.00	1.631666	1.801532	2.055223	2.421998	2.587897	2.64481	1.724017	1.948239	2.413311	2.864865	3.366772	3.645405	1.92826	2.197965	2.38893	2.547583	2.67661	2.745539	2.030967	2.267472	2.474624	2.64159	2.770506	2.847975	2.181514	2.479717	3.455465	3.987344	4.317475	4.460997
1259.235521	58.25	1.711516	1.860507	2.079583	2.393485	2.534477	2.582812	1.792568	1.987735	2.386079	2.770298	3.202815	3.441372	2.023112	2.259015	2.423521	2.559356	2.669568	2.728475	2.129614	2.336779	2.515431	2.658299	2.76845	2.834513	2.278207	2.538036	3.366432	3.81288	4.084776	4.199204
1284.635405	68.14	2.111698	2.2443	2.435427	2.706208	2.827493	2.869065	2.184561	2.355806	2.69986	3.029768	3.396948	3.60448	2.495659	2.701756	2.841392	2.955763	3.048254	3.097729	2.624178	2.804422	2.955247	3.074546	3.166236	3.221597	2.789735	3.010876	3.70649	4.090653	4.335348	4.441807
1310.25843	68.74	2.19865	2.346407	2.558656	2.859031	2.993298	3.038871	2.279611	2.47005	2.851965	3.215728	3.624857	3.851556	2.601691	2.833797	2.992067	3.121562	3.225477	3.280132	2.737276	2.94113	3.113004	3.248938	3.351279	3.41232	2.914618	3.167507	3.935602	4.345977	4.5972	4.703226
1338.623251	64.51	2.032343	2.18259	2.400399	2.711014	2.852079	2.900518	2.114711	2.309186	2.703687	3.085247	3.501664	3.732996	2.400432	2.635983	2.797624	2.930623	3.038675	3.097159	2.52477	2.73126	2.906582	3.04593	3.153423	3.219092	2.691316	2.947504	3.757703	4.195568	4.464688	4.58107
1364.314296	58.46	1.797335	1.95674	2.195381	2.537947	2.693397	2.74686	1.883811	2.095507	2.529768	2.952635	3.419607	3.67771	2.121102	2.374815	2.553243	2.699846	2.819758	2.884105	2.231753	2.454405	2.647978	2.802107	2.921557	2.99378	2.387654	2.668065	3.574348	4.071028	4.373915	4.499789
1389.794157	55.19	1.570868	1.723592	1.947491	2.274365	2.421335	2.471699	1.654344	1.853074	2.266623	2.666166	3.098161	3.337231	1.856089	2.097416	2.265649	2.406433	2.521481	2.58304	1.954404	2.166489	2.348805	2.496795	2.611541	2.680685	2.096161	2.36112	3.219713	3.680219	3.962082	4.081853
1417.991646	61.08	1.923891	2.131689	2.453567	2.91302	3.117302	3.185388	2.034301	2.316398	2.902477	3.450075	4.031655	4.335759	2.272947	2.603654	2.844776	3.035012	3.193193	3.274427	2.3933	2.682314	2.941277	3.141581	3.295426	3.388008	2.570663	2.939842	4.074906	4.621769	4.902775	5.015107
1445.201368	55.00	1.578435	1.729436	1.953887	2.282118	2.435911	2.488724	1.660289	1.860054	2.274115	2.68836	3.138615	3.385252	1.8655	2.105742	2.273957	2.414288	2.529503	2.5917	1.964263	2.174908	2.357965	2.505714	2.620343	2.689701	2.105713	2.370766	3.236664	3.706107	3.980891	4.096243
1472.395812	55.00	1.559316	1.702921	1.913673	2.219413	2.357326	2.404506	1.637864	1.824808	2.2122	2.586704	3.002017	3.233879	1.842529	2.069524	2.228181	2.360388	2.468035	2.525544	1.939797	2.139231	2.311264	2.450353	2.557813	2.622452	2.077879	2.327503	3.141646	3.59091	3.865144	3.981554
1499.473761	57.78	1.764449	1.942955	2.213545	2.608278	2.784353	2.844809	1.860584	2.099296	2.599021	3.077213	3.593215	3.8679	2.086853	2.370451	2.57219	2.737702	2.872616	2.94458	2.197971	2.446355	2.663879	2.835878	2.969677	3.050174	2.358697	2.67144	3.669625	4.186101	4.467947	4.579606
1527.581452	59.95	1.774079	1.916075	2.123383	2.408328	2.535973	2.579779	1.851551	2.036416	2.40163	2.749095	3.115846	3.309236	2.095475	2.317875	2.46539	2.585776	2.684239	2.737047	2.204561	2.398831	2.557709	2.683714	2.781703	2.840837	2.353573	2.589174	3.321064	3.69626	3.918483	4.017485
1552.034736	62.13	1.924189	2.081056	2.307152	2.62579	2.765928	2.813775	2.010446	2.212841	2.618348	3.000329	3.419559	3.651286	2.271872	2.517607	2.685891	2.823149	2.933923	2.992895	2.389808	2.605533	2.788235	2.932356	3.042699	3.108811	2.551691	2.820038	3.650827	4.095877	4.367511	4.484003
1578.928767	68.37	2.250145	2.420376	2.669051	3.024793	3.185858	3.240281	2.342929	2.565415	3.016101	3.446586	3.895282	4.12996	2.658648	2.926216	3.109565	3.259063	3.381933	3.447568	2.796573	3.031163	3.229468	3.38569	3.507648	3.580184	2.982591	3.273354	4.159021	4.602236	4.860139	4.961891
1606.423211	70.00	2.249378	2.402614	2.623627	2.936795	3.076848	3.12505	2.333345	2.53128	2.929454	3.311159	3.729254	3.951135	2.66118	2.900615	3.064467	3.198681	3.306647	3.364138	2.799694	3.009398	3.186913	3.327439	3.434586	3.498709	2.981192	3.240764	4.042047	4.458965	4.712273	4.82076
1631.795497	64.60	2.081627	2.244667	2.480202	2.818244	2.97041	3.02255	2.171403	2.38139	2.810336	3.223792	3.67616	3.919452	2.457968	2.711384	2.885787	3.029465	3.145316	3.207255	2.585006	2.806955	2.995495	3.145671	3.260428	3.329357	2.756949	3.032435	3.895766	4.348821	4.604953	4.717634
1658.205321	68.35	2.235174	2.395653	2.63529	2.964231	3.11154	3.159988	2.327893	2.536149	2.955996	3.347594	3.788349	4.024981	2.636488	2.891654	3.05344	3.197623	3.315746	3.373271	2.766907	2.992345	3.167639	3.322501	3.435637	3.499611	2.947807	3.216619	4.056491	4.505784	4.770512	4.885305
1685.232371	69.90	2.231995	2.38048	2.5941	2.901207	3.041017	3.088813	2.313673	2.504798	2.893878	3.273675	3.688296	3.899553	2.639733	2.870699	3.029152	3.159435	3.265278	3.322032	2.776596	2.978744	3.150353	3.286735	3.391503	3.454522	2.95468	3.205168	3.986821	4.382981	4.632564	4.738312
1712.496758	69.07	2.210729	2.364092	2.583994	2.89464	3.033137	3.080557	2.294747	2.492256	2.887354	3.264205	3.680793	3.910272	2.616318	2.856811	3.020775	3.155139	3.26375	3.321571	2.752971	2.964096	3.142248	3.283517	3.391837	3.456662	2.932933	3.194805	4.009097	4.449817	4.716167	4.830705
1740.127314	70.00	2.243238	2.394513	2.611066	2.918278	3.055142	3.10193	2.326129	2.520787	2.911065	3.28152	3.686007	3.90985	2.653922	2.890313	3.0511	3.183006	3.28989	3.346894	2.791981	2.999282	3.17379	3.312161	3.418499	3.482312	2.972507	3.229028	4.025858	4.450417	4.706635	4.812658
1767.524536	70.00	2.237209	2.386568	2.600674	2.901993	3.037294	3.08355	2.319057	2.51138	2.894891	3.26147	3.664061	3.886908	2.646775	2.880437	3.039098	3.168905	3.274521	3.330808	2.784411	2.989356	3.161414	3.298058	3.403406	3.466484	2.964018	3.217332	4.008416	4.432418	4.687747	4.791864
1792.175328	62.98	2.054858	2.230584	2.47999	2.835403	2.993155	3.04677	2.151105	2.37705	2.826993	3.251279	3.691011	3.932228	2.421504	2.694456	2.878201	3.031199	3.154486	3.219623	2.546203	2.785386	2.984783	3.145212	3.267391	3.339991	2.719881	3.013777	3.901091	4.33847	4.572256	4.677422

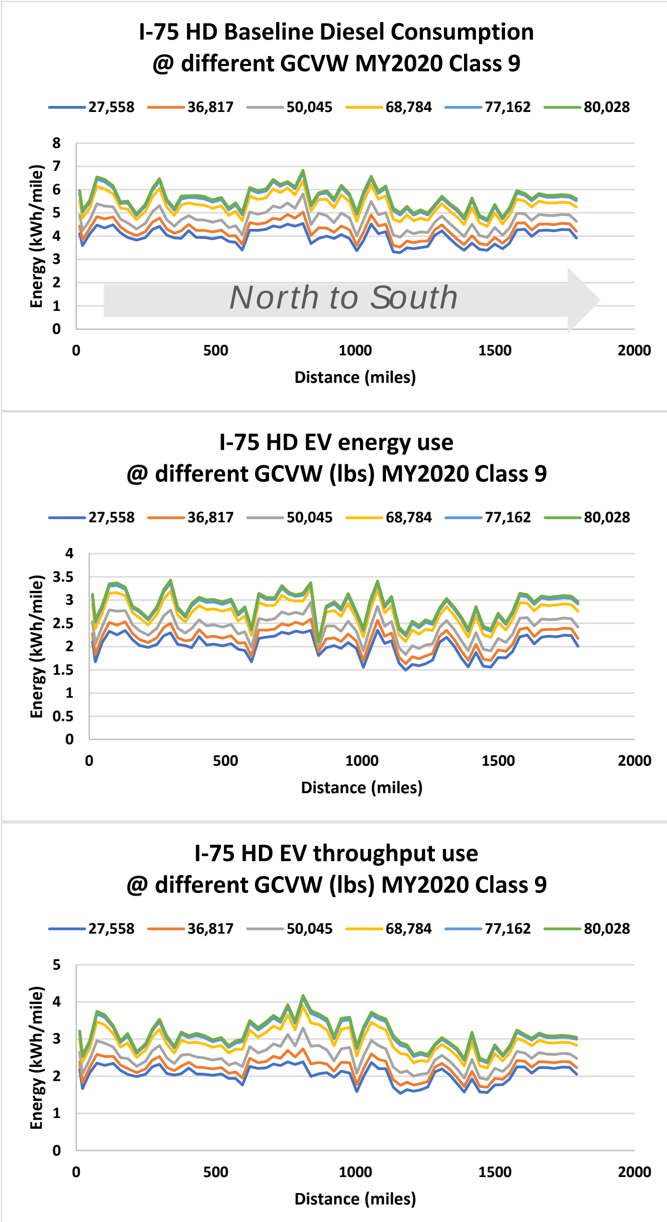


Figure 13. Sample of vehicle system energy consumption at different weights on I-75 roadway segments: MY2020 Class 9 vehicles N ➔S

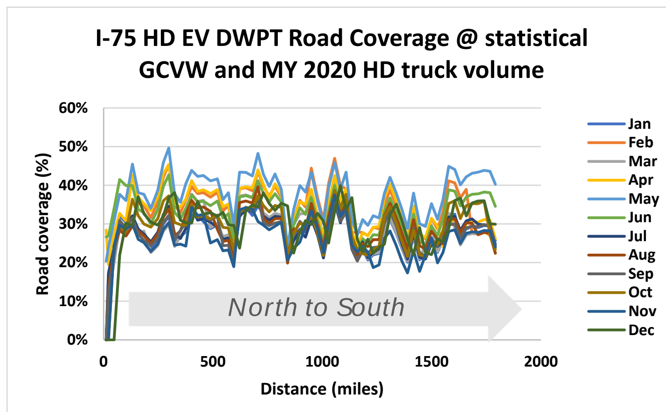
c. Roadway DWPT coil coverage requirements

Next, we assess the roadway coverage requirements using the results developed above. The specific roadway DWPT coil coverage at a given location may be determined based on the vehicle energy requirements to move through that road section, the power capability of the transmitting coils, the vehicle speed, the number of receiving coils on the vehicle and the DWPT transfer efficiency. This coverage requirements are directly computed based on the energy transfer by integrating the DWPT power transfer capacity over the duration that the vehicle's receiving coils will be above the roadway transmitting coils. The latter duration is determined from the vehicle speed and length of the coils. A simple construct of this is shown in Figure 14. Figure 15 shows the specific road coverage use-case of 200kW DWPT coils at the road to support a charge sustained solution for HD freight vehicles with four receiving coils, along the southbound route of the I-75 corridor. Due to the freight seasonal variations described earlier, we see some variation in the required road coverage for each month. In practice the largest value established for each mile along the corridor will be necessary to establish a functioning corridor. The impact of this will be discussed in the next sub-section. Figure 16 shows the impact of coverage for several alternative DWPT power capabilities for vehicles

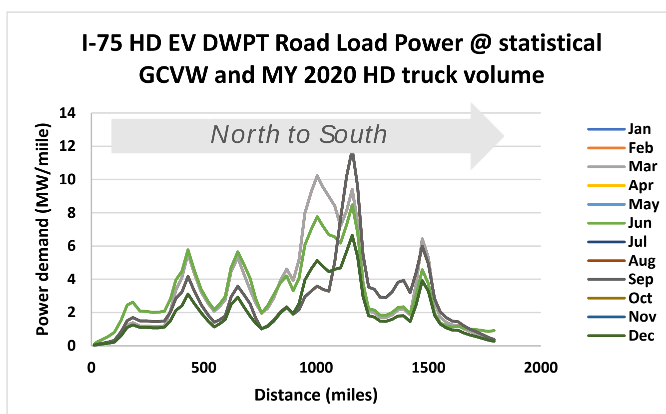
Speed Limit 65 mph | Number Veh coils 4 | Transfer effy 93%

Energy need (kWh/mi)	WPT power (kW) 50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500
0.25	9%	6%	4%	3%	3%	2%	2%	2%	2%	2%	1%	1%	1%	1%	1%	1%	1%	1%	1%
0.50	17%	12%	9%	7%	6%	5%	4%	4%	3%	3%	3%	3%	2%	2%	2%	2%	2%	2%	2%
0.75	26%	17%	13%	10%	9%	7%	7%	6%	5%	5%	4%	4%	4%	3%	3%	3%	3%	3%	3%
1.00	35%	23%	17%	14%	12%	10%	9%	8%	7%	6%	6%	5%	5%	5%	4%	4%	4%	4%	3%
1.25	44%	29%	22%	17%	15%	12%	11%	10%	9%	8%	7%	7%	6%	6%	5%	5%	5%	5%	4%
1.50	52%	35%	26%	21%	17%	15%	13%	12%	10%	10%	9%	8%	7%	7%	7%	6%	6%	6%	5%
1.75	61%	41%	31%	24%	20%	17%	15%	14%	12%	11%	10%	9%	9%	8%	8%	7%	7%	6%	6%
2.00	70%	47%	35%	28%	23%	20%	17%	16%	14%	13%	12%	11%	10%	9%	9%	8%	8%	7%	7%
2.25	79%	52%	39%	31%	26%	22%	20%	17%	16%	14%	13%	12%	11%	10%	10%	9%	9%	8%	8%
2.50	87%	58%	44%	35%	29%	25%	22%	19%	17%	16%	15%	13%	12%	12%	11%	10%	10%	9%	9%
2.75	96%	64%	48%	38%	32%	27%	24%	21%	19%	17%	16%	15%	14%	13%	12%	11%	11%	10%	10%
3.00	105%	70%	52%	42%	35%	30%	26%	23%	21%	19%	17%	16%	15%	14%	13%	12%	12%	11%	10%
3.25	114%	76%	57%	45%	38%	32%	28%	25%	23%	21%	19%	17%	16%	15%	14%	13%	13%	12%	11%
3.50	122%	82%	61%	49%	41%	35%	31%	27%	24%	22%	20%	19%	17%	16%	15%	14%	14%	13%	12%
3.75	131%	87%	66%	52%	44%	37%	33%	29%	26%	24%	22%	20%	19%	17%	16%	15%	15%	14%	13%
4.00	140%	93%	70%	56%	47%	40%	35%	31%	28%	25%	23%	22%	20%	19%	17%	16%	16%	15%	14%

Figure 14. Look up table for road coil coverage required based on DWPT power and vehicle energy needs given vehicle speed, number of vehicle receiver coils, and transfer efficiency.

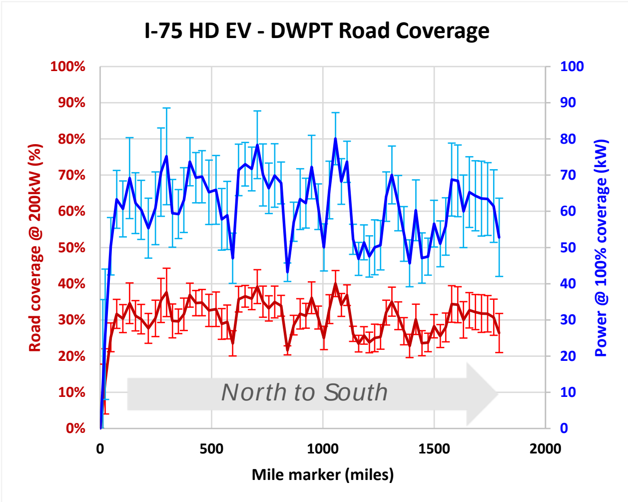


(a) Road coverage based on 200kW transmitter coils and 4 vehicle receiver coils

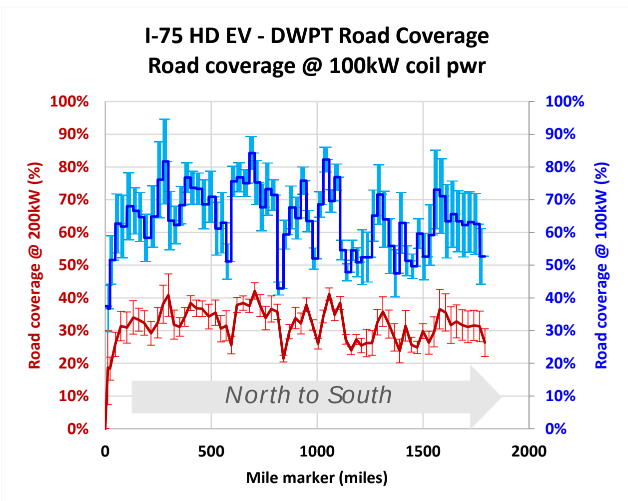


(b) Road power levels based on 100% adoption scenario (scales linearly based on adoption levels)

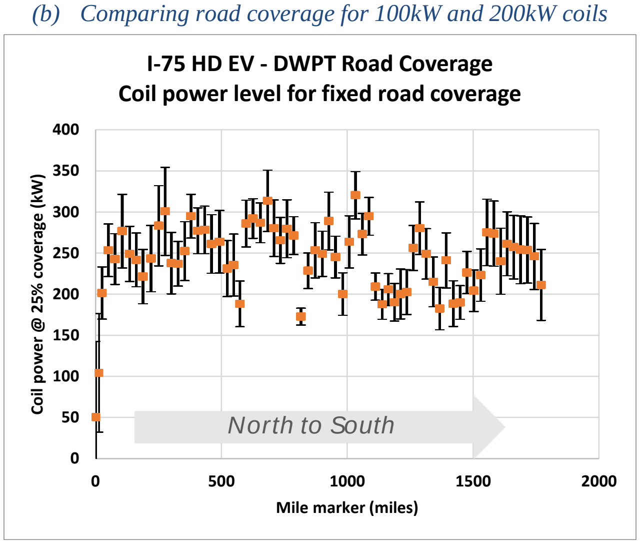
Figure 15. I-75 road coil coverage and worst-case peak demand



(a) Road coverage scenarios given 4 vehicle receiver coils



(b) Comparing road coverage for 100kW and 200kW coils



(c) Road coil power at 25% road coverage

Figure 16. Charge sustaining road coverage requirements for vehicles with 4 receiver coils

with four receiving coils. This effectively demonstrates a wide possible space of solutions that would be capable to maintaining a charge sustained transport solution of the freight vehicles. Further variations are possible as the number of receiving coils are changed in each vehicle. Thus, a complex search space based on DWPT power transfer capabilities, number of vehicle receiving coils, and the degree to which the onboard battery charge is sustained, may be generated. The full range of this optimization is beyond the scope of this paper and will be discussed in a future publication.

d. Grid capacity and infrastructure constraints

Providing reliable energy is a tremendously difficult technical challenge, even on the most ordinary of days. It involves monitoring, regulating, and coordinating the generation of power at thousands of generators in real-time, transferring electricity via a network of connected transmission lines, and then distributing electricity to millions of clients via a distribution network. As shown in Figure 17, generators fueled by a range of fuel sources, such as nuclear, coal, oil, natural gas, hydropower, geothermal, solar, and others, produce electricity at lower voltages (10,000 to 25,000 volts). Others are owned by independent power producers and customers, notably large industrial users. Some generators are owned by the same electric utilities that provide service to the end-use customer. The voltage of generator electricity is "stepped up" before being sent in large quantities across transmission lines. Power can be transported affordably over long distances thanks to high voltage transmission lines (i.e., 230,000 to 765,000 volts), which also reduce electricity losses brought on by conductor heating. At switching stations and substations, transmission lines are connected to create the power grid network. Before being distributed to customers, power is "stepped down" to lower voltages when it arrives at a load center. Due to the simplicity and low cost of converting voltages in AC systems from one level to another, the bulk power system is primarily an alternating current (AC) system rather than a direct current (DC) system. Most residential customers receive their electrical service at 120 and 240 volts, however some larger industrial and commercial clients receive service at intermediate voltage levels (12,000 to 115,000 volts) [37].

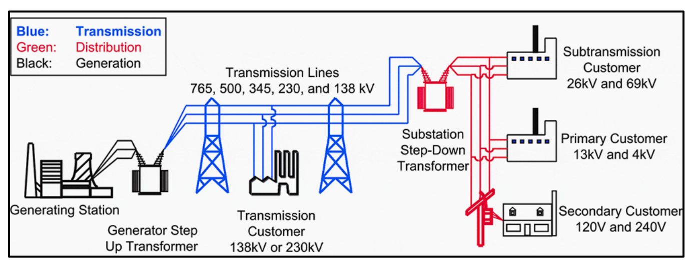


Figure 17. Diagram of an electrical power system [37]

The interconnected grid network will form a critical backbone for the sustainable deployment of any DWPT system for freight transport. Transmission substations integrate transmission lines into a network with multiple parallel interconnections, so that power can flow freely over long distances from any generator to any consumer. Typically, transmission lines operate at voltages above 138 kV. Transmission substations often include transformation from one transmission voltage level to another. Sub-transmission substations typically operate at 33 kV through 138 kV voltage levels. This kind of substations transform the high voltages used for efficient long-distance transmission. Distribution substations typically operate at 11KV/0.4KV voltage levels and deliver electric energy directly to industrial and residential consumers [38]. Typical distribution level substations may not be designed to support the additional roadway load requirements as shown in Figure 15. However, transmission and sub-transmission level substations are typical designed for additional system loads and may have the necessary margin to support the road loads for DWPT HD truck freight transport. In addition, typical guidance for the length of radial power feeder main lines from substations is 2 to 15 miles. When one includes lateral power lines, the recommended range is 4 to 25 miles [38].

For this study, all transmission and sub-transmission level within 15 miles of the I-75 corridor have been identified (see Figure 18 and Figure 19). In addition, the maximum peak demand and maximum capacity for all transmission and sub-transmission level substations have been identified. This provides an upper limit on the excess capacity at each substation (see Figure 18).

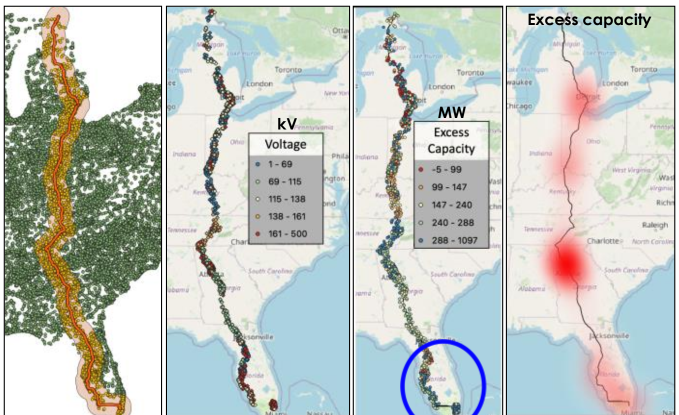


Figure 18. 2509 transmission substations and their excess capacity limits (from max peak demand) identified within 15 miles of I-75

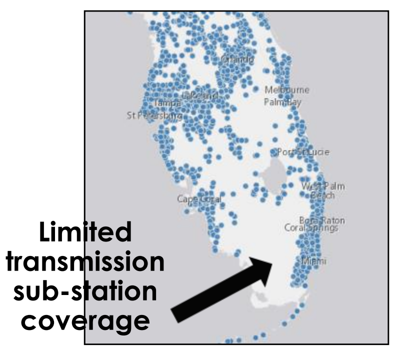
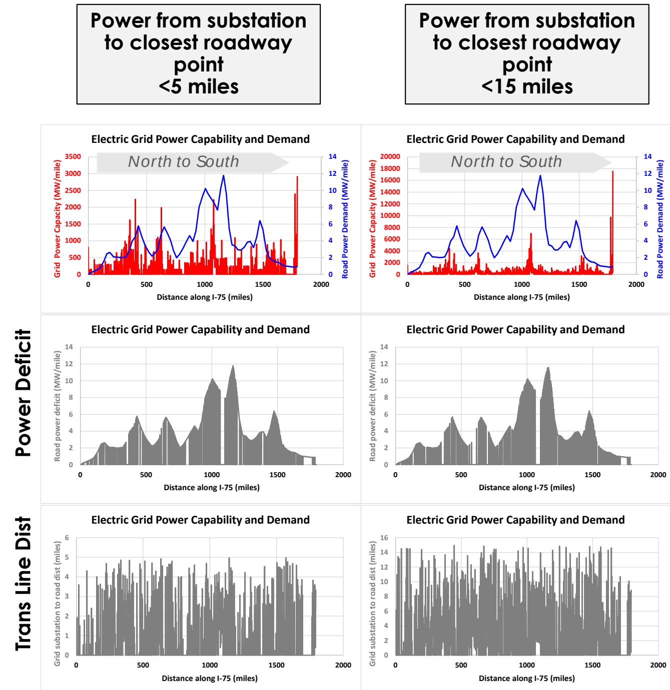
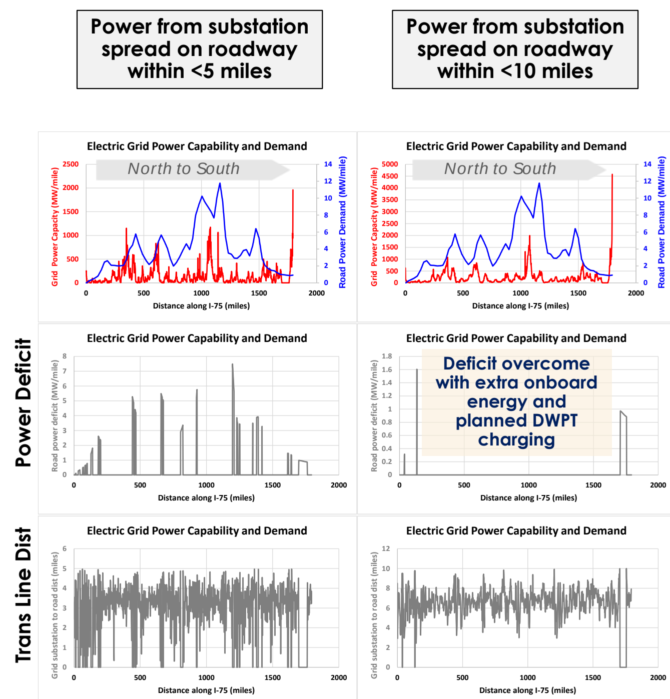


Figure 19. Close up view of southern Florida electrical substation shows limited coverage based on lower population demands

With this information it is now possible to establish the capability of providing road power to support DWPT HD freight transport. As a first consideration, we consider the road load power deficit if one were to only connect substations (and their excess power capacity) to the nearest mile on the I-75 corridor. This is seen in Figure 20a, for all substations within 5 miles and within 15 miles of the I-75 corridor. While there is significant excess capacity available, we still observe an overall power deficit through most of the I-75 corridor, as the available power is concentrated only at the nearest mile of the road to the substation. On the other hand, if this excess power is uniformly distributed along sub-stretches of the road, then this power deficit may be rapidly overcome, as seen in Figure 20b. The process of distributing



(a) Power deficit when power from a given substation is only provided to nearest roadway point



(b) Power deficit when power from a given substation is spread along the road for prescribed number of miles from the nearest roadway point

Figure 20. Assessing road coil power deficit (from transmission

substations near the I-75 corridor) given max peak demand

this power capacity is achieved linearly in this study. For example, if the nearest point to a substation on the roadway has a 100MW power capacity (per Figure 20a) then this power may be split uniformly along 5 miles of the roadway such that each of those roadway miles has 20MW capacity. It is possible to sufficiently spread the excess power available while meeting the feeder line constraints of 15 miles such that the entire I-75 corridor will have no power deficit to support DWPT HD truck freight transport (Figure 20b). Planned future work will explore optimization of this layout so that the overall cost of the infrastructure is minimized, while also building in redundancy to mitigate the impact of power failure incidents from any substation.

e. Electrified roadway economics

There are several new components that will be required in standing up the DWPT electrical grid interface and infrastructure. The basic concept is shown in Figure 21. Each lane of the road that is equipped with DWPT coils will require similar transmission substation to road power infrastructure. This system has been subdivided into three major subsystems to model the costs of this equipment and installation effort:

- Substation transformer and feeder line to road costs – shown for the I-75 corridor in Figure 22. The transformer equipment costs are based on the transformer power levels given the substation capacity and specific road point power demand [39,40]. Feeder line costs have been estimated at ~$285,000 / mile [37,39,40,41]. An aggregated value of $416,853/mi is used in the study (including equipment and labor).
- Road shoulder electrical equipment cost – the DWPT scenario used in this analysis is based on a distribution feeder serving an interstate DWPT system that consists of:
  - feeder on each side of the interstate cover 4 miles of the road
  - Serving twelve (12) 800 V inverters per mile (48 per feeder) with 25 kV : 800 V pad-mounted transformers, with
  - Necessary switches, cabinets, connectors, poles/risers, elbows, etc.
  - An aggregated value of $240,161/mi is used in this study (including equipment and labor).
- Road DWPT coils and installation costs – the effort and cost to install the DWPT coils will include the tear up of the roads and the base coil costs. These are estimated at $85,000 / mile and $6/kW x road coverage respectively [33,34,42].

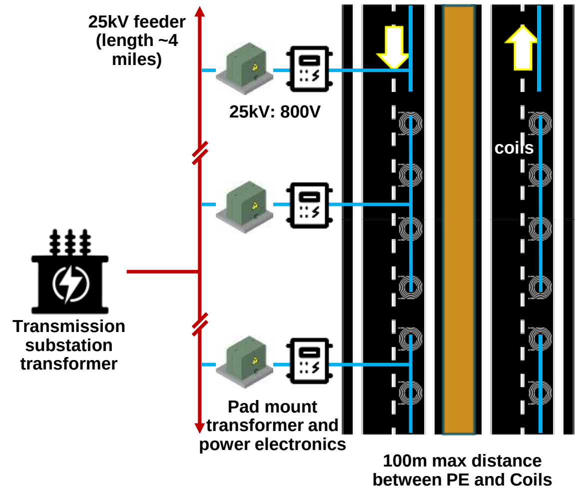


Figure 21. Transmission substation to road coil distribution infrastructure for DWPT system

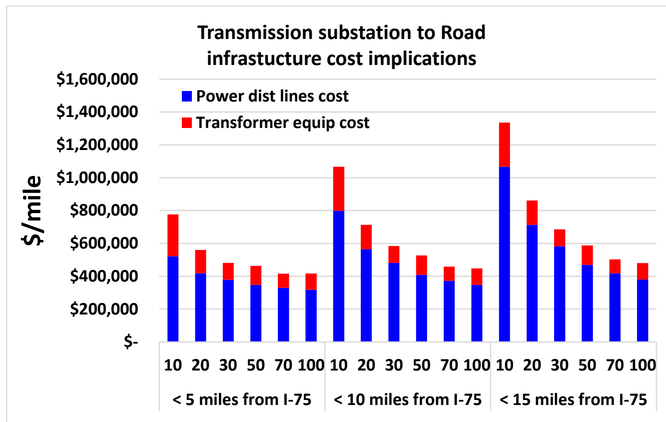


Figure 22. Infrastructure costs to establish transformers and power lines from transmission substation to I-75 road shoulder

Discussions – Technoeconomic assessments

In this section we will develop and discuss the vehicle end-user TCO (limited to CapEx and Fuel OpEx) for the various viable architecture options including both vehicle and roadway architectures. Using the methods and models described above a technoeconomic study is now conducted to gain a macroscopic understanding of the alternatives and tradeoffs in the vehicle and infrastructure architecture for the I-75 DWPT system to support HD truck freight transport.. Several critical assumptions have been made:

- It assumed that a vehicle would use the energy stored onboard in the vehicle battery to propel itself when not operating on electrified roadways. While the vehicle is operating on the electrified roadway, the energy available from the onboard battery is augmented with energy available from the road. This may allow for onboard battery SOC management (ranging from no depletion to any prescribed depletion level). We explicitly consider 0 kWh/mi depletion (charge sustaining) and 0.3 kWh/mi depletion (representing the energy usage expected from a full-size Class 1 BEV SUV).
- The results presented here are limited to DWPT transmitter coils

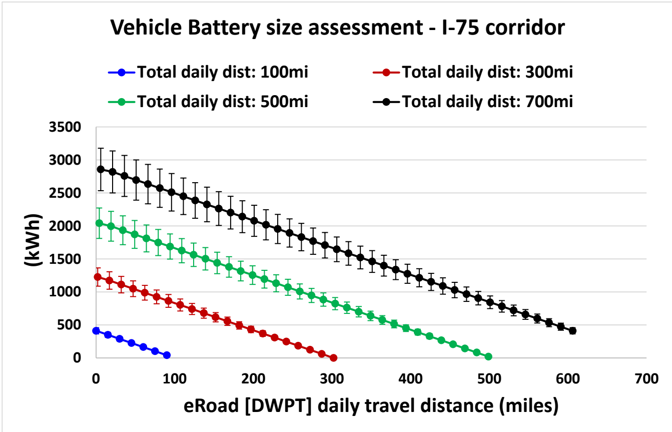
capable of 200kW with 93% transfer efficiency (given current technology demonstrations occurring within the U.S. Department of Energy Vehicle Technologies Office) with 4 receiver coils on the vehicle but several other settings have been explored. Receiver coils on the vehicle cost $6/kW [33,34].

- For this paper the vehicle is limited to MY2020 setting and travel is restricted to the southbound lanes.
- Onboard energy storage is limited to NMC and LTO battery chemistries, with vehicle operational life limited to 6 years (comprising of 5.5 operating days per week).
- Three technology adoption scenarios are explores including 10%, 50%, and 100% electrified roadway and vehicle adoption for the I-75 corridor.
- The baseline diesel vehicle engine, transmission, and associated powertrain components cost are $28,350 with diesel fuel price at $4-$6/gallon. The associated BEV powertrain and accessories component costs (excluding the battery pack system) are set at $22,900 based on 21CTP technology roadmap considerations [33,34]. The price of electricity obtained at offsite charging depots is set at the national average of $0.07/kWh for all HD freight trucks operating under this study. A 30% OEM sales margin is applied to all costs.
- End of life residual battery equipment has a non-zero value established as 35% of the battery pack system which includes housings/insulation, sensors, plumbing, controller boards, valves, and safety devices, as these are considered reusable. Further, a 30% valuation is placed on any residual battery SOH exceeding 70% as this would result in further use of the battery in the primary application (prior to any second life usage).
- Variations in vehicle class, freight weight, and truck count given month of year, based on the statistics described earlier are applied to all analysis shown here. Any added weight due to batteries and the DWPT charging coils is checked to determine if an additional vehicle trip will be necessary to transport the original freight.
- The roadway infrastructure has an assumed life of 15 years with service intervals of 3 years. During the service periods an expense of 4.5% of the installation price is assumed [33,34,42]. Residual of value of the roadway infrastructure at the end of life is variably set between 50% and 75% given that most of the components may be recycled, repurposed, or remanufactured [38,39,40,41,42].
- Electricity infrastructure at the road may be amortized through the additive price of electricity pulled from roadway. We consider four settings here:
    - No amortization
    - Only infrastructure cost is recovered
    - Infrastructure cost and IRR of 5% is recovered
    - Infrastructure cost and IRR of 10% is recovered

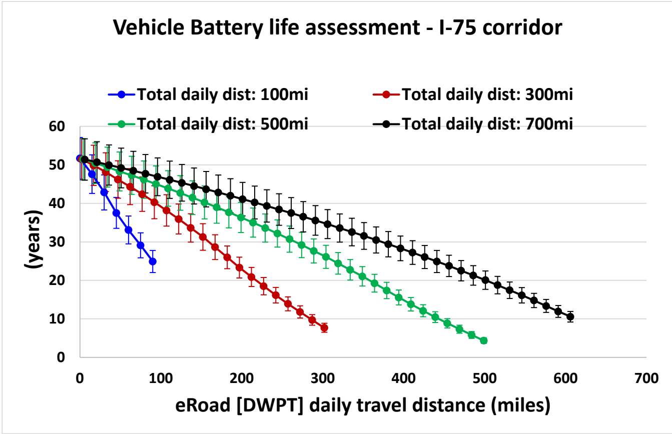
We will consider four scenarios of operation as indicated in Figure 23 and Figure 24, namely the trucks may operate 100-, 300-, 500-, and 700-mile per day missions where parts of those may be on an electrified roadway. These two figures show one specific technoeconomic assessment of LTO and NMC battery chemistries. In both cases the battery is charge sustained while operating on the electrified roadway. The battery is sized for the energy requirements for non-electrified roadway operations, while also holding charge for travel from DWPT transmitter coil to the next. Battery C-rates are monitored to mitigate safety violations. The scenario also assumes 10% electrified vehicle technology adoption and the electrified roadway equipment is not amortized though added cost of electricity.

It is notable that the NMC battery lifetime chemistry durability is significantly lower than the LTO battery chemistry durability. This is manifested in battery replacement cycles that result in increased ownership costs as shown in the "bumps" in Figure 24c. The diesel powertrain cost does not change across these views. By assessing a multitude of scenarios like these it is possible to determine when the DWPT architecture provides a CapEx + Fuel OpEx superior solution to the diesel powertrain (see Figure 25 and Figure 26) as well as the battery only solution (where the battery is sized for the full daily mission with no opportunity to capture energy through electrified roadway systems)(see Figure 27 and Figure 28).

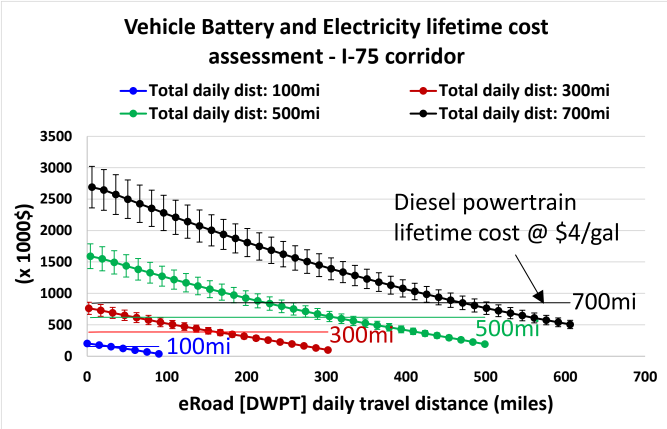
From Figure 25 and Figure 26, it is evident that as the adoption increases the opportunity for DWPT vehicle and roadway technologies to provide a superior CapEx and Fuel OpEx solutions as compared with diesel powertrains increases. NMC solutions are largely better than LTO chemistry solutions in achieving this performance (even with mid life cycle replacement costs). It is also observed that a charge depletion architecture while operating on the electrified roadway under performs the charge sustaining solution. From Figure 27 and Figure 28 it is further evident that the NMC solution outperforms the LTO solution when comparing battery only solutions against battery with DWPT architectures. In these figures we show the specific milage when the DWPT architecture outperforms the battery only solution.



(a) Battery pack size assessment

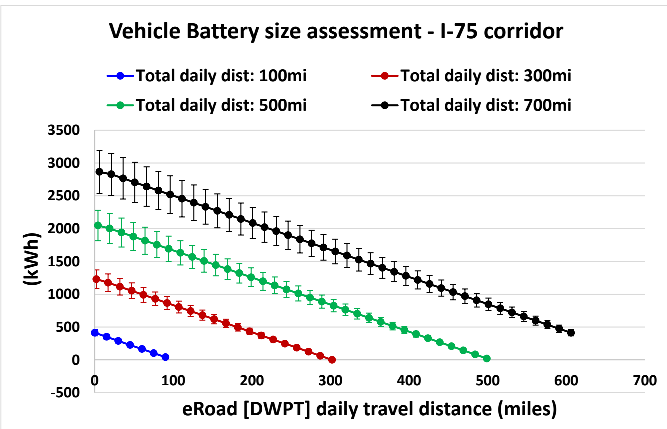


(b) Battery pack useful life assessment

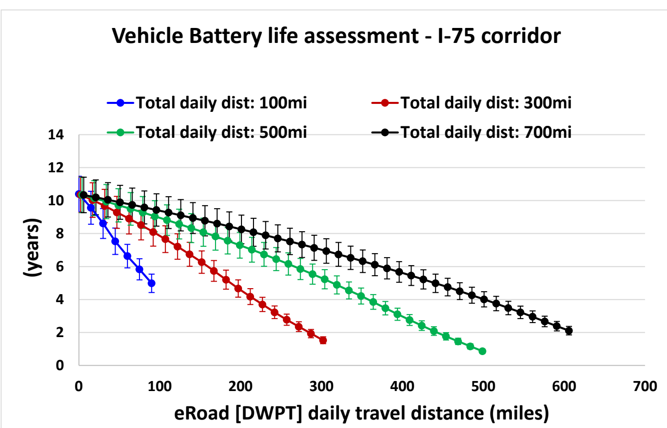


(c) Lifetime (six years) CapEx and OpEx costs

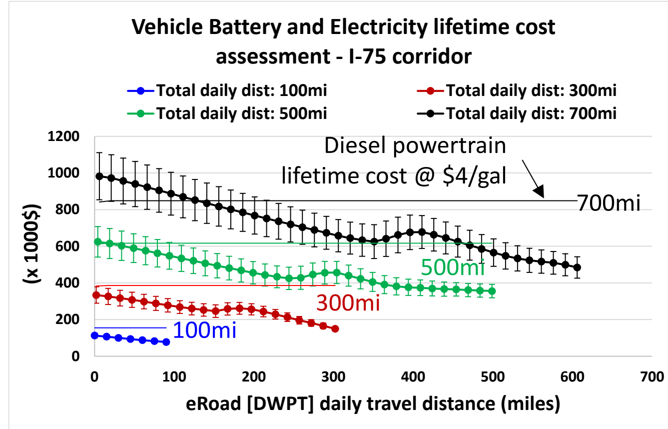
Figure 23. Technoeconomic impact of LTO chemistry battery packs on vehicle architecture considering variations in location and weight along I-75 corridor. Scenario – 10% adoption, charge sustaining, no roadway electrification infrastructure amortization.



(a) Battery pack size assessment

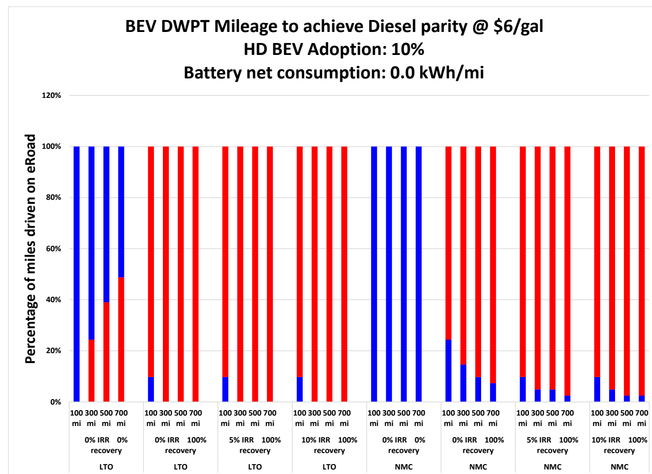


(b) Battery pack useful life assessment

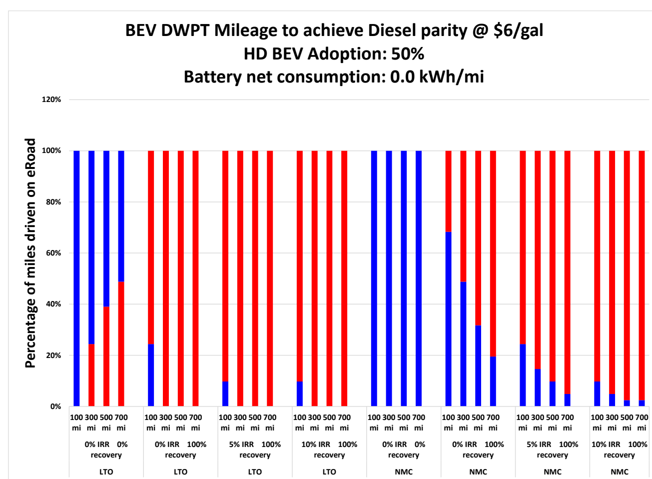


(c) Lifetime (six years) CapEx and OpEx costs

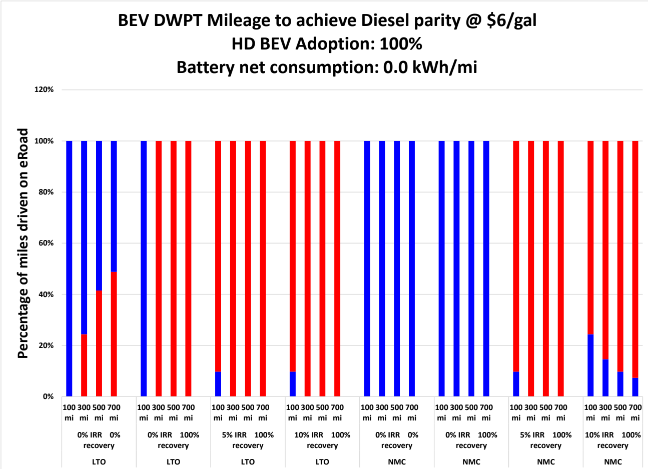
Figure 24. Technoeconomic impact of NMC chemistry battery packs on vehicle architecture considering variations in location and weight along I-75 corridor. Scenario – 10% adoption, charge sustaining, no roadway electrification infrastructure amortization.



(a) BEV adoption at 10%

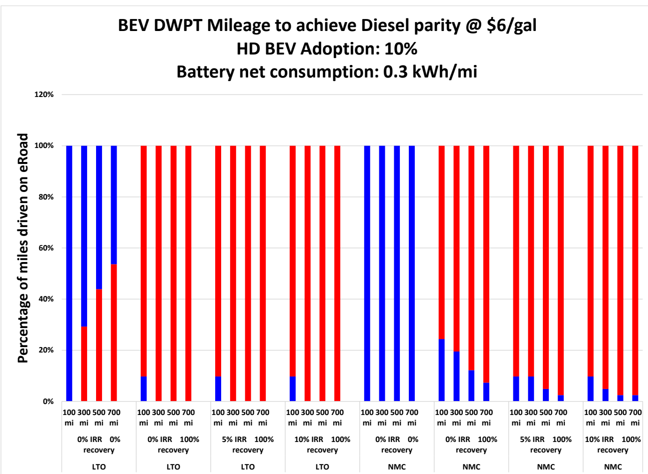


(b) BEV adoption at 50%

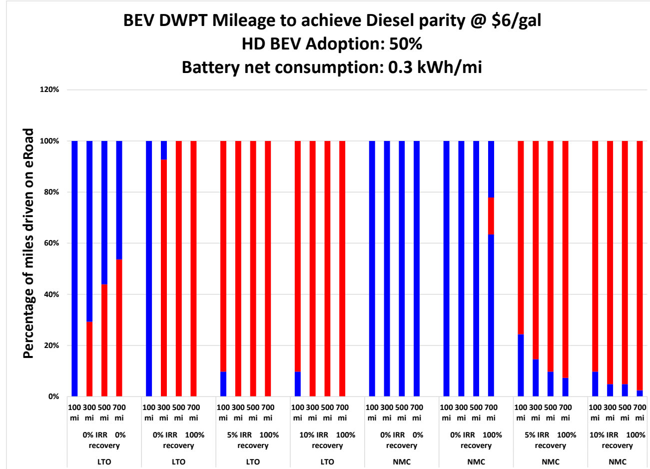


(c) BEV adoption at 100%

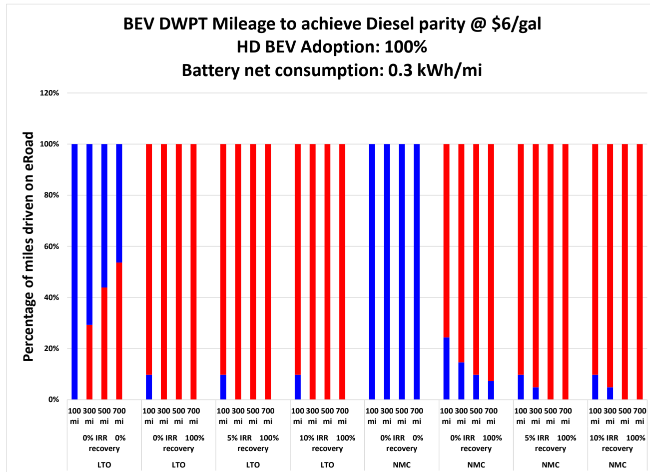
Figure 25. DWPT mileage to achieve diesel cost parity with diesel prices at $6/gallon assuming on-board battery charge sustaining (RED – diesel system provides superior lifetime cost compared to DWPT; BLUE – DWPT system provides superior lifetime cost compared to diesel system)



(a) BEV adoption at 10%



(b) BEV adoption at 50%



(c) BEV adoption at 100%

Figure 26. DWPT mileage to achieve diesel cost parity with diesel prices at $6/gallon assuming on-board battery charge depletion at 0.3kWh/mi (RED – diesel system provides superior lifetime cost compared to DWPT; BLUE – DWPT system provides superior lifetime cost compared to diesel system)

Referenced to Self			Battery usage 0.0 kWh/mi			Battery usage 0.3 kWh/mi		
			Adoption: 10%	Adoption: 50%	Adoption: 100%	Adoption: 10%	Adoption: 50%	Adoption: 100%
LTO	0% IRR 0% recovery	100 mi	0 ⇨ 100	0 ⇨ 100	0 ⇨ 100	0 ⇨ 100	0 ⇨ 100	0 ⇨ 100
		300 mi	0 ⇨ 300	0 ⇨ 300	0 ⇨ 300	0 ⇨ 300	0 ⇨ 300	0 ⇨ 300
		500 mi	0 ⇨ 500	0 ⇨ 500	0 ⇨ 500	0 ⇨ 500	0 ⇨ 500	0 ⇨ 500
		700 mi	0 ⇨ 700	0 ⇨ 700	0 ⇨ 700	0 ⇨ 700	0 ⇨ 700	0 ⇨ 700
LTO	0% IRR 100% recovery	100 mi	0 ⇨ 0	0 ⇨ 15	0 ⇨ 100	0 ⇨ 0	0 ⇨ 100	0 ⇨ 0
		300 mi	0 ⇨ 15	0 ⇨ 45	0 ⇨ 300	0 ⇨ 30	0 ⇨ 300	0 ⇨ 0
		500 mi	0 ⇨ 45	0 ⇨ 105	0 ⇨ 500	0 ⇨ 60	0 ⇨ 500	0 ⇨ 0
		700 mi	0 ⇨ 75	0 ⇨ 195	0 ⇨ 700	0 ⇨ 90	0 ⇨ 700	0 ⇨ 0
LTO	5% IRR 100% recovery	100 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0
		300 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 15	0 ⇨ 0	0 ⇨ 15	0 ⇨ 0
		500 mi	0 ⇨ 15	0 ⇨ 15	0 ⇨ 30	0 ⇨ 15	0 ⇨ 15	0 ⇨ 0
		700 mi	0 ⇨ 15	0 ⇨ 15	0 ⇨ 45	0 ⇨ 15	0 ⇨ 30	0 ⇨ 0
LTO	10% IRR 100% recovery	100 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0
		300 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0
		500 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0
		700 mi	0 ⇨ 15	0 ⇨ 15	0 ⇨ 0	0 ⇨ 15	0 ⇨ 15	0 ⇨ 0
NMC	0% IRR 0% recovery	100 mi	0 ⇨ 100	0 ⇨ 100	0 ⇨ 100	0 ⇨ 100	0 ⇨ 100	0 ⇨ 100
		300 mi	0 ⇨ 300	0 ⇨ 300	0 ⇨ 300	0 ⇨ 300	0 ⇨ 300	0 ⇨ 300
		500 mi	0 ⇨ 500	0 ⇨ 500	0 ⇨ 500	0 ⇨ 500	0 ⇨ 500	0 ⇨ 500
		700 mi	0 ⇨ 700	0 ⇨ 700	0 ⇨ 700	0 ⇨ 700	0 ⇨ 700	0 ⇨ 700
NMC	0% IRR 100% recovery	100 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 100	0 ⇨ 0	0 ⇨ 15	0 ⇨ 0
		300 mi	0 ⇨ 0	0 ⇨ 15	0 ⇨ 300	0 ⇨ 0	0 ⇨ 60	0 ⇨ 0
		500 mi	0 ⇨ 15	0 ⇨ 45	0 ⇨ 500	0 ⇨ 15	0 ⇨ 165	0 ⇨ 15
		700 mi	0 ⇨ 15	0 ⇨ 60	0 ⇨ 700	0 ⇨ 15	0 ⇨ 345	0 ⇨ 15
NMC	5% IRR 100% recovery	100 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0
		300 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0
		500 mi	0 ⇨ 0	0 ⇨ 15	0 ⇨ 0	0 ⇨ 0	0 ⇨ 15	0 ⇨ 0
		700 mi	0 ⇨ 0	0 ⇨ 15	0 ⇨ 0	0 ⇨ 15	0 ⇨ 15	0 ⇨ 0
NMC	10% IRR 100% recovery	100 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0
		300 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0
		500 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 15	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0
		700 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 15	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0

Figure 27. Conditions when DWPT system provides a superior CapEx and Fuel OpEx than a battery only solution (designed capacity for full mission) – Reference comparison against the same battery pack chemistry for the specific operating scenario

Referenced to NMC			Battery usage 0.0 kWh/mi			Battery usage 0.3 kWh/mi		
			Adoption: 10%	Adoption: 50%	Adoption: 100%	Adoption: 10%	Adoption: 50%	Adoption: 100%
LTO	0% IRR 0% recovery	100 mi	45 ⇨ 100	45 ⇨ 100	45 ⇨ 100	60 ⇨ 100	60 ⇨ 100	60 ⇨ 100
		300 mi	210 ⇨ 300	210 ⇨ 300	210 ⇨ 300	210 ⇨ 300	210 ⇨ 300	210 ⇨ 300
		500 mi	375 ⇨ 500	375 ⇨ 500	375 ⇨ 500	420 ⇨ 500	420 ⇨ 500	435 ⇨ 500
		700 mi	555 ⇨ 700	555 ⇨ 700	555 ⇨ 700	600 ⇨ 700	600 ⇨ 700	600 ⇨ 700
LTO	0% IRR 100% recovery	100 mi	15 ⇨ 100	90 ⇨ 100	0 ⇨ 0	15 ⇨ 100	60 ⇨ 100	0 ⇨ 0
		300 mi	90 ⇨ 300	0 ⇨ 0	0 ⇨ 0	150 ⇨ 300	255 ⇨ 300	0 ⇨ 0
		500 mi	210 ⇨ 500	0 ⇨ 0	0 ⇨ 0	285 ⇨ 500	480 ⇨ 500	0 ⇨ 0
		700 mi	345 ⇨ 700	0 ⇨ 0	0 ⇨ 0	465 ⇨ 700	0 ⇨ 0	0 ⇨ 0
LTO	5% IRR 100% recovery	100 mi	0 ⇨ 100	0 ⇨ 0	0 ⇨ 100	15 ⇨ 100	75 ⇨ 100	0 ⇨ 100
		300 mi	75 ⇨ 300	0 ⇨ 0	0 ⇨ 300	120 ⇨ 300	300 ⇨ 300	0 ⇨ 300
		500 mi	180 ⇨ 500	0 ⇨ 0	0 ⇨ 500	285 ⇨ 500	495 ⇨ 500	15 ⇨ 500
		700 mi	315 ⇨ 700	0 ⇨ 0	0 ⇨ 700	495 ⇨ 700	0 ⇨ 0	30 ⇨ 700
LTO	10% IRR 100% recovery	100 mi	0 ⇨ 100	0 ⇨ 100	0 ⇨ 0	0 ⇨ 100	15 ⇨ 100	0 ⇨ 0
		300 mi	45 ⇨ 300	45 ⇨ 300	0 ⇨ 0	45 ⇨ 300	150 ⇨ 300	0 ⇨ 0
		500 mi	120 ⇨ 500	135 ⇨ 500	0 ⇨ 0	135 ⇨ 500	345 ⇨ 500	0 ⇨ 0
		700 mi	240 ⇨ 700	240 ⇨ 700	0 ⇨ 0	255 ⇨ 700	555 ⇨ 700	0 ⇨ 0
NMC	0% IRR 0% recovery	100 mi	0 ⇨ 100	0 ⇨ 100	0 ⇨ 100	0 ⇨ 100	0 ⇨ 100	0 ⇨ 100
		300 mi	0 ⇨ 300	0 ⇨ 300	0 ⇨ 300	0 ⇨ 300	0 ⇨ 300	0 ⇨ 300
		500 mi	0 ⇨ 500	0 ⇨ 500	0 ⇨ 500	0 ⇨ 500	0 ⇨ 500	0 ⇨ 500
		700 mi	0 ⇨ 700	0 ⇨ 700	0 ⇨ 700	0 ⇨ 700	0 ⇨ 700	0 ⇨ 700
NMC	0% IRR 100% recovery	100 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 100	0 ⇨ 0	0 ⇨ 15	0 ⇨ 0
		300 mi	0 ⇨ 0	0 ⇨ 15	0 ⇨ 300	0 ⇨ 0	0 ⇨ 60	0 ⇨ 0
		500 mi	0 ⇨ 15	0 ⇨ 45	0 ⇨ 500	0 ⇨ 15	0 ⇨ 165	0 ⇨ 15
		700 mi	0 ⇨ 15	0 ⇨ 60	0 ⇨ 700	0 ⇨ 15	0 ⇨ 345	0 ⇨ 15
NMC	5% IRR 100% recovery	100 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0
		300 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0
		500 mi	0 ⇨ 0	0 ⇨ 15	0 ⇨ 0	0 ⇨ 0	0 ⇨ 15	0 ⇨ 0
		700 mi	0 ⇨ 0	0 ⇨ 15	0 ⇨ 0	0 ⇨ 15	0 ⇨ 15	0 ⇨ 0
NMC	10% IRR 100% recovery	100 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0
		300 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0
		500 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 15	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0
		700 mi	0 ⇨ 0	0 ⇨ 0	0 ⇨ 15	0 ⇨ 0	0 ⇨ 0	0 ⇨ 0

Figure 28. Conditions when DWPT system provides a superior CapEx and Fuel OpEx than a battery only solution (designed capacity for full mission) – Reference comparison against the NMC battery pack chemistry for the specific operating scenario

Additionally, Figure 27 only compares the DWPT solutions with a given battery chemistry against itself for battery only systems. Whereas Figure 28 compares the DWPT solution with a given battery chemistry against NMC solutions for battery only systems. Through these two figures it is evident that LTO solutions provide fewer opportunities to exceed the battery only solution as compared with NMC solutions. It is also clear that as amortization targets for the invested roadway infrastructure increases that the viability (based on CapEx and Fuel OpEx) of DWPT HD truck freight movement reduces. This suggests the need for alternative strategies including subsidies or government support. Additional opportunity may be realized if battery prices do not come down as rapidly as projected in the electrified CV segments. Finally, if base depot charging electricity prices show an increase from the assumed values in this research, further opportunities for DWPT in HD truck freight movement will be realized

Conclusions

The usage of wireless power transfer systems, which include inductive electrical coils on the vehicle and the power source, may be built for dynamic operations in which the vehicle will collect energy from transmitting coils in the road while traveling at high speeds. This could allow for substantially longer missions while lowering the need for onboard energy storage for vehicles. The method for designing a dynamic wireless power transfer corridor for heavy-duty battery-powered commercial freight vehicles is presented in this study. We reduce the minimize the vehicle TCO by architecting the electrified roadway and the vehicle battery simultaneously by taking into account the interaction of the following factors: grid capacity, substation locations, seasonal road traffic loading, freight vehicle class and weight, vehicle mobility energy requirements, on-board battery chemistry, non-electrified roadway vehicle range requirements.

Applying the method to the I-75 freight corridor serves as an illustration of the strategy, and the framework created here can be enlarged and applied to a bigger interstate system, expanded regional corridor, or other transportation network.

In this paper we have shown the specific scenarios where DWPT based HD truck freight mobility systems are superior (lifetime CapEx and Fuel OpEx) to diesel or battery only powertrains. While DWPT architectures do not ubiquitously provide superior solutions under all conditions, there is a significant opportunity space where solutions of this form not only provide technoeconomic benefits but may also go a significant way in improving the overall end-user and fleet experiences, which will be critical in motivating technology adoption.

There are several gaps in this study that are being addressed through future planned activities. These have been highlighted in the paper and include a closer study of O-D pairs, down to the GPS coordinates to assess the specific freight movement energy needs. In addition, there is a complex optimization space based on DWPT power transfer capabilities, the number of vehicle receiving coils, and the degree to which the onboard battery charge is sustained. This has not been fully explored. Further, cost optimization of the substation grid to road infrastructure layout may be minimized, while also building in redundancy to mitigate the impact of power failure incidents from any substation. Finally, the results presented here are limited to DWPT transmitter coils capable of 200kW with 4 receiver coils on the vehicle but several other settings may be explored. The full range of these optimization studies is beyond the scope of this paper and will be discussed in a future publication.

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Definitions/Abbreviations

21CTP	21st Century Truck Partnership
ACT	Advanced Clean Trucks
ATA	American Trucking Associations
BEV	Battery Electric Vehicle
CapEx	Capital Expenditure
CARB	California Air Resources Board
CCS	Combined Charging System
CFS	Commodity Flow Survey
CO2	Carbon Dioxide
CV	Commercial Vehicles
DER	Distributed Energy Resource
DOE	Department of Energy
DWPT	Dynamic Wireless Power Transfer
EPA	Environment Protection Agency
FAF	Freight Analysis Framework
FHWA	Federal Highway Administration
FuelEx	Fuel Expenditure
GHG	Greenhouse gas
GPS	Global Positioning System
HD	Heavy Duty
IRR	Internal Rate of Return
kV	Kilovolts
kW	Kilowatts
Li-ion	Lithium Ion
LTO	Lithium Titanate
MW	Megawatts
MY	Model Year
NMC	Nickel Manganese Cobalt oxide
NOx	Oxides of Nitrogen
O-D	Origin-Destination
OEM	Original Equipment Manufacturer
OpEx	Operational Expenditure
OR-AGENT	Optimal Regional Architecture Generation for Electrified National Transport
ORNL	Oak Ridge National Laboratory
SOC	State of Charge
SOH	State of Health
SUV	Sport Utility Vehicle

TCO Total Cost of Ownership

WIM Weigh in Motion