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Battery-Electric Vehicle Refrigerated Transport

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ABSTRACT

This research delves into the transformative potential of Battery Electric Vehicle (BEV) technology in refrigerated transport, addressing the significant challenges faced by the industry. The aim is to assess the viability and sustainability of BEV refrigerated transport while providing practical insights into its implications for the industry and its contribution to sustainable transportation. A mixed-methods approach was employed to investigate the practicality of BEV refrigerated transport. Qualitative insights were drawn from a major US-based grocery retailer affiliated with Volvo Trucks. This was complemented by quantitative analysis of historical engine idle time records and weekly mileage data, ensuring a comprehensive evaluation of the current state of BEV refrigerated transport. Key findings led to the critical role of opportunity charging in expanding the operational range of BEV refrigerated trucks. Engine idle time analysis revealed that substantial idling time can be harnessed for this purpose. Moreover, the average daily mileage distribution highlights the limitations of existing OEM electric trucks, emphasizing the necessity of opportunity charging infrastructure. Opportunity charging can significantly enhance the total mileage range of existing electric trucks, making them feasible for a broader range of refrigerated transport operations. Specifically, it can contribute to the sustainability of refrigerated transport by overcoming the limitations of existing electric vehicles for long-haul applications. The implications of this research are twofold. First, it underscores the immediate practicality of opportunity charging, offering a solution to the range limitations of BEV refrigerated transport. This innovation has significant implications for the industry, potentially reducing operational costs and minimizing the environmental impact. Second, this research contributes to the broader field of sustainable transportation by providing insights into a practical approach to extending the range of electric vehicles. The findings encourage further exploration and investment in opportunity charging as a viable strategy to address the challenges of electric refrigerated transport.

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Chapter 1 - Introduction

Literature Review

Refrigerated transport plays a pivotal role in the modern transportation of perishable goods, ensuring that food, medicine, and other temperature-sensitive products reach their destinations safely and in optimal condition. Refrigerated transport acts as a component within the broader cold supply chain, serving more than 56,000 businesses in the United States and projected to be worth over $21 billion by 2025 [1]. This literature review delves into the world of refrigerated transport, exploring its significance, challenges, and the need for transformative innovations that have the potential to revolutionize the industry. By understanding the evolving landscape of refrigerated transport and its shift towards sustainability, this thesis aims to shed light on the environmental and operational advantages of Battery Electric Vehicle (BEV) refrigerated transport.

Refrigerated Transport

The refrigerated transport industry serves as a medium for moving perishable goods under tightly controlled temperature environments to ensure the products' integrity and safety during transit. These goods encompass a wide range of commodities including food, pharmaceuticals, and live animals. In North America, ~117,300 and ~41,000 refrigerated vehicles and refrigerated vans/ trucks, respectively, are sold annually [2]. Temperature-sensitive shipping services are offered in various forms such as full truckload (FTL) and less-than-truckload (LTL) options, as well as refrigerated warehousing and short-term storage facilities. FTL is typically used for transporting larger loads, while LTL is more complex, designed to handle smaller loads. When managed effectively, refrigerated transport may extend the shelf life of products by days or even weeks, thus playing a significant factor in reducing food waste and ensuring safe delivery of medical supplies.

However, the refrigerated transport industry faces several challenges which can result in negative consequences if not appropriately dealt with. Refrigerated trucks entail higher initial purchase and maintenance costs, and the industry struggles with a nationwide shortage of qualified truck drivers, leading to logistics and timing concerns in maintaining the flow of the cold supply chain. Furthermore, addressing the negative environmental impact of refrigerated trailers is crucial since nearly 10% of global greenhouse gas (GHG) emissions can be attributed to the energy required to keep both humans and perishable items cold. A study indicates that 0.1% of total emissions in the United States are derived from cold chain transport. [3]

Moreover, the planet's warming climate has resulted in an increased demand for refrigerated trailers as shown in Fig 1, as businesses seek protective measures against food waste and environmental degradation.

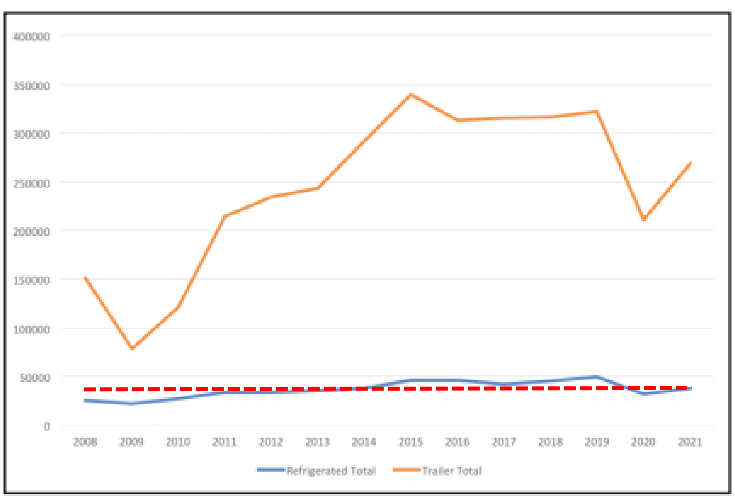


Fig 1. Refrigerated Trailer vs Total Trailer Production [4]

According to 2008-2021 production data from Trailer Body Builders and ACT Research total industry numbers, an estimated 521,800 total refrigeration trailers were produced, representing 15.2% of the total trailer production, and ~39,500 average refrigerated trailers were produced annually (indicated by the red-dotted line in Fig 1).

Battery Electric Vehicle (BEV) Refrigerated Transport

With these challenges continuing to persist and the need for more sustainable solutions to address these issues, BEV Refrigerated Transport proves to be a viable solution. Carrier Global, a leading provider of HVAC and cold chain technologies for buildings and trucks, have been actively involved in pioneering innovations. For instance, the Vector eCool Initiative converts kinetic energy from trailer axles into electricity, which is stored in a battery and subsequently powers the refrigeration system [5][6]. This fully electric and autonomous system operates without emitting CO2 or particulate emissions and can be fully charged in just a few hours when plugged into the electrical grid. Further collaborations between major industry players, such as Sysco, ConMet, and Carrier Transicold, are leading to the development of zero-emission refrigeration systems, capturing wasted braking energy, and converting it into electricity. These innovations have the potential to not only reduce emissions but also cut operational and maintenance costs, making BEV refrigerated transport a competitive and environmentally sustainable option.

Transport Refrigeration Units (TRUs), also known as ‘reefers’, are refrigeration systems used on insulated trailers, straight trucks, shipping containers, and rail cars to maintain appropriate temperatures for sensitive goods. Electric Transport Refrigeration Units (eTRUs) come in two options: a standby/hybrid TRU and an all-electric TRU. For standby/hybrid TRUs, the unit compressor is powered by a diesel engine when on road, and when stationary, the standby/hybrid feature enables the eTRU to power the compressor when plugged into the electric grid, thus eliminating idling of the engine. For all-electric TRUs, an electric motor-driven compressor is powered by onboard batteries, which can be charged with onboard solar panels and/or a wheel generator built into trailer axle. When stationary, all-electric eTRUs must be plugged in to fully charge onboard batteries. [7]

Electric Transport Refrigeration Units offer numerous advantages. Most notably, its lower operation and maintenance costs occur primarily due to the cost-effectiveness of electricity compared to diesel. Electric motors and electric/diesel hybrid equipment require less maintenance than their diesel counterparts, potentially reducing operating costs up to 70% when electricity is employed as a standby option [8]. Moreover, another significant advantage is the reduction in energy consumption, with estimates from ConMet suggesting a 35% energy savings compared to diesel when electric power is solely used for propulsion [9].

However, eTRUs also consists of several disadvantages. The initial investment is higher than that of traditional diesel-powered reefers. Moreover, the lack of widespread charging infrastructure poses a significant hurdle to customer adoption of Zero Emission Vehicles (ZEVs). Delays in power grid updates, utilities implementation, and certification processes further exacerbate this challenge. Battery limitations also persist, with power limitations resulting in a relatively limited range, rendering electric reefers less suitable for long-haul applications. Over time, batteries may degrade, necessitating replacement and incurring additional expenses. Lastly, the longer charging time required by eTRUs may lead to increased downtime, potentially impacting operational efficiency.

DC Fast-Charging

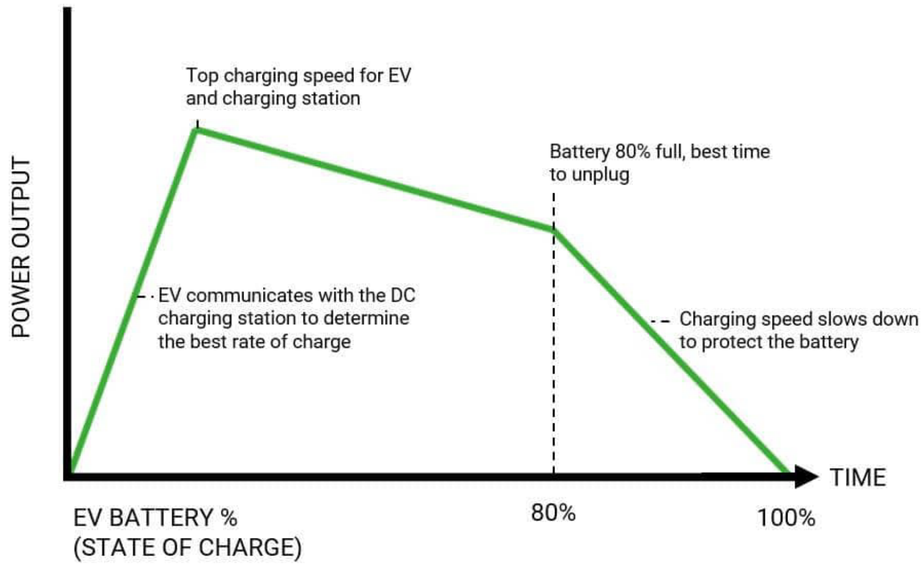


Fig 2. DC Fast-Charging Curve [10]

In the context of DC fast charging for BEVs, understanding the DC fast-charging curve is critical. The charging behavior of a BEV battery follows a distinct pattern. When a BEV with a depleted battery is plugged in, the charging starts slowly until it reaches approximately 10-20%. At this point, the charging power surges to its peak capacity, providing a rapid replenishment of the battery (this high-power phase varies based on the vehicle model). Some BEVs maintain high-power charging consistently throughout most of the charge cycle, while others may experience slight power reductions during charging. As the battery charge approaches 80%, the charging curve sharply drops. This significant reduction in charging power is designed to prevent the battery's cell voltages from exceeding their limits and to mitigate the risk of overheating. [11]

The implications of this charging curve are twofold for BEV trucks. Firstly, it underscores the importance of strategic charging practices. For long-haul applications, waiting at a charging station to reach 100% battery capacity may be counterproductive. Beyond 80%, the charging time significantly increases, thus increasing downtime. Therefore, unplugging when the battery reaches around 80% or lower can be a more efficient approach. Secondly, these insights emphasize the need for BEV trucks to strategically plan their charging stops to maximize high-power charging phases, reducing downtime during routes and enhancing operational efficiency. This is known as opportunity charging.

In summary, this literature review examined the landscape of refrigerated transport, emphasizing its pivotal role in ensuring the safe delivery of perishable goods. It highlights the major challenges faced by the industry, particularly cost, environmental impact, and the logistical complexities involved. The emergence of Battery Electric Vehicle (BEV) Refrigerated Transport, with the implementation of strategic opportunity charging, acts as a viable solution, offering advantages such as reduced operational costs and lowered energy consumption. The significance of these findings lies in the potential for BEV Refrigerated Transport to address the challenges inherent in conventional refrigerated transport methods.

Motivation & Objectives

During my 8-month co-op internship at Volvo Trucks, I had the privilege of immersing myself in a BEV Refrigerated Transport Industry Vertical project. This experience allowed me to gain valuable insights into the strengths and challenges within this sector. These insights, combined with my aspiration to contribute a viable solution to address the industry's challenges, have motivated me to further explore this area through my thesis.

The primary goal of this thesis is to assess the current state of BEV Refrigerated Transport to determine its viability and sustainability as an option for the transportation of perishable goods. To achieve this overarching aim, the research will be guided by specific objectives. First, we will evaluate

BEV insights gained from a major US grocery retailer’s experience with BEV refrigerated transport. This evaluation will provide a practical understanding of the current state of the industry. Second, we will analyze route and mileage data provided by the retailer to conduct a comprehensive analysis. This analysis aims to assess whether existing BEV trucks can effectively meet the operational requirements of refrigerated transport. Third, this study will investigate the potential benefits of implementing opportunity charging in enhancing BEV refrigerated transport mileage capabilities. Finally, the research will critically evaluate whether the current state of BEV refrigerated transport aligns with the industry's needs; key factors, such as range, charging infrastructure, and environmental advantages, will be examined in-depth.

By addressing these specific objectives, our research will provide a structured approach to answer the central question of this thesis: Is BEV Refrigerated Transport a viable and sustainable solution for the transportation of perishable goods in the present landscape?

Chapter 2 - Methodology

The methodology employed in this research serves as the framework for conducting a comprehensive investigation into the practicality of Battery Electric Vehicle (BEV) Refrigerated Transport. This section outlines the research approach, data collection methods, and data analysis procedures, justifying the chosen methods and establishing their connection with the research question and the literature review.

Research Approach

This research employs a mixed methods approach, combining both qualitative and quantitative techniques. This approach is essential for presenting a holistic understanding of the viability and sustainability of BEV Refrigerated Transport for the transportation of perishable goods. The integration of both approaches enhances the reliability and validity of the research findings.

The qualitative component involves gathering BEV insights through an interview with a major US-based grocery retailer affiliated with Volvo Trucks. This interview provides invaluable information regarding current industry trends, existing fleet and charging infrastructure, fleet operational needs, and future BEV plans, aiding in the comprehensive evaluation of BEV Refrigerated Transport's practicality. Furthermore, the quantitative aspect focuses on analyzing data related to energy consumption, operational efficiency, and mileage distribution. This aligns with the research question's need for numerical insights into the current state of BEV Refrigerated Transport.

Data Collection & Analysis

Note: *The information regarding interviews and mileage data from a US-based grocery retailer was obtained from* <u>*Volvo Group*</u>*. The information is* ***strictly confidential****, therefore, key details such as name of grocery retailer interviewed, and Volvo electric truck specifics are omitted.*

Quantitative data includes the retailer's historical engine idle time records and weekly mileage data, provided by the retailer. The engine idle time data provides insights into how much time refrigerated trucks spend idling and, by extension, the potential for opportunity charging. The weekly mileage data offers a comprehensive view of the typical mileage ranges their operational fleet covers and allows for comparison with existing BEV trucks to determine whether they meet the retailer's operational requirements and if not, how opportunity charging implementation can help the retailer achieve these needs. Furthermore, only Class 8 BEV trucks with appropriate mileage ranges (>200 miles) were utilized for this analysis since retailer operations cover up to ~670 miles of range.

Moreover, the quantitative data is analyzed through descriptive statistics and inferential statistics. Descriptive statistics are employed to present summarized information about engine idle time. Inferential statistics, such as normal distribution, are used to convey the daily mileage data. These analyses provide insights into the significance of engine idle time and daily mileage distribution in the context of BEV Refrigerated Transport.

Chapter 3 - Statistical Analysis & Results

Grocery Retailer Interview Details

Table 1 below summarizes information collected from an interview with a major US-based grocery retailer affiliated with Volvo Trucks.

Table 1. BEV Insights from Major Grocery Retailer

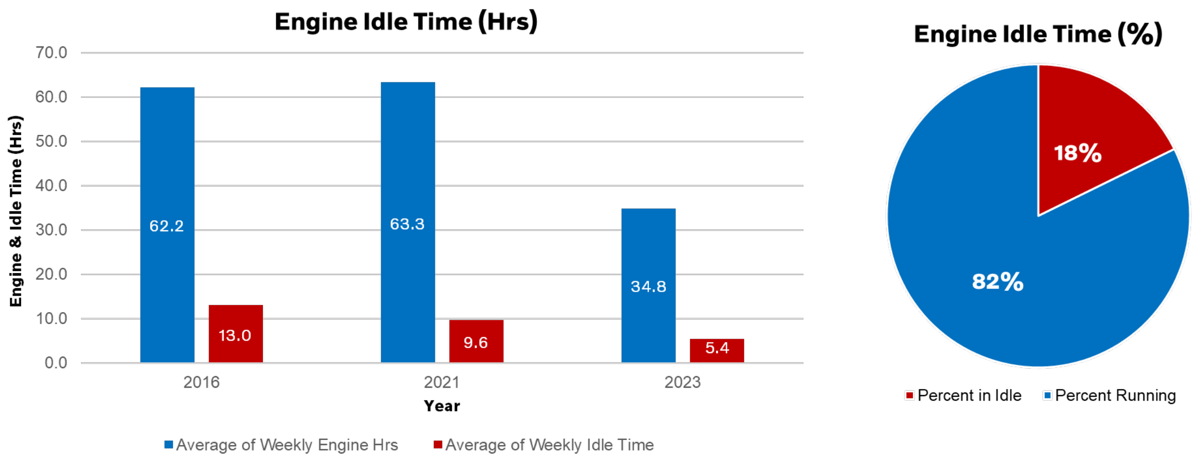
	Major Grocery Retailer
BEV Insights	- Heavy duty fleet EV target for 2025 (implementing CNG as first step) - Current: diesel primary and electric standby, Future: electric primary and diesel standby - Trailer that operates a minimum of 6-8 hours w/o charging (can extract power from tractor in emergency situations)
# of Tractors & Trailers	- 200 diesel/electric hybrid reefers (ThermoKing) - 650 reefer trailers (~1200 total) - 1:7 tractor to trailer ratio
Types of Routes (DC to DC, DC to Store, Store to Store)	- DC to DC and DC to stores, not cross country - Route from Rochester, NY down to NC - Dynamic dispatching/routing
Mileage of Routes	- Routes in Rochester that have 200 miles or less runtime
Charging Infrastructure	- 15-25 fast chargers available at Rochester - Long-term opportunity charging plan at stores; short-term plan at DC only

The retailer is currently undergoing a significant transformation in its approach to refrigerated transport, with targets set for 2025. Their heavy-duty truck fleet is shifting toward electric vehicles (EVs), beginning with the implementation of Compressed Natural Gas (CNG). Currently, their fleet primarily relies on diesel power with an electric standby option (Standby/Hybrid TRU), but they envision a future where electric power will take the primary role (All Electric TRU), while diesel remains available as a backup. Their vision also encompasses trailers that operate for a minimum of 6-8 hours without requiring charging and can extract power from the tractor in emergency situations.

Currently, the retailer possesses 200 diesel/electric hybrid reefers from ThermoKing and 650 reefer trailers. Their current routes predominantly cover shorter distances, operating between distribution centers (DCs) and stores rather than cross-country journeys. One of their longer routes extends from Rochester, NY to North Carolina (~670 miles). To ensure efficient operations, dynamic dispatching and routing are employed, with routes in Rochester having runtimes of 200 miles or less. Furthermore, the retailer is actively investing in charging infrastructure, with 15-25 fast chargers available at the Rochester location. Their short-term plan only includes opportunity charging at DCs; however, their long-term plan includes opportunity charging at stores, representing a comprehensive effort to transition to electric refrigerated transport.

Engine Idle Time

Fig 2 below presents an analysis of the retailer's diesel-powered refrigerated trucks from 2016 to 2023. It focuses on the average weekly engine hours and idle time while illustrating the proportion of time spent idling in comparison to the total engine runtime. The figure highlights that a substantial portion of engine time (18%) is dedicated to idling when the truck is stationary. This finding suggests that, in cases where trucks are parked for standard periods (>30 min), some of the idling time in their diesel refrigerated trucks could potentially be harnessed for opportunity charging in their diesel/electric hybrid refrigerated trucks.



a) b)

Fig 3. Engine Idle Time

a) Average weekly engine hours and idle time between 2016-23. b) Overall average engine idle time

Daily Mileage Distribution

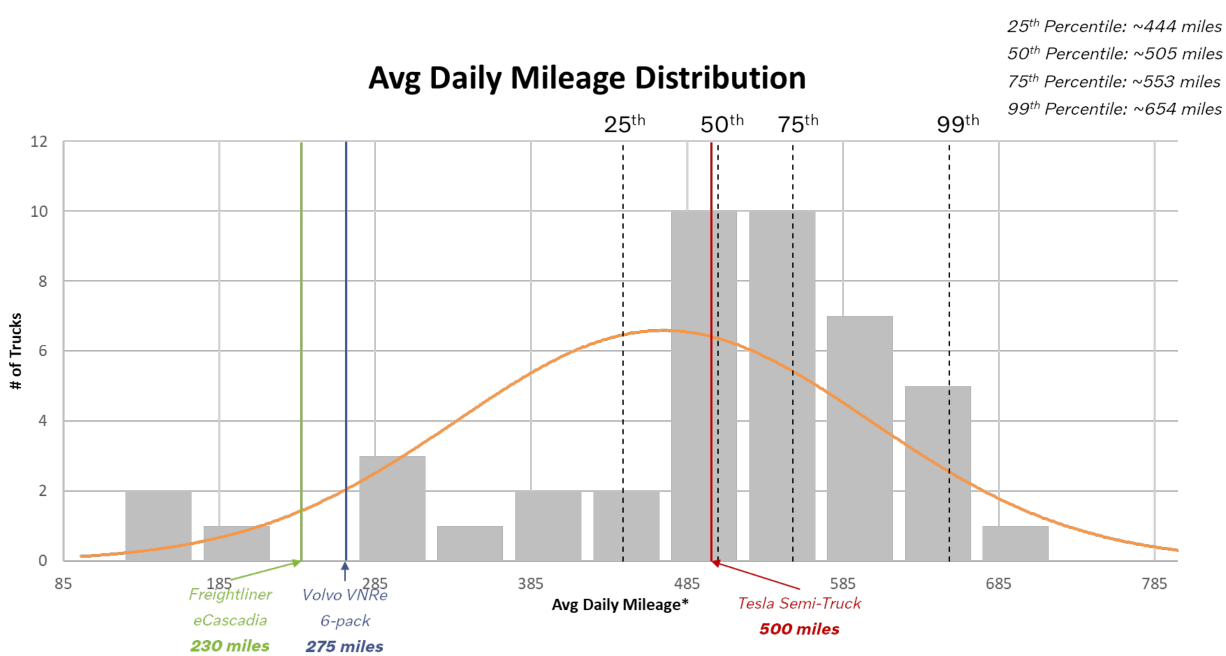


Fig 4. Average Daily Mileage Distribution of Major US Grocery Retailer

**Average daily mileage is assuming 5 days of truck utilization*

Fig 3 displays the retailer's average daily mileage distribution, with percentiles including the 25th (~444 miles), 50th (~505 miles), 75th (~553 miles), and 99th (~654 miles) overlaid on the chart. It also presents the operating mileage ranges for three major Original Equipment Manufacturer (OEM) electric Class-8 trucks: Freightliner eCascadia (230 miles), Volvo VNRe 6-pack (275 miles), and Tesla Semi-Truck (500 miles) [12][13][14].

The distribution demonstrates that even the truck with the highest advertised mileage range, the Tesla Semi, can only cover approximately 48.1% of the retailer's current refrigerated trucking fleet, with the Freightliner eCascadia and Volvo VNRe covering approximately 6.45% and 11.6%, respectively. This indicates that the current electric trucks offered by major OEMs are insufficient to meet the retailer's operational needs. However, considering the findings regarding engine idle time discussed earlier, implementing opportunity charging at distribution centers (a short-term goal) and stores (a long-term goal) could potentially increase the coverage of the retailer's fleet operations by the existing OEM trucks.

Opportunity Charging Implementation

Table 2 includes the charging rate, total battery capacity, and mileage range of the aforementioned OEMs. [12][13][14][15]

Table 2. OEM Charge Rate, Total Battery Capacity, & Mileage Range

	Freightliner eCascadia	**Volvo VNRe 6-pack**	**Tesla Semi**
Charging Rate (kW)	270	250	1260
Battery Capacity (kWh)	438	565	900
Mileage Range (miles)	230	275	500

**Note: These are advertised values from OEM websites used to provide an approximation for opportunity charging implementations.*

To calculate the total mileage range the electric trucks can potentially achieve with opportunity charging, the following equations are used:

$$\frac{stationary\ time \times charge\ rate}{total\ battery\ capacity} = \%\ battery\ capacity\ recovered \tag{1}$$

$$\%\ battery\ capacity\ recovered\ \times mileage\ range = additional\ mileage \tag{2}$$

$$mileage\ range + \ additional\ mileage\ = \ \boldsymbol{total\ mileage\ range} \tag{3}$$

**Note: The charging rates provided in Table 2 are peak (max) so values calculated for '% battery capacity recovered' and 'additional mileage' are not completely accurate. These calculations serve only to give an indication of the potential value of implementing opportunity charging.*

A sample calculation for the Volvo VNRe 6-pack opportunity charging implementation is demonstrated below:

Assuming a 0.5-hour period where the truck is stationary and a constant charge rate

$$\frac{0.5\ hour\ \times\ 250kW}{565\ kWh} = 22.1\%$$

$$22.1\%\ \times 275\ mi\ =\ \sim 61\ mi$$

$$275\ mi + 61\ mi = \boldsymbol{336\ mi}$$

Performing the same calculations for the other two OEMs, the following results are shown in Table 3 below.

Table 3. OEM Total Mileage Range with 30-minute Opportunity Charging and Percent of Fleet Operations

	Freightliner eCascadia	Volvo VNRe 6-pack	Tesla Semi
Total Mileage Range (miles)	300	336	850
% of Fleet Operations	13.6 %	14.9%	>99%

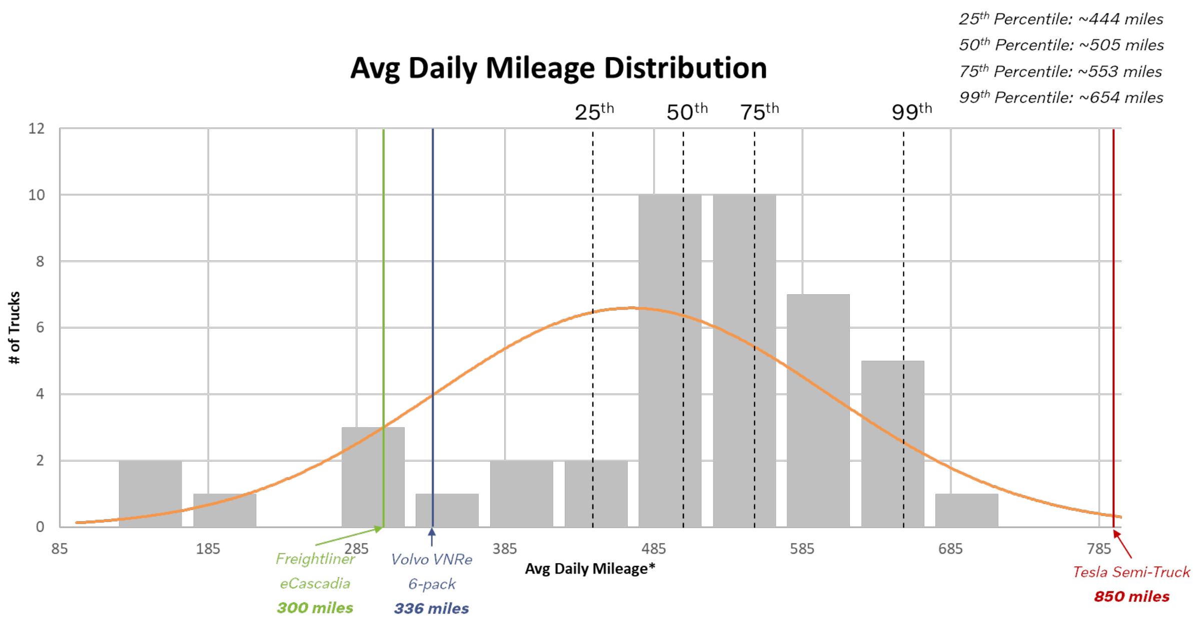


Fig 5. Average Daily Mileage Distribution (w/ Opportunity Charging)

**Average daily mileage is assuming 5 days of truck utilization*

The distribution demonstrates that implementing just 30-minute opportunity charging in the electric truck daily operation significantly affects the total mileage range. Considering several assumptions, as mentioned above in the calculations, the Freightliner eCascadia (300 miles), Volvo VNRe (336 miles), and Tesla Semi (850 miles), can cover approximately 13.6%, 14.9%, and >99%, of the retailer's fleet operations.

Chapter 4 - Discussion

The primary goal of this thesis is to assess the current state of Battery Electric Vehicle (BEV) Refrigerated Transport, with the overarching aim of determining its viability and sustainability as a transportation option for perishable goods. In the pursuit of this goal, our research was meticulously guided by a series of specific objectives. We began by evaluating BEV insights drawn from a prominent US-based grocery retailer's experience with BEV refrigerated transport, thereby gaining practical insights into the current state of the industry. Our analysis then examined route and mileage data provided by the retailer, providing a comprehensive evaluation of whether existing BEV trucks meet the retailer's operational demands of refrigerated transport. The study further delved into the potential advantages of implementing opportunity charging to enhance the mileage capabilities of BEV refrigerated transport. In this Discussion section, we evaluate whether the current state of BEV refrigerated transport aligns with the industry's requirements, with a thorough examination of factors such as range, charging infrastructure, and environmental advantages. By diligently addressing these specific objectives, our research provides a structured approach to address the central question of this thesis: Is BEV Refrigerated Transport a viable and sustainable solution for the transportation of perishable goods within the contemporary landscape?

The results of this study provide valuable insights into the viability and sustainability of Battery Electric Vehicle (BEV) Refrigerated Transport for the transportation of perishable goods. The average weekly engine hours and idle time of diesel-powered refrigerated trucks from 2016 to 2023 were analyzed, revealing that approximately 18% of engine time was dedicated to idling when the truck was stationary (Figure 2). This data suggests a major potential for harnessing idling time for opportunity charging in diesel/electric hybrid refrigerated trucks. The average daily mileage distribution of a major US-based grocery retailer's fleet, which operates routes predominantly between distribution centers (DCs) and stores, revealed percentile values including the 25th (~444 miles), 50th (~505 miles), 75th (~553 miles), and 99th (~654 miles) overlaid on the chart (Figure 3). Despite the existence of electric Class-8 trucks such as Volvo VNRe, Freightliner eCascadia, and Tesla Semi, all with various mileage ranges, the findings indicate that none of these existing OEM trucks could fully cover the retailer's fleet operations, with the Tesla Semi coming closest, covering only 48.1% of the routes (Figure 3).

However, the implementation of opportunity charging yields a remarkable increase in the mileage range for OEM electric trucks. As illustrated in Table 3 and Figure 4, our calculations demonstrate the achievable enhancements in total mileage range, particularly when BEVs are equipped with dedicated opportunity charging infrastructure. Using the Volvo VNRe 6-pack calculation as an example, during a brief 0.5-hour stationary period with a consistent charge rate, the additional mileage gained through opportunity charging approximated 61 miles. Moreover, our analysis reveals that after just 30 minutes of opportunity charging, the Freightliner eCascadia, Volvo VNRe, and Tesla Semi exhibit the potential to cover approximately 13.6%, 14.9%, and, in the case of the Tesla Semi, well over 99% of the retailer's fleet operations. This exceptional coverage not only showcases the immediate practicality of opportunity charging but also ensures that these OEM trucks operate near their peak charging rates, avoiding the 80% threshold limit where charging rates decelerate to preserve battery health. These findings highlight the pivotal role of strategically implemented opportunity charging in extending the range and, by extension, the feasibility of BEV refrigerated transport for long-haul applications. This technology, as demonstrated, offers a practical solution to address the challenge of range limitations, thus contributing significantly to the sustainability and viability of BEV refrigerated transport in the modern landscape.

The study aligns with existing literature on the potential benefits of using battery electric vehicles in the refrigerated transport sector, particularly in addressing environmental concerns and reducing operational costs. The implementation of opportunity charging further reduces operational costs because it eliminates battery storage areas for extra batteries and prevents significant downtime since charging only occurs for a short period. Moreover, the findings of this study are consistent with previous research regarding the challenges associated with electric vehicles, most notably their limited range and the need for more accessible charging infrastructure.

While this study has yielded valuable insights, it is important to acknowledge several limitations that may impact the interpretation and generalizability of the findings. First, the data used in this research were obtained from a single US-based grocery retailer. While this provided a substantial dataset for analysis, it may not fully represent the diversity of refrigerated transport operations across the entire industry. To enhance the robustness of future research, it would be beneficial to incorporate data from multiple US retailers to ensure a broader perspective. Second, the mileage range values provided by the OEMs, as presented in Table 2, are based on advertised figures from their respective websites. These values serve as an approximation for the calculations related to opportunity charging but may not reflect real-world conditions accurately. Collaborative efforts with multiple OEMs or additional empirical data could offer more precise mileage range information for future studies. Third, research exploring the cost-benefit analysis of opportunity charging implementation, including the necessary infrastructure investment and operational savings, could also be included. Furthermore, the calculations regarding mileage range extensions through opportunity charging are based on peak charging rates. Real-world results may vary due to factors such as environmental operating conditions and other confounding variables. Future research should consider conducting simulations in a controlled environment to validate the feasibility of opportunity charging in practical settings and obtain more accurate results. These limitations serve as opportunities for future research to refine and expand upon the findings presented in this study, ultimately contributing to a more comprehensive understanding of the potential of battery electric vehicles in refrigerated transport.

In conclusion, this research demonstrates that Battery Electric Vehicle Refrigerated Transport, when combined with strategic opportunity charging, can offer a practical and sustainable solution for the transportation of perishable goods on shorter routes. Despite the limitations of the study, the practical implications of this research are significant. It conveys that the implementation of opportunity charging can be an effective strategy for increasing the coverage of existing electric refrigerated truck fleets. By optimizing charging strategies at distribution centers and stores to include 30 minutes or more of charging time, refrigerated transport operators can potentially overcome the barriers associated with limited mileage ranges of electric trucks for long-haul applications. This study encourages further exploration of opportunity charging as a viable strategy to address the hindrances of electric refrigerated transport, contribute to environmental sustainability, and reduce operational costs. Future research should focus on gathering data from multiple retailers, conducting simulations within a controlled environment, and refining opportunity charging strategies to ensure its effectiveness and reliability.

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Schreyer Honors College | College of Engineering
Bachelor of Science in Mechanical Engineering — Dean's List (6/6)

Relevant Coursework: Python for Data Science, Data Visualization with Python, Cleaning & Transforming Data in Power BI, Designing Data Models in Power BI, DAX in Power BI, Creating Dashboards & Reports in Power BI, SQL for Data Science

TECHNICAL EXPERIENCE

Product Manager Intern — **January 2023 - August 2023**
Volvo Group
- Conducted interviews with industry stakeholders, performed customer end-to-end value chain analysis, and identified customer pain points & solutions to identify future business opportunities for Volvo Group
- Formulated and revised 4 questionnaires to survey truck drivers, deriving key insights on potential features for future products
- Coordinated logistics for cross-functional teams of 20+ members, collaborating with Transportation Manager
- Captured and analyzed on-site customer vehicle usage data from 4 trucks to support development of BEV (Battery Electric Vehicle) Project Requirements
- Developed Class 6-8 vehicle registration Power BI dashboards for Ad-Hoc market & industry research, training team of 13 Product Planning Managers on use of tool, improving process efficiencies by 40%
- Automated product plan budget updates by developing Budget Simulator Tool using Excel VBA, reducing operational time by 50% per iteration

Data Science Intern — **May 2022 - August 2022**
Patterson-UTI Drilling
- Produced and presented optimized tripping procedure to drilling optimization engineering team, reducing daily operational costs by 10%
- Analyzed and visualized 6 months of tripping pipe speed data across 7 wells using MS Excel pivot table, Pandas, NumPy, and Matplotlib in Jupyter Notebook
- Assisted with operations on land-based oil rig floor, including 150+ drill-pipe connections, tripping pipe, maintaining drilling fluid weight, and conducting a rig walk

Data Science Intern — **June 2021 - August 2021**
Mindshare
- Developed 4 versions of linear and random forest regression-based predictive models to forecast clicks, reducing mean prediction error by 88%
- Implemented Pandas, NumPy, and Scikit-learn in Python toward analyzing ~16,500 records of advertisement data
- Proposed key features to supervisor 2x/week using Seaborn visualizations, leading to further exploration of prediction model

Data Analyst & Research Lead — **February 2021 - August 2021**
Food AId, Nittany AI Challenge
- Created and presented dashboards of customer survey responses using MS Excel charts, reducing costs by 10%
- Analyzed ~2 years of food distribution and inventory data using MS Excel data cleaning and transformation techniques
- Strategized prediction model improvements with back-end development teams 2x/week, improving overall accuracy

Research Assistant — **February 2020 - March 2020**
ACURA, Penn State Abington
- Maximized productivity and delegated responsibilities amongst research professor and fellow research assistant
- Modified 3 versions of 3D drawings of CubeSAT frame structure using SolidWorks for 3D printing
- Utilized online tracking application to monitor path and weather conditions surrounding CubeSAT after helium balloon launch

Research & Development Intern — **July 2018**
Tata Motors
- Engaged in 2 truck factories composed of 3 stations for building components of trucks such as chassis, hydraulic, and load
- Created and presented a video displaying labeled component diagram of trucks, their functions, and entire construction process
- Awarded a certificate from Human Resources recognizing dedication, involvement, and curiosity to learn

TECHNICAL SKILLS

Languages: Python, Excel VBA, SQL, R, MATLAB (Simulink)
Machine Learning: Python (eg. Scikit-learn, Pandas, NumPy, Seaborn, Matplotlib)
Visualization: Power BI, Jupyter Notebook, MS Excel Chart

LEADERSHIP & INVOLVEMENT

Muslim Student Association – *Treasurer* — **March 2022 - December 2022**
American Society of Mechanical Engineers – *Vice President* — **August 2020 – December 2022**