# Developing Heavy Duty Electric Vehicle Energy Transportation Cost Mapping




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## Abstract

Heavy-duty transportation plays a critical role in global logistics but is also a significant contributor to greenhouse gas emissions. Transitioning this sector to electric vehicles (EVs) presents unique challenges, including high upfront costs, operational risks, and the complexity of energy management. The Forestry Electric Vehicle Energy Routing (FEVER) tool offers a solution by delivering energy-optimized routing tailored for heavy-duty EVs. FEVER's innovative approach incorporates regenerative braking, load variability, and terrain-specific dynamics to provide precise energy consumption forecasts. Field trials are planned to validate its practical applicability, demonstrating how FEVER minimizes energy usage, reduces operational costs, and instills confidence in EV technology for heavy-duty applications. This tool represents a critical advancement toward reducing carbon emissions in the heavy vehicle sector, aligning with global sustainability goals and the future of transport.

**Keywords:** GIS-based vehicle mapping, freight transport innovation, regenerative braking, managing energy transitions, energy-efficient routing, carbon emission reduction strategies, forestry and resource logistics.

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## 1. Introduction

The heavy-duty transportation sector forms the backbone of global logistics, contributing to nearly 70% of freight tonnage in the United States (Smith *et al.*, 2020). However, it is also one of the largest contributors to greenhouse gas emissions, with medium and heavy-duty vehicles accounting for 39% of life-cycle emissions from road transport (Moultak, Lutsey and Hall, 2017). Reducing carbon emissions for this sector is critical for meeting global sustainability goals and reducing dependency on fossil fuels.

While the electrification of light-duty vehicles has gained significant momentum, the transition to electric medium and heavy-duty vehicles remains a formidable challenge due to high capital costs, operational risks, and uncertainties regarding EV performance under demanding conditions such as high payloads, steep gradients, and extended routes. For an industry where downtime is costly, these barriers have slowed the adoption of electric vehicle technologies.

### 1.1 The FEVER Tool –A Specialized Routing System for Heavy Duty Electric Vehicles

The Forestry Electric Vehicle Energy Routing (FEVER) tool offers a tailored, transformative solution to address some of these challenges (Hamilton, Diederichs and Sessions, 2024). Using a given vehicle configuration, the current iteration of the FEVER tool estimates and heat maps energy expenditure across road networks on a landscape using a digital elevation model (DEM) and variable segment lengths, and assuming travel at the speed limit. Unlike conventional routing systems, FEVER incorporates regenerative braking, dynamic payload variations, and terrain-specific energy modeling to optimize energy efficiency for heavy-duty EVs. These capabilities are critical for industries reliant on predictable and reliable performance, such as forestry, resource extraction, and freight logistics.

FEVER is an innovative GIS-based routing software specifically designed to analyze the energy expenditure of Electric Vehicles (EVs) as they traverse a landscape. Unlike traditional mapping solutions such as Google Maps or the ESRI Network Analyst tool, FEVER accounts for regenerative braking, allowing for more accurate modeling of an EV's energy consumption and range. By incorporating regenerative braking into its analysis, FEVER can recommend routing solutions that maximize the efficiency of energy recovery, thereby optimizing net energy expenditure during the vehicle’s journey.

Regenerative braking is a feature built into EV powertrains that allows the electric motors to recharge EV battery cells using recaptured kinetic energy. Regenerative braking has the potential to greatly increase the range of an EV system in mountainous terrain or on routes requiring frequent braking (Hamilton, Diederichs and Sessions, 2024).

Conventional mapping tools rely on Dijkstra’s algorithm to determine optimal routes based on factors like distance, time, or fuel consumption (Lanning, Harrell and Wang, 2014). These factors are assigned as edge weights—values representing the cost of traveling a specific segment of a route. However, Dijkstra’s algorithm, a "greedy" approach focused solely on the next immediate steps, is inherently limited in its ability to handle negative edge weights. Negative edge weights, in the context of EVs, represent energy regained through regenerative braking. While Dykstra’s algorithm is highly efficient for Internal Combustion Engine (ICE) vehicles due to its low computational costs, it cannot account for the unique energy dynamics of EV systems.

FEVER overcomes this limitation by employing the Bellman-Ford algorithm, which can incorporate negative edge weights and evaluate all possible routes across a landscape (AbuSalim *et al.*, 2020). Unlike Dijkstra's "greedy" approach, Bellman-Ford examines each route comprehensively, enabling it to optimize energy recovery through regenerative braking while ensuring efficient navigation tailored to EV and hybrid systems.

Similar to existing mapping tools, FEVER can be provided with a predefined itinerary. However, FEVER offers additional functionality by allowing its user to consider changes in the vehicle's weight over the course of the day and customize its parameters to specific vehicle systems, making it an ideal solution for EVs involved in dynamic operations such as resource extraction, cargo hauling, or waste management. If the mass of an EV changes significantly during a trip, such as when a heavy-duty truck picks up a load, braking force changes and the most energy efficient route may change as well (Gao, Chen and Ehsani, 1999) Its ability to adjust routing recommendations based on weight fluctuations ensures that FEVER can optimize energy use and route planning for vehicles with varying load capacities. By also accounting for critical factors such as engine power, air resistance, and rolling resistance, it can be adapted to evaluate and compare different vehicle energy systems, including electric, hybrid, fossil fuel, and hydrogen-powered vehicles.

FEVER projects anticipated energy consumption, an invaluable metric for heavy-duty EV adopters, who are often highly risk-averse due to the significant initial investment required for EV or hybrid system adoption and the critical performance demands (Sugihara, Hardman and Kurani, 2023). Industries likely to adopt heavy-duty EVs, such as hauling, resource extraction, or waste management, cannot afford operational downtime or the risk of vehicles running out of power, making FEVER's insights valuable for decision-making.

For potential adopters, FEVER offers reassurance by showcasing potential energy savings and advising on optimal routing strategies to achieve these efficiencies. Additionally, FEVER's capability to incorporate variables such as time and labor costs allows prospective adopters to gauge how effectively the new EV systems can meet their industry's performance requirements. By providing this realistic evaluation, FEVER empowers users with the confidence needed to commit to such a substantial purchase.

FEVER is also designed to instill confidence in operators themselves. As it evolves, FEVER will be implemented as a tablet interface connected to the heavy-duty EV system, delivering real-time energy consumption updates and guiding drivers in response to specific goals, whether minimizing energy usage or travel time. By enabling drivers to make adjustments and ensuring they can reach their destination, FEVER supports both the operational and psychological assurance necessary for the long-term success of heavy-duty EV systems.

This paper outlines further planned development and validation of FEVER, by presenting findings from simulated methodological case studies on road data segmentation digitization and describing planned field trials. Development of this tool offers practical implications for fleet managers, policymakers, and technology developers seeking to accelerate the decarbonization of heavy transport.

## 2. Proposed Tool Development

FEVER currently applies an optimization routing algorithm to digitized landscapes and generates simulated results using previously established energy equations. Several assumptions in the algorithm may lead to over- or underestimation in the results as currently calculated

First, the equations used assume constant speed between nodes; i.e., do not consider acceleration or deceleration. These equations likely underestimate energy needs. It is hypothesized that an optimal combination of deceleration rate, velocity, and timing could maximize energy recovery in these scenarios with variable speeds (Gao, Chen and Ehsani, 1999). Studies of ICE timber truck have shown normal deceleration rates reach -0.6 $m/s^2$ and acceleration rates to reach 0.5 $m/s^2$ during log hauling operations (Noreland, 2024). These theoretical efficiencies remain untested, and empirical validation is needed to incorporate these dynamics into FEVER. For example, accounting for road features like stop signs with a look ahead rule, where the algorithm considers the next segment in its decision making, could further align the energy estimation with real-world conditions.

Another challenge lies in the need to validate the resolution of the input data. While initial applications employed a DEM with a resolution of 30 cm for high precision, this level of detail may not always be feasible or practical under real-world conditions. Data resolution is also important for determining speed transitions going from segment to segment, along curves in the road, or if a vehicle must stop. The best resolution for input data is still to be determined.

Another issue is to be able to measure and predict the rolling resistance and air resistance for the actual vehicles under the conditions of use. Since rolling resistance is a function of several factors such as the surface roughness, temperature and the tire pressure and condition, the resistance facing each vehicle on any given road segment is an important component in energy estimations. The air resistance facing a vehicle moving at low speeds is minimal, however, that resistance is a function of the square of velocity, which means it has a large influence on energy estimation at higher speeds. Air resistance at high speeds can be influenced by factors such as the vehicle’s frontal area configuration, the shape and drag of the trailer and weather effects such as head or tail winds.

The most pressing consideration is determining the optimal segmentation of road data. Energy expenditure and recovery depend on the distance and elevation changes along a route, requiring precise identification of road segments where energy regeneration can occur. The process involves trimming road segments and adding nodes to mark unique edges where regenerative braking is possible. Accurately capturing these segments is essential, as misidentification or imprecise segmentation can lead to underestimation or overestimation of energy needs. For example, overestimation could occur on rolling hills, where it may be preferable to conserve momentum instead of engaging the regenerative brake. A nuanced approach to road segmentation ensures that FEVER provides reliable and actionable energy consumption insights for heavy-duty EV operators. Simulations using FEVER to compare energy estimation results at several road segment lengths in a known landscape were conducted to provide a premise for future development and testing.

## 3. 580 Road Case Study - Road Segment Intervals

The 580 Road in Oregon State University's McDonald Research Forest will be a primary site for field trials. The 5km road segment includes about 100m of variation in elevation change and slopes ranging from 0-15%. It includes various terrain features representative of a typical forest hauling road in the Pacific Northwest. The road profile illustrated in Figure 1 is derived from a high accuracy digital elevation model (DEM), and a plan view of the 580 Road is shown in Figure 2.

Energy estimations simulations for round trips totaling 10km on the 580 Road segment were conducted to determine the optimal balance of detail and efficiency for input data in the model. The shortest segment was a 10m increment, approximately the length between heavy-duty truck axles, from this baseline, energy estimation was also calculated at road segment intervals of 50m, 100m 250m, 500m, and 1000m, with the aim of determining where the profile data became inaccurate. For this analysis, inaccurate data has been defined as a greater than 5% difference in total energy cost relative to the model at the 10-meter interval, and compared the energy estimation results

Analysis of road segment length enables a detailed examination of how acceleration and deceleration around curves, along with subtle variations in elevation and gradient, influence overall vehicle performance. These finer details, which may be overlooked when using a remotely digitized DEM, are critical for accurately assessing energy consumption and recovery in real-world scenarios but may not be accurately accounted for in the current algorithm.

### 3.1 Results

As the intervals increase in size, the accuracy of the energy estimations declines. For instance, at the 1-kilometer interval, many peaks and troughs visible at shorter intervals are no longer accurately represented (Figure 3).

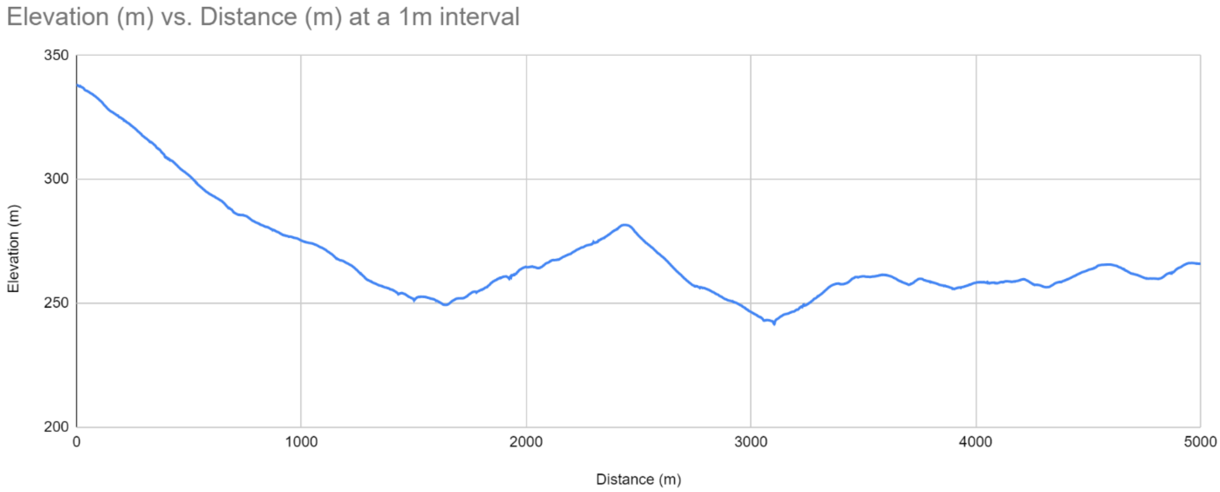


**Figure 1 - The 580 Road profile at a sub-meter interval**

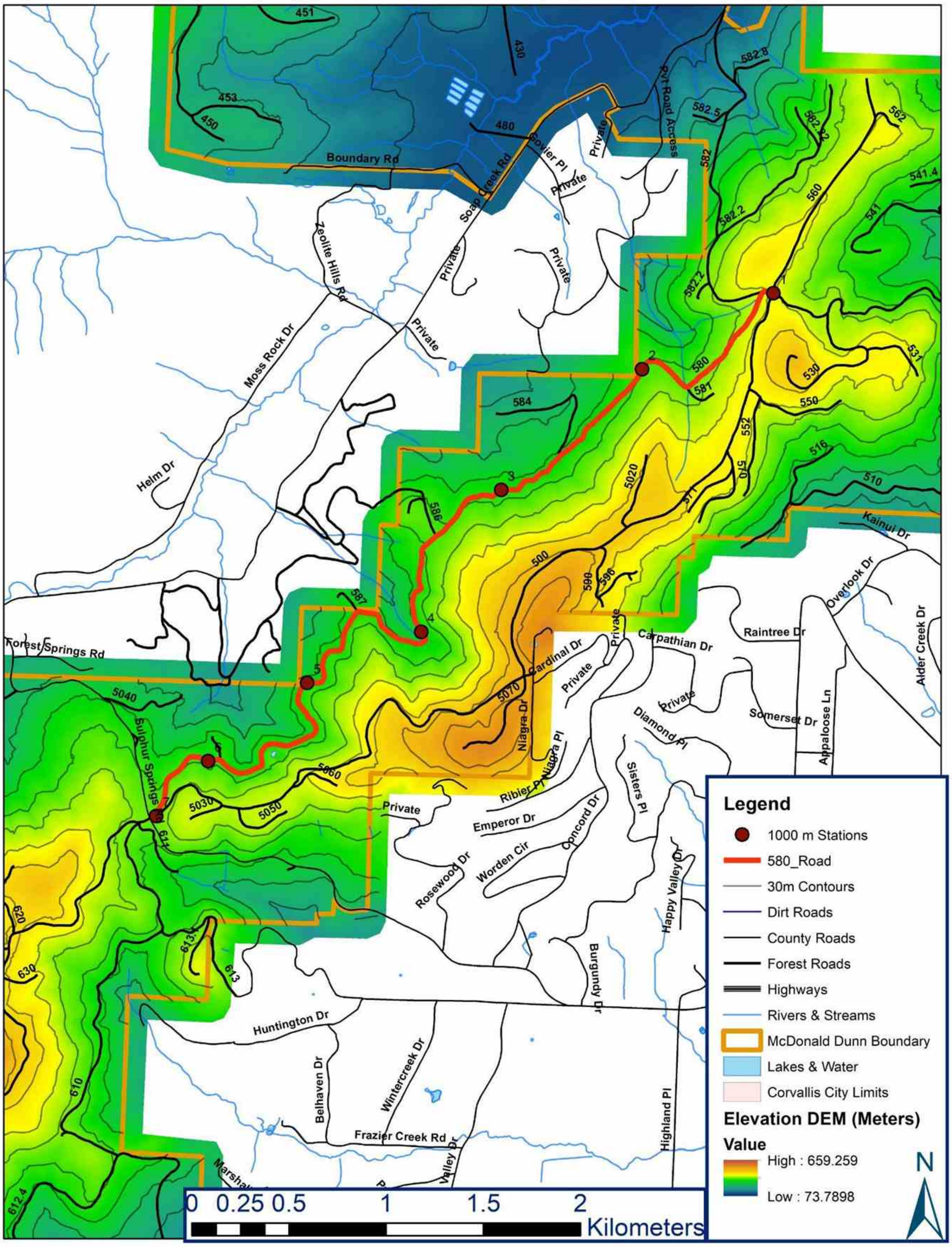


**Figure 2 - A plan view of a 5km of the 580 Road in the McDonald-Dunn research forest**

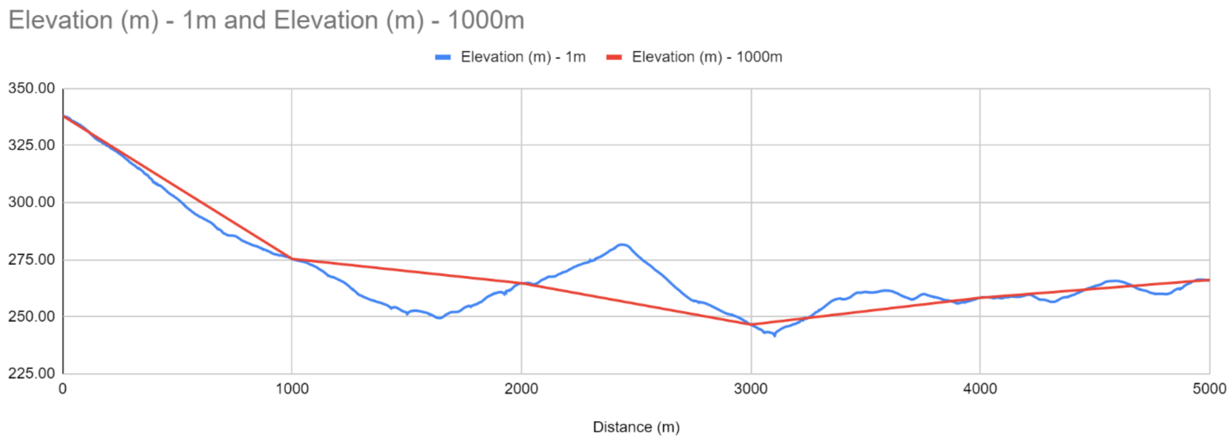


**Figure 3 - The 580-road profile with a 1km edge interval overlayed**

Energy analyses comparing round-trip journeys at various road segment lengths (Table 1) consistently show that as segment length increases, energy estimates decrease if the simple rule is to apply the regenerative brake whenever conditions permit it without considering the permissible velocity profile ahead. Notably, the results of this analysis show there was a 2% reduction in energy estimation when moving from 10-meter to 50-meter intervals. This difference increased to 5% at 100 meters, and then sharply jumped to 13% and 14% at the 250-meter and 500-meter intervals, respectively. These findings reveal threshold points where energy estimation simulation accuracy declines more significantly. The 10m interval may lead to a significant overestimation without a look ahead rule and the thresholds at larger scales may possibly correspond to the real energy expenditure of a truck which would avoid braking on rolling hills, since conserving momentum where possible is ideal.

**Table 1 – Simulated energy results from digitization of the 580 road**

| Target Edge Length (m) | Joules | KiloJoules | Dist(m) | T(min) | KWH | Joules/M | Start Stn | End Stn | Joules % diff |
|---|---|---|---|---|---|---|---|---|---|
| 1000 | 55328443.09 | 55328.4 | 10000 | 18.64 | 15.369 | 5532.8443 | 1 | 6 | -33.019 |
| 500 | 70873333.44 | 70873.3 | 10000 | 18.64 | 19.6871 | 7087.3333 | 1 | 11 | -14.2003 |
| 250 | 71796998.04 | 71797 | 10000 | 18.64 | 19.9436 | 7179.6998 | 1 | 21 | -13.0821 |
| 100 | 78425415.7 | 78425.4 | 10000 | 18.64 | 21.7849 | 7842.5416 | 1 | 51 | -5.05767 |
| 50 | 81054748.17 | 81054.7 | 10000 | 18.64 | 22.5152 | 8105.4748 | 1 | 101 | -1.87459 |
| 10 | 82603217.21 | 82603.2 | 10000 | 18.64 | 22.9454 | 8260.3217 | 1 | 501 | 0 |

Given the time-intensive nature of route digitization at shorter intervals, our objective is to maximize interval length while accurately capturing changes in road surface and profile conditions. The goal is to balance efficiency with energy estimation accuracy for the energy estimations, as the highest resolution data would be axle length (10m). Based on the results of this analysis, 100m segment length may be optimal in this terrain because it was the largest segment that presented results within 5% of the baseline. However, the baseline is likely an overestimation because  drivers can conserve momentum and avoid breaking on small rolling hills and other micro features of the road.

### 3.2 Ongoing Field Trials

Field validation is essential for scaling FEVER's utility across extensive transportation networks. These validations involve deploying heavy-duty EVs over multi-kilometer routes under actual operating conditions, comparing simulated energy usage with observed outcomes. This comparison will not only verify FEVER's algorithms with in-situ testing but also identify areas where further refinement is required.

For example, integrating data from real-world logistics operations—such as load distribution patterns, environmental factors like air resistance, temperature, and road surface variations—enables FEVER to simulate comprehensive scenarios. These tests are planned across different road conditions and grades to ensure that the tool is adaptable to diverse terrain. In forestry, macro-scale tests are planned to evaluate FEVER's ability to optimize energy use for trucks hauling varying loads on rugged roads. In the future, urban tests might assess its efficiency for electric garbage trucks operating on fixed city routes.

Beyond validation, field trials will facilitate stakeholder engagement, providing potential adopters with a transparent view of FEVER's capabilities. By showcasing accurate predictions of energy savings and operational efficiency, these trials will provide evidence to build confidence in the transition to EV systems for medium and heavy-duty vehicle industries.

Field trials using a battery-electric truck, a Class 8 Freightliner E-Cascadia operated by Titan Freight Systems (Lockridge, 2023), are taking place from January to May 2025. The testing sites are dispersed around the McDonald-Dunn Research Forest and a map with an identified sites can be found in Figure 2. The results from the field testing will be presented at the HVTT18 conference.

The vehicle’s performance is being tested in a range of conditions, both loaded and unloaded using a 20 foot (6m) trailer with a gross vehicle weight of 15,172 kilograms. The 3,919 kilogram load consisted of 3 concrete blocks, spaced equidistant inside the trailer.

To enhance its accuracy and reliability, real-world trials involving heavy-duty EVs operating across diverse terrains are essential. These trials will provide critical training data to refine FEVER’s models and algorithms. Additionally, incorporating performance data from Internal Combustion Engine (ICE) vehicles will allow for comparisons between EVs and ICE systems, offering users a comprehensive evaluation of their relative efficiencies (Smith *et al.*, 2020).

## 4. Conclusion

FEVER is a novel tool designed to provide accurate, energy-optimized routing solutions for electric vehicles by accounting for regenerative braking, load variations, and dynamic terrain. The tool has been tested in simulation and algorithm assumptions are in the process of being addressed and improved. The next phase of development will incorporate data from in-situ testing of heavy-duty electric vehicles in forest road conditions.

As the heavy-duty transportation sector moves toward decarbonization, FEVER is poised to offer a practical, data-driven pathway to accelerate EV adoption and maximize returns on investment while supporting global sustainability goals by demonstrating that these systems can meet or exceed the performance and efficiency of traditional ICE vehicles.

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