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Data-Driven Insights into Truck Electrification in Sweden and the US: a Model for Transnational Collaboration

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Executive Summary

This report summarizes a joint international effort between CALSTART (U.S.) and Lindholmen Science Park (Sweden) to evaluate the deployment of battery electric trucks (BETs) through real-world demonstration projects. The Exchange for More BETs initiative examines operational challenges, infrastructure needs, and environmental impacts from projects in both countries. Highlights include Sweden's large-scale logistics pilots (DHEELS, REEL, E-Charge) and the U.S.'s diverse demonstrations (Volvo LIGHTS, JETSI, Frito-Lay ZANZEFF, South Fresno PepsiCo). The report provides insights into BET performance, fleet readiness, charging technologies, and cross-country learning potential—moving the industry towards scaling zero-emission freight transport globally.

Keywords: Heavy Duty electric Vehicles & Buses, Off-Road & Industrial electric Vehicles, Public Policy & Promotion, Environmental Impact, International Networking

1 Background

The urgent need to reduce greenhouse gas emissions requires a strong focus on the transport sector, particularly on trucks due to their significant carbon footprint. Battery-electric trucks (BETs) have the potential to provide substantial benefits, including lower energy costs and reduced maintenance. However, these advantages must be validated and quantified through real-world deployments. While demonstration projects have been ongoing for several years, their results and broader implications for the future of transportation have not been systematically analyzed across national borders. Despite the early stage of the BET market, Sweden and the U.S. are leading the development and deployment of this technology. The accelerated adoption of BETs depends on effective data collection and open communication about both the successes and challenges experienced by early adopters. International knowledge sharing can drive innovation by highlighting different strategies used to overcome common barriers to adoption. CALSTART and Lindholmen Science Park (LSP) have played key roles in early deployment projects in the U.S. and Sweden, respectively, working to understand how these vehicles perform in real-world fleet operations. CALSTART is a mission-driven industry organization focused on transportation decarbonization and with a history of supporting the demonstration, deployment, testing, and data collection of advanced vehicle technologies—particularly medium-duty and heavy-duty vehicles—to validate performance and provide value-add analysis supporting commercialization and market success beyond the demonstration and testing period. LSP hosts multiple Swedish collaboration platforms that unite industry, academia, and public organizations to accelerate the transition to sustainable and efficient transport systems. By facilitating knowledge exchange and real-world demonstrations, LSP helps drive the development and implementation of future-ready transport solutions. This report summarizes the results of the *Exchange for More BETs* project, a collaboration between CALSTART and LSP funded by the Swedish Innovation Agency's *Future Mobility* program. The overall goal is to examine what has worked well, what challenges remain, and how lessons learned in one country can benefit the other.

2 BET deployments investigated

In this chapter an overview of the projects which the report is based on will be presented (Table 1).

Table 1: Deployment projects highlighted in this report

Project	Location	Brief description
DHEELS	SE	Deploy and evaluate energy effective logistics systems with high-capacity transport truck train configurations with lengths of up to 35 meters and total gross weight of up to 110 metric tons
E-Charge	SE	Partners collaborating to develop, test, and demonstrate BETs in real logistics operations across Sweden, with tailored charging strategies
REEL	SE	National initiative electrifying trucks in over 70 regional logistics flows which are established, operated, and systematically evaluated
Volvo LIGHTS	US	15 organizations demonstrating ZE technologies including forklifts, yard tractors, and BETs as well as solar panels and energy storage systems
Frito-Lay ZANZEFF	US	Replacing diesel-powered equipment within a large food production facility, deploying the first Tesla Semi BETs

2.1 DHEELS – Demonstrating highly energy effective logistics solutions

This project is developing and evaluating efficient logistics systems with high-capacity truck-train configurations (lengths up to 35 m and GVWR up to 90 tons) [1]. Figure 1 illustrates the locations and vehicle combinations. Some will incorporate e-trailers (trailers with battery energy storage systems (BESS) and/or regenerative braking and/or propulsion assistance). These will be tested in with both internal combustion engine (ICE) trucks and BETs. E-trailers have the potential to reduce energy consumption and extend range, significantly lowering emissions from ICE trucks while enhancing flexibility for BETs. The project will test various logistics configurations that align with future sustainability requirements.

2.2 E-Charge

E-Charge is a Swedish project gathering 14 partners from the industry and academia to demonstrate BETs for long-haul [2]. The project utilizes EU-regulated breaks for drivers: after 4.5 hours, they must rest for 45 minutes before another 4.5 hours, providing an opportunity to charge on route. A first edition of the Megawatt Charging System (MCS) capable of delivering about 800 kW are installed at three public locations, supporting fleets in southern Sweden over a year (Figure 1).

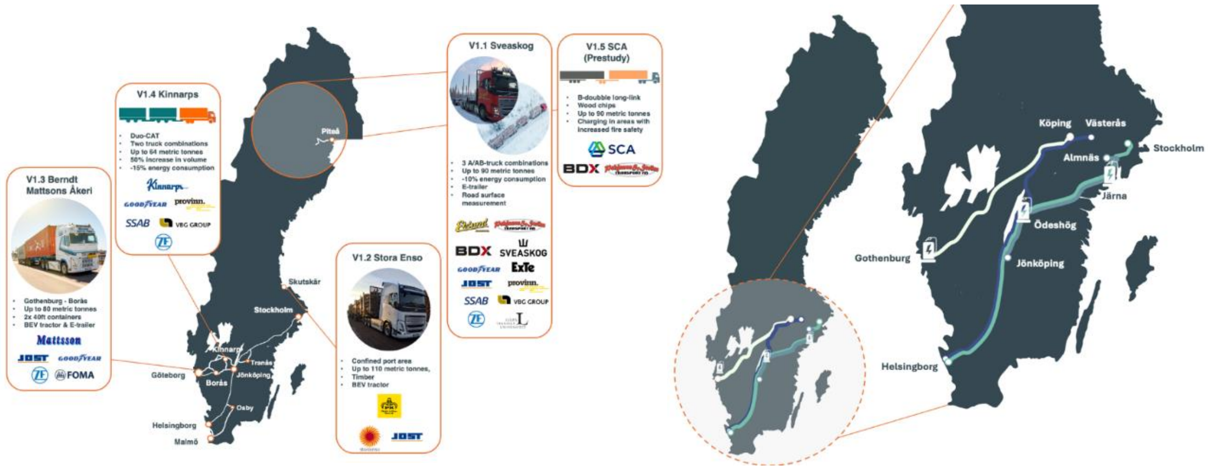

Figure 1: Map of participants in DHEELS (left); Map of routes for E-Charge (right). The charging symbol indicates MCS chargers. Three of four routes will use MCS charging

One of the MCS chargers is connected to a BESS as an alternative to upgrading the grid connection. The system demonstration in E-Charge will be one of the first tests of BETs for long-haul in Europe. A follow-up project was awarded from the Swedish state in 2024. E-Charge 2 will gather 37 organizations towards the goal of operating up to 200 BETs by the end of 2027. This will provide insights on how a large-scale transport system with BETs should be designed based on data from operating BETs on demanding routes.

2.3 REEL – Regional Electrified Logistics

REEL is a national initiative joining Swedish stakeholders to accelerate the transition to electrified, emission-free heavy road transport [3]. The project serves as one of the most comprehensive knowledge sources on BETs in Europe. Over 70 regional logistics routes covering a wide range of goods types and duty cycles have been established, operated, and evaluated. REEL brings together stakeholders including transport buyers, freight forwarders, distributors, haulage companies, terminal operators, charge point operators, utility companies, and equipment suppliers. Over 70 BETs have been in operation for at least one year. Most of the trucks remain in service under normal conditions with an expected lifespan of five to eight years. Before deploying BETs in REEL, extensive planning was conducted. The wide range of truck applications and geographical contexts has led to considerable variation in the results.

2.4 Volvo LIGHTS

Disadvantaged communities in Southern California, one of the most congested and polluted regions of the U.S., are often the most negatively impacted by goods movement as hundreds of trucks drive to and from the ports every day. Volvo LIGHTS was a collaboration among 15 organizations to demonstrate BETs at two freight facilities that run this duty cycle. The California Air Resources Board (CARB) invested in this project to promote the demonstration and deployment of clean technologies specifically within disadvantaged communities [4]. A map of the BET demonstrations below shows the routes drivers traveled during daily operations. Two 150 kW chargers were installed at the two facilities in addition to solar panels and BESS. The BETs' battery capacities ranged from 264-396 kWh. The project included the truck dealership - recognized as the nation's first certified Volvo electric truck maintenance provider - to support the BETs, offering unique insight into the costs, barriers, and business models for maintaining electric trucks. The Joint Electric Truck Scaling Initiative (JETSI) project currently underway represents an expansion of this concept by CARB, with two fleets each deploying 50 BETs along with the associated charging infrastructure and solar energy generation. This project will be a case study for understanding the kind of large-scale fleet conversion that will be necessary in coming years.

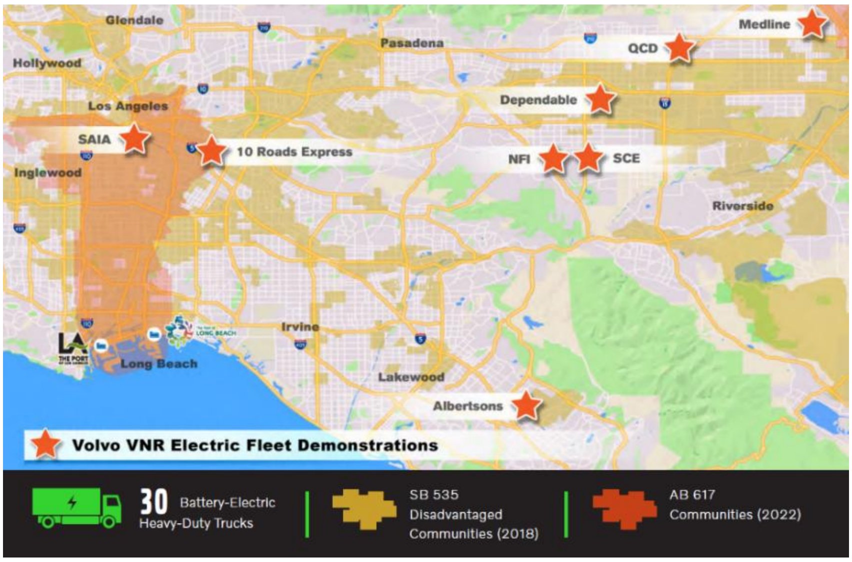

Figure 2: Map of participants in the Volvo LIGHTS project and regions most affected by air quality issues

2.5 Frito-Lay ZANZEFF

The Frito-Lay Transformative Zero- and Near-Zero-Emission Freight Facilities (ZANZEFF) project was a collaborative effort among 14 organizations to showcase several zero-emission (ZE) technologies, including 15 heavy-duty BETs and six medium-duty BETs [5]. Six 125-kW dual-port DC fast chargers were installed at the demonstration facility in Modesto, California to charge the fleet's battery-electric straight trucks as well as their off-road yard tractors. Additionally, onsite PV solar generation, two BESS, and four 750-kW fast chargers were installed to meet the energy demand from the facility and the BETs. Drivers testing the new trucks were supported by Tesla service technicians who were stationed onsite at the Modesto facility for six to twelve months after the trucks were deployed. Most operators found the Tesla tractors to be a better alternative than the baseline diesel tractors and enjoyed operating them on their daily routes.

Figure 3: Diagram of the facility and technology deployed in the Frito-Lay Modesto project (left); Photo of Tesla Semis deployed in the Pepsi South Fresno project (right).

The South-Central Fresno Pepsi Delivery Truck Electrification Project is the follow up endeavor to the Frito-Lay ZANZEFF Project, kicked off a year after that one was completed. This project is a CARB and California Energy Commission (CEC) funded project that is demonstrating the feasibility electrification of a much larger fleet than the preceding project, showing that electrification can work at scale. It includes 50 BETs, 8 EVSEs, and a BESS. Finally, the project is incorporating and developing a workforce training program. This project officially kicked off in July of 2024 and will continue until spring of 2026. Vehicles were being deployed at the end of 2024 and beginning of 2025 and are, as of writing, currently in service.

3 Demonstrated performance, costs, and operational adjustments

This chapter examines real-world BET deployments. Energy efficiency is a key consideration in comparing BETs with diesel trucks. The figures presented are preliminary, as they include trucks in diverse applications with varying levels of technological maturity. Other factors including cargo weight, refrigeration units, etc. significantly impact energy consumption. Early analysis indicates efficiency can fluctuate up to 47% (average of 34%) seasonally. A comprehensive analysis is underway and will be presented in the final REEL project report. In the ZANZEFF project (U.S.), diesel trucks averaged 482 and the BETs 293 km per day. However, on days with more than 400 km (considered the previous range limit), the BETs averaged 533 km per day over 139 days in operation with the longest single trip measuring 514 km. The average energy efficiency was 0.99 kWh/km. This level of performance has not previously been reported and opens new opportunities for electrification of routes thought to be too demanding (*Table 2*).

Table 2: Results in terms of efficiency and emissions for BET deployments in the U.S. and Sweden. Note that heavy-duty trucks in the U.S. have a maximum GVWR from ~13-36 tons, overlapping with multiple rows.

	Sweden				U.S.			
Truck GVWR	BET		Diesel kWh/km		BET		Diesel kWh/km	
tons	kWh/km	g CO_2e/km	kWh/km	g CO_2e/km	kWh/km	g CO_2e/km	kWh/km	g CO_2e/km
17 – 21	1.39	109.6	3.31	869.9	0.99	198	2.9	751
27 – 30	1.58	114.2	4.41	1,158.9				
31 – 50	1.55	113.5	3.11	817.3				
51 – 74	2.10	126.8	4.5	1,182.6				

Previous research suggests that under suitable conditions, BETs can be cost-competitive with diesel trucks [6-9]. However, most studies are theoretical rather than using empirical cost data and can incorporate anticipated advancements that are not yet market-ready [10,11]. Maintenance and energy costs are generally lower for BETs, but total cost of operation can be difficult to calculate especially beyond the first few years. Given the limited availability of data, the results gathered here aim to provide insights into the economic realities of BETs, examining initial cost and operational costs over time. This approach is widely applied within the trucking industry [12]. Current incentives in Sweden allow a maximum 20% of total cost support for BETs or infrastructure [13].

With the introduction of electric operation, the distribution of cost types shifts. For BETs, capital costs account for 35-40% compared to 10-20% for diesel. However, energy-related costs for BETs are notably lower: 5-10% compared to 30% for diesel. For Swedish stakeholders, no substantial changes have been observed in the cost categories including insurance and taxes. This may be because service contracts are similar for electric and diesel trucks due to lack of data for real costs. In the U.S., taxes and insurance are both a function of the initial cost of the vehicle without incentives. So, BETs are saddled with much higher costs in these categories even when their upfront cost has been subsidized substantially, making it harder to reach economic parity.

The DOE Medium- and Heavy-Duty Data Collection project collected data on BETs across the U.S. Using the average real-world energy efficiency for each of the six BET platforms, energy cost savings versus diesel counterparts were determined. Estimated per-mile energy cost savings were calculated using real-world BET efficiency, average diesel fuel economy, and projected average U.S. electricity and diesel prices. The average annual distance of each vehicle platform was used to estimate cost savings. When comparing EV and diesel efficiencies, MHD EVs were found to perform an average of 3–6 times as efficiently as their diesel ICE counterparts, demonstrating that theoretical efficiency advantages hold true in practice. Fleets should save on energy cost from 2021 to 2035, regardless of platform, with the greatest savings for high-mileage vehicles like transit buses ($4,459 annually) and heavy-duty trucks ($3,284 annually). Even when accounting for charging infrastructure, MHD EVs were still projected to be less expensive per mile than diesel MHD vehicles (Figure 4).

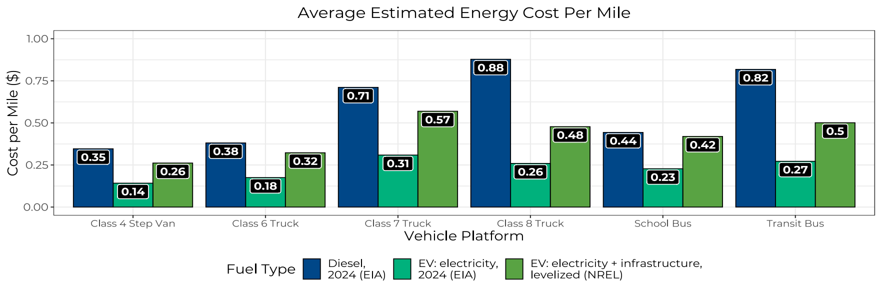

Figure 4: Average estimated energy cost per mile for medium- and heavy-duty vehicle types

As described above, BETs are more efficient than their diesel counterparts and offer significant environmental benefits. However, current limitations in range, payload capacity, and charging time necessitate new strategies for operational efficiency. Despite these challenges, BETs have some advantages over conventional trucks. Implementation of BETs in various Swedish and U.S. initiatives has demonstrated how this technology impacts logistics operations. In some cases, BETs have altered vehicle types used for specific operations and duty cycles. New charging strategies have emerged influencing mileage, freight movement, and operational flexibility. These innovations help offset any limitations BETs might have. Here we highlight several real-world cases and how adjustments have been made to facilitate operations.

Prior to Frito-Lay’s participation in the ZANZEFF project, the fleet utilized Class 8 tractors for all its on-road transportation. Class 6 BETs were adopted to accommodate local retail delivery operations. Despite having a shorter range and a smaller payload than their baseline Class 8 diesel tractors, the new Class 6 BETs completed successfully the newly designed duty cycles. Frito-Lay installed and deployed 250-kW dual-port chargers to power the Class 6 BETs and off-road yard tractors. At first, the fleet did not implement power limitations while charging, incurring about $4,000 USD per month in demand fees. After capping demand at 200 kW, the fleet saved about $24,000 annually. Limiting demand results in slower charging speeds, though one vehicle type can still be prioritized. Because of their 24-hour duty cycle yard tractors were set to receive the fastest charging speeds. The Class 6 BETs were deprioritized and received the slowest charging speeds but could still accommodate this change due to their shorter duty cycle and fewer charging events.

In multiple logistics cases in REEL related to e.g. bulk and food transport the fleets have installed charging equipment at the loading bays/gates at their terminals, to utilize the reloading time for charging. A distributor of chemical products has been operating a BET since 2022 for two shifts and 300 km daily. Their duty-cycle is well-suited to electrification since loading and unloading chemicals takes 45–60 minutes. Charging at these natural standstill periods avoids additional logistical losses. The fleet collaborated closely with its customers to establish install chargers at delivery locations. In areas with limited grid capacity, the fleet has implemented temporary charging solutions paired with BESS.

Several fleets in REEL benefit from how quiet BETs are. One company delivers wood products to construction sites, many in residential areas, and sees significant potential in BETs for early-morning deliveries thanks to their quiet operation. While many residents appreciate the reduced noise, some have expressed concern that BETs are too quiet, raising potential safety risks. Fleets are considering adding synthetic noise systems to alert pedestrians. A wholesale distributor in the REEL project got a special permit from Stockholm City Council for off-peak deliveries using BETs because they are so quiet. This improves logistics by reducing congestion and decreasing travel times. These night shifts required coordination with customers and some minor adjustments as well as more complicated changes like installing secure access points. Night operation gives the fleet a competitive advantage, allowing a BET to replace two diesel trucks by spreading deliveries across more hours of the day.

3.1.1 **Infrastructure availability**

In most REEL use cases, haulers opted to design their operations around depot and terminal charging. Public charging for BETs has been virtually non-existent until recently. Approximately half of the logistics duty cycles in REEL operate on a single-shift schedule with short daily distances ranges, allowing for simple charging solutions including AC chargers up to 44 kW. A key advantage of depot and terminal charging is cost control. Charging at public stations can be twice as expensive compared to at a depot. Additionally, haulers benefit from charging during standstill periods, such as loading and unloading.

However, in Reel, about 75% of vehicles charged almost solely at their home base. Charging at depots and terminal presents several challenges that require resolution. Charging must be synchronized if multiple BETs require charging simultaneously. A fleet's power demand may require exceed its grid capacity, although solar panels and BESS, both of which have been observed in projects in Sweden and the U.S., may mitigate this. The placement of chargers must maintain operational efficiency and balance cost. If a depot has multiple loading area designated for specific trucks, installing chargers at each one will result in low utilization and high cost. A common dilemma is the trade-off between charging speed and infrastructure cost. In real-world operations, losses between the grid and the vehicle have been observed up to 10%. Additionally, charging power curves are nonlinear and influenced by climate, SoC, and power availability.

The landscape for public truck charging in Sweden has changed significantly in recent times. In 2022, only a few public stations for BETs existed. To accelerate development, the Swedish government introduced the Regional Electrification Pilots program in March 2022, issuing 1.4 billion SEK in funding to support public truck charging infrastructure. The program aimed to:

- Establish public high-power charging stations along major transport corridors.
- Reduce industry reliance on depot charging by expanding public access.
- Support hydrogen refueling stations, included in the first funding round.

Despite initial industry calls for including private charging, EU state aid rules at the time prevented authorities from subsidizing non-public infrastructure. Up to 100% funding was offered and 130 locations were awarded. Since then, this approach has identified 250 sites across Sweden (Figure 5) [13]. At the end of 2024, approximately 60 were in operation. There are also examples of other station built without any governmental support. This program is linked to the EU regulation AFIR, Alternative Fuel Infrastructure Regulation, setting targets for member states to meet in the coming years. The Swedish program is a tool to ensure that Sweden reaches the target levels stated by AFIR in time.

Figure 5: Public charging stations for trucks in Sweden. The map illustrates charging stations dedicated for trucks granted co-funding by Swedish Energy Agency through the Region Electrification Pilots program.

The U.S. has adopted several aggressive clean transportation policies to support the widespread production and adoption of BETs. The development of public charging infrastructure is essential to support the ramp up in energy demand following the deployment of BETs. To understand the impact this may have on the national grid, CALSTART modeled commercial vehicle activity on the National Highway Freight Network—the critical backbone of U.S. truck travel—to project which proportions of traffic could be transitioned to BETs over time and the necessary infrastructure (Figure 6) [14].

Figure 6: Average annual increase in daily energy consumption from new BET sales (2023-2035)

CALSTART's projections demonstrate that the emerging energy needs of BETs can be managed through a multi-phased deployment. First, infrastructure will be focused on depots and regional charging hubs in key areas. Next, deployments will focus on key corridors to enable regional operations. The final phase focuses on the construction of networks to connect corridors to each other and other critical infrastructure (Figure 7).

Figure 7: Illustration of site configurations and functions in priority launch areas

At the depot level, efforts are underway to aggregate demand among multiple fleets at a shared infrastructure. Charging-as-a-Service strategies are now the basis of many projects within depots, utilizing a reservation systems or per-charge solutions to service a set of fleets [14]. Major investments on corridor-level pull-through charging show that this is a viable model and at scale could produce major advancements. This may not remove the need for depot charging, but it does provide the synergy required to accelerate BET adoption and allow charger utilization to increase.

3.1.2 Power supply and energy storage

Currently, BETs in Europe are equipped with CCS2 (Combined Charging System) inlets. Recognizing the limitations of CCS2, a global initiative led by CharIN was developed the Megawatt Charging System (MCS) to surpass the megawatt threshold, significantly reducing charging times for BETs. MCS is anticipated to be finalized by 2025–2026 and to be widely adopted by BETs, electric aircraft, and maritime applications. The Swedish project E-Charge will be one of the first demonstration of BETs for long-haul application in Europe. Three of the four BETs in the project will be MCS capable. Three MCS chargers with up to 1 MW are currently being built at three public locations. The BETs will use these sites regularly while on duty. The performance target is driving for 4.5 hours, charging for 45 minutes, and driving for another 4.5 hours as mandated by European regulation. The E-Charge project will be succeeded by the E-Charge 2 project funded by the Swedish strategic vehicle R&I program, FFI. The demonstration will be expanded to more fleets operating upwards of 200 BETs for long-haul applications by the end of 2027. More emphasis will be put on the public charging infrastructure which already exists in the country. The project is expected to study how an electric long-haul road transport system will perform by concentrating logistics flows along major corridors.

The transition to BETs presents new challenges and opportunities related to power supply within the logistics sector. The demand for electricity fluctuates based on factors such as fleet size, operational schedules, charging speeds, and grid availability. To address these challenges, fleets in REEL are increasingly exploring smart power management, including BESS, local energy generation, and dynamic grid agreements. BESS are becoming a crucial component of electrified fleets. They can mitigate grid constraints, reduce peak power demand, and enable participation in energy markets, enhancing financial viability. Additionally, on-site energy generation, such as solar photovoltaic (PV) systems, is gaining traction as companies seek greater energy independence and cost control. However, integrating these energy solutions requires strategic planning to balance charging demand, energy availability, and grid interactions.

One company in REEL has built one of the first public charging stations in Sweden and they are about to add another 70 BETs in Q4 2025. The station in Malmö has 30 charging points each at 100 kW. Only 1.7 MW of power is available from the grid but through a conditional agreement power can be temporarily increased to 2.5 MW by utilizing excess capacity from neighboring facilities. Traditionally, utilities are required to provide the full amount of power requested, but the lead time upgrading power levels can extend to several years. Conditional agreements offer an alternative approach by allowing customers to agree to flexibility in their maximum power supply. The agreements vary in structure but typically included dynamic power allocation (less power when during peak demand) and scalable capacity (option to expand as needed). By avoiding planning for peak demand, these agreements reduce overall lead times for grid expansion, improve power distribution, and support grid stability [15].

To optimize costs, fleets can utilize a BESS with software to minimize power demand. BESS can also participate in ancillary grid services (i.e. help maintain a grid frequency of 50 Hz), generating significant revenue and shortening the payback period for the investment. Beyond energy storage fleets can become energy producers. In Perstorp, Skåne County, a fleet has developed a solar park to generate electricity for its expanding charging network. As more stations are deployed, self-sufficiency can be improved by integrating renewable energy sources. In the first E-Charge project, one of the MCS chargers will be supported by a BESS, which was deemed more cost effective and time efficient than upgrading the local grid.

In the U.S., some utilities in California are working with fleets to deliver charging solutions meet near-term needs. In 2025, the Pacific Gas and Electric Company (PG&E) will launch its Flex Connect Pilot Program, allowing customers with controllable loads to connect to the grid without a capacity upgrade. PG&E coordinates a site’s demand based on when supply is readily available and allows a site to connect while waiting for the necessary long-term infrastructure upgrades. The site’s energy management system sends hourly power limit forecasts a day in advance. The South-Central Fresno Pepsi Delivery Truck Electrification Project site will utilize PG&E’s Flex Connect Pilot program to deploy 50 BETs sooner than the typical waiting period, which can exceed 24 months. Southern California Edison (SCE) is another large electric utility in the US. They have historically waived demand charges for commercial fleets operating BETs. Demand charges are fees that reflect the highest power level used over a given billing period, regardless of how much actual energy is consumed. These demand charges can be exorbitant and hurt a fleet's operating costs, so the waiver is a welcome reprieve.

4 Policy

The European Union (EU) and California/U.S. have implemented a comprehensive set of policies to accelerate the transition of heavy-duty vehicles to BETs. These measures encompass both enforcement-driven "push" mechanisms and incentive-based "pull" strategies, as illustrated in Figure 3. The objective of these policies is to establish incentives for adopting BETs while also disincentivizing the diesel trucks through cost and regulatory constraints. In the EU, efforts focus on harmonizing policies across member states to foster a cohesive ecosystem for BET deployment. Key areas include scaling up charging infrastructure, integrating renewable energy sources, and providing targeted funding opportunities. California, similarly, has enacted progressive policies aimed at advancing ZE technologies, emphasizing local air quality improvements and carbon reduction targets. The following sections provide a detailed overview of the primary policy mechanisms in the EU and California/U.S.

4.1 Taxation and market mechanisms

The EU provides a framework for the taxation of energy products and electricity, enabling countries to influence energy consumption patterns [16]. This can be achieved via tax differentiation (tax rates can used to promote low-carbon alternatives), tax exemptions and reductions (taxes may be reduced for renewable energy), and level of taxation (minimum levels set for energy products, allowing higher taxes on conventional fuels). The U.S. does not have a carbon tax any level. Any new tax at a federal level is a challenge in the US, but states have attempted to enact this kind of policy. The Carbon Tax Center rates eight states as promising, and six plus Washington, DC are rated as having some potential. There is a single instance of an energy tax in the U.S. in the city of Boulder, Colorado. In 2006 Boulder adopted a tax with the explicit goal of curbing energy usage and emissions in accordance with the Kyoto Protocol. The tax was renewed in 2013 and again in 2022. An additional tax is applied on all energy bills, with exceptions for low-income residents and rebates for solar and wind power.

Starting in 2027, the revised EU Emissions Trading System (EU ETS 2) will use a market mechanism to incentivize the reduction of greenhouse gas (GHG) emissions [17]. This system will cap total GHG emissions and require stakeholders to purchase a cap-and-trade system. The total quantity of allowances will decrease by 5.1% annually to reach the of 43% by 2030 compared to 2005. For reference, between 2005-2021, the annual average emission reduction was about 11 Mt CO2 [18]. The ETS 2 cap decreases by about 62 Mt CO2 per year, more than five times as fast. Allowances will be auctioned but the expected prices vary greatly. At a price of 55 EUR/ ton of CO2, the diesel price in Sweden is estimated to rise by around a 10% increase [19]. To mitigate price surges and ensure stability, the EU ETS 2 incorporates a Market Stability Reserve (MSR) to provide flexibility to as the market moves towards its goals. The U.S. does not have a single national cap-and-trade program, but individual states have experimented with systems similar to that described above. The California program (California Climate Investments) has been especially successful. California Climate Investments puts billions of dollars of cap-and-trade auction proceeds to work reducing greenhouse gas emissions, strengthening the economy, improving public health and the environment, and providing meaningful benefits to disadvantaged communities and low-income communities and households.

4.2 Funding programs and incentives

The General Block Exemption Regulation (GBER) allows EU member states to grant certain categories of state aid without prior approval from the European Commission [20]. Article 36b outlines the conditions for investment aid for the acquisition of BETs or charging infrastructure, including the purchase or leasing of vehicles at up to 100% of eligible costs. For infrastructure, it must be public access without discriminating regarding pricing, authentication, and payment methods. Further EU regulation sets mandatory deployment targets for renewable fuel infrastructure across EU member states to support ZE mobility [21]. These targets aim to establish fueling infrastructure for BETs along key transport routes by 2025-2030. Charging sites with a minimum of 350 kW must be deployed every 60 km along the TEN-T core network and every 100 km on the broader TEN-T network. Simple and transparent payment methods at charging stations is mandated, without requiring subscriptions. The stations must also provide digital access to real-time data on availability, waiting times, and prices, ensuring fleets can make informed decisions efficiently.

In the U.S., tax breaks, direct cash incentives, and benefits for green energy projects are strategies to accelerate BETs. Recently, the Inflation Reduction Act of 2022 greatly expanded these offerings, with the total amount of tax credits over the next ten years over $226 billion. As part of its Clean Truck and Bus Voucher Incentive Project (known as HVIP), CARB has provided over $1.6 billion to place 15,207 vans, buses, and trucks on California's streets since 2010. On the infrastructure side, the California Energy Commission funds the EnergIIZE program, which has invested over $146 million installing 3,555 charging or hydrogen ports for trucks.

5 Discussion of further innovation needs and pending concepts

In the U.S., commercial fleets in the freight transport industry—particularly in the drayage sector—have been pressured to decarbonize their operations by adopting BETs. However, converting this sector remains a challenge. Drayage fleets are primarily of owner-operators, or independent contractors who own or lease their trucks and contract with port terminals to haul freight. As of June 30, 2022, California Assembly Bill 5 has reclassified many owner-operators as employees rather than independent contractors, significantly impacting the 70,000 driving in California. Stakeholders stand divided, with proponents arguing that the independent contractor designation limits employee benefits and legal protections, while opponents argue this change limits business flexibility and profitability. The diffuse nature of these owner-operators makes provisioning the requisite charging infrastructure even more difficult, beyond the typical issues of long lead times, energy and power concerns, and unforeseen costs.

Public pledges to buy BETs signal to manufacturers that there is latent demand, reducing their investment risk and accelerating production timelines. Going further, if fleets can pool their orders in aggregated purchases, manufacturers could provide bulk discounts while scaling-up production, lowering future costs. As part of such a plan, hardware such as chargers, connectors, and mounting systems have an opportunity for standardization that would reduce procurement cost, simplify maintenance and parts inventory, and streamline the training for technicians. Modular charging units that arrive preassembled can help accelerate BET truck deployment.

Electrified logistic systems are expected to become more complex than diesel-based systems especially if there are variations in routing and scheduling from day to day. Grant-funded pilot and demonstration projects centered on deploying BETs at freight facilities have yielded insights into the capital and operating costs. However, findings vary significantly due to factors like duty cycles and utility costs. Data collection on BET maintenance and repairs in the long-term is also lacking. Demonstrations for scaled solutions are needed to understand the most crucial issues. Experiences from several BET deployments show that turnover times at logistics hubs might be short, requiring high power levels for meaningful opportunity charging without disturbing operations. Combining activities such as loading or unloading with charging could help. Several locations at a logistics site might be suitable for charging depending on work task, so even choosing the spot in a depot might be a challenge. When charging is not required simultaneously, power can be shared between stations at the same depot. Utilizing loading time to charge the vehicle at a terminal makes sense. However, terminal gates may be used unevenly, or a terminal might have hundreds of gates, or they may be dedicated to certain vehicles or goods. Thus, placement, amount, and power need to be modeled to ensure the that the right truck gets the right power at the right time and place. Sharing power and keeping total power as low as possible has compounded economic benefits, so fleets must optimize for cost.

To encourage implementation of BETS, strong incentives are needed. The local, regional, and national governments play an important role here. Economic benefits are required at a time when recession and unstable economic and political landscape is present to provide clear paths for the industry. Low emission zones or alternative schedules for BETS are possible measures. Truck patterns differ from those of cars: the higher power levels and larger batteries mean that battery cells, power electronics, and control strategies need to be designed to handle the strain. Access to a repository of typical real time driving patterns for different logistic applications is needed. It would be of great value if this type of data could be generated in collaboration among fleets, OEMs, and other stakeholders.

Access to charging power is a crucial problem for scaling up BETs. Publicly accessible and shared charging stations for BETs is currently in the nascent stage in the U.S. while Sweden has a more strategic national plan. Flexible market mechanisms could accelerate deployment. For example, SCE's flexible and innovative policies have facilitated the adoption of BETs by commercial fleets, with the Charge Ready Transport Program facilitating deployment of 100 BETs as part of the Joint Electric Truck Scaling Initiative. The program offers commercial fleets low-cost system upgrades to support EVSE installation, which has been instrumental in providing the planning, design, and construction that often discourages BET adoption.

6 Conclusion

Both the EU and the U.S. have enacted policy frameworks designed to incentivize the adoption of BETs while simultaneously disincentivizing diesel trucks. However, approaches diverge significantly. To regulate emissions, the EU has a prescriptive methodology, establishing reduction targets and imposing financial penalties for non-compliance. In contrast, the U.S. uses a gradual and technology-neutral approach, relying on broader emissions standards and flexible compliance mechanisms. Both the EU and U.S. offer funding and subsidies to support BET adoption. EU member states can provide aid for BETs and charging infrastructure, thanks to exemptions from state aid rules. However, non-public charging infrastructure is not included. The EU has also used road tolls to promote adoption through exemptions or reductions for BETs. In the U.S., funding is primarily channeled through tax credits and incentives, notably the Inflation Reduction Act of 2022, and state-level programs such as HVIP (to lower the upfront cost) and LCFS (to lower operating costs) of BETs. The EU directly imposes economic disincentives on non-ZE vehicles such as a carbon taxation scheme and emissions trading. The U.S. lacks a carbon tax, opting instead for tax incentives. Some U.S. states like California and Washington also have cap-and-trade programs, providing indirect support for BETs. In conclusion, both the EU and the U.S., have implemented comprehensive policy instruments to accelerate BET deployment. However, the EU favors a prescriptive and regulatory approach with clear targets, financial penalties, and infrastructure mandates. The U.S. relies more on incentives, tax breaks, and voluntary measures, with individual states such as California leading progress. Future policy development should prioritize these gaps to ensure a rapid and equitable transition to BETs.

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Presenter Biography

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