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MAIN SPREADING LIMITATIONS OF BATTERY-ELECTRIC VEHICLES

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Abstract
This paper analyzes the key limitations of battery-electric vehicles (BEVs) across both passenger (light-duty) and commercial (heavy-duty) categories. It examines scientific and practical challenges including limited driving range, high battery weight, charging infrastructure inadequacies, critical material supply, and efficiency losses.
Keywords: battery-electric vehicle (BEV); range; battery weight; heavy-duty electric truck; energy density.

Introduction Battery-electric vehicles (BEVs) have made significant inroads in both personal transportation and freight applications. However, they still face notable limitations that impact their performance and adoption in light-duty (passenger cars) and heavy-duty (buses and trucks) contexts [1]. These limitations include restricted driving range, substantial battery weight, long charging times, supply constraints for battery materials, and various efficiency losses.

One fundamental challenge is the trade-off between battery size (energy capacity) and vehicle weight. Batteries are heavy, so increasing a BEV's range by adding more battery capacity yields diminishing returns in range gained per added weight[2]. In other words, oversizing the battery beyond a certain point can actually reduce overall efficiency and practicality[3]. For instance, analyses indicate that roughly 100 kg of battery can provide on the order of 150 km of range for a typical car [4], but that 100 kg also increases the vehicle's mass and energy consumption. Smaller, lighter BEVs can achieve much lower energy consumption per km than larger ones.

In the heavy-duty sector, battery weight becomes an even more critical issue. A battery electric truck requires a very large battery to achieve long-haul range, which can weigh several tonnes. This added mass directly reduces the payload capacity and efficiency of the truck. Regulators have even raised legal weight limits (for example, an extra 2,000 lb allowance in the US) to accommodate electric trucks, yet an electric semi-truck still sacrifices around 5,000 lb of cargo capacity compared to a diesel truck due to the battery's weight [5]. Real-world tests confirm that BEVs lose more range from added weight than conventional vehicles: a Ford F-150 Lightning electric pickup lost about 24.5% of its driving range when carrying a 1,400 lb payload (dropping from 278 mi to 210 mi), whereas a comparable gasoline truck would be estimated to lose roughly 14% under the same load [6].

Another major limitation is the recharging time and infrastructure for BEVs. Fast charging stations are not yet as ubiquitous as gas stations, especially for heavy-duty vehicles on long routes. A long-haul electric truck today typically has a range of only ~150–330 miles and can take up to 8–10 hours to fully recharge with current technology [7], significantly longer downtime than refueling a diesel truck. Even

light-duty BEVs can require 30 minutes or more to fast-charge to 80% capacity, which is much slower than fueling with liquid fuels.

Although electric drivetrains are far more energy-efficient than internal combustion engines (~85–90% of electrical energy is converted to motion, versus only ~20% for ICEs) [8], there are still efficiency losses in batteries (charging/discharging heat losses), motors, and power electronics. Heavier vehicles not only require more energy to accelerate, but also incur higher rolling resistance. For a vehicle of mass m moving at velocity v, the energy usage per kilometer can be estimated as:

$$E=mgCr+0.5\rho CdAv^2$$

where g is gravitational acceleration, Cr is the rolling resistance coefficient, ρ is air density, Cd is aerodynamic drag coefficient, and A is frontal area.

Modern lithium-ion batteries rely on critical minerals such as lithium, cobalt, and nickel. The rapid growth in EV production has caused a surge in demand for these materials – for example, about 60% of global lithium production is now used for EV batteries [9]. Supply struggles to keep up, creating potential bottlenecks and price increases. External factors like geopolitical events can exacerbate this issue: for instance, battery metal prices spiked by roughly 50% after the start of the Russia–Ukraine war in 2022 [10]. Despite the current limitations, ongoing research is making progress toward solving many BEV challenges. Battery technology is advancing: manufacturers are increasing energy density (Wh/kg) and specific energy of cells to reduce weight for a given range. For example, prototype semi-solid-state lithium batteries have achieved energy densities around 350–360 Wh/kg [11] (about 20% higher than the best current Li-ion cells), which could significantly lighten battery packs or extend range without added weight. Fast-charging capabilities are also improving; new high-power charging systems can recharge batteries much faster. As an illustration, a 500-mile range electric semi-truck can charge about 70% of its battery in 30 minutes using a megawatt-scale charger[12]. In the longer term, alternative solutions such as fuel-cell electric vehicles (which use hydrogen fuel) are also being considered to circumvent some of the weight and charging limitations of batteries.

In summary, while battery-electric vehicles offer a viable zero-emission alternative for both cars and trucks, they still face important limitations in terms of range, weight, charging, and resource requirements. Light-duty BEVs must balance battery size with vehicle efficiency, and heavy-duty BEVs confront especially acute weight and infrastructure challenges in freight operations. So now we still have no robust solution and furthermore using ICE is necessary without clear alternative.

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Основні обмеження поширення батарейно-електричних транспортних засобів

Анотація. У статті аналізуються основні обмеження батарейно-електричних транспортних засобів (BEV) у категоріях легкових та комерційних транспортних засобів. Розглядаються наукові та практичні проблеми, такі як обмежений запас ходу, висока маса акумуляторів, недостатність інфраструктури заряджання, критичні поставки матеріалів і втрати ефективності.

Ключові слова: батарейно-електричний транспортний засіб (BEV); запас ходу; маса акумулятора; важкий електричний вантажівка; енергетична щільність.

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