Battery Electric Long-Haul Trucks

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1 Motivation:

Battery electric technology has clearly been the choice for light vehicles such as personal cars, as evidenced by the increasing market share of EVs. While electrification has succeeded for light vehicles, its application for trucking is currently unclear. This is mainly because trucks have larger energy and power demand, as they carry heavier loads over longer distances. There are numerous factors that need to be carefully analyzed and evaluated before battery electric powertrains can be used for long-haul trucks. Discussed below are some of the key factors:

- Long-haul trucks on average travel 600 miles per day for 11 hours [2]. This requires large batteries to supply around 1000-2000 kWh in a single charge. Batteries significantly increase capital cost, which in-turn increases trucking prices.
- Trucks are weight-constrained; heavy batteries take space that can be used to transport goods. This loss in cargo capacity ends up being paid by the truck owners as a "payload penalty".
- Battery electric trucks (BETs) do not emit CO_2 emissions while they are driven. However, emissions arrive from electricity generation. Existing and projected national electricity grid will have significant contributions from fossil fuels such as coal, natural gas, etc. We must cover emissions generated during production, distribution and end-use, ie. Well-to-Wheel analysis (WTW).

Charging infrastructure:

- Time spend charging batteries is time lost delivery goods. Given long hours of operations (11 hours), there is minimal downtime during the day.
- Long-haul trucks primarily operate with flexible routes. They need to recharge at many locations across the interstate highways. Current charging infrastructure fails to meet these needs. The existing fast charging options (50-350 kW [3]) become insufficient for long haul, which requires ultra-fast technologies (1000 W), do not exist today.

2 Methods and Results:

A comprehensive analysis of BETs is needed to better understand the possible implications of truck electrification under all these factors. This knowledge gap has motivated our work on developing a benchmark for BETs that realistically represents US long hauling. Our drive cycle built from real-world driving data was used to determine daily power requirements. We developed a technical battery model with the energy to sustain the duty cycle. The total cost of ownership was estimated for the trucks, considering penalties for charging during shifts and payload losses. Well-to-Wheel emissions were also modeled and translated to monetary terms through carbon taxes.

2.1 Battery Electric Performance:

Our model for BETs requires on average 3.25 kWh per mile travelled (payload penalty included). For an average daily range of 600 miles, the heavy duty truck demands around 1500 kWh. A battery this size will weigh roughly 6 tonnes, around 30% of the total cargo capacity. This loss of payload impacts the overall economy of the trucking business by about 17%.

In general, the operating costs (OPEX) of BETs dominate the Total Cost of Ownership, with up to $USD 1.6 million in present-day. Operating cost primarily comprises of cost of electricity, labor, payload penalty, and carbon tax. The cost of electricity at ultra-fast chargers is uncertain. A reasonable approximation is $0.35/kWh, based on electricity prices at fast chargers. At this price, the total electricity cost dominates OPEX by 40% in the long term. A daily trip will cost around $ 680 for electricity with ultra-fast direct charging. The carbon tax was estimated to be the Social Cost of Carbon (SCC). We used the SCC values reported by the Biden administration (Present day=$USD 51/ton CO_2 and Long-Term=$USD 85/ton CO_2 [1]). In the long term, the carbon tax was insufficient to reach parity between diesel and battery electric trucks. Sizeable carbon tax is then needed to drive the transition to cleaner powertrains.

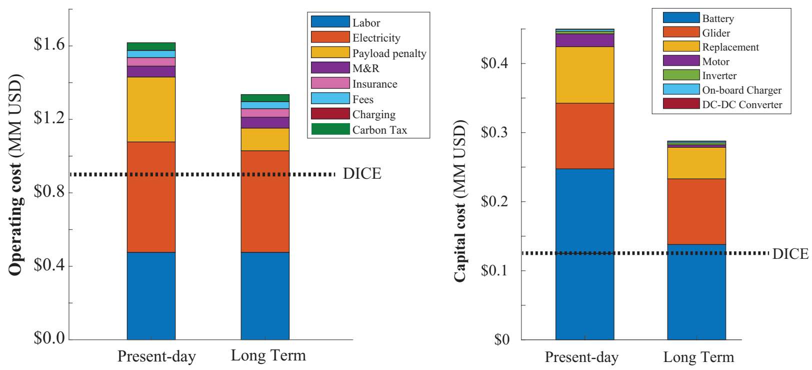

Figure 1: OPEX and CAPEX of battery electric trucks for short and long term scenarios. Diesel truck (DICE) is provided for reference

Batteries account for 55% of the capital cost (CAPEX). Battery durability heavily influences the total cost; truck owners would have to replace them as wear and tear occur over time. The number of replacements is factor of: 1) the number of cycles that batteries are manufactured for, and 2) the range in miles the battery can provide per cycle. We refer to "cycle" as the process of fully charging the battery and then using all of this energy. Truck owners can benefit from reselling batteries for a price proportional to the remaining cycles in the battery. For a 600 mi-range battery, a single replacement is needed, in which trucks saves 30% of the new battery purchase by reselling the old one. Other powertrain components such as the glider or motor, either remains constant or decreases with time due to predicted increases in market share.

Battery electric powertrains have no Pump to Wheel (PTW) emissions, unlike diesel. The WTW emissions thus correspond to the source of electricity and its distribution. Given the current grid electricity mix relying on 33% natural gas and 39% coal, emissions are estimated to be around 1.4 ton CO_2/mi, about the same as a current diesel truck in the US. The emissions decrease over time as the grid relies less on fossil fuel electricity generation and more on renewable sources. By 2050, more than 40% of the electricity is predicted to come from renewable sources, which will reduce BET emissions to 0.84 ton CO_2/mi. With renewable sources of electricity, then BETs would have a significant greenhouse gas advantage over diesel. Note: emissions calculations include payload penalty.

3 Conclusions

The above analysis clarifies the challenges that long-haul trucks face to electrify. The larger energy requirement of long-haul trucks is one of the main pain points for battery electrics. BETs suffer from a very heavy battery that reduces payload capacities. These payload losses increased the present-day Cost of Ownership by 17%. In addition, the electricity needed to charge these batteries quickly is almost 40% of the OPEX. While slower chargers would reduce this cost, charging times will be longer and could affect truck productivity due to time off the road. The lack of ultra-fast charging infrastructure is another pain point for trucks with flexible routes. Ensuring charging stations across these routes will require very large infrastructure investments. Finally, with the current national electricity grid, pivoting towards BETs has no significant advantages over diesel in terms of WTW emissions. In the future, as more renewable sources are used for electricity generation, less carbon intensity of the national grid is expected. This will help to make BETs out-compete diesel in terms of emissions.

This work focuses merely on trucks with flexible routes, with fixed routes being out of scope. However, we should mention that fixed routes could alleviate some of the pain points of truck electrification. Trucks with fixed routes return at depots everyday, where they can recharge overnight using existing fast-charging technologies. This requires less infrastructure investment than for ultra-fast chargers. In addition, they are more likely to benefit sooner from increased fast charging usage and potential associated electricity price decreases. Similarly, BETs have potential for regional and urban applications as they travel shorter distances and require less energy.

References

[1] Interagency Working Group on Social Cost of Greenhouse Gases. *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990*. 2021, pp. 1–44. URL: https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf.

[2] Rick Mihelic et al. *Run on Less Regional Report*. North American Council for Freight Efficiency, 2020.

[3] NASEO. *Demand Charges Electric Vehicle Fast-Charging*. National Association of State Energy Officials, 2021, pp. 1–24.