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ZERO-EMISSION TRUCKING IN THE U.S. — WILL BATTERIES DO THE JOB?

AGENDA

INTRODUCTION

Trucking is a sector that is hard to decarbonize, and its climate impact is significant: 40 percent of global road transport emissions come from trucking, according to the International Energy Agency.

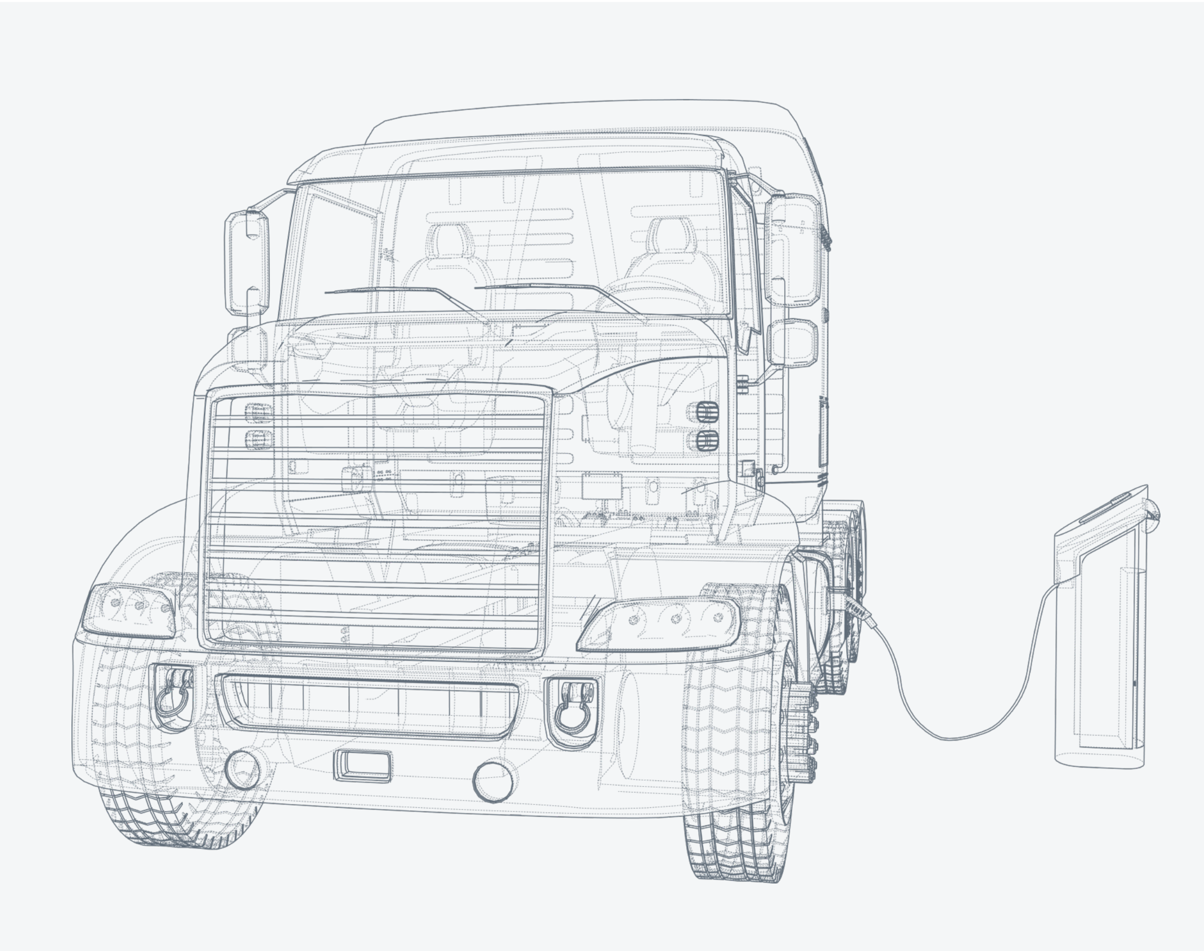
Due to the much higher gross vehicle weight and annual mileage of trucks compared to cars, their carbon footprint per vehicle is 50 times higher.

Many fleet operators are eagerly waiting for the market introduction of zero-emission trucks, as they pursue net-zero carbon strategies. Moreover, with CO_2 taxes rising, alternative powertrains also help reduce the total cost of ownership (TCO). Finally, increasing bans of Diesel trucks in urban areas make zero-emission vehicles a mere necessity.

While incumbent OEMs have been sluggish to introduce zero-emission trucks, investors are bullish about electrified commercial vehicles and funding for innovative startups is readily available. The successful launch of new entrants like Lightning eMotors and Lion Electric demonstrates this.

For a breakthrough of battery electric trucks, two things are crucial: sufficient range and charging speed to reach the required daily distances, as well as economic competitiveness to conventional trucks. In the end, vehicle operators will choose whichever vehicle fulfills their requirements and has the lowest TCO.

We have investigated the U.S. market regarding vehicle deployment, model availability, major players, applications, and technologies. Are battery electric trucks the universal solution for decarbonization of the trucking sector? Will they do the job?



JUST A DROP IN THE OCEAN

According to a report recently published by CALSTART, only some 1,200 zero-emission medium- and heavy-duty trucks have been deployed in the United States.

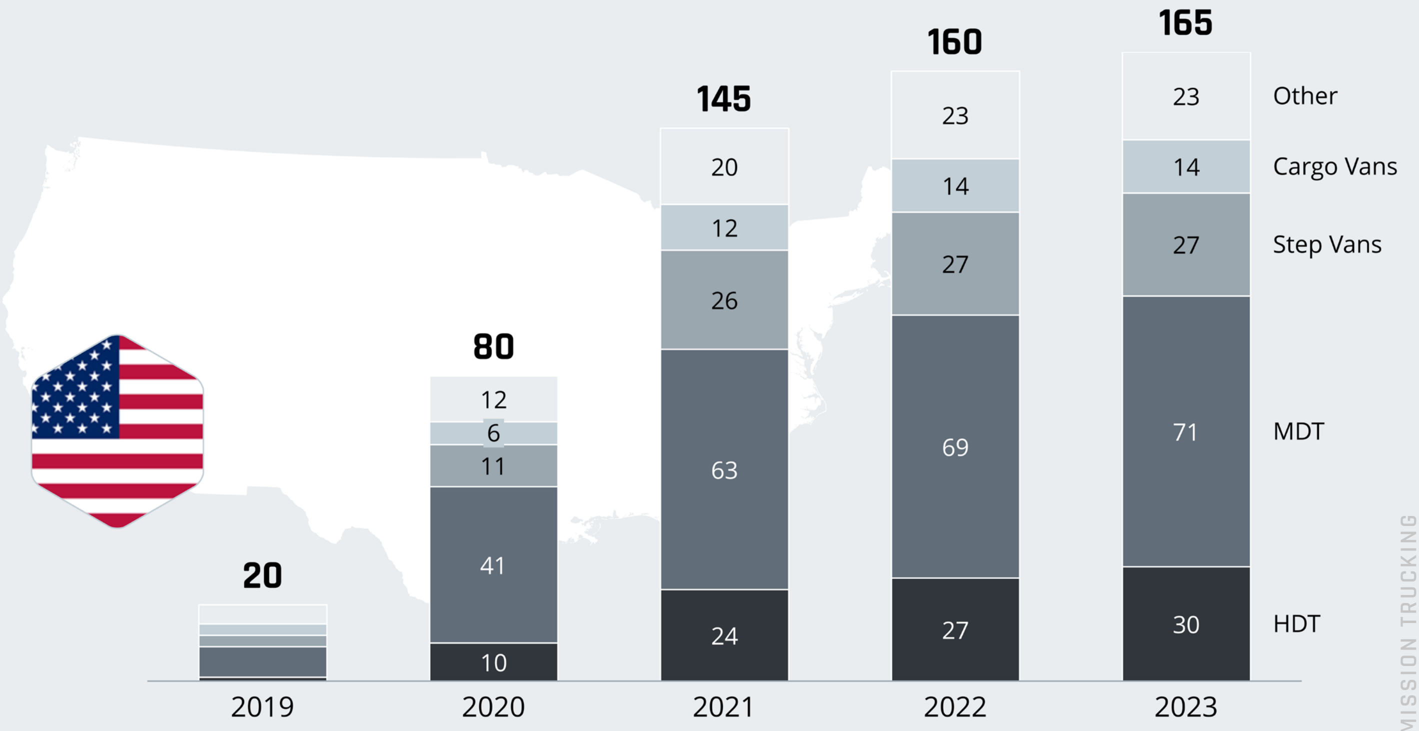
This number equals a share of 0.005% of the registered U.S. truck fleet, which is rather a drop in the ocean. However, both model availability and technical capability of battery electric trucks are changing dynamically. There is a huge latent demand for zero-emission transportation, and many fleets that are currently "test-driving" will probably continue to replace their conventionally fueled vehicles step-by-step.

The report by CALSTART also underlines that truck deployment with alternative powertrains heavily depends on zero emission policies and the respective voucher incentive programs for the time being. More than 60% of the trucks deployed are operating in California, and another 20% in the 15 U.S. States which have signed the joint memorandum of understanding (MoU) targeting 100% zero-emission truck sales by 2045.

Such political support is inevitable to develop the market and foster the decarbonization of the transport sector. But in the long run, zero-emission trucks must match their Diesel-powered counterparts in terms of operational parameters and ideally even outperform them regarding TCO. Because only then will truck operators apply zero-emission trucks at scale. And that means there is still an awful lot of work ahead.

FIGURE 1

ZERO EMISSION TRUCK MODEL AVAILABILITY IN THE UNITED STATES



Source: CALSTART

MODEL AVAILABILITY: IMPRESSIVE "FIRST WAVE", BUT YET A LONG WAY TO GO

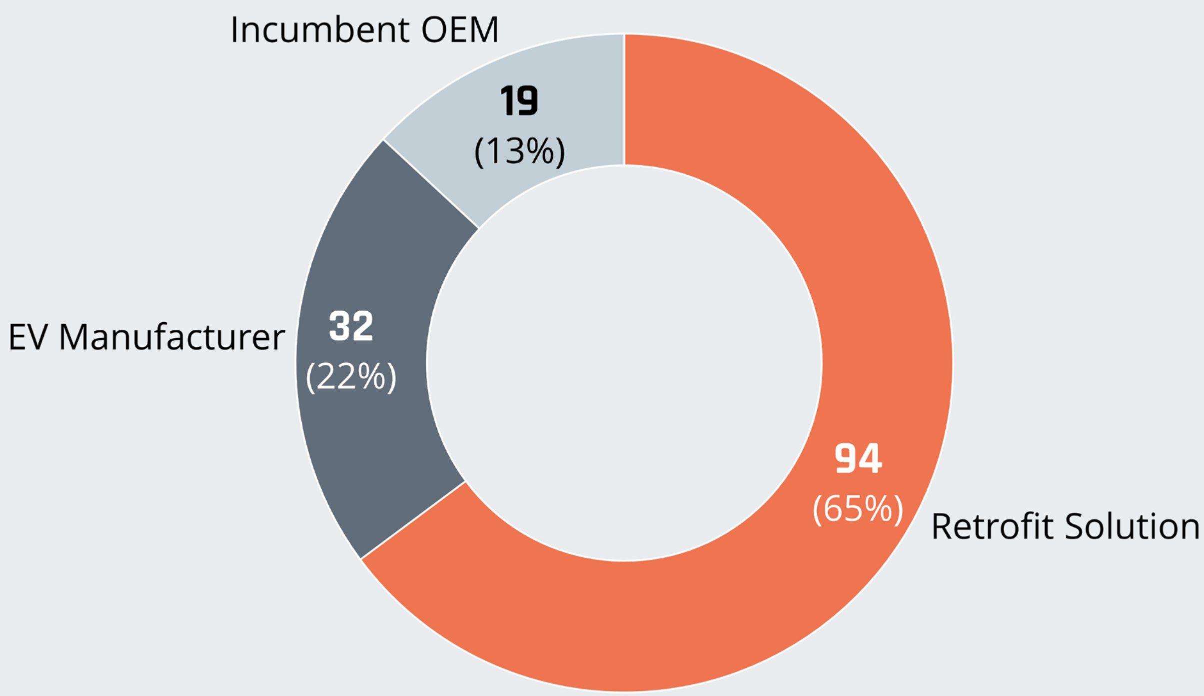
In recent years, the quantity of zero-emission truck models available in the United States has grown significantly.

While there were only 20 different products on offer in 2019, that number has increased to 145 models available now, which means that on average five new products have been launched every month! Two years down the road, another 20 truck models are expected to be available. So, the curve is flattening, and the number of new product launches will be considerably lower. Why is that? Obviously, the "first wave" of zero emission truck offerings has passed, and manufacturers now pursue proof-of-concept and increasing sales volumes before they add more complexity to their product portfolios.

During this "first wave", almost two out of three zero-emission truck models were retrofit solutions, i.e., conventional vehicles being repowered by specialized vendors like Lightning eMotors. The second biggest number of product offerings was launched by dedicated electric vehicle manufacturers like Lion Electric, providing almost one quarter of the available models. Only little more than 10 percent were developed by the incumbent truck OEMs, namely Daimler Trucks, Paccar, Volvo Trucks and Traton including Navistar. It is most likely that these shares will shift in favor of the "big four", but it is not a natural law. The electric truck startups follow ambitious growth plans, and they benefit from a first-mover advantage.

FIGURE 2

ZERO EMISSION TRUCK MODELS BY MANUFACTURER TYPE



Source: CALSTART

LIVELY COMPETITION BETWEEN INCUMBENTS AND NEW PLAYERS

Several new players – like Lightning eMotors and Lion Electric – have gone public through SPAC deals in 2021 and achieved significant cash proceeds for future investments.

By 2024, the both examples mentioned above are planning to sell 12,000 units and 18,000 units, respectively. Assuming that one out of ten class 3 to class 8 new truck sales will be zero emission, these bold numbers represent market shares between 15 and 25 percent. For incumbent OEMs, this must sound like a declaration of war.

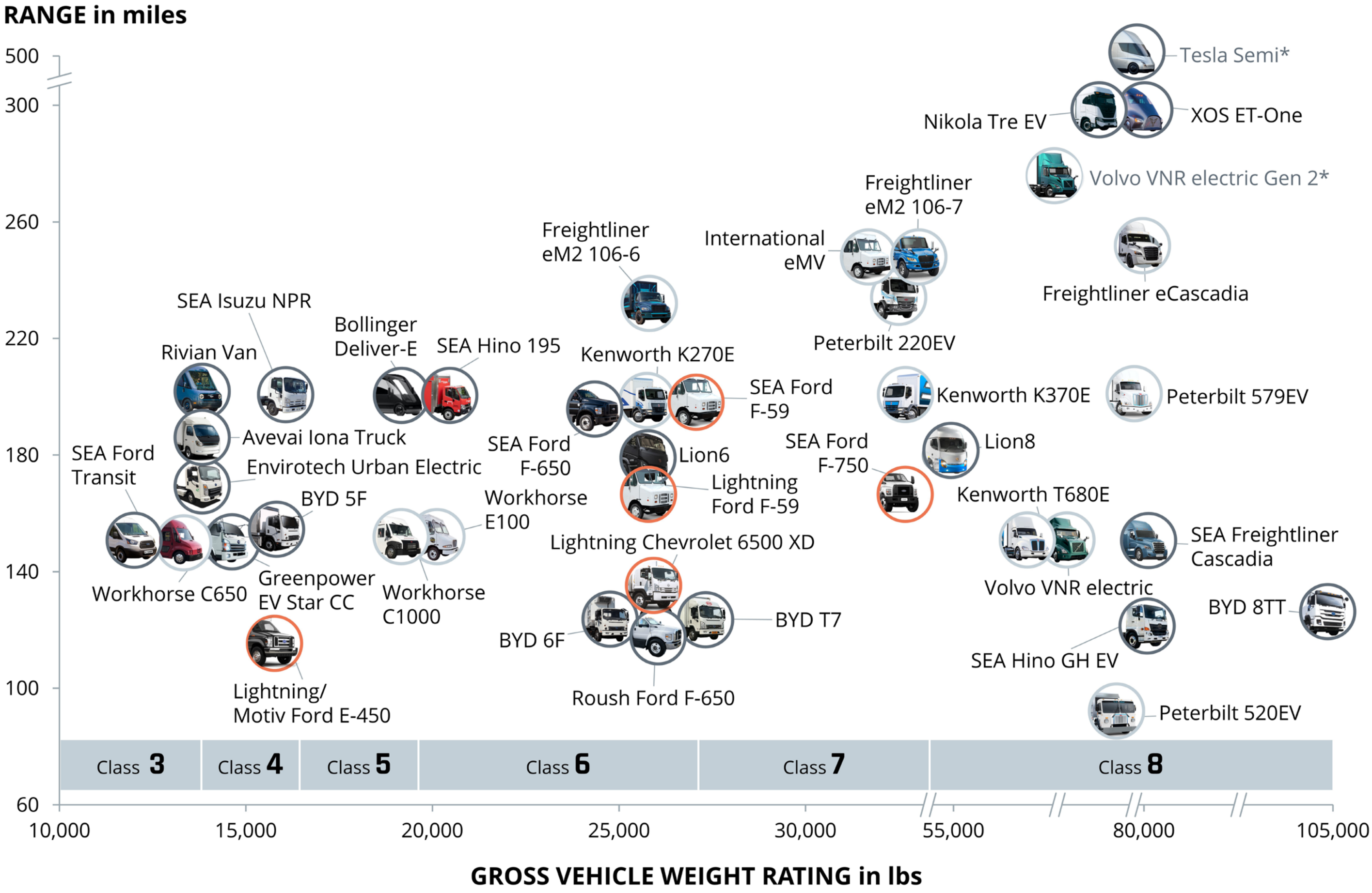
Rivian goes even beyond that magnitude. Fueled by a fleet sales contract with Amazon, they were the first new player in the electric vehicle universe to announce unit sales figures with six digits before mid of the decade. However, Rivian stocks have come under pressure recently as Q4 production volume reports were disappointing. Adding more pressure to the situation is Amazon's decision to place orders for Ram ProMaster vans at Stellantis. Announcements are one thing, but the proof of the pudding is in the eating.

In the heavy-duty segment, Chinese truck manufacturer BYD stands out of the crowd with an offering of low-range and low-cost vehicles. Notably, their 8TT is the only vehicle in the market certified for more than 80,000 lbs. gross vehicle weight, which addresses an important market niche. BYD's strategy will pay off, if they keep finding enough customers with high payload and low range requirements. Pricewise, BYD is likely a strong competitor due to its large-scale, in-house manufactured batteries.

In the premier class of the market – class 8 long-haul tractors – there are the incumbents, like Freightliner eCascadia and Volvo VNR Electric, competing with new entrants, like Nikola Tre and Tesla Semi. The latter promises a longer range, but their vehicles have yet to come to market. Especially regarding Tesla's Semi and the continued broken promises as this vehicle has been announced in 2017 and is still not available for purchase. Instead, Tesla will focus more on scaling up deliveries of their existing portfolio in 2022.

FIGURE 3

BATTERY ELECTRIC TRUCK MODELS BY RANGE AND GROSS VEHICLE WEIGHT



* Model availability later than 2022
Source: Berylls Strategy Advisors

BATTERY ELECTRIC TRUCKS: THE LIGHTER, THE EASIER

Pickup trucks and delivery vans are comparably easy to electrify, and standard range requirements are already met by the vehicles on the market.

All manufacturers have announced ranges between 150 and 200 miles, which is sufficient for the majority of use cases. According to the North American Council on Freight Efficiency (NACFE), 98 percent of class 3 - 6 trucks do not travel more than 150 miles daily. Consequently, these segments can be electrified without the need for public fast charging infrastructure. Moreover, low range use cases can be addressed by purpose-built product versions with smaller batteries, lower capex, and higher payload. Class 3 promises the highest overall market volumes, between 300,000 and 350,000 units annually.

In the medium-duty segment, which extends over classes 4 - 7 and has a combined market volume of 200,000 to 250,000 units per year, there is quite some diversity in the vehicle ranges offered. There is also the same diversity in vehicle applications, which range from delivery trucks to refuse collection and utility vehicles. Therefore, this segment also shows the biggest product variety: Almost every second zero emission model available today is a medium-duty truck. Based on data from the Vehicle Inventory and Use Survey (VIUS), most range requirements of medium-duty trucks can be fulfilled by battery electric trucks.

HEAVY-DUTY IS THE CHALLENGE

Class 8 is the most prestigious and most profitable segment and the hardest to electrify.

The U.S. heavy-duty truck market is rather volatile with an annual volume of 200,000 to 300,000 units. Heavy-duty means high payloads and – for most use cases – high range requirements. The combination of both causes an overproportionate need for propulsion energy, making batteries very heavy and expensive: 100 miles extra vehicle range cost 2,500 lbs. of payload and additional $20,000 for the battery.

Range is not everything, of course. Battery electric trucks will be even more purpose-built than their Diesel-powered counterparts. The investment cost and payload penalty of a large battery are simply too high to justify high range capability for every truck. Rather than that, a maximum fit to the customer use case will be the key to winning business.

COMPLEX SYSTEM DYNAMICS

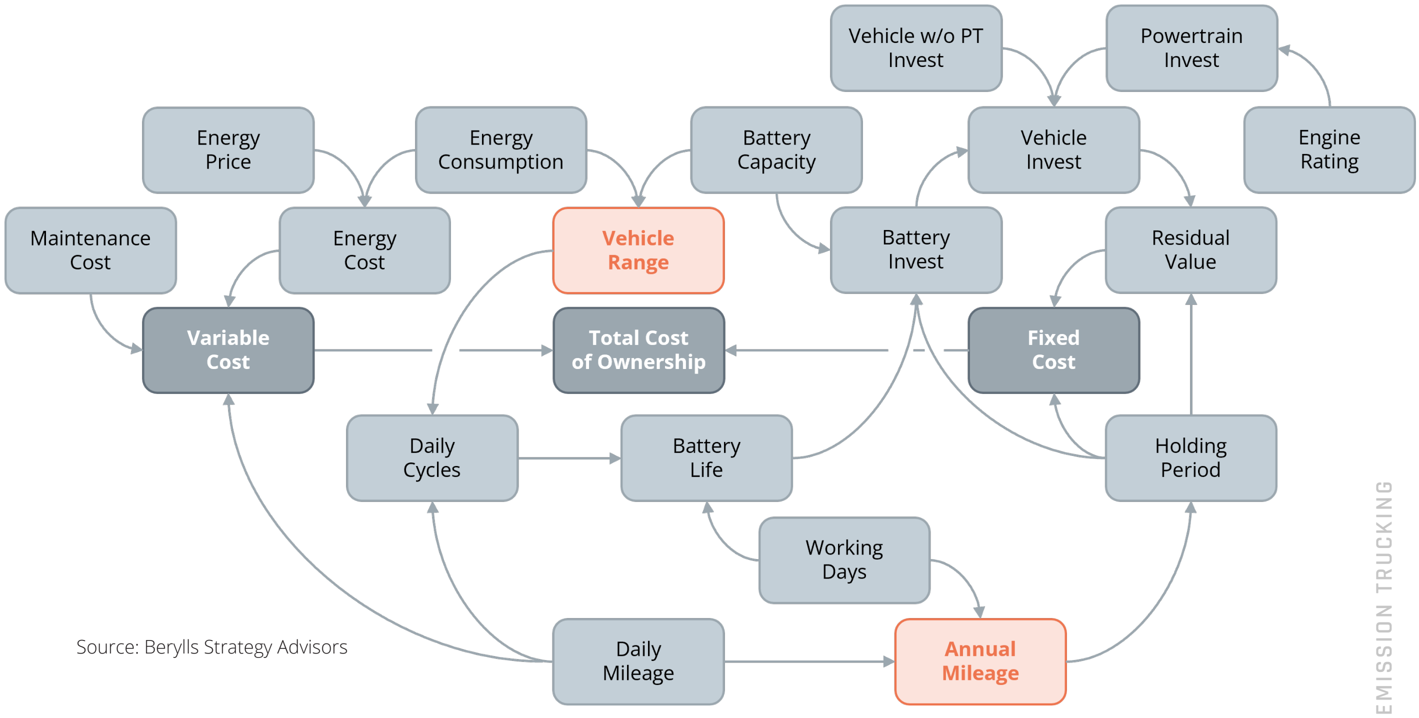
There is no simple rule of thumb under which circumstances electric powertrains outperform conventional technology.

Instead, a variety of highly interdependent system variables must be considered. Battery investment cost is one important factor, but battery life has a significant impact as well. Both depend on the chosen battery chemistry: Lithium iron phosphate (LFP)-based batteries are less expensive and more durable. High-nickel batteries, on the other hand, provide higher specific energy, which increases payload and overall efficiency of the truck. Weight-constrained transport like bulk or beverages is thus better off with the latter technology.

Energy consumption has a major impact on the variable cost of a truck. It depends on the use case and driving profile. The more recuperation possible, the more advantage an electric powertrain will have over a Diesel-powered one. Another important factor is the local price of energy. Regarding electricity, this includes any necessary upfront investment in charging infrastructure, which requires high-capacity utilization to amortize the investment in a reasonable time.

FIGURE 4

SYSTEM DYNAMICS OF BATTERY ELECTRIC TRUCK APPLICATIONS



Source: Berylls Strategy Advisors

The system dynamics of truck applications are complex. Vehicle range and annual mileage are the main factors that determine the technical and economic feasibility of battery electric trucks in comparison to other powertrain technologies. The rationale behind this is the underlying trade-off between fixed and variable costs.

Batteries are expensive, so truck operators invest significantly more upfront if they go for electric power. Up to 40 percent of the purchasing price of a battery electric truck can be attributed to energy storage. On the other hand, the overall efficiency of electric powertrains is approximately twice as high as that of Diesel engines or fuel cells. Consequently, energy cost is significantly lower, meaning that the higher investment pays off during the life cycle of the truck if the cumulated energy cost savings exceed the higher capital expenditures.

REGIONAL-HAUL FEASIBILITY CHECK – A CASE STUDY

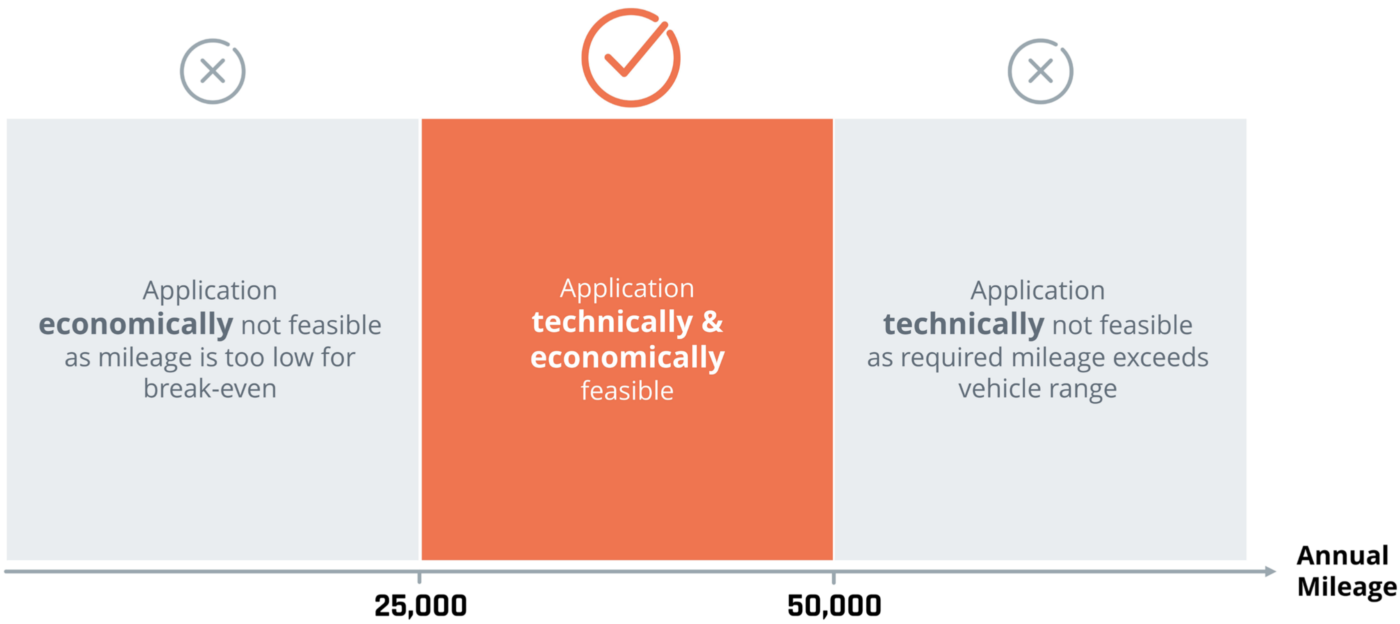
Regional-haul trucks are suitable candidates for battery electric operation.

What are the limits of battery electric trucks today? Which use cases are feasible? The technical limits are obvious: If the required daily mileage exceeds the range of the vehicle, battery electric trucks are no valid option. Opportunity charging is generally possible, but it limits the operational flexibility and reduces battery life.

At the lower end of the scale, there is another limit: If the planned annual mileage is too low to achieve the economic break-even, battery electric trucks will indeed do the job, but cause higher cost per mile than conventional vehicles. Customers will thus be reluctant to electrify such applications and rather wait until battery investment cost comes down further.

FIGURE 5

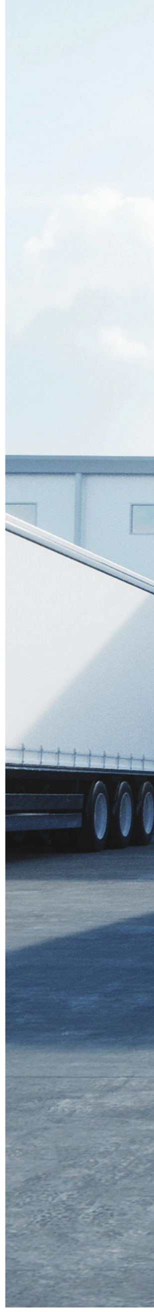
FEASIBILITY OF BATTERY ELECTRIC TRUCKS IN REGIONAL-HAUL APPLICATIONS



Source: Berylls Strategy Advisors

On behalf of a major German retailer, the Fraunhofer Institute for System Technology and Innovation Research examined the feasibility of electrification of the truck fleet at two distribution hubs in the Berlin region. They found that 42 percent of the vehicles, representing 21 percent of the transport performance, could be replaced by battery electric trucks right away. For 40 percent of the fleet, electrification was technically not feasible as the vehicle range was not sufficient. For another 16 percent – mainly in use for urban delivery resulting in low annual mileage – electrification was economically not feasible. The remaining 2 percent of the fleet were not suitable for electrification at all, because neither technical nor economic performance would be sufficient.

The example demonstrates that selling trucks is not as straightforward as it used to be. Each customer use case has its optimal propulsion technology, depending on schedules and infrastructure. As in the example, multiple propulsion technologies and different models can be necessary within a single fleet. Thus, the sales process will not only be about comparing various Diesel models as in the past. Much more, customers will expect manufacturers to provide TCO modelling, explain their products and conduct an individualized feasibility check. The fact that technology is still developing at a fast pace makes this process even more important, although not easier, in the coming years.



REGIONAL-HAUL FEASIBILITY IN THE U.S.

The case study reveals that even for applications like regional distribution there is still some way to go before decarbonization of road transport will happen on a large scale.

According to the VIUS data, only 39% of regional-haul daily driving distances are below 200 miles. The 80th percentile daily distance is 400 miles, which exceeds the range of all the currently available class 8 truck models by far.

As typical regional-haul operating cycles include longer stops for loading and unloading, the delivery trucks can be recharged during those time slots to extend the daily range. The average distance between stops of at least two hours is 198 miles according to VIUS data. With a dedicated installation of charging infrastructure at the hubs and depots as well as appropriate semi-public charging business models, regional-haul applications can run on battery electric vehicles. Public megawatt charging infrastructure is not required for that purpose.

QUO VADIS LONG-HAUL?

Long-haul trucks frequently cover over 600 miles per day, which is considerably more than the range of any battery electric trucks available.

Notably, the range requirements on the U.S. market are significantly higher than in Europe, where the driver hours of service have stricter limitations and the maximum speed is 50 mph.

Most class 8 battery electric truck models currently available in the market have ranges between 200 and 300 miles. For long-haul applications, this is insufficient. Not even the Tesla Semi – which is said to achieve as much as 500 miles of range – will reach the 80th percentile daily distance in U.S. long-haul. Public infrastructure on highways for opportunity charging along the route is not available either. Tesla claims to recharge batteries for 400 miles on their Semi in half an hour, which results in a power output of 1.6 megawatts. Unsurprisingly, researchers from the European think tank Transport and Environment found that the cost of charging infrastructure far exceeds the mere energy cost for battery electric trucks.

Moreover, customer acceptance of an operational concept that relies on running trucks in four- to six-hour intervals – with the need for recharging at least once underway – has yet to be proven. Fuel cell trucks, which will become available in the second half of the decade, provide a viable alternative with potential ranges of 600 miles and more. Taking 80 kg of hydrogen in 15 minutes equals a power output in excess of 10 MW. In other words: Compared to a battery electric truck with one megawatt charging power, fuel cell electric vehicles will require one tenth of the time and one tenth of the space for refueling.

We therefore believe that customers will use battery electric trucks mainly in back-to-base applications, especially for regional distribution, port drayage or hub-to-hub transport on medium distances. For real long-haul trucking, they are everything but the perfect technical solution.

ALTERNATIVE LOW-CARBON FUELS

Operating trucks with e-fuels, i.e., fuels synthesized from renewable energy, is the seemingly most simple solution in terms of the required infrastructure and vehicle development.

E-fuels could be distributed through the existing refueling station network and trucks would not need to be redesigned. The downside of e-fuels is their poor energy efficiency in use: Compared to battery electric trucks, at least four times more renewable energy is required for the same power output at wheel level. Due to the high amounts of energy and process equipment required, e-fuels are not expected to become cost-efficient. As of today, their production cost is around $17 per gallon, which is prohibitive for any truck application.

Natural gas can replace fossil fuels in internal combustion engines (ICE) and causes less tailpipe CO_2 emissions than Diesel. It is therefore considered to be an alternative and promoted by some truck manufacturers. The major disadvantage of natural gas is the upstream methane emissions during gas production, which can offset the tailpipe CO_2 advantage entirely. Biogas is the better option in terms of CO_2, but there is not enough usable agricultural area for a large-scale application. Consequently, both policymakers and industry acknowledge that biogas is only a niche solution.

Hydrogen can also be applied in ICE-powered trucks. They would be able to use the same refueling infrastructure as fuel cell trucks in the future. However, their energy efficiency is worse compared to fuel cell trucks and not much better than that of Diesel engines. Additionally, they also face the Diesel trucks' problem of having NO_x emissions and require expensive exhaust gas after treatment. For heavy construction trucks, hydrogen in ICEs could be a viable alternative, though. They outperform battery electric trucks in terms of power and payload, and they have advantages over fuel cell trucks regarding thermal management of the powertrain. However, volumes will be limited due to the lower overall efficiency.

OUTLOOK: BATTERIES WILL DO THE JOB – BUT NOT EVERY JOB

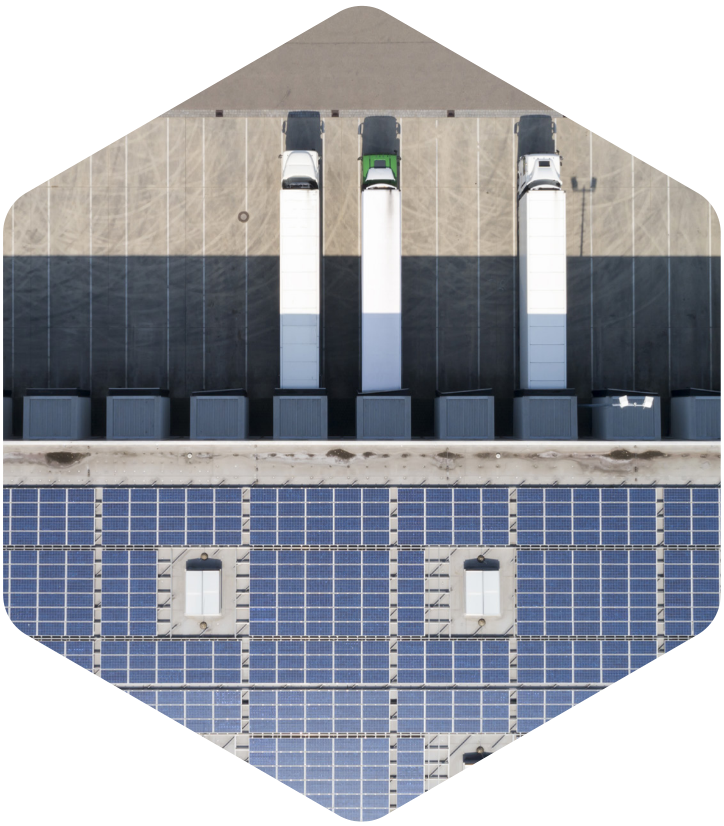
Our insight shows that battery electric trucks can be competitive, but by far not for all use cases.

The current economically and technologically feasible spectrum is a narrow one. However, the rapid development of battery technology is a major driver extending this spectrum on both ends.

For short-haul trucks, the minimum feasibility limit will further decrease due to cheaper batteries. This is driven both by decreasing cost of current technologies, and new lithium iron phosphate (LFP) batteries, which eliminate the need for expensive materials like nickel and cobalt. Inner-city driving bans for combustion vehicles, as already announced by several states, will further propel the electrification of the short-haul segment.

The other end of the applicable spectrum of battery electric trucks will also be extended due to battery development. With the development of cost effective and more dense batteries, the vehicle range will increase. High-nickel cathodes, high-silicon anodes, and solid-state batteries are just some of the innovation drivers. A further range increase of battery electric trucks can be expected as manufacturers put more focus on efficiency, e.g., with aerodynamic improvements. Despite this, the range of battery electric trucks will be below the average requirements even in the foreseeable future, and other technologies that offer a higher energy density will prevail.

There will be a pluralism of powertrain solutions in the market, and any truck purchase will be preceded by a careful weighting of the importance of technical fit, as well as capital and operational expenditure. This applies both to opting for either battery, hydrogen, or Diesel propulsion, and the truck model choice itself. Only with this careful consideration will large scale decarbonization of trucking happen.



NEED FOR ACTION

The transformation towards zero-emission trucking has just started, and the path into the low carbon future will be a steep one.

Truck operators must be prepared for significant changes in operating conditions and cost structures using electric powertrains. This change is unprecedented!

We have identified the following need for action for the major players along the value chain:

- Manufacturers and component suppliers must define viable **product & marketing strategies** to provide the **best fit for every truck application**
- Truck OEMs must completely **rethink their value added** and decide which electric powertrain components to **make or buy**
- **Supply chains** must be made **future-proof** over time – the current semiconductor crisis is the perfect example
- Markets will remain **volatile** and the timeline of technology diffusion is still highly **uncertain,** forcing all players along the value chain to pursue maximum **flexibility in operations**
- Shrinking volumes of **conventional powertrain** components raise the question of **strategic divestments**
- Electric vehicles must be embedded in an **all-new ecosystem,** including charging and refueling infrastructure, which requires **new business models** and public/private **partnerships**
- Truck customers are not familiar with the new technologies, therefore **sales forces** and **dealerships** must be trained and equipped with **appropriate tools,** especially operating simulation and TCO modelling
- Many buyers will shy away from **higher capex** and **residual value risk** of electric vehicles, thus new value propositions like **Vehicle-as-a-Service** (VaaS) will be key to success
- After sales revenues will suffer significantly from **lower wear & tear,** which gradually undermines the **parts business** and calls for alternative **profit pools**
- Last but not least, **remarketing** must be reinvented as the life cycles of components diverge, which includes **second life** and **recycling** options for the batteries

On a broader range, the shift to electric vehicles means much more than just a new product, as our study demonstrates. Critically question if your organization is prepared for such a disruption. Evaluate the long-term feasibility of your value proposition and define a target picture that is sustainable – from a carbon net-zero and business perspective.

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The future will be, but different.

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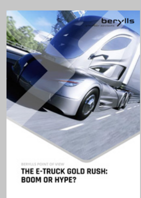

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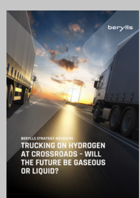

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