Commercial Vehicle BATTERY Cost Assessment

Strategic Sourcing Challenges for North American Truck and Bus OEMs and Tier 1 Suppliers

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INDUSTRY REPORT

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www.calstart.org

www.californiahvip.org

List of Acronyms and Terms

ACT = Advanced Clean Truck (regulation)
AIAG = Automotive Industry Action Group
APQP = Automotive Production Quality Process
BEV = Battery-electric vehicle (100% plug-in electric vehicle with no additional propulsion source than an electric motor with battery energy storage system)
BNEF = Bloomberg New Energy Finance
BMI = Benchmark Minerals Intelligence
BMS = Battery management system
CARB = California Air Resources Board
CBEV = Commercial battery-electric vehicle
CNG = Compressed natural gas
CO2 = Carbon dioxide
CV = Commercial vehicle (This category is most often in reference to MD/HD trucks and buses, but it can also include off-highway vehicles, terminal tractors, and other vehicles designed for dedicated commercial and industrial use.)
DOE = U.S. Department of Energy
EOL = End-of-line
ESS = Stationary (battery) energy storage systems
EV = Electric vehicle (For purposes of this report, EV may include 100% battery-electric, as well as plug-in hybrid electric.)
FCEV = Fuel cell electric vehicle
GVWR = Gross vehicle weight rating
GWh = Gigawatt hours
HEV = Hybrid electric vehicle
HVIP = California's Hybrid and Zero-Emission Truck and Bus Incentive Project
ICE = Internal combustion engine
kWh = Kilowatt hours
LD = Passenger car and light truck vehicle class (typically Class 1 and Class 2, < 10,000 lb GVWR)
Li-Ion = General reference to Lithium Ion based battery cell, module, or pack (regardless of chemistry or form factor)
LFP = Lithium Iron Phosphate battery chemistry
LNG = Liquified natural gas
LSEV = Low-speed electric vehicle
LTO = Lithium Titanium Oxide battery chemistry (also known as Lithium Titanate)
MD/HD = Medium- and heavy-duty commercial vehicles (Class 3 – Class 8 trucks, > 10,000 lb GVWR)
MOU = Memorandum of Understanding
MW = Megawatt
NA = North America
NACFE = North American Council for Freight Efficiency
N/A = Not applicable or not available
NMC = Lithium Nickel Manganese Cobalt oxide battery chemistry (also known as NCM)

NOx = Nitrogen oxides (a criteria air pollutant present in ICE exhaust products)
NRE = Non-recurring engineering
OEM = Original equipment manufacturer (typically the vehicle manufacturer)
PEV = Plug-in electric vehicle (including both BEV and PHEV)
PHEV = Plug-in hybrid electric vehicle
PM = Particulate matter (a criteria air pollutant present in diesel ICE exhaust products)
PPAP = Production Part Approval Process
SAE = Society of Automotive Engineers
SG&A = Selling, general, and administrative expenses
SOP = Start-of-production
SPAC = Special purpose acquisition corporation
TCO = Total cost of ownership (sometimes referred to as LCC, life-cycle cost)
Tier 1 suppliers = Automotive suppliers who produce/sell/ship direct to the OEM
VI = Vertical integration
VW = Volkswagen
xEV = Reference to all forms of vehicle propulsion system electrification (hybrid electric, plug-in hybrid electric, battery-electric, fuel cell electric, etc.)
ZETI = Zero-Emission Technology Inventory (CALSTART)

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Executive Summary

Those who have spent their entire careers in the automotive industry recognize the exceptional transformation taking place in the electric vehicle (EV) market. Reports of new start-ups in the EV space, or new EV ventures among established original equipment manufacturers (OEMs) and Tier 1 suppliers, arrive at an almost daily pace. China launches one new battery megafactory each week, while Europe and the United States make a concerted attempt to play catch-up. Established carmakers in North America are engaged in a make-or-break strategic planning exercise to pinpoint when EVs actually cross the chasm and begin capturing early majority customers. Yet, once that milestone is reached, will it be too late for the incumbents to launch enough new products to prevent losing significant market share?

> Established carmakers in North America are engaged in a make-or-break strategic planning exercise to pinpoint when EVs actually cross the chasm and begin capturing early majority customers.

These questions are only a few of the backdrop inquiries and dilemmas facing commercial vehicle OEMs and their Tier 1 suppliers in North America. As this report will discuss, the stakes are even higher for commercial vehicle OEMs due to their much lower volumes and scale, which make the battery sourcing challenge that much greater. Furthermore, the incumbent truck OEMs face a growing number of well-funded, talent-driven start-ups that are not constrained by the traditional product and sales channel approaches often followed by the more established players. Some of these newcomers, like Tesla and BYD, have access to some of the largest scale (and lowest cost) batteries in the passenger car EV world, which gives them a competitive advantage on the single largest cost element of the EV. For the first time in recent history, start-ups may also have an advantage in terms of how they price their EVs by leveraging shareholder capacity to subsidize EV technology pricing to secure early market share positions. Will regulators take these market discontinuities into consideration when revising incentive policies for the future? Or will today's playing field be tilted even further in the direction of industry newcomers and start-ups?

Finally, there is reason to believe that today's battery industry structure and pricing levels are not fully understood when it comes to the North American commercial vehicle OEM and Tier 1 segments. This paper seeks to provide a substantive description and discussion of today's marketplace and provide directional pricing guidance on today's battery cost structure and where it may go in the coming two to five years.

> …the stakes are even higher for commercial vehicle OEMs due to their much lower volumes and scale…

Introduction and Background

The purpose of this industry report is to provide estimated battery costs for original equipment manufacturers (OEMs) and Tier 1 suppliers in the U.S. commercial vehicle industry and to provide an overview of several important conditions regarding today's current state of e-mobility battery sourcing and supply, specifically for commercial vehicle OEMs who produce medium-duty and heavy-duty (MD/HD) trucks, buses, and other important commercial vehicles.

California's Hybrid and Zero-Emission Truck and Bus Incentive Project (HVIP) provides zero-emission vehicle incentives to cover a portion of the cost of electrified vehicles. Batteries are the dominant element of the incremental cost, therefore HVIP has a strong interest in promoting a better understanding of battery costs as they relate to zero-emission commercial vehicles. The intended audience for this document includes policy makers, investors, and senior leaders in legacy and start-up organizations working in the commercial vehicle e-mobility segment. Strategic planners and battery and e-mobility sourcing staff may also benefit from this report.

This report includes information pertaining to the battery sourcing context and is generally applicable to battery pack pricing for MD/HD commercial vehicle OEMs and their Tier 1 suppliers in North America. This report references light-duty (LD) automotive passenger car EV battery pricing and sourcing strategies throughout, since those external factors have a significant impact on the commercial vehicle battery pricing and sourcing landscape.

Figure 1 provides a simple and helpful framework for thinking about the global market for today's lithium-ion (Li-Ion) batteries.[1]

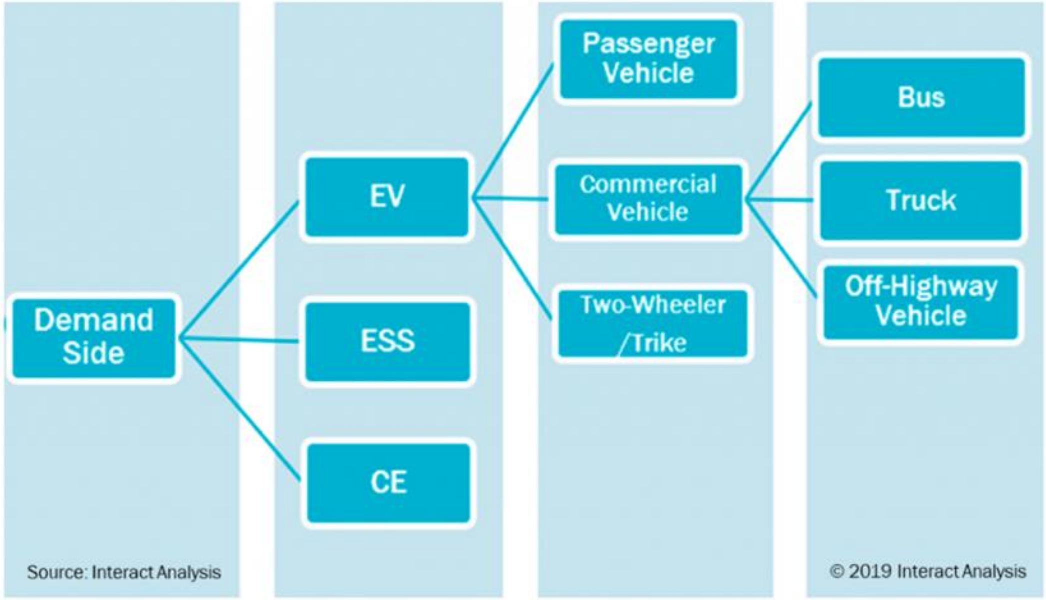


Figure 1. Li-Ion Global Demand Market Segmentation (Source: Interact Analysis)

This helpful figure shows three major battery demand segments:

- EV – Electric Vehicles (e-mobility)
- ESS – Energy Storage Systems (stationary grid and other energy storage applications)
- CE – Consumer Electronics (smart phones, tablets, laptops, power tools, etc.)

Within the EV category, demand can be further broken down by passenger car, commercial vehicle, and low-speed electric vehicles (LSEVs, including two-wheeler, trike, scooters, e-bikes, powersports, etc.). Commercial vehicles include bus, truck, and off-highway vehicles. The North American commercial vehicle e-mobility market is the focus of this report.

> Due to the frequency and sheer volume of industry news related to EV activities, it is easy to lose track of which announcements are related to *actual* events and milestones vs. those that are forward looking and characterized primarily by *forecasts*.

The level of investment among global automakers and their battery suppliers in the e-mobility space has reached remarkable levels. A *growing* number of EV platforms are being offered by a *growing* list of major automotive OEMs, and battery makers are investing in megafactories across Asia and Europe to support *growing* energy storage demand for these EVs. Simply stated, there has never been anything like this current period of rapid transformation within the automotive e-mobility industry. A renewed effort is underway in the United States to attract investment in battery production facilities and capacity to support a domestic EV market. This e-mobility phenomenon is not limited to the passenger car and SUV / light truck industry, but also extends into the MD/HD truck and bus world.

Transit bus makers in North America have been offering EV variants for many years now, and the penetration of EV buses in the total number of buses sold each year continues to grow. A recent report published by CALSTART (*Zeroing in on ZEBs*) captures the scope and location of these growing EV transit bus deployments.[2] Legacy truck manufacturers and several start-ups to the space have announced plans to begin offering their first production EVs later this year (2021). This development follows the introduction and availability of several EVs in the MD/HD truck space over the past few years. CALSTART's Zero-Emission Technology Inventory (ZETI) provides an interactive online resource for tracking commercially available offerings of zero-emission medium- and heavy-duty vehicles.[3]

Small commercial EV OEM and supplier start-ups that once struggled to access sustainable investor funding have now closed on hundreds of millions of dollars through reverse merger acquisition deals orchestrated by special purpose acquisition corporations (SPACs), which have enabled them to further finance their development and manufacturing operations.

When viewed in their entirety, these commercial vehicle developments and events are truly unprecedented in their scope and their reach. Due to the frequency and sheer volume of industry news related to EV activities, it is easy to lose track of which announcements are related to *actual* events and milestones vs. those that are forward looking and characterized primarily by *forecasts*. For example, after reading and hearing about the 10,000-unit order from UPS for Arrival EVs and the 100,000-unit order from Amazon for Rivian EVs over the past year or more, it is easy to imagine that these units are actually being produced and deployed today when, in fact, only a small number (less than 50) of pre-production vehicles have been built and are now being tested in the real world.

Similarly, after seeing and hearing that Li-Ion battery costs have decreased by more than 85% over the past 10 years, it is only natural to assume that commercial truck and bus manufacturers are enjoying low battery prices as they prepare to introduce a growing number of EVs. Unfortunately, while it *is* true that battery costs have been reduced significantly over the past decade, it does not necessarily follow that all MD/HD truck and bus OEMs are able to access attractive battery sourcing and pricing channels at this point in market development.

Based on CALSTART's ZETI database, sources have reported more than 70 makes and models of commercial EVs available in production in the North American market. This statistic is a strong leading indicator of investment and new product availability for the commercial EV market and its growth in the near future. At the same time, this large number of makes and models can also create the impression of a more robust market for commercial EVs than what actually exists today. For example, the California market for MD/HD battery-electric trucks was less than 100 vehicles sold and delivered in 2020 (based on analysis of California's HVIP voucher redemption data). Admittedly, 2020 sales were heavily influenced by the COVID-19 pandemic and HVIP voucher funding constraints. Industry response to new HVIP voucher funding in July 2021 showed momentous strength on the demand side, so this report is not suggesting that 2020 sales data reflects a complete or accurate view of today's market. Nevertheless, these are the most recent full-year sales data available, and this report seeks to build on a data-driven "current state" perspective to help readers understand the challenge OEMs face in terms of day-to-day sourcing of production batteries. On average, the 2020 California sales figures work out to roughly 1.5 vehicles sold per model. Viewed from this perspective, it is clear why battery cost and sourcing challenges for commercial vehicle OEMs and Tier 1 suppliers continue to be important issues today.

This industry report is being published with the hope that it will spur a more informed quest and additional efforts for innovation and the build out of a more efficient, cost effective, and domestic battery supply chain in the United States that helps expand the availability and deployment of commercial vehicle e-mobility models domestically and beyond at the earliest possible point in time.

> More than 145,000 EV passenger cars were sold and delivered in California in 2020, compared with less than 100 MD/HD battery-electric trucks.

Disclaimer and Forward

This report does not attempt to claim complete knowledge or understanding of the battery sourcing strategies being developed and deployed by all stakeholders in the commercial vehicle e-mobility segment. Today's marketplace is too dynamic and active for any entity to assume the capacity to track every new development and player. Having said that, this report does provide an overview of many of the core issues that are relevant and important as they relate to sourcing Li-Ion cells, transforming those cells into modules and packs for commercial vehicle applications, and validating those designs for production.

More than 20 years of relevant industry experience and data points have informed the development of this report. Nevertheless, there is a real possibility that certain key players, important data points, or other key factors have been overlooked or misrepresented unintentionally. YUNEV hopes readers will be gracious and take a moment to point out any mistakes to facilitate ongoing corrections and improvements. This living document will allow for real-time revisions to be made for relevant points that can be verified in the future.

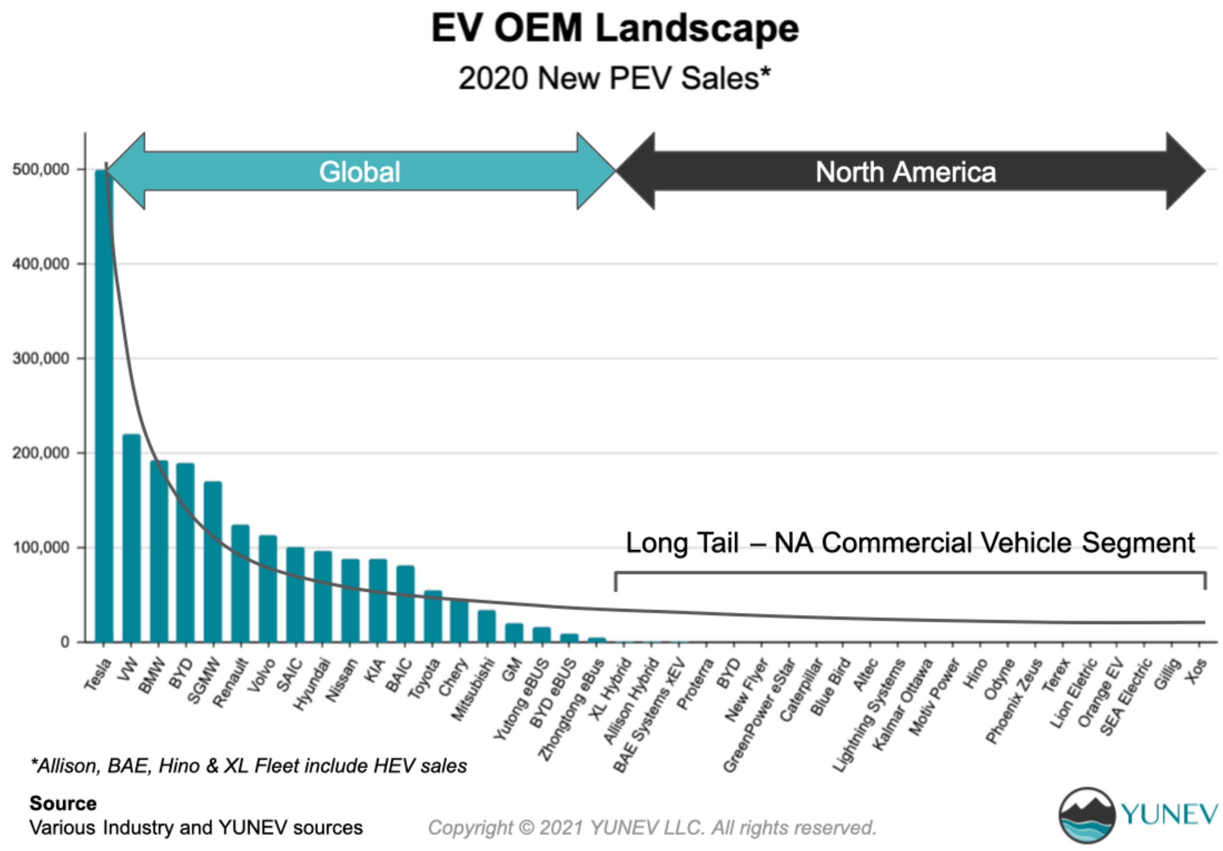
The cost data in this report are considered accurate to a degree, but YUNEV readily acknowledges that any specific numbers shared in this report are almost certainly precisely wrong. Rather than provide specific battery pack pricing data points, this report is intended to show some relative price trends, ranges, and comparisons while also giving a more holistic view of the current challenges and status of sourcing batteries for commercial vehicles at this specific point in time.

An Important Note

This report seeks to illustrate that the range of battery costs across manufacturers and industry forecasts should be viewed in the context of manufacturing volumes and experience, and that battery purchasing dynamics are different for commercial vehicle manufacturers that have not yet achieved high sales volumes. While this report notes that battery cost disparities will likely persist across the industry as electric commercial vehicle manufacturers evolve and grow at different rates, *lower battery prices and supply chain improvements can be accelerated by increasing the deployment of zero-emission trucks.* Sustained demand will drive quicker improvements, leading to more dedicated supply and lower prices for all. Purchase incentives and other policies are currently still needed to help manufacturers achieve scale and price parity with combustion vehicles.

Current State – A Snapshot of Two Very Different EV Worlds

One way to quickly understand the nature and magnitude of the battery sourcing challenge for commercial vehicle OEMs is to compare North American EV production volumes with those of the global EV passenger car and SUV market. The following chart shows manufacturers' sales volumes and is intended to help contrast the long tail of the North American commercial vehicle market vs. the dramatically larger scale of the global passenger car and SUV market. This chart clearly tells the tale of two completely different industries and highlights the early market status of electric commercial truck and buses in North America.



*Allison, BAE, Hino & XL Fleet include HEV sales

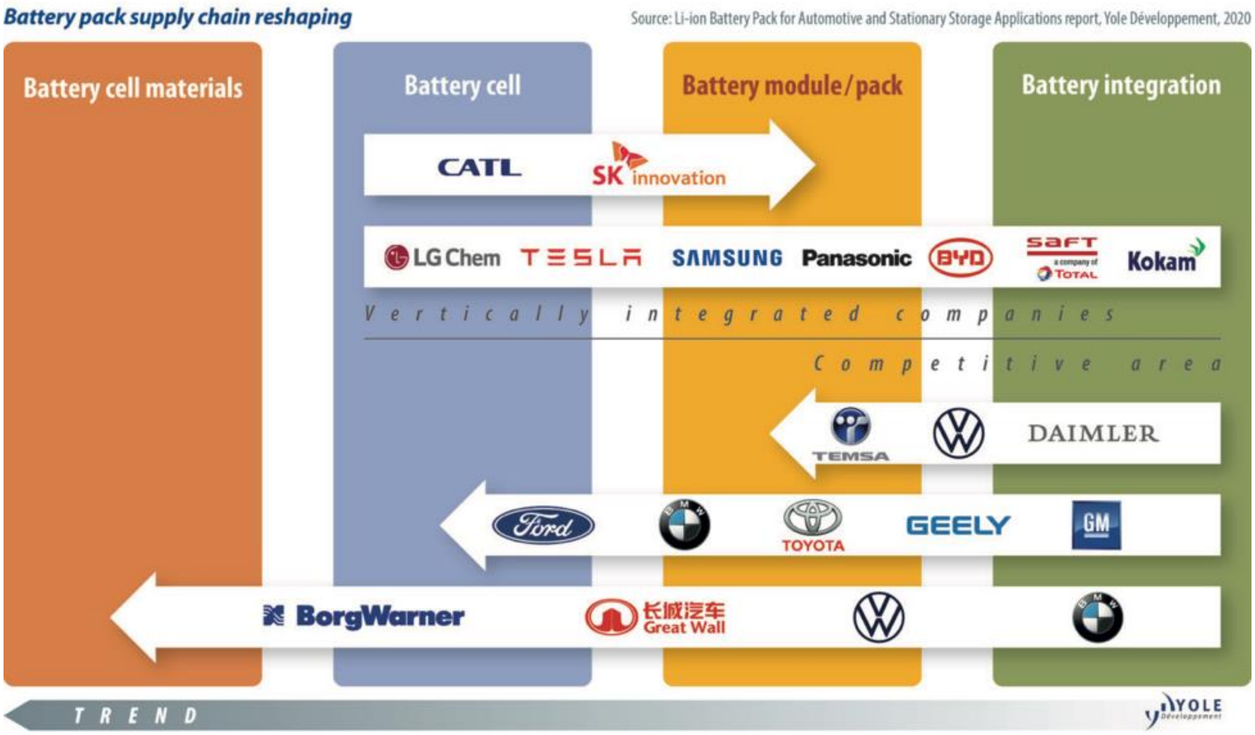
Source
Various Industry and YUNEV sources

Figure 2. Commercial EV Truck and Bus Sales vs. LD EV Passenger Cars and SUV Sales

As Figure 2 illustrates, there are a number of passenger car OEMs currently producing EVs at the rate of hundreds of thousands per year. An even larger group of OEMs is producing EVs at the rate of tens of thousands per year. By contrast, commercial vehicle OEMs and their Tier 1 suppliers in North America are currently producing and delivering EVs and EV systems at the rate of dozens, and in some cases, hundreds per year. More than 145,000 EV passenger cars were sold and delivered in California in 2020, compared with less than 100 MD/HD battery-electric trucks.[4] The scale of passenger car EVs is more than three orders of magnitude greater in California than the scale for commercial EV OEMs and Tier 1 suppliers.

This enormous difference in scale between EV passenger cars and EV commercial truck and bus vehicles matters when it comes to battery sourcing. This report will explore how this difference translates directly into a more challenging battery sourcing reality, along with unavoidably higher costs for commercial vehicle makers.

Figure 3 provides a high-level overview of the various strategies passenger car OEMs are bringing to the battery supply chain.



Battery pack supply chain reshaping

Source: Li-ion Battery Pack for Automotive and Stationary Storage Applications report, Yole Développement, 2020

Figure 3. Battery Supply Chain Strategic Examples (Source: Yole Developpement)

This chart illustrates another important distinction between these two industries. Namely, the way in which many LD passenger car OEMs are pursuing vertical integration (VI) with their battery sourcing strategy and forming significant partnerships and taking equity positions in cell manufacturers and even raw material providers in some cases. Although Figure 3 depicts such sourcing strategies as moving horizontally, conventional economic nomenclature uses the term VI to describe the practice of owning a firm's upstream suppliers, and in some cases its downstream buyers as well.

Tesla's example of expanding sourcing across battery manufacturing partners like Panasonic, LG, Samsung, CATL, and others is well known. Perhaps less familiar is the example of BMW working to secure supply from 1.) Northvolt through a $2.3 billion USD long-term supply contract,[5] 2.) Samsung SDI through a $3.4 billion USD agreement,[6] and 3.) CATL based on an $8.5 billion commitment.[7] Volkswagen (VW) recently unveiled their plans for significant VI through their electrification and battery strategy as outlined in their Power Day event in March

2021.[8] In addition to a wide range of battery technology and product design details, VW announced plans for six 40 GWh/yr gigafactories in Europe with three battery production partners (Northvolt, Gotion High-Tech, and QuantumScape). While there are a few MD/HD manufacturers that can leverage significant battery manufacturing investments, it is evident that most MD/HD truck manufacturers have not yet expanded their battery manufacturing capabilities in a similar manner to that of the LD market.

All six of the VW gigafactories appear to be captive to VW demand only and reflect a serious commitment to secure capacity and influence battery product and technology attributes that will support VW's vision for battery integration across their entire EV portfolio. In addition to these six gigafactories and three production partners, VW also reports they remain fully committed to sourcing batteries from LG Chem, Samsung SDI, SKI, and CATL for the rest of the world. This level of battery sourcing investment undoubtedly includes hundreds of VW staff and hundreds of millions of dollars of capital investment which can lead to significant cost savings and a more reliable supply chain. While other EV passenger car OEMs may not have such expansive plans to announce just yet, none of the passenger car OEMs can afford to sit on the sidelines for long.

For example, Daimler/Mercedes recently announced their decision to take a 3% equity share in Farasis Energy, including a board seat, in an attempt to secure supply, accelerate battery technology advancements, and deliver cost-competitive pricing.[9] Honda also announced their move to capture a 1% stake in CATL, with committed supply of 56 GWh/year by 2027.[10] Simply stated, these types of strategic sourcing moves by passenger car OEMs are not yet readily available or used by smaller, lower volume commercial vehicle manufacturers that serve the MD/HD truck and bus market.

While many EV passenger car OEMs have achieved scale, structural advantages, and significantly greater resources for executing their strategic battery sourcing plans, there are several commercial vehicle OEMs who are also pursuing their own strategic battery plans. The wide range of experience and organizational sourcing capability with respect to propulsion batteries between various truck and bus OEMs can be significant, as illustrated in Figure 4 below.

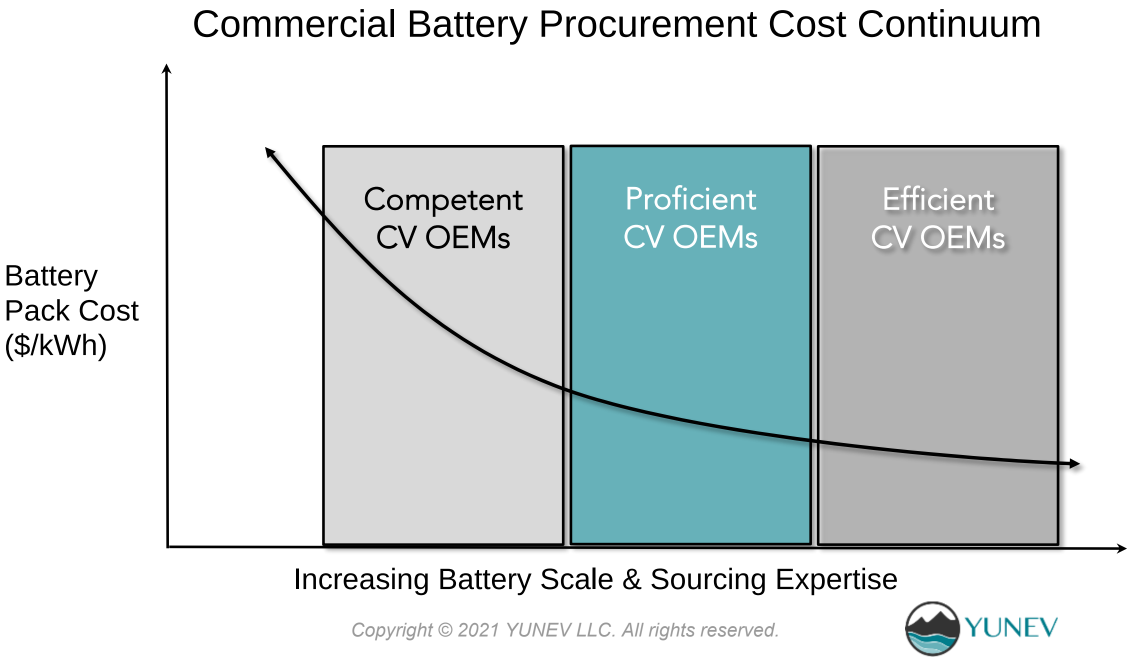


Figure 4. Continuum of Commercial Vehicle OEM Battery Sourcing Scale

BYD offers battery-electric transit buses and a Class 8 battery-electric truck (TT8) in the North American market, all of which enjoy access to their vertically integrated battery cell production operations at automotive-grade scale. Similarly, Tesla is working to release a Class 8 battery-electric truck (Semi) which will leverage Tesla's significant in-house battery production capacity and capabilities. Relative to the other OEMs, both BYD and Tesla have the highest level of scale and battery sourcing expertise that most likely results in the lowest possible battery cost of any other OEMs in the commercial vehicle market.

Other commercial EV manufacturers, such as Volvo and Proterra, have decades of battery sourcing and xEV product development under their belts. Volvo's strategic vision for battery technology and product development can be understood by reviewing a recent Society of Automotive Engineers (SAE) truck and off-highway engineering article (April 2020),[11] which outlines Volvo's modular, scalable, and multi-generational approach to designing, developing, validating, and sourcing battery packs for a wide range of MD/HD commercial vehicle applications. Proterra's battery prowess is illustrated by their ability to negotiate a $200 million leasing facility through Mitsui[12] and their strategic move to become a Tier 1 battery systems integrator and supplier to other commercial vehicle manufacturers.[13] Like Volvo, Proterra has also developed a modular, scalable approach to their battery system designs that allow them to cover a range of commercial vehicle applications with a high degree of re-use among major software and hardware components and subsystems. While Volvo and Proterra lack the scale of BYD or Tesla, their level of experience and organizational capability in terms of designing complete battery modules and packs, as well as sourcing the battery cells efficiently, is considered more mature compared with other legacy commercial vehicle manufacturers.

Like Proterra's exclusive focus on battery-electric buses, Lion Electric is focused on producing exclusively battery-electric trucks and buses. Although they lack the decades of experience that Proterra and Volvo bring to the market, Lion Electric recently announced plans for a $185 million battery module and pack manufacturing facility in the United States with up to 5 GWh/yr capacity.[14] New Flyer is also building a growing depth of experience selling production battery-electric buses to transit agencies across North America, followed by Gillig, which is earlier in the maturation process with EV bus builds.

Peterbilt, Kenworth, Freightliner, and Navistar all have experience and significant investments bringing xEV platforms to the North American market, but their scale and organizational capability at sourcing batteries is still in the earlier stages relative to all-electric manufacturers like BYD and Tesla. Freightliner recently announced their plans to build complete battery packs at their Detroit ePowertrain production facility in Detroit,[15] and Navistar is in the process of commissioning a new truck manufacturing factory with state-of-the-art EV capabilities in South Texas.[16] Freightliner could easily leverage any scale that Daimler achieves on the passenger EV battery sourcing front, and Navistar could do the same through their connection with VW via the Traton Group.[17] Of course, this is only a partial list of commercial vehicle OEMs and does not include other important makes and models that serve commercial fleets and transit agencies across North America each day.

> To say the playing field for battery sourcing among commercial EV manufacturers in the United States is not level would be a gross understatement.

To say the playing field for battery sourcing among commercial EV manufacturers in the United States is not level would be a gross understatement. The reality is that many commercial vehicle manufacturers, even those with established sales and service networks across the North American continent, are still striving to gain experience and resources to approach battery sourcing in the same manner as some of their competitors, let alone their passenger car and SUV counterparts.

Two other observations regarding EV market development in the passenger car segment are worth mentioning. First, after a decade of unparalleled success, Tesla managed to penetrate 1% of new vehicle sales in the United States for the first time in 2019. This epic event was likely made possible by the nationwide Supercharger infrastructure Tesla built out to help address customer concerns regarding range anxiety. For those in the commercial vehicle segment, such an exceptional achievement begs the question regarding how long it might take EVs to penetrate the entire North American MD/HD commercial vehicle industry by 1%, 2%, or even 5%? What level of EV charging infrastructure (both public and private) will be required to support such EV penetration? Second, those who are close to the manufacturing side of today's EV passenger cars will recognize that at the gross margin level for each electric vehicle, many manufacturers are not yet profitable. While Tesla's earnings reports now suggest they are generating positive gross margins at the product manufacturing level, many other EV OEMs have not yet achieved that critical milestone. Therefore, despite the scale that many EV passenger car makers have already reached, and the structural advantages they enjoy compared with lower volume commercial vehicle OEMs, it is good to keep in mind that many passenger car OEMs are yet to reach a point where they can produce and sell EVs on a profitable basis, particularly in North America. The commercial vehicle industry will likely face similar challenges as they scale up production as well.

Competing Technologies, Policy Drivers, and Market Factors

Competing Technologies

While truck and bus electrification efforts are enjoying unprecedented investment and attention in the United States and around the globe, they are not without competition from incumbent technologies and other alternatives. Even with new zero-emission regulations such as the Advanced Clean Truck (ACT) regulation signed into California law in 2020, the majority of MD/HD truck and bus purchases in the United States for the next decade and beyond will still be non-electrified vehicles. The truck market can be unforgiving when it comes to the importance of operating economics and productivity – most fleets look to a total cost of ownership (TCO) model when considering new vehicle purchases. The diesel engine has proven to be a formidable player over the past 30+ years as the industry has repeatedly reduced nitrogen oxides (NOx) and particulate matter (PM) emissions while also maintaining and, in some cases, improving fuel efficiency and performance, as well as maintaining access to established infrastructure and avoiding operational range concerns.

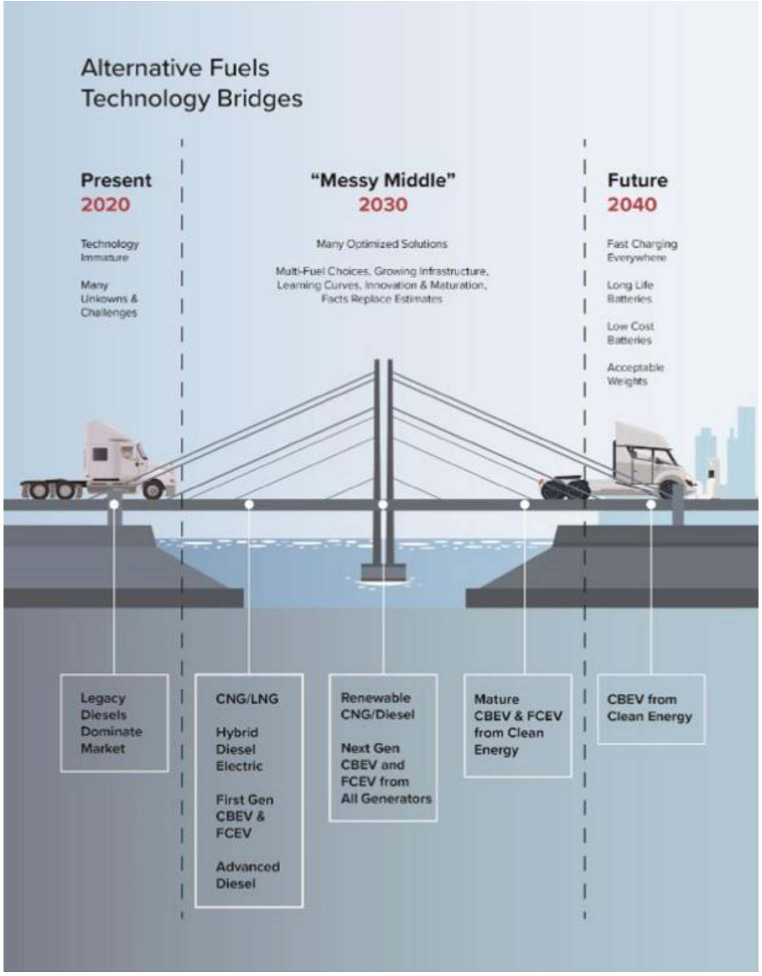


Figure 5. The "Messy Middle" Transition to Freight Trucking Electrification (Source: NACFE.org)

According to the North American Council for Freight Efficiency (NACFE) (www.NACFE.org), the U.S. freight industry is approaching a period of down-selecting between a wide range of clean-tech options vying for commercial adoption in Class 8 trucks over the next couple of decades, as illustrated in Figure 5.

According to NACFE, this "messy middle" period between 2020 and 2040 will include ongoing development and improvements to diesel, natural gas, hybrid, and other alternatives (like renewable natural gas and biodiesel) while battery and hydrogen-powered fuel cell electric technologies are likely to receive a majority of the attention.[18]

> The diesel engine has proven to be a formidable player over the past 30+ years as the industry has repeatedly reduced NOx and PM emissions while also maintaining and, in some cases, improving fuel efficiency and performance…

One recent example that supports NACFE's messy middle framework includes a webinar hosted by CALSTART highlighting diesel engine technology advancements by Achates Power where the California Air Resources Board's (CARB) 2024/2027 Low NOx targets have been demonstrated simultaneously with promising carbon dioxide (CO2) results. To quote CALSTART's Bill Van Amburg during that webinar, despite the emergence and importance of truck electrification and a move toward zero emissions policies, "it is clear that there will be [internal combustion engine] vehicles on the road for decades to come, and new vehicles bought for decades to come that will use combustion engines."[19] The point of NACFE's messy middle terminology and CALSTART's acknowledgement regarding the role internal combustion engines will play for decades is that today's hype regarding the rapid transition toward a more electric truck fleet must be balanced with a recognition of the cost challenges and operational imperatives that will be required by fleet customers. Increased electrification of the U.S. trucking fleet is a near-certainty at this point. The questions that are fundamental to battery sourcing and battery production still need to be answered, including when, where, and how much the fleet will be electrified.

Policy Drivers

The U.S. Department of Energy (DOE) recently announced their Loan Programs Office is back open for business with more than $40 billion in loans and loan guarantees available to help deploy energy infrastructure projects in the United States, with a special focus on expanding domestic battery production capacity.[20] These are promising new policies and funding sources, but it is unclear how quickly this new funding source will impact domestic battery supply, and whether the new capacity will be quickly consumed by passenger car, SUV, and light truck demand.

Time will determine what impact this funding may, or may not, have on domestic battery supply for MD/HD trucks and buses. Looking ahead, at the time of this report, President Biden has released his proposed budget for the 2022 fiscal year, which includes numerous significant investment proposals in the MD/HD electrification space, including zero-emission vehicle purchase tax credits, as well as manufacturing investment tax credits.

CARB passed the ACT regulation in June 2020, which requires manufacturers to sell an increasing number of zero-emission vehicles starting in 2024.[21] The mandate initially requires 5%-9% zero-emission vehicles based on class, increasing to 30%-50% by 2030. By 2045, all vehicles should be zero-emission vehicles "where feasible." The words "where feasible" could prove very important for certain truck applications where battery cost and EV driving range make it difficult to check the box on "feasible." As of July 10, 2020, numerous states have also signed the Multi-State Medium- and Heavy-Duty Zero Emission Vehicle Memorandum of Understanding (MOU), where signees to this MOU have pledged to enact legislation similar to the CARB ACT regulation.[22]

Market Factors

The news and excitement of an unparalleled number of newcomers to the MD/HD truck segment has dominated the industry news cycle during recent times. These announcements make it more challenging to maintain a balanced view of real market conditions on the ground. Examples of well-funded and resourced newcomers and start-ups in this space include:

- **Tesla's** Class 8 EV truck (Semi) with low volume production release in 2021[23]
- **Nikola's** parallel development of battery-electric and fuel-cell powered Class 8 trucks[24]
- **Thor/XOS's** focus on battery-electric Class 8 trucks[25]
- **Arrival's** entry into the Class 3 / 4 EV package delivery market[26]
- **Rivian's** introduction of a Class 3 / 4 EV package delivery vehicle[27]
- **Hyliion's** development of xEV powertrain platforms for Class 8 trucks[28]

These newcomers are ushering in a previously unimagined level of EV product offerings and innovations that are capturing the attention and consideration of small and large commercial fleets alike. The enthusiasm of having so many new products available is understandable and justifiable. The key question for policy makers and investors is *when* these new products will become cost-effective and *how* the transition from initial prototypes to pilot projects to production release and volume ramp to scale will play out.

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Before moving into the main section of this analysis, the recent reverse merger through SPACs deserves a brief discussion. Several high-profile start-ups and established companies in the commercial EV market secured significant investor funding in 2020 and early 2021 through SPACs. However, these high-profile companies have seen increased analyst scrutiny and short-seller activism as a result of downward revised growth forecasts and questions regarding product maturity and production viability. None of these recent events should cause anyone to question the long-term viability of e-mobility for commercial vehicle applications, but they are a good reminder that thoughtful policies and incentives are needed to help e-mobility cross the chasm from innovative fleets and early adopters to sustainable commercial deployment. Thoughtful incentives can help level the playing field between the “haves” and the “have nots” in terms of OEMs with access to automotive-grade scale when purchasing batteries.

The good news is that e-mobility has already achieved significant traction in the U.S. transit bus industry, resulting in more cost-effective offerings and increased market share and almost certainly increased adoption within the commercial truck market. The key questions are when, where, how much, and how fast? While battery cost is a dominant factor on these questions, other key enablers (or hurdles) include commercial EV charging infrastructure, domestic battery production capacity for the truck market, EV range, grid stability, and others.

Key Cost Factors

This section is meant to highlight the key cost inputs that ultimately drive battery costs for MD/HD EVs. This is not an attempt to precisely quantify each of these costs, as other industry reports provide more in-depth and expert analysis than the scope of this report. Instead, this section is meant to provide a framework when considering key cost drivers. This framework should be useful for future analysis and monitoring of industry price inputs, while an increasingly quantitative approach to battery costs is discussed in the following sections.

> Raw materials are the predominant cost factor in the production of individual battery cells.

Raw materials are the predominant cost factor in the production of individual battery cells. As Figure 6 below illustrates, raw battery materials can account for roughly 70% of the total cost of today's battery cell, with the majority of that cost driven by the cathode and anode materials.[29]

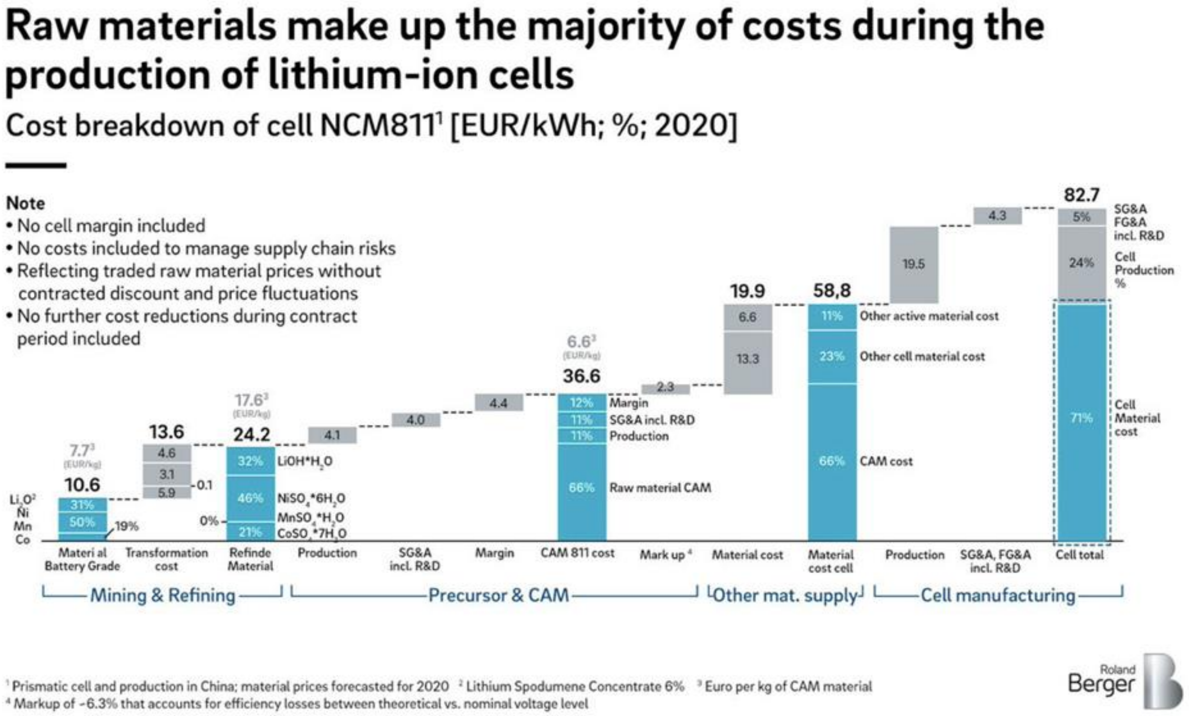

Figure 6. Battery Cell Raw Material Cost Breakdown (Source: Roland Berger)

Based on the assumption that today's Li-Ion battery global manufacturing capability has already achieved a significant scale effect (existing capacity > 300 GWh/yr), one key take-away from Figure 6 is that sustainable battery cell cost reductions beyond 10-15% in the near-term are unlikely without a significant technology or design advancement. This need for technology or design gains is due to the dominance of raw material cost (> 70% of the cell manufacturing cost) and the lack of strong evidence that raw material prices will trend downward in the foreseeable future. For example, assuming the raw material prices are likely to remain fairly stable (with volatility due to cyclical imbalance between supply and demand), Figure 6 suggests a 15% overall cell cost reduction would require a roughly 50% reduction in final cell production cost, including selling, general, and administrative expenses (SG&A) (not including battery cell raw materials). The challenge for new technologies and designs is they require significant new capital investments and corresponding lead-times and ramp-up periods to achieve cost-efficient scale. All these factors complicate the decision-making process for cell manufacturers in terms of how long to continue producing from existing facilities, compared with the investment and time required to transition to the next generation of design/technology and associated production facilities. From the commercial vehicle OEM and Tier 1 supplier perspective, it can be difficult to gain full visibility to these decision factors and the actual plans being considered and selected by current and prospective battery cell suppliers. This challenge is often the result of a complex and opaque sourcing landscape for many of the commercial vehicle manufacturers and their Tier 1 suppliers in this space.

New analytic firms like Benchmark Minerals Intelligence (BMI) (www.benchmarkminerals.com) have established indexes for tracking spot market prices for lithium, cobalt, nickel, and graphite, as illustrated in Figures 7 and 8.

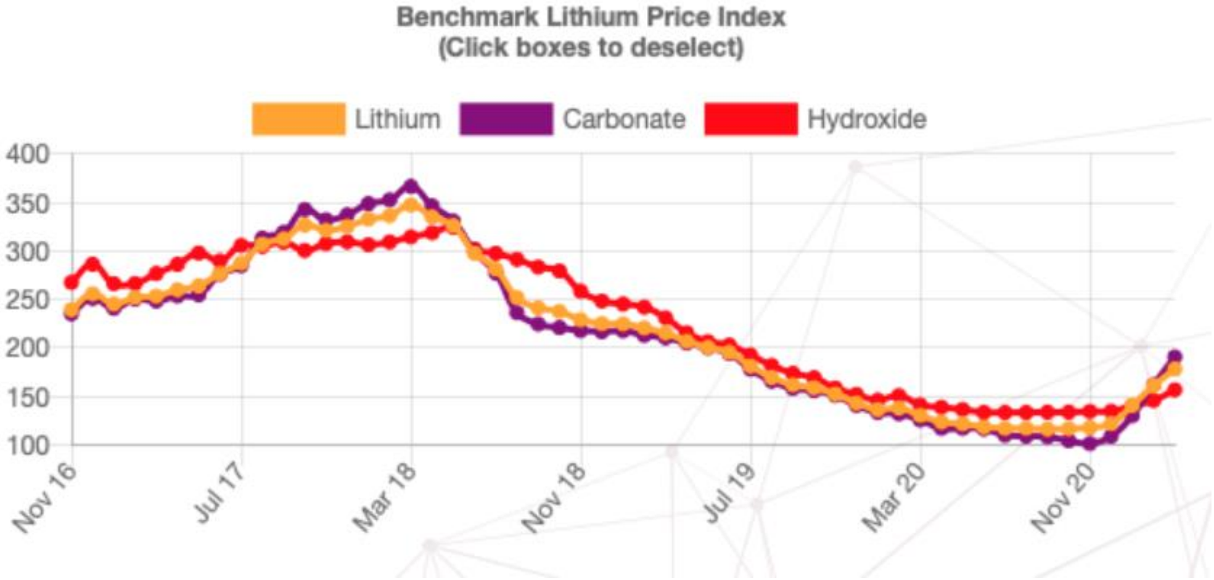

Figure 7. Lithium Price Index (Source: BMI)

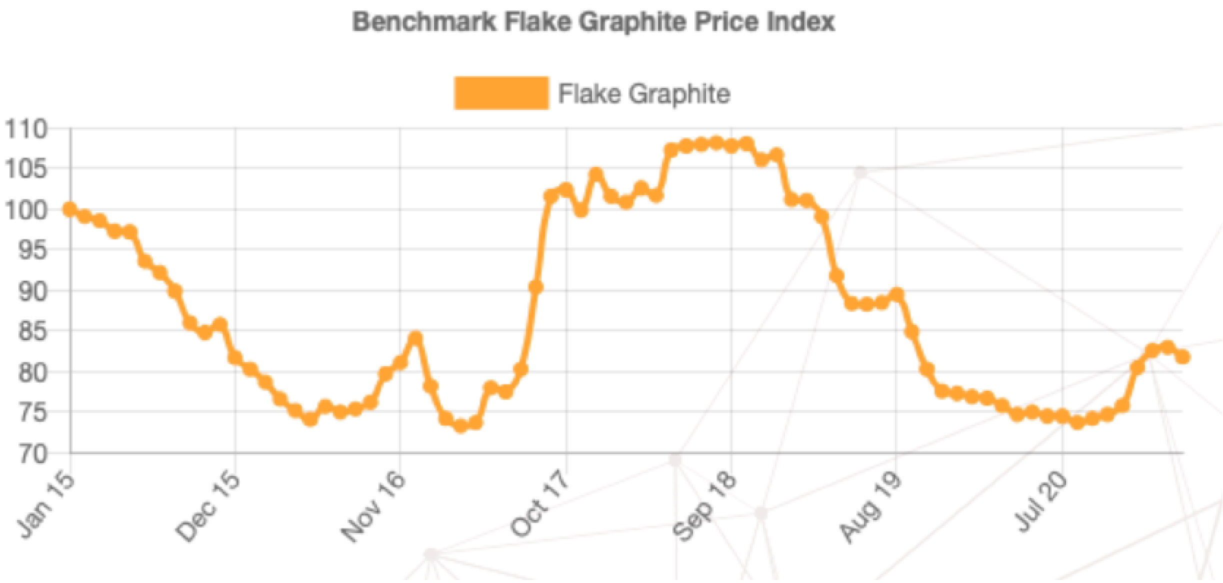

Figure 8. Flake Graphite Price Index (Source: BMI)

BMI also provides detailed raw material capacity analyses for all known mining operations globally where these key elements are being resourced and extracted. By studying the original geological capacities for each mine, the quantity of material already extracted, the remaining time on each mine's permit, and the rate of extraction (capacity), BMI is able to provide their clients with forecasted raw material capacity and pricing to help guide strategic planning, sourcing, and price negotiations.

Battery cell chemistry also has an impact on battery cost, as well as other key performance and functional attributes. As the spider diagrams in Figure 9 illustrate, lithium titanate (also referred to as lithium titanium oxide, or LTO) has a distinct advantage in terms of its ability to accept high charge rates while also delivering long cycle life vs. lithium nickel manganese cobalt oxide (NMC or NCM) or lithium iron phosphate (LFP). Such attributes are generally attractive for many commercial vehicle applications. Unfortunately, these advantages come with a higher price tag and lower specific energy (i.e., reduced driving range for a given battery mass). NMC and LFP cost levels can be similar, but NMC is more attractive than LFP based on its specific energy (therefore, it normally has superior EV driving range), while LFP generally brings advantages in terms of cycle life and safety compared with NMC. While both chemistries can be purchased at similar price points, there is no guarantee that a specific NMC cell will be the same cost as a comparable LFP cell at any given time from any given supplier. In fact, an NMC cell might actually be more, or less, expensive than a specific LFP cell at any given time from any given supplier due to specific production scale and demand vs. supply conditions. When cycle life trade-offs are taken into account, along with intrinsic safety advantages, the total life cycle cost of the two chemistries may be viewed differently than the similarity in up-front purchase cost shown in Figure 8. This pricing variability and life-cycle cost differential can become even more important when the intended application is taken into consideration (e.g., affordability vs. premium e-mobility and stationary energy storage).

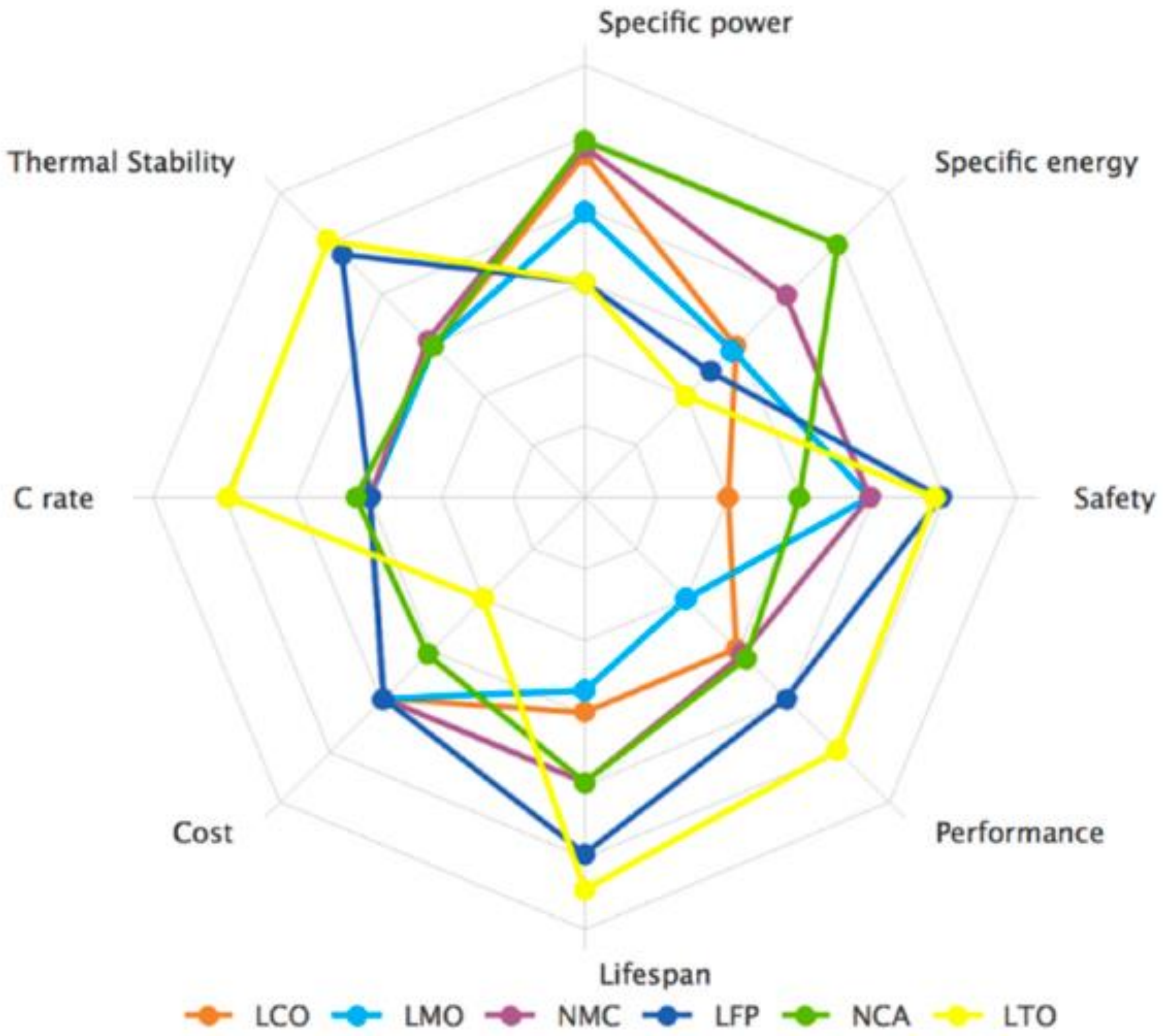

Figure 9. Battery Chemistry Performance Comparisons (Source: Nordkyn Design[30])

While the above spider diagrams are useful for understanding the relative strengths and weaknesses of the dominant cell chemistries, they do not always provide a fool-proof rule of thumb for relative battery cell pricing. For example, it is not uncommon to find a specific NMC cell being produced by Supplier A in their production Facility X at a price that is considerably higher than a similar LFP cell being produced by Supplier B in their production Facility Y and vice-versa. The explanation for this discrepancy between real-world pricing and the directional pricing comparisons in Figure 9 is that in the real world, the actual battery cell price is also determined by the total manufacturing scale (capacity) for each battery cell production line, as well as the current operating level (utilization) of that production line and the availability of that line's capacity for new customers. In some cases, an existing production line may be operating at a significant scale (> 1 GWh/yr) and at a high utilization, but almost the entire production capacity is already committed to existing customers who have contracted with the supplier and enjoy attractive pricing. However, a new customer from the commercial vehicle market may be required to pay a premium to access a thin portion of that line's capacity, and even under those conditions, the commercial vehicle customer's supply may not prove to be sustainable if the original customers' demand increases. These complications illustrate the types of challenges today's commercial vehicle OEMs must overcome in their battery sourcing activities.

Battery cell chemistry is further complicated by advances in technology and "next generation" lithium battery designs. New technologies like sodium-ion, silicon anodes, and solid-state batteries will likely introduce new levels of performance, safety, and cost in the coming years. Planning for when these technologies will reach scale and availability for commercial vehicle applications is an important element of each OEM's strategic sourcing plans.

"Actual" vs. "Forecasted" vs. "Promised" production volumes are another important element of the equation related to battery cell cost. Based on numerous trade press articles, industry news and professional conversations, it would appear that some business leaders within the commercial vehicle industry believe it is possible to secure passenger car battery pricing simply by "promising" or "forecasting" significant future sales volumes. While this tactic may prove to be effective at raising billions of dollars in SPAC funding for some xEV start-ups, it is not a robust sourcing strategy for securing sustainable battery cell supply or pricing.

When it comes to purchasing Li-Ion batteries from world-class, automotive-grade manufacturers, scale and high-volume price points are achieved predominantly by delivering "actual" production volumes, not "forecasted" or "promised" production volumes. At this point in time, the commercial vehicle market has not yet reached the milestone of "actual" production volumes as demonstrated in Figure 2 above and throughout this report. Therefore, commercial vehicle OEMs and Tier 1 suppliers continue to seek innovative pathways that will deliver sustainably lower battery prices, similar to levels currently available primarily to passenger car EV manufacturers.

Non-recurring engineering (NRE) costs are another important driver of the actual battery pack cost for commercial vehicle OEMs and their Tier 1 suppliers. In fact, for some commercial vehicle OEM and Tier 1 suppliers at this point in the development of the commercial vehicle e-mobility market, NRE costs may be one of the dominant drivers in actual battery pack cost. The math is driven by two main elements:

1. The up-front engineering cost required to design, validate, and release a new pack design into production, and
2. The most probable forecasted volume that will be produced over a fixed period of time (e.g., two, three, or even five years).

Due to the unique battery pack installation and operating requirements on commercial vehicles vs. passenger cars, the pack design is often tailored for a specific bus or truck vehicle design, configuration, and operating environment. This unique pack design must first be created, prototyped, tested, and eventually validated for the manufacturing process before it can be released into production (start of production, or SOP). Most of the major truck and bus OEMs use a product validation process that is similar to the standard industry process followed by passenger car manufacturers. This process is defined at a high level by the Automotive Industry Action Group (AIAG) in Southfield, Michigan, and is called the Automotive Production Quality Process (APQP). According to AIAG's APQP guidelines, each major component and subsystem design and its production process must be validated using the Production Part Approval Process (PPAP). Any vehicle OEMs or Tier 1 suppliers that ignore this established industry protocol introduce additional risk into their business plans and, in turn, on their shareholders.

Even if a proven, previously PPAP approved automotive production cell is used for a commercial vehicle pack design, any deviations or new content contained in the module design, pack design, battery management system (BMS) controls and software, cooling system, or other design elements should be validated according to PPAP prior to any production release. The cost for this NRE phase for commercial vehicle battery packs is typically in the range of $150,000 to $500,000. In many cases, third party battery pack systems integrators will quote the NRE to their OEM or Tier 1 customer at the lower end of this cost range and simply amortize the balance into the pack piece price ($/system) according to the pack system integrators' assessment of the volume forecast and its probability. Due to the relatively low volumes of today's North American commercial vehicle e-mobility market, this amortization of NRE costs can have a meaningful impact on the final pack price to the customer.

As truck and bus OEMs, and their Tier 1 suppliers, work to build strong value propositions for their fleet customers, the need for increasing levels of fast charging will also drive changes to battery pack design and resulting NRE costs. For example, future truck designs are being considered that enable megawatt (MW) charging systems capable of charging at 1 MW and beyond. These designs will necessitate changes to the direct current bus specifications and result in significant pack/BMS modifications. This ongoing evolution and maturation of the commercial vehicle e-mobility segment will continue to challenge rapid achievement of scale within the battery system scope of supply.

Capital costs required to create manufacturing facilities and manufacture the unique pack (and module, if applicable) will also have an impact on the final pack price to the commercial vehicle OEM or Tier 1 supplier. These costs include any specific manufacturing equipment, tooling, fixtures, facility upgrades, or other one-time costs required to produce the specific battery pack design. A portion of these costs are typically amortized into the piece price of the battery pack ($/system), and due to today's relatively low volumes, these additional costs can have a measurable impact on driving up the pack price to the OEM or Tier 1 supplier.

Due to the unfavorable impact of NRE and capital costs on the pack price, some commercial vehicle OEM and Tier 1 suppliers have initially and intentionally elected to avoid using tailored packs for their product offerings. Instead, they have leveraged proven automotive battery pack designs and adapted them to their commercial vehicle applications. This strategy has proven effective to a degree, but the battery pack pricing level remains higher than automotive standards, since the passenger car OEM will still require their own additional profit margin and often have little (or no) incentive to tailor the design or BMS to low-volume commercial vehicle applications. This approach has also introduced unplanned obsolescence and source of supply issues, when the passenger car OEM decides to migrate from Generation X to Generation Y and may, or may not, include plans to continue supplying the previous generation design to the commercial vehicle segment. Additionally, this approach may introduce some compromised performance of a specific OEM offering as they try to adopt an off-the-shelf component into their unique and competitive propulsion system designs (which may include unique power, voltage, or durability requirements). Warranty provisions for passenger car pack designs that are adapted to commercial vehicle applications can also become more problematic with these types of sourcing strategies, since the passenger car OEM is often resource constrained in terms of their ability to validate the commercial vehicle system integration design and use cases.

Another difference in battery pack costs exists between **legacy OEMs vs. start-up OEMs** when it comes to battery pack sourcing strategy and pricing to the fleet customer. Legacy truck and bus manufacturers might be much more likely to follow conventional methodologies when it comes to forecasting EV demand, estimating price/cost (margin), allocating investments across the life of the program in an industry where there are few guaranteed volumes, and evaluating the resulting business case using well-established metrics and minimum performance thresholds based on historical data and precedents. These methods and boundary conditions create significant constraints and challenges for established players working to introduce a new technology like battery-electric vehicles (BEVs) with the corresponding complications of EV charging infrastructure, limited driving range (in some cases), and other operational considerations for their fleet customers.

> …start-up OEMs and newcomers may be able to subsidize new vehicle price premiums or build out dedicated fleet EV charging stations using shareholder funds.

By contrast, start-up OEMs and newcomers may be able to subsidize new vehicle price premiums or build out dedicated fleet EV charging stations using shareholder funds. This option means that start-ups and newcomers may behave much more strategically (and speculatively) compared with legacy OEMs operating under a more traditional financial framework and business model. Tesla incorporated this strategy effectively when introducing their Model S and building out a nationwide (global) network of Supercharger EV charging facilities. Tesla’s shareholders were willing to cover these operating losses on the belief their share values would grow in value – and they were ultimately rewarded. This type of funding strategy and its impact on the delivered pack price to fleet customers might not be a viable option for many legacy commercial vehicle OEMs and their established Tier 1 suppliers.

To date, most battery cell production facilities (and operations) have been almost a pure brick and mortar play. Their operating margins have been thin, which provides little room for absorbing forecasting errors or speculative forecasts. Under this type of industry structure, OEM and Tier 1 customers who miss their forecasts will be sent to the back of the line, raising the risk of allocations and loss of supply in the event demand exceeds supply in the future.

The key takeaways from this section are that commercial vehicle OEMs and their Tier 1 suppliers face a number of fundamental structural challenges to sourcing EV batteries efficiently and at a cost that approaches parity with diesel-powered vehicles in the near-term. And, as introduced in the previous section on “Competing Technologies, Policy Drivers and Market Factors,” the playing field is far from level when all commercial vehicle OEMs and their Tier 1 suppliers are taken into consideration.

Battery Industry Structure

The Li-Ion battery *cell* is the key building block for all EV mobility applications. Over the past decade, cell manufacturers have increasingly invested in building megafactories and gigafactories to improve quality and reduce cost dramatically. BMI's time-lapse video Rise of the EV Battery Megafactories[31] provides an effective illustration of how these battery cell production factories have grown geometrically over the past five years, leading to 200 megafactories worldwide in 2021.

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Investments in battery cell megafactories mentioned above led to the 2019 *actual* Li-Ion battery megafactory global footprint as shown in Figure 10.

Source: Benchmark Minerals data, YUNEV analysis

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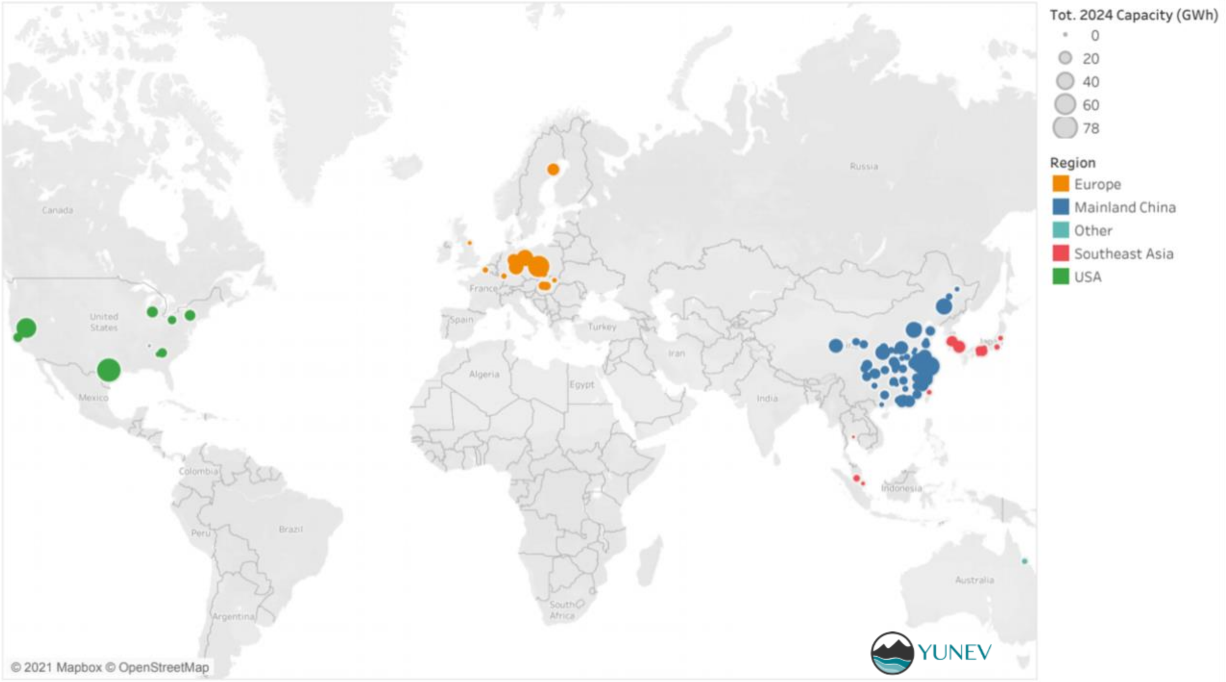
Figure 10. Global Li-Ion Megafactory Footprint – 2019 Actual

As Figure 10 clearly illustrates, China is the dominant source of battery megafactories today, with significant additional capacity in Southeast Asia (Japan and Korea). Most of the 2019 capacity in the United States was (and is) fully captured capacity for Tesla (Panasonic), and as a result, the United States has been lagging in terms of domestic battery production capacity, particularly as it relates to the commercial OEM and Tier 1 market.

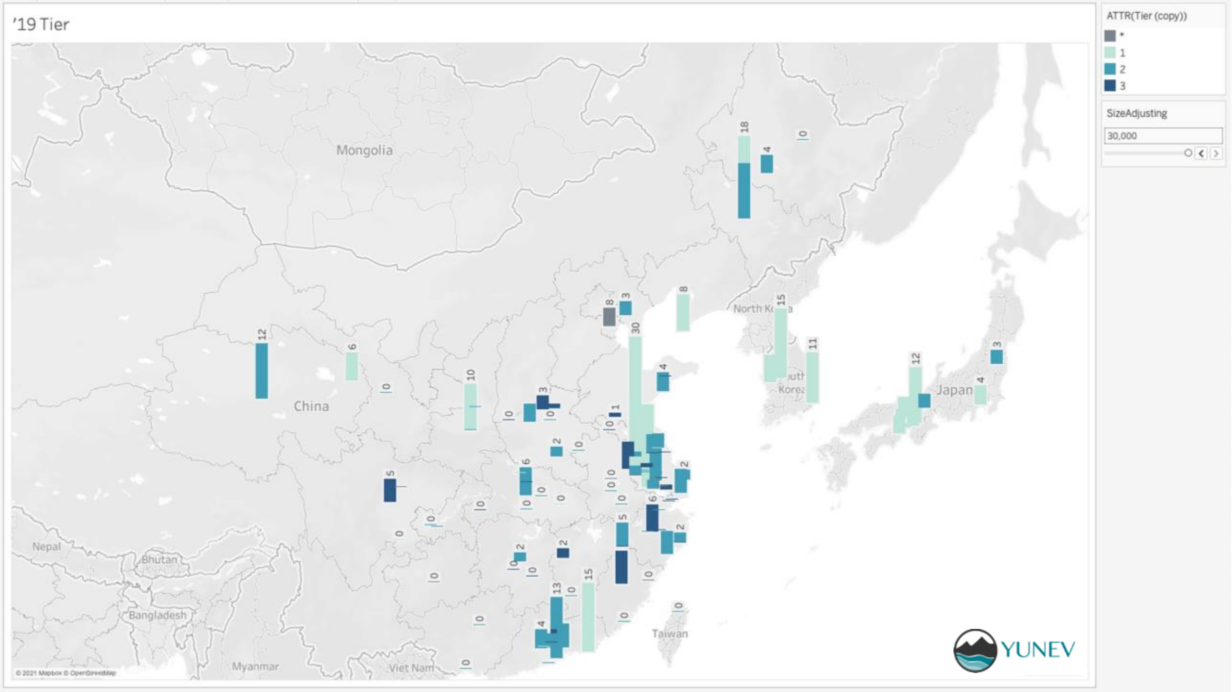
Figure 11 shows the *forecasted* Li-Ion battery megafactory footprint for 2024. This figure indicates that China plans to continue making massive investments in Li-Ion battery capacity throughout the next five years, with Europe also making significant investments, but only moderate expansion planned for U.S. capacity. As discussed earlier, new U.S. DOE loan packages and federal policies have the potential to improve the U.S. forecast in the 2024 time period and beyond, but those plans have not yet been solidified and are therefore not yet included in these forecasts.



Source: Benchmark Minerals data, YUNEV analysis

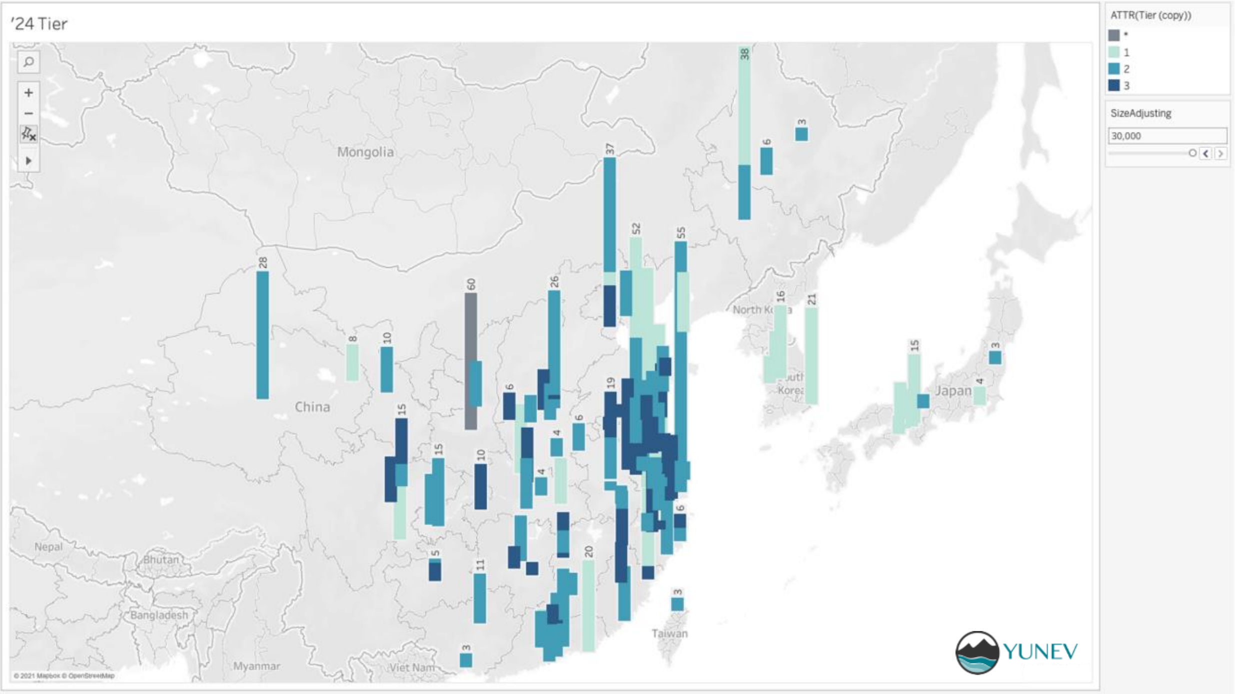
Figure 11. Global Li-Ion Megafactory Footprint – 2024 Forecast

Figures 12 and 13 show more detailed information for the megafactories located in China as of 2019 (actual) and 2024 (forecasted), respectively. These figures provide information regarding the location of each factory (depicted by the location of the base of each bar) and each factory's capacity (as indicated by the height of each bar, GWh/yr). These charts also differentiate between Tier 1, Tier 2, and Tier 3 battery megafactories by color.



Source: Benchmark Minerals data, YUNEV analysis

Figure 12. China Li-Ion Battery Cell Megafactory Footprint – 2019 Actual



Source: Benchmark Minerals data, YUNEV analysis

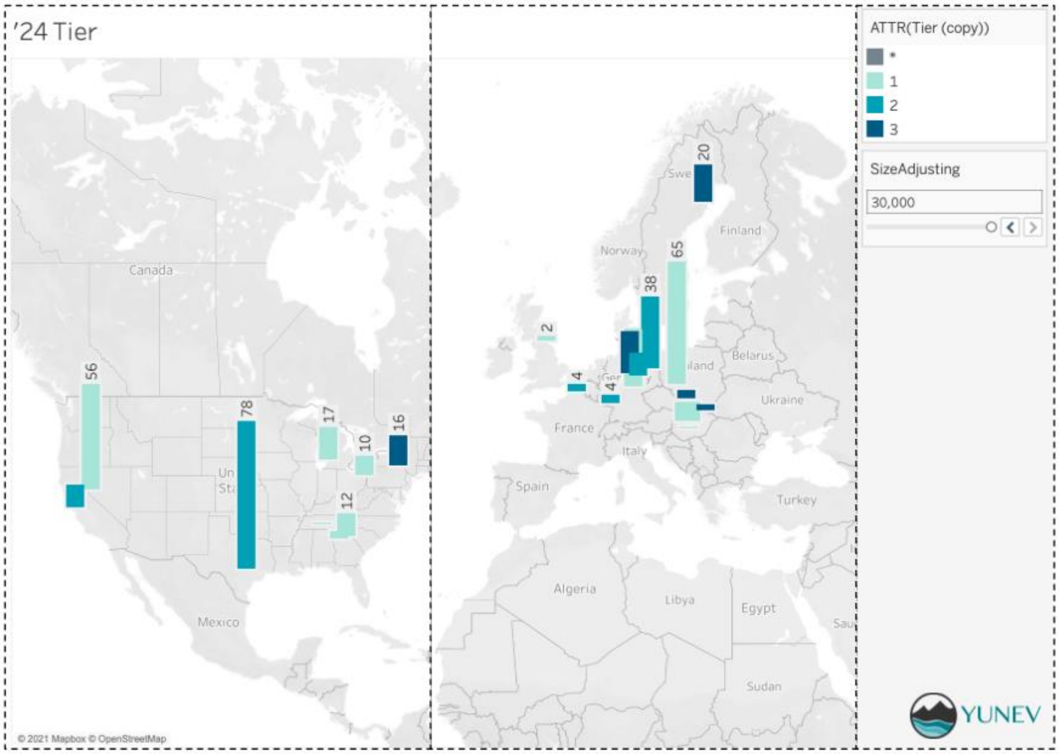
Figure 13. China Li-Ion Battery Cell Megafactory Footprint – 2024 Forecast

These megafactory categories are defined by BMI as follows:

- Tier 1 Megafactory
  - Qualified to supply more than one multinational OEM/EV producer outside of China; > 5 GWh of annual cumulative capacity.
- Tier 2 Megafactory
  - Not yet qualified to supply multinational OEM/EV manufacturers; qualified to supply domestic Chinese EV manufacturers; qualified to supply non-EV applications.
- Tier 3 Megafactory
  - Not yet qualified to supply EV end markets; annual cumulative capacity > 1 GWh; primary focus: non-EV markets including portable and stationary.

Some of the Tier 2 megafactories on this list represent virtually identical levels of scale and quality as their Tier 1 counterparts, but because they have not yet been qualified by a global automotive OEM, they are considered Tier 2 according to this framework. However, that should not be interpreted as a reflection of the quality, safety, performance, or cost of their cells, but only their success to date in winning a global OEM EV account. By contrast, Tier 3 megafactories are often focused on LSEVs and price-conscious grid storage (ESS) markets where performance, safety, quality, and cycle life considerations are not as demanding as the automotive markets. While these factories have achieved significant scale (> 1 GWh/yr), they do not yet have the quality management systems and product integrity required to successfully serve the commercial vehicle market in North America.

Figures 14 and 15 show the currently *planned* Tier 1, Tier 2, and Tier 3 megafactory footprints in Europe and the United States for 2024 and 2029, respectively. As these figures indicate, the United States expansion plans for domestic battery production capacity significantly lag those in Europe over the next five to ten years, in the absence of new policies and funding opportunities being announced by the Biden administration. While it is too early to predict the quantitative impact these new policies will have on domestic capacity, it will almost certainly be favorable. Having said that, there is already a substantial gap between forecasted domestic supply of Li-Ion battery cells vs. forecasted domestic demand by passenger car OEMs, so even with improved domestic production capacity, the question remains how much that improved capacity will actually impact commercial vehicle OEMs, since passenger car EV OEMs will almost certainly be first in line to secure source of supply from these new production facilities. Even Elon Musk announced in Tesla's Q1 2021 earnings report that Tesla's Semi (Class 8 truck) production had been delayed due to a shortage of battery cells during the same period when Tesla set new records for passenger car EV sales.[32] The point of sharing this recent news from Tesla's earnings report is to illustrate how EV passenger car OEMs have a tendency to prioritize their battery cell sourcing capacity for high volume passenger car production over lower volume (and perhaps lower priority) commercial vehicle needs.



Source: Benchmark Minerals data, YUNEV analysis

Figure 14. Planned Megafactory Capacities for Europe and United States – 2024

Source: Benchmark Minerals data, YUNEV analysis

Figure 15. Planned Megafactory Capacities for Europe and United States – 2029

These battery manufacturing footprint maps clearly reflect the dominance of China and Southeast Asia battery production capacity. This dominance is the result of nearly a decade of focused policy and economic development, not something can be changed quickly or easily, especially in a polarized and divided political climate like the United States. Therefore, most North American commercial vehicle OEMs and their Tier 1 suppliers should be prepared to include some element of battery sourcing from Europe and/or Southeast Asia (including China) if they are to secure a sustainable source of supply and reasonably competitive cost structures. Unfortunately, many of these same companies lack the organizational knowledge or capacity to achieve such complex and culturally diverse sourcing objectives.

Recent Case Study

YUNEV recently experienced a common example of this complexity that provides a good case study on the topic. One of YUNEV's clients is a well-established battery systems integrator, and they were quoting a new application for a new OEM customer. The battery systems integrator was keen to use a newer, higher performance Li-Ion cell than a more familiar and readily available option, but lacked visibility to what may be available today and in the near-term. At the same time, YUNEV was aware of a battery cell supplier with a suitable cell in their current product offering. YUNEV shared the cell specification with the systems integrator, and they responded with strong interest in learning more about pricing, production capacity, and availability. Because YUNEV was already in a business relationship with the cell supplier (NDA in place with the cell supplier, history advising the cell supplier, as well as a long-term supply agreement for purchasing product), YUNEV was able to obtain an immediate reply from the supplier.

Unfortunately, the cell supplier informed YUNEV the specific cell of interest had recently been discontinued, and the supplier provided a recommended alternative cell. The alternative cell had a higher specification, and following a first design pass, it appeared to be a good fit, until the OEM customer made a change in their system voltage specification, which in turn disqualified the alternative cell due to technical reasons. Meanwhile, the cell supplier was unwilling to provide pricing or delivery information until all system specifications were finalized and a good technical fit was validated.

Several aspects of this example are relevant to the challenge battery sourcing presents to commercial vehicle OEMs and their Tier 1 suppliers, especially during and following a prolonged global pandemic where business travel to battery makers in Southeast Asia has been essentially on hold:

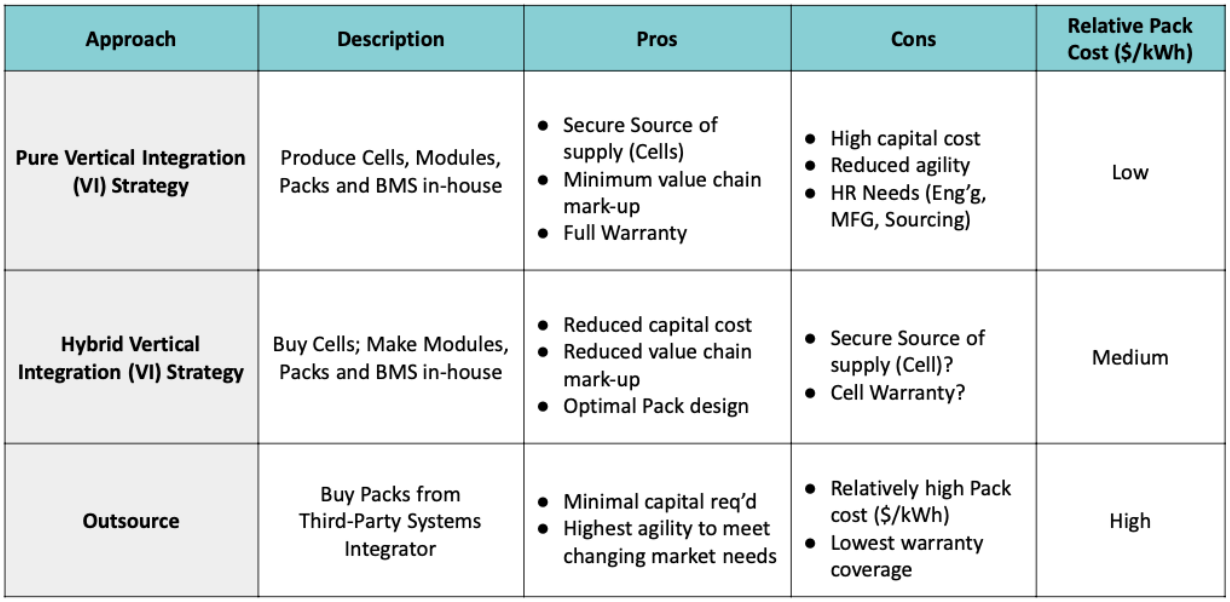
1. Without immediate access to a seasoned industry veteran with direct visibility to a range of cell suppliers and their product offerings, the battery systems integrator would never have had visibility to the existence of the original or alternative cells, since these product and technical details are not easily obtained without direct engagement under NDA coverage with the cell supplier.

2. The ability to receive prompt response and freshly updated information from the cell supplier was enabled by deep cross-cultural experience, technical expertise, and prior familiarity at the product and procurement levels.
3. Even if the cell supplier's current offering had been a good solution and they continued to respond with exceptional agility, it still would have required a minimum of four to six weeks before directional pricing could be obtained, assuming the cell supplier accepted the volume forecasts provided. Without the type of concierge service illustrated in this case study, directional pricing could easily require months to obtain, if not longer given the ongoing pandemic travel restrictions.

Existing and long-term relationships with cell suppliers like the one outlined above require years to build and maintain. As a result, many commercial vehicle manufacturers have no other practical or near-term option than to procure batteries through a third-party systems integrator. For those OEMs who outsource the design, validation, and production of the complete battery pack assembly, there are a number of third-party systems integrators available to choose from, including but not limited to:

- Romeo Power (https://romeopower.com)
- Proterra (https://www.proterra.com/proterra-powered/)
- Actia (https://electromobility.actia.com)
- BMZ (https://bmz-group.com)
- Octillion (https://octillion.us)
- Voltabox (https://www.voltabox.com)
- Enerdel (https://enerdel.com)
- Webasto (https://www.webasto-group.com/en/original-equipment/battery-systems/)

As mentioned previously, some commercial vehicle OEMs have developed VI capabilities spanning cell production, module manufacturing, and pack integration, as well as hybrid versions of a VI approach. Tesla and BYD have both adopted an essentially pure VI approach toward designing and building their own batteries in-house, including the cells themselves. As illustrated in Table 1 below, this approach yields the lowest pack price ($/kWh) and the most secure cell sourcing conditions but requires a high capital investment, which in turn creates reduced agility to respond to changing market conditions. In practice, this approach is only available to a limited number of OEMs (e.g., Tesla and BYD) with their own minimum critical scale for cell production lines (e.g., > 5 GWh/yr production demands). Another major advantage of the pure VI approach is the ability to provide the most cost-effective warranty protection to fleet customers.



Approach	Description	Pros	Cons	Relative Pack Cost ($/kWh)
Pure Vertical Integration (VI) Strategy	Produce Cells, Modules, Packs and BMS in-house	• Secure Source of supply (Cells) • Minimum value chain mark-up • Full Warranty	• High capital cost • Reduced agility • HR Needs (Eng'g, MFG, Sourcing)	Low
Hybrid Vertical Integration (VI) Strategy	Buy Cells; Make Modules, Packs and BMS in-house	• Reduced capital cost • Reduced value chain mark-up • Optimal Pack design	• Secure Source of supply (Cell)? • Cell Warranty?	Medium
Outsource	Buy Packs from Third-Party Systems Integrator	• Minimal capital req'd • Highest agility to meet changing market needs	• Relatively high Pack cost ($/kWh) • Lowest warranty coverage	High

Table 1. Comparison of Various Battery Sourcing Strategies

Other commercial vehicle OEMs have taken an interim (hybrid VI) approach where they procure cells from leading suppliers, like LG Chem, Samsung SDI, SKI, CATL, and others, and develop their own in-house modules, packs, and BMS solutions, including design, validation, and production. The advantage of the hybrid VI approach is that it greatly reduces the capital investments while retaining many of the advantages of the pure VI approach (reduced value chain mark-up, optimized pack design, etc.). However, this approach is less likely to provide the same level of cell sourcing security or cell warranty that a pure VI approach can deliver. Nevertheless, this approach will often create a competitive advantage compared with others who are sourcing the entire system solution from an independent third party.

Commercial vehicle OEMs who do not yet have the requisite scale or engineering and sourcing capacity to bring significant elements of their content in-house are best served by outsourcing their battery packs to third party systems integrators. This approach has the lowest barrier to entry in terms of capital (human and financial) with the potential for increased agility. However, this approach yields the least compelling warranty provisions at the highest pack cost ($/kWh).

As a result of these divergent sourcing strategies, there is currently a wide range in terms of the battery cost structure ($/kWh) among today's commercial vehicle OEMs and Tier 1 suppliers in North America, as is discussed in the following section.

Finally, in addition to the important aspects of the battery industry structure outlined above, the ongoing trade war between the United States and China also creates specific sourcing challenges for North American truck and bus OEMs and their Tier 1 suppliers. While most cell suppliers in Southeast Asia can easily compete with today's North American cell suppliers, even with a 25% tariff, such trade winds do lead to complications in terms of logistics. Import documentation, delivery uncertainty, cash flow forecasting, location for performing module and pack assembly/test, and overall inventory management practices are only a few of the issues that must be addressed. For example, some Chinese cell manufacturers are reportedly moving their products through neighboring Southeast Asia countries where module assembly, pack assembly, and other value-add steps are performed. This strategy is sometimes referred to as washing the cells before shipping to the United States with the goal of avoiding most, if not all, tariffs and duties. For those serving the U.S. transit bus industry, the need to meet strict Buy America requirements can also lead to OEMs and their Tier 1 suppliers committing to accelerated levels of module and pack assembly and test, compared with their preferred manufacturing footprint in the absence of such trade policy factors.

Battery Cell / Module / Pack Costs

At present, battery cell, module, and pack prices in the commercial vehicle market vary widely between OEMs and vehicle applications. Therefore, any *specific* cost/price information contained in this report should be assumed **precisely wrong** (or wrong at a high level of precision). Having said that, the goal in sharing the following cost/price information is to convey **roughly right** directional cost and price metrics. For those who take the time to review this information in its context, YUNEV is confident the insights and perspectives shared here will be valuable – especially for informing policy and strategic sourcing decisions. For those who quickly scan this report and cherry-pick specific data points, then use them out of context, YUNEV cautions that the results may be unfavorable. Therefore, readers and users of the data contained in this report are advised to use and interpret at their own risk.

According to Bloomberg New Energy Finance (see BNEF's famous battery cost reduction graphic in Figure 16), battery production investments and ongoing battery technology improvements have reduced the cost of battery packs by 85% over the past decade.

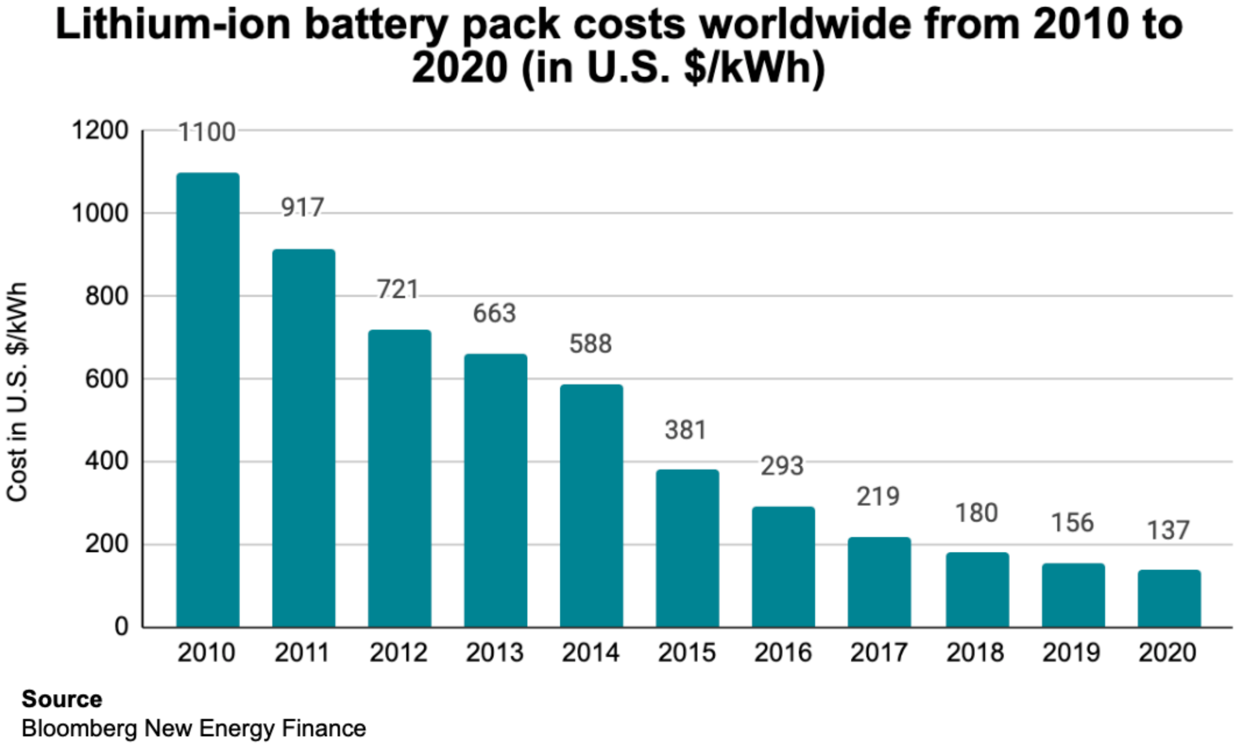
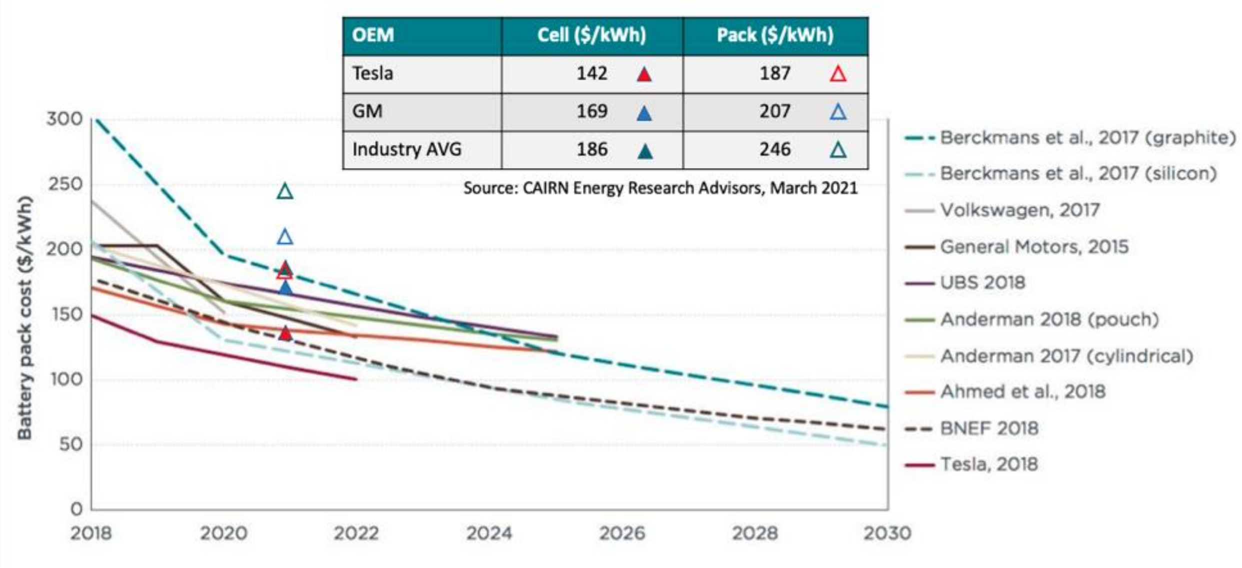


Figure 16. Li-Ion Battery Pack Costs (Source: BNEF)

While YUNEV considers the BNEF cost history chart to be one of the more important trend charts in the battery industry, YUNEV also believes this impressive cost reduction deserves further discussion and interpretation as it relates to the MD/HD commercial vehicle e-mobility market.

The BNEF chart in Figure 16 is meant to convey average battery pack costs for LD passenger vehicles over the past decade. In reality, the average pack cost is an amalgamation of numerous different pack costs and projections as illustrated in Figure 17.



OEM	Cell ($/kWh)	Pack ($/kWh)
Tesla	142 ▲	187 △
GM	169 ▲	207 △
Industry AVG	186 ▲	246 △

Source: CAIRN Energy Research Advisors, March 2021

Figure 17. EV Battery Pack Cost Projections from a Variety of Technical Studies and Automaker Statements [33, 34, 35] (Source: BNEF, CAIRN ERA).

Figure 17 demonstrates that the pack cost between various passenger car OEMs and among various industry experts varies considerably. In fact, in 2020 alone, Figure 17 indicates a range of battery pack costs of up to +/- 25%. CAIRN reports Tesla pack costs are 10% less expensive than GM's and 24% less than the rest of the industry in 2021. CAIRN data (circa March 2021) also suggests some recent upward price pressure at the cell and pack levels, perhaps due to COVID-19 supply chain disruptions, ongoing trade tensions, and strong demand.

The disparity in battery cost data among major EV passenger car OEMs should help explain the level of difficulty and range in costs for OEMs in the commercial vehicle market where the range of EV battery sourcing experience and scale is much more pronounced. YUNEV has been tracking a wide range of commercial vehicle battery costs over the past four to five years. Some of these data sources are confidential, others are proprietary to YUNEV, and some have been obtained without restrictions. Figure 18 plots some of these cost points in the aggregate to help quantify the actual range of costs of batteries within the commercial vehicle e-mobility segment.

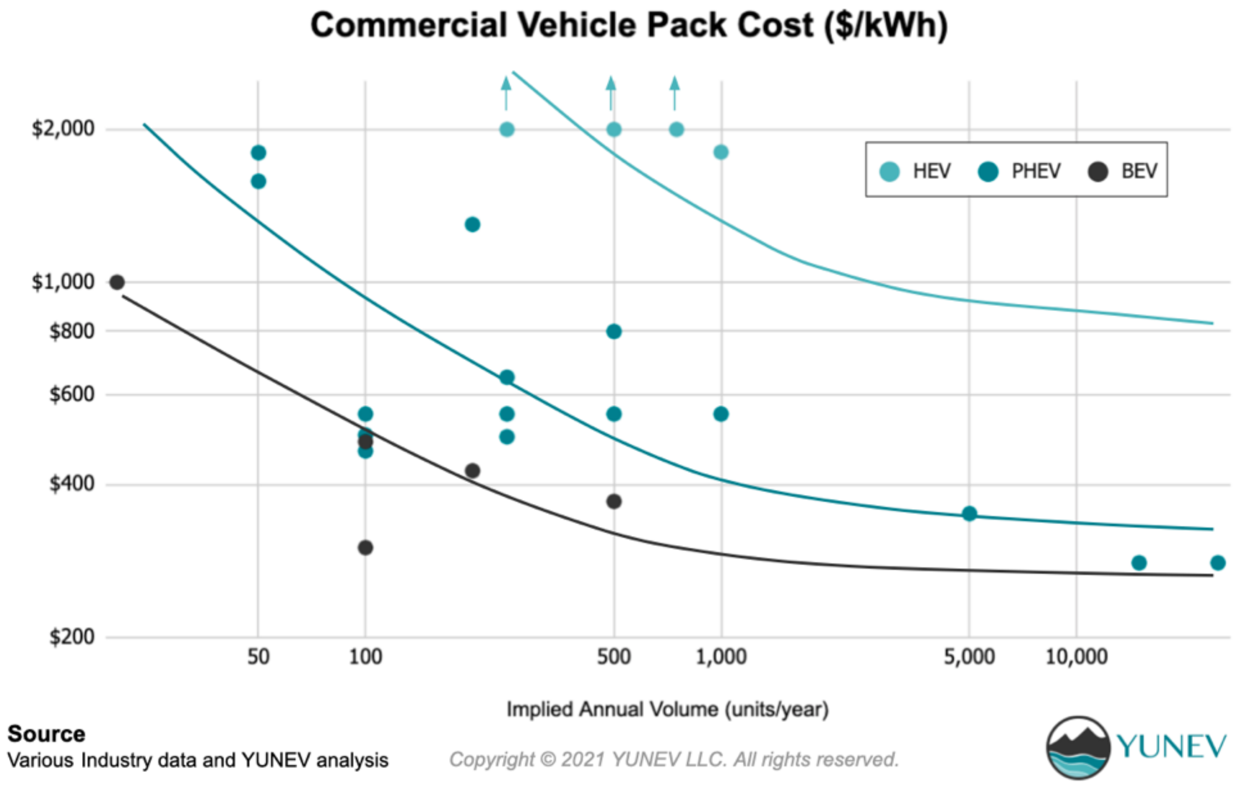
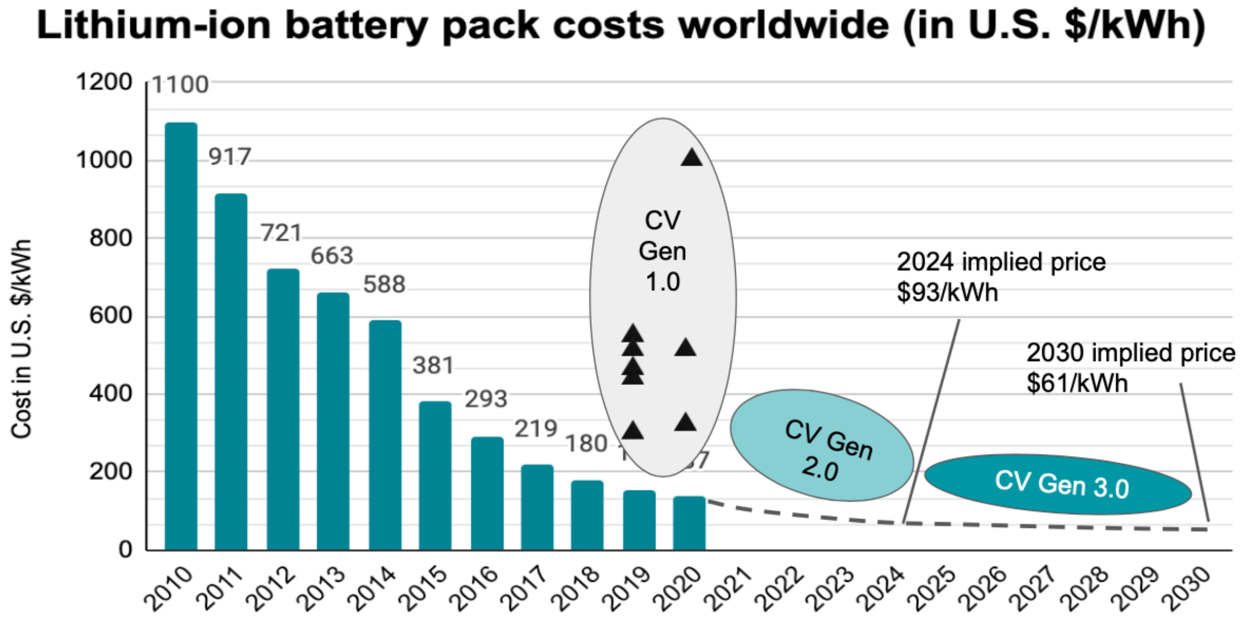


Figure 18. Commercial Vehicle Battery Pack Costs

Figure 18 demonstrates the need to distinguish between hybrid-electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), and BEV battery pack types when quoting normalized pack costs (i.e., $/kWh). As Figure 18 illustrates, the normalized cost of a BEV pack at volumes of 500 units per year can be less than $400/kWh, while the normalized cost of a PHEV or HEV pack at the same volumes can be as high as $800/kWh or more than $2,000/kWh, respectively. Thus, simply using normalized pack pricing of $/kWh without specifying the type of pack (BEV, PHEV, or HEV) introduces a high probability of miscommunication and resultant error and misunderstanding. Figure 18 also illustrates the impact annual production volume has on the unit price for battery packs. For reference purposes, it is not uncommon for conventional powertrain component costs to vary by as much as 10 times over this volume range (from small prototype quantities to > 10,000 units per year). As the commercial truck and bus e-mobility market matures, OEMs and Tier 1 suppliers will gain increasing access to lower battery costs, but crossing that chasm from early pilot production and low volumes (e.g., < 500/year) into more significant volumes (e.g., > 1,000/year) is no simple matter for many OEMs in the North American commercial vehicle market.



Source
Bloomberg New Energy Finance, YUNEV

Figure 19. Battery Cost Trends and Projections – Passenger Car/Light Truck and Commercial Vehicles

Figure 19 compares some of those data points from Figure 18 with the BNEF cost trend data for purposes of contrasting the passenger car battery market with the commercial vehicle battery market. Figure 19 is considered one of the key elements of this report. This chart begins by referencing the BNEF battery cost data from Figure 16. Then, a range of recent public and private commercial vehicle battery pack costs are superimposed on the BNEF data reflecting YUNEV's visibility to actual commercial vehicle xEV battery pack costs over the 2019 and 2020 time period.

> During the past few years, it has not been uncommon for commercial vehicle OEMs and their Tier 1 suppliers to pay two to three times, or even higher, the cost per kWh than their passenger car OEM counterparts…

Figure 19 shows a wide range of battery pack prices recently paid by commercial vehicle OEMs and their Tier 1 suppliers. These prices are considerably higher than the prices paid by EV passenger car OEMs during the same time period. During the past few years, it has not been uncommon for commercial vehicle OEMs and their Tier 1 suppliers to pay two to three times, or even higher, the costs per kWh than their passenger car OEM counterparts, for a number of reasons as explained in previous sections of this report.

The structural differences of the commercial vehicle market compared with the passenger car market help explain this fundamental disconnect.

- High product mix, low volume characteristic of many commercial vehicle applications (compared with much lower mix and higher volume for the passenger car market)
- Scale effect
    - Passenger car OEMs are now building hundreds of thousands and tens of thousands of EVs each year vs. dozens, or at most hundreds for most North American commercial vehicle manufacturers (even though a typical HD truck may specify up to 10 times the number of cells/capacity as a LD passenger vehicle, the total capacity/volume differences are still significant between LD and HD segments).
- Cyclical demand without guaranteed volumes
    - Passenger car production is largely level-loaded throughout the year to allow the entire supply chain to operate at maximum efficiency, whereas commercial vehicle production rates can swing significantly from one quarter to the next due to a changing fleet order board.
    - Many passenger car OEMs provide their key suppliers with guaranteed volumes, sometimes several years out into the future, which allows the suppliers to amortize their capital costs in a predictable and confident manner, while commercial vehicle OEMs rarely provide guaranteed volumes to their suppliers.

YUNEV has labeled the period of relatively expensive and highly variable battery costs for commercial vehicles in 2019 and 2020 as CV Gen 1.0 (for commercial vehicle e-mobility). As the North American commercial vehicle e-mobility segment develops and matures, YUNEV believes a CV Gen 2.0 era (with higher production levels factored in) will be realized in the next two to three years, followed by a CV Gen 3.0 phase in the five-year timeframe and beyond. YUNEV envisions CV Gen 2.0 and CV Gen 3.0 will introduce a reduced range of battery cost variability, and a strong downward cost trend. These trends are expected to result from a general improvement in EV battery sourcing scale, experience, and maturity across the commercial vehicle sector.

Commercial Vehicle OEM Categories: Competent-Proficient-Efficient

The wide range of commercial vehicle pack pricing in Figure 19 also reflects the disparity in terms of scale, organizational capability, and maturity of EV product design and sourcing functions within the commercial vehicle OEMs. As introduced previously in the battery manufacturing continuum in Figure 4, commercial EV manufacturers can be grouped into **Competent**, **Proficient**, and **Efficient** categories. This framework can support a discussion that promotes better understanding when it comes to commercial EV battery costs.

Competent commercial EV manufacturers may include well established and long-standing legacy manufacturers that deliver trusted and reliable commercial vehicles to their fleet customers every day. However, because these manufacturers have lower organizational experience developing and producing EVs compared with some of their peers, they often lack the same access to battery sourcing and attractive pricing as companies in the Proficient and Efficient categories. Competent commercial vehicle OEMs are the critically important commercial vehicle manufacturers that keep freight and passenger mobility moving every day across North America. In the near-term, these OEMs are at the early stage of their battery sourcing journey.

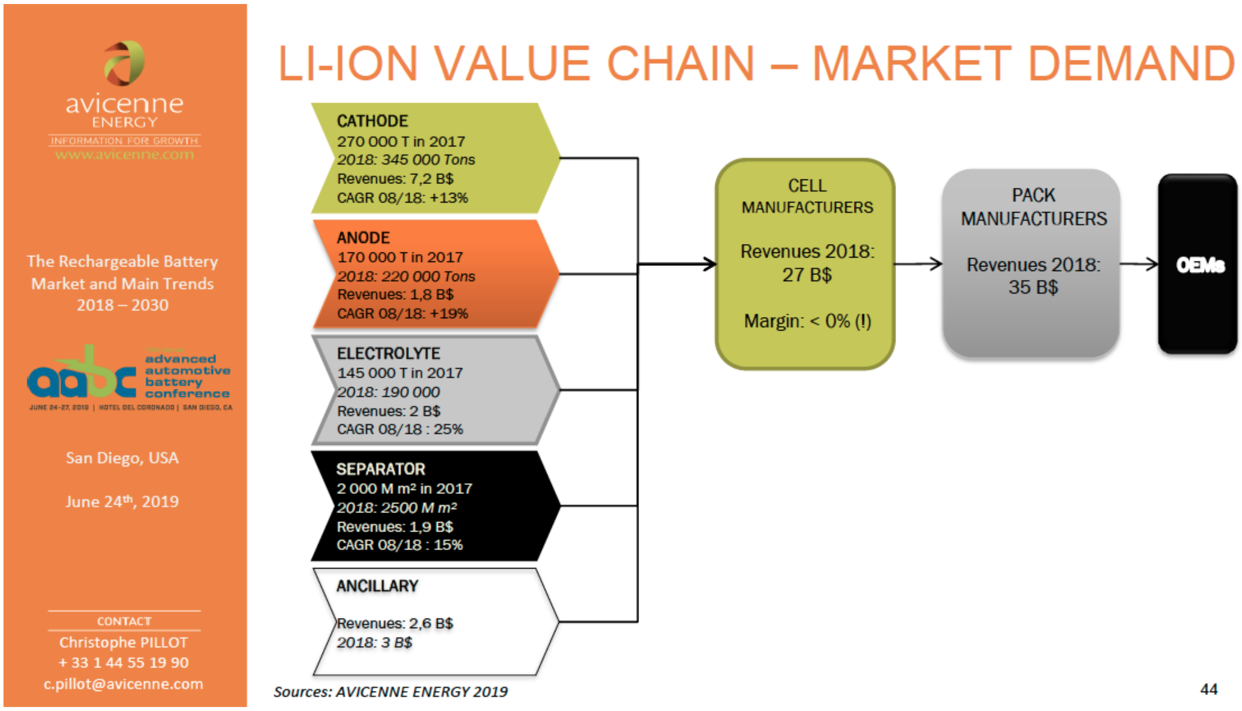
Proficient commercial EV manufacturers include established players with more experience and longevity developing and sourcing xEV powertrains and their battery systems. These EV manufacturers do not yet have the EV or battery sourcing scale of a Tesla or a BYD, but they have considerable xEV corporate experience and a level of maturity in their battery sourcing strategy that is more advanced than those in the Competent category. Some commercial vehicle OEMs have the potential to leverage battery sourcing scale and expertise through their corporate parent organization(s) and might be expected to join the Proficient group more quickly than others. Examples may include Freightliner (through their parent company Daimler) and Navistar (through their parent companies Traton Group and Volkswagen).

The **Efficient** commercial EV manufacturers are those with global scale comparable to major passenger car EV makers. This category includes commercial EV manufacturers like Tesla and BYD. These companies have designed and produced hundreds of thousands of EVs and supported those vehicles in service around the world for many years. Commercial vehicle OEMs like these companies represent best-in-class when it comes to battery sourcing maturity and the resulting cost structure they enjoy. These companies have the organizational capability to procure/produce battery packs at the lowest cost among their peer companies.

YUNEV is confident that today’s battery landscape can begin to improve dramatically for many commercial vehicle OEMs over the next two to five years. YUNEV has referred to today’s situation as CV Gen 1.0, since a large number of commercial truck and bus OEMs are bringing EV products and platforms to the market for the first time. For start-ups and those OEMs who are new to the EV market, YUNEV believes effective incentive (voucher) policy will be needed to help these manufacturers secure early fleet customers and begin growing the demand for their EVs and allowing them to move toward higher volumes and secure more favorable battery pricing. Therefore, with the right policy support, YUNEV envisions a CV Gen 2.0 condition developing over the next two to three years as the variability of battery pricing is compressed for an increasing number of commercial vehicle OEMs and the average price is reduced due to ongoing cost-out at the cell, module, pack, and BMS levels. Finally, in the five-year timeframe, YUNEV envisions most OEMs and Tier 1 suppliers within the commercial vehicle industry achieving a more sustainable and viable cost structure that enables more widespread adoption of EVs and a more virtuous cycle of increasing scale and reducing cost that further fuels electrification of truck and bus platforms, similar to what is seen in the passenger car EV world today. As this discussion has highlighted, the **Efficient** OEMs may not need the same level of incentives as **Proficient** OEMs. Most importantly, the strongest need for effective incentives exists among the **Competent** OEMs. It should also be noted that Competent and Proficient OEMs will benefit from other policies and incentives such as manufacturing tax credits to expedite the manufacturing of key components such as battery cells, modules and packs and allow them access to these low-cost components in a similar manner to the Efficient OEMs.

Li-Ion Battery Pack Value Chain

Gaining a better understanding of the battery supply chain is an important step in evaluating the battery cost structure for commercial truck and bus EV manufacturers. Figure 20 illustrates that raw materials are processed to produce Li-Ion battery cells, which are then transformed into modules and packs before being integrated into the actual vehicle. For EV passenger cars, where volume and scale are more than a thousand times greater than for EV commercial vehicles, industry experts allocate roughly 25%-50% value added at the module/pack level. For example, CAIRN ERA data for Tesla, GM, and Industry AVG cell and pack pricing shown in Figure 17 above reflects a range of 22% to 32% value added at the module/pack level. BNEF reports pack value ranges of 50%, 37%, 42%, and 38% for 2015, 2016, 2017, and 2018, respectively.[34] For purposes of simplification and illustration, YUNEV has used 30% value added for LD passenger car applications. This means that if the battery cells cost $150/kWh, the final pack is likely to cost $195/kWh ($150kWh * 1.30).



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LI-ION VALUE CHAIN – MARKET DEMAND

CATHODE
270 000 T in 2017
2018: 345 000 Tons
Revenues: 7,2 B$
CAGR 08/18: +13%

ANODE
170 000 T in 2017
2018: 220 000 Tons
Revenues: 1,8 B$
CAGR 08/18: +19%

ELECTROLYTE
145 000 T in 2017
2018: 190 000
Revenues: 2 B$
CAGR 08/18 : 25%

SEPARATOR
2 000 M m² in 2017
2018: 2500 M m²
Revenues: 1,9 B$
CAGR 08/18 : 15%

ANCILLARY
Revenues: 2,6 B$
2018: 3 B$

CELL MANUFACTURERS
Revenues 2018: 27 B$
Margin: < 0% (!)

PACK MANUFACTURERS
Revenues 2018: 35 B$

OEMs

Sources: AVICENNE ENERGY 2019

44

Figure 20. Battery Supply Chain Illustration (Source: Avicenne)

However, for commercial vehicles where total North American industry sales barely reach the prototype or pilot project volumes for the passenger car market, the value added for producing modules and packs is typically much greater than the passenger car market due to many of the factors previously discussed in this report. For example, even if a commercial vehicle OEM or Tier 1 supplier procures cells at the same $150/kWh cost mentioned above, a typical module assembly and test process can add as much as 50% to the cost of the cells, and the pack assembly and test operation can drive another 50% value added into the production cost at today's volumes. Thus, for a commercial vehicle application, the same $150/kWh cell can result in a module cost of $225/kWh ($150 * 1.5), yielding a pack cost of $338/kWh ($225/kWh * 1.5), compared with the previous illustration of a passenger car pack cost of $188/kWh. Of course, depending on the specific module and pack design characteristics and vehicle production volumes, these costs can move higher or lower.

Battery Pack Cost Drivers

The normalized battery pack cost, expressed in $/kWh, for commercial vehicle applications is heavily dependent on several cost drivers:

- Battery pack size (actual kWh capacity of the pack)
- Annual production volumes
- Uniqueness to vehicle application (vs. application of scalable building blocks, modules)
- Pack enclosure robustness (environmental and operating requirements)
- Level of pack validation and NRE costs

All else being equal, the normalized cost ($/kWh) of a 300kWh **BEV** pack will be dramatically lower than the normalized cost of an **HEV** pack that might have a capacity of only 5-10kWh, since both packs will require similar BMS, high-voltage connectors, cooling system provisions, enclosures, mounting hardware, and amortization of the NRE and test/validation costs. These factors alone can influence the normalized pack price significantly – as illustrated in Figure 18 above.

Unlike most passenger car and SUV battery packs, the battery packs used for early generation MD/HD electric trucks are often mounted to the frame rail and exposed to road debris, salt spray, high pressure wash, extreme temperatures, and reduced vibration dampening compared with most passenger vehicles. While some next generation designs might result in more integrated pack designs, this will most likely drive a higher degree of unique pack design. Regardless of the xEV application or pack size, these additional commercial vehicle requirements also drive increased pack price compared with passenger car applications.

Unlike most passenger car and SUV battery packs, the battery packs used for early generation MD/HD electric trucks are often mounted to the frame rail and exposed to road debris, salt spray, high pressure wash, extreme temperatures, and reduced vibration dampening compared with most passenger vehicles.

To control warranty costs, protect brand equity, and ensure safe, reliable operation that meets fleet customers' performance expectations, commercial vehicle OEMs and their Tier 1 suppliers must validate new module and pack designs according to AIAG/APQP/PPAP requirements.[36]

While these industry guidelines are subject to interpretation and deployment by each OEM and their suppliers, it is difficult to achieve sustainable competitiveness without subjecting all new designs to rigorous shock, vibration, salt fog, water ingress (due to high pressure spray and submersion), EMC/EMI, and other product integrity and performance tests. Similarly, the manufacturing processes used for assembly and end-of-line (EOL) testing must be validated prior to production release to ensure their ability to consistently produce quality products. For most legacy OEMs, these upfront costs are normally recovered through some level of amortization across the unit price of the product, based on the most probable sales forecast available. Some start-ups and newcomers to the commercial vehicle segment (e.g., Rivian, Arrival, Tesla) *may* be able to cover those upfront investments with shareholder funding and price their product more strategically. But, for most legacy commercial vehicle OEMs, the conventional economics will be hard to avoid. As a result, these product development and validation investments bring additional upward pressure on battery costs where there is limited volume to absorb those costs in the near-term.

What about those commercial vehicle OEMs and other industry sources who report the possibility of procuring complete battery packs at $150/kWh, or even $125/kWh? Lawrence Berkeley National Laboratory recently published a paper citing $135/kWh ("realizable when procured at scale") as the baseline battery pack cost for evaluating TCO for Class 8 electric trucks,[37] with $60/kWh as a possible pack cost by 2030. These types of cost assumptions and forecasts can easily be misinterpreted if the appropriate qualifiers are not fully explained and understood.

First, it is critical that the time and scale dimension be clearly communicated as it relates to battery pack pricing in the commercial vehicle market. Throughout this report, YUNEV strives to distinguish between current state pricing and industry conditions vs. those that may be reasonably forecasted in the next two to five years (CV Gen 2.0) and five to ten years out (CV Gen 3.0). As outlined later in this section, YUNEV believes Efficient OEMs may be able to consistently access pack pricing in the $185/kWh to $210/kWh range within two to five years, and $175/kWh to $210/kWh range in the five-to-ten-year period. While YUNEV agrees with the Lawrence Berkeley paper that $135/kWh will only be realized when procured at scale, the timing for this milestone may be further out and available to only a few commercial vehicle OEMs. The prospect of North American commercial vehicle OEMs accessing packs at $60/kWh in eight years seems to be neither a reasonable forecast nor a constructive way to approach battery sourcing for commercial vehicles at this time.

> It is possible to obtain pack pricing from China-based cell manufacturers in the $125/kWh to $150/kWh range…but not for North American truck and bus manufacturers or applications.

Second, it is possible to obtain pack pricing from China-based cell manufacturers in the $125/kWh to $150/kWh range. In fact, YUNEV has helped clients procure and deliver complete battery pack solutions for e-mobility and grid storage applications during 2020 in this price range. But not for North American truck and bus manufacturers or applications. Assuming minimum volumes are achieved, these low price points can be secured from Tier 2 (ESS) and Tier 3 (LSEV) battery manufacturers in China as depicted in Figures 12 and 13. However, the most suitable end-user applications for these lower-cost products are typically located in Southeast Asia. Generally, LFP cells for integration into low C-Rate applications (duty cycles) and reduced thermal/safety risk profiles are considered ideal for these Tier 2 and Tier 3 low-cost cells.

YUNEV and most of their industry clients and partners would not seriously consider, nor advise, sourcing these same components for deployment in commercial vehicle trucks or buses for the North American market without product design improvements followed by extensive validation and testing. At the completion of such design changes and validation testing, the more robust design and amortization of upfront design and validation costs would only serve to move the final pack price closer and closer to the numbers reported throughout this paper, not to mention introducing 9-12-18 months of additional project duration prior to product delivery. After taking into consideration these additional risk mitigation measures, those low-cost cells and packs begin to lose their luster as candidates for the North American commercial vehicle market.

The Lawrence Berkeley report also references a BNEF study that cites the following chart, which shows commercial vehicle battery costs in China at just over $100/kWh (see Figure 21 below). While YUNEV agrees that some China commercial vehicle (E-Bus) manufacturers are able to procure packs at prices below $150/kWh, it should be noted that these attractive price points are the result of some China E-Bus builders having already achieved annual volumes of almost 25,000 electric buses, which puts these OEMs on a level playing field with passenger car EVs purchasing at similar volumes and price points. BNEF’s chart in Figure 21 also indicates global commercial vehicle pack cost of roughly $330/kWh, which is consistent with the directional pricing found throughout this report.

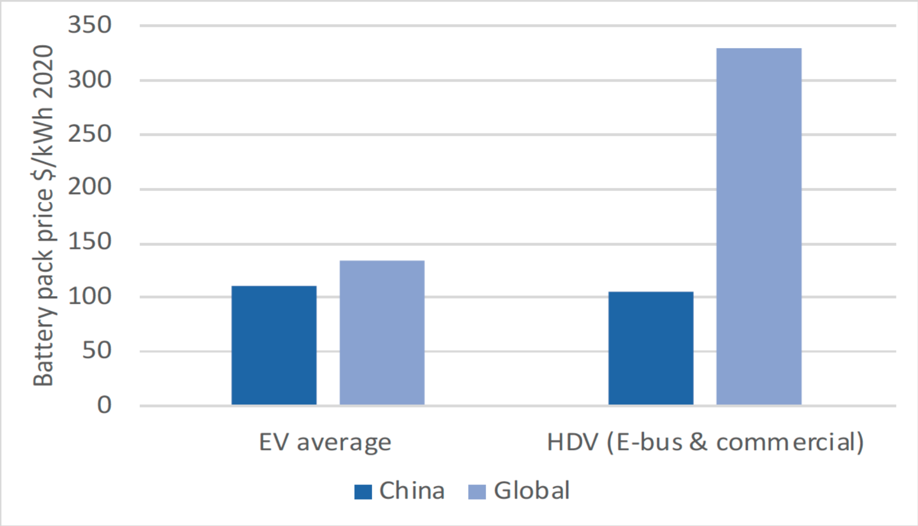


Figure 21. China vs. Global Battery Pack Prices (Source: BNEF, 2020 [37])

For OEMs or Tier 1 suppliers adopting this type of low-cost sourcing strategy, important questions should be asked (with objective evidence required) regarding how designs have been fully validated and certified according to industry best practices. Otherwise, there may be undue risk to the fleet customer and the industry at large due to potential safety hazards, performance gaps, or excessive reliability problems. The commercial fleet market is much different than the consumer vehicle market with respect to its ability to accommodate products with design or material deficiencies. The absolute number of large fleet customers is much smaller than consumers, and they tend to compare notes through industry forums efficiently and effectively. These fleets are not likely to tolerate vehicle safety or thermal events in the same way the consumer market is willing to accept them. Tesla, BMW, GM, and Hyundai have all had their own issues with battery safety and thermal events, even though they are sourcing from global Tier 1 cell suppliers with fully engineered packs that are validated per AIAG/APQP/PPAP and industry standards like SAE 2929 and others.[38] These real-world EV passenger car product examples should provide more than enough motivation and justification for commercial vehicle OEMs and Tier 1 suppliers to follow AIAG/APQP/PPAP validation processes (or equivalent) to ensure their products are robust and reliable. This is the last element of cost that should be minimized or omitted.

Do the Math

With all the discussion and data above serving as background, please refer to the following for a hypothetical commercial vehicle OEM battery price. First, choose a base cost for the cell. Based on a range of client and industry partner projects, YUNEV has seen cell pricing from Tier 1 and Tier 2 cell suppliers during the last year or so in the range of $125/kWh to $200/kWh for a number of commercial vehicle applications. This example assumes a cell cost of $150/kWh. Calculations are based on two separate assumptions: 1.) the cells are produced in China and subject to a 25% tariff when entering the United States, and 2.) the cells are produced outside China and arrive at a U.S. module/pack assembly facility without tariff. For both versions of the analysis, a 50% value added at the module level, and an additional 50% value added at the pack level is assumed. Both value-add amounts are considered to have all overhead, SG&A, amortization, and profit margin included. It is further assumed the packs will be integrated onto the vehicle by an OEM and sold through a local dealer or distributor to the final fleet customer. All key assumptions are noted below. These numbers are meant to be illustrative for policy and market research, not transactionally relevant for negotiations or contracts.

Case 1 – Cells with Tariff

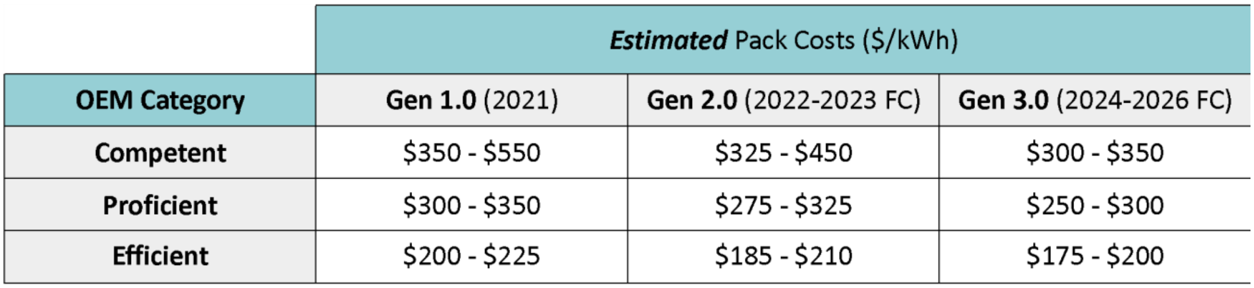
$150 * 1.25 (25% tariff) = $188 (Landed Cost). Additional transport/duties may apply.
$188 * 1.50 (50% value added) = $281 (Module).
$281 * 1.50 (50% value added) = $422 (Pack to OEM).
$422 * 1.15 (15% value added w/margin) = $485 (OEM to Dealer).
$485 * 1.05 (5.0% margin) = $509 (Dealer to Fleet).

Case 2 – Cells with No Tariff

$150 * 1.00 (no tariff) = $150 (Landed Cost). Additional transport/duties may apply.
$150 * 1.50 (50% value added) = $225 (Module).
$225 * 1.50 (50% value added) = $338 (Pack to OEM).
$338 * 1.15 (15% value added w/margin) = $388 (OEM to Dealer).
$388 * 1.05 (5.0% margin) = $408 (Dealer to Fleet).

It should be noted that YUNEV is not directly aware of any existing U.S.-based cell suppliers with available capacity for supporting significant commercial vehicle demand at these prices either now or in the immediate future. Therefore, YUNEV is not sure how Case 2 above might be realized in practice in the near term, although YUNEV is cautiously optimistic that growing European capacity might open up new opportunities for lower cost cell sourcing without the 25% tariff illustrated in Case 1 above. This pricing illustration assumes full amortization of NRE and capital costs are taken into consideration.

Considering how this analysis might translate into current battery costs for Competent, Proficient and Efficient OEM categories, the following range of pack costs seem reasonable for each category. Of course, without drilling into the confidential information of each specific OEM and their sourcing details, these numbers can only be used as a framework for considering policy and investment strategies going forward, not supporting specific transactions or pricing negotiations.



	Estimated **Pack Costs ($/kWh)**		
OEM Category	**Gen 1.0** (2021)	**Gen 2.0** (2022-2023 FC)	**Gen 3.0** (2024-2026 FC)
Competent	$350 - $550	$325 - $450	$300 - $350
Proficient	$300 - $350	$275 - $325	$250 - $300
Efficient	$200 - $225	$185 - $210	$175 - $200

Table 2. Framework for Summer 2021 Estimated and Forecasted Battery Pack Cost ($/kWh) for Competent-Proficient-Efficient CV OEMs

Note: This table represents landed cost to the OEM or Tier 1 supplier, not the fleet customer.

One final point should be emphasized regarding the lack of multi-year volume guarantees for commercial vehicles (vs. PC/SUV where multi-year, volume guarantees are more common). This lack of certainty regarding future production volumes is one more reason it can be difficult to amortize NRE and tooling/fixtures/equipment across sufficient volumes to bring the unit pricing down to a more attractive and sustainable level in the near-term. Long-term sales or purchase requirements such as the CARB ACT rule or upcoming Advanced Clean Fleet purchase rule might help alleviate some of these volume guarantee issues.

Warranty, Financing, and Recycling Considerations

Battery warranties (and extended warranty options) are a critical element of commercializing EVs in the commercial vehicle space. Fleet managers and procurement personnel will increasingly look for contractual warranty commitments from EV manufacturers and their battery system suppliers due to increased scrutiny to provide accurate TCO analysis to remain cost competitive in their respective industries. The ability of a commercial vehicle OEM to obtain meaningful warranty provisions from their battery system supplier(s) is tightly linked to their battery cell sourcing situation. It can be difficult for many low-volume commercial vehicle OEMs to get pass-through warranty protection from their cell suppliers. The reason for this difficulty is fairly straightforward: the cell supplier is not directly involved in the battery system design and validation process. The method for integrating cells into modules and packs, along with the BMS strategy and vehicle operating conditions, are important factors on real-world battery life. Therefore, the cell supplier cannot afford to accept the warranty risk without knowing what temperature, vibration, and other environmental/operating conditions the cells will be subjected to in their respective modules and packs, as well as the vehicle installation location and vehicle operating conditions and duty cycle. BMS control and monitoring provisions and calibrations also play a role in assessing warranty risk from the perspective of the cell supplier. For many commercial vehicle OEMs, it is not practical to provide the cell supplier with sufficient battery system design, integration, and validation information to allow a cell supplier to sign up for meaningful warranty coverage. In some cases, there is little motivation and economic incentive for the cell supplier to make the effort to evaluate such information.

> For commercial vehicle OEMs and third-party systems integrators, the lack of motivation and/or economic incentive for the cell supplier to offer robust warranty coverage presents a real challenge. Can the OEM or systems integrator afford to provide an extended battery pack warranty to the fleet customer without pass-through warranty protection from the cell supplier(s)?

For commercial OEMs and third-party systems integrators, this presents a real challenge. Can the OEM or systems integrator afford to provide an extended battery pack warranty to the fleet customer without pass-through warranty protection from the cell supplier(s)? If so, it may be necessary for the OEM or systems integrator to include additional cost in their pricing to allow them to set-aside funds for future warranty claims. The importance of battery pack warranty requirements from the fleet customer only serves to move the battery cost point in the wrong direction.

BYD offers a 12-year warranty on their batteries when integrated into BYD transit bus and heavy truck platforms. While it is theoretically possible that BYD's LFP packs can last up to 12 years in some commercial vehicle applications, there is good reason to believe BYD does not expect all their batteries to meet the full warranty period in North American commercial fleet applications. Some industry experts interpret BYD's ambitious warranty to include a planned cost for BYD to replace the pack as early as six years, depending on the vehicle duty cycle. Since BYD's battery supply is vertically integrated, their cost to perform a scheduled pack replacement as early as six years is presumably much lower than the majority of their non-vertically integrated competitors in these commercial vehicle segments. And, because BYD has full visibility to the entire battery design, BMS controls, and system validation, they have complete insight into the technical and financial risks associated with this type of warranty. In other words, BYD's vertically integrated battery sourcing strategy is a key enabler in their ability to offer such a compelling battery warranty. Or, viewed from another perspective, BYD's warranty strategy could be seen as up to a two-times multiplier to their battery cost (adjusted $/kWh cost).

Regardless of the specific product development process, value chain, and warranty strategy, offering fleet customers an extended warranty during the early phase of EV deployment will inevitably drive additional cost into the battery sourcing equation. At this point in time, each situation merits its own analysis and forecasted cost, but this element of battery cost should not be overlooked.

Creative financing and access to capital are important enablers to expanded deployment of EVs for commercial fleet applications. California's HVIP has been the most successful program at helping deploy xEV commercial vehicles in North America over the past ten years. The ability to continue providing sustainable financing that is economically attractive and viable for fleets is a direct function of the battery sourcing and warranty terms that are obtained from cell suppliers and extended to fleet customers. As battery costs are lowered, HVIP voucher funding amounts per vehicle could be adjusted to allow a greater number of EVs to be deployed with a fixed voucher program funding level.

Other creative financing options are also needed to help extend beyond funding constraints of government incentives like the HVIP vouchers. Proterra partnered with Mitsui to create a $200 million battery leasing program to help make it easier for transit agencies to purchase their EV buses. Under this program, upfront cost of the bus batteries could be covered through a leasing arrangement with Mitsui with the expectation that operational cost savings (vs. diesel buses) would be sufficient to cover the battery lease payments.(12) This lease program also has a built-in 12-year battery life contract, with new battery replacement scheduled at six years, similar to the earlier discussion with respect to BYD's 12-year warranty. Proterra's battery lease program is a good example of the benefit OEMs can achieve from having more control of the details of the entire battery system design and production, allowing them to ensure warranty cost allocations are fully captured in the lease repayment financial modeling. This type of creative financing is the result of Proterra's strong battery design and sourcing capabilities

(Proficient OEM category) and not something that is readily available to many OEMs that might fall into the Competent category discussed earlier.

Commercial Vehicle E-Mobility Deployment Status

As mentioned earlier in this report, the announcements of Amazon ordering 100,000 EV package delivery vans from Rivian[39] and UPS ordering 10,000 EV package delivery vans from Arrival[40] can create an impression that commercialization of EV commercial vehicles has already been achieved. The reality is that as of June 2021, both Rivian and Arrival have yet to produce their first production vehicles for the commercial vehicle segment, although both companies are making steady progress toward that goal. Deployment of a growing number of Rivian pilot test vehicles by Amazon is now expanding outside California.[41] Arrival recently announced plans for a second microfactory in the United States to support their production ramp-up for UPS.[42] Major fleet orders by Amazon and UPS, combined with substantial investor funding and organizational capabilities of Rivian and Arrival to deliver on their commitments, are game-changing events for the commercial vehicle industry. That said, these newcomers to the commercial vehicle market and their future business forecasts should be understood in the context of an accurate and up-to-date current state across the commercial vehicle industry. This section attempts to provide a current snapshot on actual number of units deployed and the latest SOP dates for some of the more highly publicized EV commercial vehicle launches.

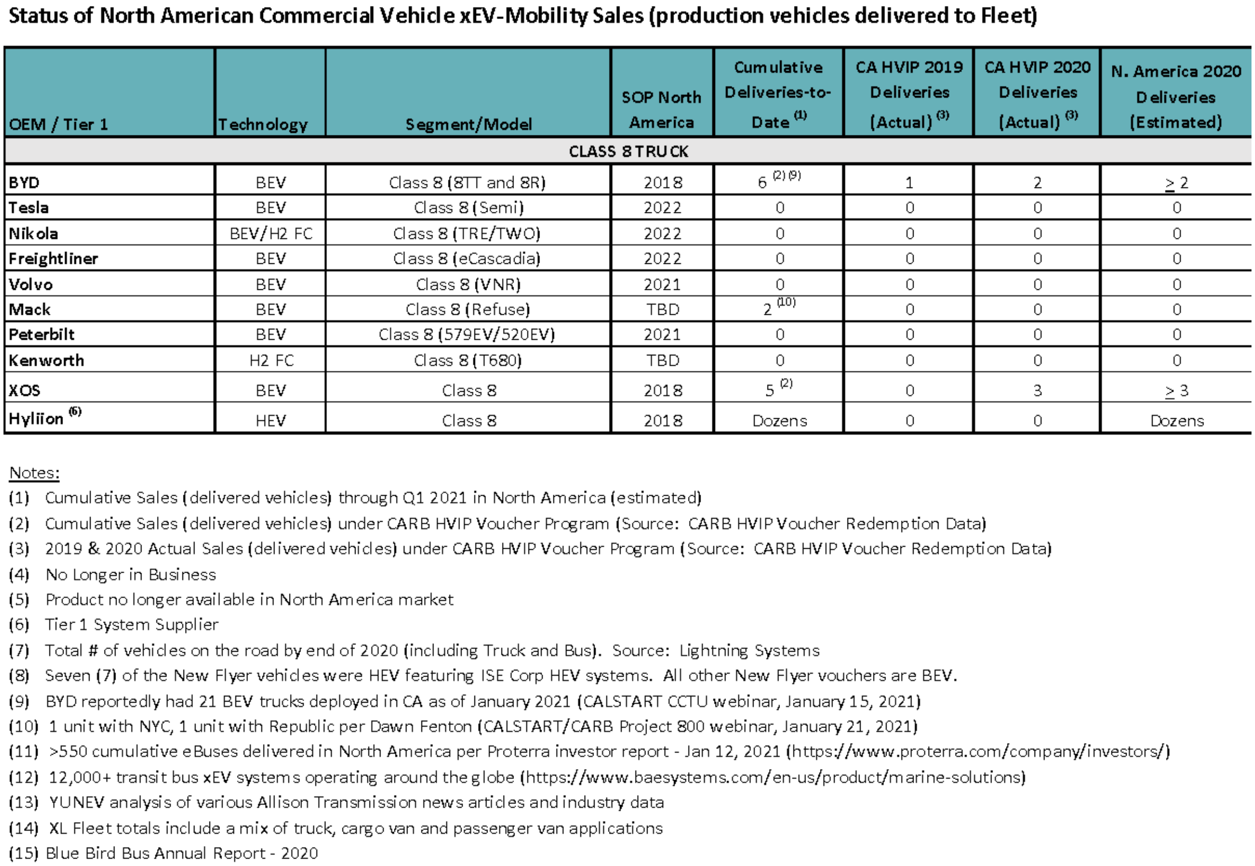
Table 3 provides a list of commercial e-mobility trucks and buses that have been released into production or are planned for production release in the very near future.

> The reality is that as of June 2021, both Rivian and Arrival have yet to produce their first production vehicles for the commercial vehicle segment…

Status of North American Commercial Vehicle xEV-Mobility Sales (production vehicles delivered to Fleet)

OEM / Tier 1	Technology	Segment/Model	SOP North America	Cumulative Deliveries-to-Date (1)	CA HVIP 2019 Deliveries (Actual) (3)	CA HVIP 2020 Deliveries (Actual) (3)	N. America 2020 Deliveries (Estimated)
E-BUS (Transit, School, Shuttle)							
BYD	BEV	40'/60' Transit, K9, K7, Coach	2014+	229 (2)	63	94	≥ 94
GreenPower	BEV	Shuttle Bus	2018	94 (2)	15	79	≥ 79
Proterra	BEV	35'/40' Transit	2016	>550 (11), 81 (2)	36	22	<200
New Flyer (6)	BEV, HEV	40'/60' Transit	2019	65 (2)	0	58	≥ 58
Lion Electric	BEV	School Bus	2016	43 (2)	20	16	≥ 16
Gillig	BEV	Transit	2019	1 (2)	1	0	
Complete Coach Works	BEV	Transit	2018	3 (2)	0	3	≥ 3
ElDorado	BEV	Transit	2018	5 (2)	0	0	
Blue Bird	BEV	School Bus	2018	>300 (15), 76 (2)	25	45	158 (15)
Micro Bird	BEV	School Bus	2019	6 (2)	0	6	≥ 6
Phoenix Electric	BEV	Shuttle Bus	2015	74 (2)	16	17	≥ 17
Allison (6)	HEV	Transit	2000	>15,000 (13)	0	0	100's
BAE (6)	xEV	Transit	2000	>12,000 (12)	0	0	100's
XL Fleet (6)	HEV	Transit Van	2012	> 4,300 (14)	27	30	1,537 (14)
Lightning Systems (6)	BEV	Transit Van, Shuttle Bus	2019	31 (2)	0	25	≥ 25
Motiv Power (6)	BEV	School Bus, Shuttle Bus	2018	21 (2)	14	0	N/A
Eaton (5,6)		Shuttle Bus, School Bus	2006	17 (2)	N/A	N/A	N/A
Zenith Motors (4)	BEV	Shuttle Van	2015	44 (2)	1	0	0
Azure Dynamics (4,6)	BEV	Shuttle Bus, School Bus	2011	8 (2)	0	0	0
TERMINAL TRACTOR							
Kalmar Ottawa	BEV	Terminal Tractor	2019	41 (2)	2	39	≥ 39
Orange EV	BEV	Terminal Tractor	2018	85 (2)	44	13	≥ 13
LD TRUCK / CARGO VAN							
XL Fleet (6)	HEV, PHEV	Class 2-3	2012	> 4,300 (14)	26	35	1,537 (14)
Azure Dynamics (4,6)	HEV, BEV	Ford Transit Connect	2011	181 (2)	0	0	0
Lightning Systems (6)	BEV	Transit Cargo Van	2018	19 (2) 120 (7)	10	9	≥ 9
Navistar	BEV	Class 3 Cargo Van (eStar)	2011	34 (2)	0	0	0
Chanje Electric	BEV	Delivery Van	2017	25 (2)	5	0	0
Zenith Motors (4)	BEV	Class 3 Cargo Van	2015	22 (2)	7	0	0
Phoenix Electric	BEV	Class 4	2015	9 (2)	0	6	≥ 6
Mercedes eSprinter	BEV	Cargo Van	2023 (Est)	0	0	0	0
Ford E-Transit	BEV	Cargo Van	2022	0	0	0	0
Arrival	BEV	Cargo Van	2022	0	0	0	0
Rivian	BEV	Cargo Van	2021	Test only	0	0	0
MD TRUCK (Cargo, Box, Utility)							
Eaton (5,6)	HEV	Class 4-6	2006	>3,000	0	0	0
Hino	HEV	Class 5 (195h)	2013	1,606 (2)	56	6	≥ 6
Altec	PHEV	Utility	2013	201 (2)	28	37	≥ 37
Smith Electric (4)	BEV	Class 3-6	2011	168 (2)	0	0	0
EVI (4)	BEV	MD, Walk In	2012	112 (2)	0	0	0
Motiv Power (6)	BEV	Class 4-5 Truck	2016	22 (2)	4	15	≥ 15
BYD	BEV	Class 5-7 (T5, T7)	2017	5 (2) (9)	0	2	≥ 2
Lightning Systems (6)	BEV	Class 6 (GM6500)	2019	2 (2)	2	0	0
Freightliner	BEV	Class 6-7 (eM2)	2022	0	0	0	0
Peterbilt	BEV	Class 6-7 (220EV)	2021	0	0	0	0
SEA Electric	BEV	Class 5-7	2020	1 (2)	0	1	≥ 1

Table 3. Partial List of North American Commercial E-Mobility Trucks and Buses



Status of North American Commercial Vehicle xEV-Mobility Sales (production vehicles delivered to Fleet)

OEM / Tier 1	Technology	Segment/Model	SOP North America	Cumulative Deliveries-to-Date (1)	CA HVIP 2019 Deliveries (Actual) (3)	CA HVIP 2020 Deliveries (Actual) (3)	N. America 2020 Deliveries (Estimated)
CLASS 8 TRUCK							
BYD	BEV	Class 8 (8TT and 8R)	2018	6 (2) (9)	1	2	≥ 2
Tesla	BEV	Class 8 (Semi)	2022	0	0	0	0
Nikola	BEV/H2 FC	Class 8 (TRE/TWO)	2022	0	0	0	0
Freightliner	BEV	Class 8 (eCascadia)	2022	0	0	0	0
Volvo	BEV	Class 8 (VNR)	2021	0	0	0	0
Mack	BEV	Class 8 (Refuse)	TBD	2 (10)	0	0	0
Peterbilt	BEV	Class 8 (579EV/520EV)	2021	0	0	0	0
Kenworth	H2 FC	Class 8 (T680)	TBD	0	0	0	0
XOS	BEV	Class 8	2018	5 (2)	0	3	≥ 3
Hyliion (6)	HEV	Class 8	2018	Dozens	0	0	Dozens

Notes:

(1) Cumulative Sales (delivered vehicles) through Q1 2021 in North America (estimated)

(2) Cumulative Sales (delivered vehicles) under CARB HVIP Voucher Program (Source: CARB HVIP Voucher Redemption Data)

(3) 2019 & 2020 Actual Sales (delivered vehicles) under CARB HVIP Voucher Program (Source: CARB HVIP Voucher Redemption Data)

(4) No Longer in Business

(5) Product no longer available in North America market

(6) Tier 1 System Supplier

(7) Total # of vehicles on the road by end of 2020 (including Truck and Bus). Source: Lightning Systems

(8) Seven (7) of the New Flyer vehicles were HEV featuring ISE Corp HEV systems. All other New Flyer vouchers are BEV.

(9) BYD reportedly had 21 BEV trucks deployed in CA as of January 2021 (CALSTART CCTU webinar, January 15, 2021)

(10) 1 unit with NYC, 1 unit with Republic per Dawn Fenton (CALSTART/CARB Project 800 webinar, January 21, 2021)

(11) >550 cumulative eBuses delivered in North America per Proterra investor report - Jan 12, 2021 (https://www.proterra.com/company/investors/)

(12) 12,000+ transit bus xEV systems operating around the globe (https://www.baesystems.com/en-us/product/marine-solutions)

(13) YUNEV analysis of various Allison Transmission news articles and industry data

(14) XL Fleet totals include a mix of truck, cargo van and passenger van applications

(15) Blue Bird Bus Annual Report - 2020

(Cont'd) Table 3. Partial List of North American Commercial E-Mobility Trucks and Buses

Compiling a list of e-mobility makes and models available in the North American truck and bus market with actual numbers produced, sold, and delivered is not a straightforward task. HVIP voucher redemption data provides reliable, accurate, and up-to-date information on units sold through the voucher program in California. Outside of the Federal Transit Administration's funding of electric transit buses, HVIP is the largest e-mobility market for commercial vehicles in the United States and a good place to begin building out a dataset. However, this information does not provide visibility to sales outside California, or for vehicles purchased without the use of HVIP voucher funds. Nevertheless, for many manufacturers on the list in Table 3, HVIP represents the vast majority of their cumulative sales to date of e-mobility vehicles in North America. However, for some OEMs and Tier 1 suppliers like Proterra, New Flyer, BYD, Allison, BAE Systems, Eaton, XL Fleet, and others, significant sales and deployments have also been achieved outside California, but these numbers are rarely reported in a comprehensive or easily accessible manner.

A few key takeaways can be obtained by reviewing the data in Table 3. For example:

- Overall, transit buses have seen some of the earliest and most consistent demand for BEVs within the commercial vehicle space.
- Terminal tractors and school buses have been at the top of the demand charts for commercial vehicle e-mobility during the past couple of years, providing important early production experience for their OEMs and fleet customers.
- For Allison, BAE, Eaton, and XL Fleet HEV systems, nationwide sales to date have greatly exceeded HVIP voucher sales in California, suggesting that HVIP either spurred expansion into the rest of the country, or these products were more commercially viable without heavy voucher support.
- Yet, for the majority of the makes and models listed in Table 3, sales of these vehicles continue to rely heavily on HVIP voucher support to gain traction with early fleet customers and begin moving toward commercialization at greater scale.
- Through Q1 2021, beyond the 126 terminal tractors (yard trucks) that had been delivered, fewer than 20 Class 8 BEV production-level, on-road trucks have been delivered to customers in California through HVIP, with less than 10 delivered in 2020. (There were 52 terminal tractors delivered through HVIP during 2020.)
    - 2019 deliveries were even lower for the Class 8 BEV on-road truck segment (excluding terminal tractors).
- Through Q1 2021, fewer than 100 total BEV production-level, on-road trucks in all weight classes were sold in California in 2020 through HVIP (not including the terminal tractors mentioned above).
    - 2019 deliveries were lower, therefore the Class 8 E-Mobility truck market is on the verge of launching a range of new vehicles by most major OEMs.

The data represented in Table 3 are considered reliable for the majority of the entries provided. However, a more comprehensive and accurate reporting of these data is outside the scope of this report. The purpose of Table 3 is to help educate and calibrate policy makers, investors, and key stakeholders in this market, to enable informed decision making without the hype or noise that can be generated by the daily news feeds.

Even when data is reported for some of the makes and models in Table 3, that data must be evaluated carefully to avoid inaccurate conclusions or observations. Market size and forecasting reports can be nuanced and risk giving the wrong impression due to the emerging nature of the e-mobility commercial vehicle segment. For example, some EV makers in the North American market have repeatedly included inflated vehicle unit counts in their cumulative sales, even though many of these units are still on back-order and not yet produced or delivered to the customer. A detailed analysis of the HVIP voucher redemption data reveals that some units delivered in 2019 were originally ordered as 2014 models, but were not delivered for nearly five years. Other examples include 2017 model year units delayed by almost four years before being delivered in early 2021. When OEMs report “cumulative sales to date,” where a significant portion of those units are yet to be built, it creates a real challenge for the audience to properly interpret the numbers. Similarly, some OEMs and Tier 1 suppliers report *cumulative* sales figures in a way that can be easily confused with *annual* sales volumes. While none of these activities are considered malicious or intentional, they do have the unfortunate effect of introducing significant misunderstandings on some portions of the audience. Therefore, Table 3 is intended to help provide a calibration for interpreting these daily news feeds in a manner that is grounded in reality.

ICCT recently published a report that provides an update on the zero-emission bus and truck market in the United States and Canada through 2020.[43] Figure 22 is a key excerpt from that report and helps visualize actual zero-emission commercial vehicle sales in the United States and Canada by vehicle type, with 2020 sales shown for major manufacturers. This figure also provides data labels with the relative market share by major manufacturer for each vehicle segment in 2020. While it is not practical to compare the data in Figure 22 directly with Table 3, both of these data sets can be reviewed for purposes of gaining a strong foundation for the actual trends and levels of zero-emission commercial vehicle activity in North America.

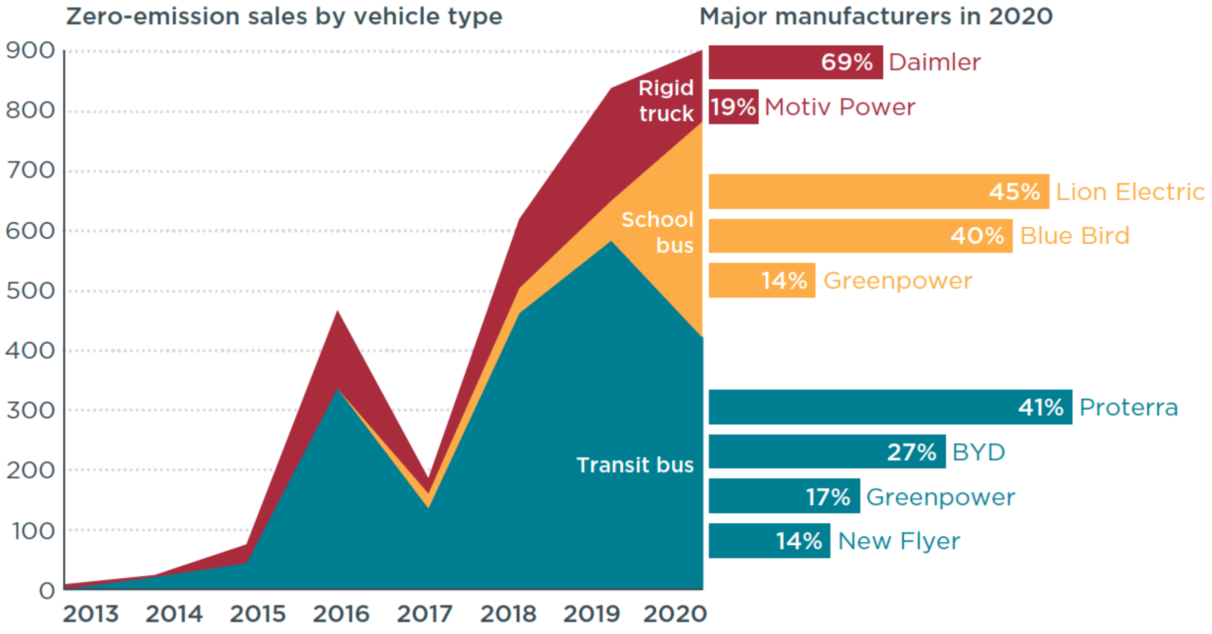


Figure 22. Zero-Emission Bus and Truck Sales in the United States and Canada (Source: ICCT Fact Sheet) [43]

Forward Looking Forecasts

Many industry observers are eager to find the most up-to-date and accurate forecast for how the commercial vehicle e-mobility segment will develop over the next two to ten years and beyond. Unfortunately, for new markets and technologies like e-mobility for commercial vehicles, virtually all forecasts are always wrong. Nevertheless, these forecasts do have value. The actual quantitative values are not the point. The thought process and reasoning behind the forecasts are where the greatest value lies. This section provides a sampling of recent forecasts by a range of industry experts to encourage informed critical thinking on this important topic.

So, what are the forecasts predicting for 2030 and beyond?

These forecasts from incumbent energy suppliers make the case that carbon-based fuels are not going away completely or anytime soon, and the range of electric vehicle penetration varies from less than 10% to 40% by 2050.

On one end of the spectrum are incumbent energy suppliers who have the largest installed infrastructure for extracting, processing, distributing, and delivering carbon-based fuels. These players have significant exposure to shifting energy sources and naturally invest massive resources in forecasting various scenarios that may play out regionally and globally. The American Petroleum Institute recently released a Climate Action Framework report[44] that cites the U.S. Energy Information Administration (EIA) as forecasting oil and natural gas as the dominant energy source through 2040, providing nearly half of all global energy demand in the EIA's Sustainable Development Scenario. This scenario assumes that every nation meets the goals of the Paris Climate Agreement. BP's annual Energy Outlook[45] also reflects growing global energy demand through 2050 and allows for a much wider range of electrification within the transportation sector – from just over 10% electrification in a business-as-usual scenario to as much as 40% electrification in a net zero scenario (BP's net zero scenario assumes 95% reduction in global carbon emissions from energy use by 2050, compared with 2018 levels). Despite the backdrop of growing energy demand forecasted throughout the next 20 years, there is broad acceptance that E-Mobility will grow significantly, while oil continues to be produced at roughly 100 million barrels per day. These forecasts from incumbent energy suppliers make the case that carbon-based fuels are not going away completely or anytime soon, and the range of electric vehicle penetration varies from less than 10% to 40% by 2050. The perspectives from this end of the forecasting continuum are worth careful consideration by those in the e-mobility space.

BNEF's forecasts imply an annual production of more than one million commercial EVs by 2030 (globally).

On the other end of the spectrum, a number of industry experts and thought leaders are also exploring possibilities for accelerated e-mobility adoption across various vehicle classes. Most experts agree that passenger car electrification will continue to represent the earliest and fastest adoption rate within the transportation sector. BNEF sees commercial EVs following passenger car EVs as potentially the second largest market segment for Li-Ion battery demand by 2030,[46] exceeding today's demand for Li-Ion batteries for consumer electronics, stationary storage, and LSEVs (see Figure 23). Assuming 300 kWh/pack average battery capacity for each commercial vehicle, BNEF's forecasts imply an annual production of more than one million commercial EVs by 2030 (globally). China is currently home to more than 95% of all commercial EVs globally, with the balance of today's commercial EVs located in Europe, which will likely represent a higher share of the commercial EV market in 2030. The portion of that growth captured by the North American market is hard to predict at this time.

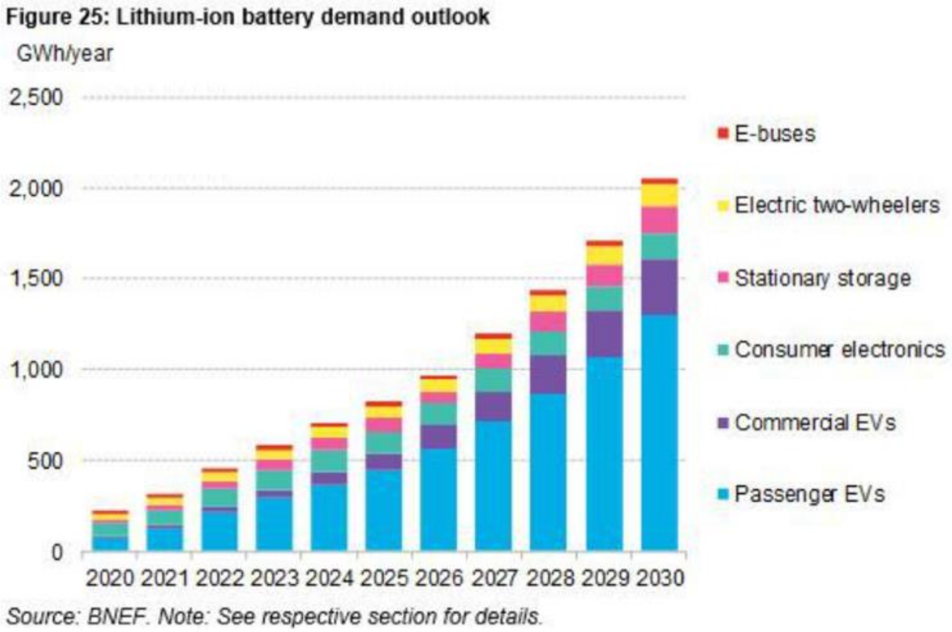


Figure 25: Lithium-ion battery demand outlook

Source: BNEF. Note: See respective section for details.

Figure 23. BNEF Forecast for Li-Ion Battery Demand 2020 through 2030 (Source: BNEF)

Brattle has compiled a comparison of EV forecasts from several well-known industry sources.[47] Figure 24 illustrates the challenge of selecting any one forecast, or even a narrow range of forecasts without extensive study and analysis of the assumptions and inputs that form each individual forecast. This forecast illustrates the uncertainty of making specific forecasts and building specific business strategies around a fixed range of volume forecasts. Clearly, a high level of agility and scalability is needed to increase any commercial vehicle OEM or Tier 1 supplier's probability of success.

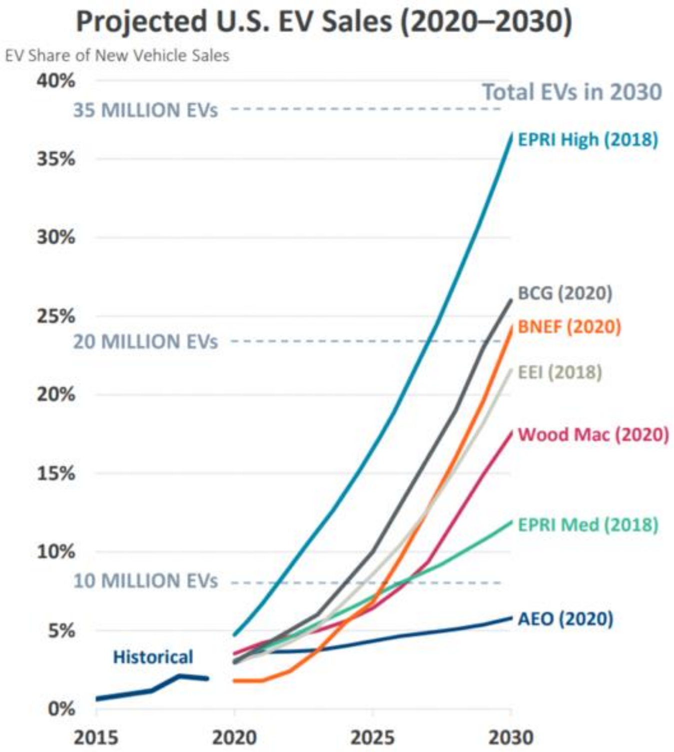


Figure 24. Comparison of Several Leading EV Forecasts (Source: Brattle Group[47])

Several OEMs and Tier 1 suppliers in the commercial vehicle e-mobility space have provided private forecasts for their prospective investors recently, but these forecasts often cite global growth predictions, not North America specific forecasts. And, in more than one case, those sales projections have been reduced significantly during quarterly earnings reports compared with pre-transactional forecasts.

On the commercial vehicle front, transit buses and niche industrial applications are expected to continue outpacing other commercial vehicle segments in terms of the penetration of EV variants among new vehicle purchases. The forecast is least clear when it comes to MD/HD trucks and a range of other commercial vehicle segments. Terminal tractors have seen strong early adoption as indicated in Table 3 above. CALSTART has outlined a beachhead framework that provides a logical progression for how various commercial vehicle segments are likely to experience growing fleet engagement and EV deployment (see Figure 25).

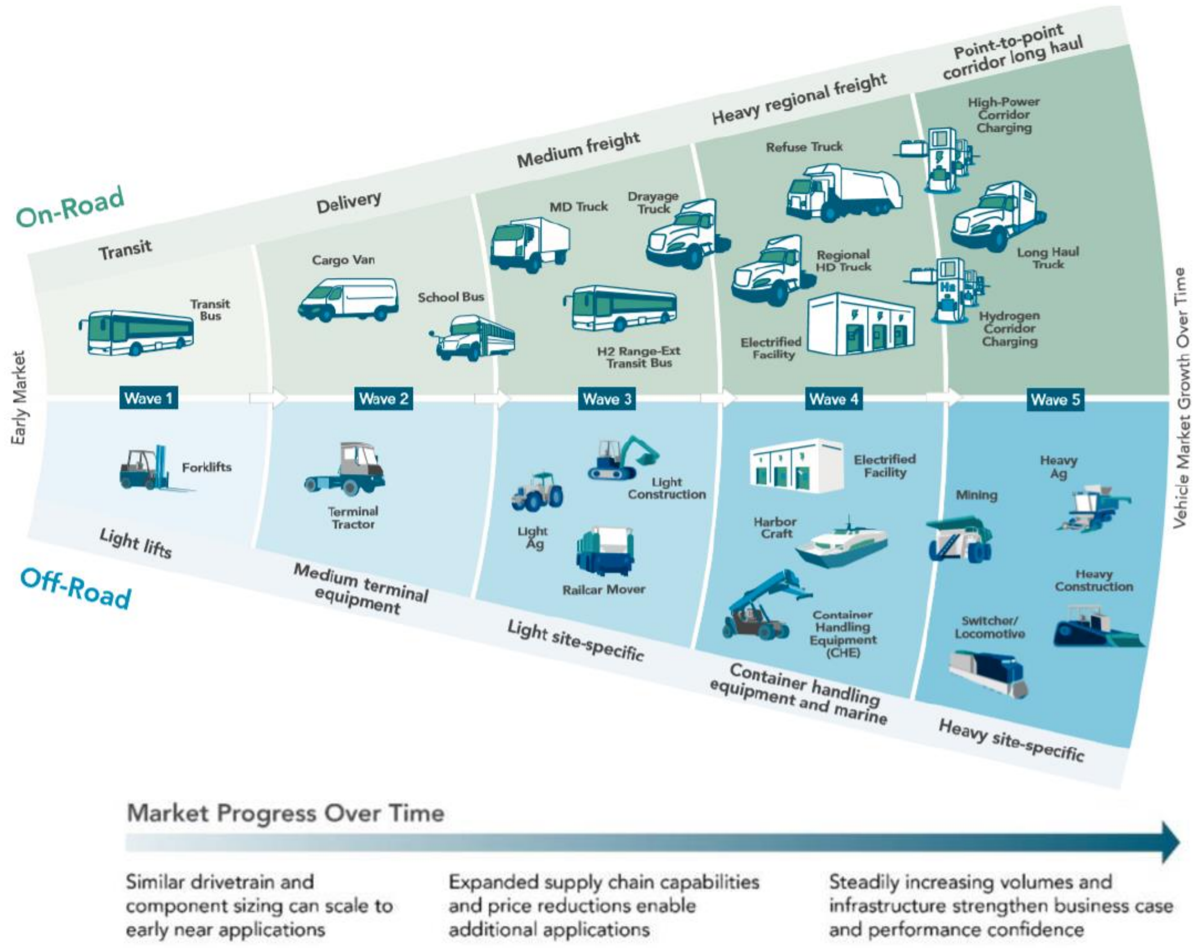


Figure 25. The Zero-Emission Beachhead – Commercial Vehicle E-Mobility Fleet Adoption Pathways (Source: CARB / CALSTART)

YUNEV is familiar with at least one market leader in this space that experienced an 80% forecasting error in one year (over predicted demand) that led to a substantial build-up of inventory at year end, only to experience a 30% forecasting error in the opposite direction (under predicted demand) the following year, which quickly consumed the prior year's inventory build-up, all current year production capacity, and still resulted in stock-outs by Q3. These types of forecasting challenges (and misses) no doubt have been responsible for the disappearance of more than one company and/or product lines listed in Table 3.

In addition to the unprecedented level of new OEMs, startups, and Tier 1 suppliers bringing a growing range of electric commercial vehicle products to the market, today's regulatory framework provides a new opportunity to forecast future sales based on the percentage of zero-emission truck sales mandated by the ACT regulation. Based on the current ACT regulations, CALSTART analysts anticipate 6,000 zero-emission commercial vehicles could be sold in California alone in 2024 (Class 2b-Class 8), and as many as 36,000 zero-emission commercial vehicles could be sold in California in 2030 across the same weight classes (excluding long haul trucks). Given other states that have signed onto the Multi-State MD/HD Zero Emission Vehicle MOU, it seems reasonable to envision more than 150,000 zero-emission commercial vehicles being sold nationwide in 2030 (Class 2b-Class 8, excluding long haul trucks).[48] Based on CALSTART assumptions regarding vehicle mix and typical battery capacity (kWh) by weight class and vocation, these zero-emission commercial vehicles represent an estimated battery production demand of roughly 700 MWh in 2024 for the California market alone, and almost 4.5 GWh estimated annual battery production demand for California plus the 14 MOU states by 2030.

Bringing It All Together – Policy and Strategy Implications

One of the most compelling changes YUNEV has observed among commercial vehicle fleet managers and transit agency leaders over the past five years is a move away from if or why EVs should be bought. The conversation seems to have shifted permanently to "How much will I need to pay for EV's?" or "Who has the right EV product for my fleet application?" or "Where and how can I buy it?" and "How do I re-charge the EVs?" After more than three decades of working to introduced advanced powertrain technologies to these commercial fleet customers, the current dialogue holds great promise for deployment of more electrified trucks and buses.

For purposes of this study, YUNEV has intentionally ignored the potential issues related to grid stability and EV recharging infrastructure. By assuming these issues will be solved and setting these issues aside, the two key challenges are:

1.) Matching EV demand with battery supply in a way that is cost efficient and logistically manageable for the OEMs and their Tier 1 suppliers, and
2.) Optimizing policy, incentives, and regulatory efforts to stretch constrained public funding to deploy the maximum number of commercial EVs on the road.

Matching EV Demand with Battery Supply

Thinking about the challenge from the perspective of a commercial vehicle OEM, procuring the ideal battery pack should include each of the following elements:

A. Sourcing from an automotive-grade cell supplier with megafactory scale and world-class quality control to secure low-cost cell supply;
B. Ensuring cell supplier meets conditions in A above, while also having sufficient excess production capacity to meet commercial vehicle OEM's requirements;
C. Validating cell supplier's excess capacity is not too high – otherwise there is a risk the cell supplier may unexpectedly shut that line down due to insufficient demand;
D. Confirming cell supplier will not put commercial vehicle OEM on "allocations" in the event demand increases from their primary passenger car EV customer(s), and the production line is no longer able to support all customer's demand (i.e., excess capacity is consumed by passenger car EV customer);
E. Securing module and pack design, validation, assembly, and EOL test partner(s) without excessive lead-time or product/channel markup; and
F. Obtaining robust pack-level warranty coverage with prompt and accurate technical support to ensure maximum up-time for fleet/transit agency customers.

As this report has endeavored to illustrate, this ideal sourcing scenario is not easily achieved. The probability that most of today's commercial vehicle OEMs will come close to the ideal battery pack sourcing scenario outlined above, at a delivered cost that is sustainable and responsive to a TCO price parity expectation among fleet customers without policy incentives, is relatively low at this point in time. While this report does not seek to propose solutions to the various challenges outlined herein, YUNEV readily acknowledges the importance of purchase incentives and hopes the issues discussed in this paper might be useful for developing increasingly more adaptive and responsive incentive policies as conditions continue to develop in the future.

Conclusions

- Li-Ion battery pricing ($/kWh) for commercial vehicle OEMs and their Tier 1 suppliers is not a discrete number. Instead, it is a wide range that reflects the early commercialization stage of e-mobility for commercial vehicles and the disparity in scale and expertise of battery sourcing that exists across the long tail of the commercial vehicle segment.
- Accelerating the deployment of all types of battery electric commercial vehicles will help drive battery prices down quicker. The current lack of actual volumes and scaled-up manufacturing capacities are among the greatest obstacles to achieve EV price parity with diesel and drive accelerated sales and deployment of EV commercial vehicles in North America.
- Battery purchasing dynamics are much different for commercial vehicle OEMs and Tier 1 suppliers compared with their passenger car counterparts, owing to a lack of scale and lower organizational experience.
- Meanwhile, some commercial EV OEMs are able to leverage much greater scale and more attractive pricing from existing battery sourcing and/or production activities in the LD EV market and MD/HD markets outside North America. As a result, the playing field for commercial vehicle OEMs in North America is not level when it comes to the price and access of OEMs to low-cost batteries.
- Therefore, purchase incentives and other policies are needed to help early-stage OEMs and specific vehicle platforms while they remain at sub-critical volumes.
- There are a few commercial vehicle OEMs and vehicle platforms that already enjoy significant advantages in terms of battery cost due to higher volumes or leveraging scale from other parts of their corporate enterprise. This disparity in cost structure brings added complexity to policy makers seeking to incentivize electrification.

About the Author

This paper is authored by YUNEV with important collaboration and support from CALSTART. YUNEV's principal, Kevin Beaty, is President of YUNEV LLC, where he consults and advises corporations, government organizations, private equity investors, startups, and other privately held firms. Prior to forming YUNEV, Mr. Beaty held a series of executive, technology, and business leadership roles at CALSTART, Eaton Corporation (NYSE: ETN), Woodward Controls (NASDAQ: WWD), and Southwest Research Institute (SwRI).

Mr. Beaty has been directly engaged in the sourcing and deployment of Li-Ion batteries for commercial vehicle e-mobility since March 2000. Mr. Beaty led Eaton Corporation's hybrid electric start-up beginning in March 2000 and through its successful launch in the MD/HD truck and bus markets of Europe, North America, and China. This leadership role provided Mr. Beaty with a deep experience level bringing Li-Ion battery powertrain systems to MD/HD commercial vehicles in North America. His experience includes delivering more than 6,000 Li-Ion based hybrid electric powertrain systems to fleet customers through leading global OEM manufacturers like Freightliner, Daimler Truck, Iveco, DAF/Leyland, Navistar, Peterbilt, Kenworth, Foton Bus, Zhongtong Bus, Hengtong Bus, Yutong Bus, Thomas Built School Bus, and others. Mr. Beaty's warranty administration experience with these Li-Ion based xEV powertrain systems spans more than 400 million miles of real-world fleet operation.

During this period, Mr. Beaty was responsible for taking four Li-Ion battery cell suppliers through full APQP/PPAP release, including one Japanese cell supplier, one Korean cell supplier, and two Chinese cell suppliers. He also directed the SOP for four battery pack assembly and test production lines including two in the United States, one in Mexico, and one in China. Under Mr. Beaty's leadership, Eaton's hybrid electric start-up grew from $0 to $75 million USD sales revenue in less than 10 years. Prior to forming YUNEV LLC, Mr. Beaty was responsible for overseeing CALSTART's xEV voucher programs in the United States for helping commercial vehicle fleets and transit agencies purchase MD/HD HEV/PHEV/BEV trucks and buses (CA HVIP, Chicago HVIP, NY HVIP).

YUNEV was formed in 2014 as part of a two-year immersive experience in China. YUNEV's ongoing advisory work includes helping leading Southeast Asia cell suppliers expand their reach into offshore markets, including the United States, while also helping commercial vehicle OEMs and Tier 1 suppliers gain cost-effective access to leading battery cell suppliers. YUNEV is currently actively engaged by CALSTART and the California Air Resources Board (CARB, or California EPA) to support their ongoing voucher program and policy analysis. In conjunction with other industry partners, YUNEV has also advised SPACs and leading battery technology start-ups on their investment strategies and plans for securing supply/demand for upcoming battery megafactories being planned for construction in the United States.

Through a variety of private conversations and consulting engagements, YUNEV has exposure to transactional-level data points and insights regarding battery costs – some confidential, others more public. Attending CARB workshops, as well as active and formal monitoring of relevant industry news and serving as an invited speaker at various venues (BMI's EV Supply Chain Festival in May 2020, The Battery Show session moderator in Sept. 2021, etc.) also provide opportunities for synthesizing additional data sources and information.

YUNEV also has experience forecasting xEV volumes in the commercial vehicle space and supporting cyclical fleet customer demand while purchasing from a battery supply base that prefers predictable, level-loaded production forecasts and scheduling.

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