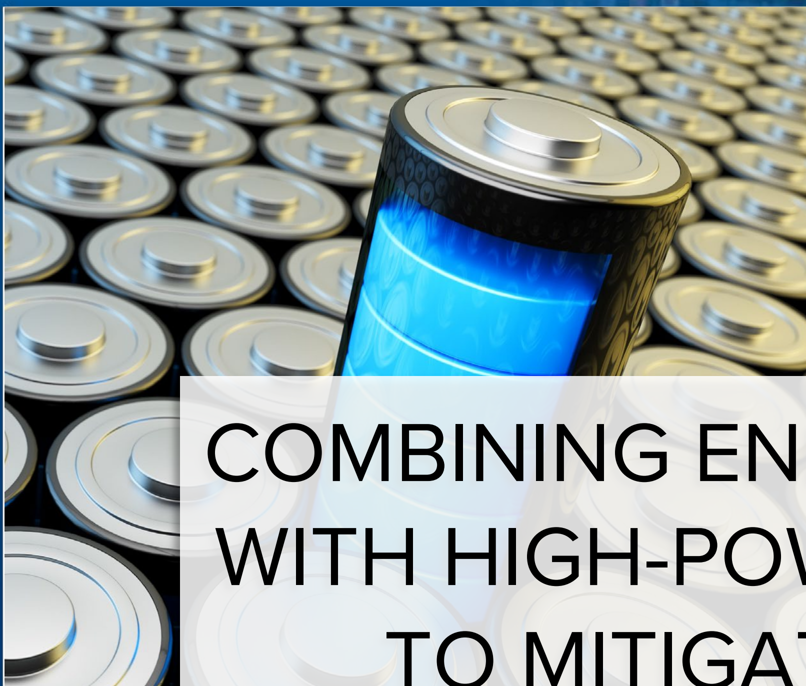
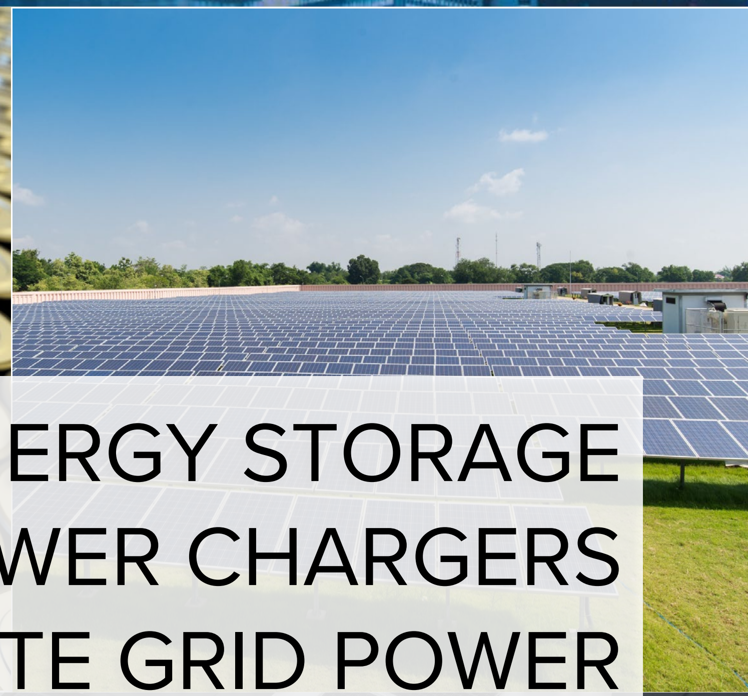
Reference Architecture





COMBINING ENERGY STORAGE WITH HIGH-POWER CHARGERS TO MITIGATE GRID POWER AVAILABILITY ISSUES FOR ELECTRIC VEHICLE FLEETS

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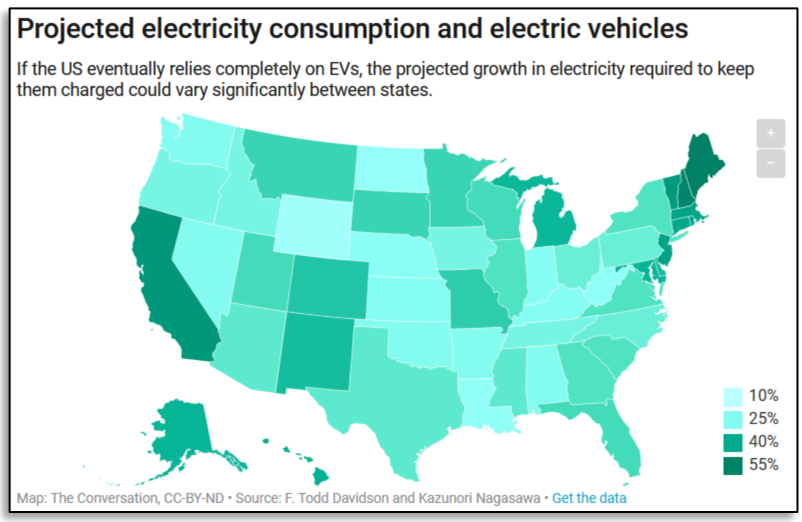
Executive Summary

While 2020 will likely see flat electric vehicle (EV) sales, the long-term trend of EV market penetration is still expected to accelerate over the next ten years, both as a percentage of vehicle sales and in absolute numbers. The cost of lithium ion batteries, the greatest component of EV costs in the last decade, are expected to drop by 60% over the next decade when measured in terms of $/kWh, going from 31% of vehicle cost today to slightly over 14% of vehicle cost in 2030. More importantly, vehicle manufacturers are moving ahead rapidly with electrification, with many stating that all of their new models will be electric by 2030.

While the long-term trend towards automobile ownership in the developed world is decreasing on a per-capita basis (especially among younger consumers), commercial and public vehicle fleets are growing significantly. When combined with the trends around vehicle electrification, which today is occurring for nearly all fleet vehicles except Class 8 long-haul trucks, one can expect that the number of EVs in fleets will grow very rapidly over the next ten years. However, this trend also means that most fleet "vehicle barns" will not have adequate power to charge their vehicles. Given the amount of time it takes to add new megawatt-level power feeds in most cities (think years), fleet EVs will run into a significant "power crisis" by 2030.

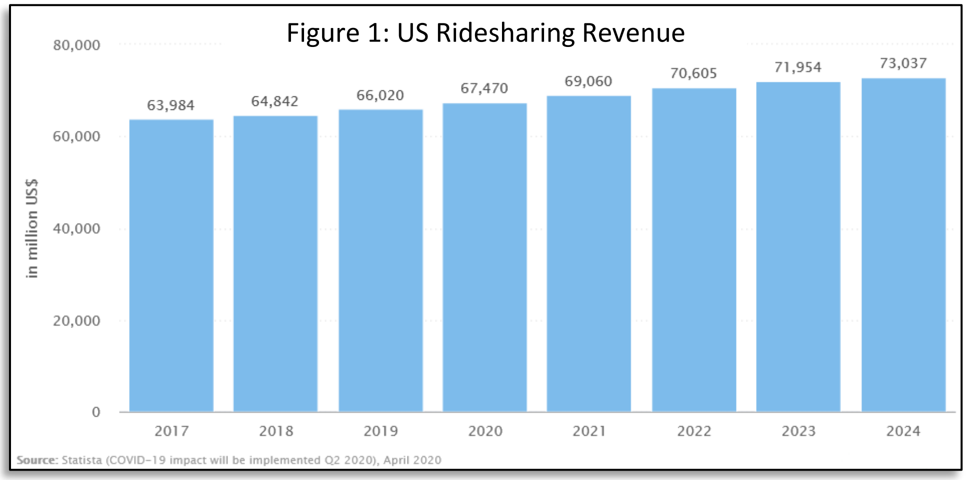


Adding energy storage resources at the grid level will only partially mitigate this issue. Grid-scale energy storage technologies such as pumped hydroelectric energy storage (PHES) are nearly as capital intensive as building power plants, take decades to build, and have unique siting requirements. Adding battery-based energy storage at the substation level may also be problematic, as space for the enormous storage needed is often not available in metro areas.

One way to address this issue is to combine energy storage resources with the fleet charging infrastructure at the point of consumption – the "vehicle barn". This approach has several benefits, including enabling the use of photovoltaic (PV) solar power by storing that energy during the day, and utilizing energy cost arbitrage approaches such as peak shaving to time-shift power consumption from peak hours (which is when most EVs would "naturally" recharge) to the day or to late-night "super-off-peak" hours which reduces EV energy operating expenses. This reference architecture will explore the technologies and economics around this approach, and provide fleet operators with a "recipe" to follow as they look to mitigate the impact of utility grid power limitations on the adoption and operation of their EV fleet.

Developed World Vehicle Ownership Trends: Consumers and Fleets

If there is one country in the world that people think about when they think about automobiles, it is the United States. Automobiles have been synonymous with America for over a century. In 2018, there were 273.6 million vehicles registered in the US (the most in the world) according to Statistica – that is more than four cars for every five (0.8) of the 331 million people in the US. Statistica also reported that there were 17.2 million car sales sold in 2018 in the US, which is only slightly lower than the 2018 sales in China (the most sales in the world in 2018).



However, there may be some clouds showing up on the horizon. If you have been following the stock market over the past year or so, two of the most notable initial public offerings (IPOs) were the ridesharing companies Uber and Lyft. In 2019, the combination of ridesharing and taxi revenue in the US was $66 billion, with a total of 92.37 million users. Prior to COVID-19, this revenue was expected to reach $73 billion, and the number of users was expected to grow to 96.5 million. Ridesharing offers a real alternative to car ownership, especially for those living in large metropolitan areas with limited and costly parking, and high insurance rates. In many cases, ridesharing also offers a means for those living in large metro areas to earn income from their vehicles.

The interesting thing about the IPOs of Uber and Lyft for the fleet vehicle market, and specifically the fleet electric vehicle (EV) market, is data that both companies cited in their IPO filings regarding the drop in vehicle ownership by consumers. Industry analysts also agree with these findings. One example of this is the data in Figure 2 from Cox Automotive, which indicates a correlation between the age of a driver, and the desire/likelihood of owning a vehicle. This is not a pattern in just the US – it is a buying pattern in most of the developed world. On the other hand, other statistics suggest that baby boomer will not reduce their ownership of their automobiles, even as they migrate to urban areas in droves. What is clear is that consumer automobile ownership is shifting, and will continue to do so.

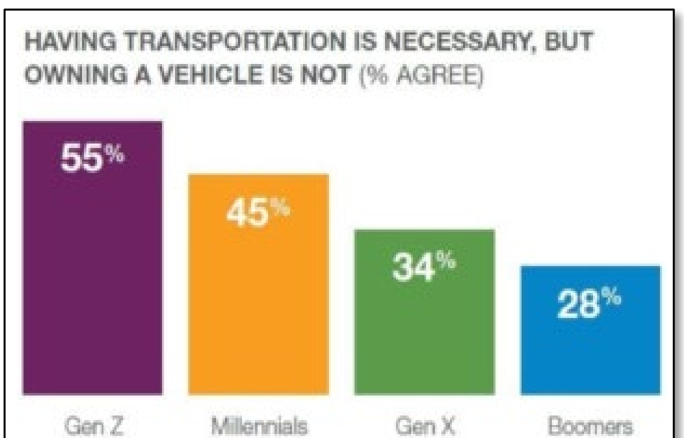


Figure 2 (Source: Cox Automotive)

However, one would be incorrect to read these consumer buying patterns into fleet vehicle purchasing behaviors (after all, who is buying all of the vehicles that are replacing consumer autos?). Fleet purchases in the US rose from 2.7 million vehicles in 2013 (17.1% of all US new vehicle purchases) to 3.2 million vehicles in 2019 (19% of all US new vehicle purchases), according to Cox Auto.

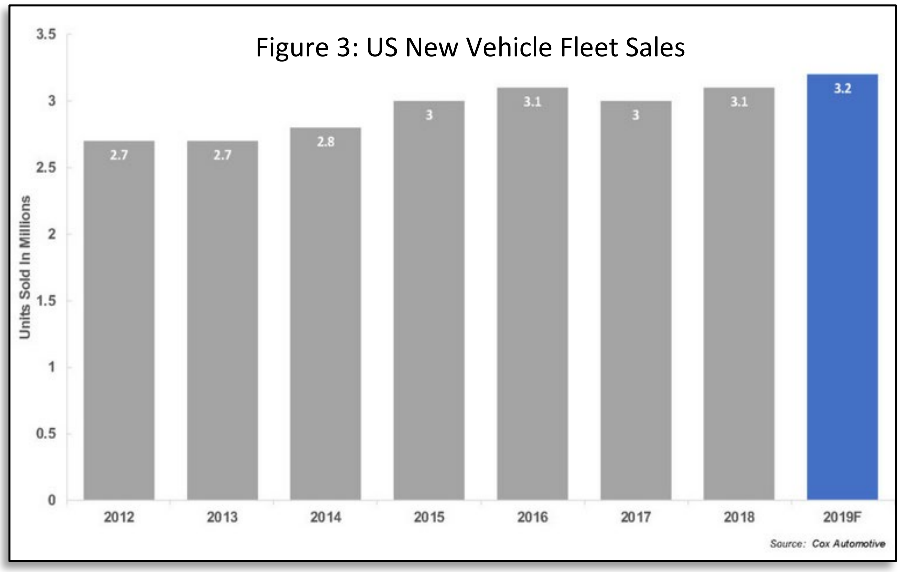
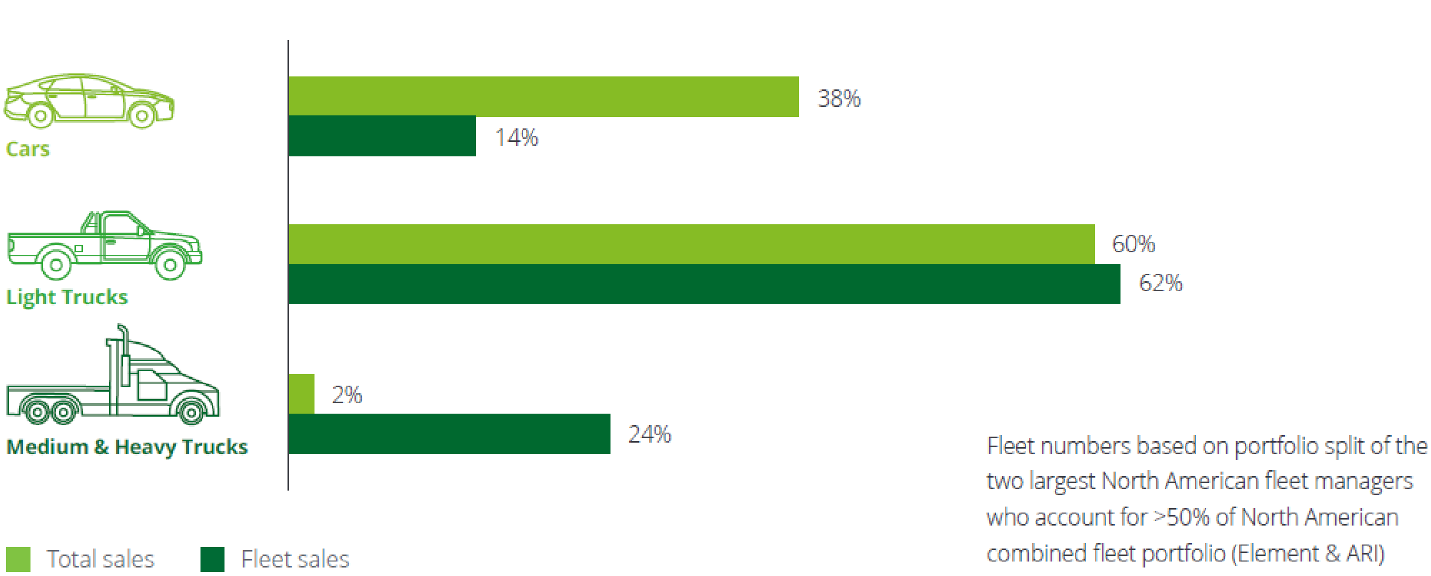


Figure 4 shows a breakdown of the vehicles being purchased by fleet operators. Light trucks dominate these purchases, followed by medium/heavy trucks (DoT Class 3 through Class 8), with automobiles coming in last. This fits with the research performed by Deloitte, who found that over 90% of corporate vehicle purchases were "functional company vehicles", and not purchased as executive perks. Unsurprisingly, the most-purchased vehicle model in the US are the Ford F-Series trucks (primarily the F-150 and F-250 trucks), with over 900,000 vehicles sold in 2019. While numbers aren't in yet, one can expect that the COVID-19 pandemic will likely increase the need for fleet vehicles as more and more people avoid going into public. This trend towards more fleet vehicles was already occurring, and is not simply an "adjustment" in consumer behavior to the COVID-19 crisis.

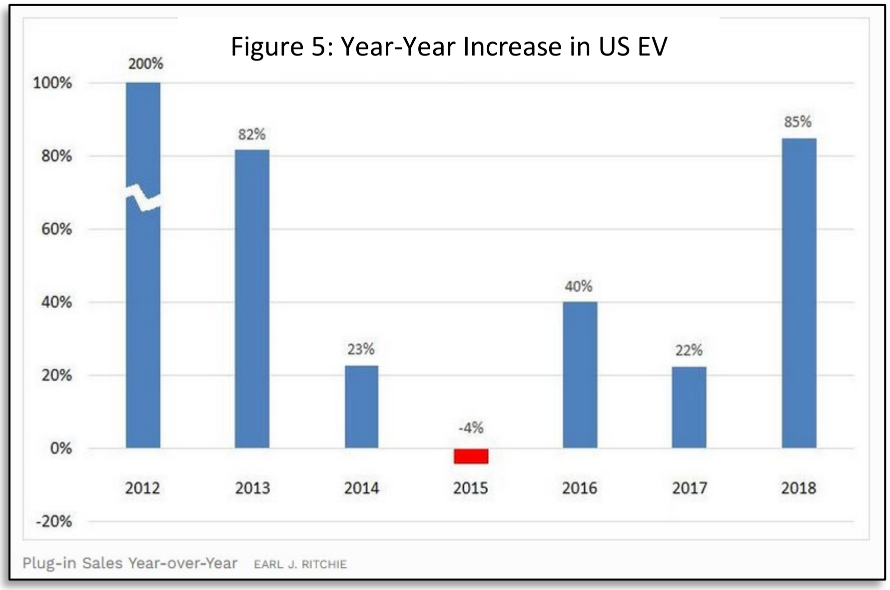
Fig. 4 – Share of vehicle segments for total sales and fleet sales in North America



Source: Deloitte Analysis, Polk/IHS (2016), Element Company Report (2014),[5] Standard & Poors ARI Rating (2015)[6]

The Trend Towards Electrification of Commercial Vehicle Fleets

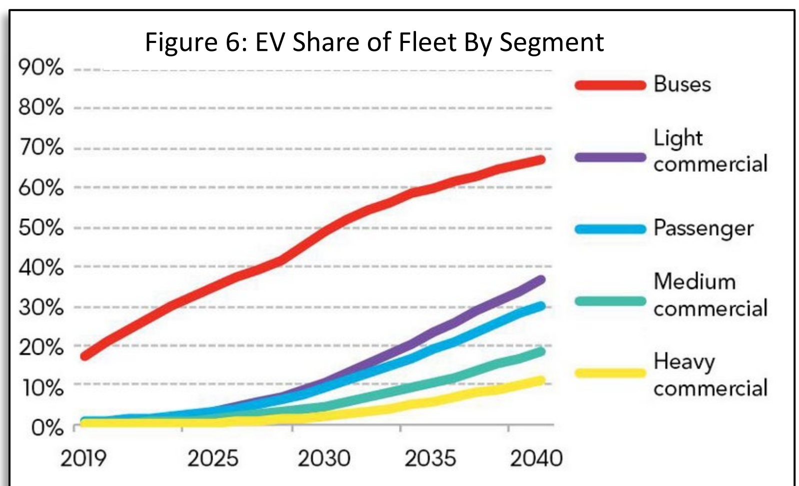
One of the trends where consumer purchasing behavior and fleet purchasing behavior are similar is vehicle electrification. The total sales of plug-in electric vehicles (EVs) in the United States reached 361,000 vehicles in 2018. This number is an 85% increase over 2017's plug-in EV sales in the US (Figure 5). As a percentage of total US vehicles, EVs went from 0.14% of all US vehicles sold to 2.1% in 2018. This is in spite of the reduction or phase-out of government financial incentive programs for EVs.



The adoption of EV technology by commercial vehicle fleets (especially trucks) is even more rapid than it is for consumer vehicles, according to a 2017 study by McKinsey. This is driven by three specific trends:

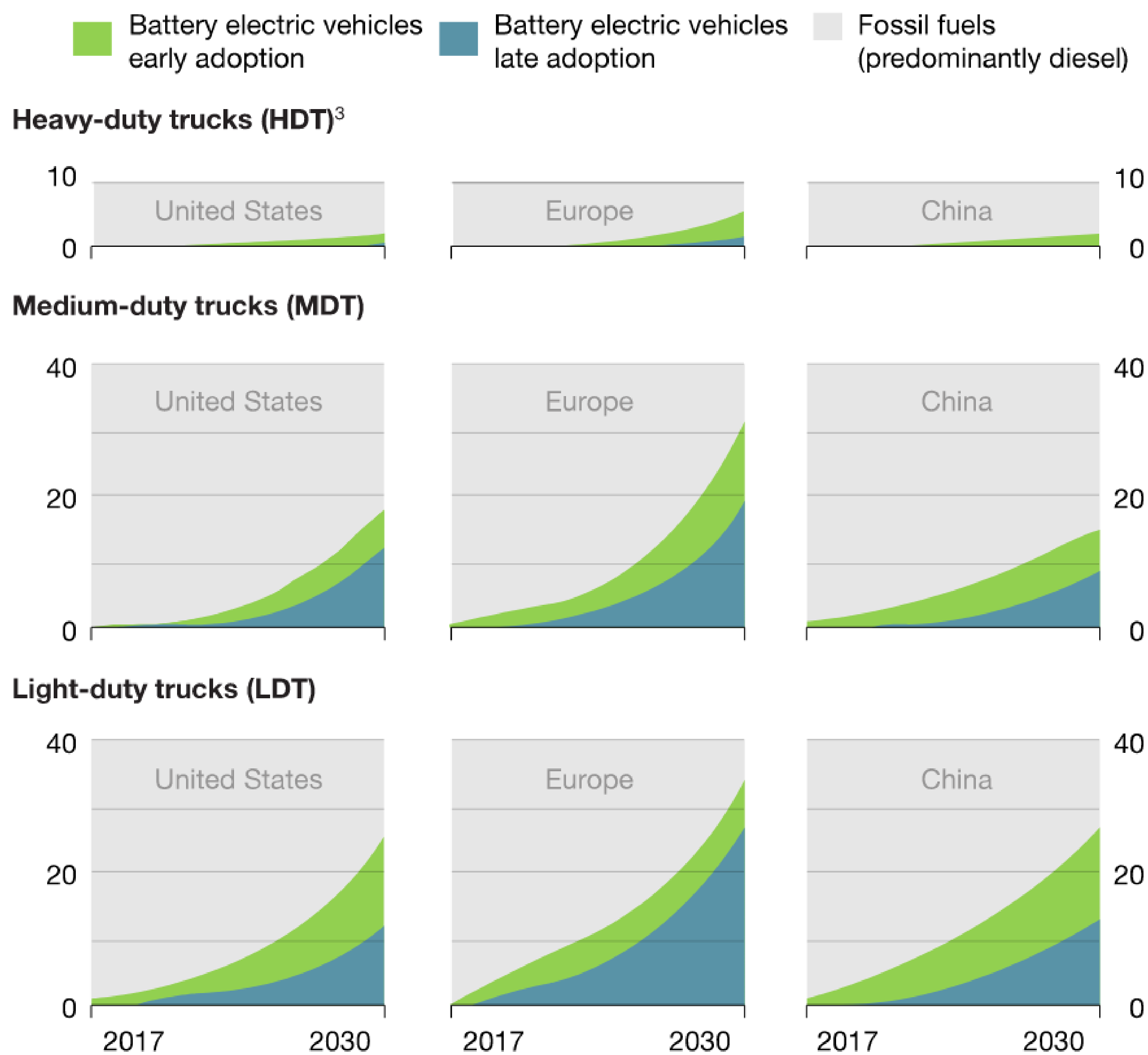
- Total cost of ownership (TCO) of a variety of EVs including light/medium/heavy duty trucks and transit buses will drop below that of diesel vehicles in the next few years.
- The infrastructure to support EVs continues to develop, even in rural areas.
- Government emission regulations at the federal and state levels continue to favor EVs.

To be sure, the adoption rates will definitely vary based on the type of vehicle; McKinsey's projections of EV market penetration for heavy-duty, medium-duty, and light-duty vehicles is shown in Figure 7 below. Unsurprisingly, uptake is slowest for heavy-duty trucks, which tend to be primarily used for long-haul and have the greatest range requirements. Hydrogen fuel cells are expected to be the predominate power source for some time for heavy trucks. For light-duty and medium-duty trucks, early adoption percentages approach 30% and 20% (respectively) according to McKinsey. Bloomberg NEF (Figure 6) expects that electric buses will represent 81% of the municipal buses worldwide by 2040, and expects that 56% of light commercial trucks and 31% of medium-duty commercial trucks will be electrified by 2040.



Source: BloombergNEF. Note: Passenger car and bus figures are global. Commercial vehicle segment adoption figures in both charts cover the main markets of China, Europe and the U.S.

Figure 7: Early- Adoption and Late-Adoption Trends for Fleet Electric Vehicles



[1]Based on set of more optimistic assumptions (for example, higher impact of regulation).
[2]Weight-class definitions: United States: HDT: class 8 (>15 tons), MDT: class 4–7 (6.4–15 tons); LDT: class 2–3 (3.5–6.4 tons); Europe: HDT >16 tons, MDT: 7.5–16 tons, LDT: 3.5–7.5 tons; China: HDT >14 tons, MDT: 6–14 tons, LDT: 1.8–6 tons.
[3]City buses not included.

McKinsey&Company | Source: McKinsey Center for Future Mobility

Challenges In Growing Utility Power to Meet Fleet EV Power Needs

If electricity were like other commodity resources, these trends might sound extremely attractive for electric utilities. However, the electricity market is different than other commodity markets:

- The creation of new "supply" (in this case, power plants) is extremely capital-intensive, significantly regulated, and often can take a decade or more;
- The actual "matching" of supply and demand is very technical – you can't just store "unused power" in a warehouse; and
- Electric power cannot be "shipped" to end-users by standard transportation and distribution methods such as trucks; it requires expensive power distribution systems.

In reality, the increasing and rapid electrification of the transportation sector poses significant issues for electric utilities. According to a [recent paper](#) by the [National Renewable Energy Laboratory (NREL)](#), in 2016 only 0.1% of transportation energy usage was from electricity (this compares to commercial buildings, where 53% of energy usage was from electricity). Figure 8 shows the projected growth in annual energy consumption through 2050, where electricity for transportation becomes significant.

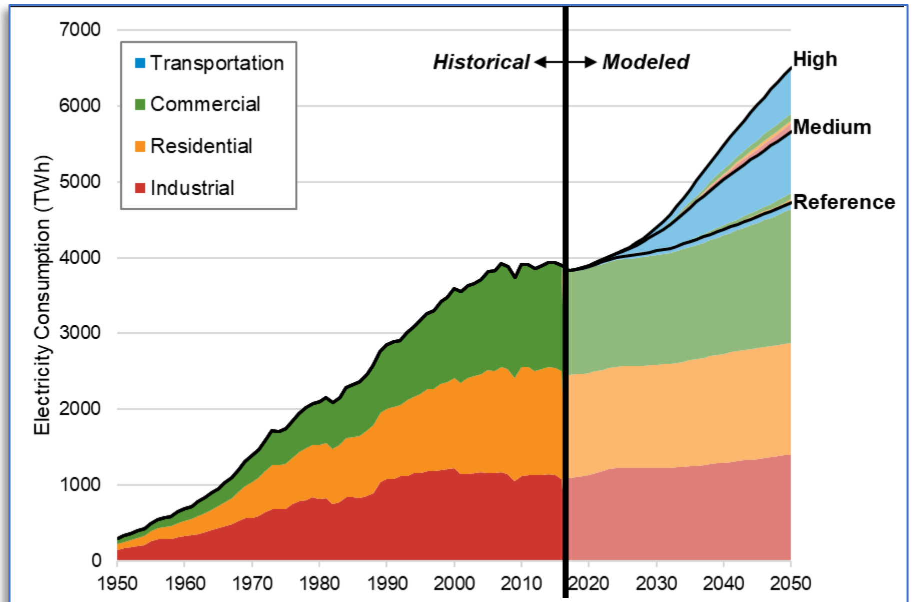
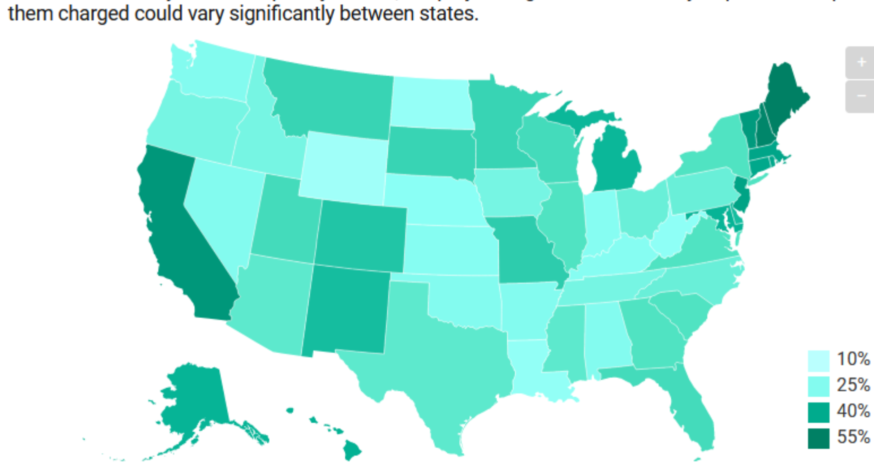


Figure 8: Historical and Projected US Annual Electricity

The impact of total vehicle electrification (something that could foreseeably be approached by 2050) is shown in Figure 9. Note that in areas of high urban population and vehicle usage (particularly California), the amount of additional power that would be required to meet the increased EV demand is greater than 50% of today's electrical output. And this is only the "macro" level view – getting the power to the end consumer (in the case of fleets, vehicle yards) requires significant construction costs and time.

Figure 9: Impact of Electric Vehicles on the US Energy Grid

If the US eventually relies completely on EVs, the projected growth in electricity required to keep them charged could vary significantly between states.



Map: The Conversation, CC-BY-ND • Source: F. Todd Davidson and Kazunori Nagasawa • Get the data

This gets back to the fourth point we made earlier – “shipping” electricity to end-users is a complex operation in many respects (see Figure 10). Power must be transmitted from the powerplant via high-voltage distribution lines to after being “stepped up” at the powerplant. These high-voltage distribution lines then carry power (often for tens to hundreds of miles) to substations in a metropolitan area. Those substation then “steps down” the power for transmission to customer locations. Since multiple generating stations may supply a given metropolitan area, the power being put onto the grid must also be “managed”, typically be an Independent System Operator (ISO).

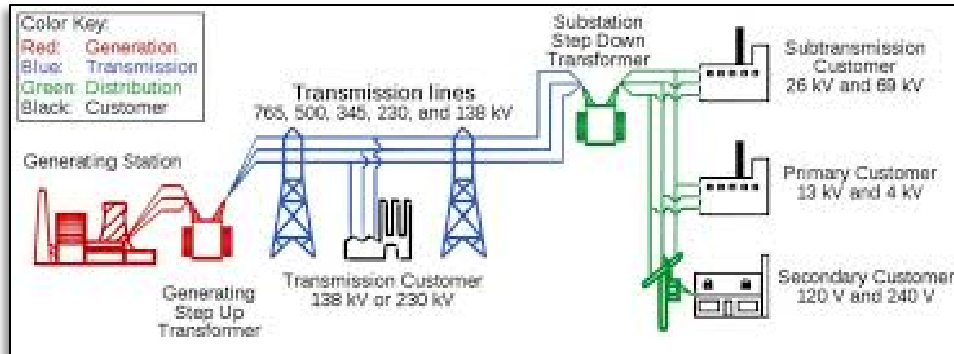


Figure 10: Typical Electrical Power Distribution System

One might be tempted to state that increased adoption of photovoltaic (PV) solar power should mitigate the increased electricity demand from EVs. The one problem with this approach is that PV solar only produces power during the daytime, and the charge window for most fleet EVs (not to mention consumer EVs) typically is from 5pm or 6pm to 6am or 7am, which is right at the peak power demand during the winter. For Californians, the peak demand time is 4PM to 9PM during the entire year, primarily due to the adoption of PV solar energy generation by both consumers and commercial customer. Thus, PV solar power can only help to mitigate increased EV demand IF energy storage resources are added to the utility grid to store the power until needed.

Utilizing Energy Storage to Bridge The Utility Power Gap

Utility providers are very aware of these issues, and are putting significant capital and manpower into energy storage. Unfortunately, the approaches that they are looking at utilizing probably don’t solve the “energy gap” problem in a timeframe that is interesting for fleet EV operators. The most widespread energy storage approach being deployed by utilities today is pumped hydroelectric energy storage (PHES, also known as pumped-storage hydroelectricity or PSH). In PHES solutions, water is pumped uphill into a storage tank or a reservoir. The gravitational potential energy of the pumped water can then be run back through the pump turbine to generate electricity. There is about 25 GW of PHES capacity


Figure 11: Adam Beck PHES Complex

in the US, which is about 14% of the total worldwide storage of 184GW. However, there are four major hurdles around the use of PHES:

1. PHES solutions are nearly as capital-intensive as building powerplants themselves – in essence, many are effectively hydroelectric projects, with similar budgets and timeframes.
2. PHES often requires additional power transmission lines to carry the solar power to the storage facility and back.
3. PHES takes a LOT of space and has specific site requirements, primarily a significant height differential. This can be accomplished with underground tanks, but usually the height differential needs to be on the order of 50 to 100 meters.
4. The cycle time of a PHES solution is typically measured in weeks or days, and not in hours.

In addition, PHES is relatively inefficient, with typical efficiencies ranging from 70% to 80%. All of these issues make PHES a power storage solution which typically doesn't work well for day-to-day peak leveling, and doesn't meet the timeframes needed by EV fleet operators.

To minimize the need to run new high-voltage transmission lines, a better solution is to deploy energy storage resources at the substation level. In this case, the energy storage would have to be battery-based, which has typical efficiencies of 90% or greater. However, this battery-based storage at the substation level presents its own issues: i) do the substations have enough space to handle battery storage in the hundreds of megawatt-hours; and ii) what if power requirements at a given substation change over time? As an example, a typical US power distribution substation in 2000 had a capacity of 340 MVA. If the substation had to provide energy storage for PV power at 25% of its capacity, a charging window of 12 hours, and battery efficiency of 90%, the substation would need a battery capacity of 816MWh. This is nearly four times the size of the largest battery-based energy storage system in the US today.

One solution to the "what happens when storage requirements change" is to use modular, containerized power storage. This approach allows battery containers to be moved as needed from one substation to another, and these containers can support energy densities of 2MWh to 4MWh per 40-foot container. However, this means that over 200 40-foot containers would be needed to support an 800MWh capacity at a single substation. While vehicle-to-grid (V2G) energy storage can certainly also play a part in storing energy, the "availability" of this power is not 100% - it depends on drivers having bi-directional chargers, and plugging their vehicles into the grid at the "right times". Also, nearly 10,000 cars with 80kWh of battery storage each would be needed to meet the energy storage of the 200 containers above.

Figure 12: Energy Storage at a Substation

Energy Storage for Fleet Electric Vehicle Operators

A better approach for fleet EV operators is to put the energy storage resources onsite at their vehicle yard. This approach has several inherent advantages to it:

1. Fleet EV vehicle yards are typically large, parking lot-like spaces that can support both large PV solar installations and a significant energy storage infrastructure.
2. Fleet energy needs are very predictable: it is based on the number of vehicles, and the routes that the vehicles drive each day.
3. The fleet EVs can also be utilized as V2G storage resources – unlike the general V2G use case, the amount of storage available through V2G and the power in the vehicles is also very predictable, and hence very reliable.

Let's look at a 200-vehicle transit bus yard as an example (buses are in a sense a worst-case scenario in that they have a large amount of storage, and a long "duty cycle"). Let's assume:

- 50% of the buses in the bus yard are EVs (100 of the total 200 buses), and each with a 660 kWh battery capacity (similar to the Proterra Catalyst E2 Max electric transit bus).
- Each bus has a 12-hour driving cycle (6am to 6pm) and charging window (6pm to 6am).
- The average electric bus utilizes 85% of its charge during its driving cycle, returning to the yard with 100 kWh of charge left.
- The bus yard, which covers 2 acres of land, has an existing 2MW power feed.

The transit bus yard scenario would work out as follows:

a) A total of **56.1 MWh** of power is needed to charge the 100 electric buses: 660kWh x 85% power usage x 100 buses.
b) The existing 2MW feed can provide **24 MWh** of power during the 12-hour charging cycle, or about 45% of what is required to charge all of the buses. That leaves a **32.1 MWh gap** in the power needs of the bus yard.
c) Using battery storage that charges during the day can add another **21.6 MHw** of power: 2MW x 12 hours x 90% storage efficiency. The bus yard would need 24MWh of battery storage (12 hours x 2MW); this still leaves a **10.5 MWh** power gap.
d) If PV solar is utilized to make up the 10.5 MWh gap and sunlight is available for 10 hours, an average of **1050 kW** would have to be generated. With modern panels producing 440 watts per panel, 2,400 panels are needed. The solar array would also require an additional **11.67 MWh** of battery storage (10.5 MWh x 90% efficiency equals 11.67 MWh of power).

The overall requirements of a program like this would be:

- **35.67 MWh** of battery storage (24 MWh for the utility feed, and 11.67 MWh for the PV solar), filling **nine 40-foot containers** (assuming 4 MWh per container).
- 2,400 solar panels taking 52,800 square feet (each panel is 22 square feet in size), or about 1.21 acres.

An alternative to this scenario would be for the fleet operator to put the power remaining on the buses back onto the grid when they return from the yard. Since this is peak demand time, the fleet operator could reduce their overall energy costs by utilizing this remaining charge for V2G. Here is how the scenario would change:

a) The buses have 100 kWh each to put back into the grid; with 100 buses, that equals 10 MWh of power that could potentially go back onto the grid. The peak load window to put power back onto the grid for the buses is 6pm to 9pm (3 hours); in that time, **6 MWh** of power could be put back onto the grid, leaving **4 MWh** of power remaining in the buses.

b) The buses would now require **62 MWh** of power (660 kWh x 100 buses, minus 4 MWh remaining after putting 6 MWh onto the grid through V2G).

c) The charging window is now reduced to nine hours (9pm to 6am); during this time the existing 2MW feed can provide **18 MWh** of power during the 12-hour charging cycle, or about 45% of what is required to charge all of the buses. That leaves a **44 MWh gap** in the power needs of the bus yard.

d) Using battery storage that charges during the day can add another **21.6 MHw** of power: 2MW x 12 hours x 90% storage efficiency. The bus yard would need 24MWh of battery storage (12 hours x 2MW); this still leaves a **22.4 MWh** power gap.

e) If PV solar is utilized to make up the 22.4 MWh gap and sunlight is available for 10 hours, an average of **2.24 MW** would have to be generated. With modern panels producing 440 watts per panel, 5,100 panels are needed. The solar array would also require an additional **24.9 MWh** of battery storage (22.4 MWh x 90% efficiency equals 24.9 MWh of power).

The overall requirements for the program with V2G would be:

- A charging infrastructure that support V2G (i.e., bidirectional chargers).
- **48.9 MWh** of battery storage (24 MWh for the utility feed, and 24.9 MWh for the PV solar), filling **twelve 40-foot containers** (assuming 4 MWh per container).
- 5,100 solar panels taking 112,200 square feet (each panel is 22 square feet in size), or about 2.58 acres.
- Net equivalent power from the grid would be **6 MWh:** 18 MWh during the charging time, minus the equivalent cost for 6 MWh of back into the grid during peak hours (assuming a 2X cost delta between the peak load time power cost and standard electrical cost). This is 25% of the grid power cost of the scenario which doesn't utilize V2G.

Energy Storage: Solving the Utility Power Gap for Fleet Electric Vehicles

Fleet vehicle operators, especially those that operate medium-duty and heavy-duty vehicles, will encounter a significant utility grid power gap as they electrify their fleets over the next decade. Depending on the vehicles that they utilize and other factors, this issue could appear for EV fleet penetration percentages as low as 25%. While electric utilities are actively pursuing energy storage projects, these are typically either long-term "grid-scale" projects such as PHEV, or demonstrator projects; in any case, they are not likely to solve the power gap in a timeframe to address the need of fleet EV operators. Adding battery-based storage and bi-directional V2G-capable charging infrastructure to fleet vehicle yards, especially if augmented with PV solar power, represents the best option for fleet EV operators to address the utility grid power gap issue, as well as reducing operational expenses (OpEx) for electrical power for charging.

As a leader in the development and manufacturing of bi-directional, high-power energy systems for both vehicle charging and photovoltaic solar applications, Rhombus is an expert in high-power charging systems for EVs, and especially in the area of vehicle-to-grid (V2G) charging. Our VectorStat® hardware and software allows fleet customers to gather data from all of their infrastructure nodes, regardless of connectivity or network issues, to effectively manage their energy resources. VectorStat's applet-based open architecture also enables the easy integration of new features and functionality, whether to support new hardware or to provide cutting-edge data analytics capabilities. Find out how we can help you by contacting us at sales@rhombusenergy.com.