Electric Truck & Bus Grid Integration

Opportunities, Challenges & Recommendations

September 2015

CALSTART, Inc.

Acknowledgments

CALSTART would like to express its appreciation to the Energy Foundation for providing funding for this project. In addition, CALSTART would like to thank the following industry stakeholders who shared their knowledge, experience, and learnings, provided valuable input and feedback, corrected our errors, and participated in an extensive review process. The views and opinions expressed in this report do not necessarily state or reflect those of the following individuals and companies.

- Edward Kjaer, Director, Transportation Electrification and Dean Taylor, Senior Scientist at Southern California Edison,
- Evelyne McCleland, Marketing Director and Matt Horton, Vice President of Sales at Proterra Inc.,
- Frank De Rosa, Chief Commercial Officer at SunEdison,
- Jana Corey, Director, Electrification & Electric Vehicles at Pacific Gas & Electric,
- Jason Greenblatt, Electric Vehicle Program Specialist at San Diego Gas & Electric,
- Jerry Estrada, General Manager at Santa Barbara Metro Transit District,
- Joshua Goldman, Vice President of Business Development at TransPower,
- Micheal Austin, Vice President & Andrew Swanton, Director of Business Development at BYD America,
- Mike Britt, Director of Maintenance and Engineering at UPS,
- Nancy Ryan, Director, Policy and Strategy at Energy and Environmental Economics,
- Paula Faust, Deputy Director of Transportation at Gardena Municipal Bus Lines,
- Peter Klauer, Smart Grid Solutions Manager at California ISO,
- Roland Cordero, Director of Maintenance and Vehicle Technology at Foothill Transit,
- Russell Musgrove, Managing Director of Global Vehicles & Thomas Griffin, Chief Engineer, Global Vehicles at FedEx Express,
- Steve Hanson, Director of Fleet Engineering at PepsiCo,
- Toni Williamson, Director of Business Development and Diversity Services at Total Transportation Services, Inc.

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Executive Summary (1)

With funding from the Energy Foundation, CALSTART researched and analyzed the opportunities and challenges faced by the medium and heavy-duty electric truck or E-Truck & Bus market. A comprehensive research of the latest literature was done to provide an up-to-date review of current and future vehicle-grid integration issues facing the industry. In addition, interviews of truck and bus fleets, early adopters of E-Trucks & Buses, were conducted. Three E-Truck & Bus manufacturers were also consulted for their past experiences with the installation of charging infrastructure. Individuals from the following companies provided input for this report. The companies are listed for information purposes only and does not necessarily imply their agreement on all points of this study.

Lastly, an extensive review process was completed with a wide variety of relevant industry stakeholders.

The E-Truck & Bus market is in its early stages where technologies and solutions are still being researched, developed and tested. However, several nationwide fleets and transit agencies across the US have shown serious interest and commitment to electrify part of their fleet of buses, refuse trucks, delivery vans, drayage trucks, shuttle buses, yard hostlers and utility trucks. As a result, the E-Truck & Bus market is expected to see significant growth in the near term, especially in transit bus applications.

Photo courtesy: Efficient Drivetrains

E-Trucks & Buses present unique challenges and opportunities compared to light-duty electric vehicles (EVs). One E-Truck or E-Bus provides substantial environmental benefits but draws more power and consumes more energy than one light-duty EV. Utility load planning will be easier for E-Trucks & Buses as they will be concentrated in fewer areas. But local distribution grid infrastructure may be significantly impacted by new E-Truck & Bus charging loads which can be much higher than for light-duty EVs.

Current utility rate structures can discourage fleets from adopting E-Trucks & Buses. Charging has to support vehicle operation and unlike light-duty EVs cannot easily be shifted. In addition, demand charges can be prohibitively costly for early E-Truck & Bus deployments. Lastly, E-Truck & Bus charging infrastructure is a limiting factor for further vehicle adoption. To electrify the truck & bus market, innovative utility rates and public utility commission policy changes are necessary to reduce the costs for fleets to install E-Truck & Bus charging infrastructure.

Executive Summary (2)

Photo courtesy: Smith Electric Vehicles

E-Truck & Bus charging, if unmanaged, can have negative impacts on the grid, but implementing smart charging systems will reduce these impacts. Range extenders, energy storage and on-site generation are of high interest to fleets to mitigate charging costs and could also enable E-Trucks & Buses to become true grid resources. Although electricity currently accounts for a small share of the California Low Carbon Fuel Standard credits, securing these credits could further reduce vehicle operating costs. Vehicle-To-Grid could benefit E-Trucks & Buses but is still years away from commercial application.

This report developed several recommendations to promote further electrification of trucks & buses:

- **Expand & enhance industry stakeholder forums to better tackle industry issues**
- **Commission a comprehensive E-Truck & Bus load study**
- **Create dedicated E-Truck & Bus program manager positions to support fleets**
- **Secure existing low carbon fuel standard credits to reduce E-Truck & Bus operating costs**
- **Continue to support the electrification of trucks & buses through grants, incentives and tax credits**
- **Fund demonstration projects focusing on advancing technologies that will enable further electrification**
- **Adapt utility rate structure to accelerate the cost effective electrification of trucks & buses**
- **Change current public utility commission policy to mitigate the costs of E-Truck & Bus charging infrastructure**

Lastly, this report identified next steps for the E-Truck & Bus industry that we believe would help implement the recommendations listed above and accelerate the commercialization of medium and heavy-duty electric vehicles.

Photo courtesy: BYD

Photo courtesy: CALSTART

Photo courtesy: TransPower

Photo courtesy: San Joaquin RTD

Although in its early stages, the E-Truck & Bus* industry is dynamic and attracting the attention of fleets nationwide

"[E-Trucks & Buses] are commercially available or in early commercialization in some heavy-duty applications. Additional promising […] platforms are in the concept and demonstration phase in many heavy-duty applications across multiple sectors." [1] Several nationwide fleets with a strong presence in California and a number of California transit agencies have purchased E-Trucks & Buses. Below is a sample of manufacturers currently offering E-Truck & Bus models (right) and a sample of E-Truck & Bus fleets in California (left).

*E-Trucks & Buses are defined in this report as medium & heavy-duty plug-in electric vehicles (GVWR > 6,001 lbs.).

E-Trucks & Buses are already moving people and goods in California and in the United States

Photo courtesy (upper row, from left to right): LA Metro, Motiv Power Systems, CALSTART, California Energy Commission, (middle row, from left to right): TransPower, Motiv Power Systems, Foothill Transit, Complete Coach Works, (lower row, from left to right): New Flyer Industries, TransPower, Motiv Power Systems, Odyne.

E-Trucks & Buses come with different levels of vehicle electrification and different charging infrastructure needs

Like light-duty EVs, E-Trucks & Buses come with different levels of vehicle electrification (Table 1). One vehicle electrification model cannot fit all the many diverse vehicle applications of the truck & bus market. For instance, some of these applications are:

- Transit bus,
- Refuse truck,
- Delivery van,
- Shuttle bus,
- Yard hostler,
- Utility and work truck.

Plug-in Hybrid Electric Vehicles (PHEV) provide zero-emission miles, operational flexibility and require charging infrastructure that is simpler and easier to install. Short range Battery Electric Vehicles (BEV) can be charged quickly to operate indefinitely without long interruptions for charging, while long range BEVs have a higher vehicle assignment flexibility as vehicles are not limited to on-route charging infrastructure. Each level of vehicle electrification has its place in the current E-Truck & Bus market and industry stakeholders should work together to facilitate the electrification of trucks and buses without picking a specific technology and stifling market innovation.

All E-Trucks & Buses will require the installation of charging infrastructure and will impact the grid. Selecting one technology over another involves trade-offs between specific vehicle operation requirements, power demand on the grid and operational savings.

Table 1: Different levels of truck and bus electrification

Truck & Bus Electrification Technology	Example	Average Peak Demand	Battery Size
Short Range PHEV	Volvo PHEV Class 8 Drayage Truck	10 kW	10 kWh
Work Truck PHEV	Odyne Advanced Diesel PHEV Truck	3.3 kW	14/28 kWh
Long Range PHEV	Efficient Drivetrain PHEV/CNG Class 4 Truck	up to 6.6 kW	40 kWh
Short Range BEV	Proterra Fast Charge Catalyst	280 to 380 kW*	53 kWh 131 kWh
Mid Range BEV	Transpower Electric Drayage Drive	70 kW	215 kWh
Long Range BEV	BYD 40-ft Electric Transit Bus	Option 1 - 80 kW Option 2 - 200 kW	324 kWh

** For bus deployments of 4 to 8 buses per fast charger.*

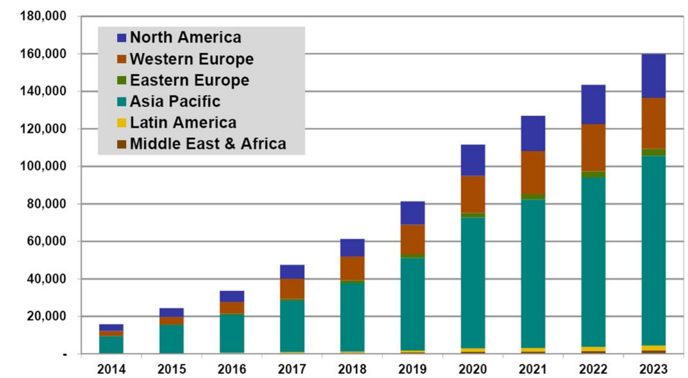
With modest sales, the E-Truck & Bus market is small but significant growth is expected in the near term

E-Trucks & Buses represent a small number of the medium & heavy-duty vehicle market in California and in the US. In California, the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) has supported the purchase of about 400 E-Trucks & Buses during its four years of existence [2] and there are now over 500 battery electric medium and heavy-duty vehicles in California, not including buses [3]. In the US overall, there are about 1,000 E-Trucks currently in operation [4].

The California Air Resources Board "believes there are opportunities in regional applications to deploy larger numbers of zero and near-zero emission vehicles near-term" [1]. Two studies have recently been released that support this:

- Navigant Research expects global sales of electric drive and electric-assisted commercial vehicles to grow from less than 16,000 in 2014 to nearly 160,000 in 2023 (Figure 1). While the Asia Pacific region will likely see the majority of the volume, sales in both North America and Western Europe are also expected to be significant. Globally, diesel Hybrid Electric Vehicles (HEV) is expected to remain the most popular format for the whole of the forecast period, followed by BEVs [5].
- In its latest Transportation Electrification Assessment, CalETC commissioned a market sizing and forecasting analysis on a wide variety of transportation technologies. Using three different cases ("In Line with Current Adoption", "In Between" and "Aggressive Adoption"), it forecasts a significant growth in the medium-duty (MDV) and heavy-duty vehicle (HDV) market in California over the next 15 years (Table 2) [6].

Figure 1: Annual MHDV electric drive sales by region world markets: 2014 – 2023



Source: Navigant Research [5]

Table 2: Electric technology total population projections in CA

		Current Adoption	In Between	Aggressive Adoption
I-710 (Truck Miles)	*2013*	0	0	0
	2020	0	30,700	76,031
	2030	0	194,000	241,000
SR-60 (Truck Miles)	*2013*	0	0	0
	2020	0	0	0
	2030	0	0	315,000
MDV (Population)	*2013*	500	500	500
	2020	4,200	6,300	16,400
	2030	96,500	183,700	834,000
HDV (Population)	*2013*	0	0	0
	2020	80	380	795
	2030	8,800	23,500	65,800

Source: ICF International [6]

Transit agencies across the country are deploying a growing number of battery electric buses

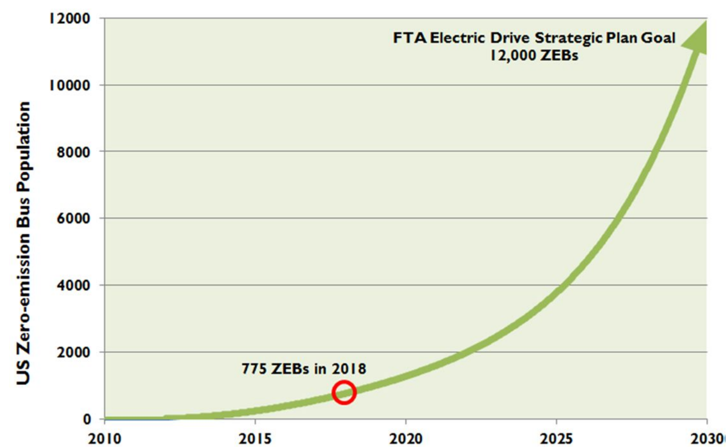
The publicly-funded transit bus sector offers an ideal platform for the validation and early adoption of advanced vehicle technologies [7]. That is why the E-Bus market is currently in a more advanced position than the E-Truck market. Electric drive and electric-assisted buses have already taken off in the US, making up 17% of the fleet in 2014 (up from 1% in 2005). So far most are gasoline or diesel hybrid buses [8]. Battery electric buses are still in the early commercialization phase but transit agencies are deploying a growing number of battery electric buses all across the US with a large number operating in California (Figure 2) [1] .

The large majority of battery electric buses have been manufactured by Proterra and BYD with about 110 and 102 buses sold in the US respectively [9] [10]. Other manufacturers of battery electric buses and shuttle buses include New Flyer, Complete Coach Works and Motiv Power Systems.

The number of zero-emission buses (battery electric and fuel cell hydrogen buses) is expected to double in 2016 and account for 20% of the transit bus market by 2030 [8]. In order to meet the FTA's Electric Drive Strategic Plan ambitious goal of 12,000 zero-emission buses in 2030 (Figure 3), rapid growth in zero-emission bus sales is necessary. Recent announcements show that the industry is on the right growth path: BYD projects to sell as many as 200 electric buses in the US in 2015 [11] and Proterra is building a second plant in California after a stream of new orders [12].

Figure 2: Transit agencies with electric buses operating or on order

Figure 3: US zero-emission bus population projection



One E-Truck or E-Bus provides substantial environmental benefits compared to one light-duty EV

Medium and heavy-duty vehicles account for 9% of greenhouse gases (GHG) in California, and approximately 20% of fuel used [13]. In addition, they are the largest contributors of NO_x in both the San Joaquin Valley and South Coast air basins, which hold more than 50% of the population of California [14] [15]. E-Trucks & Buses provide a substantial opportunity to reduce emissions and fuel used. While electric vehicles still produce NO_x through electricity consumption, power plant emissions are generally produced outside city centers where smog is the most harmful. Thus E-Trucks & Buses can provide dramatic results in criteria emission reductions. For example, Figure 4 shows that an electric bus will save about 47 kg of NO_x per year compared to a diesel bus and 19 kg per year compared to a CNG bus.

A truck or a bus consumes a large amount of fuel compared to a light-duty vehicle. Thus, one E-Truck or E-Bus can provide more environmental benefits than a light-duty EV. Table 3 shows that an E-Bus will emit 78 metric tons less of GHG per year than a conventional diesel bus, an electric Class 8 drayage truck will emit 18 metric tons less than a diesel drayage truck and an electric medium-duty delivery van will emit 10 metric tons less than a diesel delivery truck. In comparison, one light-duty EV only emits 3 metric tons of GHG less per year and a PHEV with 40 miles all-electric emits 1.5 metric tons less than a conventional car.

Figure 4: NO_x emissions from different transit technologies

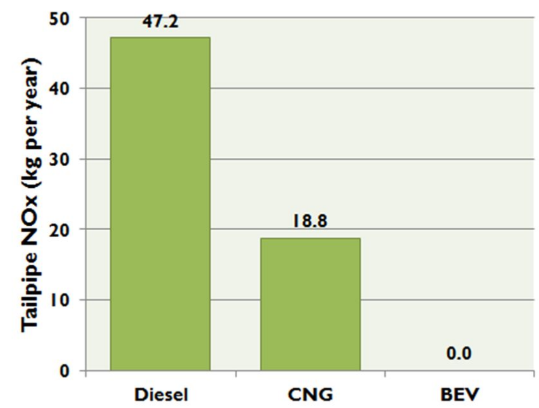


Table 3: Environmental savings comparison

	Technology	GGE/yr	kWh/yr	CO2/yr petroleum	CO2/yr electricity	Total CO2/yr	CO2/yr Savings
LDV	Conventional	400	0	3.5	0.0	**3.5**	**-**
	PHEV40	140	3,276	1.2	0.8	**2.0**	**1.5**
	BEV	0	2,800	0.0	0.7	**0.7**	**2.8**
MDV Delivery Van	Conventional	1,413	0	12.8	0.0	**12.8**	**-**
	BEV	0	12,500	0.0	3.1	**3.1**	**9.7**
HDV Class 8 Port Drayage	Conventional	3,060	0	27.7	0.0	**27.7**	**-**
	BEV	0	40,625	0.0	9.9	**9.9**	**17.7**
HDV 40-ft Transit Bus	Conventional	11,300	0	102.1	0.0	**102.1**	**-**
	BEV	0	100,000	0.0	24.4	**24.4**	**77.7**

Assumptions:

The gasoline light-duty vehicle drives 14,000 mi/yr at a fuel economy of 35 MPG, the PHEV40 14,000 mi/yr with 60% of the miles in all-electric at an efficiency of 0.39 kWh/mi and 40% in hybrid mode at 40 MPG. The light-duty EV drives 10,000 mi/yr at an efficiency of 0.28 kWh/yr. The medium-duty delivery van drives 12,500 miles/yr at a fuel economy of 10 MPG for a diesel vehicle and an efficiency of 1.0 kWh/mi for the EV. The heavy-duty Class 8 port drayage truck drives 16,250 mi/yr at a fuel economy of 6 MPG for a diesel vehicle and an efficiency of 2.5 kWh/mi for the EV. The 40-ft transit bus drives 40,000 mi/yr at a fuel economy of 4 MPG for a diesel vehicle and an efficiency of 2.5 kWh/mi for the EV. One gallon of gasoline produces 8.78 kg of CO_2, one gallon of diesel 10.21 kg and 1,000 kWh produces 244.4 kg of CO_2 (CalISO annual CO_2 total output emission rate from eGRID2012 version 1.0). Diesel NO_x emission rate for a 40-ft transit bus = 1.18 g/mile and CNG NO_x emission rate = 0.47 g/mile (from MJB&A, Comparison of Modern CNG, Diesel and Diesel Hybrid-Electric Transit Buses: Efficiency & Environmental Performance, 2013).

Utility load planning will be easier for E-Trucks & Buses as they will be concentrated in fewer areas

Figure 5 shows the distribution of Clean Vehicle Rebate Project rebates in Southern California. Many zip codes show large numbers of light-duty electric vehicles. With millions of single-family homes in California, utility load planning for personal electric vehicles is complex and uncertain. On the other hand, utility load planning for E-Trucks & Buses will be simpler, at least in the early phases of the market. A limited number of truck and bus fleets will deploy electric vehicles at a limited number of bus depots, delivery centers and truck yards. Figure 6 shows the distribution of UPS customer centers in Southern California and demonstrates that only sixteen UPS customer centers have or could deploy E-Trucks. Similarly, there are only 101 transit agencies in California and just over 35 in Southern California that have or could deploy electric buses.

At these potential deployment sites, the local distribution grid infrastructure may be significantly impacted by new E-Truck & Bus charging loads which can be much higher than for light-duty electric vehicles. E-Truck & Bus notification, where truck and bus fleets provide "information to identify new […] charging locations to electric utilities for the purpose of ensuring grid stability, reliability of safety [16]", can be achieved by encouraging the participation of a limited number of interested truck and bus fleets that are motivated and willing to participate in order to help successful deployments of E-Trucks & Buses in California and beyond.

Figure 5: Map of CVRP rebates in Southern California [17]

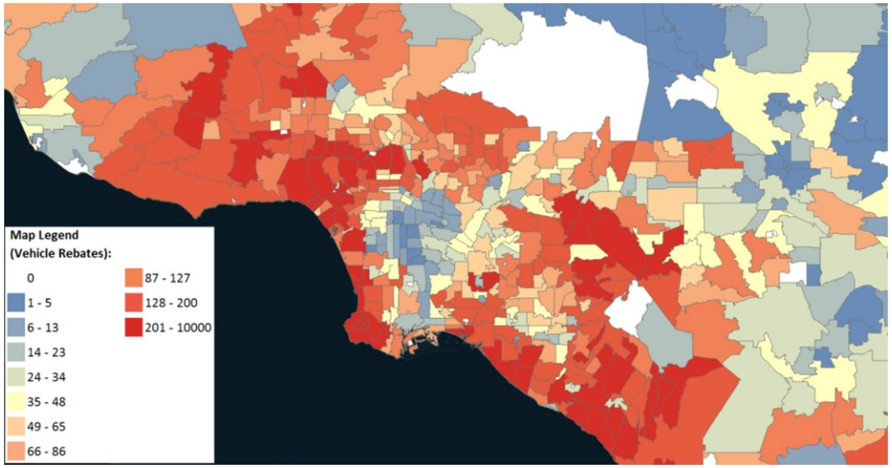
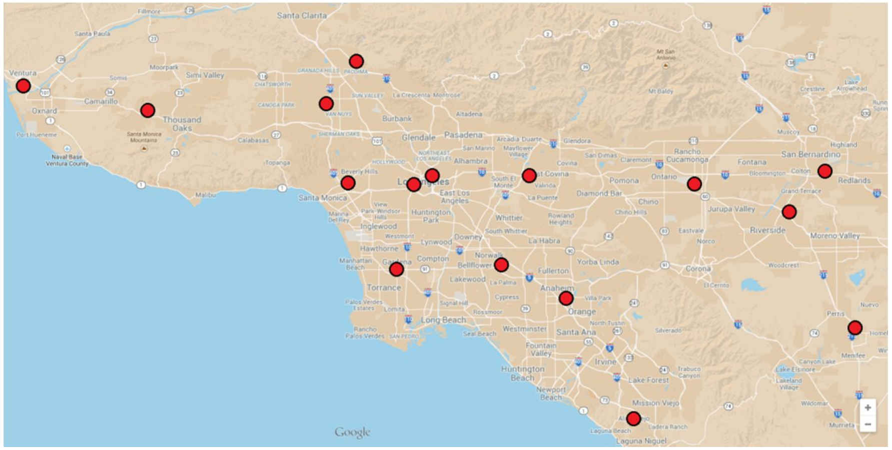


Figure 6: Map of UPS customer centers in Southern California



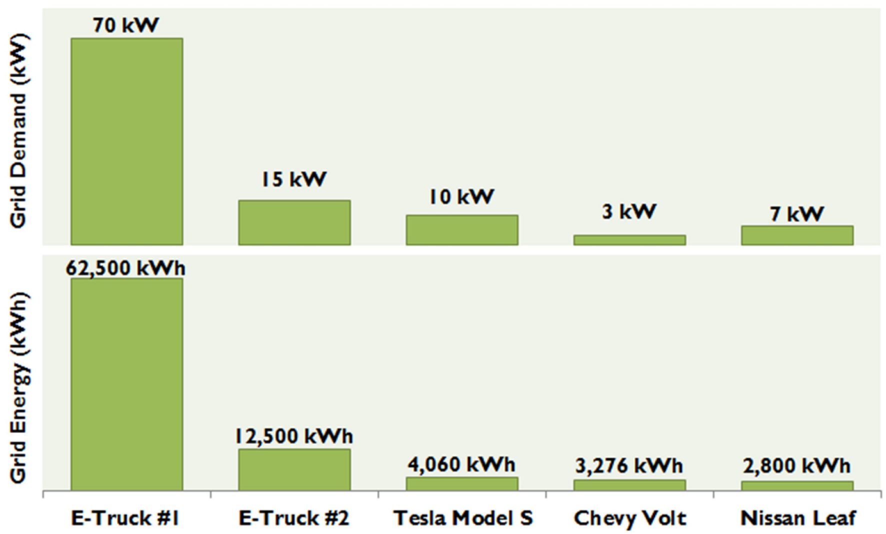
One E-Truck or E-Bus draws more power and consumes more energy compared to one light-duty EV

With much larger batteries and higher charging rates, one E-Truck or E-Bus draws the same amount of power and consumes the same amount of energy as several light-duty electric vehicles. For instance, Figure 7 shows how E-Truck #2 pulls the same amount of power from the grid while charging as 5 Chevrolet Volts and E-Truck #1 consumes the same amount of energy a year as 21 Tesla Model S.

The electrification of one truck or bus can potentially provide more benefits to utility customers and shareholders than the electrification of one light-duty vehicle. "For utility customers, [E-Trucks & Buses] can lower rates by improving asset utilization and decreasing costs. For shareholders, they can increase returns and present a new source of growth and investment" [18]. To achieve these benefits E-Trucks & Buses, like light-duty EVs, need to contribute more revenue to utilities than the cost of serving them [18]. At this stage of the E-Truck & Bus market, more information is needed to understand what the costs to generate and deliver electricity to E-Trucks & Buses will be. An in-depth analysis is needed to better understand the implications of charging E-Trucks & Buses, such as:

- The impacts on utility distribution grids,
- The need for additional infrastructure to support them,
- Utility distribution system upgrade costs, fleet facility upgrade costs and charging infrastructure costs.

Figure 7: Comparison of grid power and energy demand for different EV models



Assumptions:
E-Truck #1 drives 100 miles/day, 250 days/year, has an efficiency of 2.5 AC kWh/mile and draws 70 kW from the grid when charging. E-Truck #2 drives 50 miles/day, 250 days/year, has an efficiency of 1.0 AC kWh/mile and draws 15 kW from the grid when charging.
The Tesla Model S drives 14,000 miles/year and has an efficiency of 0.29 AC kWh/mile. The Nissan Leaf drives 10,000 miles/year and has an efficiency of 0.28 AC kWh/mile. The Chevrolet Volt drives 14,000 miles/year and has an efficiency of 0.39 AC kWh/mile. The Chevy Volt drives 60% of the miles on electric mode.

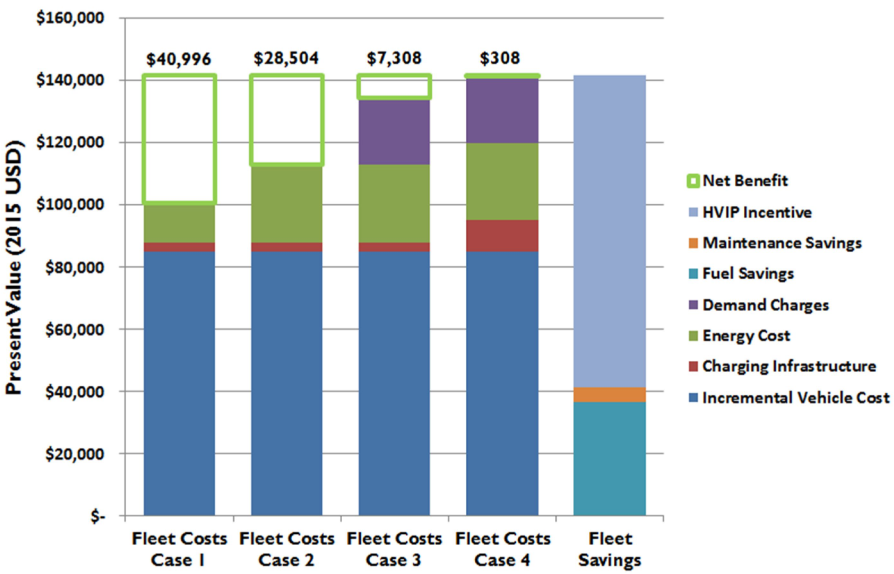
Current utility rate structures can discourage fleets from adopting E-Trucks & Buses

While the interest of truck and bus fleets in electric vehicles is diverse, the main reason why fleets are interested in E-Trucks & Buses generally revolves around operation & maintenance savings. But electric vehicles also have costs that conventionally fueled vehicles do not have. For instance, vehicle charging requires specific infrastructure and the price of electricity goes beyond a simple price per energy dispensed. Some of these costs have come as surprises to truck and bus fleets.

Following a methodology presented in [18], a simple cost benefit analysis was performed on a medium-duty electric delivery van under different cases looking at the impact of charging infrastructure, electricity and demand charges costs (Figure 8). As expected, Case 1 shows the most net benefit for the fleet. As charging infrastructure, electricity costs, and demand charges increase, the net benefit for the fleet decreases to almost zero.

As we will explore in the following pages, charging infrastructure costs can be quite large, Time-Of-Use rates can make the price of electricity increase sharply during peak hours and demand charges do apply to most large commercial and industrial utility customers. For E-Trucks & Buses to be successfully adopted by fleets, changes to current public utility commission policies that take into account the need to transform the market and reduce the costs to charge and operate E-Trucks & Buses are needed. Striking the right balance between incentivizing further vehicle adoption, staying technology neutral, and respecting utility rate design principles are key goals for the industry.

Figure 8: Medium duty delivery van costs & savings analysis



Assumptions:
The medium-duty delivery van drives 12,500 miles/yr at a fuel economy of 10 MPG for a diesel vehicle and an efficiency of 1.0 kWh/mi for the EV. A conventional medium-duty delivery van costs $65,000 and an electric one, $150,000 and both have a lifetime of 12 years. The electric medium-duty delivery van charges at a rate of 15 kW. Maintenance savings for the EV are estimated to be $0.05/mile. Diesel fuel prices were derived from the EIA 2015 Annual Energy Outlook for the Pacific Region. Electricity prices were assumed to increase by 1% every year. The discount rate is set at 7%.
Case 1: charging infrastructure cost at $3,000, electricity cost in 2015 at $0.12/kWh and no demand charges.
Case 2: charging infrastructure cost at $3,000, electricity cost in 2015 at $0.24/kWh and no demand charges.
Case 3: charging infrastructure cost at $3,000, electricity cost in 2015 at $0.24/kWh and $14/kW.
Case 4: charging infrastructure cost at $10,000, electricity cost in 2015 at $0.24/kWh and $14/kW.

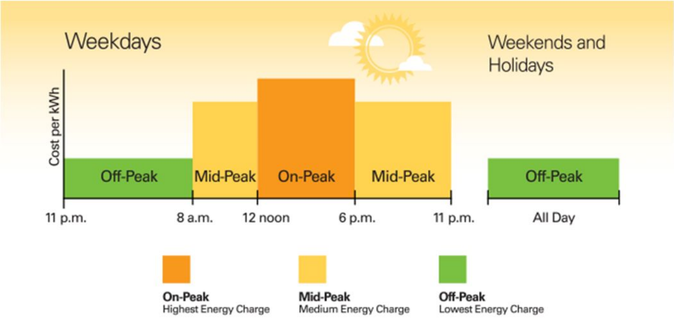
E-Truck & Bus charging has to support vehicle operation and unlike light-duty EVs cannot easily be shifted

Truck and bus fleets work with the specific requirement to provide timely and regular service to their customers. As a result, E-Trucks & Buses will generally operate on set schedules mirroring business hours or commute hours. Time-Of-Use (TOU) pricing, where energy is more expensive when the electric demand on the grid is higher (Figure 9), has been effective at shifting light-duty EV charging off peak. But truck and bus fleets do not have the same flexibility to shift charging based on utility price signals. While TOU pricing can work for some delivery vehicles operating during business hours and charging at night, they can make it difficult when charging on route, during lunch breaks, between two shifts or after an early shift. Figure 10 compares the fuel costs of a diesel, CNG and electric bus. Three different electricity prices are considered: $0.10, $0.05 (off-peak) and $0.20 (on-peak) per kWh. The price of the electricity used to recharge an E-Truck or E-Bus is an important component of its fuel costs. Charging off-peak when prices are low can lead to significant savings. On the other hand, charging on-peak when prices are high can dramatically increase fuel costs per mile [19].

In the future, TOU pricing could be replaced by real-time pricing to accommodate higher levels of intermittent energy resources into the grid. Real-time pricing could be an opportunity for E-Trucks & Buses to benefit from low or even negative energy prices but it could also add a layer of complexity for some fleets and make it more difficult for them to adopt E-Trucks or Buses. Technical solutions, such as smart charging, energy storage or distributed generation could help mitigate the impact of TOU or real-time pricing but will add costs and may prevent further electrification of trucks and buses.

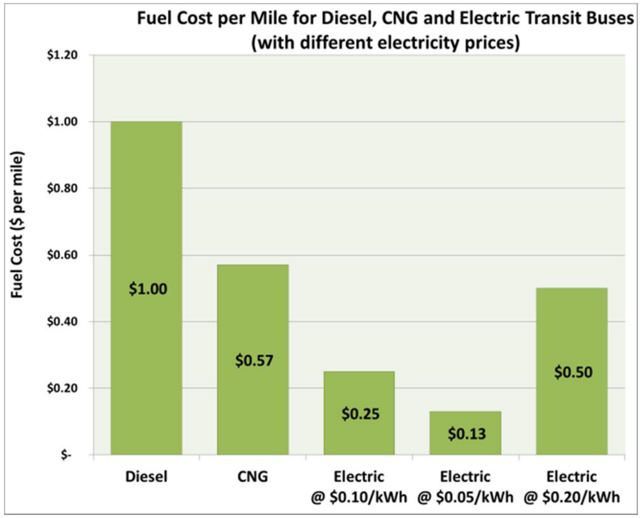
Assumptions for Figure 10: Each bus drives 40,000 miles/year. The diesel bus has a fuel economy of 4 MPG and diesel is priced at $4.00/gallon. The CNG bus has a fuel economy of 3.5 MPDGE and CNG is priced at $2.00/DGE. The electric bus has an efficiency of 2.5 AC kWh/mile.

Figure 9: Illustration of SCE Summer Time-Of-Use pricing



Source: Southern California Edison

Figure 10: Impact of TOU rates on battery electric buses



Source: CALSTART [19]

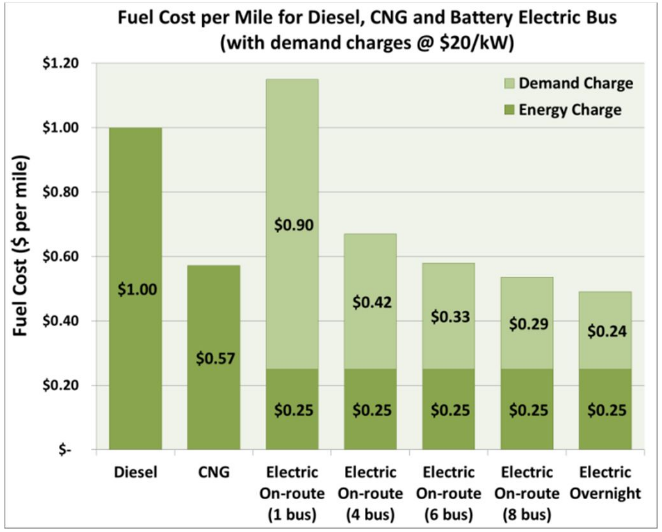
Demand charges can be prohibitively costly for early E-Truck & Bus deployments

In addition to charging for energy used (in kWh), electric utilities charge for power demand (in kW) on commercial and industrial customers to repay the fixed costs associated with the grid infrastructure needed during peak hours. Demand charges are considered as the appropriate way to allow recovery of utility capital costs and to give a price signal that pushes for market innovation promoting economically viable alternatives. However, they may discourage transportation electrification if loads cannot be shifted to off-peak periods [19]. Figure 11 gives an example of how demand charges impact fuel cost. E-Buses have a clear advantage when no demand charges are included. With high demand charges, fuel cost increase by $0.24/mile for one electric bus charging overnight and by $0.90/mile for one electric bus charging on-route. As the number of electric buses using a single on-route fast charger is optimized, demand charges can be spread over more buses and electric buses charging on-route regain their operating cost advantage.

Demand charges have a greater impact on small pilot deployments. In 2012, the California Public Utilities Commission granted a three-year reprieve on electricity rates for transit agencies with E-Buses, which allowed Foothill Transit to test three Proterra buses in real world operations that may not have been economically feasible with demand charges. Successful testing enabled by this waiver convinced Foothill Transit to purchase more buses for a current total of 17.

However, longer term solutions (explored in the following pages) are needed as the three-year reprieve only delays the application of demand charges and shift costs to non-participating customers. Vehicle deployments should be optimized to maximize the load factor, the amount of kWh used per each kW of demand. This can be achieved for E-Buses charging on-route by deploying the optimum number of buses using a single fast charger in order to maximize fast charger usage and spread demand charges over more E-Buses.

Figure 11: Impact of peak demand charges on E-Buses



Source: CALSTART [19]

Assumptions:

Each bus drives 40,000 miles per year. The diesel bus has a fuel economy of 4 MPG and diesel is priced at $4.00 per gallon. The CNG bus has a fuel economy of 3.5 MPDGE and CNG is priced at $2.00 per DGE. The electric transit buses have an efficiency of 2.5 AC kWh/mile and electricity is priced at $0.10/kWh. One electric bus charging on-route draws 150 kW from the grid, 4 draw 280 kW, 6 draw 330 kW and 8 draw 380 kW. The electric bus charging overnight draws 40 kW from the grid.

The need to electrify the truck & bus market requires innovative utility rates

The current utility rate structure promotes the efficient utilization of grid resources and allows for recovery of utility capital costs but may discourage the electrification of medium and heavy-duty vehicles. Innovative EV rates should be adopted to enable the further expansion of the E-Truck & Bus market. Specifically, electric utility rates should:

- *Acknowledge the unique needs of the E-Truck & Bus market.*

Truck & bus fleets do not have the same flexibility to shift charging as light-duty EVs so E-Trucks & Buses need to be looked as a distinct market.

- *Recognize the environmental and grid benefits of E-Trucks & Buses.*

LADWP and SCE have adopted specific rates for cold ironing to provide cleaner hoteling options to merchant ships and long-haul trucks. Georgia Power provides a very competitive rate for E-Bus operation (Table 4).

- *Separately submeter E-Truck & Bus charging where it makes sense.*

In their recent applications to the CPUC, PG&E and SCE require separate metering of EV energy consumption.

- *Be compatible with truck & bus fleet operation.*

SCE adopted several utility rates that accommodate EV charging at commercial facilities and stay true to principles of rate design. SCE's TOU-EV-3 & 4 rates waive demand charges for EV charging if the EV demand does not exceed the demand of the associated facility (Table 4).

- *Remain technology & business model neutral.*

Electrifying different truck & bus applications will require utility rates that do not favor one electrification technology over another. For instance, fleets will need both on-route opportunity and overnight charging. Considering a pricing option that charges more per kWh and less per kW could put both technologies on equal footing and allow for the electrification of more trucks & buses (Table 5).

Table 4: Examples of utility rates designed for E-Trucks & Buses

Utility	SCE			Georgia Power
Rate Schedule	*TOU-EV-3*	*TOU-EV-4*	*TOU-8 Option A*	*ET-15*
Maximum Demand	<20kW	>20kW <500kW	>500kW	N/A
EV Submetering	Required	Required	N/A	Yes
Energy Charge	Max. $0.36/kWh Min. $0.06/kWh	Max. $0.29/kWh Min. $0.06/kWh	Max. $0.39/kWh Min. $0.06/kWh	Max. $0.08/kWh Min. $0.00/kWh
Demand Charge	A - $0.00/kW B - $7.23/kW	$13.20/kW	$15.57/kW	$0.00/kW
Notes	No EV demand charges for Option B if EV account demand does not exceed General Service account demand of associated facility.	No EV demand charges if EV account demand does not exceed General Service account demand of associated facility.	For cold ironing pollution mitigation programs (vessels hoteling at the Port of Long Beach and the Port of Hueneme, and long-haul trucks hotelling at truck stops).	For the operation of electric transportation at 3Ø, 60 Hz and 19.8kV or higher.

Source: [20], [21]

Table 5: Utility charges for 2 different energy/power options

	Option 1 Lower kW / Higher kWh	Option 2 Higher kW / Lower kWh
Daily driving distance	120 miles / day	
Electric efficiency	2.5 AC kWh/mi	
Charging power	280 kW	60 kW
Energy charge	$0.15/kWh	$0.05/kWh
Demand charge	$2.00/kW	$20.00/kW
Total monthly charge	**$1505**	**$1515**

Source: CALSTART [19]

E-Truck & Bus charging infrastructure is a limiting factor for further vehicle adoption

Several truck and bus fleets that we have interviewed indicated that E-Trucks & Buses could be deployed on a much larger scale than today. Although the availability of commercial product offerings is currently the most important issue preventing further adoption, the cost to provide electricity for charging has been underestimated by many fleets. Below are observations from some of the fleets interviewed for this report:

- Vehicles generally need to be charged where they are parked (near a conveyor belt or on a yard) which may not be close to the existing utility service drop. Figure 12 shows a bus yard where the bus parking location may be located several hundred feet from an adequate power source. Figure 13 shows a sorting facility where package delivery vans have to be parked near a conveyor belt for loading and unloading.
- Bringing power to the vehicle parking location may require excavation, conduits, cabling and repaving.
- Every bus depot, delivery center or truck yard is different. In addition, the age of the electric infrastructure, the electric capacity available for expansion and the charging infrastructure costs are hard to estimate.
- The duration to complete an infrastructure upgrade can vary from several days to up to one year and depends on many parameters. While fleets wait for upgrades, vehicles cannot be operated.
- Utility rates are difficult to understand and it is difficult to analyze charging data and find ways to minimize costs without utility assistance.
- Not all electric utilities are actively engaged and provide helpful guidance to truck and bus fleets deploying electric vehicles.
- Charging systems are not all standardized, raising concerns about operability of future vehicle models using existing infrastructure.

Figure 12: Aerial shot of the Gardena Municipal Bus Lines yard

Figure 13: Parked FedEx vans being loaded at a sorting facility

Photo courtesy: NorthJersey.com

Public utility commission policy changes are needed to reduce the costs for fleets to install charging infrastructure

Some fleets have considered all-electric facilities only to realize that the infrastructure costs to fully electrify a 100 to 200 - vehicle facility would be prohibitive. Table 6 lists cost estimates for charging infrastructure from actual fleets and OEMs. Infrastructure costs are high and vary widely. In addition, the faster a vehicle needs to be charged, the more expensive the charging infrastructure will be. These costs do not include upgrades in the distribution system that may be needed if the rated capacity of the installed electric equipment is exceeded. One fleet who deployed 20 E-Trucks at a facility in Southern California had to upgrade a transformer on the customer side of the meter to accommodate the added load to the facility. In this particular case, the $470,000 transformer price tag had a significant impact on the total project cost.

Faced with these high infrastructure costs, several fleets have taken a cautious approach by limiting the number of vehicles deployed at a single location. Instead of having a set number of vehicles to deploy at a single location, fleets prefer to only deploy the maximum number of vehicles without exceeding the rated capacity of the installed electric equipment which would trigger major utility upgrades.

Public utility commission policies should be changed to reduce the cost of installing charging infrastructure. Specifically, electric utilities should be allowed to rate base some or all of the costs to bring the necessary power up to and including the "make-ready" stub. In addition, electric utilities should be allowed to play a role, along with other market players in developing and supporting charging stations to allow truck & bus fleets, E-Truck & Bus manufacturers and federal and/or state agencies to focus their resources on purchasing and deploying vehicles.

Table 6: E-Truck & Bus charging infrastructure cost estimates

Fleet cost estimates per one charger installation	*EVSE*	EVSE Installation	
		Low	High
16.5kW (220V / 75A)	*$1,000 - $3,000*	$17,000	$32,000
70kW (208VAC 3Ø / 200A)	*$5,000 - $10,000*	$20,000	$75,000
450kW (480VAC 3Ø / 640A)	*$350,000*	$150,000	$200,000

Source: [22], [23], [24] and confidential communications with truck and bus fleet managers and E-Truck & Bus manufacturers, May and June 2015.

E-Truck & Bus charging, if unmanaged, can have significant impacts on the grid

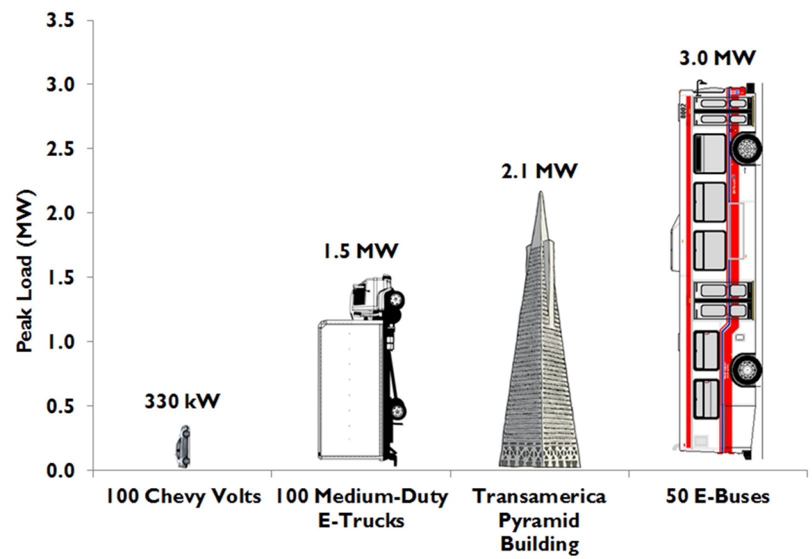
Like light-duty EVs, the grid impacts caused by charging E-Trucks & Buses represent a key issue. In page 12, we saw that E-Trucks & Buses will be concentrated in urban areas, at a limited number of bus depots, delivery centers and truck yards. If E-Truck & Bus charging is not managed properly at these locations, the local distribution grid infrastructure could be significantly impacted and would require expansive upgrades. Figure 14 makes it clear that an all-electric truck or bus facility is not feasible without ways to mitigate the grid impacts of charging. For instance, 100 medium-duty E-Trucks charging at the same time would demand 1.5 MW of power on the grid and 50 E-Buses would demand 3.0 MW. This is in the same order of magnitude as the peak power demand of the Transamerica Pyramid building, the tallest skyscraper in San Francisco, CA [25].

To remedy this issue, several fleets are actively exploring technical solutions such as:

- Smart charging,
- Range extenders,
- Energy storage, and
- On-site electricity generation.

Demand response, a solution to reduce the peak demand of buildings like the Transamerica Pyramid, is not believed to be a viable solution in its current form, as customers have to make loads available for curtailment when the utility requests. This may not be feasible for fleets who need to provide timely and regular service and may not have vehicles available for curtailment.

Figure 14: Peak loads for various electric vehicle fleets (without mitigating grid impacts)



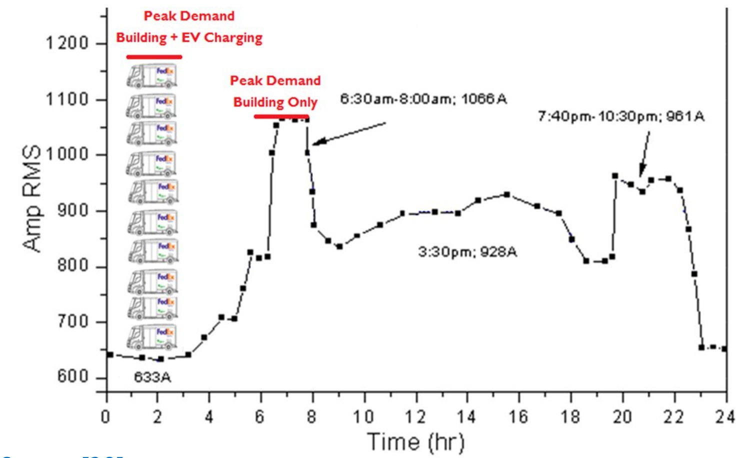
Assumptions: the Chevy Volt charging rate is 3.3 kW, the medium-duty E-Truck charging rate is 15 kW and the E-Bus charging rate is 60 kW. The peak load for the Transamerica Pyramid building is from [26].

Implementing smart charging systems will reduce the grid impacts of charging E-Trucks & Buses

Smart charging systems can enable better grid integration by balancing EV charging and building load to charge the greatest number of vehicles at the lowest cost possible and increase certainty of service for the fleets. Figure 15 shows how charging 10 E-Trucks off-peak without a smart charging strategy could increase the peak load of a 120 - truck package delivery station. A solution was developed by GE Global Research and Columbia University to be deployed by FedEx Express in New York City. The system "regulate[s] the charging rate of multiple EVSEs to facilitate cost-optimal charging subject to past and predicted building load, vehicle energy requirements, and current conditions" [27]. Figure 16 shows how for a fleet of 100 E-Trucks, the system can decrease peak facility demand by over 500 kW and save approximately $11,500 per month in demand charges compared to a fleet without the smart charging system. For a fleet of 200 E-Trucks, peak facility demand could be reduced by over 1,000 kW and demand charges savings could expand to about $23,000 per month [27]. Control systems for smart charging are in the development phase and one interviewed fleet expects costs between $5,000 and $7,000 per facility.

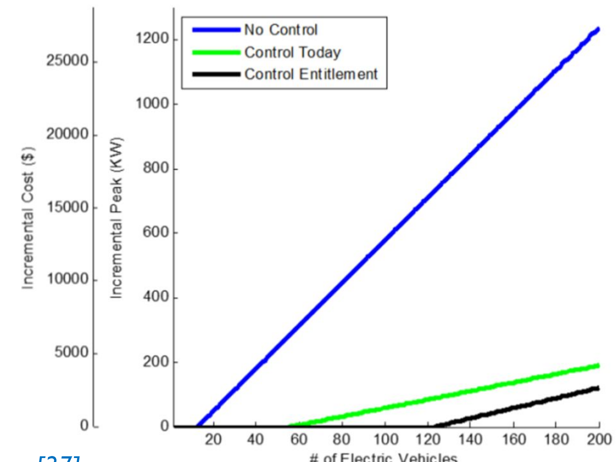
In addition to reducing demand charges, smart charging E-Trucks & Buses can also minimize the impact of TOU and reduce charging infrastructure costs. But to achieve the latter benefit, smart charging strategies need to be taken into account when calculating the load added by E-Truck & Bus charging. One fleet detailed a particular case where utility code mandated that a facility electric infrastructure be upgraded to accommodate all the E-Trucks charging at the same time at the maximum charging rate even if charging could easily be managed to reduce the peak facility load.

Figure 15: Electrical load at a 120 package delivery van station



Source: [28]

Figure 16: Incremental peak demand and associated cost incurred for demand based on EV fleet size



Source: [27]

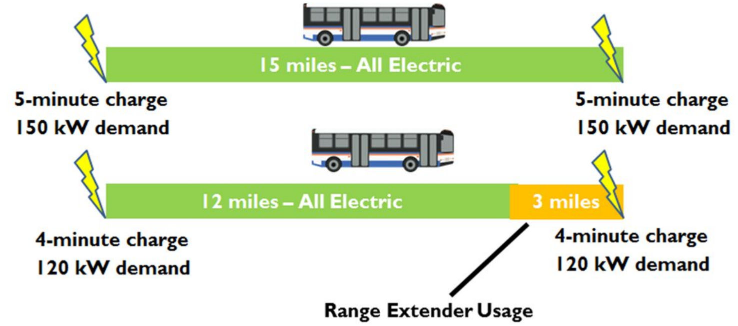
Range extenders, energy storage and on-site generation are of high interest to fleets to mitigate charging costs

Range extenders, energy storage and on-site generation have been identified as potential technical options that could mitigate the grid impacts of charging and are actively researched by several of the fleets that we interviewed [19].

Integrated on E-Trucks & Buses, range extenders could decrease the amount of electricity needed between two charging events and the overall required charging power (Figure 17). They could also decrease markedly charging infrastructure issues. For some fleets, H_2 refueling infrastructure is seen as an easier and ultimately cheaper option. Fuel cell range extenders may represent a smoother transition from current vehicle operating models and could circumvent the inconvenient need to have to charge at the location where the truck or bus is parked.

Energy storage systems (batteries, ultracapacitors, or flywheels) can be used as buffers between the grid and EV chargers to smooth out peak loads. Table 7 describes the ABB TOSA bus charging system in demonstration in Switzerland. The use of ultracapacitors decreases the maximum power demand on the grid from 400 kW to 40 kW while maintaining the benefits of on-route fast charging. In addition, lower charging power allows for easier siting of the charging infrastructure as it may not require complex and expensive upgrades to the electric infrastructure [19]. Some fleets, early adopters of hybrid, plug-in hybrid, and electric trucks & buses will start retiring vehicles in the next 3 to 5 years. These fleets are eager to reuse the batteries from these vehicles for second-life applications to facilitate the deployment of more E-Trucks & Buses. Lastly, coupling on-site electricity generation (solar PV, fuel cell or microturbine) with energy storage is another interesting option for fleets to mitigate charging infrastructure costs, reduce demand and TOU charges, and provide certainty of service during grid outages.

Figure 17: Comparison of all-electric and range extended transit bus operation



Source and assumptions: [19].

Table 7: Description of ABB TOSA bus charging system

	Grid to Charger	Charger to Bus
Maximum charging power	40 kW	400 kW
Charging duration	2.5 minutes	15 seconds
Energy transferred	1.7 kWh	1.7 kWh

Source: [19].

E-Trucks & Buses could provide additional benefits to the grid and profit from low carbon fuel standards

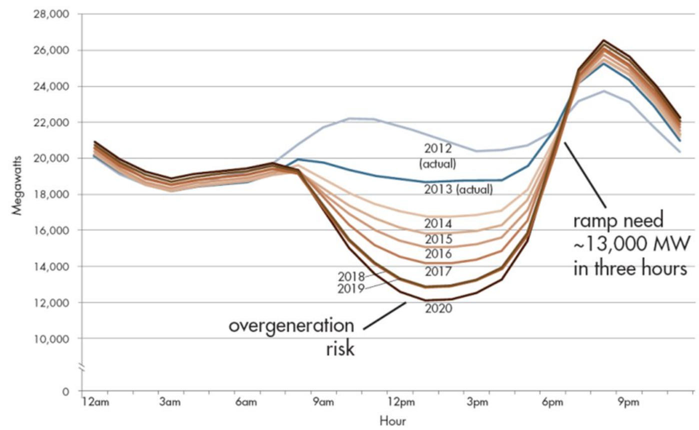
With very ambitious targets for renewable energy integration, the California grid will be stressed in new ways [29]. Spring and fall days in particular, could soon see overgeneration risks when solar generation peaks and steep ramp needs when it declines (Figure 18). Flexible resources will be needed to reliably manage these new challenges [30]. In addition to transporting goods and people, E-Trucks & Buses could provide additional grid benefits:

- E-Trucks & Buses charging on route, during lunch breaks, between two shifts or after an early shift could represent a large source of diurnal energy storage available to reduce overgeneration risks.
- Smart charging could slow down or even suspend charging during periods of high ramp needs while still guaranteeing vehicle availability.
- Energy storage systems could enable more E-Trucks & Buses to charge during periods of overgeneration, discharge during periods of high ramp needs and take advantage of real-time pricing.

For fleets to make E-Trucks & Buses serve as true grid resources, key players will be needed to aggregate loads, automate charging and adopt consistent standards and communication protocols [29].

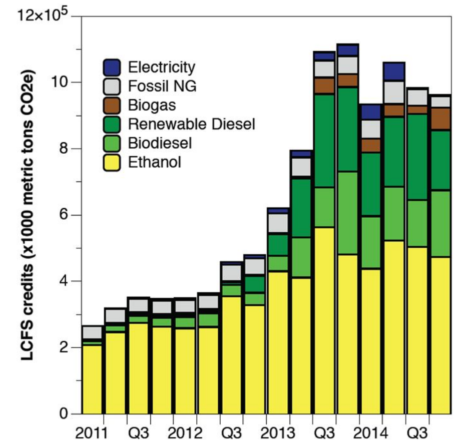
Electricity currently accounts for a small share of the California Low Carbon Fuel Standard (LCFS) credits (Figure 19). However, the California LCFS represents a viable opportunity for truck & bus fleets to decrease the costs to operate E-Trucks & Buses. With current LCFS carbon intensities, a fleet of 10 E-Buses could generate almost 1,000 LCFS credits per year, for a value of $44,000/year at current credit prices. It may be difficult for truck & bus fleets to become the credit generator and other market players may be better suited to secure these LCFS credits. These credits could then be given back to the fleets either as a rebate or as an on-bill credit.

Figure 18: The California ISO "duck curve" (March 31)



Source: [30]

Figure 19: Total net California LCFS credits by fuel type



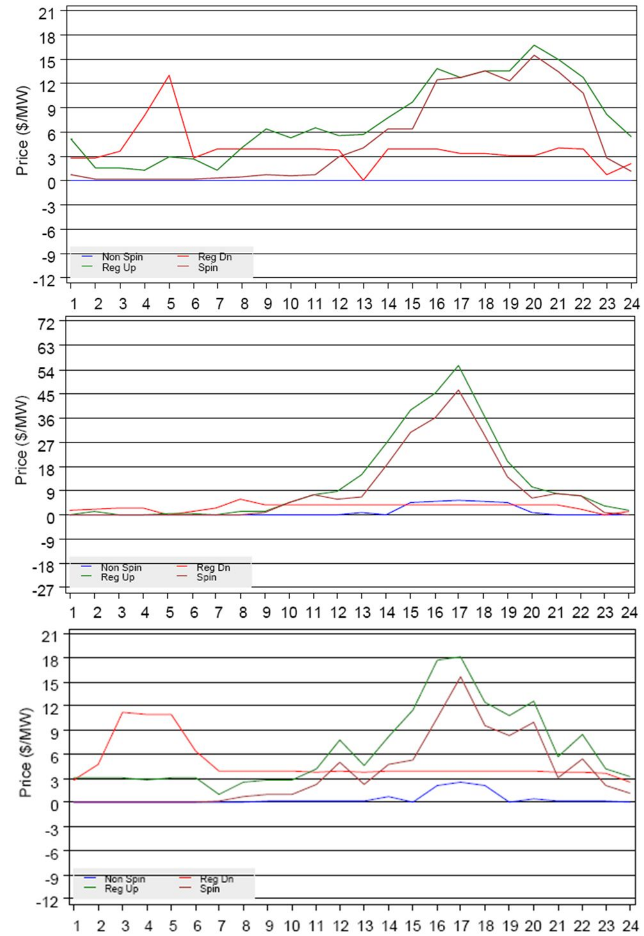
Source: [31]

Vehicle-To-Grid could benefit E-Trucks & Buses but is still years away from commercial application

Two pilot projects (one at the U.S. Army base of Fort Carson, CO and one with Frito-Lay in Texas) have demonstrated the technical feasibility of using E-Trucks & Buses as power sources for grid balancing services such as frequency regulation [32] [33]. But several of the fleets that we interviewed, while interested in V2G, did not see it as a solution that they could benefit from in the short term. Some of their observations are listed below:

- While a fleet of E-Trucks & Buses, with vehicles equipped with larger batteries and charging power compared to light-duty EVs, can more easily satisfy the minimum power requirements for participation in the ancillary market, fleets did not think they could provide enough grid services to be of interest to market regulators or aggregators.
- E-Truck & Bus charging is set on rigid operating schedules while ancillary service prices vary throughout the day depending on grid and weather conditions. For example, Figure 20 shows the ancillary service average prices for a late June weekday for three consecutive years.
- While a recent project validated the technical feasibility of V2G for commercial vehicles, it also concluded that "economics in current market structure [are] not viable for participation" [33].
- Fleets will not adopt a technology (such as V2G) that will prevent vehicle operation by decreasing range or delaying availability.
- Fleets are not opposed to third party ownership of charging infrastructure but cannot let a third party influence their operation.
- No key players in the ancillary / utility / facility market currently exist and fleets are seeing V2G more as a long term (5 to 10 years) technology, preferring simpler approaches such as Vehicle-to-Building.

Figure 20: CAISO ancillary service average price on 06/27/2014 (upper), 06/28/2013 (middle) and 06/28/2012 (lower)



Source: [34]

Recommendations (1)

There is currently a lot of interest in the E-Truck & Bus market. While E-Trucks have been deployed for several years, significant activity is now focused on all-electric buses. In its early market stages, technologies and solutions are still being researched, developed and tested. The current picture of the market is bound to change as technology matures but the decisions taken now by regulators, utilities, fleets and vehicle manufacturers will shape the future of E-Trucks & Buses and influence their success. As demonstrated in this report, E-Trucks & Buses present unique challenges and opportunities compared to light-duty electric vehicles. In addition, E-Truck & Bus loads are different from other facility loads and light-duty EVs. The success of electric vehicles in the commercial medium and heavy-duty vehicle market will require different approaches. Below are several recommendations derived from this report:

- **Expand & enhance industry stakeholder forums to better tackle industry issues**

The E-Truck & Bus community, while still small, is composed of motivated stakeholders committed to the progress of the industry. Expanding and enhancing the activities of industry stakeholder forums such as CALSTART's E-Truck Task Force would promote industry stakeholder engagement, increase information sharing between utilities, fleets, and manufacturers, and better tackle some of the industry issues identified in this report.

- **Commission a comprehensive E-Truck & Bus load study**

There is currently a lack of information on E-Truck & Bus charging infrastructure costs and charging patterns. A comprehensive E-Truck & Bus load study would monitor the actual distribution system upgrade costs and develop charging load profiles for different medium and heavy-duty vehicle vocations. Such a study could also look at answering questions fleets have: What is the available capacity (kW) and utilization (%) of the transformer that will support the E-Truck & Bus deployment? Is a single (larger) new substation or substation upgrade or several (smaller) feeder upgrades more cost effective? How would a "E-Truck or Bus ready facility" look like and how much would it cost to create a purpose-built facility that can easily accommodate vehicle deployments in the future?

- **Create dedicated E-Truck & Bus program manager positions to support fleets**

Electric utilities should create specific E-Truck & Bus program manager positions to guide fleets make better decisions when procuring E-Trucks & Buses and accelerate the electrification of medium & heavy-duty vehicles in a way that is cost effective for truck & bus fleets, "reduces rates for other customers, provides value to shareholders and minimizes criteria pollutant and GHG emissions" [18].

- **Secure existing low carbon fuel standard credits to reduce E-Truck & Bus operating costs**

A process should be developed to secure low carbon fuel standard credits from E-Trucks & Buses and make it simple for truck & bus fleets to be given back these credits either as a rebate or as an on-bill credit.

Recommendations (2)

- **Continue to support the electrification of trucks & buses through grants, incentives and tax credits**

E-Trucks & Buses are already in use today in several fleets across the nation, and we are seeing increases in sales and in interest, especially among transit agencies. Technology is improving and costs are coming down. However, grants, incentives and tax credits are still needed to reduce the costs to purchase and charge E-Trucks & Buses at this early stage of the market. In particular, more cost effective larger vehicle deployments should be targeted.

- **Fund demonstration projects focusing on advancing technologies that will enable further electrification**

Federal and state funding agencies should fund high quality, competitive projects that will accelerate the commercialization of technologies that maximize load factors (the amount of kWh used per each kW of demand) and can make E-Trucks & Buses true grid resources. Such projects should include smart charging technology, range extenders, on-site generation and energy storage systems, specifically those looking at second-life applications of E-Truck & Bus batteries.

- **Adapt utility rate structure to accelerate the cost effective electrification of trucks & buses**

The current utility rate structure promotes the efficient utilization of grid resources and allows for recovery of utility capital costs but may discourage the electrification of medium and heavy-duty vehicles. Innovative EV rates should be adopted to enable the further expansion of the E-Truck & Bus market. Specifically, electric utility rates should:

  - ❖ Acknowledge the unique needs of the E-Truck & Bus market.
  - ❖ Recognize the environmental and grid benefits of E-Trucks & Buses.
  - ❖ Separately submeter E-Truck & Bus charging where it makes sense.
  - ❖ Be compatible with truck & bus fleet operation.
  - ❖ Remain technology and business model neutral.

- **Change current public utility commission policy to mitigate the costs of E-Truck & Bus charging infrastructure**

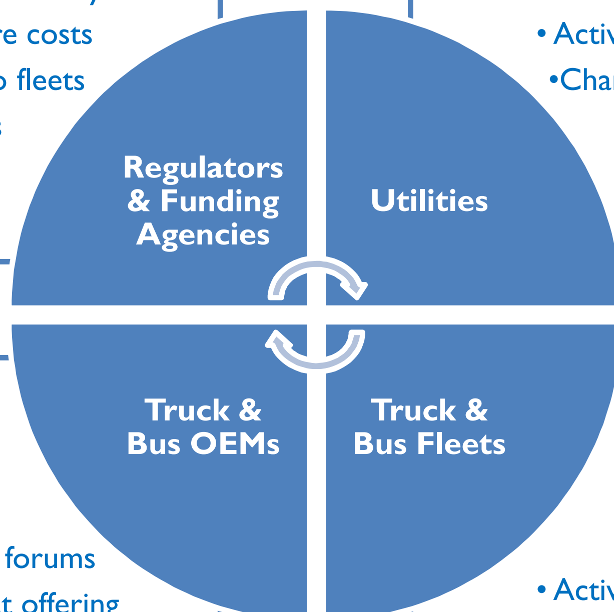
Electric utilities should be allowed to rate base some or all of the costs to bring the necessary power up to and including the "make-ready" stub. In addition, electric utilities should be allowed to play a role, along with other market players, in developing and supporting charging stations to allow truck & bus fleets, E-Truck & Bus manufacturers and federal and/or state agencies to focus their resources on purchasing and deploying vehicles.

Next Steps

Lastly, this report identifies next steps for the E-Truck & Bus industry that we believe would help implement the recommendations listed in the two previous pages and accelerate the commercialization of medium and heavy-duty electric vehicles.

- Fund relevant demonstration projects & load study
- Change PUC policy to reduce infrastructure costs
- Provide grants, incentives and tax credits to fleets
- Fund industry stakeholder forums activities
- Enable fleets to benefit from LCFS credits
- Adapt utility rate structure

- Create EV program manager positions to support fleets
- Actively participate in industry stakeholder forums
- Change PUC policy to reduce infrastructure costs
- Enable fleets to benefit from LCFS credits
- Support E-Truck & Bus load study
- Adapt utility rate structure



- Support E-Truck & Bus load study
- Participate in demonstration projects
- Share relevant duty cycle and charging data
- Actively participate in industry stakeholder forums
- Improve and expand E-Truck & Bus product offering

- Support E-Truck & Bus load study
- Participate in demonstration projects
- Share relevant duty cycle and charging data
- Actively participate in industry stakeholder forums

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