

# **Developing a Business Model for Commercial Electric Vehicle Charging Infrastructure**

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## **Abstract**

The adoption of commercial electric vehicles (CEVs) is beginning to pick up traction by fleet operators and vehicle manufacturers. Carbon emission legislation, fuel prices and improving battery technology are ever-increasing the attractiveness of the business case for electric vehicles. CEVs represent a massive opportunity to reduce global transportation emissions, vehicle manufacturers to reach new customers, and fleet operators to reduce impact and increase efficiency. There are many commercial fleet applications that are advantageous for electric operation, but require charging solutions and strategy in order to ensure the CEV's operational performance. Charging infrastructure is the essential complimentary component to providing CEVs. Research was conducted from a systematic perspective in order to identify challenges, barriers and opportunities for charging infrastructure integration into the vehicle fleet system. Some of the key challenges include issues such as range anxiety, grid integration and fleet optimization. Using these identified obstacles, potential business solutions are discussed and designed in order to alleviate pain-points and increase the attractiveness of electric vehicles in commercial operations. By leveraging Product Service System principles and the established business model canvas tool, this work provides a preliminary business model design around charging infrastructure in order to increase the adoption of CEVs by fleet operators. Key outcomes include the identification of pivotal electro-mobility and charging services needed for the chosen case, urban goods distribution.

**Keywords:** vehicle electrification, urban goods distribution, zero-emission fleet, commercial electric vehicle, electro-mobility services

## **Executive Summary**

As the globalization trend continues, reducing carbon emissions from the transport sector is becoming an increasingly important objective of governments. Private companies and consumers alike are beginning to realize the benefits and necessity of pursuing low-carbon products and services. Electric vehicles have been recognized universally by the scientific community as a pivotal technological strategy that can be implemented on a global scale in order to make this carbon reduction possible. However, to date, most focus on electric vehicles has been in the personal consumer market. Commercial electric vehicles (CEV) represent a huge opportunity to reduce emissions, while also providing a new avenue for vehicle manufacturers to capture new market value. CEVs also run on diesel fuel rather than gasoline as with consumer vehicles. Diesel emissions have more adverse effects on human health and the environment due to their NOx emissions, which is the leading cause of upper-respiratory health conditions like asthma (RPA, 2016). Commercial vehicles such as delivery trucks and refuse collection trucks also consume upwards of 25 times more fuel on average than a family car (Sullivan, 2016). This mean that for each commercial truck on the road that is converted from a conventional diesel vehicle to electric, will result in a per vehicle societal and environmental benefit that is much larger than for consumer cars.

However, there is a variety of barriers and challenges that makes the development of the commercial electric vehicle market slow. Technology, consumer acceptance, regulatory instruments, and integration with larger systems all influence the ability of CEVs to overtake diesel trucks as the dominant vehicle logistics technology. Electric vehicles inherently need charging infrastructure in order to function, however the factors surrounding charging infrastructure and how it effects CEVs are not yet well understood. This lack of clarity or certainty can deter and discourage operators from making the switch, despite the many operational, financial and environmental benefits that come with vehicle electrification. Understanding how the deployment of infrastructure or different charging strategies influence CEVs can positively benefit their adoption in the marketplace.

To start, many consumers are wary of purchasing an electric vehicle for fear that there will not be sufficient infrastructure to support their driving needs, and on the other hand manufacturers and utilities are hesitant to build out charging infrastructure without a clear demand signal from the market. Electric vehicles typically have higher upfront costs than their petrol counterparts, due to the high price of the battery that replaces the internal combustion engine. For commercial vehicles this issue is amplified, as the heavier weight and higher required daily range means that a battery of significant size is needed. The larger the battery, the heavier it will be, and payload is a central value creator for the commercial industry. The more battery weight a CEV is required to haul, the less payload that contributes to creating profit it can carry. However, by ‘right-sizing’ the battery in order to match the application and duty cycle of a given truck, this cost attributed to the battery can be minimized making a more attractive business case for fleet operators (CALSTART, 2012). Designing a charging strategy around this battery optimization question can help to reduce the size of battery and therefore reduce the price of the vehicle.

The design of this research looks to provide information to alleviate these knowledge gaps and provide insight on how some of these market and technical barriers can be overcome. The objective of this work is not to provide an extensive overview of the technical nature of CEVs and charging infrastructure. Instead, the goal is to investigate CEVs from a systems perspective, in order to give a wholesome overview of the system’s elements and influences. Aspects covered include state of development of electric truck and infrastructure technology, the market factors and policy considerations that affect the system, as well as other influencers such as standardisation or system integration. By understanding how these components interact and

influence one another will lend insight into designing charging infrastructure solutions and strategies.

The first stage of work was to conduct a review of academic databases and industry research organizations in order to compile and correlate information on CEVs and charging infrastructure. In order to compliment gaps from written materials, this study relied upon interviews with experts across critical stakeholder groups in order to provide insight on how electric trucks function in practice. Interviewees included experts with the energy utility, industry-specific research organizations, municipalities, transport agency, trucking industry, electro-mobility software platforms and more. Some of the identified key challenges revolve around grid integration of charging stations, fleet integration of CEVs, and the ancillary services that increase the value and ease the planning of CEV charging. The financial costs of upgrades to distribution grid infrastructure in order to handle the high power load of CEV battery charging is a key barrier for fleets looking to adopt electric trucks. Integrating these vehicles into fleet operations can also be challenging, in terms of the charge planning schedule and anticipating the vehicle's route. Smart charging can help to alleviate these pain points, but there is a lack of software solutions geared towards the commercial fleet industry to resolve these issues.

The next major stage of work was to determine which customer segments or vehicle applications are best suited for CEVs. There are several factors such as payload, range, route patterns, etc. that determine the suitability of replacing conventional diesel trucks with CEVs. For example, applications such as long-haul trucking require much heavier hauls and have a daily driving range that far exceeds the state of current battery technology. However, there are many existing businesses and operations that CEVs already fit well with given their inherent characteristics and advantages. Research in the field has pointed to urban applications to be advantageous for CEVs for a variety of reasons (Pelletier et al, 2014, CALSTART, 2012, den Boer et al, 2013). This is attributed to the shorter required routes, the ability to return to the depot each day which simplifies charge planning, and often the ability to take advantage of municipal regulation or incentives. Within the urban space this work chose specifically to focus on goods distribution and refuse trucks which are both strong candidates for CEVs.

Beside the technical and social barriers, a key issue is the lack of business and financing models for electric vehicle charging infrastructure (CALSTART, 2012, Quak et al, 2016, Eurelectric, 2016). Therefore, the final stage of analysis was to build upon the information compiled on CEVs, charging infrastructure, policy mechanisms and use profiles, in order to begin the preliminary stages of business model design. This work relies upon the popular method devised by Osterwalder et al, 2010, better known as the Business Model Canvas, which is comprised of nine major building blocks. This study uses these nine building blocks to channel the information learned from the earlier sections to make recommendations on a business model for charging infrastructure. The proposed business model looks to provide a suite of options to be used as a decision making tool, rather than a definitive "best" approach.

**Nine Blocks of the  
Business Model Canvas**

Customer segments  
Channels  
Customer relationships  
Value proposition  
Key partners  
Key activities  
Key resources  
Revenue streams  
Cost structure

The typical value chain for vehicle manufacturers has focused primarily on the vehicle, whereas for EVs this value chain is extended to include charging infrastructure and ICT support solutions. This extension of the value chain has given rise to a new market player, the electro-mobility service provider (EMSP). An EMSP is an entity that offers solutions related to EVs, such as smart charging, routing, charge station finding, and electricity billing. CEVs represent

an opportunity for vehicle manufacturers to break from the typical vehicle-sale business model and diversify revenue streams to include complimentary services.

In order to accomplish this, the designed business model is centred upon Product Service System (PSS) principles. PSS is an emerging trend within the business environment where products and service offerings are integrated, with the goal to improve efficiency and create positive economic and environmental benefits (Reim et al, 2014). Based on this approach, the business model canvas investigates how the product (commercial electric vehicles) and the service (charging) can be combined to create a valuable proposition to urban goods distribution fleets. This is centred around a use-oriented business model approach, which takes form in a vehicle lease rather than vehicle sale. A vehicle lease extends the revenue stream to take place over the duration of the contract, rather than a one-time sale. Lengthening the provider-user relationship creates opportunities for new sources of revenue, such as providing related charging services and support solutions.

Building upon this use-oriented framing to the business model design, this work has identified several key ancillary services that a vehicle manufacturer can offer to make CEVs more valuable to fleet operators. These electro-mobility services include route optimization and planning, automated smart charging, fleet optimization consultation, data collection and analysis. The provision of these types of services can alleviate previously noted challenges and concerns by fleets on range anxiety or total cost of ownership.

There are many external stimuli that this work could not cover in full depth such as policy, geographical constraints, company culture or specific technical barriers that influence the ability of this new business model to come to fruition. Further research across these topics could lend further insight to continue making this an attractive business case. However, this work looked to approach this from a business and systems perspective. The takeaway is that the technology and financial feasibility exists to create this transition to a more sustainable commercial transport system. What is needed are companies willing to provide innovative business solutions to the marketplace in order to make it a reality and shift the status quo.

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## **Abbreviations**

A – Amps

BEV – Battery Electric Vehide

CEV – Commercial Electric Vehide

CCS – Combined Charging System

CO<sub>2</sub> – Carbon Dioxide (emissions)

ELVIIS – Electric Vehide Intelligent Infrastructure

EMSP – Electro-mobility Service Provider

EU – European Union

EV – Electric Vehide

EVSE – Electric Vehide Supply Equipment

FCEV – Fuel Cell Electric Vehide

GHG – Greenhouse Gases

HEV – Hybrid Electric Vehide

ICE – Internal Combustion Engine

ICT – Information communication technology

IEC – International Electrotechnical Commission

NO<sub>x</sub> – Nitrogen Oxide (emissions)

OEM – Original Equipment Manufacturer

PSS – Product Service System

SAE – Society of Automotive Engineers

TCO – Total Cost of Ownership

UFT – Urban freight transport

V – Volts

V2G – Vehide-to-Grid

# 1 Introduction

Consumer electric vehicles continue to gain market share and public acceptance, while also steadily reducing in price. As a result, there is growing interest from vehicle manufacturers to offer vehicles for new applications in customer segments other than personal transport in order to access new revenue streams. With ever-improving battery technology and growing interest by companies to reduce environmental impact, electric vehicles in the commercial sector has begun to gain traction. However, the development of fully electric vehicles for commercial trucking purposes has remained slow to date (Pelletier, Jabali, & Laporte, 2014). This slow development is due to many factors, yet one of the key enablers for the successful development of electric vehicles is to deploy the necessary supporting charging infrastructure in tandem to the vehicle market (CALSTART, 2012, Pelletier et al, 2014, den Boer et al, 2013). The main purpose of this thesis is to investigate charging infrastructure strategies, technologies and best practices in order to support a new business model for commercial electric trucks. There is no clear investigation of how these factors surrounding charging infrastructure influence business model design. With greater understanding of the various barriers, challenges and opportunities, it is possible that increased adoption of commercial electric vehicles (CEV) will take place. There is a wide variety of CEV applications however the focus of this work will primarily be on urban goods distribution, but will also investigate refuse trucks for comparison and comprehension.

## 1.1 Background

The global economy is constantly growing while also becoming increasingly more interconnected. In turn the transportation networks that support these complex systems are expanding to match development. The freight industry alone produces approximately 10% of global GHG emissions, most of which is concentrated in urban areas. Emissions from the freight industry are expected to increase fourfold by 2050 as urban populations continue to grow (RPA, 2016, US EPA, 2015). Commercial vehicles represent a massive emissions reduction opportunity, as medium- and heavy-duty trucks, while only comprising four percent of the vehicles on the road, account for about 20 percent of the transportation fuel consumed (UCS 2012). Represented in another manner, a typical family car burns 2,300 litres of gasoline per year, while garbage and delivery trucks burn upwards of 53,000 litres annually (Sullivan, 2016). Beyond the typically considered carbon dioxide (CO<sub>2</sub>) effects, are nitrogen oxides (NO<sub>x</sub>) emissions, of which diesel trucks are the primary offenders. In Europe, diesel trucks are responsible for 47 percent of NO<sub>x</sub> emitted, which is a leading cause of upper-respiratory health conditions like asthma (RPA, 2016). With each commercial truck that is able to be electrified, meaning a one-to-one replacement of a conventional petrol truck with an electric-truck, will result in a per vehicle societal benefit that is much larger than for consumer cars. In countries with a greater share of renewable energy production, this effect is amplified, as the electricity that powers the CEV comes from clean sources. Even if the electricity comes from an energy portfolio that does not include a large share of renewable energy, CEVs still retain a fuel economy that is three times more fuel efficient than diesel trucks (Prohaska et al, 2016). Yet despite this massive emissions reduction opportunity, the electrification of the commercial vehicle sector remains slow, with a limited number of suppliers providing electric trucks (Pelletier et al, 2014).

In general, the commercial transportation sector faces challenges within the urban context, not only electric vehicles. Historically, urban freight has been largely overlooked by urban planners and municipalities (RPA, 2016). The current trend towards “liveable cities” favours mixed-use development, often prioritizing bus lanes, pedestrians and cyclists (RPA, 2016). While this is largely a good thing, it is ignoring the fact that freight is the life-blood that enables urban environments to exist in first place. As city streets become narrower to make way for bike lanes, bus traffic and pedestrian spaces, urban freight distribution becomes a lower and lower priority,

forcing distributors to rely on smaller trucks limiting economies of scale (RPA, 2016). A clear example of this phenomenon is in London, where trucks and vans represent 17% of vehicle miles travelled on the road network, compared to 1.7% for the city's massive bus system. However, "despite this lower utilization, policies targeting increased reliance on public transit mean busses receive disproportionate attention from urban planners and local governments. They receive more government funding and preferential treatment on the streets, a situation that is similar in most cities" (RPA, 2016). This does not mean to say that cities should completely abandon increasing public transport use or pedestrian and cyclist spaces, but rather that the inclusion of freight distribution within the urban planning formula would create compounding benefits for the inhabitants through increased efficiency.

On the other hand, other city policies such as congestion charges and Low Emission Zones (LEZ) help to further the case for electric vehicles. As transportation emissions become a more prominent priority for municipalities, reducing traffic volume within the urban centre is pivotal for improving the living and health conditions of the city. Going beyond emissions, current delivery vehicles with an internal combustion engine (ICE) generate noise during operation that can exceed 75 dB, while unloading activities such as idling or lift gate use can be between 60-65 dB (Lammgård & Browne, 2012). These high-levels of street noise have been proven to create adverse health effects on urban populations, primarily in the form of loss of sleep quality or increased stress and anxiety. Many European cities are expected to enact noise requirements in local traffic legislation (Löfstrand et al, 2015). Electric trucks are excellently positioned to take advantage of these emerging policy trends since they are inherently zero-emissions, while also providing other human health benefits such as noise reduction through quieter operation. According to the United Nations more than half of the world's population lives in urban areas, and this trend is expected to continue to increase to five billion by 2030 (United Nations Population Fund, 2007). As increasing numbers of citizens transition to an urban lifestyle, the greater the need for a sustainable freight system that can benefit or enhance the movement towards cities.

## 1.2 Problem Definition

The expansion of the electric vehicle market can be described as a "chicken and the egg" scenario. On one hand, consumers are wary of purchasing an electric vehicle for fear that there will not be sufficient infrastructure to support their driving needs, and on the other hand manufacturers and utilities are hesitant to build out charging infrastructure without a clear demand signal from the market. However, consumer trust in electric vehicles is continuing to accelerate, which in turn is beginning to spill over to the commercial sector. The commercial EV sector is able to draw some lessons from the consumer EV market in areas where commonalities exist, such as grid integration and installation. However, commercial electric trucks have different usage and charging patterns, customer needs, daily driving range and other various technological dimensions. The needs of charging infrastructure for commercial electric truck are not well understood or studied.

One of the primary authorities on commercial electric trucks is CALSTART, a USA-based non-profit organization that works with public and private entities to develop clean transportation technologies. In 2012, CALSTART conducted a major industry study to identify issues among fleet users, manufacturers and suppliers in order to determine the major barriers to electric truck adoption. Despite some aspects being specific to the North American market, many of the key lessons are applicable in all geographies. Below are the results of what various actors within the CALSTART industry group believe to be the greatest barriers to CEV deployment. While infrastructure cost is not the absolute highest priority of fleet users, it is still of high importance across all sectors and a serious concern for fleets nonetheless. In later sections, it will be

displayed how smart development of infrastructure and complimentary services can help to alleviate the higher rated concerns such as battery replacement, purchase price or range anxiety.

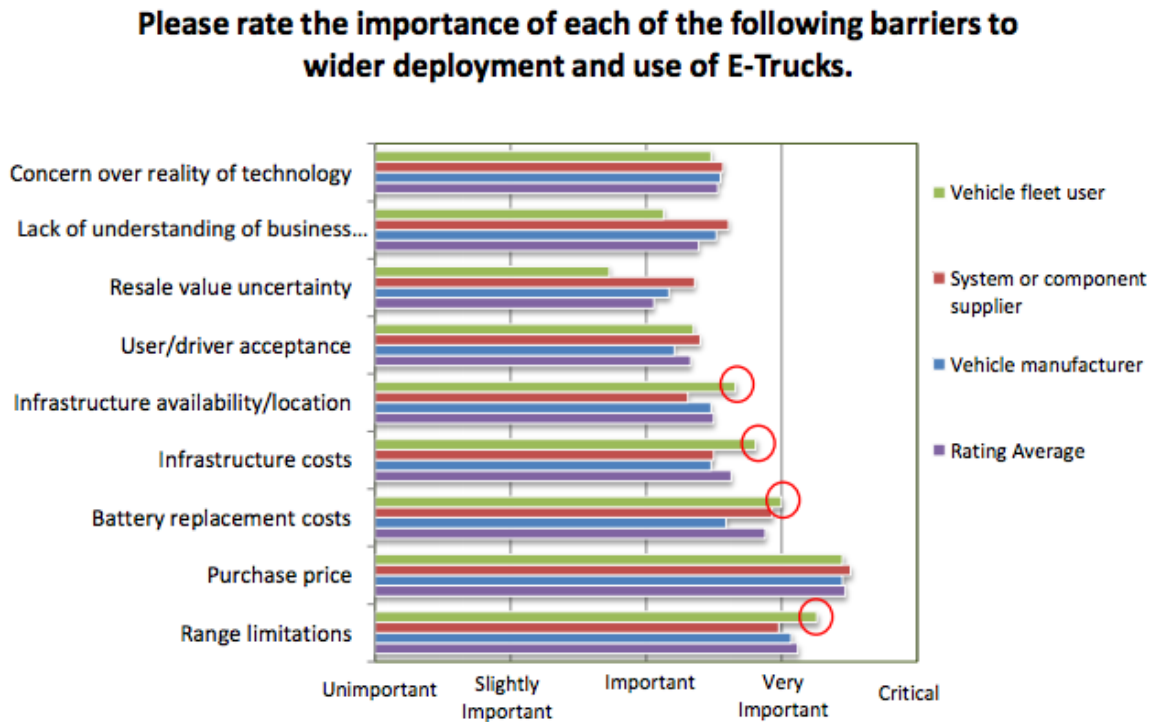


Figure 1-1. Fleet and Industry Survey Responses –Relative Importance of E-Truck Market Barriers by Sector  
Source: CALSTART (2012)

CALSTART’s survey also asked fleet users to identify key barriers specific to charging infrastructure, with the three greatest obstacles being—cost, lack of infrastructure, and the speed of charging. By ameliorating these obstacles, one can look to improve the business case for CEVs and therefore increase the rate of adoption by fleets.

Fleet operators primary concern is the ability of their fleet to complete the job in the most cost-effective way. Generally, fleets are very open to EVs as part of the operational portfolio, and are genuinely interested in a zero-emission solution, but not if the switch inhibits their ability to operate. Fleet operators and owners are experts in logistics, not electric vehicles or the electric grid. There can be unexpected hurdles, regulatory barriers or hidden costs when fleets try to convert from conventional to electrified operations. This lack of clarity or certainty can deter and discourage operators from making the switch, despite the many operational, financial and environmental benefits that come with vehicle electrification (CALSTART 2012, Quak et al, 2016, Eurelectric, 2016). Electric trucking can be commercially viable, but the high capital investment cost of the supporting charging infrastructure can deter adoption by some users. Due to these financial challenges, there is a lack of publicly accessible infrastructure. If achieving the necessary range out of an electric truck is a concern, operators will cite the lack of infrastructure as a key barrier for switching. Lastly, the speed of charging is a key issue for a business that is dependent on attaining the highest level of utilization per vehicle as possible. The greater number of hours per day a vehicle is operated rather than sitting idle, the greater a contributor it is to the profitability of the business. If the time required to charge the vehicle interferes with its ability to be profitable, fleet operators are unlikely to integrate them into their operations. Generally, as one increases the rate of charging power, the cost of the infrastructure

also increases, so balancing the benefits and disadvantages of various charging techniques is pivotal for providing a business case.

Many of these issues have been covered by a wide range of authors and experts, but are often lengthy and scattered. There is a plethora of installation guidelines, academic studies, consulting agency reports and international projects, all of which contain charging infrastructure topics and aspects, but rarely focus from the perspective of the infrastructure deployment. Simplifying the existing content, knowledge and issues related to charging infrastructure across these sources, the pivotal and necessary complimentary component to electric vehicles, will go a long way for educating and encouraging fleet operators to adopt commercial electric vehicles. Therefore, in short, the problem addressed in this thesis is:

*Factors surrounding charging infrastructure that influence the business case for commercial electric vehicles need to be compiled and simplified for vehicle manufacturers and fleet operators in order to increase adoption.*

### 1.3 Research Objective and Questions

The objective of this paper is not to necessarily to prove the environmental motivation or economic sense for vehicle electrification. This in part has been accomplished through other works (see Lee et al. 2013 on environmental benefits and Davis and Figliozzi, 2013 on economic competitiveness). However, these components are important for framing the answer to, “why should society care about electric vehicles in the commercial sector?” To answer this, one might consider human health, environmental improvements, economic viability and system-level efficiency. A significant part of examination at the systems-level is to assess the infrastructure network that will support a commercial electric truck business. By approaching the challenges and barriers for CEVs and charging infrastructure from a systems-level, it can lend insight to how these problems might be alleviated through innovative business solutions.

In order to design a charging infrastructure strategy and solution, one must understand what drives the value of commercial electric vehicles. One of CALSTART’s final conclusions was to define that, “the value proposition for E-trucks is overwhelmingly based on three variables: maximizing fuel displacement, reducing purchase price, and minimizing infrastructure installation costs.” (CALSTART, 2012). A comprehensive charging infrastructure strategy can contribute to satisfying all three of these objectives. First, by optimizing route planning and charge scheduling in tandem with infrastructure deployment, CEVs will be able to run longer and more efficient routes, displacing maximum fuel costs. Second, the battery is upwards of half of the vehicle cost, so by optimizing the size of the battery to match the use-profile and charging strategy of the vehicle, purchase price will be minimized. This optimization problem is covered in greater detail throughout this study. Lastly, an innovative business model for EVSE that incorporates industry best practices can help to lower infrastructure costs, which will result in a more attractive total cost of ownership.

The first objective of this work is to compile and condense information on charging infrastructure that will contribute to the successful adoption of commercial electric trucks. Examining this issue from a stakeholder and systems perspective will point to challenges and opportunities for vehicle OEMs to commercialize EVs. From this newly condensed information, the final objective will be to determine the decisions that can be considered when designing a business model for charging infrastructure. The goal is to be able to match charging strategies and solutions and be able to successfully adapt it to various vehicle applications and customer segments.

Based on the stated problem definition and the objectives outlined above, this study has identified two primary research questions:

*Research Question 1: What criteria must be considered when designing charging infrastructure strategies and solutions in order to support a commercial electric truck fleet?*

After the major considerations and attributes of charging infrastructure have been outlined, the next stage will be to use this information to make informed decisions on business model design. Therefore;

*Research Question 2: How might a business model be designed when offering charging infrastructure to fleet operators?*

*Sub-question 1: Who are the major partners and stakeholders involved, and who maintains ownership of the infrastructure?*

*Sub-question 2: How might a business model be adapted or changed for different vehicle applications and users?*

## **1.4 Limitations and Scope**

The focus of this analysis is on charging infrastructure, however it is impossible to completely extricate it from electric vehicles as they are inherently interconnected. The idea will therefore be to examine the relationship between charging infrastructure and commercial electric vehicles in order to understand how they influence one another and can be optimized based on these discoveries.

When examining the electrification of the commercial trucking industry, one will find there is a large range of applications, technologies, and sectors to consider. Whether it is medium or long haul, utility vehicles, garbage trucks, goods distribution, plug-in hybrids, range-extended vehicles, battery electric vehicles, electric powertrains, there are many factors to consider. In order to constrain this scope to a manageable size, a few distinctions are made. There are several varieties of vehicle electrification strategies, such as hybrid electric vehicles (HEVs), fuel cell electric vehicles (FCEVs), range-extended vehicles, with even more sub-categories within these vehicle types.

This research project deals with battery electric vehicles (BEVs), specifically within the commercial trucking sector. This analysis will not consider these other vehicle types, since the lens from which the analysis comes is on charging infrastructure, of which BEVs are the most relevant and directly applicable. ‘Fully-electric’ BEVs do not use any sort of input fuel source and draw energy from the electric grid. Throughout this paper the acronym CEV will be used to distinguish itself from consumer BEVs (e.g. Nissan Leaf) and to make it specific to the commercial trucking industry. There are other alternative denominations for CEVs among literature, such as ‘E-Truck’ for electric truck or EFV (Electric Freight Vehicle) (CALSTART, 2012, Quak et al, 2016). However, the author has chosen to use CEV as it captures other vehicle types that are not necessarily moving freight, as well as its more common usage across similar literature.

Second, this paper will focus within a city context and constrain the examined truck application primarily to urban goods distribution. Urban delivery trucks travel short distances and well-defined routes, which are less constrained by battery range and are ideal candidates for electrification (UCS 2012). This application was also chosen for its worldwide ubiquity and the necessity for a replicable business model to be designed which can be applied across many geographies and markets. There will be a brief discussion around refuse trucks in Section 4.3 on Use Case Profiles, but this is mainly in order to highlight key differences that need to be addressed when targeting different customer segments. The bulk of the business model

discussion will be centred on urban goods distribution, as there exists greater amounts of data and more in-depth studies that can support the design.

A final constraint will be to focus primarily on charging stations as it is the best-available technology for charging infrastructure. The author will briefly cover other technologies currently under development for prospective applications in order to be comprehensive while anticipating future improvements in technology.



## **2 Methodology**

The first stage of research is to collect and correlate the best-available technologies, industry best practices, and state of the market as related to electric commercial trucks and charging infrastructure. The objective is not to provide an extensive overview of the technical nature of electric vehicles and charging infrastructure, but rather to display their state of development in the market. This first stage is meant to provide a basis for the subsequent pieces of analysis that aim to mitigate barriers at a systems level and within a business context. Given this systems orientation, the first stage of research will be approached using an adapted ‘PESTLE’ analysis (Policy, Economic, Social, Technological, Legal, Environmental). The PESTLE method is very malleable and can be adapted to the needs of the research, therefore the Legal aspect will largely be left unconsidered, as this is highly geographically specific and creates a level of unnecessary complexity at the early stages of business model design. The methodology for this section is therefore based primarily on a STEEP analysis, covering Social, Technological, Economic, Environmental and Policy considerations. The final stages of the study aim to provide a business model for charging infrastructure within a service-based business model for electric trucks, therefore Technological and Economic aspects receive a strong focus given their relevance. Social and Environmental considerations are described throughout in broader strokes, in order to display their contribution to the value proposition of fleet electrification. Policy is a wide-ranging field that could be covered to include many facets relevant to CEVs such as land-use, zoning laws or vehicle design standards. Instead, a showcase of the most directly relevant policies for CEVs and charging infrastructure are presented in order to keep the information tight and focused. Rather than organizing the systems analysis section under the components of STEEP, it was more logical and comprehensible to group findings by topic area. The STEEP analysis is therefore the lens in which information gathering is conducted, not an organizational tool.

The STEEP analysis will be accomplished through collection of both primary and secondary data. The first task is to conduct an extensive review of academic literature and industry reports in order to condense the information most relevant to charging infrastructure. Research was conducted by a review of academic databases, research entities focused on electric vehicles, commercial trucking and charging infrastructure, as well as general online searches. Key terms such as; EVSE, charging station, electric truck, green logistics, zero-emission truck, charging infrastructure business models, were used in several variations and combinations in order to compile a set of resources. Some proprietary studies were provided by the sponsor of this thesis, that were used for problem framing and confirmation of public information.

In order to compliment gaps from written materials, this study relied upon interviews with experts across critical stakeholder groups in order to provide insight on how electric trucks function in practice. Interview candidates were selected based on their relevance to the topic area, whether it was electric vehicles, commercial trucking, logistic solutions, grid integration, electrical engineering or charging infrastructure deployment. Interviewees included experts with the energy utility, industry-specific research organizations, municipalities, transport agency, trucking industry, electro-mobility software platforms and more. Depending on the interviewees’ area of expertise, semi-structured interviews were conducted in order to garner insight on challenges and barriers for EVSE implementation, success factors for a commercial electric truck market, cost and system-integration considerations, or future opportunities in the marketplace. A total of 24 interviews were conducted, with some candidates being interviewed more than once. This total does not include other internal supervision provided by the thesis sponsor and Lund University.

The next stage of research is to build generic “use cases” or “use profiles” of commercial trucks that are potential candidates for electrification. The information gathered was drawn from descriptions across academic literature, studies provided by a vehicle OEM, compilation reports of electric truck pilot projects, as well as drawing from a public database dedicated to the commercial trucking industry. The main object is to understand in broad strokes how the vehicles are used in practice in order to design a business model that compliments the needs of the user and alleviates associated challenges. The primary use profile considered throughout this study is urban goods distribution. Urban goods distribution captures a wide spectrum of the market and fits best with the chosen technological focus (charging stations). In order to provide contrast, refuse trucks—another strong candidate for electrification, is also covered.

The final stage of Analysis will be to construct the environment of the business model for charging infrastructure. This conceptualization will be based on the information collected about commercial vehicles and charging infrastructure through the STEEP analysis, stakeholder influences on the system, the nature of the vehicle application as well as the qualitative information collected through interviews. The first component will be to provide a contextual overview of Product Service Systems (PSS) and how PSS principles may be applied to business model design. This will provide insight on how vehicle manufacturers can design an innovative service-based business model for providing charging infrastructure in tandem to the vehicle. Business model design will use established methods and tools such as value chain evaluation, value proposition, and the Osterwalder business model canvas. Osterwalder’s business model canvas is a visual tool for users to construct a business model using nine major building blocks. The canvas helps to display flow between the different aspects of providing a good or service. Due to time constraints, the full business model canvas will only be applied to urban goods distribution, as this use profile had the most readily available data. Urban goods distribution is ubiquitous across the globe and would benefit from an easily replicable business model. An abbreviated discussion on how this business model might be adapted for refuse trucks will also be included in order to display how the decision making process at the design stage can be used to effectively tailor the value proposition to different customer segments and vehicle applications. A secondary and complementary objective to the business model canvas will be to investigate possible ownership models for charging infrastructure in order to support a service-based commercial electric vehicle business.

### **3 System Elements and Influences**

In order to make informed decisions on designing a business model for commercial electric trucks and charging infrastructure, it is necessary to first understand the system in which the business model would operate. The aim of this section is to give a contextual overview as to the state of development of electric truck and infrastructure technology, the market factors and policy considerations that affect the system, as well as other influences such as standardisation or system integration. As mentioned in Methodology, the STEEP analysis will be the lens upon which this information is collected, compiled and correlated. The STEEP analysis draws upon several key resources groups: ranging from public reports and studies of electric truck projects, academic articles that analyse various areas of electric trucks, an online database on commercial vehicle applications, as well as interviews of industry experts and relevant stakeholder groups. The goal is to compile a highly condensed resource of the best-available technology currently on the market, industry best practices, and the associated challenges to implementation for the deployment of commercial electric trucks and charging infrastructure.

#### **3.1 Electrification of Commercial Trucks**

As aforementioned, electrified trucks in the commercial freight space represent a huge emission reduction opportunity. The environmental case for shifting to an electrified transportation system is well documented by a number of authors (Geroliminis and Daganzo, 2005, den Boer et al, 2013, Quak et al, 2016). Similarly covered are economic aspects such as payback, fleet optimization and total cost of ownership, but further work should be conducted on improving the business case. Lastly, system-integration of CEVs into stakeholder networks and supply chains has received the least amount of review. The analytical portion of this study will attempt to improve on the business case while describing how CEVs might be better integrated at a systems level. This section will first cover the current state of the market and technology of CEVs, in order to provide context for the subsequent analysis.

##### **3.1.1 History and Recent Projects**

Despite electric vehicles being a seemingly new and innovative technology, their advent onto the market and usage is over a century old. In order to provide a very brief history one can look back to 1900 to 1910, where electric trucks were actually the preferred technology over combustion engines when replacing horse-powered freight trucks due to their incredible reliability and low operating cost (Mom, 1998). Electric trucks were primarily used in the United States during this time, whereas Europe was experimenting more with electric taxicabs. However, despite this dominance by electric trucks in America within urban goods distribution, during the First World War, the military was sceptical of the battery-powered vehicles' reliability in the field and chose to endorse and utilize petrol instead. This surge of large military orders and funding allowed for petrol trucks manufacturing capacity and financial backing to scale quickly and quickly outpace electric trucks, leading to their eventual demise in the late 1920s (Mom, 1998).

Jumping forward, the first major European demonstration of electric vehicles in urban goods distribution, the ELCIDIS (**E**lectric vehicle **C**ity **D**istribution) project. The demonstration project in 1998 had several targets; to display economic, technical & social viability, analyse environmental benefits, gain insight on technical operations, demonstrate acceptance by users and operators, and to investigate values of incentives (Vermie, 2002). The ELCIDIS project was comprised of 39 BEVs and 16 hybrids across six cities, and has overall been deemed an early success at its overarching goal to demonstrate the viability of electric vehicles in urban distribution (Davis and Figliozzi, 2013). However, during these early stages in the market there were many challenges faced by operators in city logistics, such as "high procurement costs, limited range of vehicle models, little to no after sale support and long waiting time for spare

parts, low performance of the lead-acid, nickel – cadmium and ZEBRA battery technologies, limited mileage range, low vehicle speed and limited payload” (Quak et al., 2016 p161). Over time some of these issues have been at least partially alleviated, such as the advent of lithium ion batteries for CEV use – addressing issues such as range, payload and cost. However, all of the areas listed above still need vast improvement in order for CEVs to reach true market viability.

The successor to ELCIDIS is currently underway, now titled FREVUE for **F**reight **E**lectric **V**ehicles in **U**rban **E**urope. The FREVUE project covers a variety of urban freight applications ranging from goods deliveries, consolidation centres, several vehicle types, different climatic conditions and political/regulatory settings (Quak et al., 2016). The FREVUE project began in 2012 or 2013 depending on the city, and is in its final year of trials and analysis (Sunnarstedt, phone interview, June 29, 2016). At this point in 2013, the typical range of the vehicles was no more than 100 – 150 kilometres, which is largely true still today. There were several observed technical issues related to charging infrastructure, the most relevant being a relatively long charging time and the necessity to adapt charging infrastructure for fleet needs (Quak et al, 2016). However, despite these barriers, general attitudes within the freight logistics industry towards CEVs have improved, particularly on the issue of limited range.

### 3.1.2 Commercial Electric Vehicles

The objective of this paper is not to compile a registry of CEV trucks and providers. Instead, there will be a brief description of two primary providers of battery trucks, Smith Electric and Renault. The reason for this is to give an approximation of CEV characteristics in terms of battery capacity, range, vehicle size etc. Smith was chosen for several reasons, it operates in both European and North American markets, is an OEM that designed the vehicle from the ground up specific for EVs rather than a re-design of an ICE truck, and lastly due to its prominence in trucking industry news outlets. Renault was chosen for its widespread use and to be used as comparison against Smith since it is a much more mature OEM of trucking vehicles. For a complete overview of light-, medium- and heavy-duty electric trucks see Pelletier et al. 2014 or TU Delft et al. 2013; the list of medium-duty trucks from Pelletier et al. is included in Appendix Item 1.

Smith Electric manufactures two vehicles, the Newton and the Edison. The Edison has a vehicle weight range from 3,500 kg to 4,600 kg, while the Newton offers 7,500 kg, 10,000 kg and 12,000 kg options. Both vehicles have modular battery offerings, providing 40, 60, 80, 100 or 120 kwh. This is sound strategy so that customers can optimize the price they pay based on their route needs. The battery is the largest component of vehicle expense, often half the purchase price or more. Optimizing battery capacity so that it is correct-sized for the requisite operations is pivotal. Smith works with a variety of industries, ranging from food & beverage, utility, telecommunications, retail, grocery, parcel and postal delivery, school transportation, to military and government. Much of the concern surrounding CEVs is regarding the lifespan of the lithium-ion batteries. Smith conducted a multi-year study of their batteries and found that “they will retain 80% of their initial capacity after 3000 cycles of fully charging and discharging” (Davis and Figliozzi, 2013). It is acknowledged that this study was conducted by Smith itself and may have some bias; however, independent studies have confirmed similar findings for Smith and related vehicles.

### **Smith Newton**

- Payload: 5.5-7.5 tonnes
- Gross vehicle weight: 7.5, 10 or 12 tonnes
- Average operating range: 65-190 km
- Recharging time: 8 hour average
- Electric motor power: 134 kW (peak)
- Total battery capacity: modular, 40-120 kWh



Renault was the first OEM to develop and offer a full electric truck (den Boer et al, 2013). Renault has two widely used trucks in this category, the Midlum 16 t vehicle and the smaller Maxity. The all-electric Midlum was first offered to the market in 2012 (Renault Trucks Press Release, 2011). The Midlum is very similar to the Smith Newton in terms of size, range, charging time and markets served. The Maxity truck was released about a year earlier, weights between 3.5 and 4.5t, and achieves a range of approximately 100km (Renault Trucks Press Release, 2010). The Maxity has been used extensively in urban delivery and refuse applications within FREVUE and other pilot projects.

### **Renault Midlum**

- Payload: 5.5 tonnes
- Gross vehicle weight: 16 tonnes
- Average operating range: 100km
- Recharging time: standard 8 hours
- Electric motor power: 103 kW
- Total battery capacity: 150 kWh



In order to display alternative electrification strategies for expanding the CEV market, two innovative companies are presented. The first is the 'Nikola One' long-haul electric semi-truck. Nikola has built a range-extended battery vehicle, in essence, it is fuelled with compressed natural gas (CNG), which turns an on-board turbine that generates electricity for a 320 kWh battery pack (Nikola Motor, 2016). The idea behind this strategy is that long-haul trucking requires much higher range and payload requirements than current lithium ion battery technology is able to offer. By using a range-extended strategy, Nikola is able to swap emission-heavy diesel for cleaner CNG with an increase in available range while also benefiting from the various torque, power and maintenance benefits of an electric drivetrain.

In recent news, Tesla Motors, the other EV manufacturer that draws from Nikola Tesla's namesake, recently announced in their public 'Master Plan, Part Deux' that the company plans to offer a fully electric heavy-duty truck sometime in the future (Musk, 2016). CEO Elon Musk wants to expand their portfolio beyond consumer vehicles in order to address emissions in more

sectors. CEO of Nikola, Trevor Milton, rebutted a fully electric battery long-haul truck, as it would be “impossible to run [...] without some sort of generator on board,” and that “battery development would have to advance tenfold to go pure electric with no generator” (Dreibus, 2016). Milton hypothesized that if Tesla utilized a one-megawatt battery, 11 times the size of its Model S sports sedan, it would only be sufficient to power a semi-truck for four to five hours. Milton went on to say that he thinks it is more likely that Tesla will develop an urban short-haul vehicle (Dreibus, 2016). This primarily has to do with the battery’s energy density limitation, which makes CEVs more suitable for city distribution than long haul applications (den Boer et al, 2013).

Wrightspeed Powertrains also offers a range-extended strategy, in the form of vehicle retrofits. The main components are an electric powertrain, a lithium ion battery system, and a turbine that runs off natural gas or diesel. Their primary customer segments thus far have been delivery vehicles, refuse trucks and city buses (Wrightspeed, 2016). Ian Wright, CEO and founder cites several attractive business motives for companies to make the switch, describing how modern garbage trucks can cost a city \$500,000, whereas a retrofit would likely be under \$200,000, which would be paid back in fuel and maintenance over 4 years (della Cava, 2015).

### 3.1.3 Market Considerations

At the time of Pelletier et al. 2014 analysis, purchase costs for medium duty CEVs ranged from \$130,000 to \$185,000 USD, while equivalent ICE trucks range from \$55,000 to \$70,000 (Davis and Figliozzi, 2013, New York State Energy Research and Development Authority, 2014). However, despite the high price tag of CEVs, fleet operators consider the full life of the vehicle, therefore focusing more on the total cost of ownership rather than the purchase cost (Pelletier et al, 2014). The total cost of ownership discussion of CEVs, specifically how charging infrastructure contributes to this figure is detailed in the following section. CEVs also retain many positive benefits not necessarily tied to TCO such as, improved corporate image, driver satisfaction, driving comfort, and the ability to take advantage of low emission zones and longer delivery time windows (TU Delft et al, 2013, Pelletier et al, 2014). According to CALSTART’s industry survey, incremental cost is the number one largest barrier to CEV purchase and production (CALSTART, 2012). However as represented by the graph below, BEVs face the most rapid decline in incremental cost in the near future, while ICEs will see a steady incline as fuel prices rise over time.

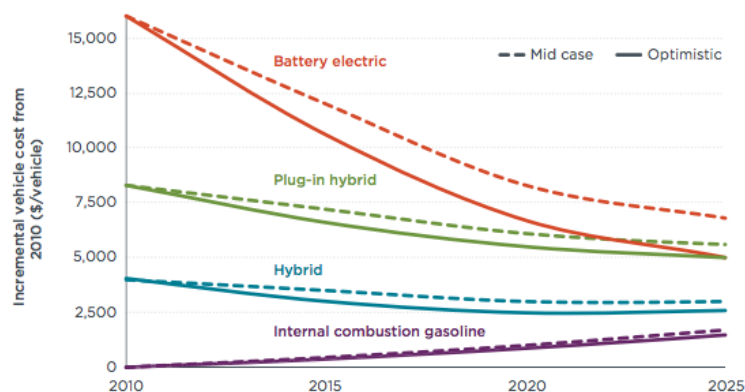


Figure 3-1. Incremental technology cost by vehicle type  
Source: Wolfram and Lutsey (2016)

With vastly improved battery technology and increased consumer trust, EVs have now made a recent comeback in the market from their initial decline in the 20<sup>th</sup> century. However, the market remains small and as of 2013, there were approximately 1,000 battery electric distribution trucks in operation globally (den Boer et al, 2013). CALSTART reports that there were less than 500

battery trucks in North America in 2012, primarily concentrated in US States that offered incentives such as California and New York (Pelletier et al, 2014). There are some inherent challenges that have made the mass-market adoption of CEVs difficult. Primarily, the battery has some significant effects on the vehicle and its usage that differs from truck users' normal operating practice. Due to the increased weight from the large battery, there are payload restrictions, and the necessity for charging reduces autonomy, when compared to internal combustion engine vehicles (Pelletier et al., 2014). The current state of battery technology also means that there is a limited achievable range when compared to its ICE counterparts.

However, CEVs retain many benefits as well, such as the absence of tank-to-wheel emissions, reduced operating noise, high levels of torque at low speeds, and a high-energy efficiency level – generally three times more efficient than ICEs (Pollet et al., 2012, MacLean and Lave, 2003, de Santiago et al., 2012). CEVs have a simple powertrain and electric motor design, with a significantly reduced number of moving parts compared to ICE trucks, while also not requiring standard oil changes (Feng and Figliozzi, 2013). The regenerative braking concept, discussed later in detail, reduces break wear and tear. This simplicity of design, reduction of moving parts and inherently different functionality reduces the vehicles' maintenance costs, greatly contributing to the business case of CEVs (Lee et al. 2013). Furthermore, these technological aspects spill over to operational and use advantages as well, the absence of an ICE allows for a more acute turning range, steering circle and improved visibility, all of which enable manoeuvrability in dense urban areas (Quak et al, 2016).

### 3.1.4 Total Cost of Ownership

Davis and Figliozzi (2013) conducted a study of the U.S. market on cost competitiveness of CEVs with diesel trucks. It compared two CEV trucks (Navistar E-Star and Smith Newton) with the most common and comparable ICE in this category (Isuzu N-series). Their results show that a high utilization of the vehicles is pivotal for EVs to remain cost-competitive, and that prices will likely need to drop 15-30% in order to make it more attractive to buyers. In order to overcome this barrier, the previously described operational benefits of CEVs must be able to exceed the high purchase cost, see their representation of cost allocation between the ICE Isuzu and the electric Smith Newton below. The high purchase cost of the Smith Newton is primarily due to the battery, which can often constitute 50% of the vehicle's cost (Pelletier et al, 2014).

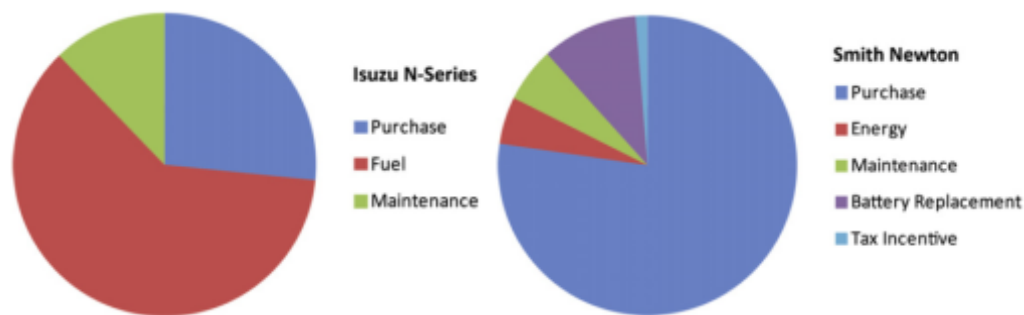


Figure 3-2. Costs by category for common medium duty trucks, comparing diesel (Isuzu) with electric (Smith)  
Source: Davis and Figliozzi (2013)

Davis and Figliozzi's objective was to design a model for fleet replacement (how to switch from conventional to electric vehicles). In order for this transition to happen they state, "if fleet size does not change, then EV purchase prices, fuel price, projections about battery costs and lifetimes, and vehicle utilization are the key factors that determine the competitiveness of electric



trucks.” Below is a list of key concepts that Davis and Figliozzi concluded must be present in order for electric trucks to be a viable alternative to conventional diesel operations:

1. Daily distances travelled are high, approaching the electric trucks maximum range of ~150km (but the battery energy constraint is not binding).
2. Low speeds or congestion and traffic jams are prevalent in the area of the route.
3. Customer stops are frequent and numerous, and a conventional truck would typically idle during these stops.
4. Since the electric engine is more energy efficient, the existence of grades or other geographical factors that increase expenditures of energy help to amplify fuel cost savings (but where the battery energy constraint is not binding).
5. Purchase price reduction by tax incentives or technological breakthroughs.
6. A planning horizon extension beyond ten years.

Total cost of ownership (TCO) is a financial estimate that is intended to help buyers determine the direct and indirect costs of a product, service or system. When analysing TCO for commercial electric vehicles, and comparing it to conventional diesel vehicles, there are of course several aspects to consider. Direct costs are fairly apparent, such as the purchase price of the vehicle and the supporting charging infrastructure. Indirect costs are less obvious, fuel costs – either diesel or electricity prices, depreciation rate, CO<sub>2</sub> emissions cost or even the rate of vehicle utilization. As is the case with both diesel and electric trucks, the greater number of hours per day the vehicle is operated, the more profitable it is and can positively contribute to TCO (Pelletier et al, 2014, Feng et al, 2013). However as aforementioned diesel trucks have much higher maintenance cost due to engine complexity and the high number of moving parts. Increased utilization of diesel trucks may contribute to acceleration of these effects. Also, as displayed by Figure 3-2. fuel is the largest contributor to a diesel truck’s TCO, so increased utilization will continue to inflate this figure. In contrast, CEVs benefit greatly from higher levels of utilization as they are advantageous in their method of fuel consumption while also not suffering from the same maintenance costs. The more often a CEV can be operated, the more it begins to eclipse the initial low cost advantages of diesel trucks (Löfstrand et al, 2015, Feng et al, 2013, Davis et al, 2013).

Comparisons of TCO between conventional diesel vehicles and CEVs can vary due to a number of factors, primarily the time-horizon that is considered. Typically, the farther into the future the casting scenario is, CEVs become more attractive in terms of their payback and profitability (Davis et al, 2013). Currently, high battery cost and limited production volume of CEVs are the main constraints on TCO profitability (Quak et al, 2016). It is for this reason that longer costing horizons allow for CEVs to pay back on their high initial capital cost due to their decreased maintenance and operating cost, as well as drastically decreased fuel costs (Quak et al, 2015, Davis et al 2013). Since CEV profitability is largely driven by their ability to offset fuel costs, the higher their utilization the better their TCO becomes over diesel vehicles (Prohaska et al, 2016). This effect is amplified when reduced electricity cost and increased diesel prices are added to the equation (Feng et al, 2013). Additionally, the longer time-horizon allows for economies of scale and manufacturer learning to enter the calculation, which will reduce purchase prices over time (Quak et al, 2016). However, a limiting factor is that the residual value and second-hand market of CEVs (particularly around the spent battery packs) is largely unknown and difficult to calculate until more vehicles reach their end-of-life and further studies are conducted (Quak et al, 2016, Pelletier et al, 2014)

Charging infrastructure has typically been excluded from TCO analyses for CEVs due to its complexity. This complexity results from the fact that many factors in the cost model for



charging infrastructure are dependent on a case-by-case basis. The associated costs of charging infrastructure are highly dependent on geographical and regulatory context, and can even range extremely from one site to another within the same region depending on electric grid resources or land-use policy. For example, CALSTART's industry report refers to a number of variables that need to be considered, such as power requirements, installation, operational cost, siting considerations, retrofit (e.g. landscaping), availability of government subsidies, metering requirements, and permitting (CALSTART, 2012).

CALSTART went further to develop a fleet calculator for evaluating the total cost of ownership for CEVs in order to determine an estimated break-even point for fleet operators in making their decision whether to pursue electrification, see Appendix Item 2. This calculator includes data entry for the current diesel vehicles used, the electric vehicle that will be used to replace it, financial parameters, and battery cost. Parameters specific to EVSE include costs attributable to smart meters, EVSE, panel upgrades, conduit and trenching. This is a highly simplified tool for a complex cost calculation, but is a useful starting point for fleets looking to adapt CEVs.

### **3.1.5 Barriers and Challenges**

It is important to highlight the general barriers and challenges the vehicles themselves face, in order to frame solutions from the charging infrastructure perspective.

The first has to do with the energy density of the battery packs required to power CEVs. Lithium ion batteries are currently the best available technology for vehicle applications, however the energy density of diesel is still approximately 40% greater than lithium ion (assuming values of 100 Wh/kg for the battery and 140Wh/l for diesel) (Den Boer et al, 2013). This represents a trade-off in terms of available power versus weight and payload. A larger the battery allows for greater range, but reduces the amount of payload capacity due to its weight. However due to the simplicity of the electric motor system (such as the absence of a gearbox and a smaller engine), allows this to be partially mitigated when switching from conventional engines (Den Boer et al, 2013). CEV users have observed other technical issues: limited or late support for failed batteries, equipment or spare part availability, and long charging times (Quak et al, 2016).

A challenge for drivers and route planners is the general lack of, or imprecise, range estimations (Den Boer et al, 2013). Temperature, terrain, traffic and many other factors make remaining distance available to the battery difficult to calculate, however this is pivotal for operators to plan routes and deliveries, as well as providing real-time knowledge to drivers in case of daily changes and unexpected delays in order to increase operational flexibility.

Aforementioned was the issue surrounding incremental cost; however, CALSTART identified three other key findings – quality and support, performance validation and infrastructure needs. Regarding quality and support for CEVs, areas such as maintenance support, availability of experts and warranty remain an issue (CALSTART 2012). CEVs are still a relatively new product and are limited in their usage, so there are few garages that have the technical expertise in order to conduct repairs (Quak et al, 2016). There have been some limited analyses around CEV performance, however most conducted work has been case studies or showcases on pilot projects. There is not yet an extensive or wide database of information on CEV operations, use-profiles and payback. Lastly are the infrastructure needs of fleets, which is the focus of this study. Planning, optimization, cost considerations, best practices, installation etc. all remain somewhat unclear to fleet operators looking to switch to electric operations (CALSTART, 2012). As explained in the Methodology, this study is attempting to match known best use-profiles with charging infrastructure strategy.

## 3.2 Charging Infrastructure Technology

### 3.2.1 Overview

CALSTART's E-truck Task Force has provided the industry an extensive overview of challenges and barriers for the production and adoption of electric trucks. Concerning charging infrastructure, the industry survey indicated three primary purchase barriers for CEVs; (1) lack of infrastructure, (2) cost and (3) speed of charging (CALSTART, 2012). This section will look to cover the current state of technology and most common charging methods in order to provide insight as to why these barriers, among others, exist for fleet operators. The objective is *not* to deliver a highly technical analysis or deep dive into the intricacies of the technology, but rather to understand their usage at a systems level and current market standing in order to assist business planning and the design of a service offering around CEVs.

Before moving into charging infrastructure, it is important to first understand the technology around what is charging, in this case, a lithium ion battery. Lithium ion batteries are advantageous in BEV applications over other chemistries for a number of reasons— having a high energy density (100Wh/kg), high power density (300 W/kg), long battery life and low memory effect (Lukic et al, 2008). This is relevant to CEV charging infrastructure for several reasons:

- (1) a high energy density equates to less battery weight required to move the vehicle, allowing for greater payload
- (2) high power density allows for faster charging times
- (3) a low memory effect means that the charging cycles and depth of charge has less influence on battery performance when compared to lead acid or nickel batteries (Pelletier et al, 2014, Lukic et al, 2008)

This report section is unique in that much of the technology described and many of the lessons learned draw from the consumer EV market. At the start, this study stated that the focus will be on commercial electric vehicles, not the private cars. However, since EVs in the consumer sector are more highly developed, propelling most of the technical knowledge that is 'state of the art'. The author will attempt to extrapolate what is relevant and applicable to the commercial sector. For example, consumer EVs are determining which plug connectors become common practice, and grid integration and installation best practices can still be applied to CEV fleets. The discussion of electric busses is due to industry crossover. Challenges, barriers, best practices and opportunities of charging infrastructure are discussed throughout section 3.2.

Another distinction discussed in section 1.4 Limitations and Scope, was that the focus will be on charging stations. Charging stations are currently the best available technology – there wide ranges of knowledge resources in this area, as well as being the most relevant for designing a solution and business model *today* for CEV fleets. Included at the end is a small innovative technology showcase in order to highlight where ground breaking changes may head in the near to mid-future, so that vehicle manufacturers can consider these technologies for longer planning horizons. This small showcase is not currently available and is excluded from the analytical study.

### 3.2.2 Charging Methods

Since the advent of the first modern EVs in the 1990s, conductive charging has been the overwhelming strategy for battery vehicles (Botsford, 2009). As the market has matured, so has the terminology and range of charging methods. The first task is to distinguish between 'slow charging' and 'fast charging' and how these terms relate to AC and DC, on-board and off-board distinctions, as well as the Level 1, 2 and 3 categorizations for EVSE. AC and DC are the two

forms of electrical current (Alternating and Direct current). An EV's battery requires DC in order to be charged, whereas electricity from the grid is in AC form. In order for this AC electricity to be fed into the vehicle, it first must be converted to DC. Slow charging is the colloquial term to describe what is typically Level 1 and 2 EVSE charging, where the vehicle has an on-board charger that takes care of the conversion of AC to DC. In contrast, Level 3 EVSE is considered fast charging, because the charge point has an off-board convertor where DC power is fed into the battery at a highly increased rate of charge. An exception to this slow/fast v. AC/DC dynamic is the addition of another standard under development for a higher rate of AC charging that uses three-phase power, most likely for use at commercial and industrial locations (Alternative Fuels Data Center, 2016). Single and three phase power refers to the wave cycles in AC. Single phase power is most common in home applications in North America, whereas three-phase power is used in business and commercial settings, as well as the predominant form in Europe. Three-phase is much for efficient due to the cycle overlap in the alternating current so the power supplied remains consistent, as well as benefit from smaller, less expensive wiring with a lower voltage, making it safer and less expensive to run. See the table below for a representation of this dynamic with additional information on typical characteristics, for more information on plug connectors see the following section.

*Table 3-1. Comparison of Level 1, 2 and 3 EVSE*

	<b>Level 1</b>	<b>Level 2</b>	<b>Level 3</b>
Phase	Single Phase AC	Single Phase AC Three Phase AC	DC
Amperage	10 to 16 A	16, 32 or 63 A	63 to 125 A (typical) Up to 400 A
Voltage	120 V (N. America) 240 V (Europe)	230 to 400 V	400 V and higher
Power Output	1.4 to 1.9 kW	3.7 to 22 kW	44 kW and higher
Plug Types	Household Plug SAE J1772	SAE J1772 IEC 62196	CCS Combo 1 & 2 CHAdeMO Tesla
Typical Application	Home charging	Home charging Public charging station	Fast charging

These differentiations are important when applied to CEVs, especially when designing a charging strategy for the fleet, as the rate of charge is pivotal when planning routes and warehouse logistics. It is also extremely important to make these considerations far upstream in the value chain with vehicle manufacturers, as the charging patterns and eventual usage profile of the vehicle is essential when designing the battery and optimizing it for size and capacity (CALSTART, 2012). For example, pursuing either an 'opportunity' or 'overnight' charging strategy can have a significant effect on the battery's longevity. Opportunity charging is loosely defined as charging at stations away from the home or depot, or 'on the road,' which could

include either fast or slow chargers. Overnight charging at the home or depot, typically slow charging, occurs when the parked vehicle is at a single location during off-hours and has the time to utilize this method. Understanding the typical daily usage of the vehicle is important since, “battery health can be influenced by the way they are charged and discharged, where frequent overcharging or frequent discharging to very deep levels can affect battery lifespan, just as keeping the battery at high states of charge for length periods” (Pelletier et al, 2014).

### 3.2.3 Geographical Context, Plug Types and Standardisation

It is important to begin the discussion on charging infrastructure by framing it within the geographic contextual differences. The three strongest driving markets for EVs are North America, Europe and Japan/China. To date, the United States has favoured Level 1 and 2 “slow charging”, Europe has a fairly even mix of Level 1, 2 and 3 slow and fast charging, and Japan has primarily focused on CHAdeMO fast charging (IEA, 2016).

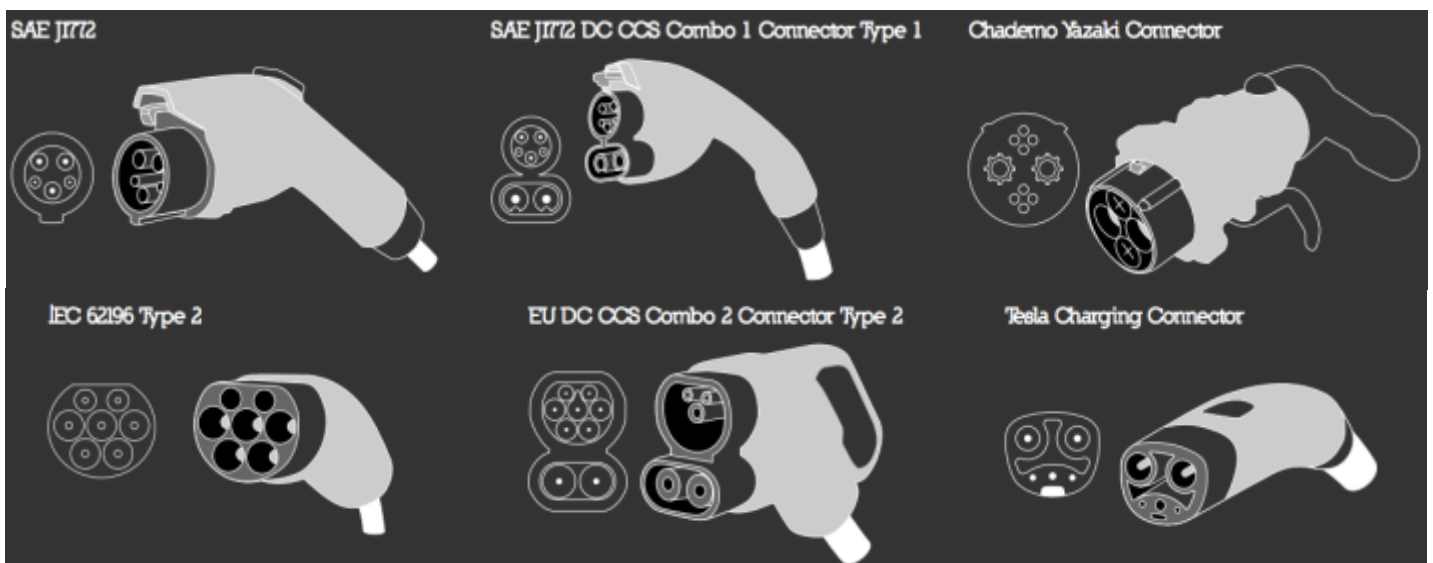


Figure 3-3. Common EV charging connectors  
Source: EV Institute (2014)

The above figure is a representation of the most common plug types globally. These plugs are very important technology tools between the vehicle and grid, in order to standardise communication, allowable current/voltage levels, and safety & control protocols (Tuite, 2012). Standardisation of these plug types draws from the three major EV regions previously mentioned, North America, Europe and Japan/China. The standards are driven primarily by electricity companies, distribution system operators (DSOs) and national electricity associations, as, “they gain early experience with business models and are better able to assess the impact on the electricity grid” (Eurelectric, 2016).

The Society of Automotive Engineers (SAE) drive North American standard. The SAE J1772 is the standard plug used in Level 1 and 2 EVSE applications, commonly known as the Yazaki plug after the commissioned manufacturer. Due to similarities in grid architecture, Japan has also adopted the Yazaki plug. In Europe, the International Electrotechnical Commission (IEC), released a set of criteria for standard EV plug design, addressing aspects such as AC voltage and current, single and three-phase compatibility, communication protocol, price, tampering, weather and durability (Bakker, 2013). The IEC 62196 standard, often colloquially referred to as the “Mennekes” plug, was released in 2011 as a result of the IEC’s efforts. The primary difference between the Yazaki and Mennekes plug has to do with the difference in power level

delivered between the American and European electricity grids, as Europe has more ubiquitous three-phase power allowing for faster recharging than its single-phase American counterpart.

Each of these two standards also have a Combined Charging System (CCS) plug, which include a double port underneath the normal plug for DC fast charging, these plugs are usually referred to as CCS Combo 1 and CCS Combo 2. The third DC fast charging is the CHAdeMO connector, developed by the Japanese car industry (Mitsubishi, Nissan, Subaru and Toyota). The CHAdeMO plug is most popular in Japan but has a presence in both North America and Europe as well, however American and European car manufacturers themselves refuse to adopt the standard, electing rather for CCS Combo 1 or 2. The main drawback to the CHAdeMO charger is that it prescribes a separate vehicle inlet that can only be used for DC charging, and that another inlet must be provided for AC charging (Bakker, 2013). The figure also depicts the unique Tesla connector for both AC and DC charging, but it is eliminated since it is unused by any commercial applications. There is some uncertainty whether CCS Combo 1 and 2 or CHAdeMO will become the dominant standard (Kane, 2016). To date, CHAdeMO has been the largest player due to support by Nissan who sells the world's best-selling EV, the Nissan Leaf (Kane, 2016). However, many of the experts interviewed for this study, in both the power and trucking sectors, agree that the CCS Combo 2 will likely dominate in Europe for commercial truck applications due to its flexibility for slow and fast charging. Standardisation is beneficial for equipment manufacturers, charge network operators and vehicle users alike, and can bring positive scaling effects and remove uncertainties. Regardless of the plug type, charging automation will be a potentially crucial aspect for commercial vehicles in order to reduce manual labour and simplify the process for the driver (Alakula, phone interview, 15 August 2016).

The three-phase fast-charging AC standard mentioned in the previous section is the SAE J3068 standard. The U.S. Department of Energy states that, "some components of the standard will be adapted from the European three-phase charging standards and specified for North American AC grid voltages and requirements. In the U.S., the common three-phase voltages are typically 208/120 V, 480/277 V. The standard will target power levels between 6kW and 130kW" (Alternative Fuels Data Center, 2016).

Beyond the issue of standardisation of plug types is a more intricate issue. There is a definite need for CEV software standardisation and connectivity to the electricity grid (Quak et al, 2016). This internal communication is essential for how the battery, EVSE and electricity grid interact with one another in order to optimize charging, ensure system safety, and allow for ubiquitous use across geographies. This also applies to the vehicle identification and billing system. In order for vehicles to travel across borders, interoperability between networks is necessary so that communication between the vehicle and the back office is possible in order to secure payment and allow for charging to take place (Bakker, 2013). Two potential approaches are to utilise either RFID cards or QR codes to identify the vehicle and communicate with the network platform.

### **3.2.4 Installation**

A large barrier to CEV adoption are the hidden costs and surprises that comes with installing the charging infrastructure equipment. Level 1 EVSE is likely irrelevant for any CEV application, as trucks would require much larger batteries than private vehicles and do not have the leisure of 8 – 12 hour charge windows due to logistical constraints, of which Level 1 charge rates would not be able to fulfil. Level 2 EVSE is much more suitable for the power needs of the larger CEV. A Level 2 EVSE unit can cost as low as \$1,800, but this figure can quickly increase depending on the installation (Pelletier et al, 2014). The average cost of installation is around \$3,300, with a range between \$1,500 and \$8,000, but can be as high as \$10,000 if conduit installation is required (CALSTART, 2012).

Fast charging stations utilize higher power levels, which result in lower charging times, but higher equipment costs. DC fast charging EVSE can cost between \$20,000 and \$50,000 USD for the charging units alone, this does not include installation or any potentially needed grid upgrades (US DOE, 2012). This balance between convenience and price must be considered. In relation to vehicle design for CEVs, it is important to note that, “using a higher power level to charge electric vehicles requires larger chargers, thus constraining on-board chargers to lower power levels because of weight, space and cost (Hagbin et al, 2010).

### 3.2.5 Grid Integration

The deployment of charging infrastructure for CEVs has an innate relationship with the electrical grid and must be planned for accordingly. Different charging technologies and methodologies have different impacts on the grid, primarily related to the rate of charge, which needs consideration when balancing the power demand on the grid and operational savings (Gallo, 2015). As fleet owners are typically not electrical engineers or grid experts, switching to an electric fleet can present unexpected, unforeseeable costs. For example, high power (voltage) requirements may raise the cost of service (Gallo, 2015). Beyond the cost of the EVSE, one must also anticipate the cost of running conduit, any trenching that may come along with the new wiring, and in the case of larger fleets – transformer and grid service upgrades.

A CEV has a much larger battery than consumer vehicles, therefore drawing a greater power demand from the grid, which can be in the magnitude of 10 times larger than typical EVs (Gallo, 2015). A medium-duty truck with a 200 kWh battery would likely achieve a peak demand of 70 kW in comparison to 7 kW for a Nissan Leaf. In the United States, utilities use demand charges during peak hours in order to recover capital costs for these large power demands causing high grid load. These demand charges can be very costly and prohibitive for CEV fleet owners, in some case new rate structures may be needed in order to improve the business case (Gallo, 2015).

More importantly, is the need to often upgrade the electrical service with the utility in order to accommodate the vehicle load on the grid. The London demonstration of the FREVUE project has shown that, “in some cases the existing power grid is not sufficient to actually charge the fleet during off hours at the depot,” in this case 16 UPS vehicles looking to be charged simultaneously overnight (Quak et al, 2016). In the U.S., a large fleet owner within CALSTART had to upgrade to a 2500 A service for 50 trucks, requiring a new 480 V service line that must be stepped back down again to 220 V for the chargers. This high current level service can significantly increase capital costs of the project. Another CALSTART member stated that the required infrastructure upgrades for a 300 vehicle fleet would likely cost more than \$1 million (CALSTART, 2012). As part of their attempt to reduce these uncertainties, CALSTART’s “E-truck Business Case Calculator” helps determine total cost of ownership and break-even points for fleets looking to switch to electric.

There are other pivotal issues with these grid upgrades; beyond being expensive for commercial vehicle fleets, they are usually non-scalable. (Quak et al, 2016). A best practice worth highlighting is to anticipate future growth of the electric fleet. In order to mitigate the high price tags of expenses like conduit extension and trenching, a fleet owner can “oversize” and prepare their facility’s wiring and infrastructure for a large electric fleet, so that the former is only a one-time expense (Quak et al, 2016). Consider the scenario below from the FREVUE project regarding infrastructure ownership;

“The upgrades (owned by the power-network company) have to be paid by the end user regardless of who is the owner. This is contradictory, because it requires a logistics service provider to make an investment in a network it does not own. Next,

the process of obtaining landlord permission for the necessary infrastructure upgrade works has proved to be more complicated than anticipated. That is largely because there are multiple levels of ownership involved. Most other cases show that some investments are necessary for charging infrastructure and sometimes in the grid (for example in Rotterdam), but these investments are limited in comparison to grid investments that we saw in the London-demonstration.” (Quak et al, 2016)

These discrepancies in the ownership model of grid upgrades can be very harmful to the fleet owner’s business case for switching to electric vehicles. However, there are opportunities for alleviation through shared ownership or special agreements in order to reduce the cost for both parties. One potential solution is to provide joint services like Vehicle-to-Grid (V2G). Conductive chargers can either be on-board or off-board the vehicle, with unidirectional or bidirectional power flow, which can allow the CEV to provide energy storage or discharge its battery onto the grid (Yilmaz and Krein, 2013). When EV batteries are idle, they have the potential to act as grid storage devices. This would reduce cost for the fleet owner, reduce GHG emissions, provide grid stability to the utility, while also spreading energy demand to off-peak (Zhao et al, 2016). Additionally, Vehicle-to-Grid regulation services for CEVs have the potential to yield additional revenues to fleet owners offsetting operational costs, somewhere in the magnitude of \$20,000-50,000 (Zhao et al, 2016). However, this application is still some years off as fleets will not adopt a technological solution that hinders their ability to operate (Gallo, 2015). In order for CEVs to be able to truly provide for the grid as a valuable energy storage resource, key players and solutions are needed to aggregate loads, automate charging and adopt consistent standards and communication protocols (Gallo, 2015). Also note that V2G services may accelerate the degradation of the batteries since their utilization windows are increased (Zhao et al, 2016). However, some studies have shown that degradation effects on the batteries are minimal. There is also great potential in the 2<sup>nd</sup> life of spent batteries to next be used as grid storage devices or as grid intermediaries with fast charging stations.

Despite these challenges grid integration challenges, utility load planning for CEV fleets will still be easier than for consumer EVs, as they will be concentrated in fewer areas. Utility load planning for consumer EVs is complex due to the sporadic nature of their deployment (Gallo 2015). However, at potential deployment sites for CEV fleets, the utility has greater clarity into the local distribution grid’s infrastructural needs from the close working relationship with the fleet operator. Exploiting this coordination effectively can provide opportunities for both parties to benefit.

### **3.2.6 Charging Strategies and Battery Health**

There are several basic strategies or approaches when it comes to charging. The first way to frame charging strategies would be when and where the charging occurs, which is typically classified as overnight charging and opportunity charging (Pelletier et al, 2014). Overnight charging for CEVs would occur at the depot during night hours when the vehicles are not in operation using Level 2 EVSE. In contrast, opportunity charging occurs during operational hours in route, perhaps during a lunch break or between shifts. As publicly available charging infrastructure for commercial vehicles are largely absent, it would be more typical to see an overnight strategy employed (CALSTART, 2012). As the CEV market expands and there are more vehicles within a given city, charging points outside the depot may see increased demand and opportunity charging will be employed more often.

An alternative strategy is also receiving traction by some experts, in which a vehicle uses smaller batteries combined with fast charging (den Boer et al, 2013). This works well with urban applications that may not have a very high daily range that needs to be achieved, while also reducing the weight contributions of the battery increasing payload. This also has the potential

to be advantageous to battery health, as shallower levels of discharge have the potential to lead to longer lifespans (Pelletier, et al, 2014). A disadvantage to this approach would be that the smaller batteries would reduce the achievable range of the CEV, as well as increase the cost of the EVSE investment. The Swedish Electric and Hybrid Vehicle Centre is investigating in coordination with Volvo Group the effects of charging speeds on various battery chemistries. This study is still in progress, however an interview with one of the principle researchers pointed to some preliminary results. Small changes in lithium-ion battery design and chemistry can be matched with the charging technique in order to extend the battery's lifetime (Groot, phone interview, 17 August 2016). Groot is in favour of a small-battery/fast-charging strategy over large-battery/slow-charging. However, he also pointed that batteries could be designed to have mixed cell chemistries, of which part of the battery could be optimized for slow charging and the remainder for fast charging, allowing for a mixed charging strategy to be utilized. NREL is also conducting tests with Frito Lay to perform, "battery life degradation analysis to quantify battery pack health, track battery performance over time, and determine how various drive cycles and battery charging protocols impact battery life" (NREL, 2014a). The objective is to understand the battery pack's degradation and be able to forecast its lifespan and the associated operational costs.

Hexeberg, 2014 presents three charging scenarios, dumb charging scenario, profit maximization scenario and the power factor control scenario. The first is the most straight-forward, in which the vehicle operator manually manages vehicle interaction with the EVSE. In this instance the operator or driver simply plugs in the vehicle at the end of the route journey and there is no control equipment or software to manage the charging. The other two scenarios could be classified as "smart charging."

Smart charging can ameliorate the load impacts of charging stations on the grid. Smart charging can be defined as, "a controlled charging process the optimises the use of the grid and the available electrical energy to minimise additional investment in the grid" (Eurelectric, 2016). Charging of vehicles can be coordinated through the use of smart and dynamic ICT systems to prevent peak loads by only drawing power from the grid at certain times. The profit maximization scenario looks to manage charging based on electricity pricing. Some utilities may have rate structures that charge higher electricity prices depending on the time of day that charging occurs (Gallo, 2015). Profit maximization looks to balance the energy demand of the vehicles, with the dynamic pricing of the utility, while still completing the necessary charge in time for the vehicle's schedule. The power factor control scenario is similar, but is based on voltage levels, rather than electricity prices. As discussed in the previous section, higher power levels demanded from the grid typically result in a higher cost of service. This scenario aims to manage the total voltage level required by the vehicles so not to exceed this threshold by reducing the power factor and avoid fees from the utility.

Smart charging can create a variety of benefits for both the electricity user and the energy utility. Some of these benefits include (Hexeberg, 2014):

- Avoidance of distribution grid congestion
- Helps to facilitate the integration of renewable energy
- Avoidance of peak demand effects and premium prices
- Mitigates fluctuations in voltage levels in the grid
- Could act as an energy reserve in case of drops in power production



### **3.2.7 Charging Management Platforms**

Smart charging services are enabled by software control processes that are able to regulate the flow of power between the vehicle and the grid. There is a wide offering of smart charging management platforms currently on the marketplace that deliver a mixture of the services and benefits described above. This report did not have the time to conduct an extensive review of possible information communication technology (ICT) solutions, most or all of which are for the consumer EV market. Instead, interviews with two CEOs and project managers of three software solutions were used to yield insight. These three platforms were selected for their potential applicability to CEVs, and because they feature certain characteristics that would make them particularly interesting when designing a service model for charging infrastructure.

As a starting point, it was important to understand the technology of the ‘basic’ charge point platform, meaning that it has mapping, billing, and routing features. Meshcrafts is one of the most advanced platforms of this category in Europe (its counterpart being Charge Point in the U.S.). Meshcrafts is optimized for both EVSE owners and users, and acts as a trading platform for energy, providing an open marketplace for EV charging (Frengstad, phone interview, June 28, 2016). Their primary client is the owner of the charging stations, who pay a monthly fee to be a part of their network, whereas a mobile app is provided to drivers.

ViriCiti is a platform specifically geared towards larger vehicles like electric buses and trucks. The primary objective is to reduce the range anxiety issues for fleet operators and drivers, while looking to optimize based on energy usage. A discussion with their CEO and lead project developer revealed that typically EV fleet operators always plan for the ‘worst case scenario’, when planning daily routes and achievable range. However, ViriCiti is able to collect data over time about characteristics of the route and the profile of the driver, in order to plan more realistic battery usage scenarios. This increased granularity of data is able to give greater clarity to the battery’s status of charge and increase vehicle utilization and range by up to 25% according to the company. The system is able to calculate and modify this estimation in real time and provide messages to operators and drivers in case of any major changes. Given the nature of the platform, it is most applicable to fixed route applications, their primary customer thus far being electric buses. However, their platform has worked extremely well with similar cases such as refuse trucks. When asked about applicability to city distribution, ViriCiti CEO referred to the variability in routing being a key challenge. This is a customer segment for future expansion as they improve their platform.

Lastly is a proof of concept trial project in Gothenburg, Sweden named **Electric Vehicle Intelligent Infrastructure (ELVIIS)**. ELVIIS was a partnership between Volvo Cars, Göteborg Energi, Ericsson, and the Viktoria Institute aimed at providing a, “user-friendly solution responsive to changing electricity prices, and cost-efficient to implement” (ELVIIS, 2016). The guiding principles of the project were, the ability to charge at any outlet, an easy pay system, the driver is control, charging is optimized for the utility/grid (Fagerholt, phone interview, 30 June 2016). The solution utilizes a mobile telecommunication network that coordinates car charging – based on best time, lowest cost and current grid demand. The other major outcome was to create an innovative billing solution like the one described in Section 3.2.3 when discussing internal vehicle communication. The general objective was to display proof of concept that charging points can be geo-located with individual identification ability, which allows the user to charge anywhere and receive a bill for the charging, rather than putting the burden on the provider of the outlet. At this early stage in the project, a QR code was necessary to improve identification accuracy, but there is potential in the future that GPS tracking would be a sufficient method while also being easier for the user. This concept has interesting potential for CEV applications. For example, a distribution truck driver might not have many instances to take advantage of opportunity charging whilst in route, but could use this system during their

lunch break. Even if the restaurant does not have a Level 2 EVSE station, the driver could still utilize Level 1 charging if given outlet access and be able to be charged for the usage of that electricity. Partnerships between fleet operators and local eateries could make this attractive for both parties.

### 3.2.8 Fleet Integration

A challenge for fleets is “the necessity to adapt charging infrastructure for fleet needs” (Quak et al, 2016). Often logistical or operational schedules and practices need retooling in order to fit the needs of individual fleets to match the capabilities of the EVs being integrated.

Even depot charging can present some challenges depending on the vehicles’ operational schedule. For example, the case of UPS in Rotterdam from FREVUE, where the vehicles are running from 8.00 till 18.00, away from the depot. In conventional operations they would then be washed and fuelled from 18.00 till 22.00, then remain idle until 2.00 when sent off for inbound logistic operations. For CEVs, this 4 hours of down time is too short for the vehicle to recharge fully, meaning that the operational schedule must be adjusted in order for the fleet to adopt CEVs (Quak et al, 2016). This analysis went on to describe how, “charging, load capacity, maintenance and the need to adapt logistic concepts for the usage of EFVs were seen by operators as the main existing operational challenges” (Quak et al, 2016).

In many cases, the most straightforward strategy is to provide a one-to-one EVSE to CEV strategy for depot charging. This means that each vehicle has its own charging stall and planning for all of the vehicles is somewhat simple. However, it is possible to reduce capital investments in EVSE by reducing the number of stations if it fits with the operations of that depot. For example, a pilot project in Paris that is able to use 10 charging stations for 19 trucks was studied. The full charge cycle of the Modec truck is 8 hours, however in practice it is fully charged after only 5 hours, since the full battery capacity is rarely used (Löfstrand et al, 2015). However, the management of this charging scenario is manually performed. The respondent in this case said that their efficiency could be greatly improved with an intelligent charging system to balance charging to minimum amount of charging stations.

Below is a list of general considerations and best practices when looking to integrate CEVs into fleet operations (Löfstrand et al, 2015):

- Distribution vehicles have strict delivery times – fitting the max number of deliveries into one shift
  - Adding charging stops to occur during a shift will put extra constraint on distribution schedule and lower productivity
  - Charging should be done between shifts when vehicles are parked at the terminal
- Charging should be managed at off-peak hours (lower electricity costs)
- Charging management should be part of solution package to transport operators
- Vehicles should be used for more than one shift (to maximize usage)
  - Time till full charge is critical for planning
- If transport operator and customer have good relationship/collaboration - charging at customer locations is possible, however;
  - Barrier: typical delivery contracts are very short (0-2 years) - investment risk for joint venture charging infrastructure

### **3.2.9 Route Planning and Optimization**

The classical logistics optimization scenario is the Vehicle Routing Problem (VRP), which looks to optimize route and fuel consumption based on factors such as distance, time, topography, traffic, payload, time windows, etc. CEVs present a unique challenge when it comes to route planning, given their inherent need for charging prior to operation. New research is being conducted around VRP to address range anxiety for CEVs while also optimizing based on energy consumption (Basso et al, 2016). A Chalmers University project with Vinnova is investigating how to design a system to address these challenges for CEVs. The project EL FORT is meant to be a, “system takes into account real-time traffic, such as traffic congestion, and vehicle information, such as battery condition and load information to dynamically assign tasks to the vehicle. The result is that the vehicle will receive appropriate assignments dynamic and will run along the routes are optimized in real time, which increases the efficiency of the entire fleet, and contribute positively to the traffic flow” (Vinnova, 2015). The project is still under development so no final results have been published as of yet, however it represents how more sophisticated data can enhance the business case for CEVs.

A current best practice for green logistics, particularly CEVs, is the use of consolidation centres. Consolidation centres aim to reduce vehicle congestion and logistical overcapacity by providing a venue for vehicles to exchange and share payload to optimize capacity. There are two main consolidation centre approaches; consolidation of supply (vehicle deployment in combination with urban logistics centres) and consolidation of demand (combining deliveries to one area from multiple suppliers) (Quak et al, 2016). An example of a consolidation of supply application would be refuse or recycling collection for a large office building. Rather than collecting waste from tenants separately by their own waste collection agency, the building would employ a consolidation scheme. All waste is pooled and then hauled by a single entity. The inverse of this would be consolidation of demand, where deliveries from multiple suppliers to a locale could be combined in order to reduce the number of vehicles travelling to that area and increasing the per vehicle efficiency. In the case of CEVs, consolidation centres provide an opportunity for charging, as goods are loaded and unloaded between vehicles. The FREVUE project has experimented with consolidation centres in several cities with success, even being able to cross-dock deliveries and pickups between CEVs and conventional vehicles (Quak et al, 2016). This helps with the range issue of outbound regional deliveries for electric vehicles, and ameliorates emissions from conventional vehicles for inbound deliveries when switching to CEVs before entering the urban area.

### **3.2.10 Alternative Methods**

The scenarios described above have been around charging stations, which utilize conductive charging through cables. The other alternative method is inductive charging, which involves transferring the power to the battery through the use of magnets without any need for physical cables (Yilmaz and Krein, 2013). For example, Daimler and Qualcomm are developing a stationary wireless charging system for EVs (Electric Vehicle News, 2015a).

Future technologies to look out for are electrified roads, which could potentially be either conductive or inductive charging. Siemens has been testing an overhead pantograph system for electrified roads in Germany and the U.S. This new approach which could be very advantageous in fixed route applications like drayage or mine transport, with future potential in long-haul trucking (Akerman, 2015). An alternative conductive method is being tested by Mats Alakula at Lund University, which utilizes a “slide-in” technology where the truck is connected to the infrastructure via a track in the road rather than overhead. This method is potentially advantageous to the pantograph approach as it could be utilized equally well by other vehicle types that might not be tall enough for overhead pantographs. It also will likely require less

physical infrastructure while also being more aesthetic than overhead wires. The UK government has been testing wireless inductive technology alternatives where coils are buried under the road, which could potentially allow for EVs to charge while being driven (Electric Vehicle News, 2015b)

A final alternative method to charging is battery swapping. The idea behind this strategy is to completely remove the time for charging the battery by physically removing and replacing the depleted unit with a fully pre-charged battery. Tesla Motors tested this concept in January 2015 in Southern California, but was met with minimal success (Korosec, 2015). Denmark is also undergoing battery swapping station trials across the country that currently consists of 17 stations (FDT, 2013). The company responsible for the technology and trial, Better Place, has hypothesized battery swapping for distribution trucks, but has not tested the technology for commercial applications yet. Better Place says that primary prerequisite for a CEV application would be that the battery is accessible on the undercarriage of the vehicle (FDT, 2013). Only one instance of battery swapping currently tested in the commercial industry was found, developed by Fraunhofer and operated by Meyer & Meyer. A 12-ton truck is undergoing trials in Berlin for a continuous 3-shift delivery to a clothing store chain in the city. The system comprises 8 battery modules with a 20 kWh capacity each, of which the truck can operate with a minimum of 2 modules loaded onto the truck at a time. The system is modular so that the truck can be optimized to use the number of batteries needed for a particular route with a range between 165 and 200km. The company states the system works well, but the challenge is in finding customers in need of a continuous 3 shift operation in order to make the system financially feasible (Bestfact, 2015). There are also some other clear challenges with a battery swapping methodology. To start, battery swapping increases the overall quantity of batteries needed in the system (those currently being used by the vehicle and those being charged at the station). Despite falling costs, the battery is still by far the large cost contributor to the purchase cost of CEVs, so increasing the number of batteries per vehicle will like break the value proposition. Next, the infrastructure needed to support the system is not standardised and would require high levels of custom engineering, which makes it complex and costly. Another issue would be standardisation between vehicles of battery types and sizes, in order to prevent stockpiling of various batteries at a station (Bakker, 2013). In addition, vehicle designs would have to construct specifically with the capability to swap batteries. It is unlikely that battery swapping will become a dominant charging strategy in the near future unless the infrastructure that supports it receives improvement and the unit cost of lithium ion batteries continue to drop.

### 3.3 Stakeholder Mapping

This section briefly outlines the actors within an Urban Freight Transport (UFT) system. The roles described below are primarily based on studies and reports within the UFT or CEV domain, but also rely on interviews and intuitive observance of the system.

#### 3.3.1 Fleet System

##### **CEV Manufacturer**

Manufacturers of vehicles can have mixed interests when it comes to urban freight. In a traditional product-based model, manufacturers are primarily concerned with technological R&D, supply chain and production efficiency and customer relationships up until the point of sale. However, in section 5.2 it is displayed how the value chain for EVs is extended to include a greater range of services. The vehicle manufacturer is the primary actor for designing and producing trucks, but could also become interested in providing complementary services (such as smart charging) for their vehicles.

### **Fleet Owner or Transport Operator**

Fleet operators are looking to provide high quality transport and logistic solutions at the lowest cost possible while satisfying the needs of receivers. Fleet operators and managers are generally interested in electro-mobility solutions, for many of the benefits previously described, however they would like to see this integration with absolutely minimal to no impact (e.g. scheduling conflicts, ability to complete deliveries, etc.) on their existing operations (CALSTART, 2012).

### **Vehicle Driver**

Drivers of UFT trucks do not want to be tasked with the complexity of route planning considerations for CEVs or worry about range anxiety. Ideally, the more seamless the transition from conventional vehicles to electric, the better for all. In general, it seems that drivers prefer CEVs, whether it is for their increased acceleration ability or quieter operation, and would willingly use them over diesel trucks (Levandi & Mårdberg, 2012, CALSTART 2012, den Boer, 2013).

### **Receivers**

Receivers are the end customer (e.g. retailers, shop owners, grocery stores) of goods distributors. Their primary concern with urban freight transport is the on-time delivery of products with a short lead-time from ordering, to processing to delivery (MDS Transmodal, 2012). Receivers may be interested in reducing the environmental impacts of their business, and give preferential treatment to delivery services that are able to offer low- or zero-emission solutions.

## **3.3.2 Energy System**

### **Utility Company**

Utility companies are an essential and unavoidable partner when it comes to providing charging infrastructure. Grid integration and interconnection is the fundamental technical underlying aspect to the provision of charging services. However, utilities are typically not interested in routine operation and maintenance of charging infrastructure, instead focusing on providing reliable electricity services to customers.

It is important to note that utility company structures vary from country to country or between regions. For example, it is very typical that a utility company in the United States is vertically integrated, from producing energy, operating the distribution grid, to providing billing services to the end-customer. Whereas a utility company in Sweden only produces energy and sells it to the end-customer, while a separate entity operates the distribution grid. From a discussion with Göteborg Energi, it was determined that a CEV fleet in Sweden would be more likely to work directly with the distribution system operator rather than the energy utility (Persson, phone interview, 3 August 2016).

Utilities bill customers not only for energy consumed (kWh), but also based on power demand (kW). As described in section 3.2.5 Grid Integration, pricing mechanisms such as demand charges or time-of-use (TOU) pricing are in the utility's best interest in order to remain financially viable, but can be prohibitive to CEV fleet owners, especially those with smaller deployments (Gallo, 2015). However, there are potential solutions to ameliorating this conflict of interest. As proposed in Gallo, 2015, innovative utility rates for EVs can be designed that recognize environmental and grid benefits and take advantage of submetering charging stations when sensible. Again, this is region specific, as not all utilities may utilize demand charges or TOU pricing.

### **Distribution system operators (DSOs)**

As mentioned above, there are cases when the energy utility is not the operator of the distribution grid. As stated in European Commission directive on the deployment of alternative fuels infrastructure, “distribution system operators play an important role in relation to recharging points. In the development of their tasks, the distribution system operators, some of whom may be part of a vertically integrated undertaking owning or operating recharging points, should cooperate on a non-discriminatory basis with any other owners or operators of recharging points, in particular providing them with the information needed for the efficient access to and use of the system” (Directive 2014/94/EU).

In earlier discussions on grid integration, it was displayed that CEVs can have significant impact on power demand (kW) required from the grid. “In order to address local congestion at system peak or to mitigate the need for peak-related network upgrades, DSOs will require a real-time and dynamic response from the charging infrastructure which can be procured through V2G services providers. In order to do this, a fully equipped, remotely controllable and smart charging infrastructure will be required.” (Eurelectric, 2016). Having “smart” infrastructure does much to improve the business case or value for all parties involved, for DSOs it eases issues such as grid demand, for fleet operators it can create cost savings and simplify charge planning, and it allows EMSPs to capture more value from their services.

### **EVSE Owner**

The owner of EVSE varies greatly depending on the location or application. For a CEV ecosystem, the ownership model is unique, and the most sensible actor for ownership needs to be determined. For consumer EVs, the ability to produce revenue from the charging station is a seminal concern, however this is not present for CEVs since it the EVSE is not publicly accessible and is solely utilised by the fleet it was optimized for. However, the ability to *recover* the cost of in the infrastructure through value creation is still important, as well as the performance of the station. The EVSE owner could be the vehicle manufacturer, the EVSE manufacturer, the utility company, the DSO, or the fleet operator. There is potential for a shared ownership model between two or more of these parties, which will be discussed further within the business model canvas.

## **3.3.3 Public Authorities**

### **Municipality and Energy Regulator**

The local government is especially invested in the quality of life for inhabitants. As related to urban freight, primary concerns would include air quality, traffic congestion, and an efficient transport network for goods and services to be provided to the city. As represented through the enactment of policies such as congestion chargers and low emissions zones, municipalities are likely to be in favour of electrified freight distribution. In most case the municipality, or an arm of the municipality, acts as the regulator of energy utilities and DSOs. EMSPs and charging infrastructure supporters may be able to leverage this support by municipalities for the adoption of CEVs in the form of financial incentives or other mechanisms.

### **Energy/Transport Associations**

Industry organizations have a large influence on coordination between different markets and actors. As displayed in section 3.2.3, entities like the Society of Automotive Engineers or the International Electrotechnical Commission drive central issues such as standardisation which has a heavy influence on auto and EVSE manufacturers alike. Coordinating with these types of organizations can help CEV and EVSE suppliers to integrate better with other partners or even competitors, in order to more effectively drive adoption and uptake.

### **Public Citizens**

Residents within an urban setting are the primary indirect beneficiaries of vehicle electrification. The previously outlined health and environmental benefits of CEVs such as air quality and noise reduction are received ubiquitously by anyone living within the locale served by the CEV network. However, an issue arises if public tax dollars are used to provide incentives for CEV fleets that are not for public use, such as private urban distribution entities, as this does not have as a directly attributable public benefit (Persson, phone interview, 3 August 2016). If financial incentives are provided to municipal owned fleets such as refuse trucks, this public benefit distribution issue is solved.

## **3.4 Policy, Regulation and Incentives**

### **EU Directives**

EU Directives are legal acts of the European Union that require member states to meet a particular objective or result, while leaving the means and tools of achieving that to the individual nation. There are many directives that broadly or indirectly relate or affect CEVs and charging infrastructure. Directive 2008/50/EC for example relates to air quality, and has acted as the impetus for the implementation of Low Emission Zones covered below. Directive 2012/27/EU on energy efficiency has direct relevance for the grid integration scenarios previously discussed, outlining the need for intelligent metering systems and grid stability. Charging infrastructure deployment must be able to comply with the objectives of member states looking to fulfil these directives, and in many cases benefit from enacted programs. As alluded, future benefits of EV and smart charging will be to provide grid storage and balancing services (Yang et al, 2016).

However, the most directly applicable would be Directive 2014/94/EU on the Deployment of Alternative Fuels Infrastructure. This Directive deals with many alternative fuels, but has a strong focus on charging stations for electric vehicles. It is meant to help drive uptake of consumer electric vehicle in Europe, primarily through the provision of public charging points. However, it also outlines specific objectives such as technology standardisation, real-time data services, and intelligent metering which will also be applied to CEVs. As displayed in section 3.2.3, consumer EVs are the primary driver for CEV plug type standards.

### **Low Emission Zones**

Low Emission Zones (LEZs) are a recent policy tool utilized by some EU members in response to European emission standards. To date, there are approximately 197 Low Emission Zones in 10 different countries” (RPA, 2016). LEZs are restricted areas, typically in urban city centres, where diesel trucks and buses over 3.5 tons are required to be equipped with particle filters. Approved particle filters intercept approximately 80% or more of the particulate matter from a diesel engine (Geroliminis et al, 2005, Directive 2008/50/EC). Of course, CEVs immediately meet these requirements for operating within an LEZ due to their inherently zero-emission nature.

However, despite these outlined requirements, “many of Europe’s largest cities are not in compliance with current EU pollution reduction targets” (Directive 2008/50/EC). However, there is an expectation that there will be future changes in legislation at both the local and national level, as there is increasing pressure on cities to improve air quality (Directive 2008/50/EC). LEZs can have a very positive effect on urban freight networks, for example, Stockholm benefited from a 15% reduction in commercial traffic, and Milan saw a decline from, “13,040 freight trips in 2008 to 9,521 trips in 2010 or 27% fewer vehicles” (RPA, 2016). London

and Berlin are also primary movers for LEZ policy and have recorded high compliance rates (RPA 2016).

### **Congestion Charges**

A congestion charge is a scheme similar to LEZs that aim, “to reduce traffic congestion in and around the charging zone, to improve the bus services, journey time reliability for car users and to make the distribution of goods and services more reliable, sustainable and efficient (Geroliminis et al, 2005). The congestion charge requires that each vehicle that enters the zone pay a set fee each day, whereas an LEZ is a regulatory emissions requirement on vehicles entering the zone. Congestion charges have been implemented in some major European cities such as London, Milan, Gothenburg and Stockholm. London witnessed a major reduction in traffic congestion, around 30%, which translates to 65,000 fewer vehicle trips into the zone per day (Geroliminis et al, 2005). Again, EVs are advantageous in cities with congestion zones, as it is typical for them to be exempt from the charge, as is the case in London (Transport for London).

### **Incentives**

There are a wide range of incentives for EVs and EVSE that varies from country to country. It is outside the scope of this work to compile and tabulate them all. However, there are broad categories that can be identified. A common mechanism are loan guarantees for EVSE investments, which help to reduce the financial risk in charging station deployments. CO2 reduction targets can also influence national regulatory measures, which can influence the provision of tax credits or exemptions that make EVs or charge points cheaper. According to a best practices guide of the Deployment of Alternative Fuels Infrastructure Directive, this often comes across in the form of a zero value-added tax (D’Appolonia, 2016). Loan guarantees and tax credits appear to be the most common incentive mechanisms for charging infrastructure.

One interesting specific case to highlight is the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) in California. This incentive is particularly relevant as it is geared specifically for kick-starting a low-carbon truck and bus industry. HVIP offers point-of-sale incentives directly to purchasers, with no requirements to submit proposals or rebate claims (HVIP webpage).

Other incentives include parking fee exemptions for CEVs, preferential parking for CEVs, municipal targets for dedicated charging parking spaces, or general subsidies for infrastructure deployment (D’Appolonia, 2016).



## 4 Use Case Profiles

### 4.1 Overview

Historically, one of the principle arguments against CEVs in freighting operations has centred on ‘range anxiety’ or the lack of ability to complete typical daily operations due to the limited range of the battery pack. As described by Taefi et al. (2014), the “direct substitution of conventional commercial vehicles with EVs does not fully exploit the strengths of EVs, hence often leading to operation that is simply not profitable.” Novel thinking can flip this mentality on its head, rather than trying to shape electric vehicles to fit the mould of diesel operations, but instead looking to determine what existing businesses and operations CEVs already fit best given their inherent characteristics and advantages (Quak et al., 2016). However, many operators do not realize that their operations may already be suitable for CEVs, as the average daily mileage by urban delivery trucks is often lower than the range offered by current technology (Wei and Figliozzi, 2013). The objective of this section is to determine what are the best ‘use profiles’ or ‘use cases’ among medium-duty trucking applications for vehicle electrification. It is essential to determine the best candidates for electrification since, “electric vehicles are not competitive if routing constraints lead to the purchase of additional vehicles above and beyond the required number of conventional vehicles,” so CEVs must be able to provide net operational benefits to fleets over diesel trucks (Davis and Figliozzi, 2013).

To the right is a typical breakdown of the trucking industry segments. Each of these segments could be further segmented to Light Duty, Medium Duty and Heavy Duty transport within each customer group. However, given the range and payload limitations stipulated by the current state of battery technology, segments that have an urban focus would be of interest to vehicle OEMs for initial entry into the market.

The primary and foremost question that needs to be answered when either designing an electric truck and determining its ideal use case, is how to optimize battery size & capacity with the duty profile & charging patterns of the end-application. The quote below from CALSTART’s E-Truck Task Force best encapsulates this predicament;

“Right-sizing the battery for the application could also reduce upfront costs. In this scenario, the battery would be customized to the well-defined needs of the particular duty cycle of the vehicle, and would be no bigger than those needs required. This would also reduce the weight of the vehicle and allow for more payload capacity. But because a smaller battery often requires more frequent, deeper discharges, suppliers advised that battery life could be curtailed since there is a correlation between depth of discharge on the battery and the number of charge and discharge cycles it can perform. There is likely a trade-off point on the business case between reduced battery cost and reduced life.” (CALSTART, 2012)

Agriculture
Building & Construction
Consumer Goods
Daily Commodities
Container Transports
Industrial
Post & Parcel
Forest and Paper
Mining
Petroleum & Chemical
Public Service/Utility
Waste & Recycling
Defence

*Figure 4-1. Trucking Industry Customer Segments*

Interrelated to the trade-off scenario described above, is the charging infrastructure strategy that should be employed in order to complement the battery range and use-profile of the designed

truck application. There are many ways of framing the battery right-sizing question; however, it is good to begin with the physics of CEV operations. Take the five parameters used to assess appropriateness of batteries for vehicle applications from (den Boer et al, 2013):

1. Energy/weight ratio
2. Energy/volume ratio
3. Power to weight ratio
4. Battery lifetime
5. Charging time

The first three parameters are interrelated and have to do with the vehicle's ability to do work based on its haul. When CEVs are applied to operations with limited payloads, "this makes them best suited for last mile deliveries in compact cities involving frequent stop and go movements, limited route lengths and low travel speeds" (Pelletier et al, 2014, ENCLOSE, 2014). CALSTART points to three characteristics/categories that are favourable for CEVs, (1) fixed-route applications, (2) facility vehicles and (3) high idle/work site applications. Fixed route applications are frequent stop and go, run dedicated routes, require short distances and would include applications such as urban delivery or refuse trucks. Facility vehicles benefit from being localized to a single area, such as airports, military bases or seaports, which simplifies charge planning and does not require high levels of range. High idle, work site applications would include utility vehicles or urban construction, where a significant bulk of energy consumption occurs at a work location, rather than moving materials (CALSTART, 2012). When vehicles return-to-base and have generally fixed routes, this allows for a high degree of certainty in the route planning and charging period. The urban environment is an ideal setting for CEVs to take advantage of these operational characteristics. To date, CEV has been tested for various applications: post & parcel delivery, garbage collection, pizza delivery, supermarkets etc. (Quak et al, 2016). Most of these applications have lighter payloads that batteries are able to handle in terms of power delivered. There is a broad agreement that CEVs are best suited for "duty cycles in suburban or urban areas involving a low daily driving range and a relatively low load capacity" (ENCLOSE, 2014). The nature of the application has a large effect on the potential achievable range of the CEV. Frequent stop-and-go applications are advantageous since, "as much as 45% of braking energy is recoverable and Gao et al. (2007) reports that this number could be as high as 60%, depending on travel speeds and other factors" (Davis and Figliozzi, 2013). Examples of use profiles that are able to take serious advantage of the benefits of the regenerative braking from electric motors are post and parcel, refuse trucks, or retail delivery with a high number of customers served.

Post and parcel service has already been a proven ideal use case for electrified vehicles given many of its characteristics: fixed route, short range, low overall payload, lightweight goods, frequent starting & stopping in order to take advantage of acceleration and regenerative braking, high drop density, and having a depot starting point close the city (Quak et al, 2016, CALSTART, 2012). The post and parcel use case will not be considered in this analysis as it is usually operated by trucks less than 7.5 tons and has been proven extensively through other studies and existing trials. However, displaying this example highlights how businesses can leverage their unique operational needs to benefit from CEVs' strategic advantages over diesel trucks.

Not all freight operations are currently suitable for CEVs, most notably long-haul (Quak et al, 2016). When considering variables such as the three energy ratios above, this type of large, heavy load capacity would be too intensive in terms of weight and available range for the current state of battery technology. This is why the aforementioned Nikola Motors chose to employ a fuel-cell strategy to address these shortcomings.

## 4.2 Urban Goods Distribution

Urban goods distribution is a trucking customer segment with huge market potential for CEVs, given its breadth of applications and ubiquity in worldwide logistics. Environmental performance and noise reduction were outlined previously as two of the key societal health benefits of CEVs. In cases where cities may have restrictions on congestion, noise or emissions, CEVs are advantageous in their ability to access larger geographical areas and time windows in city delivery, providing a distinct competitive advantage over conventional vehicles (Quak et al, 2016). However, this wide breadth of potential application areas makes urban goods distribution difficult to constrain, as different goods require different routes, delivery characteristics, payloads, time-windows etc. One of the most extensive and comprehensive studies in this area was conducted by E-Mobility NSR in 2013 titled, *Comparative Analysis of European Examples of Schemes for Freight Electric Vehicles. Compilation Report*. To begin understanding how urban goods distribution can be categorized, refer to the below summary analysis of E-Mobility NSR's report;

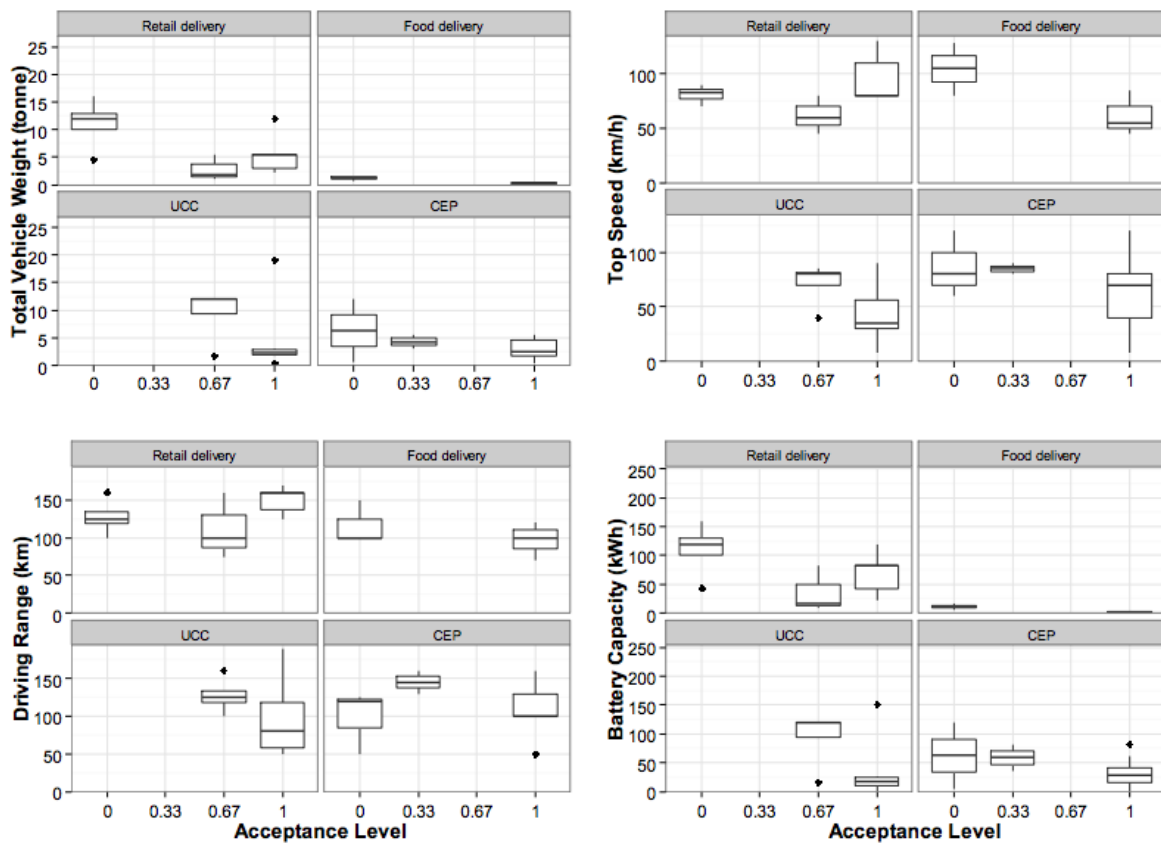


Figure 4-2. Vehicle parameters of CEV pilot projects reviewed by E-Mobility NSR  
Source: Teoh et al. (n.d.)

The graphic compares the average weight, speed, range and battery capacity of four key segments of urban distribution – retail, food delivery, urban consolidation centre (UCC) and courier-express-parcel (CEP). Acceptance level is a measure determined through qualitative data regarding how willingly operators are to integrate CEVs into their fleet, with 0 being not at all accepted and a 1 representing a very high level of acceptance. This representation is effective at highlighting the differences and similarities between some of the operational characteristics of these CEV applications, as well as their suitability for a given application based on the four parameters. Take retail and food delivery, as represented here they are fairly similar in terms of the required range and driving speed, given their similarities in route planning. However, retail

delivery typically requires a heavier payload than food delivery, which results in a larger battery capacity to compensate (Teoh et al, n.d.).

An important dimension to the profile of an urban goods distribution truck is not only the type of goods it is transporting, but also what part of the city it is serving. A joint research project between Volvo Group, University of Gothenburg, Viktoria Swedish ICT and the Swedish Transport Administration yielded some insights on the profile of a CEV urban goods distribution truck. The study examined cases in Gothenburg, London and Paris, with greater detail on Gothenburg due to proximity and coordination. For Gothenburg, there were three main route types, city centre distribution, suburban distribution and regional distribution, with average daily ranges of 40km, 80km, and 140km respectively (Löfstrand et al, 2015). A required range of 150 km can be expected for medium sized cities like Gothenburg. However, this cannot be generalized, as large cities like Paris or London might require double the distance due to sheer size or traffic (Löfstrand et al, 2015).

Within the context of charging infrastructure, it is important to remember that strict delivery times are required by customers. Urban goods distributors need to fit as many deliveries as possible into one shift in order to maintain profit margins. When considering the battery right-sizing, it is likely that these vehicles will need to pursue an overnight depot charging strategy, as adding charging during the shift will put an extra constraint on distribution and lower productivity (Löfstrand et al, 2015). For operations running less than 80 km/day the study determined that 50 kWh battery capacity is sufficient whereas the longer 140 km/day regional operation would require a battery between 80 and 140 kwh (Löfstrand et al, 2015).

The National Renewable Energy Laboratory (NREL) in the United States is dedicated to conducting research on technology that contributes to energy efficiency. NREL organized a “FleetDNA” project that compiled information on commercial fleets by vehicle type over 4,705 days of driving data from 486 vehicles across the United States. These vehicles are not exclusively CEVs, but this information is highly important to understand how these vehicles are typically used in the application area, so that CEV charging strategies can be formulated. It also should be noted that American cities have different geographical attributes than European cities, but the main deductions from the project are still relevant and applicable.

The following information is a brief summary of the most relevant data from the Fleet DNA database, see Appendix Item 4 for more detail. To start is a simple parameter, daily operating distance. The vast majority of instances equate to approximately 60km per day, with the near entirety falling between 10 and 80km per day. Delivery trucks are well within the achievable range of current battery technology. These vehicles are also traveling at a relatively lower average speed, which equates to a greater number of stops per kilometre. As previously covered, this is advantageous for CEVs due to the regenerative braking feature of electric drivetrains. Regenerative braking recharges the battery and puts less wear and tear on the physical brake pads. The bulk of delivery trucks are traveling an average speed between 45 and 55 kph and stopping between 1.5 and 3 times per kilometre.

Figure 4-3. below is a strong visual representation on the correlation between daily driving distance and the number of stops a delivery vehicle will make during its route.

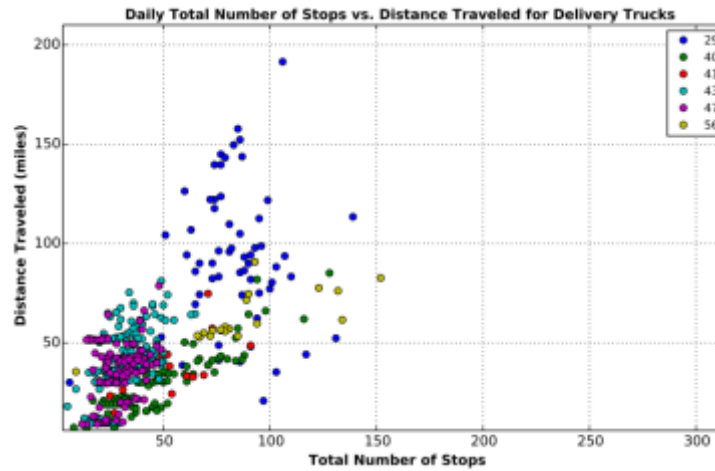


Figure 4-3. Daily number of stops v. distance travelled for delivery trucks  
Source: Walkowicz et al. (2014a)

As displayed, the vast majority of trips are 80 km or less. This is fortunate as the aforementioned study determined that this would only require a 50 kWh battery, which reduces the cost of the vehicle significantly (Löfstrand et al, 2015). In terms of the ‘right sizing’ question, most of the data points that a majority of the vehicles offered should be prepared for tighter 50-90 km routes, with an option to upgrade the battery size if a greater range is needed.

#### 4.2.1 Application in Practice: Frito Lay

A strong example of a successful urban goods distribution case is Frito Lay, who currently utilizes one of the world’s largest CEV fleets with over 200 delivery trucks within its United States operations. An interview with Steven Hanson, fleet manager in charge of Frito Lay’s electric vehicle fleet provided some real insight into these challenges in practice. Frito Lay owns one of the world’s largest electric distribution fleets, operating in Atlanta, Portland, Seattle, New York City and all across California, among others. To compliment the Frito Lay case, is a cumulative study conducted by NREL on the performance of Smith Newton trucks across the United States, which Frito Lay uses exclusively. NREL’s study included 450 Smith Newton vehicles, over half of which are owned and operated by Frito Lay. Figures 4-4 and 4-5 display key figures from the research conducted by NREL on the performance of Smith Newton trucks.

##### Route Information

Average Distance Travelled per Day	41.4 km
Average Number of Stops per Day   per Kilometre	50.4   1.9
Average Regenerative Braking Events	5.5 per km
Average Daily Driving Speed	35.1 kph

Figure 4-4. Route averages for fleets of Smith Newton trucks  
Source: Prohaska et al. (2016)

This is an excellent use case for CEVs since potato crisps have a very low weight by volume and are typically delivered to grocery stores in the early morning. This is an exemplary example of an operator taking advantage of a light payload as well as low noise levels of CEVs within an urban setting.

NREL also collected data specific to Smith Newton charging patterns. As displayed here, Frito-Lay benefited from having a very low average distance travelled between charge events, meaning range anxiety was not a major challenge.

#### Plug-In Charging Information

Average Vehicle Charging Frequency	1.8 per day
Average Vehicle Charge Energy per Day	41.8 kWh/day
Average Energy Delivered per Charge	22.9 kWh
Average Duration of Charge Event	6.8 hours
Average Distance between Charges	22.7 km

*Figure 4-5. Charging averages for fleets of Smith Newton trucks  
Source: Prohaska et al. (2016)*

However, speaking with Hanson revealed that the time of day that charging took place was more of an issue. As Frito Lay primarily serves grocery stores, the route would begin very early in the morning, around 3:00am in order to delivery before customers would arrive at the store. Meaning that the route would conclude between 12:00 and 14:00, which is also a peak time for utility rates and demand charges, making charging more expensive than it would be if it occurred overnight. Since the average duration of the charge event is about 7 hours, it would be preferred if smart charging control processes would be enacted in order to shift the charging to a cheaper time of day.

Hanson also described a variety of minor and major hurdles that need to be overcome by operators and manufacturers for CEVs to accelerate adoption. One of the larger issues described was the difficulty in siting the charging stations at the depot location. In some instances, the best location for the vehicles were often very far from the interconnection with the electrical grid, which increases aforementioned costs related to conduit and trenching. A legal challenge was posed as there is no well-defined template on permitting for EVSE, which often lengthens and complicates the process. When working with the energy utility, Hanson remarked that some utilities may take a negative attitude towards the grid integration of charging infrastructure, viewing it as a load issue rather than looking at it as an opportunity for grid optimization. From a vehicle design stand-point, Hanson remarked that the physical location of the charger connection on the vehicle had a huge impact. Depending on the application some vehicles need to be backed-in to the parking stall, whereas others need to enter head-first, which can make connecting to the station difficult.

When asked about what Frito Lay would want most from a CEV manufacturer, Hanson highlighted standardization of physical components and standardization of software communication. The need to be able to easily extract vehicle information automatically is of

huge importance. Currently they must manually download usage data from the vehicle. If communication between the EVSE, vehicle and grid are standardized and automated, this will make data analytics and smart charging much easier and more valuable. At the time of adoption, Smith Newton's vehicles were not SAE J1772 compliant, which caused miscommunication between the EVSE and vehicle when unplugging, causing electric current arcing which lead to a high rate of cable failure. Hanson estimated that the cable for each vehicle had to be replaced every year on average, costing the company about \$500 for each failure. The lack of component standardization made part replacement and repair difficult.

To summarise, below is a list of CEV fleet and grid integration challenges for Frito Lay:

- Utility attitude towards CEVs and charging infrastructure
- Siting charge points at depot
- Cost of transformer upgrades
- Lack of EVSE suppliers
- Lack of smart charging platforms for commercial applications
- Lack of template for permitting EVSE
- Accountability on design and interface between EVSE and vehicle
- Poor component standardisation
- Driver training for handling electric plug and charging
- Placement of charging cable on the vehicle

### 4.3 Refuse Trucks

Refuse trucks is another candidate with high potential for electrification. However as previously mentioned this application requires a higher payload when compared to urban goods distribution. As Figure 4-6 demonstrates, the total vehicle weight and battery capacity needed increases. Refuse trucks have a greater variety in their daily required range, the majority between 25 and 80km per day, but depending on the route of an individual truck this figure can jump to 100 or 160km per day.

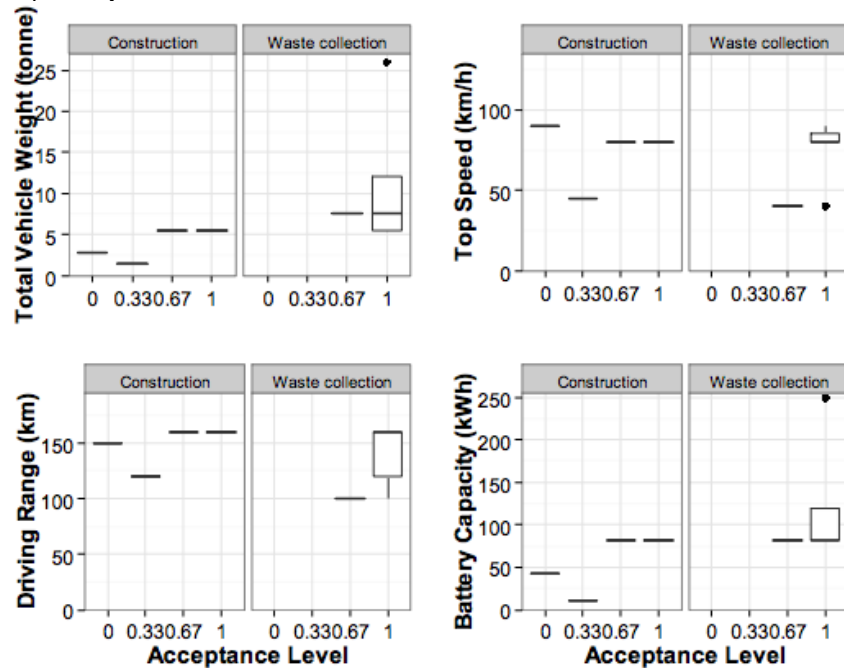


Figure 4-6. Vehicle parameters of CEV pilot projects reviewed by E-Mobility NSR  
Source: Teoh et al. (n.d.)

However, refuse trucks remain a strong business case, as they travel even slower and stop much more often than urban delivery vehicles. Figure 4-7 shows the relationship between the average number of daily stops and driving speed. On average, refuse trucks will travel between 20 and 35 kph on a given day, and make between 150 and 300 stops per day. This high frequency of stops amplifies the benefit of regenerative braking. Refuse trucks are also operating near people's homes in an urban setting, so emission and noise reduction are huge contributors to the value proposition for electric refuse trucks.

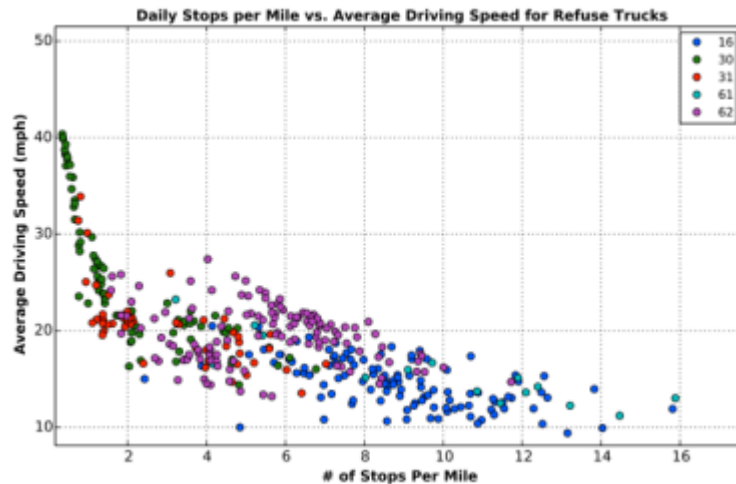


Figure 4-7. Daily stops per mile v. average driving speed for refuse trucks  
Source: Walkowicz (2014b)

It is important to reiterate that the primary underlying objective of vehicle electrification is fuel displacement. In the case of, “municipal applications like refuse collection, that operate for only 20 miles [32 km] or less per day but they will displace 28-45 diesel gallons [105-170 litres] per day. In that case, the value proposition should be phrased in terms of fuel displacement, or gallons per day [litres per day], rather than miles per day” (CALSTART, 2012). In determining the business case for refuse trucks, especially when it comes to fuel cost savings, it is important to look at actual fuel displacement, not driving distance, when making financial calculations.



## 5 Analysis and Application

The Analysis portion of this study is centred around providing the contextual information needed in order to design a business model around charging infrastructure. The business model design and the related elements aim to synthesize lessons learned through the previous sections in order to provide a suite of considerations one should make when looking to offer charging infrastructure for CEVs. A truck original equipment manufacturer (OEM) is assumed to be the central entity that the following concepts, perspectives and business model canvas is built around. The findings expressed here can be applicable to any CEV manufacturer looking to provide charging infrastructure as part of their service offerings.

### 5.1 Extending the Value Chain

As displayed through the review of the CEV system and stakeholder mapping, the electro-mobility industry is a complex market ecosystem with a wide variety of actors. High levels of coordination between these stakeholder groups, through partnerships and other agreements are needed in order to achieve a positive business case for EV charging infrastructure. A value chain can be used in order to understand where these stakeholders and partners may be leveraged or integrated. A value chain is an efficient high-level model for displaying the primary activities of a company both upstream and downstream. There are five broad categories of activities within a value chain; from (1) inbound logistics (receiving materials for production), (2) operations, (3) outbound logistics, (4) marketing and sales, and finally (5) service (Investopedia). Examining the value chain is especially relevant for electro-mobility whereas PSS is concerned, in order to evaluate what aspects of the chain will be offered by the system to customers.

Value chains have historically been used by companies that process or manufacture products, in order to identify ways of increasing efficiency within the chain (Investopedia). However, with the complexity and market demands of the EV industry there is progression towards a service-focused model that provides ancillary services (such as mobile platforms or charging solutions) to increase the value proposition of EVs. The below graphic represents this new extended value chain beyond vehicle production and sale, in order to include from the infrastructure, as well as the ICT systems that supports them both.

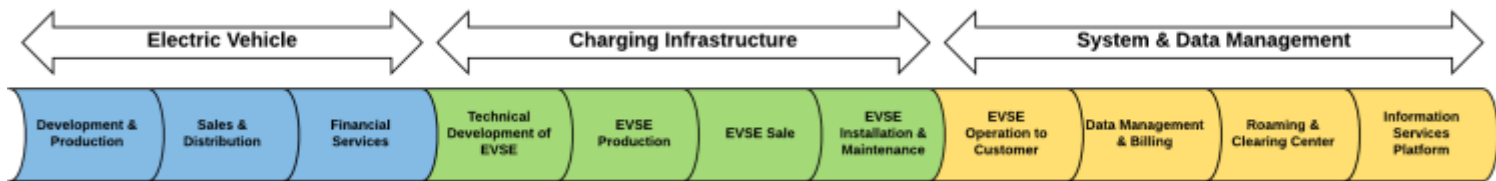


Figure 5-1. Electric Vehicle Value Chain  
Source: McKinsey (2014)

Vehicle manufacturers have historically addressed the first portion of this value chain. However, with electric vehicles, the chain is extended to emulate a Product Service System. This value chain will be useful when determining which aspects a vehicle OEM should look to provide themselves, and what aspects should be left to specialists through partnerships or agreements.

With CEVs, vehicle OEMs can look to move towards a service-focused business model, as opposed to a product-focused business model. This is different that the *product-oriented* category of PSS described above, a product-focused business model is dependent on volume throughput and favourable profit margins in order to accrue revenue, while a service-based business model is centred around providing customer value through service provision. The product-focused model is the business-as-usual scenario typical for most car manufacturers. This works well with

conventional diesel trucks, however with the system complexity of CEVs, a service-based model can better capture the new potential revenue streams from the expanded value chain.

While the system may be more complex, with this complexity comes new business opportunities for vehicle OEMs to capture greater value from the CEV market. Within this new EV-ecosystem we see the emergence of a new role, the electro-mobility service provider (EMSP). The EMSP is an entity that offers, “electro-mobility services to the end customers, which may include charging, search & find (of nearby charging stations), routing and other services. It is the legal entity that the end-customer has a contract (business-to-customer relationship) with for all services related to the EV [...] the EMSP is owner of the data of the EV users in its portfolio” (Madina et al, 2015). As providers of the central technology piece in the EV value chain, vehicle OEMs are excellently poised to act as an EMSP through the provision of related services

Below is another view into the value chain of charging infrastructure and some of the associated services available to EMSPs. This representation is a decision tool in order to provide insight when planning service provision into the different layers that are required in order to deliver a full-service offering beyond simply providing the technology hardware.

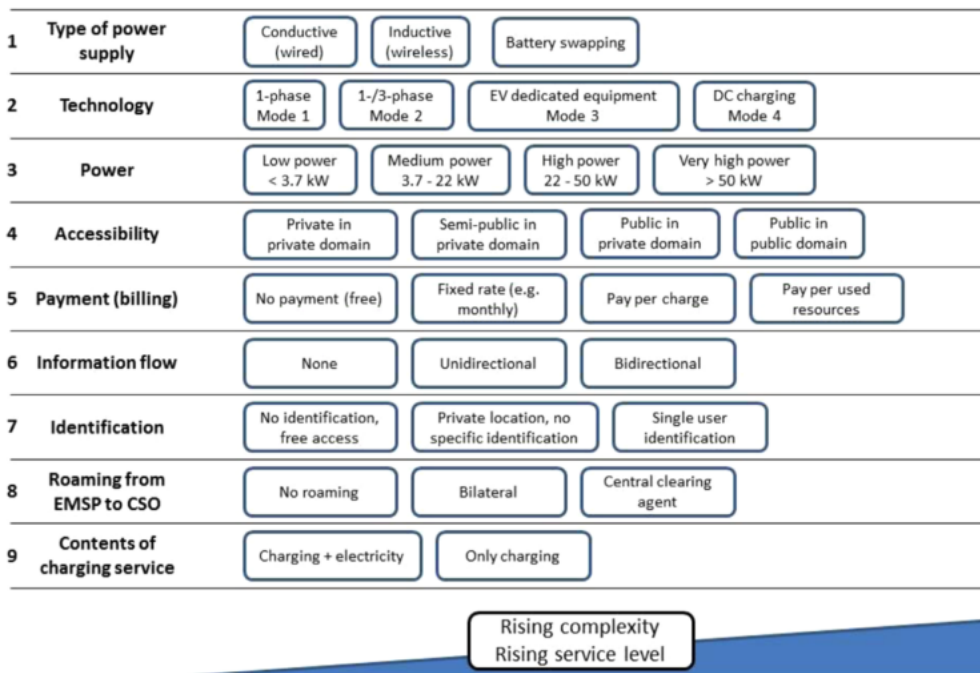


Figure 5-2. Morphological box for the different charging alternatives for EVs  
Source: Madina et al (2016)

There are some aspects that are less applicable to a CEV business model, primarily Accessibility, which has to do with siting of charging stations across different domains. However, the remaining elements are still relevant when providing charging services to a commercial EV customer. For example, a focal decision needs to be made regarding element 6, Information Flow. If a vehicle OEM is to be full service provider for charging infrastructure, this point will be pivotal when determining what to provide on the software platform. In section 3.2.6 Smart Charging and Management Platforms some of these attributes were displayed, elements such as route planning or vehicle identification for billing can the service offering from an EMSP more robust and valuable.

With a service-based model, vehicle OEMs can look to provide new offerings such as authentication and authorization, EV charging, charging station reservation, routing and clearing services (Madina et al, 2015). Since vehicle OEMs provide the central piece of the PSS system architecture (the vehicle), they can drive the standards around many of the EMSP service offerings. In section 3.2.5, interoperability and internal communication protocols were identified as key enablers in seeing large scale deployment of CEVs and charging stations. Platforms such as Meshcrafts or ViriCiti have difficulties establishing larger networks, as they must create custom solutions for how their platform integrates with each vehicle type. Vehicle manufacturers that begin to show interest in providing electro-mobility services can determine the fundamentals of how authentication, EVSE identification, billing, smart charging operate at a software level, as well as what hardware components are needed. The vehicle OEM that does so swiftly and efficiently could potentially gain large market share as an EMSP if the technology and standards become commonly used by many users and across different geographies.

## 5.2 Product Service System

In order to remain competitive in today's global business environment, companies are more often integrating products and services. This trend has become an explosive area of study in the last decade, a phenomenon aptly called Product-Service Systems (PSS). The integration of product and service offerings, "has the potential to improve efficiency, which can lead to positive economic and environmental effects for industry and society" (Reim et al, 2014). PSS strategy can be broadly broken into two facets, (1) at a strategic level – the design of the business model and (2) at an operational level – the tactics and choices a company makes in order to implement the PSS (Reim et al, 2014).

There are three general categories of Product-Service System business models – product oriented, use-oriented and result oriented. In a product-oriented model, "a provider, in addition to selling a product, commits to deliver a service related to the product." A clear example of this case would be household appliance, which a provider sells to a customer, but extends the system to include a take-back program of that appliance at its end of useful life. A use-oriented model is differentiated by the fact that, "a provider does not sell a physical product but instead makes the product available under rental or leasing agreements." This model is very prevalent and widely implemented, as rentals and leases are common across many diverse industries. Whereas the result-oriented model, "a provider agrees to provide the customer with a certain result or outcome rather than a specific product or service." This type of PSS business model is less common than its counterparts, an example may be a cleaning or consultation service where compensation is dependent on the outcome of the service or project (Reim et al, 2014).

At the strategic level, the three PSS business model typologies each contribute to value creation, value delivery and value capture in unique ways. As one moves from product- to use- to result-oriented, the level of complexity and risk increases for the provider of the PSS, as they bear more responsibility for the product/service delivered to the customer. See the table below for a generalized outline of differences between the three business model types when providing value (through products and services) to the end-user. For the remainder of the discussion on PSS business models, "provider" will refer to the entity providing the PSS, the vehicle OEM, and the "user" or "customer" will be the fleet owner or operator that is purchasing the provision of CEV and charging infrastructure products and/or services.

Table 5-1. Comparison of PSS business models orientation

	Product-oriented	Use-oriented	Result-oriented
Value creation	Provider takes responsibility for the contracted services.	Provider is responsible for the usability of the product or service.	Provider is responsible for delivering results.
Value delivery	Provider sells and services the product sale and service (e.g., maintenance or recycling)	Provider assures the usability of the physical product along with service.	Provider actually delivers result.
Value capturing	Customer pays for physical product and for the performed services.	Customer can make continuous payments over time (e.g., leasing).	Customer payments are based on outcome units; that is, they pay for the result.

*Source: Reim et al. (2015)*

From these three models, a use-oriented model in the form of a vehicle lease could be a strong strategy for a vehicle OEM to utilize. A lease, as opposed to a vehicle sale creates duplicitous benefits for both the provider and the customer. Early in this study it was defined that, “the value proposition for E-trucks is overwhelmingly based on three variables: maximizing fuel displacement, reducing purchase price, and minimizing infrastructure installation costs” (CALSTART, 2012). The formulation of a PSS for CEVs and charging infrastructure centred around a vehicle lease can help contribute to this value proposition in several ways. First, it helps to alleviate concerns by the user regarding the high purchase price and installation costs. A lease spreads the cost of ownership over a period of time, making the high capital investment for a CEV less daunting for fleets looking to adopt electric solutions. The capital investment for the EVSE can also be absorbed into the vehicle lease cost. By spreading the infrastructure cost over the course of the lease as part of the vehicle lease, fleets are more likely to accept this value proposition favourably as it the EVSE no longer a costly up front expense, which will be easier to sell to users than a typical vehicle sale. However, this means that the provider– the vehicle OEM, is responsible for a higher level of capital investment at the start of the project, and must be able to accurately calculate how to build the cost into the lease price in order to recoup expenses. Second, a lease will also reduce the risk assumed by the user in several ways. A risk concern of fleets is the achievable useful life of a CEV’s battery (Pelletier et al, 2014). If the vehicle OEM retains ownership of the vehicle, it makes it easier for the manufacturer to manage the physical replacement, absorb the costs into the larger system, as well as remove the need for implementing a battery take-back program.

In contrast, a product-oriented model is more similar to business-as-usual for a vehicle OEM. In this instance the vehicle itself would be sold to the user, but the vehicle OEM would still be responsible for the provision of charging services. At this point the vehicle OEM can decide to also sell the charging infrastructure outright to the user along with the vehicle, or retain ownership and responsibility of this element of the PSS. As previously mentioned, these decisions will be made based on the level of responsibility and risk the provider is willing to take.

The last option is a result-oriented model, which may be the most complicated to design services around. Likely it would be very similar to the use-oriented case, but rather than charging a monthly fee for the vehicle lease, the price could rather be set using how many kilometres per

day the vehicle is achieving. A result-oriented model is performance based, of which the provider is responsible for. This would be a difficult relationship to manage, as the user would be the entity operating the vehicles, so the provider has a small axis of control over the direct performance. "Performance" could instead be determined by the provider's ability to deliver indirect performance measures such as smart charging management so that the vehicle is able to achieve its daily routines or optimize route planning. In order to uncomplicate the performance measurement component of this approach, the vehicle OEM could instead stick with a use-oriented approach, but rather than charging a flat lease for the use of the vehicle, base the leasing rate on the amount of kilometres driven.

### **5.3 Business Model**

The final stage of this work is to construct a business model around charging infrastructure from the perspective of the vehicle original equipment manufacturer (OEM). As the vehicle manufacturer is the central entity in the provision of CEVs and the associated infrastructure and services, it is the most reasonable to design a strategy from their orientation. Business models are essential to establishing a new market or deploying a new technology, as they are able to, "describe the design or architecture of the value creation, delivery and capture mechanisms" (Reim et al, 2015). The vast majority of work conducted within the EV charging infrastructure industry to date has been exclusively focused on consumer EVs- installation guides, regulatory regimes, business models, cost reduction analyses, etc. are focused on home and public charging stations. Of the studies and reports that did have a commercial focus, a fair number pointed that a key issue there is a lack of business and financing models for electric vehicle charging infrastructure (CALSTART, 2012, Quak et al, 2016, Eurelectric, 2016). The CEV market is still a nascent industry, so there is a great need for development for the commercial customer segments. The challenge is that the commercial industry has a fundamentally different set of needs than charging stations for public use by consumers. There are certainly some lessons and financial mechanisms that can certainly be cross-applied, however in some instances they need to be retooled in order to mesh with CEVs. In order to accomplish the business model design portion of the analysis, this study will rely upon the widely-accepted Business Model Canvas developed by Alexander Osterwalder.

To begin, infrastructure management has some general challenges that need to be overcome through the business model design. Infrastructure management is a cost-focused industry that is highly dependent on providing standardization and predictability. The infrastructure manager must cope with high fixed costs, which make volumes essential to achieve low unit costs. Due to these attributes the field is usually dominated by a few larger players, all of whom battle for scale and consolidation. (Osterwalder et al, 2010)

In the majority of market conditions, charging station business models that relies, "solely on direct revenue from EV charging services currently are not financially feasible" (Nigro and Frades, 2015). A traditional EV charging station model for public use faces financial challenges, as it must be able to display to investors that the owner-operator will receive direct and indirect revenues from the station that exceed the total project cost (installation, grid service, maintenance etc.), in order to generate a profit. Beyond profitability, investors must feel confident that their return on investment from an EV charging station project will be equal to or exceed alternative investments opportunities (Nigro et al, 2015). Since public EV charging stations to date have not been able to provide this profitable business case, they have been predominately provided by public municipalities or vehicle manufacturers attempting to bolster the market (McKinsey, 2014). In general, there are four broad strategies for improving the financial performance of charging station projects; increase revenues, decrease capital costs, decrease operating costs, or decrease cost of project funding. Increasing revenues or decreasing costs can be extremely difficult to achieve at the scale needed, so a promising strategy to improve

performance would be rather to, “develop business models that, through private partnerships and joint investment strategies, capture other types of business value in addition to selling electricity” (Nigro et al, 2015).

Fortunately, the nature of a charging infrastructure business model for CEVs is potentially able to circumvent some of these key challenges outlined. The business model canvas in the following section will focus on charging stations for urban goods distribution from the perspective of the vehicle manufacturer. The perspective of vehicle manufacturer was chosen for two primary reasons. First, we are witnessing that within the consumer EV market it is becoming common practice for the EV manufacturer to also deploy charging infrastructure, not only due to the investor interested in expanding the market, but also because they are the stakeholder best poised to provide these complementary services and become a fully-integrated EMSP. Second, the key issue for public charging stations discussed above (regarding the unprofitability of charging stations that solely rely on charging service revenue) can be nullified through the business model design.

### 5.3.1 Infrastructure Ownership

A crucial point that needs to be determined in business model implementation is ownership of the charging infrastructure. There is no clear precedent on which actor is best suited or benefits most from retaining the ownership of the installed EVSE. Potential stakeholders include the vehicle OEM, the fleet operator, EVSE supplier, the utility company or eventually the municipality. However, each of these actors has different vested interests in the provision of EVSE.

For consumer applications, it was discussed in the previous section that EVSE suppliers or providers that rely solely on the sale of electricity for profit are not financially feasible. Therefore, EVSE suppliers rely primarily on the sale of the hardware for revenue.

The high upfront capital cost required for EVSE investment has been marked as one of the foremost barriers for fleet operators that would like to adopt CEVs. If CEVs are purchased, rather than leased, the price premium of an electric solution plus the infrastructure investment will likely prohibit adoption by fleets without significant incentives to offset cost. It is less likely that fleet owners and operators will express real interest in owning the charging infrastructure for the CEVs. Their primary concern is the delivered service, which is a zero-emission logistics solution, not necessarily to own electric trucks and charging stations.

With the surge of Tesla’s success, the market has witnessed vehicle OEMs begin to offer charging stations. This of course has a multi-faceted agenda to increase publicity, encourage market adoption and reduce driver’s concern about EVSE availability and range anxiety. For commercial EVs the approach would have to be adopted but the strategy largely intact. While Tesla provides their charging services free of charge to Tesla owners, this would not necessarily hold for CEVs, given the higher power requirements and larger overall total energy used. If vehicle OEMs moved into EVSE ownership, this of course would make the business case of CEVs for fleet operators more attractive, as they would no longer have to front the large share of capital upfront. Of course this has cost implications for the vehicle OEM, who would then be claiming the responsibility for the investment. If the vehicle OEM is able to front this investment and believe it can reasonably have it paid back over the course of providing CEV leasing and electro-mobility services to the fleet, then it may be in their interest to do so in order to expand their vehicle’s market share.

The ownership of the EVSE is not only relevant for the cost implications, but also for accountability in case of failure and repair. Frito Lay faced serious issues with cable failure as

the vehicle supplier and the charging station supplier disagreed on who was culpable for the equipment malfunction. This disagreement led to operational delays and replacement cost for the fleet operator which could ultimately discourage expansion of the electric fleet.

An important consideration that cannot be neglected is the related non-EVSE infrastructure investments such as transformer upgrades or conduit. Section 3.2.5 highlight how this presents a real challenge, as this type of infrastructure will ultimately be owned by the utility yet still paid for by the entity requiring the upgrade. However, if utilities or DSOs can be involved in the ownership of the EVSE, then perhaps they would be willing to work with vehicle OEMs to reduce the cost of these investments. There is evidence of this trend, as utilities in California were previously prohibited from owning charging infrastructure in the state, however after petitioning the Public Utilities Commission this rule has since been changed. Now, three of the largest utilities in the state have filed requests to operate and own charging stations (Gartner, 2015).

### **5.3.2 Business Model Canvas**

The following page is a completed Business Model Canvas for charging infrastructure from the perspective of a vehicle original equipment manufacturer. CEVs and charging stations are inherently linked but the EVSE and their associated services have their own business elements to consider apart from the vehicles. Discussion on the business model are fit in the larger picture of the PSS vehicle model lease, but it focused on the charging infrastructure specifically. In-depth explanations for the nine building blocks of the business model canvas follow afterwards.

# Business Model Canvas

## Vehicle Manufacturer

Business Entity

## CEV Charging Infrastructure

Product/Service

<b>Key Partners</b> <ul style="list-style-type: none"> <li>• EVSE Supplier</li> <li>• EVSE Installer (preferably Supplier)</li> <li>• Utility and/or Distribution Operator</li> <li>• Regulator (Municipality)</li> </ul>	<b>Key Activities</b> <ul style="list-style-type: none"> <li>• EV fleet optimization</li> <li>• EVSE Installation &amp; grid integration</li> <li>• Data collection &amp; analysis</li> <li>• Platform management &amp; Back office support</li> <li>• CEV expert consultation</li> </ul> <b>Key Resources</b> <ul style="list-style-type: none"> <li>• EVSE Technology</li> <li>• ICT Platform</li> <li>• Evaluation tools &amp; algorithms</li> <li>• Back-office services and IT infrastructure</li> <li>• Software development and automation experts</li> </ul>	<b>Value Proposition</b> <ul style="list-style-type: none"> <li>• Zero-emission trucks</li> <li>• Full-service solution trucks, EVSE and services</li> <li>• Singular platform for all related electro-mobility services</li> <li>• Simplicity of single point-of-contact for customer</li> <li>• Automated or semi-automated smart charging management</li> </ul>	<b>Customer Relationships</b> <ul style="list-style-type: none"> <li>• Expert planning during consultation phase</li> <li>• High level of individual attention in service provision</li> <li>• Sophisticated and robust interaction through online platform</li> </ul> <b>Channels</b> <ul style="list-style-type: none"> <li>• Primary channel: online management platform</li> <li>• Pre-project consultation</li> <li>• Client relationship management (I to I support)</li> </ul>	<b>Customer Segments</b> <ul style="list-style-type: none"> <li>• Small to medium distribution companies</li> <li>• Large urban logistics firms</li> <li>• Small businesses with delivery needs</li> <li>• Secondary customer: utility company (vehicle-to-grid services)</li> </ul>
<b>Cost Structure</b> <ul style="list-style-type: none"> <li>• EVSE hardware, installation and maintenance</li> <li>• Grid integration and service fees</li> <li>• Platform development and maintenance</li> <li>• Employee wages for expert consultation</li> <li>• Depreciation of EVSE assets</li> <li>• Replacement cost of EVSE hardware</li> <li>• Risk of early-commitment to a developing technology</li> <li>• Look to leverage shared ownership opportunities</li> </ul>			<b>Revenue Streams</b> <ul style="list-style-type: none"> <li>• Vehicle lease (with EV 'price premium')</li> <li>• EVSE joint-sale with partner</li> <li>• Consultation, platform access and services</li> <li>• Revenue becomes extended over period of service rather than one-time product sale</li> </ul>	

Source: [www.businessmodelgeneration.com](http://www.businessmodelgeneration.com)



## Customer Segments

As covered in section 3.5.2, urban goods distribution is a customer segment that has a wide breadth of profiles and applications. However, there are many commonalities that exist that are able to be cross-applied through this business model canvas. In most instances urban goods distributors utilize a return-to-base logistical operation, where the truck returns to the depot or store after a day's shift/route is complete. This type of case is best suited for a charging station – overnight charging approach. There is risk associated with utilizing a particular innovative technology that is still undergoing development and improvement. Charging technology is sure to experience changes in the near future, with potential for inductive charging, battery swapping, or improvements in battery chemistry that makes fast charging more attractive. Urban goods distribution does not need massive technological improvement for CEVs to be feasible, as it primarily needs charging only in the depot. Therefore, it would be sound strategy to focus on this customer segment first to insulate against risk of technology change.

Within urban goods distribution there is a wide range of customers in terms of the size of the fleet they operate. CALSTART classifies fleets into three sizes, small fleets with less than 5 vehicles, medium with 5-10, and large with more than 10 vehicles. The vehicle OEM acting as electro-mobility service provider, will be more likely to provide the range of services described in the business model canvas to smaller and medium sized fleets. The larger a fleet is, the more likely it is to have its own individual logistics platform. Large companies that operate dozens or thousands of vehicles across multiple markets will be less likely to adopt a new platform for CEVs, electing rather to use their own software. Distributing giants such as Coca Cola or UPS may instead need a customized solution for some of the offered capabilities to be integrated into their existing platform. In contrast, smaller fleets may outsource their route planning to a logistics firm depending on the complexity of their operations, or may have no software platform at all. These smaller operations are in greater need of a full service package to handle charge scheduling, route planning, data analysis etc.

**Urban goods distribution is a strong initial customer segment for vehicle manufacturers to focus on for two key reasons: (1) it has many of the inherent characteristics advantageous to EV operation and (2) operations centred around depot are unlikely the change, so manufacturers are less likely to face technology change investment risk for this segment.**

## Value Proposition

A vital first stage to developing a business model using Osterwalder's methodology is to construct a value proposition. The value proposition canvas used below is an optional tool that provides greater granularity into the larger business model canvas regarding two interrelated areas, the value proposition and the customer segment. This is meant to display how the service offering fits with the customer's wants and needs. The right half is used to describe the customer's profile, the jobs they need to achieve through their work, and the related "pains" in doing so, and finally the positive "gains" or positive outcomes or benefits they'd like to see come forth from their business. The left half is used to make explicit *how* the value proposition's products and services alleviate the customer's pains or contribute to their gains. The objective is to create a "problem-solution fit" when the features of the value proposition align with the customer's pains and gains (Osterwalder et al, 2010, Strategyzer, 2014).

In the Research Objective, it was identified that the value proposition for CEVs was based primarily on three variables: maximizing fuel displacement, reducing purchase price, and minimizing infrastructure installation costs (CALSTART, 2012). NREL's examination of Frito-

Lay's Smith Newton trucks have been demonstrated to have three times better average fuel economy over diesel vehicles (Prohaska et al, 2016). Figure 5-3 below is derived from data collection on Frito-Lay's fleet, and represents of how CEVs can create these drastic cost savings through their reduction in fuel consumption.

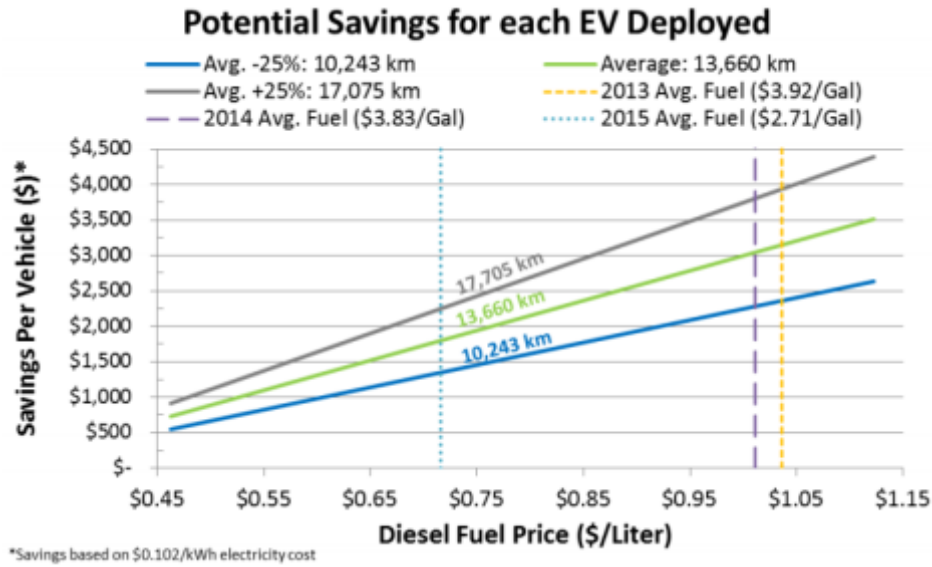


Figure 5-3. Fuel cost saving projections per CEV deployed  
Source: Prohaska et al. (2016)

As part of their value proposition to CEV fleet customers, “electro-mobility service providers, in cooperation with the EV industry, are expected to strive for the promotion of common open standards, data interoperability and efficient data exchange to pave the way for the necessary behavioural change” (Eurelectric, 2016). A compelling feature of the proposed business model is that the EV industry and EMSP are one in the same, which provides compounding benefits for the customer in terms of ease of service, uniformity and system integration. This dynamic can also help contribute to achieving the final two variables of CALSTART’s value proposition – reducing the purchase price and installation costs. It is for this reason that the below value proposition is not delineated to only charge infrastructure, but includes the CEV as part of the larger ecosystem. The full business model canvas is better poised to be specified to the charging infrastructure component.

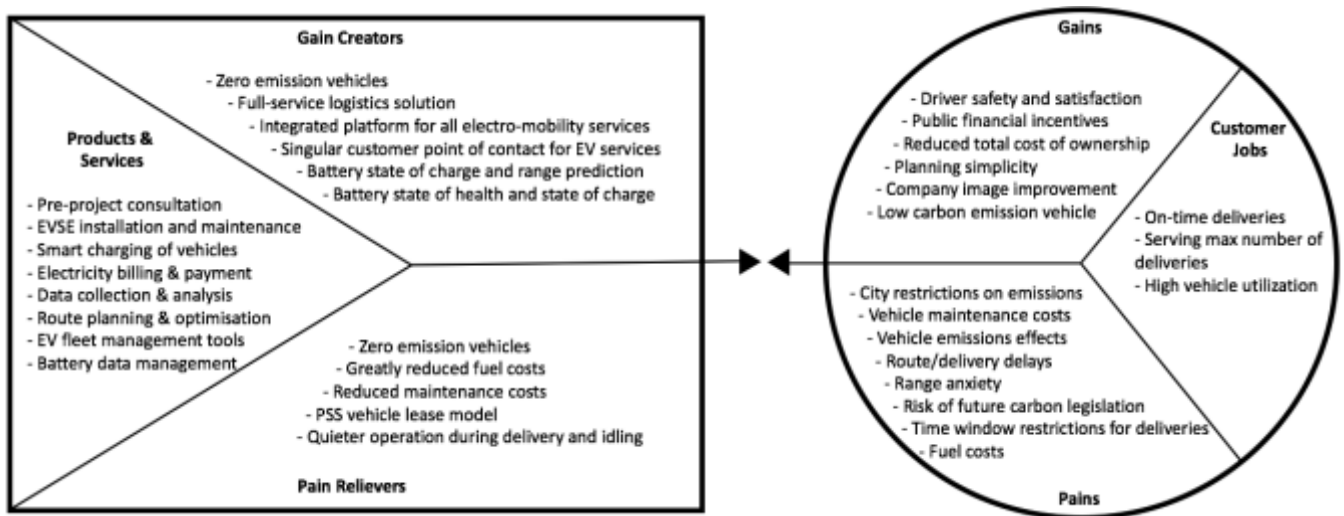


Figure 5-4. Value proposition canvas for CEV, charging infrastructure, and associated services

**A key feature of the value proposition to prospective CEV customers is that the simplicity of the leasing contract is able to absorb the costs of the associated services and provide a singular offering to fleet operators. The appeal is then a full-package zero-emission logistics solution, rather than a more complicated process of acquiring vehicles, charging stations and management software individually. This is the conversion of products into services through the creation a PSS.**

### **Key Activities**

A unique value that vehicle OEMs can offer will be to provide a full service package, from the vehicle to the charging infrastructure to the ICT support solutions. By acting as the central entity for zero-emission logistic solutions, it increases the ease of purchase for potential customers.

The first challenge the vehicle OEM needs to overcome is to convince fleet operators to convert from the strategy that they are familiar with and know how to operate. There must be a strong value proposition during this first point of contact that demonstrates cost savings, environmental improvements, or operational benefits of CEVs over diesel trucks. The key activities of the provider must be able to deliver on the value proposition. In order to accomplish this, a pre-sale consultation service can be offered. This stage of interaction with the customer needs to be able to display *what* value the PSS is offering and *how* it will deliver that value.

The pre-sale consultation should aim to fulfil several goals:

1. Determine what CEV vehicle-type should be used based on the customer's needs i.e. matching the use case profile with the truck able to complete that duty
2. Optimize the size of the electric fleet based on economic and technological breakeven values of a fleet replacement methodology (can be based upon the methods devised by Feng & Figliozzi, 2012)
3. Demonstrate estimates of how charge planning may operate for their business
4. Determine the charging speed and number of charge points needed based on their vehicle selection and operational schedule
5. Display the value and ease of the leasing service, as well as discuss the other electro-mobility service offerings

Section 3.2.7 demonstrated that integrating CEVs into existing fleets can be a challenge due to the new operational requirements (primarily charging) that CEVs require. By conferring with the customer during pre-sale, this can help to alleviate this concern early on and help to demonstrate how the transition may take place. The provider can utilize tools such as the E-truck Business Case Calculator (Appendix Item 2) in order to display financial benefits, which can be further developed and customized to mesh with the vehicle OEMs service offerings. This stage will serve a dual purpose of conducting due diligence and evaluating the site in order to prepare for grid integration and determine what upgrades may be needed.

The EVSE supplier will also be essential in determining a methodology for evaluating how to optimize the number of charge points needed based on the size of the CEV fleet. For the smallest sized fleets, it is usual to see a one-to-one (one charge point for each CEV) in a depot charging setting. However, as the fleet grows larger, it could be possible to reduce the number of chargers needed with intelligent scheduling (Löfstrand et al, 2015). There are several parameters that make this possible, the time required to charge each vehicle is often less than the time they are not be operated, vehicles will return from a daily route with charge still

remaining, and some vehicles may not require as much charging or will leave at a different time (Dielissen, phone interview, 28 June 2016, Hanson, phone interview 21 July 2016, ViriCiti).

Therefore, the next major activity will be to provide, install and eventually maintain the EVSE. This stage will be largely dependent on the EVSE partner that will provide the hardware. It would likely be in the vehicle OEM's best interest to delegate the responsibility of installation and maintenance to the EVSE supplier as they are best equipped to conduct this work. Having a clear division of labour and risk at this stage is essential, as this is also tied to the ownership of the EVSE as well.

Next will be to provide the ICT support solutions, the primary of which being smart charging solutions for the fleet. Smart charging is an extremely beneficial service for fleets of all sizes, but is of increasing importance as the number of vehicles and charge points increase. Smart charging is a central component of the value proposition for customers, as it can help to continue to drive down fuel costs, as well as address the issue of range anxiety. As the vehicle OEM continues to build a customer base in a given locale, this service will become more and more valuable. At early stages, it can be expected that overnight-depot charging will be the overwhelming strategy for most fleets. However, as demand increases, it may become financially feasible for the vehicle OEM and EVSE supplier to begin offering opportunity charging throughout the city. At this point, with the established software platform, the provider can begin to offer more complex charging solutions that can utilize these charge points during operational hours. With intelligent and connected EVSE, the vehicle OEM can emulate the platform offered by Meshcrafts. The driver would be able to see what stations are nearby and see whether they are available or currently in use, from which the software platform can give intelligent route planning of when and where to charge in order to stay on schedule.

An essential activity will be billing and payment services for the electricity used by the charging stations. If all charging is localized at a single site by a single customer (at a depot), which is the likely scenario at early stages in the market, then this is fairly simple. However, if multiple customers are charging at a single location then a more sophisticated billing service is needed. An example of this may be a consolidation centre, such as the project in Stockholm within FREVUE. These billing services will also be needed in the public charge point future opportunity described above. The ELVIIS project began to explore how this might function in practice. The two key components are to have the ability to identify individual charge points and vehicle owners, and be able to attribute the amount of charging that takes place to the associated customer. In this case QR codes, RFID, or a log-in system will be required in order to match charging with vehicle customers.

The most sophisticated electro-mobility services will be those related to data collection and analysis. These services are more capital intensive to offer initially due to the amount of expert R&D that may be required to develop these services. In section 3.2.8 there was discussion of how software solutions can help to increase fleet efficiency through analytics for route optimisation and by actively measuring the battery state of charge. Vehicle OEMs can anticipate these future system improvements in the vehicle design so a fleet will not have to be retrofitted. Being able to provide these services may require minor hardware components. However, once the software and hardware capabilities are available these services will provide compounding benefits to the fleet customer. Drivers will have greater flexibility in their routes as they will better understand their vehicle and can see how much distance they are able to achieve from the data provided by the battery. These offerings can be combined with the smart charging services to increase operational capabilities and alleviate range anxiety.

A similar yet separate service will be to analyse battery state of health. This originally was hypothesized as a service to users (Pelletier et al, 2014), however if the vehicle OEM is retaining ownership of the vehicle and battery by providing the lease, it will also be in their own interest. As previously described, various charging techniques and strategies, will have an effect on the longevity of the battery. Acquiring data about battery health will better inform the vehicle OEM how the implemented charging strategies are affecting the lifespan of their vehicles. This will also give insight to when batteries need to be replaced and reduce downtime for the fleet operator.

**The key activities performed by the EMSP should be aimed at fulfilling the PSS model objective by addressing the full value chain. The EMSP must of course provide the system components, but what is really attractive to customers is the ability enhance CEV value through complementary services, primarily through data collection and analysis.**

### **Customer Relationships**

In a PSS based business model, especially with a use-oriented approach, the development of a positive working relationship with the customer is pivotal. Establishing trust between the provider and the customer throughout the duration of the service has significant impact on customer loyalty in the PSS context (Reim et al, 2015). In order to ensure this longevity between parties the proposed business model looks to leverage strong communication at each stage.

The first provided service outlined by the canvas is the pre-sale consultation. In order to garner loyalty early on (and to acquire sales), experts consulting for the customer must portray strong interpersonal skills while also displaying in-depth knowledge of the CEV system. This first point-of-contact between the provider and the user will go a long way for establishing trust, as well as convincing the customer of the value proposition.

After the sale has taken place it will be even more important to maintain a strong customer relationship through the online platform. The customer will expect the online services to be highly responsive and customizable to their needs. The customer may also presume that training for the software platform should come standard, and if they have difficulties with usability that they will be able to contact the provider for support. If the software platform is not personable enough for a given need, the customer may prefer to discuss with a consultant, so the provider should have staff available that is able to answer questions regarding the CEV or charging. With larger clients such as a municipality or distribution firm, it would be good practice to designate a single point of contact which will help to build familiarity.

**In this business model the central features are a vehicle lease and a service-oriented approach. These characteristics demand a focus on maintaining positive customer relationships for the length of the contract through service provision. This approach is atypical for the usual vehicle manufacturer business model and will likely require restructuring and institutional learning until the organization becomes used to providing vehicle services rather than vehicles as products.**

## **Channels**

Osterwalder outlines five basic stages that a business model will undergo when interacting via channels with the customer:

- (1) Awareness (often in the form of marketing)
- (2) Evaluation (when customers recognize the Value Proposition)
- (3) Purchase, or point of sale
- (4) Delivery, where the provider conveys the product or service to the customer
- (5) After sales, where the provider continues to contribute in the form of maintenance, billing, or any other form of post-delivery support

The first stage of Awareness can of course occur through typical marketing and sales channels. However, there is opportunity for vehicle OEMs, if coordinating with municipalities looking to meet environmental goals or set emission standards through tools such as LEZs, to have a joint program providing CEVs and charging infrastructure to local businesses. It may be possible to piggyback on the message perpetuated by public authorities in order to garner new customers.

Evaluation holds a particular importance, as this aligns with provision of the pre-sale consultation service offering, therefore being one of the most important stages. This consultation serves several agendas, it is the first opportunity for customers to recognize the value proposition, it helps to determine the products and services a given customer may need, and of course is an effective tool to garner sales and lead into stage 3, Purchase.

Delivery is the most extensive channel of interaction between provider and customer. It begins with the delivery of the key resources and products needed, such as the vehicles, EVSE and software installation. However, delivery will continue for the duration of the service contract, as the use-oriented PSS model is an ongoing relationship with the customer, as the service is delivered daily. For example, ViriCiti not only provides real-time information to drivers, in order for them to make informed decision making on their route, but also gives daily or monthly updates. These updates could include recommendations for improvement to increase efficiency, anomalies in the usage or charging, or analytics on performance. This type of on-going interaction will continually remind customers of the value they are deriving from the service.

After sales includes services such as maintenance, billing or support. As mentioned in Customer Relationships, it can be anticipated that the customer may expect a high level of responsiveness during this stage. As displayed in the Value Proposition diagram, the customer's profitability is driven by their ability to perform as many deliveries as possible and have a high vehicle utilization. If the charging infrastructure or online platform require maintenance and are inhibiting the customer's ability to perform work, it should be handled as expediently as possible.

**The establishment of an online platform for EMSP and fleet operator to interact requires a high level of investment for development. However, once the software intellectual property has been created, it becomes easy to duplicate for each new customer. Client relationship managers will become a key employee group required in maintaining this system.**



## Key Resources

Osterwalder et al, 2010 breaks the key resources a firm will need to deliver a business proposition into four main categories: physical, intellectual, human and financial. Below is a concise list of resources that a vehicle OEM might need to provide the key activities and services described in this business model.

Physical	Financial
<ul style="list-style-type: none"> <li>○ EVSE hardware</li> <li>○ Servers for data collection and analysis</li> <li>○ Office space</li> </ul>	<ul style="list-style-type: none"> <li>○ R&amp;D for software platform and future technologies</li> <li>○ Capital for upfront infrastructure investments</li> <li>○ Wages for installers, programmers, managers and consultants</li> </ul>
Human	Intellectual
<ul style="list-style-type: none"> <li>○ EVSE installation and maintenance</li> <li>○ Software programmers</li> <li>○ Software platform managers</li> <li>○ Consultation experts (pre- and post-sales)</li> </ul>	<ul style="list-style-type: none"> <li>○ Systems understanding of CEV, charging infrastructure, grid and fleet integration</li> <li>○ Algorithms and software platform creation for: <ul style="list-style-type: none"> <li>▪ Smart charging</li> <li>▪ Route optimization</li> <li>▪ Battery management</li> </ul> </li> </ul>

## Key Partners

Partners are selected by their ability to contribute to, “optimization and economies of scale, reduction of risk and uncertainty, acquisition of resources or activity” (Osterwalder et al, 2010). When considering the breadth of the EV value chain, it cannot reasonably be expected that the vehicle OEM will be able to provide each aspect of the chain. Therefore, partners must be strategically selected in order to supplement the gaps that the OEM cannot offer by themselves.

The primary and most pivotal partner will be the EVSE supplier, as the vehicle OEM will likely not have the technical knowledge nor manufacturing capacity to dedicate the time and money to develop the technology itself. The EVSE supplier will also be the most qualified actor to install and maintain the charging infrastructure. Joint teams of CEV experts and EVSE experts may be needed at the consultation stage as well as project delivery to the customer. Working with the EVSE supplier is also essential in order to ensure coordination regarding the important issues on standardisation. To start, vehicle OEMs will drive the demand for which plug types are offered by EVSE suppliers. If the vehicle OEM wants to offer both fast and slow charging services, it will be important to endorse CCS combo plugs with suppliers. Beyond this, the more complicated issue is regarding internal communication protocols between the grid, EVSE and vehicle. In order to provide the suite of electro-mobility services outlined in Key Activities, it is essential for the software elements to be coordinated. By working with EVSE suppliers directly, before projects sales begin, there will be better integration between these system components. Whereas developing a software platform solution after work with customers has already begun will be much more expensive, complex and time consuming.

Section 3.2.5. Grid Integration presented several key challenges when it comes to the provision of charging infrastructure. Some of the foremost barriers include:

- Capital cost for grid upgrades
- Ownership of grid upgrades
- Load planning
- Utility rate structure for high power levels

The vehicle OEM can look to partner with utility companies in order to mitigate some of these issues by creating solutions that create value for both parties. Opportunities such as vehicle-to-grid services provide a common ground for both utilities and electro-mobility service providers to share investment.

Lastly the vehicle OEM/EMSP can look to partner with municipalities in order to provide CEV and charging infrastructure. A municipality that is looking to enact any policy that endorses the reduction of carbon emissions, green logistics, electric vehicles, or related fields, would greatly benefit from private actor partnerships in order to achieve their targets. The partnership does not have to be directly attributable to climate or energy policy, as the municipality can help reduce costs and barriers for the firms in other ways. As displayed by the Frito-Lay case, related elements such as permitting can be a huge hindrance for fleets, and by standardizing or expediting this process with municipalities for charging infrastructure deployment can greatly improve the business case.

**For CEV manufacturers, there are two essential partnerships needed for successful PSS deployment. First, with EVSE suppliers, in order to maintain standardization and offer a robust system to fleet operators. Second, with utilities/grid operators, in order to mitigate the physical challenges and financial costs of the integration of CEVs and charging stations to the electrical grid.**

## **Revenue Streams**

The primary revenue stream in this PSS business model is the vehicle lease. This is advantageous to a typical product sale model as it allows for the vehicle to be turned over multiple times for profit. It also extends the revenue stream to take place over the duration of the contract, rather than a one-time sale. The price premium for a zero-emission logistics solution can still be built into the lease price. This of course includes the charging infrastructure. The main contributors to the lease price are as follows:

- Monthly use of vehicle
- Infrastructure installation and maintenance expenses built in
- Electricity usage
- Online platform fee (modular based on services)
  - Electricity billing and payment (basic free service)
  - Smart charging
  - Route optimization
  - Battery management

Depending on what services the vehicle OEM is able to provide, the ancillary services that are meshed into the online platform can be modular. This also allows a level of customization for the customer based on their fleet needs. The level of complexity of some services may be higher than others, and therefore be more a more expensive service than others. To start, billing and



payment for the electricity is a necessary and simple feature, the energy usage itself will be the main contributor to revenue here. Smart charging services however have a great value add for fleets, making planning more efficient and easy as well as reducing the time or money needed to charge all the vehicles. As the number of CEVs within a fleet increase, so does the complexity of smart charging, so the fee for this service may need to reflect that. Once the intellectual property for route optimization and battery management is built out, this can be a huge contributor to future revenue, as the bulk of capital expense for these services is rooted in the R&D, not the delivery. As mentioned, some larger firms may not need some of these services and elect for a more product-oriented approach and either buy the vehicles and charging infrastructure outright, or purchase a lease only for those components.

A vehicle lease also enables the vehicle OEM to retain ownership of the battery. There is financial potential for second-life use of batteries, whether it is for grid storage or other applications. This extends the value chain of the CEV product-service system even further, by creating a new revenue stream for vehicle batteries that have reached their end of useful life. It is possible for these second-life batteries to even be paired with charging infrastructure, in order to alleviate utility load issues. This is especially beneficial when paired with fast charging EVSE, so the batteries can be charged when electricity is cheap or a vehicle is not connected, which can then be quickly discharged to a vehicle when needed (Persson, phone interview, 3 August 2016). There is also potential for batteries to be re-manufactured and fed back into the production process to create new CEVs. If the vehicle is purchased by the customer rather than leased, a take-back program should be established.

**In the provision of CEVs and charging infrastructure as an electro-mobility service, vehicle OEMs are shifting from a product-oriented to a service-oriented business model. This is beneficial as it extends the length of revenue accumulation, but is challenging as it requires higher initial capital investment on behalf of the OEM. However this can be thought of as a short- to mid-term strategy in order to grow the market and encourage adoption, after which a more typical approach can be utilized in order to reach a wider breadth of the marketplace.**

## Cost Structure

Excluding the CEV, there are two main cost contributors for charging infrastructure within this PSS offering – the EVSE hardware and the support platform. Below is a generalized cost breakdown analysis from Rocky Mountain Institute as part of their ongoing research on EVs and charging infrastructure deployment.

As displayed below, the largest costs associated with the EVSE installation is the hardware and labour. Fast charging infrastructure is in the magnitude of being ten times more expensive across all categories than Level 2 EVSE. Approximately a third of this cost is attributed to the high-power transformer required for fast charging. If the fast charger is sited in a location where this transformer upgrade is not needed, these costs may fall, however the upgraded service for the higher power level discussed in section 3.2.5 will still be needed.

Maintenance is not included in these figures, which can be a significant contributor. As shown in the Frito-Lay case, improper handling or equipment malfunction resulted in a high rate of cable failure, leading to significant replacement and maintenance costs. Operational and maintenance costs include aspects such as demand charges, management time, billing transaction costs, preventative and corrective maintenance, and repairs (New West

Technologies, 2015). The depreciation of EVSE assets must also be recognized, as charging stations like vehicles will require replacement over time.

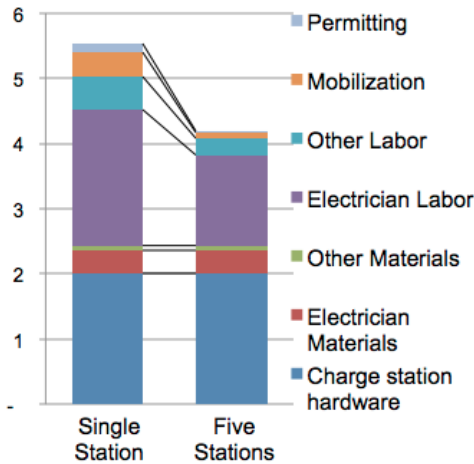


Figure 5-5. Parking Garage Installation – Cost per charger, thousands USD  
Source: Agenbroad and Holland (2014)

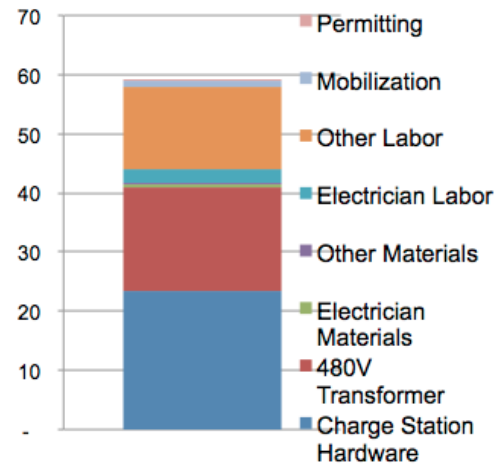


Figure 5-6. Curbside DC Fast Charger Installation – Cost per charger, thousands USD  
Source: Agenbroad and Holland (2014)

Incentive credits are also not included in these figures, which can have a positive effect on the cost calculation. Rebates, tax credits and exemptions, grants and loans provided by national and local regulators can help reduce the total cost of infrastructure deployment (New West Technologies, 2015).

The other major cost contributor, the support platform, has several cost considerations. First and foremost is the R&D costs of developing the intellectual property. This includes the creation of any proprietary algorithms, software, or analytical methods needed to provide smart charging, route optimization, or battery analysis. This also includes soft costs such as time and labour factor of employees to acquire these skills and know-how on charging and electro-mobility services. Also included are hard costs such as maintenance and improvement of the platform over time, as well as the costs associated with data centres in order to process, analyse and store information.

The final and most intangible cost is regarding risk. This refers to both the risk associated with adopting a cutting edge technology under development, as well as the risk associated when pursuing a new business model. In Madina et al. 2016's assessment of EVSE business models, the following reference was made to that point, "on the one hand, there is the risk associated with being the first company to experiment a new business model (Hannon et al., 2013), including the risk of becoming obsolete, if a better solution, resulting from technological development, appears as a competitor in the market (Wiederer and Philip, 2010). On the other hand, they also have the advantage of being able to gain competitive advantage (Bohnsack)" (Madina et al, 2016). However, despite this risk, urban goods distribution is a strong customer segment to focus on due to its inherent characteristics. Distributors need individualized solutions based on their operations and are in need of a depot charging strategy regardless of the current state of technology. Charging stations are the best-available technology and remain an efficient solution for the short to mid-term future. Inductive charging, electric roads and battery swapping still require significant improvements before they are prepared for

commercialization on a large scale. Vehicle OEMs can begin to capture market share and obtain institutional learning by focusing on customer segments that are prepared for a zero-emission logistics solution immediately, and leverage that competitive advantage when changes in technology arise in the future.

**Hard costs in the system are easy to identify; such as R&D, labour, materials and hardware, permitting, etc. The key lesson is for vehicle OEMs to maintain invested in current development of charging technologies as the market expands in case a more efficient approach arises. This is interrelated to the selection of urban goods distribution as the initial customer segment, to help insulated against this risk.**

### 5.3.3 Business Model Adaptation - Refuse Trucks

Refuse trucks can emulate much of the business model canvas derived for urban goods distribution above, however there are some unique aspects that should be considered in order to adapt it for this application. Refuse trucks are often owned and operated by the municipality, rather than a private firm. This provides a big opportunity for synergies between partners. As mentioned, permitting and other soft costs can be an administrative barrier for fleets looking to integrate CEVs. However, since the municipality is also the customer, these challenges will likely be expedited due to their involvement.

Refuse trucks are very similar to electric buses and could replicate the charging strategy currently employed by buses. Refuse trucks follow a designate set of routes and can benefit from infrastructure distributed throughout the city for charging, rather than solely at the depot. Since routes of various refuse trucks would likely have points of overlap, there is a high likelihood that fast charging stations could be employed across the urban service area that could be employed by multiple vehicles. ViriCiti's second largest customer segment after electric buses is refuse trucks for these exact reasons. Their platform works best when routes are repeated so optimization scenarios can be run based on the collected data.

There is even future potential for refuse trucks and buses to share charging infrastructure, which would increase the utilization rate of the capital intensive fast charging stations. This coordination between bus and refuse fleets has high potential as they are both owned and operated by the municipality so joint-scheduling and platform integration would be easier than it would be to coordinate competing urban delivery firms.

## **6 Discussion**

This section serves to cover future considerations and limitations that were not able to be covered by this study. The author reflects on challenges that may be experienced when pursuing the solutions presented, external influences, future opportunities, and credibility of central sources used.

The foremost challenge that must be acknowledged is that vehicle OEMs have not typically pursued service-based business models. Vehicle manufacturer profit is primarily driven by the number of units that can be sold. Company culture and ingrained business strategy will be a significant barrier that will need to be overcome. Further proof of concept through smaller scale pilot projects will continue to be needed in order to endorse larger scale strategy re-structuring by manufacturer. The business model canvas proposed here is a future-oriented approach that provides a suite of options, rather than a clearly defined “best” approach. Further adaptation and experimentation should and will take place in order to find a business model that fits with vehicle OEMs market positioning.

Vehicle OEMs will also need insulate themselves against risk of technological improvement. This study alluded to possibilities with inductive charging, electric roads and battery swapping that may arise to become the dominant and preferred technology. These innovations still have many years until they reach the point for market commercialization, but OEMs will need to actively monitor these technologies and be prepared to adapt strategy based on their progress. This research focused on applications/customer segments that are less likely to utilize these developing technologies in order to mitigate this risk. Vehicle OEMs can also actively participate and contribute to R&D with these technologies to ease the transition and prepare for future integration if they prove viable and more efficient than charging stations.

There is also future complementary solutions and services that may come to fruition as CEVs continue to develop and gain market share. These alternatives present their own challenges and opportunities within the future business model for CEVs. CALSTART has outlined several of these opportunities:

- Establishment of a formal commercial vehicle charging rate
- Performance-based purchase incentives
- Battery lease or extended battery warranty options

The establishment of a CEV charging rate would exorbitantly increase the already attractive value proposition of reduced fuel costs. With increased focus on emission legislation, performance-based incentives for vehicles could see a real rise, of which electric vehicles would benefit greatly from. Lastly, an alternative business strategy to a vehicle lease is to lease the battery only. This would require customer’s purchase the vehicle, but the vehicle OEM would retain ownership of the battery to reduce risk for the customer and make it easier for the OEM to reuse or resell the battery.

A final future opportunity is the integration of renewable energy or battery storage with charging stations. Pairing on-site renewable energy generation with EVSE helps to create a truly “zero-emission” logistics solution. However, the deployment of renewable energy is its own unique challenge and could not be covered fully enough to be included in this study. The same applies to batteries. It was alluded to that batteries no longer able to be used in vehicles could be repurposed for grid storage, however this will intentionally left out as this was being studied by a colleague in tandem to this research. Pairing EVSE deployment with either renewable energy or grid storage can create duplicitous benefits for both types of infrastructure.

This study did not have time to cover in depth how geographical context influences the many factors covered. For one, different countries or regions will have a wide variation of policy that inhibits or endorses CEVs in different ways. There are many city parameters such as, “size, population density, number of businesses (and potential customers) and the architecture of the city,” that may have significant effects on the use profile of the vehicles and may necessitate charging strategy to be adapted to handle these differences (Löfstrand et al, 2015).

At this point the author also means to acknowledge reliance on a few central sources such as CALSTART, 2012, Pelletier et al, 2014 and den Boer et al, 2013. The primary reason for this is that these works were of the few that were focused specifically on providing a comprehensive overview to commercial electric vehicles. Use of these sources was not dependent on numerical figures that may have changed by the writing of this work (2016), so the time-dimension is not a huge negative factor. This work instead looks to leverage these sources for their strong ability to identify conceptual knowledge, trends, and general challenges/barriers in the CEV market.

## **7 Conclusion**

Commercial electric vehicles are on course to enter the market in full force. Their development and uptake has been slow thus far, but the pace is expected to increase as more vehicle manufacturers participate. The technology required to power CEVs are available and ready, but require innovative strategies and business models in order to foster their adoption with users. This study approached research with a high-level systems approach in order to identify barriers in technical integration, social, political and environmental context, and a business implementation perspective.

The first research question looked to identify and discuss the criteria that must be considered when looking to design charging infrastructure strategies and solutions for a commercial electric fleet. In order to accomplish this four main sections were undertaken, an overview of CEVs and their current status, the state of charging infrastructure technology, a showcase of relevant policies and lastly a case study of a potential application. Several central conclusions can be drawn from each of these topic areas.

One of the key identified barriers for CEVs is the high purchase price premium that comes with electric, over conventional diesel. In order to mitigate this, vehicle providers need to be able to display the value of electrification from a total cost of ownership perspective. Lower total cost of ownership is primarily driven by fuel cost savings from electricity over diesel.

For charging infrastructure, a wide range of elements were covered, however several lessons are prominent. The two biggest challenges would likely be grid integration and fleet integration. Grid integration is primarily an issue due to the high capital costs for grid upgrades that often comes with installing charging stations. Conduit, trenching and paying for a higher level of power service can be expected, however paying for a 480V transformer upgrade can significantly impact the business case. Working with utilities and distribution system operators is pivotal in order to solve grid investment issues. The second integration challenge is to smoothly incorporate CEV into existing fleet operations. Charge scheduling and range anxiety can be an issue for fleet operators. Providing service solutions to alleviate these concerns will be a large part of the value proposition.

Policy can be a big enabler for CEVs and charging infrastructure. Municipalities that enact legislation such as low emission zones or congestion charges provide an entry point for CEV development. In countries that provide incentives or tax credits for infrastructure investment, this positive effect is amplified.

Finally, the use profiles of vehicle applications are a central aspect to designing a charging strategy. Focusing on customer segments that are inherently advantageous for CEV operation can bolster CEV uptake. Urban applications are a strategic entry point for vehicle manufacturers to focus on. Applications that have fixed-route and return-to-base attributes such as post & parcel, refuse trucks, and goods distribution are able to utilize the best available technology and provide zero-emission solutions to fleets today. The Frito Lay case was able to highlight specific challenges that are experienced on an individual level. There are simple changes such as the placement of the charging point on the vehicle or driver training that can greatly improve issues with charging. Some of the more complex or costly challenges include the permitting process, component standardisation, interoperability and communication, and a lack of software platform solutions for commercial applications.

## 7.1 Recommendations for Future Research

In section 6 there were several areas discussed that were not able to be covered fully by this study. The foremost recommendation would be to explore how the deployment of complementary infrastructure can be paired with charging stations to improve the value of both. Grid storage and solar energy are both extremely valuable resources in transitioning to a sustainable energy system. Integration between EVSE, grid storage and solar can create compounding benefits for the energy grid and increase overall system efficiency. Better understanding how these technologies influence and interact with one another, as well as beginning to quantify that value, may help to propagate their deployment. Interrelated is also vehicle-to-grid services. V2G was covered as a potential future opportunity for CEV fleet operators to tap into new revenue streams, increase vehicle utilization, and decrease total cost of ownership. V2G services can also be paired with the technologies above to increase the value proposition of CEVs and charging infrastructure.

This study focused on applications that were able to employ current best-available technology. Therefore, the focus was charging stations at the depot. However, as CEVs gain market share there will be a real need for charging stations sited throughout an urban area so that they can take advantage of opportunity charging which will increase range and operational flexibility. Where these sites should be located and how they are selected will be an area that will require investigation in the near future. This could be complemented with how partnerships with municipalities could help with infrastructure deployment.

Another realm for further study may include how the “profile” of the city will effect CEV routes and charge planning. Large metropolises vary from one another and even more so when compared to small to medium sized cities. Cities that are more widespread or have greater traffic congestion will need to be planned for accordingly when optimizing routes or deciding where to site public charging stations.

## 7.2 Final Remarks on the Business Model

This study chose to employ the Osterwalder et al. Business Model Canvas as the central tool for the design. This is a fairly simplified tool and there are other approaches that may capture some of the other complexities that come along with implementing a new business model. The nine major areas that were covered were meant to be the preliminary stages of designing this new model, and could use future investigation in order to be applied to a specific context or company.

However, there are still many useful outcomes from the utilized method. The identification of electro-mobility services needed to complement CEV and charging infrastructure deployment can greatly assist vehicle manufacturers and fleet service providers in designing service offerings. Below are some of the key highlights from the analysis:

### *Ownership*

Finding opportunities for shared ownership between involved stakeholders can help to assist the deployment of charging infrastructure and lower overall system costs.

Involving the utility or distribution system operator is a pivotal partner for EVSE ownership.

### *Value Proposition*

Displaying how CEVs can lower total cost of ownership through fuel cost savings is pivotal.

Offering a centralized and robust platform for all related services for zero-emission truck is a big draw for fleets looking to adopt low-carbon solutions.

### *Key Activities*

Smart charging, fleet integration, route optimisation, automated data collection and analysis are big value-adds for electric fleets.

Future opportunities exist with complementary technologies and services such as solar, grid storage and vehicle-to-grid services.

### *Revenue Streams and Cost Structure*

A PSS approach with a vehicle lease model can help to alleviate customer purchase price concerns while extending the length of revenue accumulation.

CEV providers should anticipate future technology change risk.

The activities and services described in this thesis are by no means exhaustive. As the market continues to mature and develop, it may be required that these services be adapted to anticipate this change, or that entirely new services may present themselves as an opportunity. With new technologies and services, the key to success is constant adaptation and experimentation in order to find efficient, profitable and sustainable solutions.



## List of Interviews

Electrical & Embedded Systems  
Vehide OEM  
14 June 2016

Electro-mobility Product Development  
Vehide OEM  
15 June 2016

Electro-mobility Charging  
Vehide OEM  
15 June 2016

Transport Solutions  
Vehide OEM  
15 June 2016

Electro-mobility Subsystems  
Vehide OEM  
16 June 2016

Electro-mobility Subsystems  
Vehide OEM  
16 June 2016

Jean-Baptiste Gallo  
Senior Project Engineer  
CALSTART  
16 June, 20 July 2016

Route Optimisation  
Vehide OEM  
17 & 22 June 2016

Alternative Fuel Trucking Solutions  
Vehide OEM  
22 June 2016

Asmund Frengstad  
CEO  
Meshcrafts  
28 June 2016

Jan Willem  
CEO  
ViriCiti/Maxem  
28 June 2016

Freek Dielissen  
Managing Director  
ViriCiti  
28 June 2016

Torbjörn Thiringer  
Professor – Energy & Environment  
Chalmers University  
28 June 2016

Eva Sunnerstedt  
Clean Vehicles in Stockholm  
City of Stockholm  
29 June 2016

Anders Fagerholt  
ELVIIS Project Engineer  
Ericsson  
30 June 2016

Mike Roeth  
Trucking Efficiency  
Carbon War Room  
30 June 2016

Mats Alakula  
Industrial Electrical Engineering  
Lund University  
1 July 2016

Anders Grauers  
Professor – Automated Systems  
Swedish Electric and Hybrid Vehicle Centre  
1 July 2016

Christoffer Widegren  
Traffikkontoret Göteborg  
4 July 2016

Elna Holmberg  
Director  
Swedish Electric and Hybrid Vehicle Centre  
7 July 2016

Steve Hanson  
Fleet Manager  
Frito Lay  
21 July 2016

Fredrick Persson  
Project Manager  
Göteborg Energi  
3 August 2016

Frank DeRosa  
Advanced Solutions  
Sun Edison  
10 August 2016

Jens Groot  
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# Appendix

## Appendix Item 1: Medium Duty Commercial BEVs

Model (Manufacturer) (Sources)	GVW (Payload) (Cargo capacity) (Class)	Range (energy consumption)	Top speed	Battery capacity	Charging time and details	Motor power	Price
<b>AMP vehicles</b> (AMP Electric Vehicles) (AMP (2014), NYSEV-VIF (2014))	5,445 kg - 10,660 kg (-) (-) (3 - 6)	(-) (-)	(-)	85 kWh 100 kWh	(-)	120 kW or 160 kW (continuous/peak not specified)	100 kWh battery and 6,350 kg - 8,845 kg GVW range: \$133,000
<b>Boulder 500-series</b> (Boulder Electric Vehicle (Boulder (2013b), Boulder (2013c), NYSEV-VIF (2014))	4,765 kg - 5,215 kg (1,405 kg) (-) (3)	130 km - 160 km (-)	120 km/h	72 kWh	Different options depending on requirements	100 kW continuous 140 kW peak	130,000 US\$ to \$155,000 depending on configuration
<b>Boulder 1000-series</b> (Boulder Electric Vehicle) (Boulder (2013a), (Boulder (2013c))	7,030 kg (2,950 kg) (-) (4)	130 km - 160 km (-)	120 km/h	105 kWh	10 - 12 hours with 220 V. Different options depending on requirements	120 kW continuous 220 kW peak	(-)
<b>eStar</b> (Navistar) (Gallo and Tomić (2013), Davis and Figliozzi (2013))	5,490 kg (1,860 kg) (11.8 m <sup>3</sup> ) (3)	160 km (0.65 kWh/km)	80 km/h	80 kWh	8 hours with 220V	76 kW peak	\$150,000
<b>EVI Walk-in Van and Medium Duty Truck</b> (Electric Vehicles International) (EVI (2013b), EVI (2013a), NYSEV-VIF (2014))	7,255 kg - 10,435 kg (-) (18.7 m <sup>3</sup> - 27.5 m <sup>3</sup> ) (5 - 6)	145 km (-)	105 km/h	99 kWh	6 hours with 220 V / 75 A (16.5 kW)	120 kW continuous 200 kW peak	\$185,000
<b>Ford E450</b> (Motiv Power Systems) (Motiv Power Systems (2014b))	6,575 kg (3,445 kg) (-) (4)	130 km - 195 km (-)	95 km/h	80 kWh 100 kWh 120 kWh	8 hours with on-board charger	150 kW (peak/continuous not specified)	(-)
<b>Modex Box Van</b> (Modex) (Modex (2010))	5500 kg (1530 kg - 2000 kg) (11 m <sup>3</sup> - 15 m <sup>3</sup> ) (3)	95 km - 160 km (-)	80 km/h	(-)	(-)	(-)	(-)
<b>Mule M100</b> (Balqon) (Balqon (2013a), Balqon (2014a))	GVW not available (4000 kg) (-) (6)	240 km unloaded. 160 km loaded. (-)	115 km/h	312 kWh	1) 3 - 4 hours with 100 kW 2) 8 - 10 hours with 40 kW	168 kW peak	(-)
<b>Newton</b> (Smith Electric Vehicles) (Smith Electric (2013), Smith Electric (2011b), Smith Electric (2011c), NYSEV-VIF (2014))	6400 kg - 12000 kg (2800 kg - 7400 kg) (-) (4 - 6)	65 km - 160 km (0.58 kWh/km)	80 km/h	40 kWh 60 kWh 80 kWh 100 kWh 120 kWh	8 hours with on-board charger	134 kW peak	Depending on battery: 60 kWh: \$136,000 80 kWh: \$150,000 100 kWh: \$166,000 120 kWh: \$181,000
<b>PVI L-line Powertrains</b> (Power Vehicle Innovation) (PVI (2014))	3500kg - 7500 kg (-) (-) (2 - 5)	120 km - 160 km (-)	90 km/h	Up to 100 kWh	6 - 7 hours with 20 kW	47 kW continuous	(-)
<b>Zerotruck vehicles</b> (Zerotruck) (Zerotruck (2014), US DOE (2012b))	5,445 kg - 8,845 kg (2,720 kg - 3,175 kg) (-) (3 - 5)	115 km - 200 km (-)	(-)	(-)	Optional 70 kW charger available.	150 kW peak	\$155,000 for class 5 vehicle

## Appendix Item 2. CALSTART eTruck Business Case Calculator

<http://www.CALSTART.org/Projects/htuf/E-Truck.php>

**CALSTART eTruck Business Case Calculator**

**Conventional Diesel Vehicle Information**

Vehicle Life	<input type="text" value="10"/>	years		
Vehicle Class	<div style="border: 1px solid #ccc; padding: 2px;">Class 4</div>			<input checked="" type="radio"/> Driving <input type="radio"/> Work Site
Vehicle Daily Range	<input type="text" value="80"/>	miles/day		
Vehicle Capital Cost	\$ <input type="text" value="65000"/>			
Maintenance Cost	\$ <input type="text" value="0.22"/>	/mile		
Diesel Fuel Price	<input type="text" value="4.478"/>	/gallon		
Fuel Escalation Rate	<input type="text" value="3"/>	%		

**Electric Vehicle Information**

Maximum Charging Power	<input type="text" value="6.60"/>	kW		
Maintenance Cost	\$ <input type="text" value="0.14"/>	/mile		
Electricity Costs	\$ <input type="text" value="0.12"/>	/kWh		
Include Demand Charges?	<div style="border: 1px solid #ccc; padding: 2px;">No</div>			
Demand Charges Cost	\$ <input type="text" value="10.00"/>	/kW		
Electricity Escalation Rate	<input type="text" value="0"/>	%		
Electric Vehicle Capital Cost	\$ <input type="text" value="140000"/>			
Smart Meters	\$ <input type="text" value="0"/>	for 1 vehicle		
EVSE	\$ <input type="text" value="3000"/>	for 1 vehicle		
Panel Upgrade	\$ <input type="text" value="0"/>	/33 kW		
New Conduits	\$ <input type="text" value="0"/>	/33 kW		
Trenching	\$ <input type="text" value="0"/>	/33 kW		
Load Management Software Costs	\$ <input type="text" value="0"/>	per fleet		
Contingency Costs (over 10 vehicles)	\$ <input type="text" value="0"/>	/vehicle		

**Financial Information**

Cost of Capital	<input type="text" value="7"/>	%		
State EV Incentive (HVIP)	\$ <input type="text" value="20000"/>			
Federal EV Incentive	\$ <input type="text" value="0"/>			
EV Infrastructure Incentive	\$ <input type="text" value="0"/>			

**EV Battery Information**

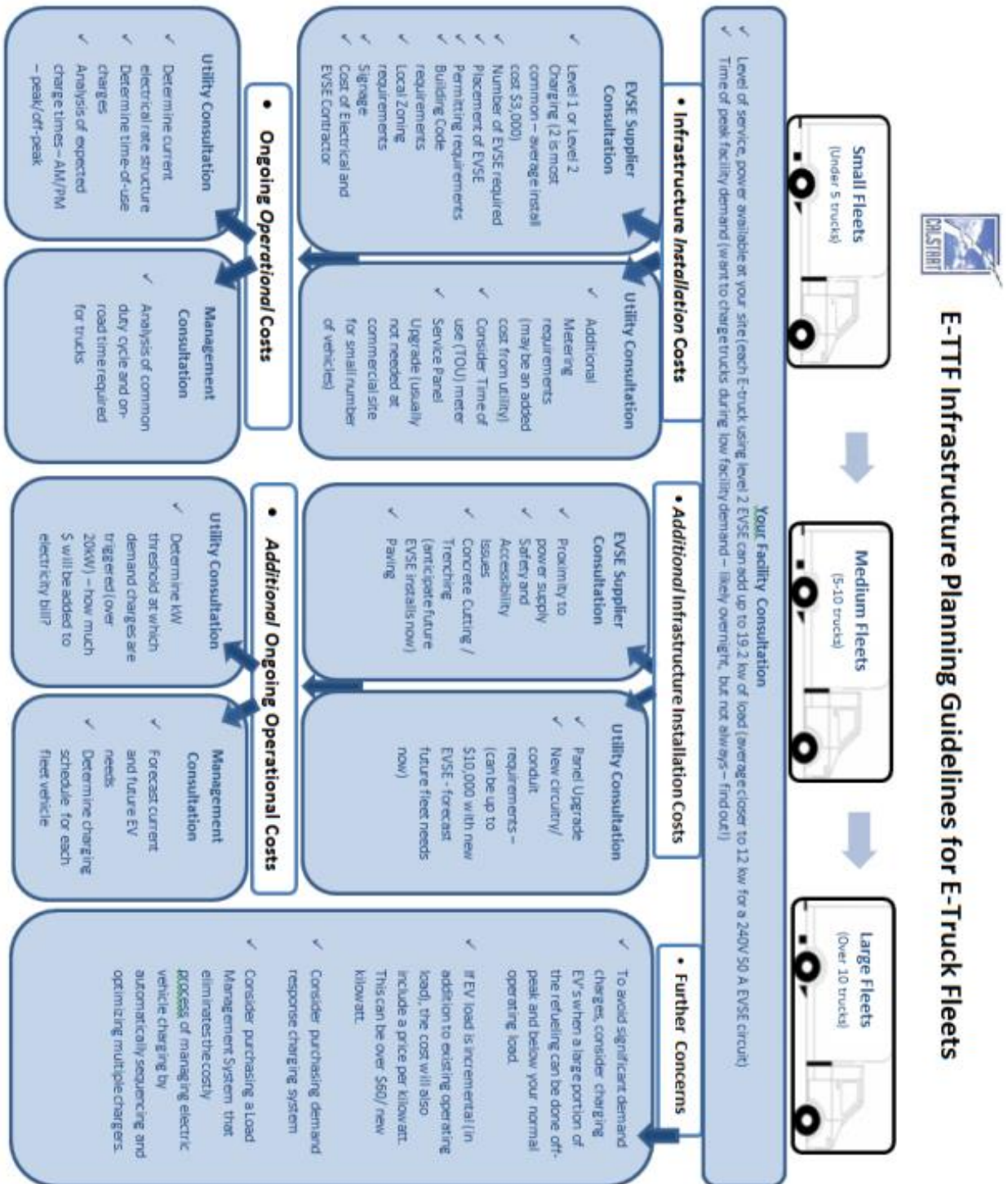
Battery Cost (per vehicle)	\$ <input type="text" value="300"/>	/kWh		
Battery Size	<input type="text" value="67.2"/>	kWh		
End of Life Value	\$ <input type="text" value="0"/>			

**Fleet Information**

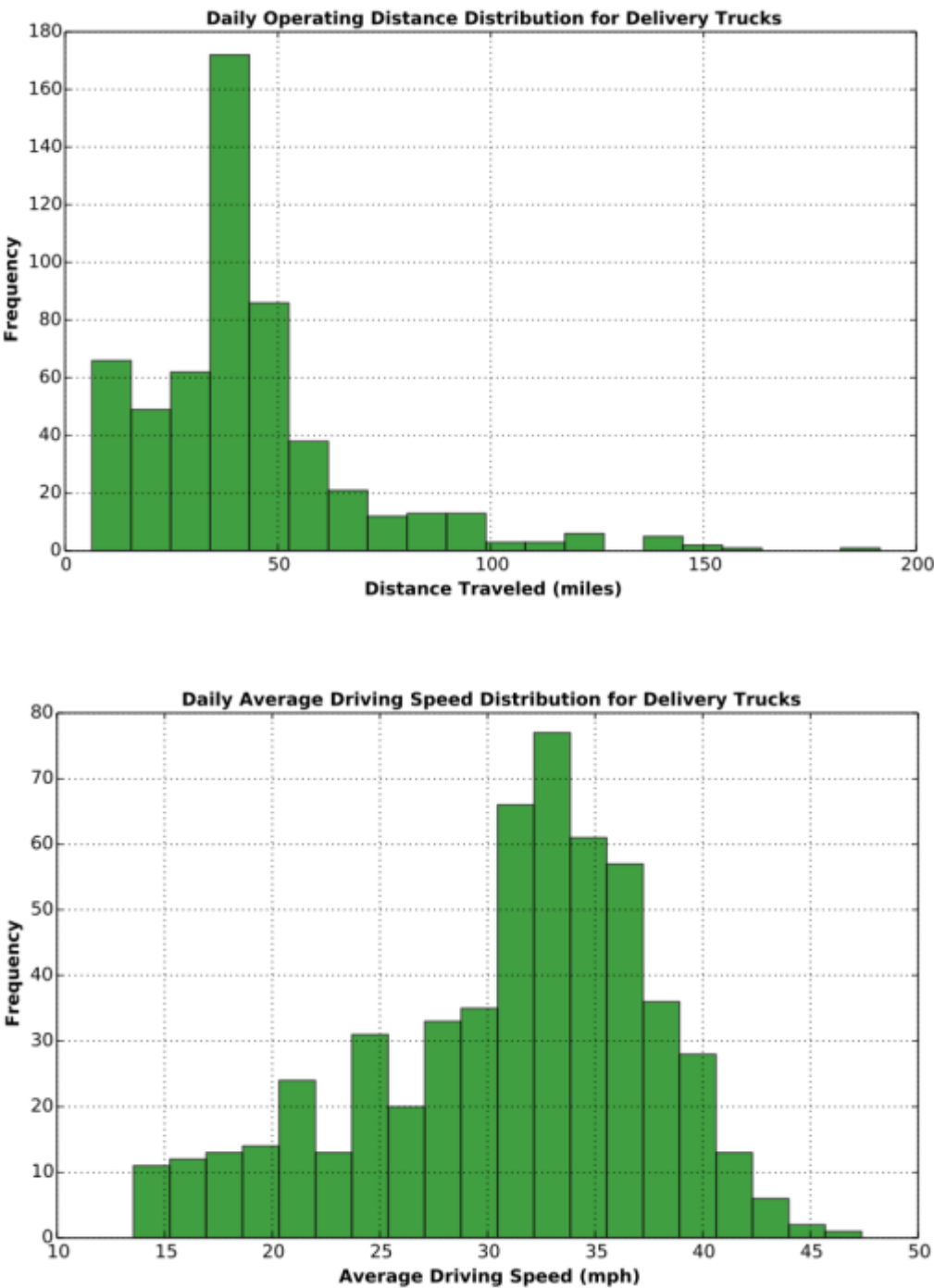
Fleet Size (Number of vehicles)	<input type="text" value="1"/>	
---------------------------------	--------------------------------	--

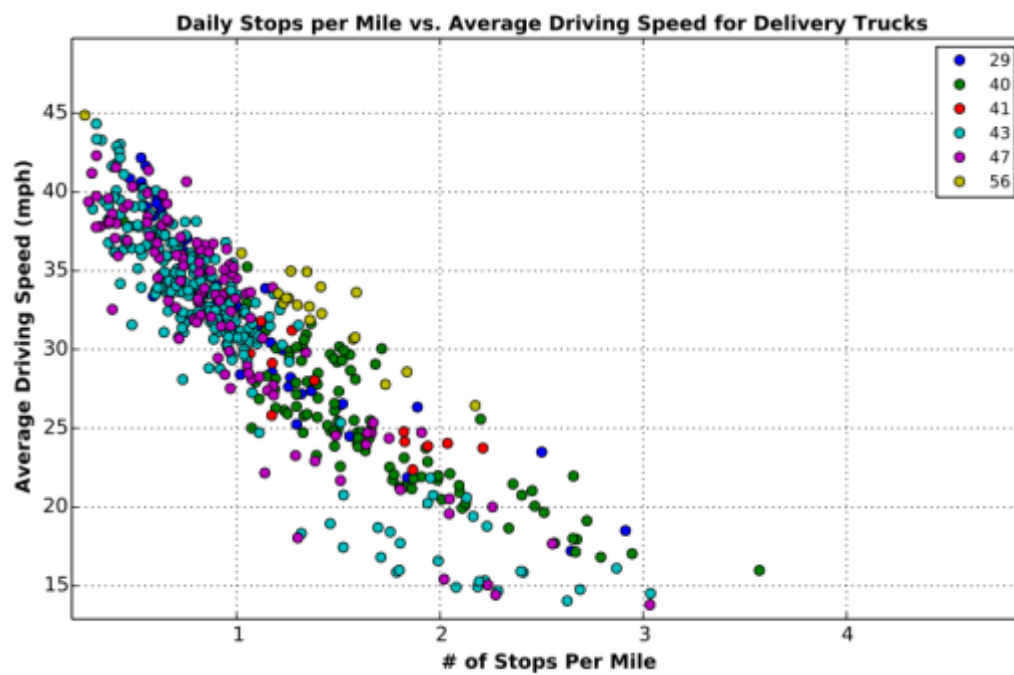
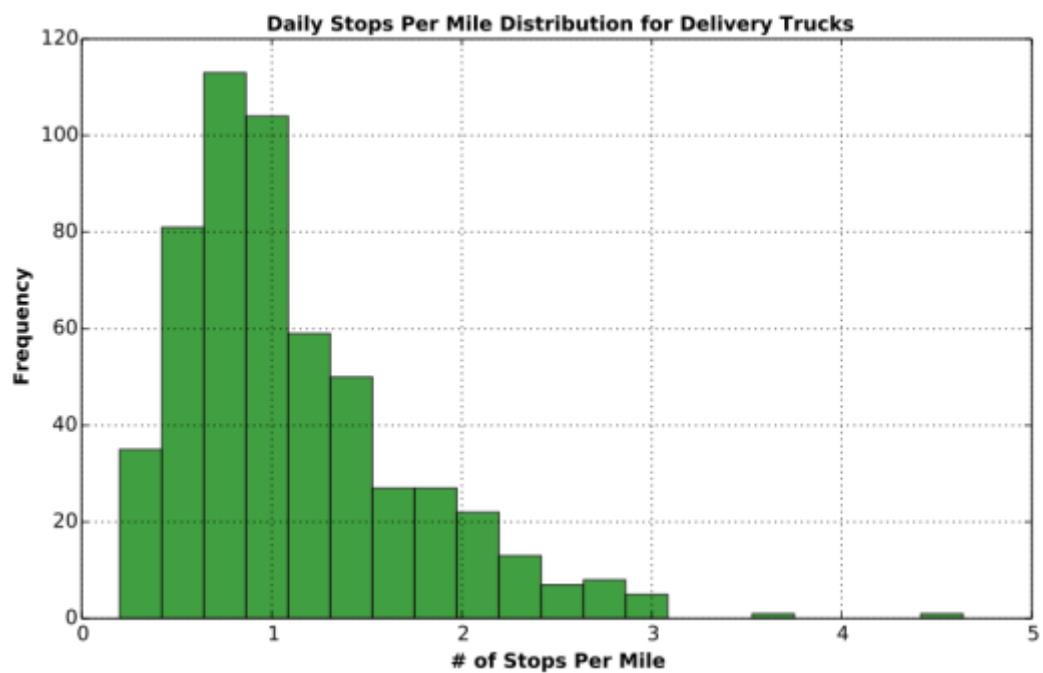


### Appendix Item 3. CALSTART Charging Infrastructure Planning Guidelines



Appendix Items 4. NREL Fleet DNA Data for Delivery Trucks





Appendix Items 5. NREL Fleet DNA Data for Refuse Trucks

