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Battery Electric Vehicles for Goods Distribution: A Survey of Vehicle Technology, Market Penetration, Incentives and Practices

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Abstract. Over the past decade, electric vehicles have gained in popularity in several countries, even though their market share is still relatively low. However, most gains have been made in the area of passenger vehicles and most technical and scientific studies have been devoted to this case. In contrast, the potential of electric vehicular technology for goods distribution has received less attention. The aim of this survey paper is to close some of this gap. Using scientific articles and a host of recent technical reports, the paper provides a survey of the most relevant information needed to assess the current situation and the potential of battery electric vehicles in the goods distribution sector. It presents an overview of the technology involved in such vehicles with a focus on batteries and charging. It describes the available battery electric vehicles and their market penetration. It then analyses under which circumstances these vehicles can become a viable alternative to conventional vehicles and lists some incentives put forward for their adoption. The paper closes with examples of companies and concepts involving electric vehicles for goods distribution, and with some conclusions.

Keywords: Electric vehicular technology, batteries, market penetration, profitability, incentives, green transportation, city logistics.

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1. Introduction

Ever since the introduction of models by global manufacturers at the beginning of the decade, electric vehicles have been gaining increased attention as a way to decrease road transportation pollution. While most of this attention has gone to passenger vehicles, the potential of electric vehicular technology for goods distribution has been somewhat less studied.

While electric delivery vehicles have the ability to significantly decrease greenhouse gas emissions in areas with clean electricity generation sources, this environmental-based business case is harder to make with more coal intensive production, in which case local pollution is simply replaced by upstream emissions (Lee et al. (2013)). However, the benefits resulting from displacing polluting and noise emissions from dense urban areas to more remote areas where power plants are located should not be ignored (Ji et al. (2012)). In addition to these uncertainties surrounding environmental impacts, there exist performance and financial issues associated with integrating electric freight vehicles into distribution schemes. These vehicles typically have significant autonomy and payload limitations and involve much larger initial investments in comparison to internal combustion engine vehicles. However, significant operating savings can be gained through lower energy and maintenance costs, and a wide range of incentives can be offered for integrating electric vehicles into fleet operations.

The objective of this paper is to provide a survey of the most relevant information needed to assess the current situation and the potential of battery electric vehicles for goods distribution. With this goal in mind, Section 2 presents an overview of the technology involved in different types of electric vehicles; Section 3 identifies the key issues pertaining to batteries and charging; Section 4 identifies freight battery electric vehicle models on the market; Section 5 adresses the market penetration of these vehicles; Section 6 aims to determine if they can be a viable option from a financial point of view; Section 7 lists the most common incentives associated with purchasing and operating these vehicles; Section 8 offers examples of companies and concepts involving battery electric vehicles in distribution schemes; and finally conclusions are drawn in Section 9.

2. Electric Vehicle Types

Electric vehicles are generally classified into hybrid electric vehicles (HEVs), battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs). An advantage of BEVs and HEVs is their ability to use their electric motor as an energy generator through regenerative breaking (i.e. to recuperate kinetic energy) and as a form of frictionless breaking (Larminie and Lowry (2003)). FCEVs can also allow for regenerative breaking if a battery is used to assist the fuel cell (Emadi et al. (2005)). When only considering plug-in electric vehicles (PEVs; i.e. electric vehicles whose batteries can be charged by plugging into the electricity grid), vehicles can be divided into battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) (Electrification Coalition (2013b)). Fuel cell electric vehicles can also have a connector for charging their battery packs from the grid (CALSTART (2013b)), in which case they are also PEVs. Although this article will focus much more on BEVs rather than PHEVs and FCEVs, the following are brief descriptions of each of these vehicle technologies.

2.1 Battery Electric Vehicles

A BEV is propelled by one or more electric motors and only uses the power provided by its on-board battery for propulsion (Electrification Coalition (2013b)). The large battery is charged from the electricity grid and the powertrain is simple by design (Tuttle and Kockelman(2012)). Benefits include the absence of tank-to-wheel emissions, high energy efficiency, as well as much less operating noise; technical disadvantages include a relatively low achievable range and the long time required for charging the batteries because of their low energy density (Pollet et al. (2012)). Their motors can produce great torque at low speeds (MacLean and Lave (2003)) and are generally three times more efficient than internal combustion engines (de Santiago et al. (2012)). BEVs have much fewer moving parts than internal combustion engine vehicles (ICEVs) and do not need regular oil changes (Feng and Figliozzi (2013)). In addition, the regenerative breaking allows for less break wear, further reducing the vehicles' maintenance costs (Lee et al. (2013)). Typical ranges for freight BEVs vary from 100 to 150 kilometers on a single charge (Nesterova et al. (2013)) but have been reported to diminish over time due to battery ageing (Taefi et al. (2014)). Factors which temporarily reduce achievable range include extreme temperatures, high driving speeds, rapid acceleration, carrying heavy loads and driving up important slopes (US DOE (2012b)). Battery size and weight will reduce maximum payloads for electric vans and trucks compared to equivalent ICEVs (AustriaTech (2014b)). In several cases, models on the market are conversions of ICEVs where the engine has been replaced by the necessary electric components (US DOE (2012b)). Payload reductions are more significant in converted vehicles than in original equipment manufacturers' (OEM) products because in the latter case the gross vehicle weights (GVW) are simply increased to compensate battery weight (Stewart (2012)).

2.2 Hybrid Electric Vehicles

HEVs can either be classified according to their powertrain architecture (series, parallel, series-parallel, complex), the level of electric power and function of the electric motor (micro hybrid, mild hybrid, full hybrid) or their capacity to be plugged into the electricity grid to recharge their batteries (Chan (2007)). In a series configuration, the internal combustion engine (ICE) is only used to power a generator and the electric motor is the only propulsion component coupled to the final drive shaft, while a parallel configuration allows for both the ICE and the electric motor to be coupled to the final drive shaft and to be used simultaneously or individually (Chan (2007)). Whereas the former offers a simpler design, the latter is more efficient due to fewer energy conversions and to the nonessential sizing of components for maximum power demands (Chan (2007)). A plug-in hybrid electric vehicle (PHEV) is essentially an HEV with a larger battery which can be charged from the electricity grid (Tuttle and Kockelman (2012)). A series PHEV is often referred to as an extended range electric vehicle (EREV) (Tuttle and Kockelman (2012)). EREVs usually function in charge depleting mode, i.e., all the battery's energy is used for propulsion before the engine kicks in to power the generator (CALSTART (2013b)). Parallel PHEVs only allow a short electric range in the lines of 30-60 km with lithium-ion batteries (Chan (2007)), but have a very fuel-efficient hybrid drive (Tuttle and Kockelman (2012)). PHEVs could be a viable transition technology as it allows short trips to be made in electric mode and alternative fuels to be used for longer itineraries (Abdallah (2013)).

2.3 Fuel Cell Electric Vehicles

In an FCEV, a fuel cell generates electricity from hydrogen's chemical energy, from which the output is water; then it either powers the electric motor or charges the battery (Chan (2007)). Fuel cells are electric generation devices, while batteries are electric storage devices (Chan (2007)). A battery can be used in an FCEV to store the electric motor's regenerative breaking energy and to assist the fuel cell during sudden load variations that it cannot handle by itself (Emadi et al. (2005)). The hydrogen must be stored on-board either in gaseous or liquid states, or through physical or chemical adsorption (den Boer et al. (2013)). FCEVs also offer quiet operation thanks to few moving parts (Emadi et al. (2005)), but are less efficient than BEVs since the fuel cell must convert the hydrogen's energy into electricity before powering the electric motor (den Boer et al. (2013)). Neverthless, they are more efficient than ICEVs and fuel cell efficiencies are approximately 50% in terms of the proportion of the hydrogen's energy being converted to electricity (US DOE (2013a)). FCEVs can be refueled in a few minutes and can achieve ranges of several hundred kilometers with compressed gaseous hydrogen storage tanks (Eberle and von Helmolt (2010)). Fuel cells could also be an option for auxiliary power units in conventional heavy-duty vehicles (Emadi et al. (2005)). The cost of FCEVs is still an important market barrier for this technology (Shulock et al. (2011)). Another significant barrier is fuel cell durability, which is currently 10,000 operating hours at best (den Boer et al. (2013)).

3. Batteries and Charging

The main options for batteries in BEVs include lead acid batteries, nickel metal hydride batteries, and lithium-ion batteries (Chan (2007)). Since lithium-ion batteries, compared to other options, have a high energy density (100 Wh/kg), high power density (300 W/kg), long battery life and low memory effect (Lukic et al. (2008)), they are the most commonly used alternative in modern passenger and commercial BEVs. Nickel metal hydride batteries could still be appropriate as a secondary energy source in HEVs (Pollet et al. (2012)), but important limitations due to low specific energy and power in lead acid batteries (Lukic et al. (2008)) should limit their applications in goods distribution. Large automotive battery manufacturers include Panasonic Sanyo, LG Chem, Samsung, Li-tec, Toshiba, and A123 Systems (Bernhart et al. (2014)), just to name a few; for a more exhaustive list of electric vehicle battery manufacturers, see EV-INFO (2014b).

3.1 Forecasted Developments

Batteries are a critical factor in the widespread adoption of electric vehicles since they have a much lower energy density than gasoline (Hannisdahl et al. (2013)). This is mainly caused by the important amount of metals used in their production (den Boer et al. (2013)). Energy densities could potentially be tripled by 2030 with the development of technologies such as lithium-sulfur batteries (Duleep et al. (2011)). The battery pack is also the most costly component in PEVs and significantly augments their purchase cost compared to similar ICEVs (Electrification Coalition (2013b)). However, significant reductions in battery costs are also expected in the next decades, with some predicting a potential reduction by a factor of up to 10 by 2030 compared to 2009 prices (US DOE (2010)). Using lower and upper bounds from several cost estimates for BEV lithium-ion batteries in the last few years gives the following past and forecasted cost interval estimates: \$1000-\$1200 per kWh in 2008 (Electrification Coalition (2013b), IEA and EVI (2013), Howell (2011)), \$700-\$1000 per kWh in

2010-2011 (Khaligh and Li (2010), Shulock et al. (2011), Howell (2011)), \$500-\$800 per kWh in 2012-2013 (Electrification Coalition (2013b), IEA and EVI (2013), Davis and Figliozzi (2013), Hensley et al. (2012)), \$200-\$500 per kWh in 2020 (Electrification Coalition (2010), Mosquet et al. (2011), Shulock et al. (2011), Hensley et al. (2012)). These improvements will be due to both technological advancements and increased production volumes (IEA (2011), Hensley et al. (2012)). Nevertheless, there is much uncertainty in these estimates, as shown by Figure 1 in which Stewart (2012) has averaged battery cost projections from 18 different sources, showing the significant variance that exists among various battery cost projections due to assumptions made on future developments.

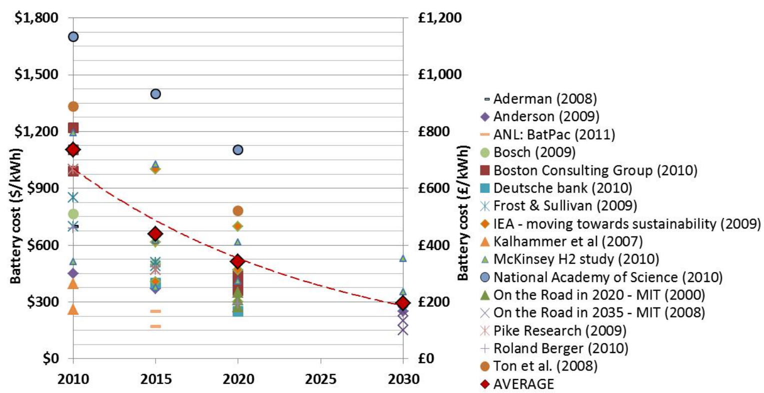

Figure 1: Summary of battery pack cost projections 2010-2030, source : (Stewart (2012), p.30)

3.2 Battery Life

Batteries are considered to no longer be suitable for PEVs when their capacity has been reduced to 80% of the original value (McMorrin et al. (2012)). Deep cycle life refers to the amount of times a battery can withstand discharging to low state of charge levels, while shallow cycle life is rather the number of times a battery can withstand small state of charge variations (Duleep et al. (2011)). Many battery manufacturers have reached 200,000 cycles for shallow cycle life (Duleep et al. (2011)). Lithium-ion batteries in current freight BEVs used typically provide 1,000 to 2,000 deep cycle life, which should last around six years (den Boer et al. (2013), AustriaTech (2014b)). Some freight BEV manufacturers claim that the batteries in their vehicles have already surpassed 2,000 deep cycle life. For example, Smith Electric Vehicles claim that the lithium-ion batteries used in their Newton battery electric truck already achieve 3,000 cycles at 100% depth of discharge (DOD) (Fleet News (2010)), while Balqon refers to 2,500 cycles at 80% DOD and 5,000 cycles at 70% DOD for its Mule M100 battery electric delivery truck (Balqon (2013a)). Some manufacturers expect a 4,000 to 5,000 deep cycle life within 5 years (den Boer et al. (2013)), but there are often trade-offs to be made between different lithium based battery chemistries (Duleep et al. (2011)). For example, lithium-titanate batteries already reach 5,000 full discharge cycles, but have lower energy densities than other lithium-ion technologies (Botsford and Szczepanek (2009)). Calendar life, on the other hand, is a measure of natural degradation with time and was in the 7-10 years range as of 2010 with a projected range of 13-15 years by 2020 (Duleep et al. (2011)). Typical battery warranty lengths for electric trucks have been reported as being in the three to five years range (Pitkanen and Van Amburg (2012)).

3.3 Battery Degradation

Battery health can be influenced by the way they are charged and discharged. For example, frequent overcharging (i.e., charging the battery close to maximum capacity) can affect the battery's lifespan (Sweda et al. (2014)), just as can keeping the battery at high states of charge for lengthy periods (Electrification Coalition (2010)). As expressed through deep cycle life, battery deterioration can also occur if it is frequently discharged to very deep levels (Millner (2010)). This generally implies that only 80% of the marketed battery capacity is actually usable (den Boer et al. (2013), Valenta (2013)). Using high power levels to quickly charge batteries could also have negative impacts on battery life, especially if used in the beginning and end of the charging cycle (Zhang (2006)). However, there is still much uncertainty about the efficacy of using high power levels on battery life (Hatton et al. (2009)), and recent testings suggest the negative impact of high power rates on BEV batteries is overestimated (Idaho National Laboratory (2014)). The uncertainty regarding the effect of extreme operational temperatures on lithium batteries is another issue that should be further considered (Duleep et al. (2011)). All these potential deteriorating factors can speed up the reduction of maximum available battery capacity, hence shortening vehicle range and battery life (Electrification Coalition (2010)). Besides technology improvements, one way to prolong battery life and reduce their size could be to use them in a hybrid power source alongside ultracapacitators, which have much higher power densities than batteries (Khaligh and Li (2010)). Having to replace the battery during the vehicle's life can seriously impact the business case of BEVs for distribution applications, thus highlighting the importance of minimizing battery deterioration through good charging and discharging habits.

3.4 Battery Charging

The most common way of charging the battery is conductive charging, thus implying the need of a cable and vehicle connector (Yılmaz and Krein (2013)). Charging modes are defined by the safety communication protocol between the vehicle and the charging equipment, while charging types refer to the connector used. Overviews of modes and connectors variations can be found in Cluzel et al. (2013) and Naberezhnykh et al. (2012b). Charging levels are divided according to the power rate used to charge the battery, and different classifications can be used according to nationally available power levels (Haghbin et al. (2010)). Yılmaz and Krein (2013) refer to three levels based on SAE Standard J1772: level 1 (1.4 kW to 1.9 kW), level 2 (4 kW to 19.2 kW) and level 3 (50 kW to 100 kW), also referred to as fast charging.

Conductive chargers can either be on-board or off-board the vehicle, with unidirectional or bidirectional power flow (Yılmaz and Krein (2013)). For an overview of opportunities and barriers regarding vehicle-to-grid technology (i.e. sending energy back into the grid via bidirectional power flow), see Tomić and Kempton (2007), Kempton and Tomić (2005) and Tanguy et al. (2011). 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 (Haghbin et al. (2010)). Level 3 charging therefore uses an external charger to directly supply the battery with direct current, while in level 1 and 2 charging, the on-board charger is fed alternating current before converting it to direct current (Botsford and Szczepanek (2009)). Integrating the charger into the electric powertrain is an option to allow on-board charging without the weight, space and cost constraints (Haghbin et al. (2010)).

Higher power levels typically imply lower charging times but higher equipment costs; while level 1 charging can be supplied with a convenience outlet, levels 2 and 3 require dedicated electric vehicle supply equipment (EVSE) and are the viable options for non-residential charging stations (Yılmaz and Krein (2013)). Level 2 EVSE can cost as low as $1,860 to as high as $14,400 including installation costs (Lee et al. (2013)), while DC fast charging EVSE can cost between $20,000 and $50,000 for the units alone (US DOE (2012b)). An overview of a few EVSE manufacturers and products can be found in Valenta (2013), Tanguy et al. (2011), and May and Mattila (2009).

Regarding non-residential charging infrastructures, the IEA and EVI (2013) provide information on public charging infrastructures in several countries. Their report shows that the preferred power levels for non-residential charging stations vary from country to country. For example, Japan, more than any other country, has focused on fast (level 3) charging stations, while the US has focused on slower (level 2) charging stations and the Netherlands has tried to provide a balanced mix of both. The report notes that the importance is to tailor the charging network according to local needs. A larger charging infrastructure is considered to be a factor which could significantly increase adoption of electric vehicles in road transportation, and the large investments required to provide this infrastructure makes locating the right number of stations at the right places crucial (Touati-Moungla and Jost (2012)). For this reason, quite a few studies have considered the problem of optimally locating electric vehicle charging infrastructures (Chen et al. (2013), Wang et al. (2010), Hess et al. (2012), He et al. (2013), Xu et al. (2013), González et al. (2014), Nie and Ghamami (2013), Dong et al. (2014), Frade et al. (2011), Jia et al. (2012)).

Concerning charging times, charging BEVs' batteries with cables and connectors varies largely depending on the size of the batteries and the equipment used (US DOE (2012b)). For example, the passenger BEV Nissan Leaf with its 24 kWh battery can be charged in 12-16 hours with a 1.8 kW charger, 6-8 hours with 3.3kW charger, and 15-30 minutes with 50 kW fast charger (Yılmaz and Krein (2013)). On the other hand, a battery electric truck with a 120 kWh battery would require a charging power level of 15 kW to be able to charge in 8 hours, and the same vehicle with a battery pack of 200 kWh would require a power level of 400 kW to be able to be charged in 15-30 minutes (den Boer et al. (2013)). Some EVSE manufacturers already offer power levels up to 250 kW for fleet solutions (AeroVironment (2011)). The marketed time for fast charging the vehicle's battery is usually for 80% of maximum capacity. This is because battery charging times are not linear during the entire charging process. As Bruglieri et al. (2014, p.20) point out, "the first phase allows to recharge the battery almost fully and it is linear with respect to time. The second phase is not linear with respect to time and can require some hours to achieve the full charge of the battery and to ensure a uniform recharge of all the cells that compose the battery".

In most cases where BEVs are used for goods distribution, they are mainly charged at depots overnight and do not use public charging stations other than during drivers' lunch breaks (Nesterova et al. (2013), Naberezhnykh et al. (2012b), Taefi et al. (2014)). This can be explained by the need to make effective use of driver time and by security concerns (Naberezhnykh et al. (2012b)). Also, charging during off-peak hours can allow for reduced electricity rates (Mock and Yang (2014), Botsford and Szczepanek (2009)). Furthermore, fast charging would be required to charge vehicles outside the depot (Naberezhnykh et al. (2012b)), but important fast charging infrastructures remain relatively scarce in most countries except Japan (IEA and EVI (2013)) and frequently using fast charging during delivery routes could potentially reduce battery life (Taefi et al. (2014)). However, as mentioned previously, this effect may not be that significant, and some expect upcoming improvements in batteries' ability to withstand high power level charging (Hatton et al. (2009)). Even so, the high cost associated to level 3 EVSE is still a significant barrier to a wider adoption of fast charging (Hatton et al. (2009)), and the impact of the high power demand from the electricity grid is another issue to be considered (Dharmakeerthi et al. (2014)). This could limit the amount of vehicles in a depot which could simultaneously be charged with high power levels (Etezadi-Amoli et al. (2010)), potentially requiring further investments for transformer upgrades (Electrification Coalition (2010)). Nevertheless, fleets using electric vehicles should have access to level 2 or 3 charging so that reasonable charging times allow high vehicle utilization rates needed to take advantage of the vehicles' lower operating costs (Finlay (2012)).

3.5 Other Charging Methods

While conductive charging is by far the most common method for charging electric vehicle batteries, there are a few other options as well, such as inductive charging and battery swapping. Another option for powering larger electric vehicles is overhead catenary wires. Following are very brief overviews of each of these alternatives.

Inductive charging involves transferring the power to the battery magnetically via an on-board charger, thus eliminating the need for cables and chords (Yılmaz and Krein (2013)). Stationary inductive charging would be used to charge the battery while the vehicle is stopped, such as on garage floors, in parking lots or at bus stops, while in-road inductive charging could allow for charging the battery or powering the electric motor even while the vehicle is in motion (den Boer et al. (2013)). Infrastructure costs and acceptable efficiencies are concerns surrounding in-road charging (den Boer et al. (2013)), not to mention the business model that would need to be elaborated for accessing it (CALSTART (2013b)). However, the concept of providing power to the vehicle while it is in motion could allow battery sizes to be reduced in electric vehicles since the energy is supplied directly through the roadway (Wu et al. (2011)). Another advantage of inductive charging is the complete absence of risk of electric shock (Chawla and Tosunoglu (2012)). Electric buses could be ideal candidates for both types of inductive charging, but the power necessary for several trucks traveling close to each other could be problematic for a wider application of in-road charging in freight transportation (CALSTART (2013a)).

Battery swapping is a concept that involves using automated battery swapping stations which remove the depleted battery and insert a fully charged one (CALSTART (2013b)).

This would allow rapidly getting a fully charged battery (Hatton et al. (2009)) and could reduce the price premium of electric vehicles since the battery is no longer purchased with the vehicle (den Boer et al. (2013)). Users could also more easily take advantage of anticipated battery technology improvements (Mak et al. (2013)). However, major technical barriers include the space and cost associated with the large stock of batteries needed, huge infrastructure costs for the swapping stations, the necessary standardisation of vehicles and batteries, and the risk of battery damage from excessive swapping (Mak et al. (2013), Hatton et al. (2009), CALSTART (2013b), den Boer et al. (2013), Hazeldine et al. (2009)). The stations would also need to recharge a very large amount of batteries at the same time, which could impact the electric grid (Mak et al. (2013)). Better Place was considered a frontrunner in the battery swapping industry but it recently filed for bankruptcy (Fiske (2013)).

Finally, using catenary wires as a power supply would only be a viable option for heavy electric trucks on highly used freeways, and would involve overhead wires being charged with electricity and a truck using a pantograph device to slide along the wires and retrieve the power (CALSTART (2013b)). It is particularly interesting for catenary hybrid trucks, as it would allow for them to be in electric drive on highly occupied corridors where the catenary wires would be located, while still achieving reasonable ranges for local and regional movements (Neandross et al. (2012)). This option would also reduce the need for large batteries while allowing additional payload capacity and unlimited range when connected to the wires (den Boer et al. (2013)). Despite these advantages and the fact that it is a well-known technology, infrastructure costs, business models for access, and visual pollution are significant barriers for a wider application in freight transportation (CALSTART (2013b)).

4. Freight Battery Electric Vehicle Models

Several global vehicle manufacturers began producing passenger plug-in electric vehicles in 2010 (Tuttle and Kockelman (2012)), but smaller manufacturers have been producing BEVs in many segments before this (Sierzchula et al. (2012)) and there are BEVs available in many vehicle classes used by the logistics sector (Element Energy (2012)). However, manufacturers of heavy-duty BEVs are still quite scarce. This section will present the basic features of a few notable battery electric vans and trucks most likely to be used in distribution applications. Intervals for vehicle weight and payload are results of different available options regarding chassis, bodies, lengths, battery sizes, wheelbase dimensions and roof heights. Similarly, approximate achievable range is subject to vary due to such factors as battery capacity, driving habits, road conditions, vehicle configurations, auxiliary usage and loads carried. All values regarding weights and distances have been rounded to the nearest multiple of five. Fast charging times (typically 15 to 30 minutes) are always for 80% of maximum battery capacity. All battery chemistries are lithium based unless otherwise specified.

All technical specifications come from manufacturers' websites whenever possible. For unavailable information directly on manufacturer websites, previous overviews of electric vans and trucks can be useful for complementary technical information, such as Finlay (2012), Nesterova et al. (2013), Naberezhnykh et al. (2012a), AustriaTech (2014a), Electrification Coalition (2010), Valenta (2013), TU Delft et al. (2013)). Furthermore, some models have recently been discontinued due to manufacturers' financial difficulties or restructuring plans; these include Azure Dynamics' Transit Connect Electric in 2012 (Schmouker (2012), Navistar's eStar in 2013 (Truckinginfo (2013)), and Modec's Box Van in 2011 (Birmingham Post (2011), Shankleman (2011)). Other resources for quickly finding BEV and PHEV manufacturers in all vehicle segments include EV-INFO (2014a), US DOE (2014a), and Plug In America (2014). Valuable sources for vehicle prices include Source London (2013) and New York State Energy Research and Development Authority (2014), refered to as SL (2013) and NYSEV-VIF (2014) in the tables. Some models' prices are simply not available, most likely because, as Lee et al. (2013, p.8025) point out, "commercial vehicle prices can vary depending upon negotiation between fleet operators and truck manufacturers, and truck volumes to be purchased". This could also imply that the prices listed here could vary depending on specific purchasing contexts.

Segmentation is based on US vehicle classes by gross vehicle weight (GVW), as shown in Figure 2. Classes have also been grouped accordingly into three groups: light duty vehicles (classes 1-2), medium duty vehicles (classes 3-6), and heavy duty vehicles (classes 7-8). Tables 1 to 4 present overviews of typical battery electric van and truck models and powertrains which could be used in goods distribution applications for each of the above mentioned groups.

Gross Vehicle Weight Rating (lbs)	Federal Highway Administration		US Census Bureau
	Vehicle Class	GVWR Catagory	VIUS Classes
<6,000	Class 1: <6,000 lbs	Light Duty <10,000 lbs	Light Duty <10,000 lbs
10,000	Class 2: 6,001–10,000lbs		
14,000	Class 3: 10,001–14,000 lbs	Medium Duty 10,001–26,000 lbs	Medium Duty 10,001–19,500 lbs
16,000	Class 4: 14,001–16,000 lbs		
19,500	Class 5: 16,001–19,500 lbs		
26,000	Class 6: 19,501–26,000 lbs		Light Heavy Duty: 19,001–26,000 lbs
33,000	Class 7: 26,001–33,000 lbs	Heavy Duty >26,001 lbs	Heavy Duty >26,001 lbs
>33,000	Class 8: >33,001 lbs		

Figure 2: Segmentation of commercial vehicles by GVW, source (US DOE (2014c))

Table 1: Light 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**
Berlingo Electric (Citroën) (Citroën (2014), EV-world (2013))	(-) (695 kg) (3.7 - 4.1 m^3) (1)	170 km (-)	110 km/h	22.5 kWh	1) 30 min. fast charge with 380 V 2) 8 hours with 230 V/14 A (3.2 kW) 3) 15 hours with 230 V/8 A (1.8 kW)	49 kW peak	£21,300
Ecomile (I'Moving) (I'Moving (2014a), SL (2013), Green Waco (2008))	2,100 kg (935 kg) (-) (1)	120 km (-)	80 km/h	150 Ah with 96 V	8 hours with 3.2 kW	19 kW continuous 28 kW peak	£35,100†
Edison (Smith Electric Vehicles) (Smith Electric (2011a), SL (2013))	3500 kg - 4600 kg (820 kg - 2500 kg) (-) (2)	90 km - 160 km (0.31 kWh/km)	80 km/h	36 kWh 40 kWh 51 kWh	1) 6 - 8 hours with on-board charger 2) 4 hours with optional fast charger	90 kW (peak/continuous not specified)	£50,500
Electron (Fraikin and Fiat) (Geodis (2014))	3500 kg (1000 kg) (20 m^3) (2)	105 km - 155 km (-)	90 km/h	(-)	6 - 8 hours	(-)	(-)
e-NV200‡ (Nissan) (Nissan (2014b), Nissan (2014d))	2,220 kg (615 kg - 705 kg) (4.2 m^3) (1)	170 km (0.165 kWh/km)	120 km/h	24 kWh	1) 30 min. fast charge with 50 kW 2) 4 hours with 6.6 kW 3) 10 hours with 3.3 kW	80 kW peak	£14,000 with battery leasing starting at £60/month or £17,000 with battery ownership†
Jolly 2000 (I'Moving) (I'Moving (2014b), SL (2013))	3,500 kg (1,820 kg) (-) (2)	110 km (-)	80 km/h	150 Ah with 256V	6 hours	30 kW continuous 40 kW peak	£49,950†
Kangoo Z.E and Kangoo Maxi Z.E (Renault) (Renault (2014c), Renault (2014b), Renault (2014a))	Kangoo Z.E 2125 kg (650 kg) (3 - 3.5 m^3) (1) Kangoo Maxi Z.E 2175 kg (650 kg) (4 - 4.6 m^3) (1)	170 km (0.155 kWh/km)	130 km/h	22 kWh	1) 6 - 9 hours with dedicated EVSE 2) 10 - 12 hours with regular socket	44 kW peak	£17,000 for Z.E. and £18,000 for Maxi Z.E. with battery leasing starting at £60/month
Maxity (Renault/PVI) (Renault Trucks (2011b))	4,500 kg (2,000 kg) (-) (2)	Average range above 100 km (-)	90 km/h	40 kWh	(-)	47 kW (peak/continuous not specified)	(-)
Mega e-Worker (Aixam Mega) (Aixam Mega (2014a), Aixam Mega (2014b))	1,900 kg (630 - 870 kg) (approx. 3 m^3) (1)	60 km - 110 km (-)	40 km/h	8.6 kWh 11.5 kWh 17.3 kWh	8 - 12 hours (depending on capacity)	(-)	(-)
Mia U (Mia Electric) (TU Delft et al. (2013), Torregrossa (2014), SL (2013))	1,195 kg (350 kg - 430 kg) (-) (1)	130 km (-)	105 km/h	(-)	3 - 5 hours with 230 V	(-)	£17,000†

†After application of UK plug-in van grant (20% of cost)

‡Nissan is also developing an all-electric light truck, the e-NT400 (Nissan (2014c))

Table 2: Light Duty Commercial BEVs (continued)

Model (Manufacturer) (Sources)	**GVW (Payload) (Cargo capacity) (Class)**	**Range (energy consumption)**	**Top speed**	**Battery capacity**	**Charging time and details**	**Motor power**	**Price**
Minicab i-MiEV (Mitsubishi Motors) (TopSpeed (2012), Mitsubishi Motors (2011))	1090 - 1110 kg (350 kg) (-) -1	100-150 km (0.125 kWh/km)	115 km/h	10.5 kWh 16 kWh	Depending on capacity: 1) 15 - 35 min. fast charge with 200 V (50 kW) 2) 4.5-7 hours with 200V/15A (3 kW) 3) 14-21 hours with 100V/15A (1.5 kW)	30 kW peak	2,400,000 yens - 2,971,000 yens
Partner Panel Van (Peugeot) (Peugeot (2014), Nesterova et al. (2013))	2225 kg (635 kg) (3.3 m^3) (1)	170 km (0.139 kWh/km)	110 km/h	22.5 kWh	1) 35 min. fast charge with EVSE 2) 8 hours with EVSE 3) 12 hours with standard outlet	49 kW peak	£21,300
Peugeot eBipper (converted by Allied Electric) (Allied Electric (2014a), SL (2013))	1700 kg (350 kg) (-) (1)	100 km (-)	100 km/h	20 kWh	1) 3 hours with three-phase power 2) 8.5 hours with single-phase power	15 kW continuous 30 kW peak	£41,000
Peugeot eBoxer (converted by Allied Electric) (Allied Electric (2014b), SL (2013))	3,500 kg (800 kg - 895 kg) (-) (2)	155 km (-)	100 km/h	56 kWh	10.5 hours with three-phase power	30 kW continuous 60 kW peak	£58,000
Peugeot eExpert (converted by Allied Electric) (Allied Electric (2014c), SL (2013))	2930 kg - 2965 kg (660 kg - 665 kg) (-) (2)	155 km (-)	105 km/h	43 kWh	1) 8.5 hours with three-phase power 2) 14.3 hours with single-phase power	30 kW continuous 60 kW peak	£51,000
Peugeot ePartner (converted by Allied Electric) (Allied Electric (2014d))	2185 kg (680 kg) (-) (1)	95 km (-)	100 km/h	27 kWh	1) 5.2 hours with three-phase power 2) 9 hours with single-phase power	15 kW continuous 30 kW peak	(-)
Smile (I'Moving) (SL (2013), I'Moving (2014c))	1100 kg (365 kg) (-) (1)	110 km (-)	45 km/h	(-)	(-)	4 kW continuous 9 kW peak	£14,200
Transit Connect Electric (Ford/Azure Dynamics) (Azure Dynamics (2011), Dolan (2010), Bunkley (2010))	2,270 kg 465 kg (3.8 m^3) (1)	80 km - 130 km (-)	120 km/h	28 kWh	6 - 8 hours with 240V/30A (7.2 kW)	52 kW continuous 105 kW peak	$57,400
T-truck (Comarth) (Comarth (2014))	1,460 kg (635 kg) (-) (1)	Up to 120 km (-)	45 km/h - 60 km/h (depends on motor)	9 kWh 13 kWh	1) 1 hour with 380 V/32 A (12.2 kW) 2) 4 hours with 220 V/16 A (3.5 kW)	1) 5.4kW 2) 8.5 kW (peak/continuous not specified)	(-)
Vito E-cell (Mercedez-Benz) (Mercedes-Benz (2012))	3,050 kg (850 kg) (5.7 m^3) (2)	130 km (0.22 kWh/km)	80 km/h	36 kWh	1) 5 hours with 400V 2) 10 hours with 230V	60 kW continuous	(-)

Table 3: 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**
AMP vehicles (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: $133,000
Boulder 500-series (Boulder Electric Vehicle (Boulder (2013b), Boulder (2013c), NYSEV-VIF (2014))	4,765 kg - 5,215 kg (1,405 kg) (-) (3)	130 km - 160 km (-)	120 km/h	72 kWh	Different options depending on requirements	100 kW continuous 140 kW peak	130,000 US$ to $155,000 depending on configuration
Boulder 1000-series (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	(-)
eStar (Navistar) (Gallo and Tomić (2013), Davis and Figliozzi (2013))	5,490 kg (1,860 kg) (11.8 m^3) (3)	160 km (0.65 kWh/km)	80 km/h	80 kWh	8 hours with 220V	76 kW peak	$150,000
EVI Walk-in Van and Medium Duty Truck (Electric Vehicles International) (EVI (2013b), EVI (2013a), NYSEV-VIF (2014))	7,255 kg - 10,435 kg (-) (18.7 m^3 - 27.5 m^3) (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
Ford E450 (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)	(-)
Modec Box Van (Modec) (Modec (2010))	5500 kg (1530 kg - 2000 kg) (11 m^3 - 15 m^3) (3)	95 km - 160 km (-)	80 km/h	(-)	(-)	(-)	(-)
Mule M100 (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	(-)
Newton (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
PVI L-line Powertrains (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	(-)
Zerotruck vehicles (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

Table 4: Heavy 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**
All-electric refuse truck (Motiv Power Systems) (Motiv Power Systems (2014a))	27,215 kg (9000 kg) (15.3 m^3) (8)	95 km (-)	80 km/h	200 kWh	8 hours with 60 kW Vehicle-to-grid capable	280 kW (peak/continuous not specified)	(-)
e-Truck (emoss) (EMOSS (2014))	10,000 kg - 18,000 kg (5,000 kg - 12,000 kg) (-) (6 - 8)	Up to 300 km with 200 kWh (0.95 kWh/km)	85 km/h	80 kWh 120 kWh 160 kWh 200 kWh	(-)	(-)	(-)
Midlum (Renault) (Renault Trucks (2011a))	16,000 kg (5500 kg) (-) (8)	100 km (-)	(-)	150 kWh	8 hours	103 kW (peak/continuous not specified)	(-)
Nautilus MX30 short-haul tractor (Balqon) (Balqon (2013b), Balqon (2014b))	GCW: 36,285 kg Towing capacity: 25,000 kg (Class 8)	240 km unloaded 145 km loaded (-)	115 km/h	320 kWh	1) 3 - 4 hours with 100 kW charger 2) 8 - 10 hours with 40 kW charger	242 kW peak	(-)
Nautilus XRE20 drayage truck[§] (Balqon) (Balqon (2014c), Balqon (2014d))	GCW: 49,895 kg Towing capacity: 30,000 kg (Class 8)	95 km loaded (-)	40 km/h	230 kWh	4.5 hours with 40 kW charger	75 kW continuous 168 kW peak	(-)
PVI XL-line Powertrains (Power Vehicle Innovation) (PVI (2014))	12,000 kg - 16,000 kg (-) (-) (7 - 8)	120 km -160 km (-)	90 km/h	Up to 170 kWh	6 - 7 hours with 30 kW	103 kW continuous	(-)
PVI XXL-line Powertrains (Power Vehicle Innovation) (PVI (2014))	18,000 kg - 26,000 kg (-) (-) (8)	(-) (-)	90 km/h	Up to 255 kWh	6 - 7 hours with 45 kW	103 kW continuous	(-)

5. Market Penetration

This section will provide brief overviews of the state of both passenger and commercial plug-in electric vehicles' global market. While passenger plug-in electric vehicles are less important with regard to distribution purposes, their market penetration can still accelerate technology improvements and give more visibility to electric vehicles as a whole. These vehicles can also be used in the delivery of lighter goods. For example, battery electric cars have been tested in pizza delivery operations in Hamburg (TU Delft et al. (2013)). Furthermore, light BEVs can be used in several other fleet applications, such as company and municipal cars, car sharing schemes and taxis (Electrification Coalition (2010)). Approximately 37,000 BEVs and PHEVs were expected to be sold for fleet purposes in 2013 (Berman and Gartner (2013)).

[§]Transpower and U.S. Hybrid have also delopped class 8 heavy duty BEV drayage trucks similar to Balqon's (Transpower (2014), Port of L.A. (2014))

The city of Houston, for example, has 25 Nissan Leafs which it reserves for employee trips of less than 70 miles (Electrification Coalition (2013a)), and the city of Oslo has established a policy under which all municipal service vehicles are to use zero-emission technologies by 2015 (European Commission (2013)). The world's largest electric car sharing scheme is Autolib in Paris (IEA and EVI (2013)), and other car sharing schemes using electric vehicles can be found in Barcalona, Berlin, Rotterdam, Nagasaki, s'Hertogenbosch, Stuttgart, Amsterdam and San Diego (IA-HEV (2013), EVI et al. (2012)). Electric taxis are used in Shenzhen and Hangzhou in China (IEA and EVI (2013)), as well as in Amsterdam and Nagasaki (EVI et al. (2012)). Tokyo has experimented with the idea of using electric taxis with battery swapping (Schultz (2010)).

5.1 Passenger Vehicles

When considering electric bicycles and scooters, global electric vehicle sales in 2011 were over 27 million, with the majority of these two-wheelers being sold in China (Crist (2012)). The portrait is much different when excluding electric two-wheelers. According to the ICCT (Mock and Yang (2014)), global sales of plug-in electric passenger vehicles were less than 10,000 in 2009 and grew to about 45,000 in 2011, to more than 110,000 in 2012, and to more than 210,000 in 2013, with only a few national markets exceeding a 1% market share of all passenger vehicles in 2013. These include Norway with a 6.1% market share (close to 6% for BEV share), the Netherlands with 5.6% market share (5% for PHEV share), and California with a 4% market share (in the USA as a whole, the market share was 1.3%). Other notable BEV and PHEV 2013 market shares include 0.8% in France (almost all BEVs), 0.6% in Japan, 0.5% in Sweden, 0.3% in Denmark, 0.2% each in Austria, Germany, and the UK, and 0.1% in China. The report also evaluates the impact of different fiscal incentive policies on passenger BEV and PHEV uptake, finding that these incentives tend to be higher for company cars than for private cars because of company car tax exemptions. Figure 3 presents national market shares for BEVs and PHEVs in 2012 and 2013 according to different fiscal incentives expressed as percentages of purchase costs. Regarding distribution of all PEV sales, according to IEA and EVI (2013), the US, Japan and the Netherlands accounted for respectively 70%, 12% and 8% 2012 global PHEV sales, while Japan, the US, China, France and Norway accounted for respectively 28%, 26%, 16%, 11%, and 7% of 2012 global BEV sales.

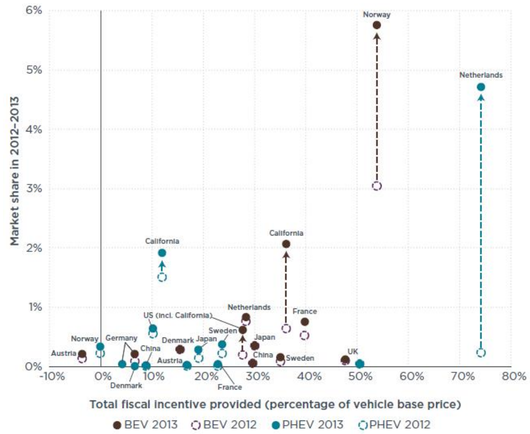

Figure 3: 2012 and 2013 market share vs. per-vehicle incentive for BEVs and PHEVs (where applicable, only company car market incentives shown here), source (Mock and Yang (2014), p.iii)

5.2 Commercial Vehicles

According to Jerram and Gartner (2013) from Navigant Research, plug-in electric trucks and vans (class 2 to 8 vehicles) have generally only penetrated niche applications, while remaining dependent on government incentives. They attribute this to key industry players going out of business, the conservative nature of fleet operators when it comes to new technologies, renewed interest in natural gas, and the important cost premium of these vehicles. The report's executive summary also states that the global stock of class 2 to 8 HEVs, PHEVs and BEVs was around 20,000 at the time of publishing (4Q 2013) with forecasted sales of 10,000 in 2013 (compared to expected global commercial truck sales of 15 million units) and over 100,000 in 2020. The vast majority of expected sales are from HEVs which do not require plug-in recharging.

Den Boer et al. (2013) state that approximately 1,000 battery electric distribution trucks were operated around the world as of July 2013. CALSTART's report on the demand assessment of electric truck fleets (Parish and Pitkanen (2012)) claims that industry experts have estimated there were less than 500 battery electric trucks in use in North America as of 2012, with most sales made in US states like California and New York, which offered incentives for these vehicles. Also, approximately 4,500 hybrid electric trucks were sold in North America as of 2012. The large majority of hybrid and battery electric trucks sold were in medium duty and vocational applications rather than long-haul class 8 applications. Stocks of freight electric vehicles (vans and trucks) as of January 1st 2012 in Europe included 70 in Belgium, 106 in Denmark, 338 in Germany, 1,566 in France, 217 in the Netherlands, 103 in Norway, 38 in Austria, 13 in Portugal, 459 in Spain, and over 2000 in London (TU Delft et al. (2013)). However, most of the electric vans in the UK are old low performance vans with lead-acid batteries, with only a few hundred modern electric vans with lithium-ion batteries sold in 2012 (Cluzel et al. (2013)).

According to the Electrification Coalition (2013b), the lack of vehicle availability by OEMs in heavier PEV segments is another reason for their limited market penetration. Most of these vehicles are therefore offered by small start-up firms. The report states that even if fleet operators tend to focus more on total cost of ownership than purchase costs, they also tend to be risk averse. New small manufacturers offering plug-in electric trucks therefore have difficulty in convincing these fleet operators to do business with them. One of project FREVUE's reports (Nesterova et al. (2013)) identifies other factors explaining the limited use of electric freight vehicles in city logistics, namely doubts regarding technology readiness, high purchase costs, and the limited amount of models on the market. The report also states that the rapid technology improvements themselves can be a market barrier since fleet operators fear that an electric freight vehicle purchased today could quickly lose all residual value. The uncertainties surrounding the vehicles' residual value also limit leasing companies' interest in electric freight vehicles.

However, the Electrification Coalition (2010) has also identified several factors making fleets an interesting market for electric vehicles, notably their lower energy and maintenance costs combined to high utilization rates, predictable routing involved in fleet operations (which allows battery right-sizing, easier charge scheduling, and eliminates range anxiety), centralized depot charging (independence from public charging infrastructure), commercial and industrial electricity rates, and corporate image. Nevertheless, the bottom line is that a wider adoption of BEVs in distribution applications can only be achieved if these prove to be cost-effective when compared to using conventional ICEVs for the same application.

6. Cost Competitiveness of Battery Electric Vans and Trucks

While commercial BEVs' energy costs can be nearly four times cheaper than diesel equivalents, the downside is that their purchase costs are approximately three times higher (Feng and Figliozzi (2013)). Furthermore, the cost of the equipment necessary for charging the vehicle's battery, which can reach several thousands of dollars, should be considered. Maintenance costs should also be significantly less than for ICEVs (Taefi et al. (2014)) and this advantage should increase as the vehicles get older (Electrification Coalition (2010)). Because of these different cost structures between ICEVs and BEVs, the only way to appropriately compare the cost competitiveness of battery electric vans and trucks for goods distribution is to study their whole life costs (McMorrin et al. (2012)), according to which all costs incurred over the vehicle's life are actualised to a net present value. Whole life costs are also referred to as the vehicle's total cost of ownership (TCO). The following are brief descriptions of the cost structure and TCO of battery electric freight vehicles compared to their conventional counterparts.

6.1 Cost Structure: High Fixed Costs and Low Variable Costs

Purchase costs for medium duty battery electric trucks offered by AMP Trucks, Inc., Boulder Electric Vehicles, Electric Vehicle International, and Smith Electric Vehicles range from \$130,000 to \$185,000 US, while equivalent ICE trucks go within the \$55,000 to \$70,000 range (New York State Energy Research and Development Authority (2014)). One way to decrease the cost premium of these larger BEVs is to be able to right-size the costly battery according to the application (Electrification Coalition (2013b)). However, while this measure could significantly improve the vehicles' business case and allow for additional payload capacity, the smaller battery would require more frequent deep discharges, which could cause accelerated battery deterioration ((Pitkanen and Van Amburg (2012)). Another option for reducing upfront costs while also addressing fleet operators' concerns about battery life is to lease the battery for a monthly fee based on energy consumed or distance traveled (McMorrin et al. (2012)). However, uncertainties regarding battery residual value limit many fleets' interest in battery leasing (Pitkanen and Van Amburg (2012)), most likely because these uncertaintites will be integrated into the leasing fee. Furthermore, battery leasing currently only seems available for a few battery electric vans but not for trucks, for whom it could significantly help the business case based on whole life costs (Valenta (2013)). Purchase costs for battery electric vans vary largely depending on GVWs and the availability of battery leasing. Large manufacturer products with battery leasing go for about \$25,000 for GVWs close to 2,100 kg. Examples of these include Renault for its Kangoo Z.E. vans and Nissan for its e-NV200 van, with monthly battery leasing fees starting at approximately \$100 per month and varying according to monthly mileage and contract lengths (Renault (2014c), Nissan (2014d)). Typical purchase costs with battery ownership range from approximately \$25,000 for lighter battery electric vans (GVW starting at 1100 kg) with limited battery capacities, to about \$100,000 for larger battery electric vans (GVW up to 3,500 kg) with higher battery capacities. Conventional cargo vans with GVWs close to 4,500 kg cost between

$30,000 and $40,000, GVWs close to 3,500 kg are within the $25,000-$30,000 price range, and GVWs around 2,500 kg are closer to $20,000 (Nissan (2014a)).

As previously noted, the advantage in the cost structure of BEVs comes from their lower variable costs (i.e., energy and maintenance costs) (McMorrin et al. (2012)). Maintenance costs for electric freight vehicles have been reported to be 20 to 30% lower than conventional vehicles (Taefi et al. (2014)). Combined to lower energy costs, this makes them more interesting for long planning horizons. Typical energy consumptions of battery electric vans and trucks vary from as low as 0.15 kWh per km for light duty vans to approximately 0.6 kWh and 1 kWh per km in some medium and heavy duty vehicles respectively. However, electricity rates incurred depend on geographical location, average consumption levels, and time of use (Hydro-Québec (2014)). Charging during off-peak hours can allow for reduced electricity rates and seasonal price variations may also occur. It is therefore necessary to evaluate the potential of lower energy costs of commercial BEVs according to one's specific context.

Gallo and Tomić (2013) provide an overview of the performance of delivery BEVs (class 4-5) operated by a large parcel delivery fleet in Los Angeles. The findings showed that in comparison to similar diesel vehicles, the electric trucks were up to four times more energy efficient, offering up to 80% lower annual fuel costs. The report estimated maintenance savings ranging from $0.02 to $0.10 per mile, finding these savings "will vary widely depending on driving conditions, vehicle usage, driver behavior, vehicle model and regenerative braking usage"(p.53). Other findings included the need for drivers to be trained to adapt their techniques to electric trucks, that a minimum utilization of 50 miles per day is necessary to recuperate purchase costs in a reasonable time span, and that incentives are still necessary at this stage to make the vehicles a viable alternative. Additionally, some repairs needed to be provided by the vehicle manufacturers because of the limited experience of fleet mechanics with electric trucks. TU Delft et al. (2013) also reported several companies having experienced a lack of available resources for quickly solving technical issues with freight BEVs. This is important to consider because in order to profit from lower variable costs, companies must have access to reliable maintenance services and spare parts.

6.2 Whole Life Costs Analysis

While there have been several studies concerned with whole life costs for battery electric cars (e.g., Tuttle and Kockelman (2012), Hannisdahl et al. (2013), Mock and Yang (2014), Cluzel et al. (2013), Prud'homme and Koning (2012), Thiel et al. (2010), Lee and Lovellette

(2011), Delucchi and Lipman (2001), EPRI (2013), Offer et al. (2010)), the business case of commercial BEVs has been less studied. Nevertheless, a few have been undertaken and they have aimed to assess the operational environments and time spans in which the total cost of ownership (TCO) of freight BEVs have the potential to converge with their conventional counterparts.

Stewart (2012) studied the whole life costs of battery electric vans and other low emission vans with different GVWs (up 3,500 kg). The TCO of the vehicles were calculated for 2011, 2020 and 2030 using UK parameters regarding depreciation and financing costs, fuel costs, servicing and insurance. Forecasted reductions in battery costs were used for the 2020 and 2030 scenarios. Residual values for all vehicles were set at 30% of the retail price. Maintenance costs were assumed equal for all technologies in view of the lack of available data, as were insurance costs. Utilization rates were set to 27,000 km per year. No incentives were considered. The results showed that over a four year period, small battery electric vans (2,100 kg GVW) were found to cost £9,000, £7,000, and £2,000 more than the ICEV equivalent in 2011, 2020, and 2030 respectively. Concerning standard panel vans (GVW 2,600-2,800kg) with larger batteries, findings indicated a premium of £23,000 in 2011, £14,000 in 2020, and £5,000 in 2030. However, considering the cost structure of BEVs, a longer horizon than four years would probably be more representative of the electric vans' competitiveness.

Crist (2012) demonstrates the impact of considering factors that can reduce purchase costs (i.e. subsidies and battery leasing) and longer time horizons on battery electric vans' business case. The author has compared the TCO of equivalent pairs of BEVs and ICEVs (two pairs of cars and one pair of commercial vans) using parameters representative of France's context. The battery electric van considered was Renault's Kangoo Z.E, with a purchase cost of €21,200 and battery leasing for a monthly fee of €89. A cost of €1,200 was considered for the charging equipment. A French subsidy of €5,000 for BEVs was also included. Vehicle lifetime was set to 15 years and no residual value was considered. In their baseline scenario, the electric van was initially operated for 90 km per day for 260 days per year with a 1% annual decrease, energy consumption was set to 0.165 kWh per km, electricity prices were set to €0.088 per kWh with a 1% annual increase, and annual maintenance costs were assumed to be €70 more for ICEVs than BEVs. The results indicated that the electric van would cost about €4,000 less to operate than the ICE van over the fifteen years, and only €300 more over three years. The passenger BEVs evaluated with lower utilization rates were found to cost consumers between €4,000 and €5,000 more than their ICE counterparts. A sensitivity analysis further demonstrated the positive impact of high utilization of the vehicles on their cost competitiveness.

Lee et al. (2013) investigated the cost competitiveness of battery electric delivery trucks. The authors compared a Smith Newton truck to a Freightliner ICE truck with a similar GVW (about 7,500 lbs) using operation data from 219 Newton trucks utilized in 63 US cities. Purchase cost premiums ranged from $25,000 to $37,000 for the Newton compared to the $60,000 diesel truck price. No financial incentives were considered. Maintenance costs were assumed to be 25% to 50% lower for electric trucks compared to the diesel reference. Battery deep cycle life was assumed to be 2,800 cycles. Different fuel and electricity cost predictions were considered. Utilization rates tested ranged from 30 to 60 miles per day, with the vehicles being retired after 150,000 miles. The effect of including a battery and EVSE replacement was also evaluated. Three drive cycles were tested to compare different fuel economies. Findings indicated that using the electric truck was more cost-effective in several scenarios; these usually involved low speed city driving with frequent stops and high daily mileages. Electric trucks are less interesting in suburban routes with fewer stops and higher speeds, when they are used for highway driving, if the battery must be replaced early, and if costly charging equipment adds to the initial investments. The sensitivity analysis indicated that the electric truck's TCO was most influenced by assumptions regarding diesel fuel consumption, utilization rates, diesel fuel price forecasts, battery replacement, battery price and EVSE price.

Davis and Figliozzi (2013) also compared whole life costs of battery electric delivery trucks to a conventional diesel truck serving less-than-truckload delivery routes. The BEVs are the Navistar eStar (priced at $150,000) and Smith Newton (priced at $150,000), while the diesel reference is a Isuzu N-series (priced at $50,000). Different urban delivery scenarios were designed based on typical US cities values and different routing constraints. Thus, 243 different route instances were simulated by varying values for the number of customers, the service area, the depot-service area distance, the customer service time, and the customer demand weight. Different battery replacement and cost scenarios were also studied. The planning horizon was set to ten years, with the residual value of the vehicles set at 20% of their purchase price. In spite of the fact that the electric trucks had a higher TCO in 210 out of the 243 route instances, a combination of the following factors would allow them to be a viable alternative: high daily distances, low speeds and congestion, frequent customer stops during which an ICEV would idle, other factors amplifying the BEVs' superior efficiency, financial incentives or technological breakthroughs to reduce purchase costs, and a planning horizon above ten years. With a battery replacement after 150,000 miles at a forecasted cost of $600/kWh, the diesel truck always had a lower TCO.

Feng and Figliozzi (2013) developed a fleet replacement optimization model considering both diesel and battery electric trucks. The objective was to minimize the discounted sum of all costs over a certain planning horizon. The vehicles compared were the Navistar eStar (priced at $150,000) and one of the Isuzu N-series (priced at $50,000). Electricity consumption was set at 0.8 kWh/mile at a price of $0.0983/kWh with an inflation rate set at 1.8%. Residual values (15% to 25%) were considered to depend on different annual utilization levels. Maintenance costs were assumed to be 50% lower for the electric truck. Several scenarios with varying annual utilization rates and diesel truck fuel efficiencies were analysed based on US market data. The planning horizon was set to thirty years while maximum vehicle ages were set to fifteen years without battery replacement in the initial scenarios. Findings indicated that the BEVs should only be acquired if used over 16,000 miles per year (60 miles/day), more so in environments where the diesel truck has low fuel efficiency. The breakeven analysis indicated a planning horizon of at least twelve years was necessary to recuperate high capital costs, and that in environments where the fuel efficiency of the diesel truck was high, a price reduction ranging from 9% to 27% for the electric truck (depending on vehicle utilization) would be necessary to achieve cost-effectiveness. The sensitivity analysis identified the planning horizon, the purchase price and the utilization level as being very important factors for the competitiveness of the BEVs, and showed that including a battery replacement significantly decrease their business case.

In sum, battery electric freight vehicles currently fit much more into city distribution than long haul applications because of the battery's energy density limitations (den Boer et al. (2013)). Typical daily miles traveled by urban delivery trucks are often lower than the range already achieved by electric commercial vehicles (Feng and Figliozzi (2013)). Combined to limited payloads, this makes them more viable for last mile deliveries in urban areas involving frequent stop-and-go movements, limited route lengths, as well as low travel speeds (Nesterova et al. (2013), AustriaTech (2014b), Taefi et al. (2014)). With forecasted reductions in battery costs and evolution of diesel prices compared to electricity prices, as time goes by, BEV distribution trucks should become more competitive with equivalent ICEVs based on their own economic proposition (den Boer et al. (2013)). However, commercial BEVs will also have to compete with other fuel alternatives such as compressed natural gas, in which case their business case can be even harder to make (Valenta (2013)). Furthermore, significant improvements in ICEV efficiencies are expected in upcoming years (Mosquet et al. (2011)). Nevertheless, for now, the appropriateness of using delivery BEVs ultimately depends on the context of their intended use, but the high purchase cost has been extensively pointed out as a huge cost effectiveness barrier, and the need for incentives at this stage of the market seems like a recurring requirement for a viable business case.

7. Incentives

Several national governments around the world have already set up measures aimed at increasing the commercial use of electric vehicles. Local policies can also be very useful for the promotion of BEVs in urban distribution applications (den Boer et al. (2013)). The following are brief presentations and examples of a few interesting financial and non-financial incentives used for freight BEVs.

7.1 Financial Incentives

The goal of financial incentives is to reduce the upfront costs of electric vehicles and charging equipment (IEA and EVI (2013)). One form is purchase subsidies granted upon buying the vehicle (Mock and Yang (2014)). An example of this is the California Hybrid Truck and Bus Voucher Incentive Project (HVIP) which provides up to $35,000 towards hybrid truck purchases and up to $50,000 towards battery electric truck purchases to be used in California (Parish and Pitkanen (2012)). Eligible vehicles can be found in CEPAARB (2014). Another similar program is the New York Truck Voucher Incentive Program, which offers up to $60,000 for electric truck purchases to be used New York (New York State Energy Research and Development Authority (2014)). The city of Amsterdam also covers up to €40,000 for purchases of battery electric trucks (den Boer et al. (2013)). An additional example is the UK government's Plug-in Van Grant, which covers 20% of the cost of commercial battery electric vans, capping at £8,000 (McMorrin et al. (2012)). Eligible vans must have a GVW of 3,500 kg or less, and can be found in UK OLEV (2014). Companies are also eligible to receive similar purchase subsidies for participating in demonstration or performance evaluation projects (US DOE (2013b)). In Germany, for example, up to 50% of the investment into the vehicles can be covered by participating in such projects (Taefi et al. (2014)). Other subsidies target the installation of charging equipment for fleets of electric vehicles, with examples of this in Norway, the Netherlands, the UK and France (AustriaTech (2014b). Tax exemptions are another alternative form of financial incentives used for lowering ownership costs of electric vehicles. Examples of these are exemptions from VAT, vehicle registration taxes, fuel consumption taxes, and company car taxes (AustriaTech (2014b)). Overviews of tax exemptions related to electric vehicles can be found in IEA and EVI (2013), Mock and Yang (2014), ACEA (2014), and US DOE (2012a).

7.2 Prioritized Access Incentives

Local incentives for prioritized access can often permit significant daily cost and time savings (Cluzel et al. (2013)). A recent report by AustriaTech (2014b) provides an overview of common access incentives used for electric vehicles in urban logistics. One is to grant them access to high occupancy lanes or bus lanes. Examples of opening up bus lanes to electric freight vehicles can be found in Utrecht, Lisbon, and Trondheim (Nesterova et al. (2013)). Other tests using bus lanes for electric freight vehicles have been conducted in London and Oslo, where some issues were identified, such as conflicts with buses and insufficient coverage of the road network by the bus lanes (AustriaTech (2014b)). BEVs can also be exempted from certain road tolls, as is the case in Norway (Hannisdahl et al. (2013)). Another motivation is low emission zones in dense city centres to exclude or charge polluting vehicles and promote cleaner alternatives such as electric vehicles by exempting them from the ban or the charge (AustriaTech (2014b)). In Rome, diesel freight vehicles pay an annual fee of €570 to have access to the historic city centre, while battery electric freight vehicles pay only €300 (AustriaTech (2014b)). The London Congestion Charge is another example of the provision of prioritized access to commercial electric vehicles. The daily rate for accessing central London is £10 while electric freight vehicles are 100% exempted from this charge (McMorrin et al. (2012)). Another form of priority access offered to electric freight vehicles is an extended delivery time window due to their noiseless operation (Nesterova et al. (2013)). For example, in the Dutch city of s-Hertogenbosch, only silent trucks such as BEVs can enter the city centre between 12am and 7am , and similar testings have taken place in Barcelona and Dublin where the extended time window was 10pm to 7am (AustriaTech (2014b)). Electric freight vehicles can also be exempted from restrictions regarding the maximum weight of vehicles allowed in city centres, as is the case in Amsterdam (TU Delft et al. (2013)). Finally, preferential parking is another way to encourage the use of commercial electric vehicles, either by allocating to them free spaces or designated loading and unloading docks (AustriaTech (2014b)). For example, in Bremen, an environmental loading point close to the city centre provides a dedicated loading area exclusively for Euro 5 diesel vehicles and electric vehicles up to 7,500 kg GVW (MDS Transmodal Limited (2012)).

8. Deployment Initiatives and Innovative Distribution Concepts

As shown in the previous sections, there are at the least some contexts in which using battery electric vans and trucks can represent a viable option compared to conventional vehicles, especially when the right duty cycle is combined with attractive incentives in a long term planning horizon. While some deployments of electric freight vehicles have indeed been undertaken for financial reasons in these contexts, often it is more a case of exploring options and preparing in response to expected future developments. As Taefi et al. (2014, p.3) point out, “many initiatives and involvement in EV experiments are driven by companies’ awareness and anticipation of regulations for less environmentally-friendly vehicles becoming more restrictive in the future”. Nevertheless, deployment initiatives of electric freight vehicles can certainly play a large role in actually demonstrating their operational performance in distribution applications (Nesterova et al. (2013)), and are often used to experiment with innovative logistics concepts as well. These initiatives can also help give companies a more eco-friendly image (Taefi et al. (2013)). This section will look to identify a few current and past deployment initiatives as well as interesting logistical concepts with regards to goods distribution with BEVs.

8.1 Companies Experimenting with BEVs

In North America, large companies using battery electric delivery vehicles include FedEx, General Electric, Coca-Cola, UPS, Frito-Lay, Staples, Enterprise, Hertz and others (Electrification Coalition (2013b)). Frito-Lay alone has been operating 176 battery electric delivery trucks in North America since 2010 (US DOE (2014b)). Fedex also operates over 100 electric delivery trucks (Woody (2012)). Many U.S. companies which operate battery electric trucks have received funding from the American Recovery and Reinvestment Act to cover a portion of the vehicles’ purchase costs (US DOE (2013b)). In Europe, many project reports provide examples of practices with BEVs for goods distribution.

The previously mentionned report of project FREVUE (Nesterova et al. (2013)) also provides overviews of European companies and projects using these vehicles. It finds that BEVs in city logistics have often been used for parcel delivery, deliveries to stores, waste collection and home supermarket deliveries. A few notable private initiatives identified in the report include Deret’s 50 electric vans for last mile deliveries to city centres in France, UPS’s 12 Modec vehicles for parcel and post delivery in the UK and Germany, Tesco’s 15

Modec vehicles for on-line shopping deliveries in London, Sainsbury's use of 19 electric vans for supermarket deliveries and its intention to purchase 50 Smith electric vehicles, La Poste (France) and Poste Norge's (Norway) respective use of 250 and 40 Comarth electric vehicles for postal service, TNT Express' use of a Smith Newton for parcel delivery in Scotland, and L'Oréal's use of a 10 tonne electric vehicle to deliver goods in Paris.

Another notable logistics company using BEVs is DHL, which operates hundreds of electric vehicles in France, Aruba, Belgium, Denmark and Germany (DHL (2014)). DHL has also participated in a project alongside freight forwarder Meyer & Meyer to test BEVs for urban distribution services in Berlin (Ehrler and Hebes (2012)). Within the project, DHL operated three electric vans (up to 3.5 ton GVW) in its delivery routes in residential areas of Berlin, while Meyer & Meyer used two converted eight ton GVW electric trucks for deliveries in the city centre. The project showed the technical suitability of the vehicles in terms of achievable range. However, drivers expressed concerns regarding the reduction in payloads.

Taefi et al. (2013) provide information on 15 cases of companies using EVs for urban freight transport in Germany, for a total of 79 electric vehicles including two towing vehicles, twelve electrical scooters, 48 vans up to 3.5 tons GVW and 17 trucks from 3.5 to 12 tons GVW. Delivered products include parcel, courier, textiles, fast food, bakery, hygienic articles and household articles. Only seven of the 15 cases reported or expected using the vehicles to be more profitable than their conventional counterparts. In these cases, the combination of several measures led to the profitability of the EVs, summarized in Figure 4.

TU Delft et al. (2013) also present a prodigious number of deployment initiatives of electric freight vehicles in Denmark, Norway, Germany, London, the Netherlands, Belgium, and Sweden. The main experienced strengths and limitations from these deployments were then identified. Positive factors included corporate image, drivers' satisfaction, driving comfort, high manoeuvrability, low operational costs, taking advantage of low emission zones and flexible time windows. Negative factors experienced included the required investments (vehicles and EVSE), reduced payloads, limited range, the effect of cold temperatures on range, imprecise marketed vehicle ranges, the lack of resources to fix technical problems, incompatibility of vehicles' connectors with public charging infrastructure, and the need to train drivers to better adapt to the vehicles. All in all, the case studies indicated that the vehicles were found to be most adequate for last mile and night deliveries.

1. Investment reduction

- Conversion of depreciated ICE vehicles into EVs
- Purchase of discounted, discontinued models
- Engagement in EV projects to profit from subsidies
- Use of electrical scooters for small, light cargo

2. Kilometrage increase through process adaptions

- Intermediate charging, quick charging or battery change
- Energy efficiency training of drivers
- External energy for heating or cooling cargo and preheating of driver cabins
- Improvement of routing and scheduling of EVs

3. Capitalizing on image

- Enhancement of customers base with 'green' customers through marketing
- Apply for environmental labels or prices
- Factor-in EV costs into sustainable, high price products

4. New business opportunities

- Night time delivery with silent EVs
- Unlimited access to zones with spatially or temporally limited access

Figure 4: Strategies pursued to operate EVs profitably, source (Taefi et al. (2013), p.8)

8.2 Two-phased Deliveries Integrating BEVs

FREVUE's report (Nesterova et al. (2013)) also points to two-phase delivery as being an interesting logistics concept for electric freight vehicles, where goods are first brought to a logistics facility near the denser urban area by conventional trucks before being transferred to the electric vehicles for last mile deliveries. When multiple organizations use the same facility it referred to as an urban consolidation centre (UCC). Allen et al. (2007, p.61) define a UCC as "a logistics facility situated in relatively close proximity to the geographic area that it serves (...), to which many logistics companies deliver goods destined for the area, from which consolidated deliveries are carried out within that area, in which a range of other value-added logistics and retail services can be provided".

One example of a UCC using BEVs can be found within project ELCIDIS (Vermie (2002)). However, this project was carried out between 1999 and 2002, before lithium-ion batteries were introduced. Therefore the vehicles tested had even more important limitations with regards to range and payload (Element Energy (2012)). Additionally, in some cases technical problems led to the non-reliability of the vehicles such as in Rotterdam, where seven battery electric vans used for last mile deliveries were unavailable 40% of the time due to technical issues (Vermie and Blokpoel (2009)). In the context of project ELCIDIS, the municipality of La Rochelle in France set up a UCC which used battery electric vans to deliver parcels to businesses in the city centre. Because of the vehicles' limited performance, more trips were made and urban congestion in the city centre actually increased during the project (van Rooijen and Quak (2010)). That said, more recent models of electric commercial vehicles should be able to perform more efficiently in UCC applications (van Duin et al. (2013)). According to Element Energy (2012), the experimental UCC in La Rochelle has reportedly turned into a permanent centre since the initial trial, and runs 7 battery electric vans (5 Citroen Berlingos and 2 Modec vehicles) which perform last mile deliveries for 15 organisations to 350 clients per month.

Another example of a UCC being used for last mile deliveries with BEVs is the Cargohopper project in Utrecht (MDS Transmodal Limited (2012), TU Delft et al. (2013), Nesterova et al. (2013)). The Cargohopper 1 is a battery electric towing vehicle (payload 1000 kg) which tows three mini-trailers carrying light-weight retail goods and parcels destined for the Utrecht's historic city centre. These goods are first received from multiple distribution companies in logistics operator Hoek Transport's depot outside the city. The goods are then transported to a transfer site near the border of the city centre with a conventional truck, where the goods are transferred onto the Cargohopper by means of a forklift. The Cargohopper then makes the last mile deliveries. It can access pedestrian zones due to high manoeuvrability and make deliveries outside regular time windows because of the municipal incentives for electric freight vehicles. The vehicle also collects dry carton, paper and empty packaging for recycling from shops in the city centre. The system has been operating since 2009. The Cargohopper 2 was launched in 2011, designed for heavier loads (2500 kg), increased range and faster speeds. An innovative idea in the Cargohopper project was to use solar panels to extend the vehicles' range.

Other examples of the experimentation of UCCs with BEVs are provided by van Duin et al. (2010), who presented a survey of six UCCs in Europe in order to advise the municipality of The Hague on the feasibility and desirability of a UCC. The experimentation of UCCs with one or a few electric vehicles can be found in Leiden, Bristol and Malaga.

UCCs using BEVs for last mile deliveries also often use smaller vehicles ideal for tight urban areas, which can lead to increases in vehicle kilometers per tonne delivered (Allen et al. (2012)). These smaller vehicles are typically electric tricycles, which have payloads of up to 200 kg (AustriaTech (2014b)) and low driving speeds. These tricycles can find parking locations more easily than larger vehicles, can often use bicycle lanes for faster access to customers in congested and pedestrian areas, and from a cost point of view are more affected by driver costs than purchase costs and utilization rates (Tipagornwong and Figliozzi (2014)).

Allen et al. (2007) present an example of the use of electric tricycles by a UCC. La

Petite Reine used a consolidation centre in the centre of Paris for last mile deliveries of food products, flowers, parcels, and equipment/parts with electric tricycles with a maximum payload of 100 kg. The initial trial in 2003 was deemed a success, with monthly trips growing from 796 to 14,631 and number of tricycles from seven to 19 in the first 24 months. Operations are now permanent and La Petite Reine operates three locations in Paris with over 70 collaborators, 80 tricycles, 15 electric light duty vehicles and 1 million deliveries per year (La Petite Reine (2013)).

Nesterova et al. (2013) present two other cases of two phased deliveries in Paris integrating to some extent electric bikes and tricycles. The first is Chronopost International, which offers express delivery of parcels and uses two underground areas in Paris for sorting last mile deliveries. The parcels are first transported from their facility at the border of Paris to their underground areas, where they are sorted per route and distributed to customers by electric bikes and vans in inner Paris. The second is Distripolis, a delivery concept tested by road transport operator GEODIS. A depot in Bercy receives shipments from three organisations and delivers the packages under 200 kg to multiple UCCs in the city centre of Paris (heavier packages are directly delivered to the receiver). From here, electric trucks and tricycles are used for the last mile deliveries of the light packages. Distripolis operated 10 light duty electric vehicles (Electron Electric truck, GVW 3.5 tons) and one electric tricycle in 2012, and aims at having 56 tricycles and 75 electric vehicles by 2015.

BESTFACT (2013) provides another case of two-phased deliveries with electric vehicles. Gnewt Cargo operates a transhipment facility for the last mile deliveries of an office supplies company in London (Office Depot). They use an 18 tons vehicle to transport parcels from the office supplies company warehouse in the suburbs of London to the transhipment centre in the city, where the parcels are transferred onto electric vans and tricycles for final delivery to customers. Initially a trial in 2009, the company has permanently implanted this system because it involved no increases in operational costs, and it plans to implement similar delivery systems in other cities (Browne et al. (2011)).

Finally, TU Delft et al. (2013) also present a two-phased delivery scheme with BEVs which was been tested in Amsterdam by Peter Appel (transport company) and Alber Heijn (grocery company). The grocery products were first transferred from Alber Heijn's distribution centre to a transhipment facility near the border of the city, from where a 4500 kg GVW electric truck assured the final home deliveries. However, the experiment was very short as the operators found the operating range and loading capacity to be too constraining.

8.3 Other Interesting Distribution Concepts for BEVs

An interesting experiment regarding last mile deliveries with BEVs can be found in the context of project STRAIGHTSOL, during which TNT Express integrated a mobile depot into their operations in Brussels with electric vehicles during the summer of 2013 (Nathanail et al. (2013), Anderson and Eidhammer (2013), Verlinde et al. (2014)). A large trailer equipped as a mobile depot with typical depot facilities was loaded with parcels at TNT's depot near the airport in the morning. Next it was towed by a truck to a dedicated parking spot in the city centre, where last mile deliveries as well as pick-ups were made with electric tricycles by a Brussels courier company, which then returned to the mobile depot with the collected parcels. At the end of the day, the mobile depot was towed back to TNT's depot, from where the collected parcels were shipped. Challenges included gaining exclusive access to the parking location for the mobile depot, significant increases in operating costs, and decreases in the punctuality of the deliveries and pickups (Johansen et al. (2014), Verlinde et al. (2014)).

Another interesting concept was presented by Taniguchi et al. (2000). The objective was to apply the idea of car sharing to urban goods distribution in Japan. This involved the provision by an organisation of electric vans in various public parking locations, which were to be used by several companies for delivery operations. Tests were conducted in Osaka City with 28 electric vans and 79 companies. Users would book an electric van in advance online, walk or bike to the van's location, pick up goods at the company, deliver the goods to a set of customers, leave the van at the nearest parking place, and use public transportation to return to the office. The system was implemented without any major issues, and 73% of participants felt the electric vans performed as well or better than conventional vehicles. While no charge was imposed to users during the trial, the willingness of the users to pay for such a service proved to be too low compared to the operating cost of the system.

Finally, while current heavy duty BEVs are not appropriate for long haul operations because of their range limitations (den Boer et al. (2013)), they could find a niche application in short haul port drayage operations (CALSTART (2013b)). One example of this practice is found at the Port of Los Angeles, where 25 heavy duty battery electric drayage trucks manufactured by Balqon were tested for operational suitability. In exchange for the purchase of the trucks, Balqon agreed to locate its factory in L.A. and pay the port a royalty for future sales (EVI et al. (2012)). The Port of L.A. also tested similar heavy duty battery electric trucks from Transpower and U.S Hybrid, as well as a fuel cell heavy duty truck (Port of L.A. (2014)).

9. Conclusion

The goal of this article was to present the current status of BEVs for goods distribution. While their future widespread adoption in distribution logistics remains conjectural, some urban environments exist in which the technical performance and cost benefits of this technology can at the least be amplified. Long-haul applications may also become feasible with these vehicles in the future, depending on technology and cost improvements. The argument that BEVs will not be able to have significant environmental benefits because of well-to-wheel emissions rather than tank-to-wheel emissions could also gradually phase out in the next decades if electricity production becomes cleaner. Developments since roll outs of electric vehicles by global OEMs in 2010 with regards to market penetration and vehicle availability can be seen as encouraging for the future of BEVs, but the electric passenger vehicle market has taken off much more significantly than the electric van and truck market. Incentives still play a critical role in the business case of these vehicles, but the long-term unsustainability of certain financial incentives, and recent trends suggesting their imminent phasing out (Bernhart et al. (2014)) will require that these vehicles be cost competitive independent of such incentives. One could argue that these vehicles are not ready for this challenge, in view of current cost dynamics, recent financial setbacks of key industry players, often resulting in discontinued vehicle models (Schmouker (2012), Shankleman (2011), Truckinginfo (2013), Everly (2014), Torregrossa (2014)). In the end, only the future will tell if these vehicles can become a more widespread alternative for goods distribution.

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