32nd Electric Vehicle Symposium (EVS32)
Lyon, France, May 19 - 22, 2019

"Electrifying freight transport in Europe"

Harm Weken[1], Floris Jousma[2] , Edwin Bestebreurtje[3], Rob Kroon[4]

[1]*Managing Partner at FIER Automotive & Mobility, harmweken@fier.net*

[2]*Clean Mobility Specialist at FIER Automotive & Mobility, fjousma@fier.net*

[3]*Partner at FIER Automotive & Mobility, ebestebreurtje@fier.net*

[4]*Project Manager at FIER Automotive & Mobility, rkroon@fier.net*

Summary

In this paper we focus on application areas for electric freight transport in different segments, and have included example use cases. This is followed-up by a more in-dept description of an implementation project about realising seven battery-electric 44-ton electric trucks with (ultra-fast) charging infrastructure, on which the first insights can be shared. Additionally, an analyses of the current availability of electric trucks and charging infrastructure is shown, including a forecast of suppliers, technologies and developments with regards to the future of electric freight transport.

BEV, Heavy Duty, Freight Transport, Truck, Fast Charge

1 Introduction

Freight road transport plays a significant role in CO_2 emissions and in local hazardous emissions as well as in noise pollution. This paper provides an overview of a diverse portfolio of electric truck deployments both for inner city distribution in various application areas as well as for heavy duty regional (container) transport.

The paper shows the already available options for electrifying freight fleets. It describes the various uses cases and also for which distribution applications the currently available e-trucks are most suitable for and in which the economics are best. Moreover, the unique project eGreenLastMile is described, in which 6 German and Dutch transport companies, are creating a common fleet of 44-ton electric trucks for container transport and general cargo. An initiative which enables comparing the identical trucks in multiple applications, different ranges and with different charging patterns.

The paper also leads the reader through the recent developments for electric trucks from AC "slow" charging towards ever increasing speeds of DC ultra-fast charging and other possible future alternative technologies. As the real breakthrough of electric trucks for distribution and transport will depend on the future availability of more affordable electric trucks, with longer ranges and (ultra-)fast charging options, the paper provides a short insight in expected electric truck market introductions.

Thanks to EU projects like EAFO [1], FREVUE [2], I-CVUE [3], eGLM [4] and proEME [5], as well as assignments for individual transport companies, the authors of this abstract have gained knowledge and experience about sustainable freight transport. Since 2013, FIER has been building knowledge and experience in the electrification of transport and logistics. Based on working with 1) transport & logistic

companies 2) truck manufacturers and 3) governmental organisations, we have contributed to the actual and substantial increase of the number of electric trucks on the road:

- The authors of this paper have supported over 30 companies in the uptake of electric trucks in their fleets. Not only for companies based in the Netherlands, but also for the UK, Italy and Germany. This support included suitability assessments incl. datalogging, calculations of the Total Cost of Ownership (TCO) specific for their application area and supported them in the application of local, national and European funding & legislation and with the implementation of the electric trucks.
- In the electric truck market, there are several manufactures: converters and Original Equipment Manufacturers (OEM's). We have supported truck manufacturers in project development and in business development.
- The authors have supported governmental organisations on different levels. On the level of policies, we have given advice on different financial and non-financial incentives, which have different levels of impact on the uptake of electric trucks. We also have managed market stimulation programs for local governments.

In this paper the experience and knowledge gained in our work on electric freight and distribution are shared, to give guidance on making freight transport more sustainable by introducing electric vehicles within fleets.

2 Inner city distribution and freight

Electric trucks are not yet a solution matching all transport and logistic needs. However, the available vehicles are already suitable for specific application areas. So far, the majority of initiatives on heavy duty electrification has been on transport and distribution in inner-cities. With cities as a driving force aiming to improve air quality and reduce noise emission, resulted in recent announcements of cities on targets to block future (2030) access of Internal Combustion Engine (ICE) trucks into the city. Meanwhile a growing number of cities are implementing policies on stimulating zero emission distribution. For example, by closing certain areas for diesel trucks or by providing privileges for zero-emission trucks on parking, on increased delivery time-windows and/or on access to tram/bus-lanes.

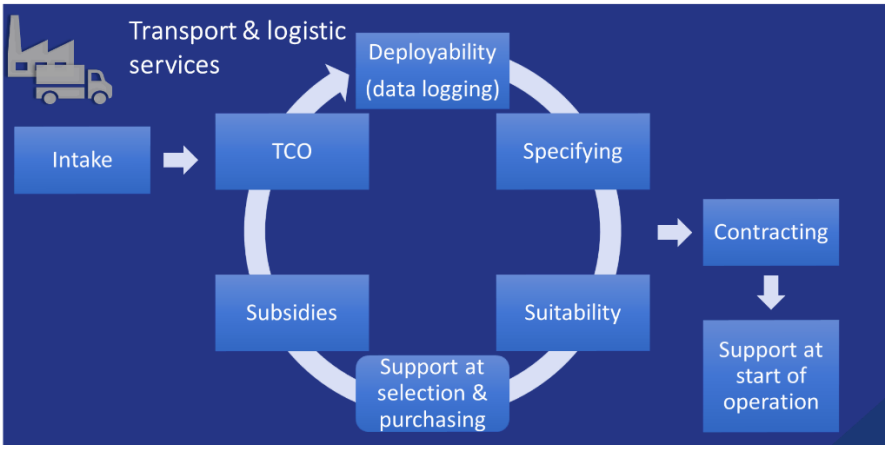

Figure 1: Transport and logistic services

It goes without saying, that once cities are closed for ICE trucks and zero emission vehicles will become the only alternative. But until cities are closed for polluting vehicles, the privileges for zero emissions trucks, can have a positive effect on both the business proposition of transport companies as well as on the total-cost-of-ownership of operating the truck.

Nevertheless, even when being used in cities, electric trucks are so far hardly economic feasible, due to the high investments. These investments are high because up-to-now the truck volume manufacturers do not have electric trucks in their product portfolio. Meaning that the available electric trucks, can be bought from conversion companies, converting diesel trucks to electric trucks. Production volume is low, production cost are expensive and purchase prices for components and batteries are high. More-over due to the small scale of operations of the conversion companies and the absence of service network, service and maintenance cost are high.

Until the production volumes go up, until e-trucks are supplied by truck manufacturers instead of as conversion and until component- and battery prices come down, the economic feasibility depends of electric distribution-trucks depends very much on the availability of subsidies.

Since 2010 FIER Automotive has been working with e-truck conversion companies, transport companies and wholesalers in Dutch and European cities to electrify their vehicles for urban freight and distribution. See figure 1 for the methodology used for guiding transport companies in assessing the potential, in defining the requirements and specifying the vehicles characteristics and finally in implementing the vehicles and the charging infrastructure.

In total we have supported over 30 companies in their decision-making process, with a potential of over 100 trucks to be electrified, of which for more than 60 vehicles this resulted in a positive investment decision for e-trucks. A number of the companies decided that it was too early, for various very situation specific reasons, and had postponed the decision making. Most of these 60 vehicles are either already implemented or will be implemented in 2019.

Electrify higher mileage logistics is challenging, but economic more rewarding

Interesting in many of the cases, is that the characteristics of the logistic process vis-à-vis the e-truck characteristics, was decisive for considering electrification. Or in other words: relative short distances and a limited number of trips per day (also due to the slow average speed and the required loading/unloading time); able to do the daily routine with only overnight charging or maybe with one additional charge during lunch-break; 22/44KW AC “slow” charging. These characteristics are not very supportive for a good business-case, whereas multiple trips and longer distances and fast charging during the operations, will lead to a better capacity utilisation of the vehicle and hence better economics.
On the other hand, this preference for electrifying the trucks for these shorter distances is very understandable, taking in mind the technical restraints of a) the available vehicles with the limited ranges and the slow speed on-board AC charging equipment and b) the limitations to equip and operate faster charging infrastructure at the (inner city) delivery destinations.
Obviously, in our analyses we saw that the companies that deploy the vehicles over longer distances, understandably realise better economic results.

The TCO and utilisation profiles within our case studies show that tailor made configurations of battery pack, range, charging infrastructure, route planning and battery planning are important for making the electrification suitable and economic viable in zero emission inner city distribution. The successful cases all have a combination of dedicated charging infrastructure, operate from a dedicated consolidation centre and use fit for purpose (so far retrofitted) electric vehicles with a range with small overcapacity in the daily routes. Most of them have the possibility to recharge (partly) during the operations (at customer destinations for example).

(Inter)national differences do have a large impact on economics

The economic feasibility of the vehicles very much depends on the local tax-situation, the availability of privileges and if and how much subsidy is available. See below for an example of a comparative calculation for a refrigerated 18ton distribution truck. In this specific example calculation (2017), the business case with for the e-truck in the Amsterdam is not economic feasible without subsidies and with a subsidy of € 40.000,-- only when based upon challenging assumptions (10 years, same battery) and with the uncertainties of residual value and maintenance cost. Whereas deploying the same electric truck in Olso, would be very profitable compared to an diesel truck, without subsidy and even more with the (at that time) available subsidy. The difference cost, by the absence of toll-cost in 2017 for electric vehicles. See figure 2.

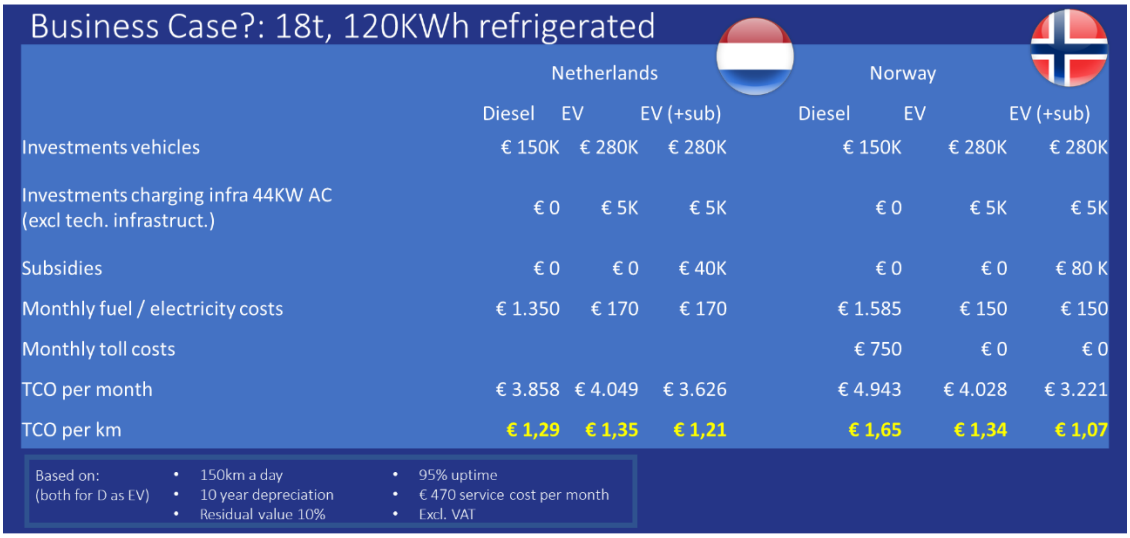

Figure 2. TCO comparison between the Netherlands and Norway of a 18t electric truck

See figure 3 for a schematic overview of the segments in which the coached transport companies are active. Within these segments, we describe some use cases (routing, goods, charging type, economics, etc) where we have built our knowledge and experience, for instance in the programs Amsterdam Electric and as consortium-partner in the EU funded FREVUE project (Freight Electric Vehicles in Urban Europe).

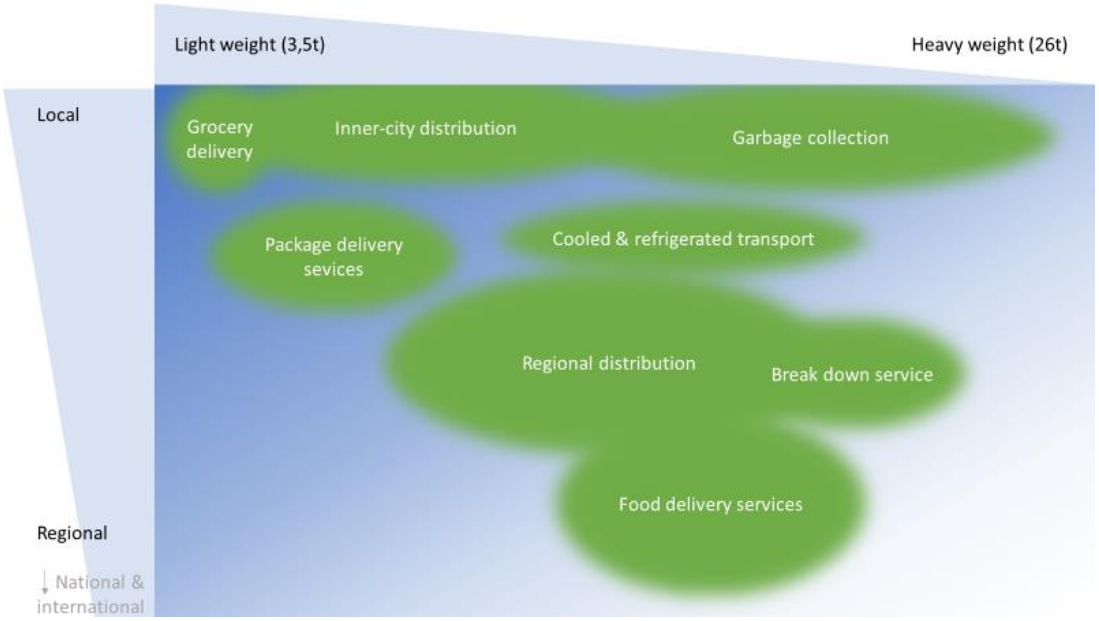

Figure 3. Different electric truck segments shown in an overview comparing operational area (local – regional) and weight class (light 3,5t – heavy 26t)

Use case Inner city distribution

One of the use cases within this segment is a wholesale company in technical materials with daily routes to the shops in the city of Rotterdam. The wholesale distribution centre is 40 kilometres outside the inner city of Rotterdam (highway kilometres). The daily route in total is 130 km including 50 km's in the city of Rotterdam. The truck being used for these daily routes is a 12 tonnes truck. The difference in purchase price between the diesel truck and the converted electric truck is € 120.000. For the electric truck we calculated a 120kWh battery pack. Due to a subsidy and tax advantages, the difference after subsidy and tax advantages is still € 75.000. In the decision-making process of the wholesale company the TCO is leading. The operational costs of the electric converted truck are less than the diesel truck, due to lower energy costs and

no yearly road tax for the electric truck. In this case the TCO gap between the diesel truck and electric truck was closed after 12 years, taking into account an extra investment in the battery and some renovation of the chassis after 8 years, compared to investing in a new diesel truck after 6 years. The wholesale company decided to take the step and invest in the electric truck from 2018 onwards, not only because of the calculated TCO, but TCO including other advantages such as the company image, possibility to operate very early in the morning and at night-time and using the bus lanes in the inner city of Rotterdam. Another decisive topic was readiness for the future and having knowledge and experience before 2025 when the first cities are expected to become closed for diesel trucks.

Use case garbage collection

In In garbage collection there are two use cases in which companies decided to invest in electric solutions. The first use case is a waste collection organisation using 18 tonnes container pickup trucks. These vehicles have a daily route of 170 kilometres, of which 50% on the highway and 50% within the inner city. The difference in purchase prices between the diesel truck and the electric converted truck was € 180.000. For the electric truck we calculated a battery pack of 200 kWh, mainly due to the electric power take-off (PTO) for lifting the containers, while using a hydraulic PTO in the diesel truck. After subsidy the difference was € 135.000. The operational costs of the electric converted truck are less than the diesel truck due to lower energy costs, no yearly road tax for the electric truck and lower maintenance costs for the PTO. In this case the TCO gap between the diesel truck and electric truck was closed after 10 years. An advantage which was not calculated is the possibility to collect the containers very early in the morning due to the silent electric drive and electric PTO.

Use case cooled & refrigerated transport

Within cooled and refrigerated transport a use case TCO was calculated for a wholesale company delivering food to restaurants in the inner cities. The distribution centre is at the border of the city and the company drives 12 tonnes refrigerated trucks. In the decision-making process we calculated TCO's within a bandwidth to show results on vehicles used for daily short routes and vehicles used for longer routes (including faster charging during the routes). Calculations in all variants were for an operational period of 10 years. The difference in purchase prices after FREVUE subsidy and tax advantage for the shorter routes was € 80.000 and for the long routes € 110.000. The trucks driving the shorter routes only drove 80 km per day and the trucks driving longer routes 150 km per day. Due to the fact that in both variants the daily distances still are low and the refrigerated transport costs a lot of electricity leading into a bigger battery pack, there was no possibility to close the TCO gap between electric trucks and diesel trucks after 10 years in use. The company decide to wait a few years before starting investing in electric trucks.

3 Short to mid-range distance, 44 ton tractor-trailer e-freight

eGreenLastMile project

Even more challenging than for cities, is the electrification of regional, mid-range and long-distance transport. Nevertheless, the impact on the liveability of the urban areas in these regions can be heavily impacted by the transport in their vicinity. Moreover, due to the higher daily mileage compared to city distribution, the CO2 impact of electrifying transport, can be more substantial.

The Ruhr area and the southern province of Limburg in the Netherlands are heavily populated and industrialised areas. Cities in this region like Venlo, Maastricht, Duisburg and Cologne, are close to multiple highways. Also, EU's largest multi-modal inland ports and rail terminals are located in this area, which leads to the roads in this region being full of trucks for local transport and distribution, trucks forwarding goods from the ports and terminals and trucks passing through from the ports of Antwerp and Rotterdam into the hinterland.

It is in this region that in 2013, several logistic companies and public authorities started, together with FIER Automotive, to develop a roadmap for reducing CO2 from regional road-transport, resulting in 2017 in the official start of the electric Green Last Mile (eGLM) project. An initiative to electrify the semi-trucks for

transport of containers (later expanded beyond container transport) over trips up to 100 kilometres. The project is supported by the Ministerium für Wirtschaft, Innovation, Digitalisierung und Energie des Landes NRW, the province of Limburg and EU co-funded by the "Interreg VA Netherlands-Germany Rhine-Maas-North" program.

Logistics, vehicle and charging characteristics

Meanwhile the consortium has grown to 6 transport companies, regional development company LIOF and FIER Automotive, and has formed a cooperative which owns (initially) 7 e-trucks of 44 tons, and enables the share of the electric trucks, in order to increase capacity utilisation. It is foreseen that the e-trucks and charging infrastructure will be in operation for at least 8 years, and the expected yearly mileage of the vehicles will be around 50.000 kilometres.

The project is unique in the diverse portfolio of applications (routing, type of goods, distances etc), as it is unique in being the largest test of electric trucks in this heavy weight category and is the first project testing the latest 350 kW CCS DC ultra-fast charging at such a large scale. With a network of 5 ultra-fast charging stations, the project sets the standard for charging electric trucks.

The transport companies are foreseen to be utilising the e-trucks in the following application areas:

- Container distribution over a distance up to 50 km, to and from the rail- and inland port-terminals in Venlo (NL) and Duisburg (D). Overnight slow DC charging and ultra-fast DC charging during breaks and at the port-terminal in Venlo and Duisburg;
- Heavy transport from a factory in Roermond (NL) to the manufacturing site near Cologne (D), over a distance of almost 100 km and multiple trips per day. Ultra-fast DC charging at each end of the trip and overnight DC slow charging;
- Container distribution from and between the inland container ports in Venray, Venlo and Roermond (NL), over a distance of up to 60 km. Overnight slow DC charging and ultra-fast DC charging during breaks and at the port-terminal;
- Chemical tank container transport, in the Ruhr Area. Electric trucks are AC "slow" charged during the time the containers are being filled/emptied at the chemical plants and distribution points. With the option for DC ultra-fast charging in the harbour area of Duisburg.
- Heavy transport from the port of Genk (Belgium) to a plant in Maastricht, consisting of various routes of each 120 to 150 km per day and enough time for AC slow charging overnight and at the plant location.

For this purpose, the electric trucks are build according to the following specifications: 44 ton GTW capacity 9.500 kg nett weight tractor unit (almost no loss of cargo weight capacity in comparison to ICE truck); 320 kWh battery pack (nett capacity); 400 kW electric engine power (peak 495 kW); CCS DC charging, maximised at 300 kW; max speed of 90 km/h.

Main difference between the vehicles is that the majority of the fleet will be capable of 300 kW CCS DC fast charging, whereas only 3 vehicles will have an additional AC 44 kW on-board charger. As a consequence, the majority of the fleet, will use 50 kW DC "slow" chargers for overnight charging, eliminating the need for a costly on-board AC charger. Only these 3 trucks will be capable of AC charging, for their overnight charging and for charging at day-time at the loading-dock.

Thanks to the recent availability of 350 kW CCS DC charger, we were able to request an electric truck with an increased charging of 300 kW instead of 150kW. Also, the cost reduction of 50 kW DC chargers makes it possible and economic feasible to use DC for overnight charging as well, instead of the so far common use of AC for slow charging.

Whereas the slow chargers will be for dedicated use of each of the transport companies individually and located at their premises, the ultra-fast charging stations, will be public accessible for being used by other (non eGLM) electric trucks as well. The locations of the ultra-fast chargers are optimised for being used by the various transport companies in the eGLM project and will as much as possible be integrated in their logistic operations.

It is clear that for 44 ton electric trucks with a price mounting to well above € 300.000 per vehicle and expensive service cost accompanying these trucks, there is no positive business case yet. Hence the public funding at this stage has proven to be of an inevitable importance for the project to happen

What will be tested

Although the vehicles will run in normal operations, the first 1 to 2 years of the operations will partly be used for tests, solving issues and for optimisation of the system, like for logistics and for charging. Logically, the testing period will include the vehicle performance and durability, but also the behaviour of the vehicles and of the charging infrastructure, in the different logistic processes, routings and distances (which are in some of the planned routes certainly challenging). High emphasise will be on analysing driver behaviour and satisfaction.

As these vehicles are new configurations, with much larger battery capacities than was common so far, with substantially increased charging speeds, with (for electric trucks) relative new DC charging technology and with increased engine power, the vehicles will be monitored intensively by the manufacturer. This will also be needed, as the vehicles will be used intensively, and have high frequency of super-fast charging, in order to increase the mileage and to improve the business case. Focus will also be on monitoring battery performance and battery degradation.

Once the deployment of the e-trucks is running smoothly and the vehicles are well established in the logistic routine of the companies, the project will start testing multiple users per trucks and also truck-sharing, all with the purpose to increase the capacity utilisation and hence improving the economics of these high investment vehicles.

This monitoring will be done, in cooperation with the Fontys University (NL) and by the Fachhochschule Aachen.

Status of the project

In Autumn 2018, the electric trucks have been ordered from the German e-truck conversion company FRAMO, which converts diesel MAN trucks. eGLM has invited FRAMO to show their demonstration truck at an eGLM event in December 2018. A demo-truck will be tested by the partnership in April/May 2019, after which the first electric truck will be supplied by FRAMO to eGLM. By the 3rd quarter of 2019 all 7 trucks should be delivered.

The same applies to the charging infrastructure. The suppliers of the super-fast charging infrastructure have been preselected together with FRAMO, and currently the final decision making takes place. Currently the site development is taking place. The first e-trucks being delivered will be operated on the basis of overnight charging, during a test period of approximately two months. Moreover, as the 350 kW inlets/charge ports are currently being tested and are expected to be delivered early 2020, the vehicles will be supplied with 150 kW inlets and upgraded as soon as the new inlets are available.

Picture 1: FRAMO Promotion Truck at the presentation of the truck manufacturer in December 2018 in Düsseldorf

The basis for this decision, was an in-depth feasibility study, in which the different vehicle and battery configurations, have been studied vis-à-vis the application areas (routing, length and number of trips, waiting time). The same has been done for the

alternatives for charging. A broad range has been studied, from battery swapping, to pantograph fast charging, to conductive static charging. The outcome was that for this application based on the status of technology, ultra-fast CCS DC plug charging matches the application needs best.

A thorough study of suppliers of electric trucks and of charging infrastructure has been executed. We have been in contact with almost all conversion companies and large truck manufacturers in Europe. Whereas the project came too early for the large OEM truck manufacturers, as they will introduce vehicles in this vehicle weight class well after 2020 and beyond, the electric truck conversion has professionalised substantially over the last years, with good product offerings at several conversion companies.

Together with the transport companies in the consortium, we have defined the best configurations for the vehicles and the charging infrastructure. Routings and applications were selected, and economic calculations (total cost of ownership per kilometre) have been made.

In line with tender regulation of the EU Interreg program, a public tender has taken place. In a highly innovative market with small suppliers, it has proven to be very difficult to select the electric truck supplier via a tender procedure, resulting in a delay of approximately one year and therefor instead of the electric trucks being in operation already in 2018, the first vehicle is expected to be delivered in May 2019.

4 Expected future of electric freight transport

Currently the market of electric trucks is dominated by niche manufacturers/converters. It is expected that they will hold their current position in the heavier weight classes, because most of the announced short term market introductions from OEM's are for the lower weight classes. As soon as the OEM's start investing in new product development (Ansoff's matrix: existing market, new product), the purchase capacity in combination with economy of scale, there will be no viable business opportunities for converters in the 'standard' truck segments.

Here we will explain more about the expectations of battery electric trucks that will come to market, by taking some examples from current developments:

- Vehicles like for example, the Volkswagen e-Crafter are already available (Mercedes-Benz eSprinter will follow in Q3 2019). With these type of vehicles, VW and MB are also aiming at the weight class of max 4.250kg, where a driver with a normal B driving license is allowed to drive a 3,5t+ electric vehicle. The 750kg difference is to compensate for the higher weight of the electric version (caused by the batteries). Although this new regulation is not yet a standard in the EU, countries like France and Germany have already adopted it and the Netherlands will follow soon.
- In a slightly higher weight class, Mitsubishi and Daimler have been working on the FUSO eCanter (7,5t), which is currently being built in small scale series and is being tested by selected customers. It is expected that large scale production (in Portugal) will follow soon.
- Also Volvo has introduced full electric trucks. In the weight class to be considered medium duty trucks, they have introduced the "FL electric" (16t) and the "FE electric" (27t). Based on the knowledge and experience from their electric busses, they expect to have a fast market introduction. Series production is expected to start this year, but already these trucks are being tested together with customers in Sweden. Expected is that these trucks will have a battery package between 100 and 300 kWh, but prices are still undisclosed.
- DAF and VDL are working together on their "DAF CF Electric VDL E-Power", and have delivered the first electric trucks to their customers at the end of 2018. The semi-truck in the weight class of 44 tons has a range of about 100 kilometres with a 170 kWh battery. It is unknown when the truck is going to be produced in larger series and what the price will be.
- MB/Daimler also announced an eActros back in 2016, and has recently started to test the vehicle in real life situations as a 25t truck driving 168 kilometres in 3 shift operation at 'Logistik Schmitt' in Germany. The next step is to test the technology in a semi-truck. MB expects that the truck will be on the market in 2021.
- The Tesla Semi was presented last year, which in the meantime has received many orders. The truck is currently being tested in the US, and the production is planned to be started later this year. The truck will be able to drive 800 kilometres on one battery charge and can charge 650 kilometres

in 30 minutes. The pre-announced prices in the Netherlands are almost unbelievably low at € 130.000 (range 475km) / € 150.000 (range 800km) [6] and it is announced to be available in some European countries like the Netherlands in 2020. Although it remains to be seen what the actual price-level and market introduction data will be.

Next to the mentioned developments with regards to full electric trucks, almost all truck manufacturers are investing in the development of electric drivetrains. Next to the full electric trucks there are also developments with regards to plug-in hybrid trucks.

- It is expected that several OEM's will come to market with PHEV trucks in the heavier segment. This might be seen as a solution where inner-city distribution can be done without local air pollution by driving in full electric mode. Outside of the city centres the truck will shift to diesel mode. This can be regulated by geofencing systems.
- Expectations are that the trucks will have a rather small battery capacity (30 – 40 kWh).
- The expected additional costs of the hybrid system at first will be about € 100.000. To earn back the additional investment, the truck has to drive a significant amount of kilometres in electric mode in combination with smart planning and regular (fast) recharging, while unloading and loading of cargo.

Another drivetrain technology is hydrogen/fuel cell. There are a number of interesting developments in regards to this technology.

- This technology can be seen as a sustainable solution for the issues with the limited range of battery electric trucks, and their long charging time. However, this technology is currently significantly more expensive and the Technology Readiness Level (TRL) is lower than the battery electric trucks. It could be a viable solution in the future, mainly for long distance transport.
- There are a couple of truck manufactures who are investing in the development of this technology, like Nikola, Toyota and Hyundai.
- Nikola is also working on 3 different trucks. The third one, called Tre, is aimed at the EU market. All truck technologies are using hydrogen technology. The Nikola Tre is expected to have a range between 500 and 1.200 kilometres and a refill time of 20 minutes is expected. The prices have not been announced.
- Toyota has tested their first hydrogen truck in LA and Long Beach, and took their lessons learned in the beta version which is now being tested. The range of 200 miles was improved to 300 miles in the second version. There is nothing known about expected production date and price levels.
- Although the technology is promising, it seems that most OEM's are investing more in Battery Electric Vehicle (BEV) technology than in Hydrogen. Currently, the TRL level is lower and the production costs are higher. This means the purchase cost will be higher. The operational cost per kilometre are currently still higher as well, leading to a difficult combination to build a positive business case.

Currently, a heavy duty semi electric truck build by a converter, is between € 200.000 and € 250.000 more expensive than a regular diesel truck. We expect that (due to economies of scale) the prices of electric trucks build by OEM's will be lower. Next to the economies of scale of the truck manufacturers, the battery prices per kWh keeps going down, leading to an even sooner break-even point.

However, there will still be a price difference between the diesel and the electric truck for a while. The operational costs per kilometre are lower for an electric truck, so the break-even point in kilometres for being cost neutral will become more realistic. Given the fact that the range of an electric truck is limited, a cost neutral point is only to be reached by smart logistics planning and ultra-fast charging.

Governmental incentives can stimulate the electric truck uptake, until the market is more mature and electric trucks become cost-neutral. That is, until sales prices like announced for the Tesla Semi Truck, become a market reality, and a total-cost-of-ownership advantage over ICE-trucks is easily attained.

The business case for an electric truck might become more attractive, by restrictions posed by governmental organisations, like environmental zones in cities. There's a large number of developments where cities in western Europe are closing their cities for polluting vehicles.

We can conclude that the forecasts of electric truck market introductions by OEM's, combined with the expected price drop, the market for local and regional operating trucks will change significantly in the near future.

5 Experienced developments in charging infrastructure

Current situation

The type of charging infra which is needed for an electric truck, depends very strongly on the type of application area and on the availability of technology and costs. The current level of technology still limits charging the truck with a cable, especially when charging is done in publicly accessible areas.

Currently, most trucks are charged during night time with onboard AC/DC converters. This means that the truck is attached to an AC charger, usually with a charging capacity between 11 and 22 kW, to charge the battery.

The first DC/DC (e-truck) chargers are being implemented in 2019. With this charging solution, there is no need to have an onboard convertor build into the e-truck. This saves weight and costs on the e-truck itself. Charging the e-truck directly with DC current, means the convertors are not placed inside the truck but in the charging point, where weight, size, etc, are less of a problem. DC chargers are currently available between 11 kW and 350 kW for use in public areas and are commercially available.

Identified challenges

When being limited to charging at a standstill, or "slow" charging, it imposes extra costs when having a truck driver at work that's not moving. So especially during the day-time working hours, charging needs to be done as fast as possible and preferably in the logistics process (for instance during a break, during loading/unloading or when filling in paper work).

Most application areas demand that charging time is minimised as much as possible, allowing the maximum distances travelled during the day and therefor the most efficient use of the electric truck and the driver. Therefor the most logical choice is the highest possible charging speed that is technically available within the budget available. In the case of eGLM, it was decided to use 350 kW DC chargers with CCS for day-time fast charging.

Opting for such high power, will in most cases have consequences for the grid connection. Even at most industrial locations, there's not enough capacity available for an extra 350 kW load, especially not during day-time when buildings and machines are already using a lot of energy. So, in most cases, a new grid connection and a new transformer are needed, or at least the transformer needs to be upgraded. These requirements to the grid connection bring significant extra costs to the realisation of the charging infra (about 25% of the total all-in costs per charger). In total, costs of the implementation of an ultra-fast charging can be estimated around € 150.000 up € 250.000 depending on supplier choice and necessary gridworks. The need for such a grid upgrade, also has a significant impact on the planning of the project. In most countries you have to take into consideration the long delivery lead time of the grid upgrade by the DSO and also of the transformer. Both could take up to 4 to 5 months' time.

Future perspective

There have been, and still are, a couple of different interesting developments in terms of charging infrastructure.

- It is currently not likely that charging via a cable is going to exceed 350 kW, since the cables are already getting almost too heavy to be operated by a person. There are other types of connected charging, which are currently being developed, where higher charging speeds could be possible. There are systems with 'mechanical arms' which could connect a charge point to a truck, for example via the side of a truck, or underneath a truck.
- Like currently often used by electric busses, a static pantograph system could be an interesting solution. Because the contact area is larger than what is possible via cables, a higher charging

speed could be applied. Current solutions work with about 450 kW, but there are tests executed with conduction reaching over 1.000 kW. There is also no need for a driver to preform several actions, but can simply park the truck at the right spot and start the charging procedure by pushing a button.

- There are also tests conducted with dynamic charging via pantograph systems like the electrified railroad (eHighway[7]). This opens the option of not being depended on 'location charging' and fully integrating charging in the operations. An alternative dynamic connected charging system is by charging from underneath or behind a truck and dynamically charges the battery while driving.
- Next to the above mentioned connective charging solutions there are different test with inductive charging, static as well as dynamic. Theoretically it is an interesting charging solution since there are limited wear and tear parts on this system. In a lab environment it is also possible to achieve a high efficiency in a static application, but currently this solution is still too expensive.

All these alternatives to AC and DC plug charging, need further development, need significant cost reduction before being viable in real applications. Although static pantograph charging is more and more standardized and used for electric bus fleet operations, it meets technical hurdles and limitations for trucks which need to be overcome. For the other charging solutions mentioned above, the future is even more uncertain, as technology developments are not stable yet and new alternatives are popping-up. We even see that technologies like battery swapping systems are back on the road-map of certain manufacturers, after it had become less of a viable variant during recent years. But before any of these options, can become an alternative to alternatives to AC or DC plug charging and static pantograph, charging, standardisation is needed, to enable market acceptance

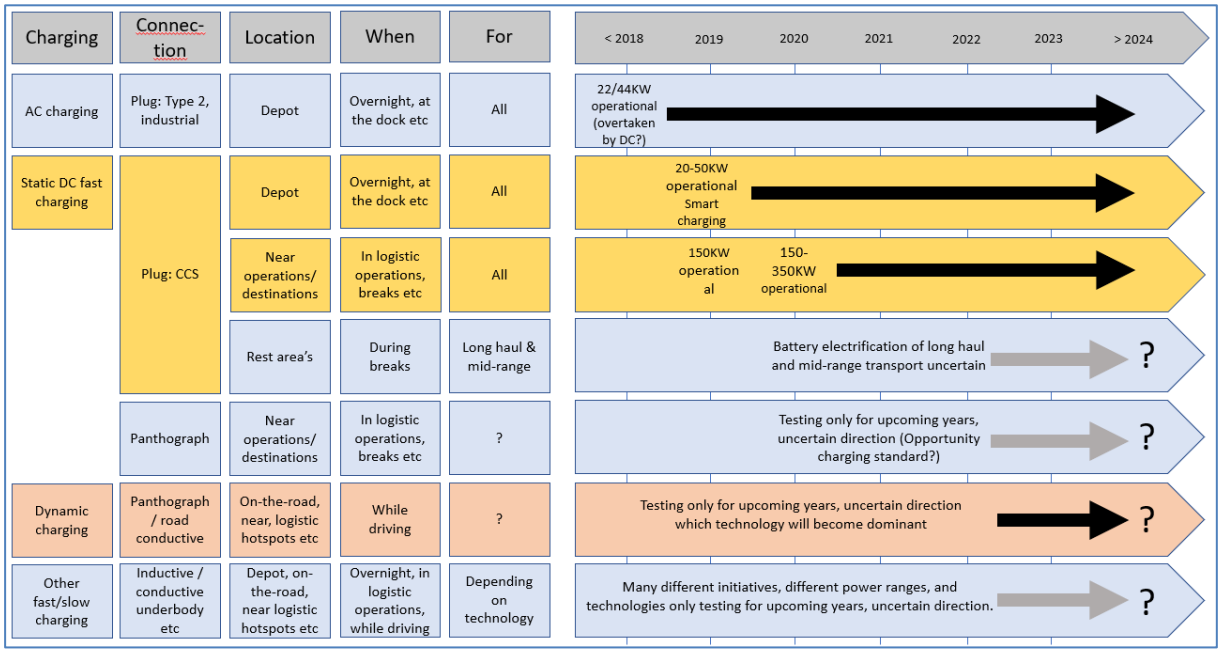

Figure 4, Simultaneous tracks in charging infrastructure for heavy duty freight vehicles

6 Overall conclusions and recommendations

Considering the cases described in this paper, it shows that electric trucks can already be deployed in many logistic application areas. However, from an economic perspective, most of the electric trucks do not have a positive total-cost-of-ownership compared to their ICE equivalents. Even more so when considering the extra investments in the charging infrastructure, and the adaptation of logistic concepts because of range limitations and charging requirements.

The technical aspects of electric trucks are constantly improving. Although the market of the heavier electric trucks is still dominated by converters, the OEM's are soon going to compete on this market with better

quality, better service and maintenance and most likely also better prices. We also experience that the conversion companies are professionalising and are moving towards becoming OEM's or specialised in niche application/technologies.

Step-by-step, the supply market becomes more mature. Because of the improvements in energy density of batteries and because of new chemistries allowing for higher charging speeds, the ranges and performance of the vehicles is increasing and has less or even no relevant impact on nett cargo weight.

Charging solutions with regards to charging speed is also significantly better than before; ultra-fast charging is soon going to be implemented, increasing the daily driveable range for a better capacity utilisation. But also allowing for refraining from additional on-board AC chargers, reducing cost and complexity.

The downside of these fast innovations is that the value of an existing electric truck may decrease faster.

Even when taken into consideration the current limitations and high investment cost, electric trucks do fit already in many use cases and the potential for electric trucks is quickly rising, both for inner city use, as well as for regional transport. In general transport companies, their drivers and their customers provide very positive feedbacks on their experiences with electric trucks. Nevertheless, the number of vehicles included in the fleet are still small and targeted at establishing a "green" image of the company, and or at creating first experience in order to be future ready one the market uptake of etrucks accelerates.

In general, we encounter a positive demand from transport, logistics and retail companies for zero emission alternatives. Lack of knowledge, experience, (technology) uncertainty and high investment cost are withholding them from large scale investments. Increased market uptake will only take place, once purchase prices of the electric trucks come down, which will only happen once production economies of scale are realised, both in vehicle assembly as in parts and battery supply. However, volume truck manufacturers will only start and scale up the production of electric trucks, once market demand forces them to do so.

History with passenger car manufacturing has proven that industry is not able to breakthrough this vicious circle (see historic EU emission and CO2 regulation date). Local and national governments are of imminent importance of pushing this initial "demand".

In terms of CO2 emissions, air quality and noise levels, the road towards zero emission transport is irreversible and several cities have chosen a path towards blocking access of ICE trucks to inner city areas. But until there is either a positive business case or an obligation for driving zero emission, stimulation measures via privileges or subsidies, will be very necessary for stimulating demand. Stimulation can also take place via including zero emission criteria, in tendering for transport services: An instrument more and more seen at public authorities.

In parallel to government initiatives, the transport sector together with their customers can by joining forces and by visualising their bundled market demand for e-trucks, accelerate the developments at truck manufacturers.

References

[1] EAFO www.eafo.eu/europe accessed on 2018-10-29

[2] FREVUE. Freight Electric Vehicles in Urban Europe: www.frevue.eu accessed on 2018-10-29

[3] iCVUE www.icvue.eu accessed on 2018-10-29

[4] eGLM. electric Green Last Mile: www.eglm.eu accessed on 2018-10-29

[5] proEME www.pro-eme.eu accessed on 2018-10-29

[6] Tesla https://www.tesla.com/nl_NL/semi accessed on 2019-03-13

[7] Siemens eHighway https://new.siemens.com/global/en/products/mobility/road-solutions/electromobility/ehighway.html accessed on 2018-12-10

Authors

Harm Weken is since 1995 managing Partner of FIER Automotive, a business development company in the international automotive sector, with a focus on sustainable and electric mobility. Harm is co-founder and co-owner of GoodMoovs.com, the largest all electric business-to-business car sharing program in the Netherlands and part of an EU network of electric car sharing programs. Moreover Harm, supports electric mobility initiatives and the academic sector as board member, advisory council member and in scientific reviewing committees at universities and electric mobility foundations, in Europe and overseas. The core of the work of Harm and his company FIER, is (EU and national) project initiation and business development in electric mobility for private companies, public authorities and consortia. During recent years, the focus has been on: Stimulating electric vehicle (EV) uptake in fleet; Effectiveness of national EV incentives and policies; Stimulating electric trucks in distribution and inner-city freight and; Electric car sharing and smart charging infrastructure.

Edwin Bestebreurtje MSc is partner and senior consultant of FIER Automotive & Mobility**.** Edwin has been specialized in business development projects in the automotive and mobility sector. He was responsible as project manager for developing the Automotive Campus in Helmond and project manager in European projects on (e-) mobility, such as ENEVATE and I-CVUE. Edwin was also responsible for several innovation missions inside and outside Europe with important mobility topics. He has been involved in many projects and initiatives.

Rob Kroon BSc has a wide experience in the automotive and (electric) mobility sector. Employed as Project Manager / Consultant at FIER Automotive & Mobility, he worked on several EU projects like ENEVATE, I-CVUE, FREVUE, eGLM, proEME and their spin-of projects. Due to the involvement in these EU projects and other business development projects, Rob has built experience, knowledge and an interesting network in the field of electric/sustainable mobility.

Floris Jousma BSc, clean mobility specialist, works on the bridge between the world of Energy & Utilities, IT and Automotive at national and international companies. He has built up his knowledge and experience in different managerial and business consultancy roles, which he now employs to realise projects in the field of alternative fuels and vehicles, smart grids and charging infrastructure solutions, such as the European Alternative Fuels Observatory and eGLM. Combined with his great interests in automotive, clean and smart mobility and logistics, his ambition is to speed up the transition towards a safer, smarter and cleaner world of mobility.