TØI report 1655/2018

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Norwegian Centre for Transport Research

MOZEES
Mobility Zero Emission Energy Systems

Technological maturity level and market introduction timeline of zero-emission heavy-duty vehicles

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State of the art

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Sammendrag:

Mens innfasingen av batterielektriske personbiler og busser skyter fart i det norske markedet, gjelder det samme ikke for varebiler og lastebiler. Dette skyldes kostnadsmessige barrierer, men også at tilbudet av denne typen kjøretøy enten er mangelfullt eller ikke-eksisterende i det kommersielle markedet dag. Når det gjelder kjøretøy med hydrogen-brenselcelleteknologi, er dette et mer umodent marked enn for batterielektriske kjøretøy, men også for disse kjøretøyene er tilbudet bedre for personbiler og busser enn for varebiler og lastebiler.

I denne rapporten gis en gjennomgang av teknologisk modenhetsnivå og forventet markedsintroduksjon for varebiler, busser og lastebiler med nullutslippsteknologi, samt tilhørende infrastruktur for fylling og lading.

Summary:

While the phasing-in of battery-electric passenger cars and buses speeds up in the Norwegian market, the same does not apply to vans and trucks. This is due to cost barriers, but also that the availability of this type of vehicles is either inadequate or non-existent in today's commercial market. Hydrogen and fuel-cell technology, has an even more immature market, but for these vehicles, the availability is also better for passenger cars and buses than for vans and trucks. This document is a review of the technological maturity level and expected market introduction for vans, buses and lorries with zero emission technology, as well as related infrastructure for filling and charging.

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Preface

This report has been prepared in RA4 for MoZEES, Mobility Zero Emission Energy Systems, a research centre for environmentally friendly energy, led by the Institute for Energy Technology. The work is funded by the Research Council of Norway. In MoZEES, basic research is carried out on batteries and hydrogen-fuel cell technology for heavier applications such as buses, lorries and vessels. The purpose of this document has been to provide technology status and expected market introduction of zero-emission solutions for heavy vehicles, and is the first report prepared within RA4 in MoZEES.

The work at TØI has been carried out by Guri Natalie Jordbakke, who has written the chapters on vans and trucks, Astrid Helene Amundsen, have written the chapters on buses and charging infrastructure and Ingrid Sundvor, who has written the chapter on hydrogen filling infrastructure. Erik Figenbaum and Inger Beate Hovi have guided the work, written chapter 1, 2 and 7 and contributed to the others. Secretary Trude Rømming has been responsible for organizing the report for publishing, while divisional leader Kjell Werner Johansen has had the final quality assurance responsibility.

This work was performed within MoZEES, a Norwegian Centre for Environment-friendly Energy Research (FME), co-sponsored by the Research Council of Norway (project number 257653) and 40 partners from research, industry and public sector. We would like to thank our MoZEES research partners for comments and input to the report. However, any remaining errors or omissions are TØI's responsibility.

Oslo, October 2018

Institute of Transport Economics

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Content

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Summary

Technological maturity level and market introduction timeline of zero-emission heavy-duty vehicles

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While phasing in of battery-electric passenger cars and buses speeds up in Norway, this does not apply to battery-electric vans and trucks. Differences in the phase-in progress are partly due to differences in the framework conditions, and the differences in the incentives to offset the economic additional costs associated with zero-emission solutions. In addition, this review shows that the technological maturity level for large vans and lorries has come much shorter than for passenger cars, small vans and buses. A start of serial production of battery-electric alternatives is expected in the coming years also for heavier vans and lorries. Hydrogen fuel cell technology is less mature than battery-electric alternatives, but also here buses are more mature and nearer serial production than freight vehicles are.

This document summarizes a review of the technological maturity level and expected market introduction for battery-electric and hydrogen-fuel cell technology for vans, buses and trucks, and associated charging and filling infrastructure.

Battery electric HDVs

A battery electric vehicle (BEV) uses chemical energy stored in rechargeable battery packs as a source for electricity used for propulsion in electric motors and motor controllers, instead of using fuels in an internal combustion engine (ICE).

In 2015, nearly all the electric buses in use globally were to be found in China. Since 2013 small European pilot projects involving 1-2 electric buses, have grown into larger pilots where entire bus lines are utilizing electric buses (ZeEUS report 2016) in more than 40 cities. These pilots include different models of electric buses and charging options, where both fast charging and over-night charging systems are tested out. Ruter, a public transport service provider in Norway, have 6 electric buses operating in their network (from November 2017) in Oslo and have recently issued operator contracts that will lead to the delivery of another 70 electric buses in 2019 (Ruter 2018). According to findings in ZeEUS, *serial* ***production of electric buses could reach maturity already in 2018-2020.*** However, this only applies to city buses, while coaches do not currently have a battery-electric alternative. Others have indicated that electric buses and their infrastructure should reach technological and economical ***maturity for*** *serial* ***production by 2020-2025*** (Hagman et al. 2017; Bloomberg 2018).

Although the electric bus market is near an economic maturity level, it is far from the case for goods vehicles. There are still only small electric vans that are serial produced, but this is about to change, and both serial produced large vans and trucks will soon come on the market. Until now, pilot tests with battery electric trucks have been limited to vehicles originally fitted with an ICE, that are refitted with a battery electric drivetrain. There are at least two companies in Europe, offering such services, Emoss in the Netherland and the French company PVI (Power Vehicle Innovation) which is owned by Renault.

Goods distribution services in cities operate in similar conditions as buses and can potentially be electrified with similar technology, motor and battery sizes. For trucks, that have a less predictable transport pattern over the day, it is more important with bigger batteries and longer range. Transport costs will increase when the cargo or passenger capacity is reduced and the time to fill energy into the vehicle increase compared to operating a diesel truck or bus, since more vehicles (and drivers) are needed to fulfil the same transportation tasks. Therefore, these parameters have a strong impact on the economics of freight and public transport using BEVs.

Postal companies have been some of the first to acquire battery electric vans in Europe. BEVs are suitable for postal deliveries because daily routes are usually fixed. For HDVs the early stage segments that can be electrified are most likely to be found within waste management, grocery trade and city logistics. Public tenders can help to phase-in BEVs within these segments.

Although the energy density in batteries have increased in the recent years, BEVs are often heavier than similar vehicles with ICE, which usually results in a reduced passenger or cargo capacity. The driving range of the vehicles is also a limiting factor, and there is a trade-off between the cargo/passenger capacity, driving range (battery size) and charge time. Battery packs are therefore tailored to specific bus routes based on charging potential at the end stops.

Different kinds of batteries are used, but it seems like lithium ion batteries is the most common battery type used for HDVs in Europe. In China lithium iron phosphate batteries, a variant of Li-Ion batteries, are commonly used in buses. Iveco's battery electric mini-buses use Sodium-$NiCl_2$ batteries, a battery type which is supposed to perform better during colder temperatures, as the battery chemistry operates at some 270°C.

Some operators are worried about the durability of batteries. In China a reduction of battery capacity after 3-5 years of bus usage has been reported (Shengyang Sun 2018). The battery electric buses on today's market typically have a battery warranty of four to up to ten years (Bloomberg 2018), the same as for the charging systems. The Lithium-Titanate-Oxide Li-Ion variant (LTO) have a warranty of up to 15,000 charging cycles, but the life expectancy of the batteries is about 18,000 full recharge cycles (Linkker 2017).

Three main options exist for recharging battery electric city buses; depot charging overnight, opportunity fast charging during the day at stops, and dynamic charging while driving (conductive as used by trolleybuses, or inductive buried in the road surface which is under development). In reality, combinations of these may be used.

Fuel cells HDVs

A fuel cell electric vehicle (FCEV) is an electric vehicle using compressed hydrogen as its fuel source. The fuel cell vehicle will most often also include small batteries to boost the acceleration, capture braking energy, and act as a power buffer. These batteries can, but need not, be externally rechargeable.

In Europe 82 fuel cell buses are being tested out in different pilot projects (CHIC 2017). The testing of a further 200-300 fuel cell buses in Europe in 2018-2020 is already being planned for by the EU projects Jive 1 and 2 and other projects (FCH Joint Undertaking 2017; FCH Joint Undertaking 2018). Ruter, Oslo, will be a partner in Jive2.

According to CHIC (2017) the availability of both buses and infrastructure needs to be improved further to give confidence to initiate further hydrogen fuel cell bus operations. This includes technical improvements, improved capabilities of suppliers and maintenance facilities, improved availability of spare parts, and reduced response and repair times when trouble arises.

As for BEVs, fuel cell vans and trucks are lagging behind the bus development. There are few concrete plans for *serial* production of this type of vehicle among European companies. Scania, in cooperation with the Norwegian wholesaler company Asko, is preparing five delivery trucks for fuel cell technology, which will be used in the Trondheim area from the late autumn of 2018.

Lack of hydrogen refuelling infrastructure, together with the higher current cost levels for hydrogen vehicles, are barriers to phasing-in this type of vehicle. This is a reason why Asko also established its own hydrogen production plant within their terminal area outside Trondheim. Hydrogen is produced by a solar systems on the warehouse roof and, will in addition to the trucks, also supply hydrogen-powered fork-lift trucks used inside the warehouse.

The pilots in the US experienced some of the same problems as in Europe: poor availability of spare parts, high maintenance costs for a relatively small number of vehicles, and competition with other zero emission technologies.

Sammendrag

Teknologisk modenhetsnivå og forventet markedsintroduksjon for tunge nullutslippskjøretøy

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Forfattere: Guri Natalie Jordbakke, Astrid Amundsen, Ingrid Sundvor, Erik Figenbaum og Inger Beate Hovi
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Mens innfasingen av batterielektriske personbiler og busser skyter fart i Norge, gjelder ikke det samme for batterielektriske varebiler og lastebiler. Forskjeller i innfasing skyldes dels ulikheter i insentiver for å utligne for de økonomiske merkostnadene som er knyttet til nullutslippsløsningene og dels teknologienes modenhetsnivå. Gjennomgangen i denne rapporten viser at det teknologiske modenhetsnivået for tunge varebiler- og lastebiler er kommet mye kortere enn for personbiler og busser, men at det også forventes en nokså snarlig oppstart av serieproduksjon av batterielektriske alternativ for disse kjøretøykategoriene. Hydrogen-brenselcelle teknologien er for disse kjøretøykategoriene mer umoden enn de batterielektriske alternativer, men også her er modenhetsnivået kommet lenger for busser enn for godsbiler.

Dette dokumentet oppsummerer en gjennomgang av teknologisk modenhetsnivå og forventet markedsintroduksjon for batterielektriske løsninger og hydrogen-brenselcelleteknologi for varebiler, busser og lastebiler, samt tilhørende lade og fylleinfrastruktur.

Batterielektriske kjøretøy

Et batterielektrisk kjøretøy er en type elektrisk kjøretøy som bruker kjemisk energi lagret i oppladbare batteripakker som kilde til strøm som brukes til framdrift av kjøretøy ved hjelp av elektriske motorer og motorstyringer, i stedet for forbrenningsmotorer slik dagens tradisjonelle lastebiler og busser gjør.

I 2015 var nesten alle batterielektriske busser i bruk i Kina. Siden 2013 har små europeiske pilotprosjekter med 1-2 elektriske busser vokst til større piloter hvor hele busslinjer bruker batterielektriske busser (ZeEUS-rapport 2016) i mer enn 40 byer. Pilotene er gjerne basert på forskjellige modeller for elektriske busser og ladealternativer, hvor både hurtiglading og systemer for natt/depotlading testes ut. Ruter i Norge har for tiden 6 elektriske busser i bruk (fra november 2017) i Oslo, og har nylig gjennom endringsordrer i eksisterende anbud bestilt ytterligere 70 elektriske busser som skal leveres 2019 (Ruter 2018). Ifølge funn i ZeEUS, kan serieproduksjon av elektriske busser bli teknologisk og økonomisk modent fra 2018-2020. Dette gjelder imidlertid bare bybusser, mens langdistansebusser foreløpig ikke har et batterielektrisk alternativ. Andre antyder at elbusser og deres ladeinfrastruktur bør kunne nå teknologisk og økonomisk modenhet innen 2020-2025 (Hagman et al. 2017, Bloomberg 2018).

Selv om elbussmarkedet er nær et teknisk og økonomisk modenhetsnivå, er det langt fra å gjelde for tyngre nyttekjøretøy og lastebiler. Det er fortsatt bare små elektriske varebiler som serieproduseres, men dette er i ferd med å endres, og både serieproduksjon av store varebiler og lastebiler forventes å snart igangsettes. Hittil har pilotforsøk med batterielektriske lastebiler vært begrenset til kjøretøy som opprinnelig var utstyrt med forbrenningsmotor, men som er blitt ombygget til batterielektrisk drift. Det er minst to selskaper i Europa som utfører denne typen ombygninger, henholdsvis nederlandske Emoss og det franske selskapet PVI (Power Vehicle Innovation), som er eid av Renault.

Distribusjonstjenester i byer opererer på lignende vilkår som busser og kan potensielt elektrifiseres med tilsvarende teknologi og batteristørrelser, der lademuligheter f. eks. kan være ved en terminal eller et grossistlager. For lastebiler, som har et mindre forutsigbart transportmønster over dagen, er det viktigere med større batteri og lengre rekkevidde. Dersom lastekapasiteten reduseres og tiden det tar å fylle energi inn i kjøretøyet øker sammenliknet med kjøretøy med forbrenningsmotorer, vil også transportkostnadene øke fordi flere biler og sjåfører trengs for å utføre de samme transportoppgavene. Derfor har disse parameterne en sterk innvirkning på økonomien til gods- og kollektivtransport ved bruk av batterielektriske kjøretøy.

Selskaper som distribuerer post har vært blant de første til å investere i større flåter av batterielektriske varebiler i Europa. Små elektriske varebiler er egnet for postleveranser fordi de daglige rutene vanligvis er faste og dermed har et forutsigbart rekkeviddebehov. For tyngre kjøretøy er avfallshåndtering, dagligvarehandel og bydistribusjon de segmentene som mest sannsynlig er best egnet for elektrifisering i en tidlig fase. Offentlige anbud kan bidra til å forsere innfasingen av batterielektriske løsninger innenfor disse transportsegmentene, ved å vektlegge miljø høyere enn kostnader.

Ulike typer av batterier brukes, der litium-ion (Li-Ion) batterier den vanligste batteritypen i Europa. I Kina er litium jern fosfat batterier, en variant av Li-Ion batterier, vanlige i batterielektriske busser. Ivecos minibusser har Sodium-Nikkel klorid (Na-NiCl2) batterier, en batteritype som skal fungere bedre under kaldere temperaturer, da batterikjemien opererer ved 270 ° C.

Selv om energitettheten i batterier har økt de senere årene, er batterielektriske kjøretøy fortsatt tyngre enn tilsvarende kjøretøy med forbrenningsmotor, noe som vanligvis resulterer i redusert passasjer- eller lastekapasitet. Bilens rekkevidde er også en begrensende faktor, og det er gjerne en avveiing mellom laste-/passasjerkapasitet, rekkevidde (batteristørrelse) og ladetid. Batteripakkene til busser er derfor gjerne skreddersydd for spesifikke bussruter basert på kjørerute, topografi og lademuligheter ved endestoppene.

Noen operatører er bekymret for batterienes holdbarhet. I Kina er det rapportert om en reduksjon av batterikapasitet etter 3-5 års bussbruk (Shengyang Sun 2018). Elbussene på dagens marked har vanligvis en batterigaranti fra fire og opp til 10 år (Bloomberg 2018), det samme som for ladestasjonene. Litium-Titan-Oksid (LTO) batterier har en garanti på opptil 15000 ladesykluser, mens forventet levetid på batteriene er ca 18000 full-oppladningssykluser (Linkker 2017).

Tre hovedalternativer finnes i dag for å lade batteriet til elektriske bybusser. Dette er depotlading over-natten, hurtiglading i løpet av dagen ved stopp, og dynamisk lading under kjøring (som brukes for eksempel av trolleybusser). I virkeligheten brukes gjerne kombinasjoner av disse alternativene.

Hydrogen-brenselcelle kjøretøy

En brenselcellebil er et kjøretøy med elektrisk drivlinje som bruker komprimert hydrogen som energikilde. Brenselcellebilen vil ofte også inkludere små batterier for å øke akselerasjonen, oppta bremseenergi og fungere som en energi- og effektbuffer. Disse batteriene kan, men trenger ikke, være eksternt oppladbare.

I Europa blir 82 brenselcellebusser testet ut i forskjellige pilotprosjekter (CHIC 2017). Testingen av ytterligere 200-300 brenselcellebusser i Europa i perioden 2018-2020 planlegges av EU-prosjektene Jive 1 og 2 og andre prosjekter (FCH Joint Undertaking 2017, FCH Joint Undertaking 2018). Kollektivselskapet Ruter i Oslo, er partner i Jive2.

Ifølge CHIC (2017) må tilgjengeligheten av både busser og infrastruktur forbedres ytterligere for at videre bussvirksomhet kan initieres. Dette inkluderer tekniske forbedringer, forbedrede muligheter for leverandører og vedlikeholdsfasiliteter, forbedret tilgjengelighet av reservedeler, og redusert respons- og reparasjonstid når problemer oppstår.

Tilsvarende som for batterielektriske kjøretøy, er også utviklingen av brenselcelle varebiler og lastebiler bak personbil- og bussutviklingen: Det er få konkrete planer for serieproduksjon av denne typen kjøretøy blant europeiske selskaper. Scania, i samarbeid med dagligvareleverandøren Asko bygger for tiden om fem lastebiler for brenselcelleteknologi. Disse er planlagt brukt i Trondheimområdet fra senhøsten 2018, og er med det Europas første hydrogenlastebiler. Det finnes også noen eksempler på pilottester med hydrogenlastebiler i USA, hovedsakelig tilknyttet distribusjonskjøring til/fra havner.

Mangel på hydrogenfyllestasjoner regnes sammen med høyere kostnadsnivå for hydrogenkjøretøy gjerne som en barriere for innfasing av denne type av kjøretøy. Dette er en årsak til at Asko også har etablert sitt eget hydrogenproduksjonsanlegg inne på eget terminalområde utenfor Trondheim. Hydrogen produseres ved hjelp av solcelleanlegg på taket, og forsyner i tillegg til lastebilene, også hydrogendrevne gaffeltrucker på anlegget.

Pilotprosjektene i USA opplevde noen av de samme problemene som i Europa: Dårlig tilgjengelighet på reservedeler, høye vedlikeholdskostnader for et relativt lite antall biler og konkurranse med andre nullutslippsteknologier.

1 Introduction

The sales of battery electric passenger vehicles (BEVs) have expanded rapidly since 2010 in Norway. In 2017 BEVs reached a share of 20.8 % of new passenger car sales, while the same share for battery electric vans was only 2.2 %. Battery electric heavy-duty vehicles (HDVs) are now on the agenda for most HDV manufacturers, yet few products are presently on the market. While *serial* production of electric buses and small vans started some years ago, trucks are currently on a pilot stage, although several manufacturers have announced that they will start *serial* production of electric trucks from 2018. The first battery electric truck in Norway became operative as late as September 2016. It was a MAN chassis, originally with an Internal Combustion Engine (ICE), that was refitted with a battery electric drivetrain by the Dutch company Emoss.

At the beginning of 2018, 139 000 battery electric passenger vehicles were registered in Norway, while the number of electric vans was 3 800, for trucks there were only three. There were 11 full size buses and 10 minibuses in the fleet, as well as 5 fuel cell buses. Close to 100 fuel cell passenger vehicles were also registered.

The focus of the present report is on HDVs; trucks, buses and heavy vans. In these vehicle groups battery electric propulsion is not yet in commercial production. Small battery electric vans are now considered commercial products, profitable for users with the present Norwegian tax incentives. In the late 1990s the French vehicle manufacturers Renault, Peugeot and Citroën developed small battery electric vans equipped with NiCd batteries. During the production phase a few thousand vehicles were produced. Some of these vehicles found their way to Norwegian customers between 2000 and 2002 and as second hand imported vehicles until 2008.

The first production of electric vans with Li-Ion batteries started with a cooperation between Azure Dynamics and Ford Motor Company from December 2010, where Azure Dynamics rebuilt the Ford Transit Connect with an electric drivetrain. However, the real shift started in 2012/2013 with full *serial* production of the Renault Kangoo ZE (from 2012), Peugeot Partner Electric (from 2013), Nissan E-NV200 (from 2014) and the Citröen Berlingo EL (from 2014). About 30 000 Kangoos have been produced since the market introduction. The first versions of these models had a limited range of 170 km, but this changed from 2018. An increasing number of vehicle brands are launching electric vans with increased size and range, which will be suitable for certain types of freight transport, as well.

There are several reasons why battery electric trucks and buses are so limited in numbers. However, the most obvious reason is the maturity level of the technology. There has been a trade-off between gross weight, loading capacity and range. BEVs have therefore only to a limited extent been suitable for freight transport, and passenger transport using buses. Battery electric buses seem, in 2018, to be close to a commercial breakthrough, whereas trucks still have a way to go.

In the MoZEES project, the socio-technical aspects of electric and hydrogen solutions for heavy-duty transportation applications on roads, rails and on sea are investigated. As part of this work, the present report contains a study of battery electric and hydrogen fuel cell HDVs on the market, i.e. trucks and buses, as well as small and large vans. The overview includes launched models and various pilots and concept developments of vehicles as well as demonstration and pilot projects.

The presented products and pilot projects for road transport in this report are at different maturity levels. Products that are sold commercially are better tested and will be more reliable than prototypes and small series of vehicles developed for demonstration and testing purposes. Commercial products are also available in more or less unlimited quantities (although there may be production constraints), whereas prototypes and small serial products are only available in small numbers for testing and demonstration.

At the moment, electric HDVs are not cost effective compared to conventional diesel vehicles, but for urban distribution HDVs can be close to competitive. While costs are not a focus in this report, they will be investigated in a later phase of the case study this report was written as part of.

2 Zero emission propulsion solutions

Zero emission propulsion means that the vehicle produces no tail-pipe emissions from the system that provides the propulsion. These vehicles can only use electricity or hydrogen for propulsion energy, or a combination of these two. These vehicles will, however, still produce particle emissions from the interaction between the vehicle's tyres and the road surface and cause a resuspension of dust already on the road, as all vehicles do. The production of electricity or hydrogen may produce emissions elsewhere in the energy system.

BEVs have a battery large enough to provide all the power and energy the vehicle needs to accomplish its mission. The battery is the most important part of a battery electric HDV. However, the battery weight and volume may affect the available passenger or freight loading capacity and weight as well as the range the vehicle can drive between recharges. The battery type and size also affect the time it takes to recharge the vehicle. These parameters have a strong impact on the economics of HDVs. When the passenger capacity or cargo space or loading capacity in tons is reduced, and the time to fill energy into the vehicle increases, transport costs will also increase since more vehicles (and drivers) will be needed to fulfil the same transportation tasks. Moreover, the flexibility to perform different transportation tasks may be reduced, which will also have cost impacts, especially for smaller transportation enterprises.

The driving range of light duty vans has been measured using the "New European Driving Cycle" test. This test produces unrealistic range estimates. A rule of thumb based on results from private users of BEVs is that the real range is about 25% lower than the NEDC official range in the summer and a further 25% lower in the winter (Figenbaum and Kolbenstvedt 2016), due to the low ambient temperature, and the need to heat the vehicle. The range of these types of vehicles will from the fall of 2018 be measured in the World Harmonized Light Vehicles Test Procedure (WLTP). The range figures stated in WLTP is lower than in the NEDC and intended to be reflecting real world driving to a greater extent. WLTP figures will be close to the range that users can expect in summer conditions. There is currently no official range test for heavy-duty battery electric trucks or buses. The buyers may however specify specific requirements in the procurement process. They will likely suffer less range loss in the winter time than passenger BEVs do, as the energy required to heat the cabin will be a much lower share of the overall energy consumption of the vehicle.

BEVs can be combined with static fast charging during short stops during the day where energy can be transferred while the vehicle has stopped to load/unload passengers or cargo. These systems extend the effective range over a day and allow for the installation of a smaller battery.

BEVs can also be combined with dynamic charging of the batteries while the vehicle is moving, from overhead lines or groove tracks in the road. It is also possible to eliminate the battery entirely and only use dynamic electricity supply to the vehicle, which is essentially the traditional trolleybus system. Modern trolleybus systems can utilize a battery in the bus to reduce the complexity of the overhead lines used for the energy transfer, or to avoid overhead lines for instance in historic city centres.

Hydrogen fuel cell electric systems use a fuel cell to produce electricity on board for electric propulsion using hydrogen stored in the vehicle's hydrogen tank. The main advantage is the ability to store more energy in the vehicle and the much faster filling time for hydrogen than for charging batteries.

Plug-in hybrid hydrogen fuel cell electric solutions combine a rechargeable battery with a hydrogen fuel cell system allowing both systems to deliver energy to the electric motors. In hybrid hydrogen fuel cell electric solutions, the battery is smaller and not externally rechargeable. It is used for boosting acceleration and to recapture brake energy.

3 Battery electric HDVs

3.1 Light goods vehicles - vans

Small battery electric vans have been commercially available the last 3-6 years from Renault, Peugeot, Citroën and Nissan. More brands are now launching such vans and vans with increased size. These new vans also have longer range. The vans are, because of their size only to a limited extent capable of performing freight transport tasks such as last mile deliveries. These electric vans have about the same available cargo volume and weight as the ICE variants of the same vehicles.

Renault has launched two new fully electric vans in 2017, respectively Kangoo.ZE and Master.ZE. Master.ZE is a medium sized van and is in the size class of the Mercedes-Benz sprinter which will be discussed later. Kangoo.ZE is a small van with a stated range of 270 km (140-200 km in practice). The much larger Master is equipped with the same battery and therefore has a significantly lower range of around 120 km (Valle 2017; Ayre 2017). The Master is sold in France with a pre-tax price from 48 200 Euros with battery lease. The battery lease cost is 122 Euros/month for an annual driving distance of 20,000 km (Renault 2018). The vehicle will be launched in the Norwegian market in December 2018 (Bilnorge 2018). " La Poste", a public postal service company in France, and Renault have a collaboration on new forms of mobility, a collaboration that includes the delivery of 5,000 Kangoo.ZE to use for postal services (Renault 2014). Between 2012 and 2017 the Kangoo.ZE was available with a smaller battery with a range of 170 km (80-120 km in practice).

Both ***Citroen and Peugeot*** introduced their electric vans on the market in 2013. *Peugeot Partner Electric* was launched in 2012 with deliveries starting in 2013. With a stated range of 170 km and a cargo capacity of 3.7 m^3 or 685 kg of payload (Dalløkken 2012). *Citroen Berlingo* was also launched in 2013 and available for purchase in late 2013 (Skogstad 2013). Since then it has been upgraded. Two versions are available, the L1 and L2, referring to different lengths of the car. L1 has a cargo capacity of 3.3 m^3, and L2 a capacity of 3.7 m^3, with the opportunity for further expansion to 4.1 m^3. Both versions have the same range of 170 km, and a maximum payload of almost 700 kg (Automotive world 2017).

In the same segment of the market, ***Nissan*** has also launched a van, the *E-NV200*. The van has a payload of 658 kg, a cargo volume of 4.2 m3 and originally a stated range of 170 km. It has been available on the market since 2014. In 2016 Nissan e-NV200 won the German Commercial Vehicle Award (Nissan; Nissan 2016). A new version of the vehicle with a 67% larger battery was introduced in late 2017, with deliveries commencing in the summer of 2018 (Kane 2017). The official range in the new WLTP test is 200 km for mixed driving and 300 km for city driving (the official range in NEDC would have been around 280 km).

Mercedes-Benz also offers a van in this segment, the Vito e-Cell, which has a range of 130 km. In addition, in 2018, Mercedes-Benz will launch a new electric Sprinter (Hubbard 2018). This Sprinter will have a maximum payload of 1.25 tons and a range of about 270 km (167 miles). Mercedes-Benz has a contract with one of the major independent logistics firms in Germany, Hermes, implying that they will produce and deliver 1500 electric vans in the period 2018-2020 (Lambert 2017; Daimler 2017b).

Another car supplier that cooperates with postal services is ***Ford***. Ford, the Deutsche Post and subsidiary StreetScooter will collaborate on the production of electrical vans. StreetScooter has produced smaller electric vans before. These vehicles have a cargo capacity of 4.3 m^3, a payload of 700 kg and a range of 80 km (Ivarson 2017). These vehicles are amongst others used by Deutsche Post in Germany. DHL, which is a part of Deutsche Post, has used these vehicles in its distribution both in Milan and Rome (Ivarson 2015).

Now, this co-operation will lead to production of larger BEVs, named WORK XL, based on the chassis of a 2T Ford Transit (Ivarson 2017). Production started in the summer of 2017. WORK XL will have a cargo volume of 20 m^3 (Ford 2017). The contract between Deutche Post and Ford includes the delivery of 2,500 vehicles, which will have a range between 80 and 200 km (Ivarson 2017; Ford 2017).

LDV[1] *EV80* electric van (Dimensions Med Roof LWB) was launched on the market in late 2016. This big van has a range of 192 km, payload of 950 kg and cargo volume of 10.2 m^3. At the same time, they will also make a Chassis Cab with a range of 192 km and a payload of 900 kg (LDV 2014; Fleet transport 2016).

[1] LDV is owned by the Chinese SAIC Motor.

The Australian LDV importer, ATECO Automotive, is planning to import a fleet of these vans. This is to test the potential for such vehicles in the Australian market. ATECO, will market themselves towards transport companies (carriers) and Australia Post (Hammerton 2017).

Volkswagen *e-Crafter* is a big van where the cargo space has a volume up to 11.3 m3 (or a cargo capacity of 1.7 tons). The van was shown at the utility vehicle fair in Germany (Hannover) in the autumn of 2016, and are available for sale from autumn 2018 (Valle 2016b; Volkswagen 2018). With a stated range of 200 km and a cargo capacity of 1.7 tons, this van provides competition to both the 2T Ford Transit and the LDV EV80 mentioned above (Frydenlund 2016). The van will be delivered for the Norwegian market in a smaller version with a max gross weight of 3,5 tons. In addition, Volkswagen announced that they will begin production of an electric truck, e-delivery, for last mile distribution with the same range as the e-Crafter. Furthermore, they plan for medium and heavy-duty trucks, beyond 2018 (Szymkowski 2017).

As mentioned earlier, postal companies have been some of the first to acquire electric vehicles. This was also the case when **Iveco** presented a battery electric van in 2015, called the *Iveco Daily*. This large van has a gross weight of 5.6 tons, a range of over 200 km and an allowable cargo volume up to 19.6 m^3 (Iveco 2017). Posten/Bring, which is a Nordic postal and logistics group, purchased two vehicles. These should have been put into service from summer 2017, as the first serial -made electric vans in their size class (Dalløkken 2017a; elmagasinet 2017). However, the vehicles were delivered with a lower battery capacity and range than initially promised and were therefore returned to Italy.

Two tables summarize the above findings. In table 1, vans introduced to the market are reported, while table 2 shows vans that are expected to be launched onto the market in the near future. The price is excluded VAT, since electric vehicles are exempt from VAT in Norway.

Table 1. Vans in the market, by model, range, capacity, size and year.

Vehicle model	Battery options kWh	Range, km (NEDC)	Cargo capacity, tons	Gross-weight, tons	Year on the marked	Price in kNOK in 2018
Renault Kangoo 2012-2017	22	170			2012	
Renault Kangoo 2017-	33	270			2017	250
Ford Transit Connect Electric	28	130		2.3	2012	
Citroen Berlingo	22.5	170	0.7		2013	230
Peugeot Partner Electric	22	170	0.685		2013	235
Mercedes-Benz Vito e-Cell	36	130	0.78	3.0	2013	
Nissan E-NV200		170	0.658		2014-2017	
Nissan E-NV200	40	200 (in WLTP)			2018	284
LDV EV80	56	192	0.95		2016	
LDV EV80 Chassis Cab	56	192	0.9		2016	
Iveco Daily Electric		200	3	5.6	2017	
T Ford Transit	30-90	200			2018	
VW e-Crafter (L3H3)	36	160	0.95	3.5	Late 2018	630
VW e-Crafter (L3H3)	36	200	1.7	4.5	Late 2018	
Renault Master Z.E	33	120			Dec 2018	
MAN eTGE	36	160	0,95-1,7	3,5-4,25	2018	795

From table 1 it's clear that there has been a development in both range and cargo capacity between 2012 and 2017. Table 2 presents vans that are expected to come onto the market soon. As seen, more information is lacking for some of the parameters, but it seems like the range is increasing continuously, as also seen in table 1.

Table 2. Vans expected to come on the market by model, range, capacity, size and year-

Vehicle model	Battery options (kWh)	Range, km	Cargo capacity, tons	Gross-weight, tons	Expected marked introduction
MAN eTGE	36	160	1.7		2018
Mercedes-Benz Electric Sprinter	41 and 51	270	1.25		2018
Volkswagen e-Delivery	35.8	200			2020

3.2 Buses and coaches

Buses come in different sizes and layouts targeting different segments. City buses, which are used in inner city traffic, have a robust interior layout allowing for the efficient entry and exit of passengers, and have room for many standing passengers and fewer seats than long distance buses. Articulated buses are typically 18 meters long and have a pivoting joint between the front and the rear part of the bus to allow for cornering. Buses for regional transport are another segment. They have seats for all passengers and are designed for higher speeds, greater comfort and longer distances. Long distance buses, driving, for instance, between cities, are called coaches. Mini-buses have typically 8-19 seats for passengers and are used both for public transport and as Maxi-Taxis.

As for trucks, the main parameters for a battery electric bus are the size and the capacity of the battery, which, again, influence the range between recharges, the recharge time, and the capability of carrying passengers. For buses in public transport the main focus is on the cost of the capability to deliver a certain passenger volume. Therefore, the bus's characteristics only provide a partial answer. The other part of the equation is the characteristics of the route the buses will be used, which differs on each route, and on the manner in which the buses will be recharged. Three main options exist for recharging battery electric city buses; depot charging overnight, opportunity fast charging during the day at stops, and dynamic charging while driving (as used by, for instance, the trolleybus). In reality, combinations of these may be used.

The Chinese company ***BYD*** has produced Ebus K9 (12m) since 2010. The Li-Iron-phosphate battery has a capacity of 324 kWh, which gives a range of approximately 250 km (BYD 2017). It takes 3-5 hours to fully charge the bus, depending of the type of charging. The company offers a 12-year battery warranty (Mass Transit 2015). In addition to the K9, BYD offers the K6 (7m), K7 (8m), K8 (10m) and K11 (18m) for urban traffic. For coaches the following models are available: C6, C7, C8, C9 and C10 (14m). In 2017 the company sold 14 336 electric buses (8m, 10m and 12m) worldwide (Chinabuss 2018). The electric buses have been sold to 35 different countries. In Oslo, Norway Nobina have ordered two 18m articulated buses (K11) from BYD. These buses will be used on line 31 from Snarøya to Grorud. These buses will be delivered with a battery capacity of 270 kWh (Vestreng 2017). BYD was the second largest seller of electric buses in Europe in 2016.

The bus company ***Van Hool*** recently started cooperating with the American company Proterra. Proterra will produce the batteries (E2 battery technology) for the Van Hool buses. They will launch their first fully electric version, the CX45E (14m) in 2019 (Van Hool 2017). Later, a shorter version, the CX35E (10m) will be launched. The CX45E can be used as a coach, with a range of more than 300 km. Van Hool also produces a trolley bus, the Exqui.City (18m or 24 m), and the 18m is also available in a fully electric version. The batteries have a warranty of five years. The bus has been on the market since 2017 and has a range of about 120 km (Van Hool 2015).

The Dutch company ***EBUSCO*** has developed electric buses since 2010 (Ebusco 2018a). The Ebusco citybus 2.1 (12m) has a standard battery capacity of 311 kWh, but the customer can specify their specific needs for capacity. The bus has a range of up to 300 km when filled with passengers (Ebusco 2018b). The Ebuscos off-board charging system is offered with 35, 75 and 150 kW of power (Ebusco 2016). With a charger with 75 kW charge power, the charging time is approximately 4 hours. Ebusco also has an on-board charging system option using a pantograph for opportunity charging. The bus has already been tested in more than 24 different cities, including Stavanger (Norway) which has five electric buses from Ebucso in traffic (Dalløkken 2017b). The buses in Stavanger have battery capacities of 249 and 311 kWh, and a range of about 250 km with the 249-kWh battery. The buses in Stavanger use over-night depot charging. Brakar in Drammen has ordered six Ebusco buses that should have been delivered in 2017. However, the delivery has been delayed (Drammens Tidende 2017). The buses in Stavanger were also delivered behind the original schedule (Dalløkken 2017b). The Drammen buses will have 75 kWh batteries giving a range of about 50 km (Dalløkken 2017b), as well as an opportunity charging system for charging at bus stops. Drammen has chosen to use an opportunity charging system from Siemens, and not the Ebusco solution. The charging system from Siemens is now in place at Mjøndalen station and another one will be placed at Drammen bus station (the two end stations for bus route 51) (Drammen Live 24 2017). The charging time will be approximately 6-8 minutes.

Volvo first launched a fully electric buss, the 7900 Electric (12m) in 2015. The *serial* production of the electric bus started in 2017. A new and upgraded version of the 7900 Electric will be available on the market from the end of 2018 (Volvo 2017). The new model offers a choice between three different battery options: 150, 200 or 250 kWh. It is also possible to choose the method of charging, either by cable or by OppCharge. The range can be up to 200 km depending on battery capacity, topography, driving conditions and temperature. The OppCharge system is delivered by ABB. Electric buses from Volvo are in use in e.g: Malmø (Sweden), Gøteborg (Sweden), Differdange (Luxemburg). Tide in Trondheim has ordered 25 electric buses (12m) to be delivered from Volvo in 2019 (Sæter 2017).

The polish company ***Solaris'*** electric bus model Urbino is available in 9, 12 and 18m. They are using lithium-ion batteries, and the standard charging system is plug-in depot charging (but a pantograph opportunity charging solution is optional). The standard battery capacity is 240 kWh. The battery warranty is up to 5-10 years, the same as for the charging systems. The electric version of Urbino 12m has been in production since 2013/14, and an upgraded version has been available since 2016. Solaris Urbino 12m electric was awarded "Bus of the year" in 2017 (Avtobusi 2017). The electric Urbina is already sold to more than 17 different cities in Europe (Brakar 2016). Solaris also offers a trolley bus solution, the Trollino in 12 or 18 m. Solaris have sold more than 1 440 electric buses (Zielinski 2016). Unibuss Norway have bought two Urbino 12m to be used on line 74 in Oslo (Vika- Mortensrud). These buses have a battery capacity of 74 kWh, and will be using an opportunity charging system with 300 kW charge power from Siemens at the two end-stations (Dalløkken 2017b). Norgesbuss have also bought two buses, these with battery capacities of 125 kWh. The two buses will be used on line 60 in Oslo (Vippetangen-Tonsenhagen), and with opportunity charging (from the German company Schunk) at just one of the end-stops (Vippetangen) (Dalløkken 2017b). Boreal in Kristiansand have also bought five Urbino 12m to be delivered in 2018 (Terjesen 2017). They will have 146 kWh batteries. The buses in Kristiansand will both be able to be charged over-night (plug-in), and by a pantograph (OppCharge). The buses will be used on lines 10 and 13 in Kristiansand.

The ***VDL*** group manufactures their buses/coaches in the Netherlands or Belgium. The Citea SLF is a low floor 12 m buss (VDL 2017a) which can be delivered with two or three doors (SLF-120 or -121). Citea is also offered as an articulated model, the SLFA (SLFA-180, -181, or -187). The 181 is 18.1m long and the 187 is 18.75m long. Citea LLE is a 10m (LLE-99) electric lightweight bus. The first version of the Citea SLF was introduced at an exhibition in 2013 (Ventura 2013), and *serial* production started in 2017 (InnoTrans 2018). The standard battery capacity is 124 kWh on both the SLF and the SLFA, and 180 kWh on the LLE model (VDL 2017b). However, all models of the Citea electric can be customized to suit the customer's specifications, including the capacity of the batteries and the charging systems (plug-in and/or pantograph). The pantograph is delivered from Schunk, and has a charging power of 250 kW, so that the bus can be sufficiently charged in 5-10 minutes at the end stops (VDL 2015). The Citea SLF electric can achieve a range of about 200 km with the biggest battery pack, but this will limit the allowed total number of passengers. VDL is the greatest-selling manufacturer of electric buses in Europe (Tackett 2017), with 31 percent of the European electric bus sales in 2016 (VDL 2017b). About 200 electric Citea buses were delivered in 2017 (Fleet Transport 2016). In 2018 100 new VDL battery electric buses will be in operation around the Amsterdam airport (VDL 2018). These buses will be equipped with batteries with a capacity of 169 kWh, and a charging power of up to 420 kW (fast-charging). 23 opportunity fast charge stations will be placed on the six different bus-lines, in addition to possible depot-charging (83 slow-chargers with 30 kW capacity each). Heliox will deliver the charging infrastructure for the buses.

Linkker from Finland offered a 12m prototype in 2012, with *serial* production starting in 2016 (Erkkilä 2016). 15,000 charging cycles of the batteries are warranted, but the life expectancy of the batteries is about 18,000 full recharge cycles (Linkker 2017). The batteries are of the Lithium-Titanate-Oxide type (LTO). The buses are using opportunity fast charging with a max charging power of 350 kW (Erkkilä 2016). Charging time at bus stops is stipulated to last from 2-5 minutes. The bus has a low weight due to use of aluminium materials, and small batteries compared to other makers. Buses from Linkker are tested out in Helsinki, Espoo, Turku, Moscow, Berlin and Copenhagen.

IVECO produce an electric minibus, the IVECO Daily (Iveco 2018). The minibus can take 16-19 passengers depending on the model chosen. Ruter have 10 of these electric minibuses in traffic in the Lillestrøm/Jessheim area in Norway. These buses have a battery capacity of 84 kWh (TU 2016). The buses have Sodium-$NiCl_2$ batteries, a battery type which is supposed to perform better during colder temperatures, as the battery chemistry operates at some 270°C. With fast charging, the charging takes about 2 hours. Oslo Taxi have ordered six electric minibuses (Iveco 2017). These buses are used as school buses.

Bozankaya Sileo (Germany and Turkey) offers the following models of electric buses: Ebus S10, Ebus S12, Ebus S18 and Ebus S25. The S12 has a battery capacity of up to 310 kWh, and a range of up to 400 km under optimal conditions (Sileo 2017a). They use lithium iron phosphate batteries. Top speed is approximately 75 km/h. Energy consumption of the S12 is 0.7-0.8 kWh/km and about 1.2-1.3 kWh/km for the S18 model. The batteries have a warranty of four years. The Sileo uses plug-in depot charging, with a charging time of 3-8 hours depending on the type of charging (Sileo 2017b). Sielo buses are in use in Bonn, Thüringen, Schleswig-Holstein, and in several Turkish cities. The company expects to sell about 200 electric buses in 2018, and about 500 in 2019 (PressReader 2017).

Irizar's headquarters are in Spain and they have bus production plants in five different countries. Irizar i2e electric buses are delivered in 10, 12 and 18m (Irizar 2017). The buses have lithium ion batteries, with battery capacities between 280-380 kWh (Irizar 2017). Plug-in charging, with a charging time of about 6-7 hours, is used. The i2e is already in use in Madrid, Barcelona, Valencia, Bilbao, San Sebastian, Marseille and London.

Other models of electric buses than the ones mentioned above are also available on the European marked. The EU-project ZeEUS has made an overview of current and planned pilot projects on electric buses in Europe (ZeEUS report 2016).

The findings above have been summarized in table 3.

Table 3: Overview of some models of electric buses available in Europe and their characteristics.

Bus model	Battery options[2], kWh	Range, km	Gross-weight, tons	Year on the marked
Volvo 7900 Electric (12m)	150, 200, 250	up to 200	19	2017/18
BYD Ebus K9 (12m)	324	250	19	2010/13
BYD articulated K11 (18m)	550	275	29[3]	2016
Van Hool CX45E (14m)		300+		2019
Van Hool Exqui.City (18m)	215	120	28	2016
Ebusco citybus 2.1	311	250-300	12,3	2014
Solaris Urbino (12m)	240		19	2012/16
Solaris Urbino (18m)	240	200+	28[4]	2017
VDL Citea electric SLF (12m)		40-160	19,5	2014/15
VDL Citea electric SLFA (18m)		40-160	29	2015/16
Linkker (12m)	55	50	16	2016
Sileo S12 (12m)	310	400	19,5	2015
Sileo S18 (18m)	450	400	28	2016
Irizar i2e (12m)	380	200+	19	2014
Bollore Bluebus (12m)	240	200	20	2016
Iveco Daily Electric (mini)	84	Up to 200	5-6	2016/17
Trolley buses				
Van Hool Exqui.City (18m)	35		29	2014
Solaris Trollino (18 m)	69		28-30	2005

China dominates the global e-bus market. In 2015, 98.3 percent of the electric buses in use globally were to be found in China (about 170,000). The Chinese domination of fully electric buses is expected to remain well after 2020. Since 2013 small European pilot projects involving 1-2 electric buses, have grown into larger pilots where entire bus lines are utilizing electric buses (ZeEUS report 2016). The focus is mainly on city lines ranging from 10-20 km, which permits more flexibility in terms of battery capacities and charging options. In Europe, about 1,560 fully electric buses were in operation (1.6% of all municipal buses in Europe) by the end of 2017 (Bloomberg 2018). The leading countries in absolute numbers are: Netherlands, UK, Lithuania, Germany, Austria and Poland. 18 percent of the European fleet of electric buses (in 2015) were to be found in the UK. The Netherlands, Switzerland, Poland and Germany had around 10 percent of the European E-bus fleet each (ZeEus report 2016). More than 40 European cities have or are still testing

[2] For most of the bus models it is possible for the customers to choose between several different battery capacities.

[3] 64,600 ibs gross weight

[4] 28 000 kilo curb weight

out electric buses. These pilot projects have been carried out mainly in city centres, and on bus lines with a maximum driving distance of 10-20 kilometres. Both fast charging and over-night charging systems are tested out. Ruter in Norway have recently ordered 70 electric buses to be delivered in 2019 (Ruter 2018). Unibuss, Nobina and Norgesbuss will operate these new vehicles on 13 different bus lines in Oslo. Ruter already have 6 electric buses in use (from November 2017) in Oslo, on bus-lines 31, 60 and 74. According to the findings in ZeEUS *serial* ***production of electric buses could reach maturity in 2018-2020.*** Others have indicated that electric buses and their infrastructure should reach technological and economical ***maturity for*** *serial* ***production by 2020-2025*** (Hagman et al 2017; Bloomberg 2018).

Some bus operators are worried about the ***durability of batteries***. In China a reduction of battery capacity after 3-5 years of bus usage has been reported (Shengyang Sun 2018). The el-buses on today's market typically have a battery warranty of five to up to 10 years (Bloomberg 2018). Bus suppliers tend to use the more robust variants of Li-Ion batteries to improve battery life.

3.3 Heavy goods vehicles

The Dutch firm ***Emoss*** develops and produces complete electric powertrains for trucks which can be inserted into a HDV chassis. They state that they can convert any chassis, in weight classes 3.5 to 27 tonnes gross weight, into BEVs (Emoss 2016a). Also, the French company ***PVI*** (Power Vehicle Innovation), acquired of Renault, are offering rebuilding of chassis from ICEs to electric powertrains.

Until 2016, Emoss had converted 30 trucks (Dalløkken 2016), whereof eight were in collaboration with Hytruck[5] for a project on zero-emission trucks in the Netherlands (Emoss 2016b). These eight trucks were delivered in the period 2013-2014. One of these trucks was delivered to Heineken - a conversion of a diesel engine Volvo to a full BEV configuration by Hytruck and Emoss (Dalløkken 2016; Hytruck 2017). Emoss electrical trucks have been supplied to several companies. As mentioned above, to Heineken (Pink 2015) but also to Lidl, DSV, Albert Hein, Tedi and Asko. All of them were delivered in 2016 and all of them were meant for inner city logistics (Emoss 2016).

[5] Hytruck was basically a project that assessed the potential for hydrogen. Hytruck, presented this truck in 2007 on the RAI truck show. The financial crisis in 2008 resulted in a delay, and the first result of a 16 ton GVW battery electric truck (Hytruck) was launched in 2011.

Asko's (Norway) battery electric truck has a gross weight of 18 tons and a payload of up to 5 tons, distributed on 18 pallets. The payload of 5 tons is a reduction with 3 tons, from 8 tons, that is needed for the distribution route the vehicle should operate. Payload capacity and gross weight are about the same as the Scania combustion vehicles (before converting). The range is about 200 km (Valle 2015), and it is operative in the Oslo area. Provided that the test with the first truck was successful, Asko had the option to purchase two more trucks (Dalløkken 2016). However, the truck has had several periods out of order, so Asko cancelled these options, and will wait for serial produced trucks to be introduced onto the marked before they purchase more electric trucks.

Heineken has also ordered electrical trucks from other suppliers, including, among others, a battery electric truck built from scratch using a Mercedes-Benz chassis by ***Ginaf*** (Pink 2015; GINAF 2017).

Daimler announced its arrival on the electric truck market with the Mercedes-Benz urban eTruck. This truck will have a range of 200 km and a gross weight of 25-26 tons. The estimated start of *serial* production is early 2020 (Valle 2016a). They have, from the presentation of the concept in September 2016, already been in contact with around 20 potential customers within the segments of waste management, grocery trade and logistics. The first customers started testing the vehicle in 2017 (Frydenlund 2017).

In the meantime, Daimler has already been testing a smaller truck, called FUSO Canter E-Cell, since 2014, which entered small *serial* production in 2017 (Valle 2016a). Canter E-Cell has a range of 100 km and a cargo capacity of 2-3 tons (Daimler 2017).

Terberg YT202-EV is a battery electric truck that has been on the road for ***BMW***, from summer 2015 (Terberg 2015). This truck was introduced on the market in 2014 and is in use at several distributor's centres and container terminals in The Netherlands, Germany, Denmark and Switzerland. The use of YT202-EC between BMW production facilities in Munich and SHERM warehouses is the first time the truck has been on public roads. The distance between the warehouse and the production facilities is 2-3 km, making it possible to drive eight round-trips a day, and

save about 12 tons of CO_2 emissions annually (Terberg 2015), compared to operation with a diesel truck.

The initial pilot project for TEBERG and BMW was implemented in 2015 and lasted for a year. They stated that if the project met the targets, it would be expanded. This seems to have occurred, as Electric-vehicles news reported that BMW put another electric truck in service in 2016 (Electric-vehicle-news 2016) to supply the Leipzig plant producing BMW i3 and BMW i8 (battery electric and plug-in hybrid passenger cars).

Volvo has also started tests of battery electric HDVs. The vehicle (Volvo FL Electric) is in 2018 being tested in Gothenburg. Volvo plans to start serial -production of the vehicle in 2019 (Volvo 2018). The vehicle will be delivered with user selectable 2-6 lithium batteries with a total capacity between 100 and 300 kWh. The range will be up to 250 km, depending on batteries, cargo weight and usage. The vehicle can be charged either by slow charging (22 kW AC) or fast charging using CCS/Combo2 connectors with up to 150 kW capacity. It was announced in May 2018 that **Volvo** (Green car 2018a) will also launch a second BEV with sales starting from 2019, as well, the Volvo FE Electric. The Volvo FE Electric is designed for heavier city distribution and refuse transport operations with gross weights of up to 27 tonnes. The charging system is identical to Volvo FL.

Another provider of electric trucks and tractors for terminals is ***BYD***, a Chinese manufacturer of automobiles, buses, forklifts, rechargeable batteries, trucks, etc. They offer three types of trucks, class 8, 7, 6 and 5, and a terminal tractor (Lambert 2017; BYD 2017). BYD, will produce a small fleet of class 8 battery electric yard trucks, built for California ports and other freight handling facilities (Lambert 2017). An overview of these classes, common in the US, is shown in the table below (Murray 2016).

Table 4. US classification of trucks.

Class	GVWR (Gross Vehicle Weight Rating)
1	2,700 kg
2	2,701 – 4,550 kg
3	4,551 – 6,350 kg
4	6,351 – 7,260 kg
5	7,261 – 8,850 kg
6	8,851 – 11,800 kg
7	11,801 – 15,000 kg
8	>15,000 kg

Renault Truck has collaborated with ***PVI*** to make a lager truck called Renault Truck D, which is a 100% battery electric truck with a maximum gross weight of 16 tons, and a payload capacity of around 6 tons. The usable range is around 120 km (Renault-trucks 2014; Field 2015).

Renault Truck D was tested by carrier Speed Division Logistique and used for deliveries to Guerlain's boutiques in Paris. The test lasted for a year and was finished late 2015 (ibid). The test vehicles covered more than 200 km a day, resulting in a need to recharge several times during night and day. The route was therefore planned so that the batteries could be recharged two times along the route and fully recharged overnight (PVI 2014 ; Kane 2014).

Another truck that is soon out to be tested, is ***Man's*** el-truck models TGM and TGS. The TGM will have a range of 200 km, while the range of TGS will be 130 km (Ludt 2017). They will be tested by nine CNL-members (Austrian Council for Sustainable Logistics) from the end of 2017 in Austria. These include food retailers, construction product suppliers and freight forwarders. Maximum gross weight is 26 tons and the range is about 150 km (max) (GreenCarCongress 2017b). Serial production is presumed to start in the beginning of 2021 (Ludt 2017).

Tesla has also announced plans to introduce battery electric trucks. The Tesla Master business plan part two was presented in 2016. The company stated that in addition to passenger vehicles, the company would also develop heavy-duty trucks and buses. Both were said to be in early stage development at Tesla at the time (Tesla 2016; Lambert 2016). The Tesla semi-trailer concept was presented to the public in the autumn of 2017. No less than two Norwegian companies have already pre-ordered the Tesla semi. Asko, has pre-ordered ten, while Bring has pre-ordered one. These trucks are presumed to be delivered in 2020 (Wardrum 2017; Størbu 2017).

Tesla will get real competition from the newly launched class 8 truck from ***Thor trucks*** (ThorTrucks 2017). Thor trucks will offer two versions of the ET-one, with respectively 100 and 300 miles driving range (160 and 480 km). These ranges are for full-load trucks with a capacity of 36 tonnes of cargo. In addition, they have plans to convert other trucks to electric propulsion systems.

Also, the USA based ***Cummins*** presented in August 2017 the world's first fully electric heavy-duty class 7 truck, with a range of 160 km and haul capacity at 22 tons. The charging time is about an hour, but they assume that it will be dropped to about 20 minutes before the truck enters production in 2019 (Hanley 2017; Løvik 2017).

In table 5 and 6 below, battery electric trucks and tractors on the market and those that are expected to launch on the market in the near future, are presented respectively.

Table 5. Battery electric trucks and tractors in the market, by model, range, capacity, size and year.

Vehicle model	Battery kWh	Range, km	Cargo capacity, tons	Gross-weight, tons	Year on the market
FUSO Canter E-Cell		100	3		2014
Terberg YT202-EV					2015
Renault Truck D		120	6	16,0	2015
Renault Truck D		200-300	6	16,0	2018
Emoss converted truck(s)[6]		200	8	18,0	2016
BYD Auto	150	250		7,3	
BYD Auto	221	200		8,8	2018
BYD Auto	175	200		11,8	2018
BYD Auto		250		15,0	2018
BYD Auto T9	350	200		28,0	2018

[6] Here the information is reported from the converted truck to Asko Norway's largest foodstuff wholesaler.

Table 6. Future battery electric trucks and tractors by model, range, capacity, size, and expected year of market introduction.

Vehicle model	Battery kWh	Range, km	Hauling capacity, tons	Gross-weight, tons	Expected market introduction
Mitsubishi eCanter	82.8	120			
Freightliner eM2 106		370			
Renault Truck D.Z.E	300	300			
Volvo FL	100-300	250		16	2019
Volvo FE	100-300	200		27	2019
Mercedes-Benz urban eTruck	200-300	200		26	2020
Man E-Truck TGM		200			2021
Man E-Truck TGS		130		26	2021
Freightliner eCascadia	550	400			2021
Cummins		160	22	Class 7	2019
Tesla semi		800	40	Class 8	2020
Thor ET-one		480	36	Class 8	2019

3.4 Assessment

According to the IEA Hybrid Electric Vehicle Technology Cooperation Program working group on the electrification of transport logistic vehicles, ***eLogV*** (IEA 2017), the market for electric freight vehicles (EFV) is still in an early stage. Most of the EFV production models do not exceed a gross weight of 3.5 tons, and the availability and choice of EFVs is limited. Range and payload are limited and volatile (IEA 2017).

A typical development path for electric HDVs seems to be that after initial development, pilot tests are carried out over a period of months or years to gain practical operational experience before *serial* production is introduced. These tests are conducted in fleets of large existing customers to ensure real world use and conditions. In passenger vehicle development these pilot tests can be done internally by the employees of the manufacturer, as they are also motorists.

The timeline of introduction of battery electric alternatives in the different vehicle segments shown in figure 1, have been estimated by the authors based on the market information collected in this chapter.

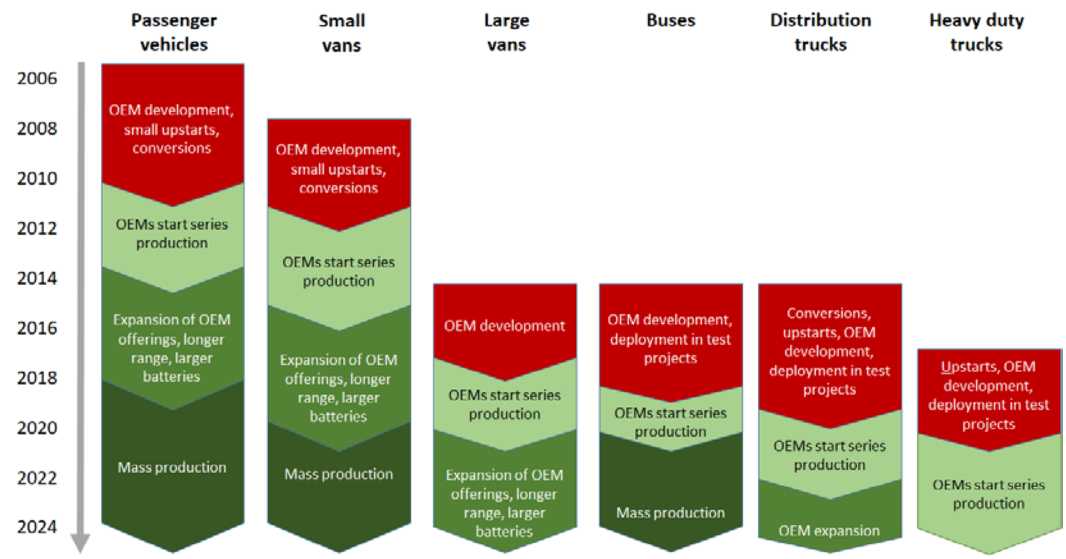


Figure 1 Timeline of introduction of battery electric versions in different vehicle segments. Authors assessment of the based on publicly available market information.

4 Fuel cell HDVs

A fuel cell vehicle is an electric vehicle using compressed hydrogen as its fuel source. The fuel cell vehicle may also include small batteries to boost the acceleration, capture braking energy, and act as a buffer that enables the fuel cell to operate at a more or less constant output. The result is that the life of the fuel cell is extended. These batteries can, but need not, be externally rechargeable.

Most of the development work on fuel cell vehicles have focused on passenger vehicles, and 3 models from Toyota, Honda and Hyundai have reached small *serial* production (thousands). Toyota and likely Hyundai will enter a phase with larger small *serial* production from 2019-2020, potentially producing more than 10000 vehicles annually.

4.1 Light goods vehicles - vans

There are only a few producers that offer light goods vehicles (vans) with hydrogen fuel cell propulsion. The offerings are limited to the conversion vehicles listed below.

Hyundai Motor introduced a hydrogen fuel cell concept version of its H350 light commercial van at the 2016 IAA Commercial Vehicle Show. The van had a hydrogen tank of 175 litres to contain up to 7.5 kg hydrogen at 700 bar pressure. It has a range of 422 km and cargo space of 10.5 to 12.9 m^3, or 14 passenger seats. It is however unsure when or if such a vehicle will come onto the market (Green Car Congress 2016).

Symbio FCell has added fuel cells to a Renault Kangoo Maxi ZE, which Skedsmo municipality (Norway) started using in October 2017. The system's total range is 340 km. The vehicle is a BEV using the fuel cell system as a range extender. The hydrogen is, as opposed to earlier models, tanked with 700 bars. Symbio's converted Kangoos are also entering the UK market through Arcola Energy, and are to be part of fleets belonging to the Yorkshire Ambulance Service, to the city Sheffield, to Amey construction and BAM construction, as well as to CitySprint for last-mile deliveries in London (Symbio 2018). Symbio's main market is in France, where more than 200 vehicles are in circulation. Symbio also unveiled that they are converting a Nissan e-NV200 in a similar way, resulting in a 500 km range (Green car 2017a). That vehicle will be put out in *serial* production in September 2018. Also, the Peugeot Master ZE is a model which Symbio will install their range extender system in, increasing the range from 200 to 350 km. The model is expected to come on the market in 2018 (Norsk hydrogenforum, 2016).

Lightning systems will convert a Ford Transit (Greenfleet 2018), which will be on sale in the US in 2018. The electric motor, with a range extending system on fuel cells, will allow for a range of more than 322 km.

4.2 Buses and coaches

There are several hydrogen fuel cell buses in operation in different parts of Europe as seen in the overview in **Feil! Fant ikke referansekilden.**.

Van Hool offers 13, 18 and 24 meters fuel cell buses (Van Hool 2017). The articulated version Exqui.City is available in 18m and 24m configurations, and the A330 in 13m. The buses are equipped with a fuel cell-module from Ballard Power Systems (FCvelocity-HD7). An A330 bus, with a hydrogen storage tank containing 30kg hydrogen, has a range of about 300 km before needing to refill. The hydrogen consumption is reported to be 8-10 kg per 100 km (Pocard 2016). Fuel cell buses from Van Hool are being tested out in several European cities, including: London, Aberdeen, Antwerp, Cologne, Oslo, Rotterdam, San Remo. The city of Oslo has five fuel cell buses in use. Testing in Oslo started in 2013 as part of the EU project CHIC (CHIC 2017), and it is still ongoing. Van Hool recently got a contract to build 40 A330 fuel cell buses for Wuppental and Cologne (Germany). These buses are to be delivered in 2019 (Green Car Congress 2018). The buses (12m) will be hybrid configurations with FCvelocity-HD85 fuel cells from Ballard Power Systems, an electric motor with 210 kW power and a Li-Ion battery. The tank capacity of hydrogen will be 38 kg, and the buses are reported to use about 8 kg hydrogen on a 100 km distance. The range of the fuel cell buses is reported to be about 350 km.

Fuel cell buses from ***EvoBus/Mercedes-Benz*** Citario Fuelcell are being tested out in the cities of Aargau, Bolzano, Milano, Stuttgart and Karlsruhe (Norsk Hydrogenforum 2017). A new model of the 12m bus is expected to come onto the market in 2018.

Solaris' first fuel cell bus was tested out in Hamburg starting in 2015. Fuel cell buses from Solaris are now also being tested out in Riga. An 18m Solaris Urbino (Fuel Cell Buses 2017) has a H_2 storage capacity of 45kg at 350 bar. The fuel cells (FCveloCity-HD) are delivered by Ballard. In addition, the Urbino has a 120 kWh battery.

Wrightbus offer fuel cell electric buses in both a single and double decked version. Full production was scheduled to start in 2017 (Wrightbus 2016). The first model of double decked fuel cell bus was launched in London in 2016. In London different versions of fuel cell buses have been tested out since 2010.

The Dutch company ***HyMove*** have incorporated their fuel cell into a ***SolBus.*** The Solbus/HyMove is a 12m bus with a H_2 storage of 30 kgH_2. In addition to fuel cells the bus also has a 74 kWh Lithium-ion battery (TÜD SÜD 2016).

VDL model Phileas is available in a version equipped with a fuel cell system from Ballard. The H_2 storage capacity is about 40 kg (VDL 2011), at 350 bars. The bus has been tested in Amsterdam and Cologne. VDL started testing fuel cell buses in 2011.

Table 7 provide ***an overview*** of the different manufacturers buses.

Table 7: Fuel cell buses by bus model/ brand, range, capacity, size and year.

Bus model	Range, km	H_2-storage[7], kg	Net weight, tons	Year on the market*
Van Hool A330 (13m)		30-50	16	?
Van Hool Exqui.City (18m)		40-45		?
Solaris (18m)	250-300	45		2015?
Mercedes/Evobus Citario (12m)		35-40	13	2018?
VDL/APTS (18m)		40		?
Solbus/HyMove (12m)	300+	30		?
Wrightbus (12m)	250-300	30	11	2017?

* Some producers already offer fuel cell electric buses for sale. But the buses sold now are part of different EU or national test projects.

Different versions of fuel cell buses have been tested out for the last 8-10 years. In Europe 82 fuel cell buses are now being tested out in different pilot projects (CHIC 2017), and a map of locations is presented in figure 2. The testing of a further 200-300 fuel cell buses in Europe in 2018-2020 is already being planned for by EU projects Jive 1 and 2 and other projects (FCH Joint Undertaking 2017; Jive2 2018). Ruter, Oslo, will be a partner in Jive2. In August 2017 a total of 26 fuel cell buses were in active service in pilot studies in the US (Eudy, L. and Post, M. 2017), and there are plans to test a further 42 fuel cell buses over the next few years.

[7] The customer can specify the required storage capacity, depending on range needed.

Figure 2 - Map of fuel cell bus locations in Europe (https://www.fuelcellbuses.eu/).

The ***EU project CHIC***, which ended in 2016, had 54 fuel cell buses in operation. The 12m fuel cell buses had an average hydrogen consumption of 10kgH_2/100km, with a variation of 8-16kg H_2/100km (CHIC 2017). Filling of the H_2-tank took 5-10 minutes, which is considerably shorter than for an electric bus with the same range. The lifetime of the fuel cells varied considerably between different batches, from 3,000 to 23,000 hours. The fuel cell buses of today are prototype-models, and the CHIC project experienced several problems getting hold of spare parts. In Oslo, four buses had to be sent back to the factory for servicing (due to oil contamination). One bus was back in Oslo after six months, and the remaining 3 buses were back after a year at the factory. Software failures and incorrect warning lights were also issues for some of the buses. The overall availability of the buses was about 70 percent in the second phase of the project (CHIC 2017). According to CHIC (2017) the availability of both buses and infrastructure needs to be improved further to give confidence to further operations. This includes technical improvements, improved capabilities of suppliers and maintenance facilities, improved availability of spare parts, and reduced response time.

In the US, 26 fuel cell buses have been tested out in different cities in California, Ohio and Illinois. The average availability of the buses was 76 percent (Eudy, L. and Post, M. 2017). The buses had an average lifetime of 4.9 years, and an average range of 300 km (40-50 kgH_2-capacity). The fuel cells had an average lifetime of about 14,000 hours. The newest buses had fuel cells with a higher life expectancy than the older models (an average of 21,000 km on the newest buses). The hydrogen filling time depends on the station design/type, and can vary from up to 24 minutes to under 10 minutes. While one of the filling stations had a typical filling time of 1 kg per minute, other stations could fill faster. The pilots in the US experienced some of the same problems as in Europe: poor availability of spare parts, high maintenance costs for a relatively small number of vehicles, and competition with other zero emission technologies.

4.3 Heavy goods vehicles

All heavy-duty goods vehicles with hydrogen fuel cell systems which have been tested on the road so far, have been test vehicles or converted vehicles produced especially for demo-projects and pilots:

Renault has, as mentioned in section 3.1, supplied the French post authority (La poste) with electric vans. They have also provided an electric truck with a hydrogen-powered fuel cell range extender, called Maxity H2 (Nicolas 2015; Field 2015). The hydrogen fuel cell system allows for a range of 200 km, which is 100 km more than the vehicle with only a battery electric engine. This truck has a gross weight of 4.5 tons and payload of 1 ton (ibid). The rechargeable battery has a capacity of 42 kWh. The vehicle can carry 4 kg of hydrogen in two tanks and the fuel cell output is 20 kW. Surplus heat from the fuel cell system can be used to heat the cabin. Although the added range with the hydrogen system is limited the vehicle will also have the ability to fill energy much faster than with a battery only solution.

Also, in Switzerland, a fuel cell powered truck has been tested on public roads. This 34 tonnes distribution truck, will be a part of the daily logistics of Coop Mineralöl, a gas station company (esoro 2017). The truck is provided by a collaboration project which among other includes ***ESORO***, a Swiss automobile contractor (Barrett 2017). The range is stated to be 400 km. The truck was delivered in January 2017 and has been in operation ever since.

Asko, a Norwegian grocery wholesaler, has chosen ***Scania*** to supply four hybrid 27 tonnes distribution vehicles which use hydrogen as the source of energy. These trucks will have a range of 500-600 km (Asko 2016; Arnesen 2016). Scania, a well-known provider of trucks, and Hydrogenics, a company that specializes in hydrogen technology and provides the fuel cells, cooperate to supply these vehicles to Asko (hydrogenics 2017). The base vehicle is originally a hybrid electric configuration. The battery will still be in the vehicle and be used to capture brake energy and boost acceleration. Asko has also installed a solar cell powered facility to produce their own hydrogen in their distribution centre in Trondheim.

Asko's pilot project will last from 2017 to 2019, and the trucks will be operative from late autumn 2018. Asko has a long-term strategy to use zero-emission solutions, so the plan is to continue using the vehicles also after 2019. Payload capacity and gross weight are about the same as the Scania combustion vehicles (before converting), but a lack of public refuelling infrastructure in the area will limit the operating range to an area that allows the vehicle to return to the filling station at the distribution centre.

Nikola is aiming to release ***Nikola One***, a hydrogen fuel cell truck, in 2020. Nikola One is designed for long-haul freight transport with a claimed maximum range of nearly 2,000 km. This semi-trailer is a class 8 truck, and in 2016 the company claimed that they had over 7,000 pre-orders (Vijayenthrian 2016; Mendelsohn 2016), among those are the Norwegian dairy, Tine. In addition to selling the vehicles, Nicola will also establish a network of hydrogen filling stations to support these vehicles. The Norwegian company NEL has been awarded a large contract to deliver hydrogen station equipment to Nicola (Nikola 2017).

California air quality regulators and the federal Department of Energy have partly funded the development of hydrogen fuel cell trucks for the Los Angeles and Long Beach Ports. These projects will use trucks from Toyota, Kenworth and US Hybrid.

Toyota Motor Corps, launched a class 8 truck and trailer combo in April 2017 (Hawkins 2017; O'dell 2017a), related to this project. The truck has a range of 320 km per tank. The truck was deployed in October 2017 at the port of Long Beach to carry cargo between the port and warehouses located up to 112 km away.

Kenworth is also in the process of developing a hydrogen fuel cell Class 8 drayage truck. The truck was presented in January 2018. This truck, like the truck developed by Toyota, will be part of the test program hauling freight containers to warehouses in the Los Angeles area, from the ports of Los Angeles and Long Beach (O'dell 2017b).

US hybrid announced a fuel cell truck class 8 at the ATC expo in 2017. This truck will have a range of 320 km and the purpose is, as for the others, to move containers at the ports of Los Angeles and Long Beach (O'dell 2017c).

In addition to the three fuel cell trucks mentioned above, California has helped fund a van development project by ***UPS***. UPS will start using hydrogen electric delivery vans in California. This project consists of 17 hydrogen fuel cell electric Class 6 delivery vans, to be delivered by the end of 2018 (Hanlin 2015; O'dell 2017d).

FedEx rolled out a fuel cell delivery van in May 2018 in New York state, which will be used on a standard delivery route. The van was built by Workhorse Group Inc. converting an EGEN van using fuel cells from Plug Power Inc. The Class 5 van is expected to have a range of more than 250 km (Edelstein 2018).

These findings are summarized in table 8 below. As before, the classes refer to the US classifications of trucks shown in table 4.

Table 8. Hydrogen fuel cell trucks by brand, vehicle model, range, capacity, size and year.

Vehicle model	In use for	Range in km	Load capacity in tons	Gross weight in tons	Year on the market or road
Renault Maxity H_2	French post office (La poste)	200	1	4.5	??
Esoro	Coop Mineralöl, gas station company	400		34	2017
Scania	Asko, Norwegian wholesaler	500			2018
Toyota /International Prostar	Test program: port of LA and Long Beach	320	36	Class 8	2017
Kenworth				Class 8	2017/2018
US Hybrid /International Prostar				Class 8	2017/2018
UPS	UPS	200		Class 6	2018
EGEN, Workhorse	FedEx, Delivery in New York	250		Class 5	2018
Nikola One	7000 pre-orders	2000		Class 8	2020

4.4 Hydrogen trains

In Norway, most trains run on electricity from overhead lines, but some railway stretches are still not electrified. An alternative to electrifying these stretches could be to use hydrogen powered trains instead. A zero-emission fuel cell train powered by hydrogen has been successfully tested in Germany. Tests with passengers will start in early 2018 (Molloy 2017). With this train, ***Alstom*** is the first railway manufacturer to offer a zero-emission alternative to mass transit trains not based on overhead or side-mounted powerlines. This technology is expected to be ready for freight train operations in 2020 (Tønseth 2016).

A shunting locomotive called BNSF HH20B use hydrogen as a source of energy. This locomotive is a conversion of the GG20B Green Goat diesel-hybrid locomotive built by Railpower Technologies Corp. The original diesel engine has been replaced by a hydrogen fuel cell and an electric motor. It was publicly demonstrated in the summer of 2009. It is said to be the largest land transport "vehicle" exclusively powered by hydrogen fuel cells in America.

4.5 Assessment

The timeline for the introduction of hydrogen versions in the different vehicle segments shown in figure 3 is the authors assessment based on the market information gathered in this chapter. Most of the published plans for *serial* production of fuel cell HDVs focus on long distance trucking. Little information is known about when and even if mass production of vans, distribution trucks and buses will commence. City buses and city logistics will likely be using battery electric propulsion combined with charging during the day, but hydrogen could be needed for buses and distribution trucks in sub-urban areas in addition to long distance trucking. Buses are an arena where fuel cell hydrogen solutions are tested out, but no producers have yet announced plans for regular production.

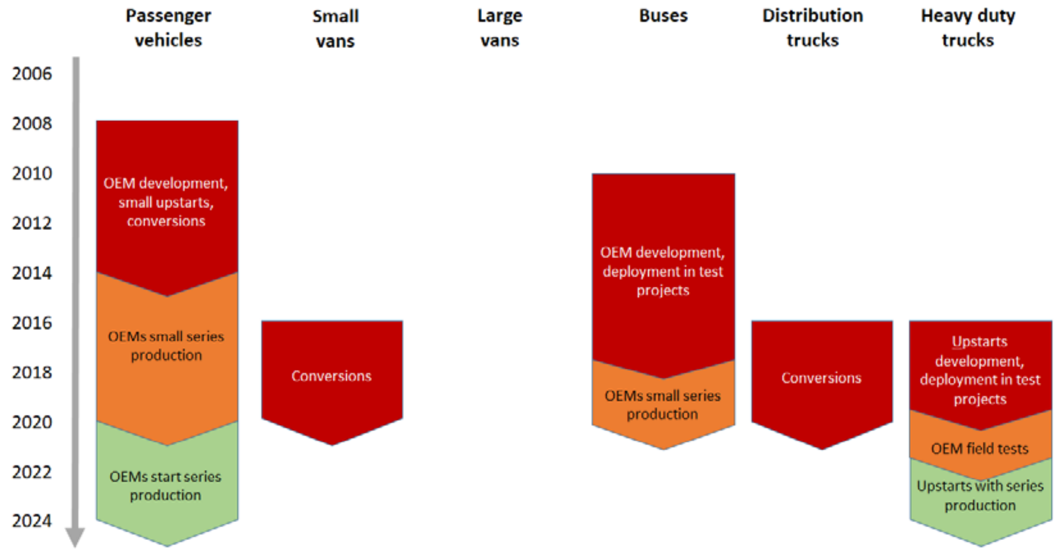


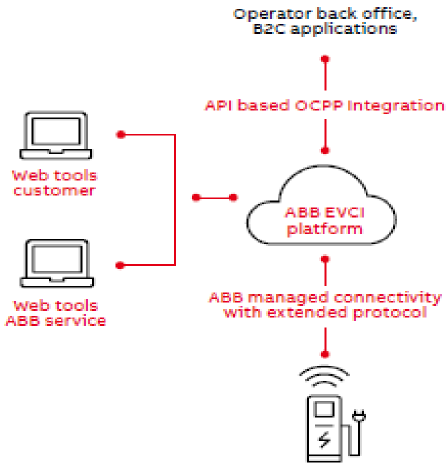
Figure 3 Timeline for introduction of hydrogen versions in different vehicle segments. Authors assessment based on publicly available market information.

5 Charging infrastructure

5.1 Plug-in conductive charging

Manual charging with a cable, i.e. conductive plug-in charging, is the most commonly used charging method. For this type of charging in Europe, the industry and the EU Commission has agreed on using the CCS[8]/Combo2 standard and plug (Siemens/ABB). Chademo is another standard used on some Japanese, Korean and French BEVs. Depot charging typically require 4-6 hours of charging time depending on the charge power available (or up to 10 hours with slow charging). The standard levels are up to 22-44 kW AC from a type 2 connector and 50 kW from the DC high power connector. Higher power DC chargers of 150-350 kW power are also available from 2018 and may be needed as the battery sizes increases. The first of these high-power chargers enters service for passenger vehicles in Norway in 2018. Even higher power levels may be required for HDVs.

If a HDV relies solely on depot charging, the batteries need to be sufficiently large to last for the entire operation of the vehicle during a full day. Big batteries are expensive and add weight (and space) to the vehicle and may reduce the number of possible passengers or the permitted freight weight. If the batteries are not large enough to last the entire day, or the number of passengers or the permitted freight weight is reduced, it may lead to the need to purchase an additional vehicle, which is costly. The cost of operating the service will also increase because of the need for additional drivers. For buses it may be a challenge to rely solely on depot charging as they can be in use for up to 18-20 hours per day. As these buses would have a large battery they would need a high power charger, likely 50-100 kW to be fully charged during 4-6 hours at the depot. The grid connection will therefore become a major issue if a large number of buses are depot charged simultaneously.



Most companies offer their customers conductive plug-in charging as one of their charging options. ABB offers depot charging infrastructure for buses and trucks. The system offers charging powers from 50 -150 kW, depending on their customer's needs (ABB 2017a). One 150 kW charger can charge up to three buses at the same time. The system is OCPP (Open Charge Point Protocol) and CCS compliant. The CCS/Combo2 connector used is already a standard for DC charging of passenger cars (ABB 2017b). ABB offers a system for remote management of the charging process and can start or stop the charging of the independent vehicles

[8] CCS Combined Charging System

depending on the customer's needs and the capacity of the power grid. ABB offers diagnostic support and can set up different energy management solutions.

Siemens offers a DC fast charger. The system offers charging solutions from 30-150 kW and can charge any CCS or GB/T-compatible vehicle (Siemens 2018). The system can be remotely accessed to start/stop the charging process and is compliant with OCPP.

Heliox also offers plug-in depot charging. They use a Combo2 plug and a charging system with 700V DC. The charging options are 40, 80, 100 or 120 kW, and the system is CCS compliant (VDL 2016).

5.2 Pantograph opportunity fast-charging

OppCharge is a cooperation between ABB, Siemens, Heliox, Faiveley Stemmann-Technik, Volvo, Ebusco, Iveco, Solaris, HeuliezBus and some other companies (OppCharge 2017). The companies have agreed to use common technology in their opportunity charging systems based on a pantograph connection between the charger and the vehicle. The following specifications are used: charging power of 150 - 600 kW, a top-down system where the vehicle mounted part is 15 kg, the system follows the ISO/IEC 15118, uses the DC connection standard IEC 61851-23, and the pantograph is centred above the vehicle's front axle as seen in figure 4. All the OppCharge partners are committed to adjusting the different parts of their charging system to comply with further international standardisation.

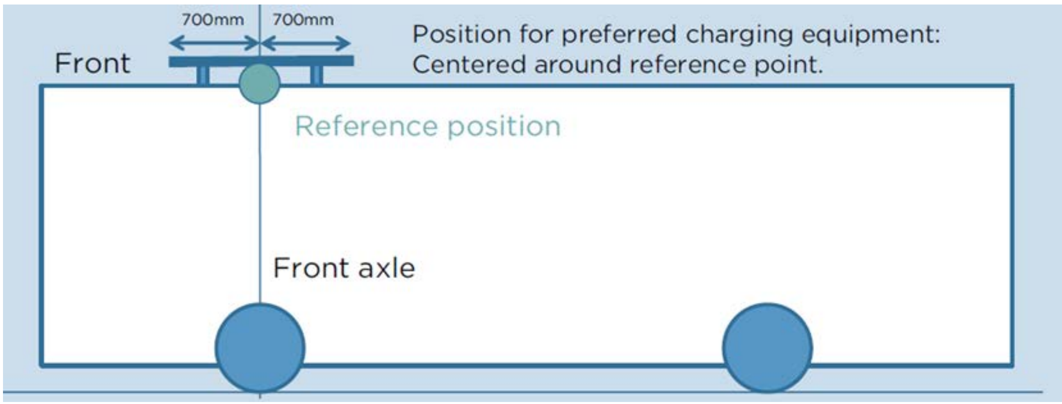


Figure 4 - Placing of charging equipment for OppCharge-systems.

Opportunity charging (OppCharge) from ***ABB*** offers a typical charging time of 3-6 minutes (ABB 2018), using charge powers of 150, 300, 450 or 600 kW. The system is compatible with several different HDV models (both buses and trucks). The system is based on the international standard IEC 61851-23, and the system is OCPP compliant for remote management (ABB 2017c). ABB has been developing charging infrastructure since 2010. The OppCharging system from ABB is already in use in Sweden, Canada, UK, Luxemburg, France and Belgium. Gothenburg has recently ordered two 450 kW chargers from ABB (ABB 2017d), which will be delivered in the spring of 2018. ABB has recently received orders for the delivery of eight OppCharging chargers to Trondheim, each with 450 kW DC power (ABB 2018). The eight chargers will support the 35 new electric buses ordered by the city. The contract with Trondheim is for 10 years and includes remote management support.

Ebusco produces their own top-down pantograph, the *Opbrid Busbaar V3* (Ebusco 2017).

Siemens offers top-down pantographs with charging power of 150, 300, 450 or 600 kW (Siemens 2018). The charging has remote access via the bus's Wi-Fi system. The average charging time is 4-10 minutes. The system is interoperable with different bus models and types and is also compatible with other HDVs such as trucks. An on-board bottom-up version of the pantograph is also available (this on the other hand, is not compatible with trucks). The bottom-up system can, for example, be combined with a city's overhead tram-wires. The charging power of the bottom-up pantograph system is 60 or 120 kW. Top-down pantograph systems add about 15 kg to the bus, while bottom-up systems add in the region of 70-200kg (OppCharge 2017). Charging systems from Siemens are already in use in cities such as Montreal (2017), Hamburg (2016), Stockholm (2015), Gothenburg (2015) and Vienna (2012). Drammen has placed orders for charging systems from Siemens for two different locations. The one in Mjøndalen was finished in late 2017 (Drammen Live 24 2017). The charging time in Drammen is expected to be about 6-8 minutes. Unibuss will also be using pantographs from Siemens at the two end-stations (Dalløkken 2017b) on the line 74 in Oslo (Vika-Mortensrud). The pantographs in Oslo will have a charging power of 300 kW.

Schunk offers systems to be used in both top-down and bottom-up pantographs. Their SLS 201 (top down) is available with a charging power of up to 500 kW, while the SLS 102 (bottom-up) offers a charging power of up to 750 kW (Schunk 2017). Their new model SLS 103 (bottom-up) has a power transfer of up to 1 MW, and a reported charging time of just a few seconds. The system can be used on vehicles of different heights and is customized according to the customer's demands. Pantographs from Schunk are installed on more than 300 electric buses worldwide (Schunk 2018), and 43 buses with roof-top pantographs are located in Eindhoven (Netherlands). Busses with charging systems from Schunk are also used in several cities in Germany, as well as in Barcelona, Helsinki and Winnipeg. Norgesbuss has ordered pantograph systems from Schunk for the electrification of bus line 60 in Oslo (Dalløkken 2017b). The operator, Norgesbuss, has ordered a top-down solution with a charging power of 400 kW, with a charging time of 6-8 minutes. The charging solutions from Schunk are not only suitable for buses but can also be adapted for other HDVs. The Finnish company Kalmar are producing an electric crane vehicle with the Schunk system (Schunk 2018), that handles containers in terminals.

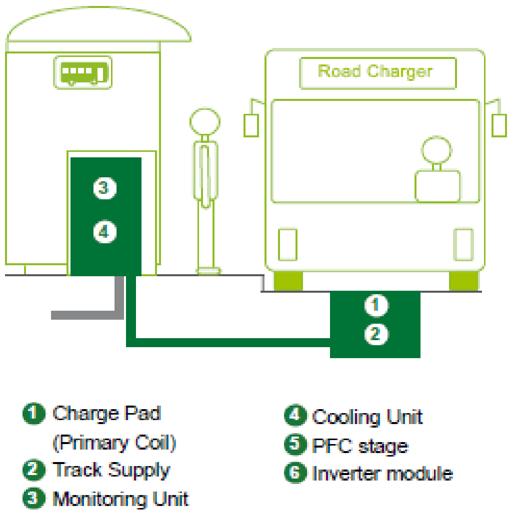
Heliox uses an SLS 201 from Schunk in their OppCharge charger (Paakkinen 2017). They offer solutions with 300, 450 and 600 kW. Their systems support connections to Schunk and OppCharge systems (Paakkinen 2017). Heliox has delivered charging solutions to several cities in the Netherlands and to Differdange (Luxembourg), Turku (Finland), Helsinki (Finland), Copenhagen (Denmark) and Cologne (Germany) (Heliox 2017). Heliox has more than 20 e-bus chargers in Scandinavia (Paakkinen 2017).

Faively Stemmann-Technik produce pantographs for e-buses, but also charging infrastructure for ferries, railways and other electric HDVs (Stemmann-Technik 2018). Their Charging-Panto for buses is based on the OppCharge system.

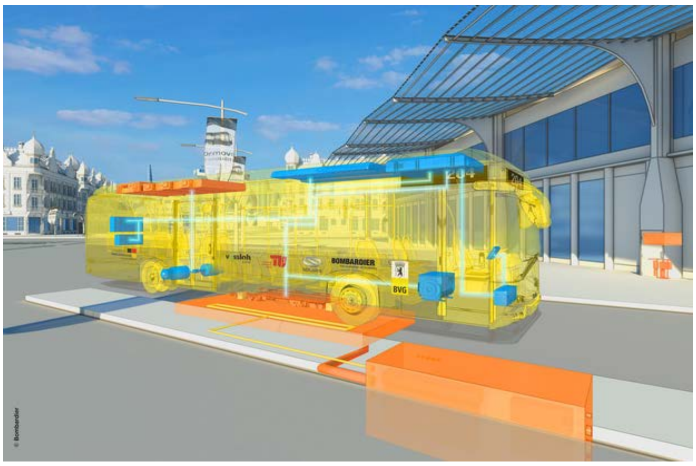
ABB's TOSA system of 20-second *flash-charging* with a 400 kW power-boost was first introduced in Geneva in 2017 (ABB 2017e). The Geneva bus gets a flash charge of 20 seconds at selected bus-stops from a top-down power source, in addition to 3-5 minutes of charging with OppCharging at the end-stops. Flash-charging means that the stopping time at the end-stops can be reduced (to 1-5 minutes). The city of Nantes has also ordered the flash-charging system from ABB, with a 600 kW power-boost (ABB 2017f). Such rapid charging can be very demanding for the batteries (Brecher & Arthur, 2014).

5.3 Inductive opportunity charging

Former Conductix-Wampfler, now ***IPT Technology,*** started field testing their inductive charging system (IPT) in Turin and Genoa in 2002 (Fast in Charge 2014), serving 30 e-buses. The buses can be charged with 60, 120 kW or 180 kW at bus stops while passengers embark or disembark, with over 90 percent energy transfer efficiency (Conductix-Wampfler 2013). The number of charging points, and the charging power can be adjusted according to local needs. The system can withstand a wheel-load of up to 6 tons. All cables and charging components are underground and are protected from weather and vandalism. An upgraded version of the IPT system was first tested out in the Netherland from 2012 (Conductix-Wampfler 2012), using a charging power of 120 kW, and even if the operation time of the bus was 18 hours it was possible to reduce the battery size from 240 to 120 kWh (Conductix-Wampfler 2013). Milton Keynes (UK) have been using their system from 2014, London from 2015 and Madrid since 2018 (IPT Technology 2018). A similar system is also used for rail.



Bombardier offers inductive charging for buses, vans/trucks and trams/rails. The charging is contact-free and partly buried under ground beneath the station. When the bus stops at the bus stop the charging starts, and the charging continues until the bus leaves the station. Their PRIMOVE fast charging system can incorporate high power charging on the most convenient points along a bus route using lighter, smaller and longer-life batteries (Bombardier 2013). Berlin was in 2015, the first capital city to refurbish a complete bus line for electric buses to wireless charging using the Bombardier system (Bombardier 2013). Bus line 204 is operated by four e-buses from Solaris with 90 kWh batteries, and a charging power of 200 kW. The batteries on the buses in Berlin are charged for 4-7 minutes at the two end-stops, and can also be charged at the depot for 7-17 minutes if necessary. The number of charging points and the charging time can be adjusted according to local needs. Demanding bus-lines may need more charging-points if the route-times offer little flexibility in terms of stop-times. The PRIMOVE system for buses was first tested out in 2010 in Lommel (Belgium), and is now, in addition to Berlin, also used in Mannheim (Germany), Södertälje (Sweden) and Bruges (Belgium).

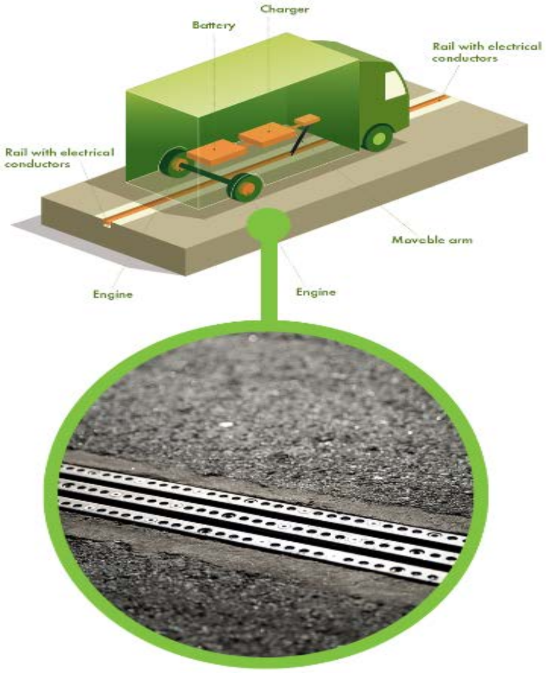


5.4 Electric roads – Dynamic charging during travel

Dynamic charging, i.e. charging while driving can be conductive using an overhead powerline in combination with a pantograph or a groove in the road and a trailing arm. It can also be carried out using inductive power tracks that transfer charge from power circuits beneath the road surface to a receptor in the vehicle. Dynamic charging generally has high costs of infrastructure, but compared to over-night charging (ONC), which requires heavy batteries, some costs can be saved due to a smaller battery being required. Having a smaller battery increases the capacity of the HDV (more passengers or goods on each vehicle, which means, in turn, that the necessary numbers of vehicles/drivers can be reduced). Compared to opportunity charging, in-motion charging doesn't require that the vehicle stop to charge, which makes it suitable for high demand bus-lines, where additional stop time, even at the end stops, can be difficult to achieve.

Several types of ***catenary and other conductive energy transfer systems*** are being developed.

In Sweden a 2 km road section of E16 was equipped with an overhead powerline system delivered by Siemens (Scania 2016) in 2016. Scania trucks are equipped with pantographs, and over-head wires (catenary system) charge the trucks while in motion (see picture). The ***eHighway*** system is soon also to be tested out on public roads in Germany (Siemens 2018). Also in Italy Scania and Siemens are planning trails of electric roads (GreenCarCongress 2018) . Catenary system for trucks are also tested out by Siemens/Volvo in California (from 2017), and in several German pilots (Moultak et al. 2017).



eRoadArlanda is another Swedish pilot testing out in-motion charging. The test track is located on a 2 kilometres section of the road between Arlanda Cargo Terminal and the Rosenberg logistics area outside Stockholm (eRoadArlanda 2018). The project is testing out a charging track embedded in the road surface. The trucks have a movable arm under the vehicle that can be lowered down onto the tracks. Trucks are used in this pilot project, but the system can also be used on buses or cars. The system was first tested in 2012 on a fenced test section near Arlanda.

Trolleybuses use an overhead line to transfer power to the bus while driving. These systems have recently been upgraded so that a battery is included in the bus. The bus can then travel without overhead power through curves and other stretches where these powerlines are expensive to install.

Further, such a system will have less of an impact on the visual quality of the city, for instance by avoiding having these lines along historic roads and places.

Different ***WPT (Wireless Power Transfer) charging systems*** are still in their pilot phases. Further documentation of lifecycle, safety of operations and maintenance of infrastructure and on-board sub-systems is needed (Brecher & Arthur, 2014). Some of the things that need to be verified are the durability of the charging pads, the public's exposure to EMR (electro-magnetic radiation), how to reduce vulnerability to damage from heavy traffic, weather extremes, thermal cycles, winter salting, snow ploughs etc. (Brecher & Arthur, 2014). It is also important to assess whether the TCOs (Total Costs of Ownership) of this type of infrastructure (and e-HDV) are economically attractive in a life-cycle perspective as compared to other electrification options.

Several trial sections on public roads (e-roads), where *electric vehicles can be inductively charged while driving,* are being tested out (or there are plans to do so), e.g. in Paris, Israel, and UK (Gammon 2017, Kelion 2015). One major disadvantage of this system is the potential cost, especially now that the price of batteries is decreasing. This system is still very much in the pilot phase compared to the somewhat more mature technology of overhead catenary systems (see chapter 2.2, last section). However, this system does not have the same visual disadvantages as the catenary system.

The ***OLEV system*** (Korean Online Electric Vehicles) is designed to be able to reduce the battery size of the buses with 20 percent, saving costs and battery weight (Brecher, A. & Arthur, 2014). The *road embedded power tracks* are embedded in segments of 1m – 1km in length along 15 percent or more of the bus route, depending on local needs. The system generates a magnetic field of 20 Hz for buses (60 Hz is used for rail) and has been used in Korea (Deajong campus and Gumi) since 2013 and in Boston, USA. Transmission efficiency in South-Korea is at 85 percent.

5.5 Battery-swapping

Swapping a discharged battery with a recharged one, is one way of reducing long charging times. Today, this method is not much in use, partly due to the high prices of batteries. But with decreasing battery prices, this might, in the future, be a more attractive solution than it is today. Since the batteries are usually heavy, a lifting-mechanism is required to help with the swapping. A big barrier to such solutions is the lack of standardisation with respect to the size of batteries and their position and mounting in the vehicle. In many ways this solution is similar to electric roads in that it requires special facilities (swapping of batteries and charging of empty batteries), standardization of vehicles and technologies, as well as a new business model where users pay for access to and usage of the system.

In Berlin/Brandenburg battery swapping was tested out on two medium-duty commercial vehicles (7,5 tons) in the NaNu project (Schaufenster elektromobilität 2015). The vehicles had three batteries, one of which was always connected to the charging station.

Some of the electric buses in China are using battery swapping (Shengyang Sun 2018, Morland 2017). The picture shows a battery swapping station in China (side-swapping). It takes about 5 minutes to change a battery, compared to 4-6 hours of depot-charging.

5.6 Power grid adaptions

When implementing a new fleet of e-vehicles into a depot/area, the existing capacity of the power-grid must be investigated. If the current capacity of the grid is not large enough, it can be a costly investment to upgrade the system. Depending on the size of the fleet, an intelligent computer-based system that manages the charging might be necessary. One example is Waterloo bus station in London where 46 e-buses are being depot-charged. They are using an intelligent computer-based system to control the charging. The smart-charging, can take place when the electric demand is low, such as during the night. Even if all the buses are plugged into the system at the same time, the managing system can decide which vehicles to charge- and at which times. This can reduce the load on the power-grid considerably.

The *Bus2Grid* project in UK are investigating 30 electric buses using smart technology when charging (Airquality news 2018). The University of Leeds, the bus company BYD, SSE Enterprise and UK Power Networks are partners in the project. At peak hours, when electric power is in high demand (Pratt 2018), the buses can transfer un-used energy from the batteries to the grid (V2G), and during low demand periods such as the night and mid-day, the batteries can be recharged (G2V). Using spare capacities in the batteries during peak-hours can benefit the customers and reduce the need to upgrade the capacity in the power-grid. It is also possible to imagine “selling” the stored energy back to the grid and buying it back later for a lower price.

In table 9 a summary of the findings in this chapter is presented. Plug in conductive charging is well known and chargers at different power levels can be considered to be a mature technology although increasingly higher power chargers are being developed continuously. Trolleybus pantograph energy transfers systems are well known in many cities but are now combined with batteries in the buses to reduce the complexity and cost of the overhead lines. Conductive heavy duty vehicle charging is in the demo-phase focusing on the ability to transfer energy while driving at highway speeds. Inductive charging is still at the demonstration phase but near maturity for stationary charging at bus stops. Battery swapping does not seem to be an option that are pursued at the moment.

Table 9: Maturity of charging infrastructure for HDVs

Charging options	Costs	Maturity
Plug in		
- slow	Low	Mature
- fast	Low/Medium	Mature
Pantograph		
- at terminal/bus stop etc.	Medium	Mature
- in-motion	High	Nearly mature*
Induction		
- at terminal/bus stop etc.	High	Nearly mature
- in-motion	Very high	Not mature
Battery swapping	Medium/High	Nearly mature

*Depending on necessary speed. Mature for use in low-speed areas, and in Trolleybus systems.

6 Filling infrastructure for fuel cell vehicles

6.1 Refuelling stations in Norway

Retail hydrogen refuelling stations (HRS) in Norway are, at the beginning of 2018, quite limited in number and mainly centralized around Oslo. See Table 10 of stations in operation as of March 2018. However, more stations are planned, as can be seen in Table 11 (Norsk Hydrogenforum, 2016). Until resent there has been two companies operating the retail refuelling stations in Norway; Hyop and Uno- X Hydrogen, both with production facilities for hydrogen. But this fall, September 2018, Hyop had to shut down their operation due to lack of working capital.

Most hydrogen refuelling stations can be adapted such that they can be used by all brands of vehicles, because the fuelling connectors, nozzles, and receptacles meet iso-standards. The most common pressures in Europe are 350 or 700 bar (35 and 70 MPa) with 700 for passenger cars and other light duty vehicles, and 350 for heavier vehicles and buses (Isenstadt and Lutzey, 2017). However, most retail stations in operation, as well as those which are planned in Norway, are intended only for passenger and light duty vehicles.

For heavy duty vehicles there are only two refuelling stations in Norway, at Tiller and Rosenholm. The station at Tiller in Trondheim is used by forklift trucks for Asko and will by the end of 2018 also be used by four 27 tonnes distribution trucks. The hydrogen will be produced locally in an Electrolyser using electricity produced in solar cells on the roof of Asko's logistics centre. At a bus depot at Rosenholm, outside of Oslo, the second station is used by five buses, and has been in operation since 2012 through the EU-project CHIC (2017). The station was built and is operated by Air Liquide Norway. The CHIC project ended in 2016, but the operation of the buses and station was prolonged three more years with extra funding from Oslo municipality and Akershus county.

Table 10 Table of hydrogen refueling stations in Norway

Location	Operation starting date	Operator	Comment	Payment
Bærum, Høvik	November. 2017	Hyop	closed down	For registered users
Porsgrunn, Herøya	2007	Hyop	closed down	Card terminal
Skedsmo, Lillestrøm	2012	Hyop	. closed down	For registered users
Gardermoen (Airport)	Since 2015	Hyop	closed down	For registered users
Trondheim, Tiller	December 2017	Asko (Nel Hydrogen Solutions)	Intended for Asko's forklifts and four 27 tons delivery trucks. The trucks will be in operation by end of 2018. Hydrogen can be sold to others, and some passenger vehicles also use the facility.	
Bergen, Åsane	December 2017	Uno X Hydrogen		Mobile phone app Uno X Pay
Oppegård, Rosenholm	2012	Air Liquide Norway	The station is only for buses and was established as part of the EU project CHIC (2012-2016), but operation has been extended to 2019.	
Sandvika-Bærum	November 2016	Uno X Hydrogen	The hydrogen is produced by excess energy from roof mounted solar panels in an industrial park nearby.	Mobile phone app Uno X Pay

Table 11 Overview of planned hydrogen refueling stations in Norway. Source: UnoX, 2018.

Location	Year	Operator
Hvam, Skedsmo	2018	Uno X Hydrogen
Søreide, Bergen	2019	Uno X Hydrogen
Ås	2019	Uno X Hydrogen
Sandmoen, Trondheim	2018/2019	Uno X Hydrogen
Hell, Stjørdal		Uno X hydrogen

6.2 Infrastructure in the rest for Europa and World

As in Norway, the publicly available HRS equipment and stations in Europe are mainly intended for passenger cars and light commercial vehicles. Fuel cell bus operations have dedicated depot refuelling facilities.

Germany has the most stations in Europe, with up to 60 stations operational by the end of 2017. There are also several initiatives to increase the number of stations. A Consortium named H2Mobility plans to have 100 stations by 2019 in Germany, while the German government's goal is to have 400 stations spread out in the whole country by 2025, which would mean a sharp increase in the number of stations built per year. The goal is set to 400 because this will lead to a good coverage for the population, with most residents living within a 10-minute drive away from a station.

In the UK, 15 stations are currently in operation, but the goal is set to have 65 stations by 2020. Estimates have indicated that 1100 stations would cover the demand until 2030, depending on hydrogen fuel cell vehicle penetration in the fleet. Denmark has 11 stations, Sweden has 4. The Nordic Hydrogen Corridor project is planning eight new refuelling stations for light vehicles and buses in Sweden to connect the Nordic capitals with the rest of the infrastructure in Europe (Scandinavianhydrogen 2017 and IEA 2017).

Outside of Europe, the US, Japan and South Korea are leading the way for more hydrogen vehicles. For instance, Japan has more than 90 stations in operation and have a target of 160 by the Olympic games in 2020. China is also picking up the pace of hydrogen vehicles on the road and has goals set for 300 stations by 2025 and 1000 by 2030. In the US most stations, so far, are located in California and on the east coast.

Nikola Motors announced at the launch of their new long-haul truck model Nikola One, that they will open 350 hydrogen refuelling stations nationwide (USA) for HDVs (Norsk hydrogenforum, 2016). Nel, a Norwegian hydrogen company, will provide solution for production, storing and distribution of hydrogen (Nikolamotor 2017). In addition, stations will be built in Canada and the hydrogen will be produced by Nikola's own solar farm (Mendelsohn 2016).

Stations intended for a larger number of HDVs would need considerably larger volumes of storage tanks. According to Reuter et al. 2017 the experience with HRS across Europe has so far been limited to capacities of maximum 10 buses. Hence, there is lack of experience with large scale facilities.

6.3 Standardisations

Several standards are already in place, related to technology and the safety of refuelling stations and vehicles (both for light and heavy-duty), such as hydrogen fuel quality, connection devices and the refuelling process. This means that technical barriers for establishing a hydrogen station network have been reduced. In the European Union, stations follow the International Organization for Standardization (ISO) 17268, ISO/TS 20100, ISO 14782-2. However, there is still variation in payment-possibilities. Standardisation work is required to make systems that contribute to a positive customer experience, such as payment systems, more universal and user friendly (IEA 2017).

7 Discussion and conclusions

Electromobility has got a firm foothold in the passenger vehicle segment in Norway and huge industrialization efforts are underway among major OEMs such as Volkswagen, Mercedes, Volvo, BMW, Nissan, and others. The push has also extended into the small van segment since 2012, with several manufacturers offering commercially mass-produced vans. A new generation of these vans offering 50% longer range came on the market in 2018. Larger battery electric vans will enter the market from 2019, albeit with more limited range capabilities than the small vans currently have.

The HDV segments have lagged behind in this development, with the exception of city buses where electric buses are about to breakthrough. Some battery electric bus models are already available in *serial* production according to the producers, but mass production has so far only been initiated by the Chinese manufacturers. Battery electric buses are solutions that require that the charging infrastructure is an integral part of the system, especially when opting for a system where the buses are fast charged at bus stops. Worldwide, there were about 386,000 electric buses in operation in 2017 (Chediak 2018), and about 98-99 percent of these are in China. The global number of electric buses is now increasing rapidly, and is expected to triple by 2025 (Chediak 2018). Deliveries of new electric buses and infrastructure are in high demand, and some problems with delivering the buses on time have occurred. Electric buses are still more expensive than conventional combustion buses, but the price of batteries has been reduced by 75 percent in the last five years (SMMT 2017, Bloomberg 2018). (Hagman et al. 2017) state that electric buses and their infrastructure should reach technological and economical maturity by 2020-2025, whereas the ZeEUS project expects maturity to be reached already by 2018-2020 (ZeEUS report 2016). Bloomberg's (Bloomberg 2018) calculations indicate that el-buses will be comparable to diesel buses in price closer to 2030, but the rapidly increasing demand for vehicles can bring the battery prices down faster, making vehicle prised comparable to diesel buses by mid-2020. However, the lower energy cost of electric buses compared to diesel buses will enable total cost parity earlier than that. Coaches requiring longer driving range may take somewhat more time to reach maturity in Europe.

In comparison, there are expected to be about 1,000 fuel cell buses in operation worldwide by 2020 (Fuel Cell Buses 2017), from todays about 300-400 (80-90 in Europe per 2017). Hydrogen fuel cell buses are suitable when longer ranges are needed, in challenging topography, and in situations where the (bus-) route does not have the flexibility required for opportunity charging at the bus stops. Fuel cell technology also offers considerably shorter refuelling times (only a few minutes), compared to today's depot-charging of electric buses (where fully charging a bus can take 4-6 hours). The experience from pilot studies with buses in Europe and the USA (CHIC 2017, Eudy, L. and Post, M. 2017) is that the limited production level is a major barrier to the operation of existing vehicles today. It is difficult to get new parts when something breaks, and there is still a lack of understanding as to how to solve different faults.

The technology for long-range electric HDVs is rapidly improving, but the market is still limited to demonstrations and pilot programmes. Battery electric trucks have already achieved driving ranges of more than 300 km on test tracks and the cost of the batteries has rapidly decreased, opening the possibility to electrify larger shares of the HDV transportation segment. HDVs are to a large degree adapted to the customer's specific needs, which leads suppliers to provide scalable battery solutions allowing customers to choose different range and charging options. The first segment that can be electrified economically will probably be the city distribution of goods from warehouses to stores and municipal waste management. Distribution trucks and trucks for waste management are often used along regular routes where the range requirements are known, and it might even be possible to provide charging at warehouses/terminals and combustion plants. The phasing-in can be enforced by including zero-emission solution requirement for tender information, where a public agency is the principal. Several OEMs have in 2018 stated that serial produced battery electric distribution trucks will come on the market in the 2019-2020 timeframe. Electrification of long-haul trucking seems to be more challenging, and less likely in the near future, although Tesla and Thor trucks both claims that they will provide a semi-tractor, coming on the market in 2020, that will be able to handle transportation requirements in this segment. Before that, starting in autumn 2018, there will be a trial of an electrified semi on a shuttle service between Oslo and Moss, where the aim is a yearly driven distance of 120 000 km per vehicle. This semi, originally fitted with and ICE, will be converted to electric propulsion.

Heavy-duty hydrogen fuel cell trucks are suitable when longer ranges are needed, and in challenging topography and colder climates, or when there is no time available to charge a battery electric truck during the day. Fuel cell technology also offers a refuelling time of only a few minutes, compared to today's depot-charging of electric trucks (where fully charging can take 4-6 hours). Today, fuel cell technology for heavy-duty trucks is very much at the pilot stage. The fuel cells themselves are still somewhat variable when it comes to life-expectancy, but this has improved in recent years. The cost is still one of the main reasons why fuel cell technology has been slow in uptake. The pilot studies in Europe have received founding from the EU and others to enable them to test different solutions. If the cost of buying and operating fuel cell heavy-duty trucks is reduced to the extent that some deem possible within the next 5-10 years, it is possible to achieve *serial* production of fuel cell heavy-duty trucks by the mid-2020s, and comparable costs to diesel vehicles by 2030. Nikola has, however, announced their intention to start *serial* production of hydrogen fuel cell semi-tractors already from 2021.

One of the main barriers to the introduction of battery electric and fuel cell vehicles is the cost compared to conventional combustion technology, both for the vehicles and for the refuelling or charging infrastructure. These two zero emission technologies have also, to a certain degree, competed for funding. Most cities/regions will face problems funding two different types of infrastructure for charging/filling buses at the same time, and the infrastructure for electric buses has so far been prioritized in most European cities. Private actors face the same challenges when it comes to infrastructure for heavy-duty trucks. Should they go for charging infrastructure or hydrogen filling stations? Without the necessary infrastructure it is difficult for any company to adopt new technology on a larger scale, especially if the company depends on their vehicles having a long-range.

Table 12 summarizes the findings in the report and the authors' assessment of maturity level of electric and fuel cell vans, bus and trucks.

Table 12: Predicted maturity level for vans, buses and trucks.

	City level		Regional level	
	Technical maturity	**Economical* maturity**	**Technical maturity**	**Economical* maturity**
<u>Electric</u>				
Trucks	2020-25	2025-30	2025-30	2030+
Vans	Yes	Yes	2020-25	2025-30
Bus	2018-20	2018-25**	2025-30	2025-30
<u>Fuel cell</u>				
Trucks	2025-30	2030+	2025-30	2030+
Vans	2025-30	2030+	2025-30	2030+
Bus	2022-25	2030	2025-30	2030

- *Total costs of ownership (TOC) compared to diesel vehicles
- **With opportunity charging, electric buses can already be cheaper than diesel buses, depending on the bus-route and the daily travel length of the vehicle.

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Infrastructure – hydrogen

Scandinavian Hydrogen
Scandinavianhydrogen 2017

UnoX
https://unox.no/hydrogen/hydrogenstasjoner

Institute of Transport Economics (TØI)
Norwegian Centre for Transport Research

Established in 1964, the Institute of Transport Economics is an interdisciplinary, applied research centre with approximately 70 professionals. Its mission is to develop and disseminate transportation knowledge that has scientific quality and practical application.

A private, non-profit foundation, TØI receives basic funding from the Research Council of Norway. However, the greater part of its revenue is generated through contract research. An important part of its activity is international research cooperation, mostly in the form of projects under the Framework Programmes of the European Commission.

TØI participates in the Oslo Centre for Interdisciplinary Environmental and Social Research (CIENS) located near the University of Oslo. See www.ciens.no

TØI covers all modes of transport and virtually all topics in transportation, including road safety, public transport, climate change and the environment, travel behaviour, tourism, land use and urban planning, decision-making processes, freight and travel demand, as well as general transport economics.

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