EMPIRICAL REPORT

PIONEERS IN ELECTRIC CITY BUSES

STOCKHOLM, GOTHENBURG, UMEÅ, HELSINKI, COPENHAGEN, HAMBURG

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1 Stockholm

1.1 Ambitious environmental objectives

Stockholm is one of the core demonstration cities in the EU-funded project for zero emission urban bus systems (ZeEUS). The city has ambitious environmental plans for sustainable public transportation for the coming decades. Stockholm’s environmental objectives for 2030 are:

- All fleets to be running on 100% renewable fuel (already achieving in 2020)
- Reducing 75% of particles and NOx based on 2009
- Reducing 35% of the energy usage per passenger/km in public transport based on 2007

As it is apparent, Stockholm city council does not call for any particular technology in achieving the abovementioned environmental goals. Today, a large proportion of the bus fleet in Stockholm are running on either biogas or bio-diesel (Olsson, 2015; Olsson et al., 2015). However, achieving the other two set of goals i.e. reducing NOx/PMs and decreasing energy intensity rather require hybridization or electrification of the bus fleet on top of the renewable fuel changeover strategy over the long run. Thus, participation in the ZeEUS project is seen as the first step towards implementation of hybrid/electric vehicles in the city bus operations in real life conditions. According to ZeEUS website: “The demo wishes to prove that this system can be an important factor in the future public transport systems in the EU without big changes in the infrastructure. In the long term, the ZeEUS project will give important contribution to the cities strategic plans regarding electric buses and demo aims to continue operating after the project lifetime for a demo operational span of 8-12 years.” (ZeEUS, 2016)

As the below figure shows, Stockholm council (SLL) has a plan to overhaul the inner city bus contracts by 2026 and until then the transport administration is going to test and demonstrate new powertrain technologies in small-scale projects to gain experience and make a decision to invest on related infrastructure before large scale implementation in 2026.

![Scenario based on the recommendations](image)
The Stockholm project covers running of 8 plugin hybrid buses supplied from Volvo with fast opportunity charging (150Kw/h) provided by Siemens and the possibility for night charging at depot (11KW/h). It is coordinated at the EU level by UITP and is sponsored through the ZeEUS project based on cooperation without direct procurement of buses from the city council. Project partners are: UITP, Volvo, Vattenfall, Viktori ICT, Keolis, and SLL as well as Siemense for charging stations.

1.2 Cost efficiency in real time performance

According to Maria Övergaard, bus development strategist from Stockholm County Council (SLL), the plugin electric hybrid buses are functioning in full scale traffic conditions with the same contractual terms as other traffic buses and replaced the previous diesel buses on route 73 in central Stockholm. This means that the operation demands and requirements are exactly the same as ordinary buses, so that if the bus is late or malfunctioning due to technical failure or any other problems, they will receive a fine the same way as ordinary operating buses in the fleet. She emphasized that “the objective is to show that we can have environmentally friendly buses in operation and at the same time being cost efficient and run with the highest reliability.”. She further emphasized that project is “to demonstrate buses in public transport with low emissions, energy consumption and noise level while maintaining high performance and cost efficiency”. The results and experiences from this project will form the input to future plans for environmental targets and further electrification of buses in Stockholm. These new buses started operations in Spring 2015 and by the end of 2016 (≈1.5 years of operation) the city council will no longer support the project (through ZeEUS funding?). By the beginning of 2017 Volvo, Vattenfall and Keolis will continue to operate and they have their own agreement and they will run commercially until 2026. Below figure shows the overall timeline for Stockholm project.
1.3 Choosing the right route for demonstration is a challenging task

Route 73 (Ropsten-Karolinska) was chosen after considering several other alternatives. According to Övergaard, it’s not an easy task to find good routes for demonstrations due to many factors involved in the decision making process such as length, slope, the charging and its implications on the built infrastructure, as well as bus stops and neighborhood areas where you want to have the highest visibility to demonstrate a new technology. The route is 8.5 KM and is currently has only one charging station at one end (in Ropsten) but we’re building another one in Karolinska. So currently the bus goes full electric until Karolinska and then runs on hybrid-electric on return to Ropsten. Below figure shows the route map its major bus stops.
1.4 Preliminary results

First bus came into operation since March 2015 and later all eight buses have been in operation since April 2015. The preliminary results from running of buses in route 73 with approximately 17 km total drive on one charging station is that buses have been running 71% of the time on electric which corresponds to 41% of the distance (almost 7KM on full electric). The functioning of buses and charging functions so far are above the expectations and the advantage with plugin hybrids is that when charging is not possible, buses continue to operate as non-charging hybrids. They will have no implication on the existing schedule and this is a great factor both for the operator and the PTA because we don’t want to risk our operations!

1.5 Lessons learned

Some of the challenges encountered during planning phase and implementation which can serve as input to future projects are as following:

Planning and tendering cannot go hand in hand

We could not plan the project with the operator before the contract was signed; due to confidentiality and legal aspects. This is a significant constraint since the planning cannot be done before the operator is chosen and the operator cannot be chosen unless the terms of tendering are clearly defined. Defining tendering conditions for electric buses is difficult task and there is no prior experience that can be referred to.

Uncertainties arising from potential changes in the chosen demonstration route

Many requirements on the chosen route, like visibility, place for charging, depot space, length of route need to be controlled and make sure that they are not going to be changed during the contract because any change may result in reducing visibility or even affecting the efficiency and the overall functioning of the chosen vehicles for that particular route. In the case of Stockholm, the first choice of route was not possible and then it was hard to find a new route since many requirements need to be met at the same time.

Diverging tendering rules among companies, local authorities and the EU regulation

Tendering rules differ between companies and authorities and EU regulations have to be understood well when engaging partners from abroad. Therefore, thorough analysis needed before contract was signed between project partners, and it’s a learning process between all the parties involved.

Charging post require more space underground than above

After the actual building of the charging pole started, it was realized that it requires much more space for digging under the ground which could be difficult to justify in central city environment. This is an important factor that also needs to be taken into account when planning for the demonstration project is being done.

Difficult questions ahead: new business models + choosing the right charging infrastructure

With all the changes in the organizing and coordinating of these new technologies, it seems that managing new business models are harder than the new hardware! Moreover, choosing charging infrastructure depends on many different aspects that vary a lot at different locations depending on the local conditions.
Charging time is considered as driver’s cost for the operator so that reducing charging time is in favor of operators (insight from Keolis, Thomas)

Need for cooperation (networked experiments)
- Reuse knowledge and lessons learned
- Needs to be time efficient
- Formalized network could be a success factor (such as Nordic Bus project)
- Tools to support decision on which technology to use (trolley, battery, opportunity charging)
- Calculations on costs of Financing and business models

How to achieve 2030 goals:
1. To reduce costs
   a) High cost to change existing contracts
   b) Also high cost to remove buses before planned age
   c) Higher risk with immature charging technology, try it in projects instead of big bang
   d) Standard interfaces for charging will be agreed on in time
2. Major implementation at the start of the new inner city contract in 2026
3. Requirements to decrease energy usage in new contracts
4. Use already made investments in infrastructure - Existing biogas fueling systems
5. Test and demonstrate electric bus systems
6. Learn from others and share experiences
7. Perform further studies

Goals concerning three major areas:
- Attractive public transport
- Customer satisfaction
- Cost efficiency

Maria Övergaard presentation at NEBI (Gbg): [https://vimeo.com/139555940](https://vimeo.com/139555940)
2 Gothenburg

2.1 An extensive public-private partnership for testing electric bus systems

In Gothenburg, the ElectriCity project was founded in the form of a cooperative venture between the business community, research society and municipal actors to investigate the benefits and potentials of sustainable public transport in connection with electromobility. It brings together about 15 different partners under the same roof including Volvo Group who initiated the project and supplied the electric buses, Västrafik who is the provider of all public transport within the Västra Götaland region, the City of Gothenburg and other parties from municipality as well as the Chalmers University of Technology as the research partner in the project.

The original financing came from Swedish Energy Agency for a rather limited testing project, but later there was an agreement among parties involved in the project to accept greater costs in order to turn this into a demonstration project and a platform for research and development on a greater scale (Västra Götalandsregionen, 2013 in K2 report 2016). The ElectriCity project involves the Swedish Innovation Agency (Vinnova) as a governmental investment body, Business Region Göteborg who acts as the coordinating body, Keolis as the operator of electric buses, Siemens as the provider of charging equipment, Lindholmen Science Park where the in-house charging station is located and many other collaborations between business and academia takes place, Akademiskahus, Chalmersfastigheter, and Johanneberg Science Park where the other charging is located and has a primary focus on urban development, new construction materials and sustainable energy in city design and planning. Another partner important partner is Göteborg Energi who provides electric buses with renewable electricity and seeks for new business models and other opportunities based on increased emphasize on sustainable transport and electromobility in the future. The municipal company Älvstranden Utveckling is also involved in the project and works together with other local actors to realize Vision Älvstaden’s goal of developing an inclusive, green and dynamic inner-city environment on both sides of the river in Gothenburg. Lately, Ericsson also joined as a new partner in the project to work with telecom related research and development as well as new business models based on smart electromobility solutions. It is important to mention that the initiative efforts by Volvo and Lindholmen Science Park were quite instrumental in bringing together such variety of actors into this project. Altogether, it is one of the largest collaborative initiatives between private and public organizations in implementing electric public transportation in Sweden.
2.2 Making a new route from scratch

Unlike the Stockholm project, where the PTA had to search among the existing routes to choose a candidate route for demonstration, the consortium in Gothenburg decided to construct a new route from scratch mainly for demonstration purposes. The two science parks at the two sides of the river in Gothenburg was chosen to serve that purpose. This is where two campuses of Chalmers university are also located so that it was easier to justify that the new busline would be able to connect the two campuses on both sides of the river in Gothenburg (see Figure 6). The route is completely integrated into the ordinary schedule of Västtrafik and is ticketed exactly the same way as the ordinary buses in traffic. It is operated by 7 plugin hybrid buses as well as an additional 3 full-electric prototype buses all supplied from Volvo (see Figure 7). They came into traffic since June 2015 and are part of the total 1827 fleet of buses owned by the operators who are being contracted by Västtrafik to provide public transport services.

The fully electric buses are considered extra vehicles and are still in test and development phase. Nevertheless, they enable silent and emission-free public transport which can operate in areas that are currently closed to vehicle traffic such as roofed places and indoor ambient, thus opening up new scope for planning in cities and towns. To clearly visualize such potentials, the full electric buses have been running inside non-conventional areas such as libraries and indoor environment (see Figure 8).
2.3 Overcoming conflicts of interest in the choice of sustainability solutions

There is a strong presence of biogas production facilities and the related politics in Sweden which has also influenced the formal requirements for public purchasing of vehicle by PTAs. This has long been perceived as a barrier for electric powertrain to penetrate the city bus transport in Gothenburg despite of the potentials for greater environmental performance (interview with Edward Jobson in 2012). For normal procurements, the operators or bidders provide vehicles and they should meet both the functional as well as emission targets and though the powertrain technology is not formally specified for public transport vehicles, the biogas fuel is prioritized by the region and the use of biogas should be considered before any public procurement (K2 report). But eventually, the role of Lindholmen Science Park as the testing arena for novel technologies in Gothenburg and Volvo as the producer of electric powertrain technologies for public transport came into a common vision that could justify the ElectriCity project in the form of a cooperative joint venture that could promote the growth of the region inline with sustainable public transport solutions. According to Gunnar Ohlin from Lindholmen Science Park who was presenting at the Swedish Hybrid Center (SHC) conference in Gothenburg 3-4 June 2015, these common visions are:

- An innovative and forward-thinking city in sustainable mobility
- A region at the forefront of sustainable solutions and mobility which attracts competence, investment and new business opportunities
- An arena for testing new products and services in public transport
- A source of inspiration and power of motivation for future urban development
- A world-class automotive industry

Taking the abovementioned visions into account, it is clear that the objectives of the ElectriCity project goes beyond merely electrification of the city bus powertrain but rather to engage a broader spectrum of actors and investments in new areas of growth and technological advancement. This is also reflected in the official statement by the city of Gothenburg as the collaborating partner in the project: “ElectriCity is another aspect of Gothenburg’s clearly defined objective and strategy for continuing to attract skills and investment to the city on a national and international level. As part of the ElectriCity project, we will also have the opportunity to expand our cooperation with the public sector, industry and the academic world in a forward-looking area.”*

2.4 Developing new services and business models based on electromobility

New investments in public transport operations and development of an open platform for innovative development projects and project offices in Electric City, was estimated to cost around 20 million SEK between 2014-2018 (K2 report). Other project participants account for investments in development and investment in electric buses, charging stations, operation of the buses, service and maintenance, etc. It also involves a unique demonstration project in Gothenburg that includes future bus stop solutions, an indoor busstop, ITC solutions, safety concepts, green depot and energy solutions. Västrafik also develops innovative bus stops at Götaplatsen and Chalmersplatsen, equipped with technical values/services for an enhanced experience during the waiting time, such as seamless Wi-Fi. There is a dedicated webpage for the ElectriCity project on Västrafik website which reads: “On line 55, you will find features that you may not see so often in public transport. For example, you can charge your phone, both on the bus and at the bus stops and use the free Wifi. Additionally, there is an indoor charging station along the line where the bus drives into an indoor stop to let travelers get on and off the bus (see Figure 9). On the bus, and some stops there are TV screens which broadcast news, sports, weather forecast and live traffic information. At several bus stops there are also touch screens with interactive information, including information about the ElectriCity project. It is also possible to search trips in a trip planner.”

According to a recent survey by Västrafik, 80% of passengers appreciate the free WiFi capabilities on board and 93% have expressed positive feelings regarding the lowered noise levels on electric mode drive. Another survey by Keolis similarly shows highly positive perception regarding the lowered noise levels from outside as well as improved working environment for the bus drivers. Buses on route 55 are equipped with Zone Management System, which automatically limits the speed and switches to full electric mode in certain areas of the city to improve safety as well as noise levels.

![Figure 9. The indoor charging busstop at Teknikgatan in Gothenburg](source: www.siemens.com/press/IM2013060828MOEN)

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1 Translated from Swedish: [http://www.vasttrafik.se/#!/reseinformation/electricity/](http://www.vasttrafik.se/#!/reseinformation/electricity/)
2.5 A platform for open innovation

Alongside the ElectriCity project, an innovation platform has been developed to engage a greater range of actors in development of new technological solutions related to electromobility and intelligent transport (see Figure 10). According to its official website, the “ElectriCity Innovation Platform” is an innovation platform created within the project ElectriCity in order to enable internal and external development of new services and products. The innovation platform provides information regarding the buses that operate on route 55 and on the bus stops along the route in particular, but also about public transport in the Västra Götaland region in general. The information can among other thing be used as a basis for creating concepts and prototypes in Electricity Innovation Challenge 2015.¹

Lindholmen Science Park is the coordinating body for this innovation platform and its related events. According to Gunnar Ohlin, the overall objectives of Lindholmen Science Park can be summarized to:

- Developing working methods for demonstration projects between academia, the business sphere and the public sector and to produce new business models for sustainable mobility in the city that can be scaled up outside the demonstration arena.
- Create an innovative electrified bus system as a part of the public transport system in the City of Gothenburg.
- Develop and test new services and products that contribute to a more attractive public transport system.

More recently, the giant Swedish telecome/datacom solutions provider (Ericsson) has also joined as the ICT provider partner to ElectriCity project. The announcement from the company

¹ [http://platform.goteborgelectricity.se/](http://platform.goteborgelectricity.se/)
states that: “The buses running on route 55 are already connected to our platform allowing developers controlled access to data to build smart applications,” says Orvar Hurtig, Head of Industry & Society at Ericsson. “Now we’re taking the next step as a partner in ElectriCity. It’s an exciting project in which we, together with the other partners, will be able to develop and test sustainable transport solutions for smart cities – in real life.”¹

Another aspect of electric buses is the afterlife treatment of the batteries which are considered as a critical component of electric vehicles in general, and for heavy duty vehicles in particular due to the large capacity of the batteries. In this regard, there was a recent example provided by the demonstration arena of the EletriCity project regarding the afterlife cycle of the batteries in collaboration with external partners: “When the three-year test on route 55 comes to an end the bus batteries will be used in a new scientific trial. In a joint project involving Volvo, Göteborg Energi, Riksbyggen and Johanneberg Science Park the batteries will be used to store electricity produced by solar cells at the Viva housing association, which will be ready for its new tenants in 2018.”²

² www.goteborgelectricity.se/en/demonstration-arena
3 Umeå

3.1 Local air quality problems and the birth of a local business enterprise

In Umeå, local emissions from private and public transport vehicles combined with the cold climate and limited solar radiation during winters cause inversion conditions and result in poor air quality particularly in dense areas of the city. The city has been extensively involved in measuring local emissions together with central departments and private companies in order to control the air quality in Umeå\(^1\). In response to such problems, the city has set stiff environmental objectives in the public transport sector. These objectives are formulated in three main areas (K2 report):

1. **Energy and climate objective:**
   
   At least 90% of all public transport shall be based on fossilfree sources of energy until 2020

2. **Air quality objectives:**
   
   At least 25% reduction of energy intensity per passenger/km until 2020 (*based on 2007*)
   
   50% reduction of NOx and PMs until 2020 (*based on 2009 measures*)

3. **Noise level objectives:**
   
   Citizens shall be satisfied with the noise levels in the public transport sector.

Umeå is an expanding city and the population has increased by 70% since 2005. During the same period (2005-2015), the number of passengers using public transport has increased by 65% (Interview with Frerik Forsell, 24 Feb 2016). The long-lasting local air quality problem in Umeå city together with the global surge in oil prices of 2008 gave birth to a new technology-based company whose founder Boh Westerlund saw opportunities to launch electric vehicles at a large scale as a response to the chronic fossil fuel economy. In 2009, Hybricon conducted a project together with Umeå municipality parking company (UPAB) to convert Toyota Prius hybrids into plugin hybrids (*see Figure 11*). Later, the company decided to shift its main focus from private passenger vehicles into public transport vehicles and in particular development of electric buses that are adapted to cold climate with extra insulation and batteries that can be charged with ultrta high power and capable of functioning in extremely low temperatures (K2 report).

![Figure 11, Boh Westerlund founder of Hybricon (left) and converted Toyota Prius II into plugin hybrid in 2009 (right)](http://miljofordonsyd.se/wp-content/uploads/11-Hybricon-Boh-Westerlund-ver-2.pdf)

Due to the abundance of renewable sources of energy such as wind and hydropower for electricity generation, the electric propulsion has been prioritized over other sources of energy for public transport in Umeå.

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\(^1\) Source: [www.umea.se/greenumea/technicalvisitsstart/inenglish/technicalvisits/airenvironment.4.36381231134679bd1dfe.html](http://www.umea.se/greenumea/technicalvisitsstart/inenglish/technicalvisits/airenvironment.4.36381231134679bd1dfe.html)
Meanwhile, the amount of investments required for electric trams were considered to be too high and the city did not wish to install overhead wires allover the city for trolleybuses either. Therefore, electric buses came out as the most appropriate option for the city public transport. However, existing battery electric buses were not able to meet the 18 hrs of operational demand by the municipality at that time, while hybrid electric buses on the market were considered to be too expensive to gain 20-30% in fuel efficiency (Bedell et al., 2011).

Such problems provided a favorable situation for Hybricon to engage in the development of fast-charged plugin hybrid buses that were very attractive to the city. The CEO presented the electric bus concept and got the political attention from Umeå municipal company in this newly emerging area of technology to address both the environmental problems as well as support for local business growth. Umeå municipal company Umeå kommunföretag (UKF) is responsible for the planning, development and procurement of public transport services together with the county traffic authority (Länstrafiken). In 2010 UKF signed a contract with Hybricon for the development of electric buses. Umeå was among the first cities in Europe to order electric buses. Two sets of Volvo 7700 buses have been converted into fast charged plugin battery electric with series hybrid engine as backup and started to traffic already in autumn 2011 (see Figure 12). Financing for the project was partly covered by the Swedish Energy Agency and UKF as well as Hybricon (Forsell, 2016).

Main electric drive components such as the in-wheel electric motors came from the Dutch company e-Traction while the charging pole for fast charging was designed by the Spanish Opbrid company. Hybricon was able to integrate components from different suppliers and this was achieved without any reduction in the interior space of the buses.

Preliminary results from running the converted buses showed very promising potentials for scaling up the product line and in 2012 the company decides to develop its own buses specifically designed for electric propulsion. The Polish bus manufacturer AMZ was contacted to produce bodies based on the order requirements from Hybricon and in autumn 2012 another agreement was signed with UKF for the delivery of two prototypes and a fast charging station (300 kW) at the Umeå Airport. However, the company soon ran into financial liquidity problem as a result of heavy investments needed for further developments. The company had previously plead for financial support from the Swedish industry¹ but due to the high risks involved with immature technology and the short term expectations from investors it was very difficult to absorb external funding. Consequently, the company filed for bankruptcy in March 2013.

¹ See: www.svensktnaringsliv.se/regioner/skelleftea/hybricon-soker-langssiktiga-relationer_559948.html
3.2 Umeå pledged to support the emerging local industry

When Hybricon filed for bankruptcy, UKF was ranked among the highest creditors for the assets of the company and thus took over the ownership. In total, there were four strong entities who finally got the control of the company together. But instead of selling out the properties and laying off the employees, they decided to continue the development process with electric buses for Umeå which had previously showed promising results. Hybricon Bus Systems AB was established out of the previous company. A new CEO was appointed and the former CEO Boh Westerlund who created the concept from the beginning became the chief technology officer. The new company took on the previous developments, established new contacts and found new suppliers and continued working on the new prototype. January 2014 the first version of Hybricon Arctic Whisper 12 meter low entry (HAW12LE) was delivered to UKF which is still running in regular traffic as the shuttle bus between Umeå airport and the city center (Figure 13).

Following successful implementation of the newly designed bus, the company received a new order in March 2014 from UKF for another 8 buses (HAW 12 LE) among which 3 of them 18-meter articulated four-wheel drive (HAW 18 LE 4WD). It was considered the world’s first 4WD articulated electric bus and became the company’s emblem for an advanced design adapted for extreme climates of the Nordic region. The contract included 66 million SEK for 8 buses and the equivalent charging station plus service and maintenance of about 2.5 million SEK per year for a period of 10 years. The charging station includes ultra-fast charging of 650 kWh which is double the capacity of charging stations both in Stockholm and Gothenburg. In autumn 2015, the first version of the 18m articulated 4WD bus was delivered. As of February 2016 two of them are in operation (see Figure 14) and the rest are to be delivered during spring-summer 2016.
3.3 Hybricon’s further growth and projected expansions in the Nordic region

Since 2015 the company’s shares are listed publicly to secure more financial channels. Together with the launch of serial production, the company is now able to offer different types of electric buses (12 and 18 meters) with ordinary or 4WD axels as well as the option for range extenders as back-up (usually 2.5-liter diesel engine but also possibility of other choices) as well as a simple heat generator if the outside temperture drops below -17C. The charging stations are now capable of providing upto 650 KWh which allows ultra fast charging of 3-5 min for 1-hour driving full electric.

According to Hybricon’s experience, it is now clear that if electric buses are going to be used in major trunk routes where they are often need to run for up to 22hrs a day in traffic, then the slow charging would not be enough but instead requires high power (i.e. fast or ultra-fast charging). The slow charging is always the option for night charging and balancing the state of battery at the depot during long idle hours, but there needs to be fast/ultra-fast charging facilities to quickly recharge the batteries at end stations during the day. We prefer this solution i.e. conductive fast/ultra-fast charging using inverted pantograph, but we can also deliver slow charging solution so that customers can choose start with night charging as a trial and then upon satisfaction with the electric bus performance, they can also add fast/ultra-fast charging. This is something that other manufacturers like Volvo has also focused: i.e. fast charging and endstation charging. And this confirms that we have been right in our approach from the beginning. "We are delighted that Volvo has chosen our solution!" says the senior manager at Hybricon.

On the production side, the body manufacturing recently moved from AMZ in Poland to Ekova in the Czech Republic. The buses are made based on a modular design which is easier to add or change different components based on orders. From a technological viewpoint, there are two type of challenges that the company is now dealing with: 1) to improve reliability and 2) to improve efficiency with the heating system in the bus.

From an administrative viewpoint, the company is transforming from a pure engineering startup towards a more diversified business environment. Hybricon’s staff have previously been mostly engineers, but the company has recently recruited to a number of sales and key account managers to ensure its marketing and sales organization. The company is also looking for partners to expand its service and maintenance organization. Hybricon is now very keen to expand its business throughout the Nordic region. The company is approaching different cities in the Scandinavian market, among which Norway seems to have greatest potentials. The sales target is 36 units for 2016 (a unit is considered either as a bus or a charging station) and 54 units for 2017. A "normal projet" often includes about 5 buses and a charging station. Hybricon sees itself as a system builder offering both buses and charging stations. The price for buses ranges from 4.8 to 7.5 million SEK (depending on the size and specifications) and a charging station between 2.5 to 5.5 million SEK depending on the size and capacity. When asked what Hybricon perceives as its main competitors on the market, Dennis Jensen (CFO) responded that it is primarily manufacturers of traditional diesel buses: "tragically there are still orders of diesel buses". Customers do not know much about electric buses. It is a new technology and is difficult to sell and market it since it is rather a system solution than simply a [stand alone] product. Cost is another important issue but positive developments on the battery side (lighter, smaller, and greater capacity) suggests that the future will be in favour of electric buses (interview with senior managers of Hybricon Robert Åkerlind, KAM & Dennis Jensen, CFO on 25 Feb, 2016).
3.4 The Umeå experience

Environmental innovation through public procurement

It was direct procurement of local innovative solutions through the municipal company that gave rise to this new industry in Umeå. Umeå municipality has so far purchased 11 electric buses and 3 charging stations from Hybricon as summarized below:

- 2x Volvo 7700 coverted electric buses + 1x fast charging station in 2010
- 1x HAW12LE in 2013, and
- 5x HAW12LE + 3x HAW18LE4WD + 2x ultrafast charging stations in 2014

*All electric buses and charging stations are owned by Umeå municipal company (UKF).

The 5KM vision

Umeå is implementing a long-term plan to replace the current fleet of buses running on diesel with electricity instead. If the municipality is satisfied with the performance of current electric buses, there will be orders of another 24 buses to be purchased until 2019. This decision is particularly motivated by the recent incentive package of 2 billion SEK provided by the Swedish government which covers 50% of the costs for electric buses and charging stations (K2¹). Umeå municipality owns buses as well as charging stations and the introduction of electric buses in the city traffic is part of the vision of becoming more environmentally friendly known as the 5KM city (femkilometersstaden). It implies that no resident lives more than five kilometers away from the city center, requiring densification of population in the city center. The choice of electric buses instead of other alternatives such as biogas is motivated due to the greater potentials in reducing CO₂, NOₓ, PM₅ as well as noise. “We would not be able to cope [with those reuiqrements] if we chose biogas” commented by Fredrik Forsell.

Encouraging more people to take the bus instead of car

In our interview, Fredrik Forsell also pointed out that it is about raising the status of the bus services too: "it strengthens our product" [referring to the public transport services provided by the city transport authority]. Thus creating the conditions for more people to choose the bus instead of taking their own car to the streets. Fredrik Forsell was clear that "electric buses cost money." A prerequisite for Umeå's investments in electric buses has been that public transport has been effective, with sound finances. The cost has not become a big issue as public transport in general has gone very well financially.

Stable local political settings

A further condition has been a consistent municipal board, where the mayor has been the same for many years. There are also close links between UKF and the political leadership "our board are the same people sitting in the municipal government." On a question Fredrik explains also why biogas buses never been an option in Umeå: "Our policy has rabidly said no."

Full battery-electric buses are not completely matured yet

The municipality still considers electric buses as a demo project, meaning that it may not be able to immediately substitute all diesel buses on the street. Fredrik Forseel explains that the technology is still immature with more downtime than traditional diesel buses. It is also important to evaluate carefully where to run electric buses, to ask the question: "what do we need to do with it in our traffic?" And prioritize lines where there is a lot of traffic and in dense areas of the city. Fredrik compares electric buses with trams and sees them as "the little city tram traffic".

This is different from the approach taken in Stockholm where the plugin-hybrid electric buses are running under the same conditions as ordinary buses, perhaps due to the enhanced reliability of a parallel hybrid configuration which can continue to work as a normal diesel bus if the battery goes out of charge.

Spreading the risk mong more actors and the need for standardization

The municipal energy company Umeå Energi has not yet shown any interest in running the charging stations. UKF has said it will buy an additional 24 electric buses. Thus, we need to consider sharing the risk of development with more actors. This is particularly the approach that is taken in Gothenburg by involving a rather large number of actors in the running of ElectriCity project and sharing greater risks and making greater synergies.

Frederick Forsell says that as long as the market is not confident it will not take any risks, but it will change, "perhaps in 5 years." It is also important for the industry to agree on a standardized interface for charging. The ultra fast charging and wireless communications between the bus and charging station need to be standardized so that electric buses can diffuse into the market.
4 Helsinki region

4.1 Environmental objectives and electric public transport

The Finnish government has set clear objectives to reduce emissions and noise levels many of which are ultimately in favour of alternative fuels and electric mobility. In fact, e-mobility and smart-mobility are among the strategic areas where research and innovation budgets are dedicated by the Finnish government (see next section for more elaborations on this). In addition to that, the Helsinki region has set stringent environmental objectives for the year 2025 (based on 2010 measures). These requirements include sharp reduction in particulate matters and noxious gases (-95% in PMs and -92% in NOx) as well as cutting down 90% from CO₂ emission. Other environmental objectives for road transportation are:

- Reduction in noise emissions of over 55dBA by 2020 so that 50,000 people should be less “infected” by the noise in that frequency range and above.
- Increase the use of alternative energy sources by economic incentives
- Increase the use of Public Transport
- Decrease the use of private cars

These objectives are reached through the increasing share of environmentally enhanced buses as well as zero-emission public transport. Accordingly, the Helsinki Regional Transport (HSL) announced that they are aiming to ramp up the share of fully electric buses as following (HSL News bulletin, 05.06.2014 in Laurikko et al., 2015):

- 1% until 2015
- 10% until 2020
- 30% until 2025

Moreover, the remaining conventional diesel buses will be running on 100% biofuel from 2020 onward. Below figure demonstrates how the phasing out of diesel and phasing in of electric and hybrid-electric buses are going to be implemented until the year 2025.

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**Figure 15, HSL fleet strategy 2025,**
Source: Presentation by Reijo Mäkinen, Nordic Bus Initiatives 2015, Gothenburg
Available online: [www.nordicenergy.org/article/nebi](http://www.nordicenergy.org/article/nebi)
4.2 Government-sponsored research program and test facilities for e-buses

Finnish Funding Agency for Innovation (TEKES) is the government body who funded the national research program on electric vehicle systems performance (EVE) for the period between 2011 to 2015. The EVE program was part of the Smart Living focus area of TEKES with a total budget of 100M€ consisting of 100 projects and more than 100 participating partners from different fields. The EVE program was not limited to electric buses but also a wide range of different electromobility applications from private passenger cars, to snow scooters as well as heavy and commercial vehicles in mining, harbor, construction and forestry sectors. Other areas of EVE program’s support have been charging infrastructure and service platforms, wireless control solutions for park-charging, etc.

Test and demonstration platforms for electric bus development (eBUS/eBusSystems)

“eBUS” was a 5 years’ project within EVE program (2011-2015) that was specifically focused on test and development of electric bus solutions as well as identifying important aspects of planning electric bus operations in real life conditions. An important aspect of eBUS project was its comprehensive laboratory simulations using existing test facilities, knowledge and expertise at Technical Research Centre of Finland (VTT) as well as real operations of buses on roads in Helsinki region (Espoo line 11). A prototype bus called “eMULE” was specifically designed at VTT laboratory facilities to be used as a reference for component testing and generating commensurable data on electric city bus performance measures (see Error! Reference source not found.).

The justification for running such comprehensive testing on electric buses in Finland was that if it worked in Nordic climate conditions it should be able to work everywhere in Europe, since the cold climate often has negative impacts on the performance of batteries. In addition, temperature can range from -25°C to +35°C degrees (60-degrees difference) between winter and summer in Finland, which can highly stress batteries and other components to their limits. The project included testing of commercial electric buses from different manufacturers in Helsinki region for more than 100,000 KM in total. According to interviews with VTT research engineers, the eBUS project was endorsed by UITP and later became a follow up of the EU-wide ZeEUS project for testing electric buses in Europe. On top of that, “eBusSystems” was an affiliated

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1 Read more about EVE program here: www.tekes.fi/en/programmes-and-services/recently-ended-programmes/eve/
The project was a part of the EVE program that aimed at integrating data collected from the eBUS project and analyzing it at a broader systemic level (Laurikko et al., 2015). The eBUSe project involved a broad range of public and private actors in Finland including:

- **VTT**: provided the test bed facility, R&D platform, and systemic aggregation of data. As the research partner in the project, VTT validated all the data and made aggregiations so that everyone could have an overview of the data such as how much is the consumption of each bus and similar topics in very details. The data was then provided to the suppliers of vehicles (bus manufacturers) so that they could get real-time information of their bus performance from the test platform.

- **City of Espoo**: provided urban infrastructure and requirements for real traffic operations of electric buses in line 11. The line is simulating upcoming feeder traffic to the metro railway, which is scheduled to start service in this part of the Helsinki Metropolitan region in the fall of 2016.

- **HSL/HRT (Helsinki regional traffic)**: is the public transport authority for the Helsinki region and provided traffic system design and integrating electric buses in the daily operations of their bus fleet.

- **Electric bus manufacturers**: Six different bus manufacturers put their electric buses to test in the project including VDL, BYD, Ebusco, Caetano, Siemense (and later Linkker). The eMULE bus was driven only on test labs. All tested vehicles were 2-axel 12-meter full electric with LFP battery packs and average driving of 100-300KM per day (see *Error! Reference source not found.*).

- **Transdev (formerly Veolia)**: Veolia was the local subsidiary of Transdev in Finland who drove the buses in real-life conditions and in real revenue service and provided the data to VTT and other parties involved\(^1\).

- **Fortum**: provided electric power and charging facilities and made different assessments throughout the project such as how the charging would affect the electricity network and how much power is needed to run electric buses in larger scale and how the electricity distribution should be handled between different means of transport (i.e. buses, metro, trams, etc.)

The project produced valuable data about operational reliability, power demands and energy management, maintenance & repair, workshop requirements, safety aspects, battery life estimations and cold climate effects on batteries as well as considerations regarding electric bus procurement and calculations about total cost of ownership (TCO) for electric buses\(^2\).

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1. See presentation from the operator here: [https://vimeo.com/138600396](https://vimeo.com/138600396)
2. To find more information about the project see: Laurikko et al. (2015) and Pihlatie et al. (2014)
Later, the eBusSystems project brought in more actors including Ministry of transport, Transport Safety Agency and other actors in pursuing the question as to how electric buses fit into the public transport system.

4.3 The birth of Linkker as a local electric bus spin-off

The electric bus initiatives in Helsinki region also helped Linkker Oy as a local spin-off to transpire as a new actor in this emerging market. In particular, existing facilities as well as local knowledge and expertise at VTT combined with the ongoing prototype tests helped Linkker as a new electric bus manufacturer to quickly catchup with early technological development processes including test and validation through the eBUS project. According to Sami Ojamo, CEO of Transdev (Finland) who was presenting at the Nordic Electric Bus Initiative in Gothenburg:

“The project helped bus manufacturers to improve their vehicles using the feedback they received from test platform. BYD is not the same as it used to be, Ebusco has its third generation now, we have technical competence, we have system-level thinking, we have new ways to handle the fleet in the depot and the workshop environment, maintenance issues, noise reduction, energy consumption, TCO calculations, high voltage safety, etc... When we started, there was no instructions, we had to make everything from scratch.... Linkker prototype test run came out as a spin-off from the test platform project. ...In the beginning it was supposed to be a research platform. This is an empty bus where you can put your components on it and evaluate (measure) the effects in the electric bus platform.”

Another important element in accelerating development of full electric buses by Linkker was Helsinki regional transport (HSL) as the first customer who put the vehicles in use from the early beginning. In fact, the first two versions of Linkker buses were directly acquired by HSL and went to operation in Espoo. This gave the company more space to improve its technical performance on the one hand and the PTA on the other hand to get a better understanding about electric bus behaviour and the required arrangements related to this new technology. Later into the EVE program, Linkker Oy became an important partner for test and validation of electric buses in Finland. This is to the extent that the next stage of the electric bus experimentation (ePELI project) took 12 set of full electric buses only from Linkker, but no other electric bus manufacturer. This has been a great opportunity both for the company to receive its first solid orders with a public transport authority in its home market and for the PTA to get customization and made to order electric buses suitable for the climate and specific requirements of the city. Meanwhile, Linkker will also be able to learn from the pilot project as a reference for actual electrified bus lines to be implemented in the future. Like Hybricon, Linkker has also chosen the fast charging solution with 350 kWh end-stop charging with inverted pantograph (fig. 18).

![Linkker electric bus, presentation by Sami Ruotsalainen at NEBI2 conference in Helsinki May 2016](https://www.nordicenergy.org/article/nebi)

It is specified in the EVE program description that the learnings from these experimentations would help the company to develop new electric bus products targeting
mainly the European markets. The company also seeks business opportunities to expand its export market beyond Europe in Indonesia, Singapore and Malesia.

4.4 An accumulative approach in electrifying the bus system

The Helsinki regional transport (HSL) has a clear goal to overhaul the bus fleet by increasing the number of electric buses in that region. The goal is to achieve carbon neutral public transport using fully electric buses. However, before large scale adoption of electric buses, HSL wants to secure the following aspects:

1. Productivity: the size of the bus fleet must not be increased when replacing conventional buses with electric ones. In other words, at least the same level of productivity in terms of capacity must be reached with electric buses. This is to ensure that the fleet costs are not increased due to reduced capacity.
2. Operability: the operability of the electric buses must be at the same level as that of the conventional buses, and
3. Reliability and comfort: the level of service, reliability and passenger comfort need to be the same or better compared with conventional buses. This requires proven and reliable technology as well as established value network and actors with business models

HSL believes that the abovementioned objectives can be reached through a longtime stepwise process. The earlier steps of this process have already initiated with the ‘e-Bus’ and ‘eBusSystem’ projects and is going to continue on with a pre-commercial pilot project called ‘ePELI’. At the end of this comprehensive process, it is expected that electric buses to become part of the ordinary commercial procurement and to go through the standard tendering process. Meanwhile, the charging infrastructure, value chains and service providers will be available for utilization.
Figure 19 illustrate the step-wise approach into the commercialization of the bus systems in Helsinki region. This is an accumulative process that builds upon knowledge and experience gained from each phase and passes them on to the next phase. Helsinki Region Transport (HSL) usually procures public transport services, but not the vehicles. However, HSL realised that electric buses are a challenge for the bus operators and decided to absorb the risk and purchase the buses. And similar to the public procurement project in Umeå, the PTA in Helsinki has made a decision to purchase electric buses directly from the local electric bus company to run the first commercial fleet of electric bus routes in that region. The PTA then rents out or sells electric buses to the operators to a very reduced price. According to announcement from HSL:

"For this case we will make an exception and buy the buses ourselves, because it would be unreasonable to make a traffic company shoulder the risks of the new technology. This arrangement also enables HSL to test and develop new passenger services on their own buses and to try out various installations." Reijo Mäkinen, Director of services at HSL

Commercialization through the ePELI project
According to presentation by Mikko Pihlatie (VTT) and Reijo Mäkinen (HSL) at NEBI2 conference, the ePELI project consists of two parts:

1) Innovative public procurement (i.e. market creation) which entails initiating open-market dialogue with bus operators, charging systems, bus manufacturers, service providers, as well as creating actor-networks ecosystem for normal tendering. It includes following steps:
   a. Procurement and ownership of charging infrastructure
   b. Definition of procurement of charging operations
   c. Procurement of transport services
   d. International co-operation

2) Ensuring productivity of electric bus systems
   a. Verifying electric vehicle performance and reliability
   b. Verifying system-level productivity
   c. Scalability according to strategy

Like previous projects, the ePELI project involves a variety of stakeholders each of them having an active role in the commercialization process of electric buses. These actors and their roles are briefly listed below:

<table>
<thead>
<tr>
<th>ACTOR</th>
<th>ROLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>City of Helsinki/Espoo</td>
<td>Procurement of charging infrastructure</td>
</tr>
<tr>
<td></td>
<td>Helsinki City transport (HKL) owns the charging station</td>
</tr>
<tr>
<td>Helsinki Region Transport (HSL)</td>
<td>Direct procurement of 12 Linkker buses</td>
</tr>
<tr>
<td>Electric bus Linkker Oy</td>
<td>12 electric buses to different operators</td>
</tr>
<tr>
<td>Operators (4 different companies)</td>
<td>Electric bus operations &amp; service improvements</td>
</tr>
<tr>
<td></td>
<td>TCO calculations based on real life operation</td>
</tr>
<tr>
<td>HELEN (Helsinki Energy)</td>
<td>Low electricity price as the incentive</td>
</tr>
</tbody>
</table>

1 Source: www.vttresearch.com/media/news/first-finnish-fast-charging-electric-buses-to-enter-into-service
Smart grid integration with dynamic grid load and vehicle to grid (V2G) charging possibilities

For this project, the Helsinki Regional Transport (HSL) owns the pilot buses (12 fully electric Linkker buses) and will lend them out to 5-6 different operators who will be operating them alongside conventional diesel buses in different lines (1-2 lines in Espoo and 4-5 lines in Helsinki). The Helsinki City Transport (HKL) would own the charging infrastructure (i.e. stations and electric charging equipment). Therefore, the two supporting organizations (HSL and HKL) carry their own part of the risk in introducing new technology.

### 4.5 Lessons learned from Helsinki

**Electrification challenges and the imperative role of operators**

According to the presentations made at the second Nordic Electric Bus Initiative (NEBI.2) conference which was held between 14-15 of May in Helsinki there are a number of pros and cons with this kind of arrangement (see table 2). Nevertheless, it is important for HSL and other actors that this project results in the diffusion of electric buses further into the normal procurement process. One of the major hinders is that operators are generally reluctant to make investments into new powertrain technologies including electric buses since the risks and costs are higher than conventional diesel buses. This is why one of the main objectives of the ePELI project is to reduce the total cost of ownership (TCO) by improving the service and maintenance as well as standardization and availability of the infrastructure for charging. Moreover, by investing in

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Short procurement process</td>
<td>Costly for PTAs to maintain such procurement practice on the long run</td>
</tr>
<tr>
<td>Close partnership between the bus manufacturer, the PTA and the cities</td>
<td>Direct procurement is only possible for small projects (less than about 200,000 €) and test and development projects</td>
</tr>
<tr>
<td>Possible to make the buses fit to the PTA’s and cities’ specific needs</td>
<td>Difficult to justify legal aspects for this kind of local procurement by the PTA outside test or development phase</td>
</tr>
</tbody>
</table>

An interesting observation is that Transdev (formerly Veolia) is one of the most active operators in running electric buses in different regions within Europe. According to the CEO of Transdev in Finland, the company is engaged in a number of similar projects as following:
- 97 micro-midi-mini buses in France, Finland and the UK
- 3 standard and 1 double-decker « full autonomous » electric buses in operation (3 in Stanford, 1 in York)
- 12 e-buses being tested (Finland, NL, US, Portugal and France – Nice, Watt project)
- 45 hybrid buses in France

This is one of the few operators who is seeking competitive advantage in the long run as well as improved environmental performance and reputation through electric mobility in Europe. The company believes that once the standards are established and electric buses are diffused around the world, the total cost of ownership would be lower for electric buses. According to VTT, the experiment with electric buses have shown at least a 60% reduction in energy intensity between traditional diesel buses with over 3 kWh per kilometre and the Linkker full electric buses with around 1.0 kWh consumption per kilometer.

**Standardization in fast charging infrastructure**

One of the main concerns of the governing body for the ePELI project is the necessary standardization for fast charging infrastructure which is crucial for further diffusion of electric buses in the city. This is currently one of the main obstacles and there is a need for cross-industry collaborations i.e. between bus manufacturers and power technology companies as well as cooperation with other Nordic cities. There are several Nordic cities having similar challenges and many of their questions are the same so that they could team up in solving them:

- Several Nordic cities have the same challenges
- Many of the questions are the same
- Could we team up in solving them?

**Buslines and permits**

Another important aspect of the ePELI project is to seek integration with other infrastructure such as the grid network and the built environment particularly in the city center. The existing bus stops are available to be used but the challenges are:

- More space is needed for electric buses in comparison to conventional diesel buses
- The needs to be even more space available near the bus stop for charging equipment such as transformers, extra batteries, ventilation room, etc.
- The pole’s height is another issue that needs to meet both the safety requirements as well as permissions for construction in the city environment
- There should be the possibility of other buslines to use the same bus stop as well
- Buslines scheduling should not be disturbed

Other challenges:
One bus stop is not on public area, private owner
- Acceptation, Documents and plans for permit
Permit processing from different department’s of Helsinki City takes some weeks
- Permitting Authorities
- Building Control
- City Planning Department
- Cityscape Advisory Board

**Challenges**

- Chargers must be near of bus stop for losses and cabling sizes

• Ground: sand, mud, water or something else?
• Landscaping
• Area is famous for architectural and historical buildings
• Future and construction plans for Central Railway station

From Miko’s presentation at NEBI2:

- Designing an efficient ebus system requires systemic approach
- Optimised vehicle and battery
- Operation concept analysis and design
- Charging infrastructure and energy management
- Co-operation of key players required: city, PTA, PTO, energy company, service providers (e.g. charging service)
- Information exchange and co-creation e.g. at Nordic level?

- The technology is not yet mature and proven at systemic level – careful engineering is required
- Level of standardisation is low (progressing)
- Ownership, operation and service models not fully established
- All actors are not yet active / established

http://ecv-fi-bin.directo.fi/@Bin/05801c8e6e889c5e8c2d43fe71243ba/1470588804/application/pdf/212170/09_Pihlatie_Mikko_HSL_Helsinki_region_ePELI_ECV-seminar3.pdf

Summary and conclusions

- The technology is not yet mature and proven at systemic level – careful engineering is required
- Level of standardisation is low (progressing)
- Ownership, operation and service models not fully established
- All actors are not yet active / established

→ We are about to start the necessary "ePELI" activity as the last step before commercial roll-out of electric bus systems

Summary and conclusions

- Electric bus systems are fast emerging
  - Both vehicle technology and charging equipment available
  - Electric city buses are heavy duty sweet spot, other use cases and applications will follow
- Designing an efficient ebus system requires systemic approach
  - Optimised vehicle and battery
  - Operation concept analysis and design
  - Charging infrastructure and energy management
- Co-operation of key players required: city, PTA, PTO, energy company, service providers (e.g. charging service)
  - Information exchange and co-creation e.g. at Nordic level?
5 Copenhagen

5.1 Carbon neutral public transport through electrification: one path to the target

Copenhagen has an ambitious plan and to become carbon neutral in public transport by the year 2025 and to cut nitrogen oxides (NOx) by 60% based on 2011 measures. For this reason, the city has chosen to go for full electric (and probably plugin hybrid) buses in order to meet the targeted plan. This means that even non-plugin hybrid buses are excluded from the plan. This was clearly stated by Mikkel Krogsgaard Niss from Center for Urban Development in Copenhagen who was presenting at NEBI conference in Gothenburg in September 2015 by saying that “we will not focus on hybrid buses because they will not get us to our target to become carbon-neutral until 2025.” Nevertheless, the region has an established tradition of biogas as a fuel for transport which is still strongly present until today. Therefore, it may worth considering alternative usage of biogas in other applications such as heavy vehicles for commercial transport or combined heat and power generation. There are also interesting studies on the conflict resolution between green solutions and in particular biogas for example by Khan (2004) that is very relevant in this case.

Below figure illustrates the plan for carbon-neutral targets in Copenhagen (figure 20). Note the “one path to the target” that is pronounced in the heading, referring to the sharp increase in the number of electric buses and the freezing in growth on the number of biogas buses from 2020 onward.

![Figure 20. Carbon-neutral plan 2025 for Copenhagen public transport](image)

The city has already tested several electric vans (mini-buses) in the centeral Copenhagen (from 2009-2014) with a daily milage of 140KM, but there have been lots of technical issues according to Victor Hug from Movia. Additional projects have been initiated to investigate the possibility of electric urban transport by test driving 12-meter city buses as well. For this purpose, two trial projects have been so far carried out which are elaborated in the next section.

1 Watch the recorded presentation here: [https://vimeo.com/138623545](https://vimeo.com/138623545)
5.2 First trial: 2x BYD night-charged buses (2014-2015)

When the city of Copenhagen decided to test full electric city buses for the first time, there were not that many suppliers out in the market. Moreover, night charging was an easier and more feasible option because it didn’t require investments on charging infrastructure. The night-charged buses could enter the fleet and start running without the need to make any changes in the existing infrastructure. All charging was done at the depot during nights. For this purpose, Copenhagen chose two 12m full electric buses from BYD (K9 model) with 324kWh battery capacity which usually took around 4-5 hours to charge during night. Total budget for the project was 8.3 million DKK funded by the Danish Transport and Construction Agency (DKK 4.6M), the City of Copenhagen (DKK 2M) and the rest was co-financed by DONG Energy and Movia. The purpose of the trial was to check feasibility of nightly charged electric buses for reducing CO2 and NOx emissions. The trial ran for two complete years from January 2014 to December 2015 on different lines including 3A, 12, 40 and 141/149.

However, test results showed that buses were out of order many times during the year for several reasons such as mechanical and heater problems, battery leak (due to unauthorized disassembly), problems with charging of start battery, motor coolant leakage, untrained drivers and malfunctioning due to the operator faults. The uptime for bus 1 and 2 was 59% and 64% respectively. The total amount of operation and failures are illustrated in the below figure:

![Figure 21](https://www.ecv.fi)

5.2 First trial: 2x BYD night-charged buses (2014-2015)
Presentation by Mikkel Krogsgaard Niss at NEBI2 Conference, Helsinki May 2016
Available at: www.ecv.fi

Other technical challenges were high internal noise and particularly noise from the rear axle (70-73 dBA, even up to 80.7 dBA). Air compressor oil leakage, parts reliability, and turning radius (12m). Average energy consumption for these buses were about 1.33 kW/h per kilometer according to estimations from City of Copenhagen. More detailed information from Movia showed the consumption rate for BYD buses from 1.15-1.41 kWh/km in light traffic to 1.24-1.77 kWh/km in heavy traffic. This can be considered higher than the average energy consumption for electric buses. This is mainly due to the large battery packs (3.2 ton) as well as the overall heavy weight of vehicles which is around 18-ton (gross weight). This has also resulted in reduced capacity in the cabin to about 58 passengers of which 28 are seated. Airconditioning during warm days and diesel heater during cold days was another contributing factor for increased energy consumption together with driving styles. Some of the energy consumption data are provided in figure 22 and 23.
Nevertheless, test results showed positive customer experience with electric buses. 76% emphasized that the bus is a good environmental friendly initiative. A customer survey by Movia showed that at least 58% of passengers have been willing to pay an extra amount of 2DKK to ride on electric buses (figure 24).

Trials also convinced the city of Copenhagen about further investments into the electrification of city buses as well as charging infrastructure. That led to the second trial project which is explained in the next section.
5.3 Second trial: 2xLinkker fast-charged buses (2016-2018)

For the second trial, the city of Copenhagen decided to make an EU tendering due to the increased number of suppliers in comparison to the previous project. Moreover, night charging was not the only option, if not the least favored choice due to reduced efficiency gains. However, most emphasize this time was on the tendering process and increased reliability so that it could pave the way for electric buses to become part of normal tendering routines in Copenhagen. Mikkel Krosgsgaard explained the decision-making process as following: “We saw that there were a lot of electric bus producers who were able to meet our requirements such as Oprid, EBUSCO, BYD, VDL, Solaris, Linkker, Valo, and probably Hess. And then we were [also] looking at the charging equipment and we saw a lot of options there as well. So we decided to make a tender because we saw it not only as a development project but also on how to choose different people to cooperate with. […] in our test projects we heavily focused on reliability because it is our top priority”1. Public transport authorities in Copenhagen are decisive to make electric buses part of the normal operations for the city transport and tendering is an important aspect of that.

However, it turned out that tendering was not an easy task because they had to specify all the details related to e-buses which have never been thoroughly specified before. Krosgsgaard later added that “We started in summer 2014 to make a tender and it’s very difficult to make tenders for electric buses because we have to take a lot of aspects into account”. Some of these issues are elaborated below:

- Battery lifetime, range, efficiency drop of batteries, after life usage, recycling, etc.
- Noise – what kind? during or after acceleration? outside or inside noise?
- Energy efficiency including heating and cooling equipment
- Urban integration, charging poles, digging, height,
- Number of passengers and flow in the bus.
- Bus layout, number of doors, driver compartment
- Charging time, night charge, fast charge, ultra-fast charge
- Price, payment, devaluation, etc.
- Local emissions, in case of hybrids/plugin hybrids
- Uptime, maintenance, repair, failure
- Smart solutions, WiFi/IT-equipment, integration with other urban infrastructures

Finally, it was announced that Linkker buses have been chosen for this project together with a fast charging station from Heliox/Shunk to feed line 3A in central Copenhagen. The electric buses are lightweight and need 1.5 to 3 minutes to recharge using ultrafast charging and thus can operate round the clock. This is a major difference with slow charging that sometimes required the whole night to get recharged.

Line 3A was particularly chosen for it has no hills in its route. It is a 10KM route in each direction. Total budget is 12 million DKK and is organized as a cooperation project between the City of Copenhagen, Movia, E.ON. Denmark and with support from Danish Transport Authority. Project preparations started already since January 2014 with the tendering during September 2015 and delivery of buses and charging station during 2016. The operation will last for two years between August 2016 until August 2018 during which opportunity charging will be tested and results will feed the decision making process for designing e-bus tendering as part of the normal operations in Copenhagen.

1 https://vimeo.com/138623545
Meanwhile, a thorough study of potentials for electrifying Copenhagen’s public transport was done by Siemens. It estimated a reduction of 37,000 tons of CO2 per year and 10 times reduction in particulate matters if all the current diesel buses are converted into electric. The study also showed that 28 out of 33 routes could be immediately electrified with no changes to the existing schedules and services (see figure 25).

![Copenhagen made greener with full-electric bus routes](image)

Figure 25. Study results from Siemens investigation of electrifying public transport in Copenhagen


According to Mikkel Krogsgaard, the goal is to have tendering of electric buses in normal operation by 2017 and normal operation of 25-27 electric buses until 2019. The ultimate goal is to have normal operation of all 385 (electric) buses until 2028 financed by City of Copenhagen.

### 5.4 Lessons learned from Copenhagen

**Lack of tender experience for electric buses is a major issue**

The Copenhagen experience with EU tendering of electric buses showed that tendering process can be more complicated than it is expected. This is due to the lack of prior experience as well as differences in technologies involved. For instance, measuring noise in electric buses is (and should be) different from that of diesel buses due to differences in powertrain characteristics. The same goes for pollutions and energy intensity including lifecycle analysis instead of end-of-pipe assessments i.e. how the electricity has been produced. There is also a lack of benchmarking available which means that in some cases authorities have to make everything from scratch. PTAs may find it very difficult to formulate every aspect of the tendering for electric buses and fit them to the special requirements of their cities. There are also risks involved due to technological uncertainties and the incompatibility of these technologies to the needs of cities.
**Private operators need to increase their knowledge about electric buses**

The report from K2 pointed out that there are a large number of bus manufacturers involved in supplying electric buses, while bus operators are not as active. This was also confirmed by Mikkel Krogsgaard who was concerned about operators’ knowledge about electric buses: “More e-bus knowledge is essential for the private bus operators. We also need to get more knowledge [education] to our operators because they don’t have enough knowledge today.”

Another important concern is the price difference between diesel and electric buses. Although battery prices are falling, the price of electric buses is still high and may go up to two times higher than ordinary diesel buses. This has large implications on the total cost of ownership for operators and may partly explain their reluctance to adopt electric buses in addition to technological uncertainties and lack of knowledge. According to Victor Hug from Movia, the price of a BYD bus is approximately 425,000€ in comparison to a diesel bus of a similar size which costs around 230,000€. Based on the first project test results in Copenhagen, the TCO for BYD bus was estimated around 1.31€ per km in comparison to a similar diesel bus which costs around 1.01€ per km. This corresponds to a 30% increase in TCO for an electric bus\(^1\). However, it has also a lot to do with energy intensity and the efficiency gains with proper choice of powertrain (i.e. hybrid, plugin hybrid, or full electric), the vehicle size and the battery weight as well as charging technology (i.e. slow, fast, ultrafast) and the uptime of the vehicles. Driving behavior may also affect between 10-15% the energy efficiency, which highlights the fact that operators need to train bus drivers to adapt with new driving styles to save more energy.

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\(^1\) Access the full speech record here: [https://vimeo.com/138600270](https://vimeo.com/138600270)
6 Hamburg

6.1 Local emissions and CO2-free strategy at stake

As the second largest city in Germany with a population over 1.7 million inhabitants, Hamburg is considered as an important urban area in Europe. The metropolitan region covers more than 5.1 million inhabitants which is served by the Hamburger Hochbahn AG (HHA). Besides the tube system, HHA oversees a large part of the city bus system as well. Since 2007 the city of Hamburg has made firm decisions in reducing greenhouse gas emissions including at least 30% (or possibly 40%) cut down in CO2 emission until 2020 and 80% until 2050 (based on 1990 measures) aiming to contribute to the national goals of decarbonization. The Hamburg Climate Action Plan has emphasized on reducing emissions from transport sector which is currently responsible for 25% of CO2 emissions mostly caused by passenger cars and smaller commercial vehicles. Mobility shift from private passenger cars to public transport and biking together with electrification of the transport systems are critical strategies for reducing local emissions and CO2. The target set by the mayor of Hamburg is that from 2020 onward there would be only procurement of emission-free buses in the public transport sector.

6.2 National programs for electricity and hydrogen as fuel for transport

In 2009, the city of Hamburg together with partners from power and automotive industry was able to receive subsidies as one of Germany’s Electric Vehicle Model Regions. It is one of the eight model regions in Germany and received a funding of 10 million Euro from the Federal government. An important area of this funding scheme concerns the trial of 100 electric vehicles, mainly in commercial transport including city buses. Since December 2014, Hamburger Hochbahn together with other partners carries out test and demonstrations with a number of high capacity buses for urban transport at the Innovation Line 109 in Hamburg. Moreover, the city of Hamburg is building up the infrastructure for 100 public charging stations including Europe’s largest hydrogen fuel stations in Hamburg’s HafenCity district.

In fact, the Dutch federal government has made huge investments on electrification for the short to medium term as well as hydrogen for the long term future transport. The National Organisation for Hydrogen and Fuel Cell Technology (NOW GmbH) is a platform organization which coordinates research and development activities in the field of fuel cell technology and hydrogen economy all over Germany (top logo in figure 26). Since 2008, this organization overseas two major development programs related to electricity and hydrogen: The National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP) as well as the Electromobility Model Regions programme of the Federal Ministry of Transport and Digital Infrastructure (BMVI). Both programs are aiming to advance the operation readiness for the daily use of electric and hydrogen related technologies in transport sector. The funding for Hamburg Innovation [bus] Line is part of the second stimulation package within the model region program with a total budget of 115 million Euros for the eight regions (right logo in figure 26). When it comes to hydrogen, fundings from NIP program (left-side logo) is available together with additional support from EU.

6.3 Hamburg Innovation Line 109

The public transport in Hamburg is categorized into the tube and bus systems and the traffic is evenly distributed between the two i.e.: 50% traffic in the tube system with total 104 km long routes and 50% bus system with around 1,000 KM routes all-over Hamburg city. With such numbers, reducing local emissions as well as CO2 from the bus system is a critical priority for the city. The Innovation Line 109 is thus the starting point for real time operation of alternative powertrain technologies for the bus system.

The Hamburg Innovation Line 109 is an approximately 10 km distance route starting from the newly built electric charging station at the central part of Hamburg which expands towards north and reaches the Alsterdorf underground station connecting the metro line to the center of the city by bus. This is where comparative test and demonstration of innovative powertrain technologies are being done under strict real life conditions of scheduled bus services. Different powertrain technologies are being tested side by side and under identical conditions on this line. The identical driving and terrain conditions provide a solid ground to make comparisons among alternative technologies in terms of operational performance, energy intensity, quality, flexibility, charging efficiency, control center, volatility and many other important factors which are important when it comes to choosing the right technology for public transportation. Powertrain technologies being tested on this line include varieties of hybrid-electric configurations (i.e. series, parallel and plug-in hybrids) as well as full electric and hydrogen fuel cell as range extender. With such variety, Innovation Line 109 is considered as one of the most comprehensive test and demonstration platforms in Europe where nearly all the possible (available) alternative powertrains are being tested alongside each other. Hochbahn has an in-depth understanding of new platform technologies and related infrastructure based on field trials and provides data to the Association of German Transport Companies (Verband Deutscher Verkehrsunternehmen-VdV) and other interested parties in Germany as well as UITP. Today, most focus is on electric buses and hydrogen fuel cell buses. Among the novel technology buses currently being tested are plugin hybrids from Volvo (figure 27) as well as battery electric buses with hydrogen fuel cell as range extender from Solaris and Daimler (figure 28).

![Figure 27, Volvo plugin hybrid electric bus with inverted pantograph on Innovation Line 109 in Hamburg
Photos: Benny Borghei](image-url)

Plugin hybrid electric buses from Volvo have been in operation since December 2014 and use end-station charging solution similar to that of Stockholm and Gothenburg. With fast charging through the inverted pantograph, they are able to run on full electric mode for most of the route (82%) which corresponds to 8 out of 9.8 km before the diesel engine kicks in (according to statistics as of April 2015 provided by Peter Schrauwen, Volvo Bus Hamburg Project Lead).
Hydrogen fuel cell buses from Solaris (articulated 18.5 meter) and Daimler also run on electricity stored in their 120 kWh battery packs as well as hydrogen as the range extender instead of diesel engine. Hydrogen as fuel for transport has been already tested for more than ten years in Germany and there are already dozens of fuel stations where vehicles can fill up their tanks with hydrogen like ordinary gas stations. The photos at the bottom side in figure 28 show HafenCity hydrogen charging station for buses and passenger cars in Hamburg. According to representatives from Hamburger Hochbahn, Hydrogen as a fuel has 100% flexibility in terms of centralized distribution and would have less stress on the existing fueling infrastructure. Nevertheless, there are still technological and market uncertainties when it comes to complete replacement of current fossil fuels, which may probably explain the slow rate of adoption for hydrogen as the ultimate alternative fuel yet.
6.4 Lessons learned from Hamburg

Inside climate control is a big challenge

Today, one of the key challenges in electric buses is the cooling/heating system. No matter if it is a full electric vehicle on battery or hydrogen as range extender, the energy that is needed for warming up or cooling down the inside climate is considerable. Hybrid powertrain vehicles might have less problem due to the fact that the engine is still present on board to provide power and even extra heat, but for full electric buses this is a big challenge. The main problem is that often an extra engine is needed only for the purpose of climate control inside the bus which in this case would be a small diesel engine. However, due to the cost and complexities involved, a very simple engine is being installed which usually ends up not complying with exhaust emissions standards. Some of these engines do not even comply with Euro-0 standard and that can severely offset the efficiency gains from electrification efforts.

Full battery electric poses several challenges

According to experts from Hamburger Hochbahn, full battery electric buses create bottlenecks in the system due to charging time as well as potential breakdowns with charging equipment which may essentially make these vehicles out of service. However, plugin hybrid electric buses provide greater flexibility because in the worst case scenario with charging, they may still run as ordinary diesel buses. Another problem is the ‘range anxiety’ among bus drivers who get nervous when the charging state goes down during their service, this will not happen if they drive a plugin hybrid or an electric bus with hydrogen range extender. But in any case, drivers on buses equipped with electric powertrain technologies, often have a feeling of ‘under control’ because of the constant measuring for efficiency and reports about charging state, battery status and alike.

More parallel charging systems are needed

Experts at Hochbahn anticipate that more parallel charging systems are needed in the near future as more and more buses are equipped with electric powertrains. This is to the extent that the charging facilities have become the determining factor for the number of buses in Hamburg. According to the board of directors at Hamburger Hochbahn, future orders of electric buses would be based on (i.e. limited to) the capacity of charging platforms.

More staff and more skills are needed

Another observation from experiments in Hamburg is that more staff will be needed in the future due to the increased tasks related to charging, maintenance and additional services related to new powertrain technologies. Meanwhile, there is are significant requirements for training and acquiring skills in these areas of operation such as charging, electric safety or proper handling of hydrogen as well as new safety equipment installations at bus depots and workstations. Moreover, the move towards electrification makes it necessary to integrate knowledge and expertise from very different disciplines. The public transport is not about moving vehicles, but passengers and this should include every means of transportation not only city buses. This is how Hamburger Hochbahn see the future and current business models do not allow such comprehensivity. Currently, even bikes become competitive means of transport and negatively impact the revenue flows during summer time, this should not be the case!