



**Fast and Smart Charging Solutions for
Full Size Urban Heavy-Duty Applications**

ASSURED Innovation in e-Bus Rapid Transit

Issued by

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ACRONYMS

EC: European Commission

DSO: Distribution System Operator

FUA: Functional Urban Area

HD: Heavy Duty

MD: Medium Duty

OEM: Original Equipment Manufacturer

PT: Public Transport

PTA: Public Transport Authority

PTO: Public Transport Operator

SUMP: Sustainable Urban Mobility Plan

UG: User Group



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1. Executive Summary

If electric buses are the natural step in the evolution of urban bus systems, autonomous, electric, bus rapid transit (BRT) is the ultimate step into the future, combining the best of the electric technology (emissions-free, silent), BRT (segregated lanes, right-of-priority) and autonomous and connected driving (comfort, safety, efficiency).

The scale up phase of the e-buses should also cover the most demanding routes. Therefore, the biggest benefits to reduce GHG emissions and improve air quality can derive from switching the longest, fastest, and busiest routes into electric lines. High power opportunity charging systems for battery electric buses at two-ends stations and major stops can be tested in BRT systems operations.

ASSURED has contributed to advance this vision with the development and demonstration of high power, (ultra) fast charging solutions. According to the surveys conducted in the frame of the ASSURED pre-normative roadmap, BRT lines will preferably rely on opportunity charging.

In this light, the combination of battery bus technology, supported by interoperable, high power fast charging (as developed in ASSURED), has the potential to improve European BRT systems and operations by enabling e-BRT lines with superfast high-power charging capabilities.

This report aims to provide an overview on how BRT systems can benefit from the ASSURED innovations, concretely the solutions developed for standardised, interoperable high-power fast charging.

2. Understanding Bus Rapid Transit

Bus Rapid Transit (BRT) is one of the biggest innovations the bus domain has ever seen. It offers a powerful, deeply transformative potential for cities to transition from a car-oriented system into a strong, reliable public transport-based mobility, helping make cities healthier, more liveable, and sustainable.

Achieving modal shift from private modes to collective modes is one of the most effective tools to reduce carbon emissions from transport and reduce congestion. This is especially relevant for fast-growing regions and emerging economies, where BRT systems are seen as a rising trend, mainly due to its affordability and its high-capacity system capability, in addition to urban rail transport systems.

According to BRTdata.org, today, there are 190 BRT systems in operation around the world. Traditionally, BRT systems are a well-established transport mode in Latin America and Asia. However, many other parts of the world are increasingly becoming interested in BRT projects, like Africa, North America, MENA region, China, and Turkey.

This report aims to provide an overview on how BRT systems can benefit from the ASSURED innovations, concretely the solutions developed for standardised, interoperable high-power fast charging.

3.1. WHAT IS A BRT SYSTEM?¹

BRT is a bus-based mass transit system. The system has a concrete design, services, and infrastructure oriented to improve service quality and reduce delays. Sometimes described as a surface subway, BRT aims to combine the capacity and speed of a light rail or metro system with the flexibility, cost, and simplicity of a bus system.

Its main drawback compared to other urban transport systems is its demand for urban space. In many cases, when BRTs are being constructed, road space for private vehicles is reduced, as there may be no opportunity to expand the total road space.

For this reason, to be most effective, BRT systems, as well as other modes, should be integrated into a comprehensive mobility and transport strategy to support and promote public transport that can include measures to discourage car use, for instance increasing vehicle and fuel taxes, land-use controls, limits, and higher fees on parking, and integrating transit systems into a broader package of mobility for all types of travellers.

2.1.1 Core elements of a BRT system

The Institute for Transport and Development Policy (ITDP) clearly identifies the most important elements of a successful BRT system. Based on them, the most important ones best fitting the European reality are:

- Dedicated right-of-way to ensure that the buses can move quickly and unimpeded by congestion. Dedicated lanes matter the most in heavily congested areas. Intersections should be set up to maximise the green signal time for the bus lane. Passing lanes at stations allow additional travel time savings. In addition, stations should be located at least forty metres from intersections to avoid delay.

¹ Definition by the UN Climate Technology Centre & Network: <https://www.ctc-n.org/technologies/bus-rapid-transit>



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- A high-frequency service and extended operating hours.
- Clean vehicle technologies to reduce emissions in order to decrease greenhouse gas emissions as well as to improve the health of the passengers and the urban population at large.
- Rapid boarding. This should be enabled by off-board fare collection and pre-board fare verification. Also, having the bus station platform level with the bus floor is an important way to reduce boarding and alighting times per passenger.
- A control centre for monitoring bus operations, identifying problems and rapidly responding to them. Automatic vehicle location technology through for example GPS to manage vehicle movements should be integrated.
- Safe and comfortable stations. The stations should be weather protected and have security. The distance between the stations should on average be between 300 and 800 meters. The stations must guarantee access for all customers, with additional care to special-needs customers, thus ensuring universal accessibility.
- Excellence in marketing and customer service. This includes a unique brand and identity, clear route maps and signage, and real-time passenger information both on stations and buses.
- Integration with other public transport, which includes physical transfer points, an integrated fare system and integrated information. BRT stops are encouraged to be planned as small intermodal hubs, of course including other public transport services but also bicycles, other personal-mobility vehicles, and car sharing.
- Good pavement quality which ensures better service and operations for a longer period by minimising the need for maintenance.

2.1.2 Contribution of BRT technology to operational, environmental, societal and economic challenges of public transport

As already underlined, BRT systems can make an important contribution to a sustainable urban transport system. It is more energy efficient than conventional bus systems per person-kilometre due to the higher speeds and higher capacity buses. Also, it can help improve the modal split towards more use of public transport.

Operational

- Reduced travel time
- Increased commercial speed
- Increased image bus service and PT and city attractiveness

Economic

- More reliable product deliveries
- Increased economic productivity
- Increased employment
- Better work conditions

Environmental

- Reduced GHG emissions
- Reduced noise levels
- Reduced traffic congestion

Social

- Improved citizens' health
- Increased equitable accessibility
- Less accidents
- Sense of community

Figure 1. Contribution of BRT systems to address PT challenges. Source: UITP elaboration on UNCTCN

3.2. THE ORIGINS OF BUS RAPID TRANSIT SYSTEMS

Bus Rapid Transit (BRT) systems emerged in Latin America as an innovation that could transform cities and the way people move. While they constitute a first step towards integrated public transport networks (IPTN) and could be a catalyst for urban development, they should not be treated in isolation as a mere substitute for rail infrastructure where public funds are scarce.

Indeed, public transport excels when it is treated and conceived as a network, rather than modes or lines disputing for a certain market share. Moreover, the integration of mass public transport and urban planning was key to the success of worldwide-exported Curitiba's BRT concept launched already in 1970s. Bogota of course is an example of a city where the BRT system boosted the implementation of a hierarchical transportation network including pure BRT corridors, mixed-traffic trunk lines, feeder lines, and an incoming metro.

BRT developments in Europe are conceived to increase capacity in the existing network, improve quality of service (reliability, headway adherence) and/or efficiency in bus operations, even they may suppose a unique opportunity to boost an entire bus network redesign, but don't play the same disruptive role seen in Latin America or more recently in Africa.

For that reason, the concept of BRT embraces nowadays multiple approaches which can be observed around the globe. A BRT corridor is composed of many features that add up together to a high-capacity bus-based system. Dedicated right-of-way, traffic signal priority, transit-oriented street design, off-board fare collection, all-doors boarding, off-board fare collection, and dedicated service branding are the key characteristics that uplift bus corridors to BRTs.

The urban layout also plays a key role in BRT corridors implementation, which lead to very different outcomes. Curitiba's and most of the systems in Latin America follow the classical or full BRT approach, which benefits from wide and straight road axes. This classical approach uses high-floor buses, closed stations, and fully segregated busways aligned in the median of the road axes. On the other side, the BHLS or BRT-lite approach is taken in most of the European BRT deployments, which offers more possibilities to integrate within an existing intensive-land-use urban area. Here, in general, low-floor buses run on less intrusive but more permeable infrastructure and stops, which is the reason why the BHLS approach offers lower capacity and commercial speed than full BRT systems.²

3.3. E-BRT SYSTEMS AROUND THE GLOBE

Battery-electric buses for BRT systems are still in a ramping-up phase. However, a few examples of electric BRTs are described below.

The Sunway Line in Subang Jaya Selangor (Malaysia) is a 5.4 km-long elevated BRT corridor that connects two commuter rail stations and other major points of interest since

² Ferbrache, Fiona. (2019). The value of bus rapid transit in urban spaces.

2015. Only the 15 battery-electric buses that make-up the system drive on the exclusive infrastructure.³



Figure 2. Electric bus on the Sunway BRT line. Source: Sirap bandung⁴

An ambitious e-BHLS line started operations back in 2017 in Marrakech, Morocco. A total of 15 e-buses run on this first line, with a total length of 8 km, 3 of them equipped with overhead wires that charge on-board batteries while in motion.⁵

The first BRT line was inaugurated in Quito (Ecuador) in 1995.⁶ It was operated by trolleybuses since the very beginning, reaching more than 100 electric units in the fleet. During the last two decades the system grew with four additional lines operated by traditional buses with internal combustion engines, and diesel buses were added to increase capacity on the trolleybus corridor. Quito committed to replacing the BRT fleet with e-buses by 2025 to achieve the goal of zero emissions by 2030.⁷

³ The Future of Bus Rapid Transit (BRT) in Malaysia. [https://www.volvobuses.com/content/dam/volvo-buses/markets/malaysia/210511%20BRT%20Report%20FINAL%20\(SQUARE\).pdf](https://www.volvobuses.com/content/dam/volvo-buses/markets/malaysia/210511%20BRT%20Report%20FINAL%20(SQUARE).pdf)

⁴ CC BY-SA 4.0 <<https://creativecommons.org/licenses/by-sa/4.0/>>, via Wikimedia Commons

⁵ Alsa Marrakech <https://www.alsa.ma/marrakech/bus-electrique>

⁶ Empresa Pública Metropolitana de Transporte de Pasajeros de Quito <http://www.trolebus.gob.ec/index.php>

⁷ Solutions Plus Quito Factsheet http://www.solutionsplus.eu/uploads/4/8/9/5/48950199/factsheet_quito_new.pdf



Figure 3. Quito's trolleybus running on exclusive BRT lanes. Source: Mariordo (Mario Roberto Duran Ortiz)⁸

Looking into the future, the new BRT system in Nairobi, Kenya is planned to start operations by the end of 2022. On 1st February 2022 the call for offers was officially launched by the Nairobi Metropolitan Area Transport Authority, inviting firms to present their bids for operations with clean buses (i.e., battery electric, hydrogen, or biogas or hybrid).⁹

⁸ CC BY-SA 3.0 <<https://creativecommons.org/licenses/by-sa/3.0/>>, via Wikimedia Commons

⁹The EastAfrican February 2nd, 2022, <https://www.theeastafrican.co.ke/tea/business/kenya-locks-out-diesel-buses-from-brt-project-3702482>

3. BRT systems in Europe

4.1. COMPILATION OF BRTS IN EUROPE

4.1.1. Nantes Busway line 4

In November 2006, Busway (line 4) was set up to complete the core backbone of Nantes Metropole public transport network made of 3 tramway lines with the goal of having at least a similar high level of service at lower cost.



Figure 4 e-BRT in Nantes. Source: Semitan

Nantes busway resulted in a major improvement in quality of service. Average commercial speed increased from less than 16 km/h to more than 20 km/h, and service punctuality increased from 75% to 95%. Compared to non-BRT bus operations, to achieve the same level of service, Nantes public transport operator Semitan quantifies in 5 vehicles de additional number of buses needed to achieve the same level of service. A clear sign of the busway success is that 25% of the riders three months after starting operations were driving a car for the same commute.

To face an urgent extra capacity requirement, Semitan engaged in the project of electrification of the BRT corridor. The articulated CNG buses were substituted by biarticulated electric buses, adding around 35% extra capacity to the system. To top-up the electric vehicles, (super) fast opportunity chargers operating at 600 kW were installed at both end-stops and two intermediate stops. According to Semitan, transitioning from CNG to electric BRT had no impact on operations.

4.1.2. Amsterdam R-net line 300

Line 300 BHLS line has been running since January 2002. The BRT-line connects one of the biggest suburbs of the Amsterdam, Bijlmer, located around the Johan Cruyff Arena soccer stadium and an employment stronghold, via Amsterdam Schiphol Airport to Haarlem Central Station. Formerly known as Zuidtangent, the entire line is around 40 km long and drives on a completely segregated bus lane of 25 km.



Figure 5. Amsterdam R-Net Line 300. Source: Transdev/Connexxion

Line 300 was integrated within the regional R-net network in 2011 and is currently operated by Connexxion (Transdev subsidiary) since 2017. Connexxion operates around the Schiphol area with over 200 battery-electric buses, bringing passengers to the airport and running transfers between terminals. This BRT-line was operated with articulated diesel buses and during 2021 these buses were replaced by new fully electric-BRT-buses.

4.1.3. Castelló Tram

In 2008, a trolleybus BHLS line opened in Castelló, Spain. Since the last expansion in 2014, the 8 km-long electric line connects the city centre with the seaside-neighbourhood of El Grau. The line counts with an exclusive busway, electrified overhead wires and optical guidance system. Currently, a mix of hybrid-trolleybuses and diesel buses operate the line, while 4 battery-electric fast opportunity charging vehicles will be soon added to the fleet. It is planned to renew the BHLS fleet of hybrid-trolleybuses with battery-electric buses, thus dismantling the catenary system by the end of the decade.

4.1.4. Pau Fébus

Fébus is the name of the first hydrogen BHLS system rolled out in late 2019 in Pau, France. Up to 8 articulated buses drive on the 6-km-long route with exclusive right-of-way and priority at crossings.



Figure 6 Pau's BHLS hydrogen articulated bus. Source: Pau Béarn Pyrénées Mobilités

4.2. BATTERY-TROLLEYBUS INNOVATIONS FOR MODERN E-BRT SYSTEMS

There are currently more than 300 existing trolleybus systems worldwide.¹⁰ Since many decades they are a proven zero-emission public transport system for urban areas. However, so far they have lacked the flexibility that battery-equipped electric buses provide. The trolley:2.0 project (2018-2020) combined the advantages of both systems, developing trolleybuses further into battery-equipped trolleybuses that allow for the partial off-wire operation while making more efficient use of the trolleybus catenaries to charge the batteries in-motion. trolley:2.0 has therefore proven that modern trolleybus systems can build a strong backbone needed for zero-emission public transport systems in European cities.

Trolleybuses are considered as clean vehicles/ zero-emission vehicles when equipped with a battery and thus capable of in-motion charging (IMC). Therefore, they form an integral part of the Clean Vehicles Directive. With in-motion charging buses can load the batteries without stopping while connected to the overhead line and the battery allows the bus to leave the overhead network. Therefore, modern trolleybuses can run off-grid up to 20km or more.

Unlike previous trolleybus systems electric infrastructure is not needed in all sections of the network and can therefore be cut down to approximately 50% (and up to 30-40% under perfect conditions)¹¹ for trolleybuses to still serve on the respective bus line. They can even extend existing services to areas in which catenaries cannot be build, e.g. due to low cost-effectiveness or difficult built environments (e.g. heritage old towns).

Because of these features, IMC-based trolleybuses are especially well-suited for routes that have the following characteristics that are very well in line with BRT requirements:

- Long routes: no need to recharge en-route, or long unproductive recharging times at terminal stations

¹⁰ <https://www.trolleymotion.eu/trolleytaedte/>

¹¹ https://www.trolleymotion.eu/wp-content/uploads/2021/08/trolleymotion_Folder_IRSP.pdf



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- Hilly areas: the external supply of energy allows for lighter vehicles, operating in a more economic and ecologic way
- Routes with high demand: IMC allows for double-articulated vehicles even under difficult conditions
- Routes with high frequency: which enables the investment in long routes or any combination of the above.¹²

One of the first European showcases for further developing existing trolleybus systems towards e-BRT systems is Rimini, Italy. Rimini is a town of about 150,000 inhabitants and the capital of the province of the same name in Emilia-Romagna. The territory extends for 15 km along the upper Adriatic coast towards Riccione, a town of about 35,000 inhabitants.

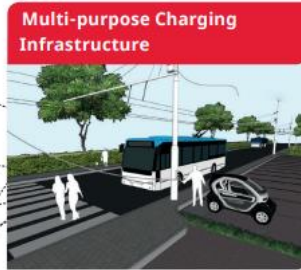
A “BRT System” called Rapid Coastal Transport and branded “MetroMare” is active in Rimini since 2019 and in operation with articulated vehicles. New overhead wire lines were being installed for the Rapid Coastal Transport between Rimini and Riccione as an electrical Bus Rapid Transit (BRT) during the past years. Since 2021 the service has been successfully operated with fully electric trolleybuses. The route is designed to accommodate for 25 m trolleybuses in the future. The batteries with which the trolleybuses are equipped allow for an operating range in off-catenary mode running for about 12-15 kms.

Future developments in the field of trolleybuses will also allow for additional services to be integrated in e-BRT systems, especially around the topic of integrating multi-modal services at trolleybus stations and utilising the trolley grids for additional services (charging hub concept). The trolley 2.0 project has investigated the technical and operational feasibilities for some of these elements. This includes, among others, innovative solutions for shared and multi-purpose charging infrastructure, lightweight-constructions of a new mid-trolleybus type, automated wiring technology and concepts for the integration of renewable energy sources.

¹² <https://cms.uitp.org/wp/wp-content/uploads/2021/01/Knowledge-Brief-Infrastructure-May-2019-FINAL.pdf>



Source: DiaLOGiKa



Smart trolley grid, Franses TS



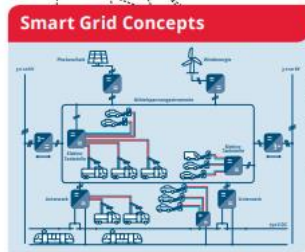
Direct charging of electric cars with photovoltaics, TU Delft



Source: Electroline



Source: Evopro midi-bus prototype



Source: ELIPTIC, Prof. Müller Hellmann



Source: ZeUS Poject, TMB

Figure 7. trolley 2.0 innovations that enable trolley-battery based zero-emission e-BRT systems. Source: trolley 2.0

4. ASSURED contribution to the electrification of urban bus fleets

The ASSURED project aimed at boosting the deployment of urban commercial electric fleets (buses, trucks and vans) across Europe and ensure their integration with high power fast charging infrastructure.

With a strong focus on electric buses, the project has developed and delivered key innovations that enable the optimisation of fleet operation, like the interoperability and standardisation of e-bus charging through high power fast charging solutions, and the introduction of intelligent tools for smart charging and energy storage systems.

These solutions have contributed to reducing the total cost of ownership (TCO) and operational costs, thus increasing the competitiveness of the technology, user acceptance, and facilitating mass adoption and fleet upscale. By reducing the cost and improving the efficiency, operators can fulfil the service requirements at ease and provide high-quality public transport. Additional elements explored within the project were how to improve grid stability to ensure a secure energy supply, essential for future uses when a larger number of vehicles will rely on the charging infrastructure.

One of the project's key milestones has been the release in July 2019 of the ASSURED 1.0 Interoperability Reference, and its updated ASSURED 1.1 version issued in March 2022, which has made it possible to test and verify the interoperability of charging infrastructure for battery electric heavy-duty vehicles.

This reference was tested and successfully demonstrated in the ASSURED demonstration sites Barcelona and Osnabruck to charge buses with chargers of different brands in real operation, and the results of the tests were the basis for the final updated reference. In the same spirit, the Gothenburg demonstration has demonstrated several interoperable charging solutions for different types of vehicles (e-bus, e-truck, and e-car).

Another key milestone has been the development of smart tools for the optimized fleet operation, charging and energy storage targeted to the demo fleets in Eindhoven and Jaworzno. The Eindhoven demo fleet will be scaled up from 43 to 100 e-buses this year. The solutions applied to the Jaworzno demo fleet have achieved significant cost reductions and increased the efficiency of the charging.

Still, the work to ensure cleaner and more sustainable cities does not end here. The bus sector must keep working to ensure that citizens choose public transport and urban buses because it is more convenient, comfortable, and efficient than private cars.

BRT systems combined with electric powertrains and automation and connectivity have the potential to improve efficiency and overall service of bus systems. The ASSURED legacy, concretely the ASSURED innovations like interoperable high power fast charging, the ASSURED Interoperability Reference, and IT tools for fleet optimisation can be transferred to e-BRT applications.

The following sections describe the main features of future e-BRT systems and how the ASSURED innovations can support them.

5. ASSURED contribution to e-BRT systems in Europe

If electric buses are the natural step in the evolution of urban bus systems, autonomous, electric, bus rapid transit (BRT) is the ultimate step into the future, combining the best of the electric technology (emissions-free, silent), BRT (segregated lanes, right-of-priority) and autonomous and connected driving (comfort, safety, efficiency).

The advantages of autonomous, connected e-BRT and autonomous e-bus are many, and very powerful. The autonomous driving and the electric powertrain components enable a gentle driving without rushed accelerations and brakes ensuring a comfortable ride. The bus sensors adapt speed accordingly to the route development and needs. Parking at the bust stop is automatized, keeping the same gap bus-stop platform, easing the entry and exit of the passengers. Also, dedicated, segregated lanes enable opportunity charging whenever needed at convenient bus stops. At the bus depot, vehicle handling is simplified as the bus can drive himself to the charging, washing lane and parking slot, releasing the staff who can focus on other maintenance and service tasks.

Autonomous e-BRT would add flexibility to the operation as it would enable adapting to demand and add capacity whenever needed. Bus platooning is currently being explored as in theory, it could scale up to as many vehicles as needed, which would help operators maintain bus headways (the time between consecutive buses) and adapt to demand peaks and rush and off hours.

ASSURED has contributed to advance this vision with the development and demonstration of high power, (ultra) fast charging solutions. According to the surveys conducted in the frame of the ASSURED pre-normative roadmap, BRT lines will preferably rely on opportunity charging. In this light, the combination of battery bus technology, supported by interoperable, high power fast charging, as developed in ASSURED, and in combination with automation and connectivity constitutes the next step for e-BRT innovation¹³.

6.1. ASSURED LEGACY APPLIED TO E-BRT

With a strong focus on electric buses, the project has developed key innovations that enable the optimisation of fleet operation, like the interoperability and standardisation of e-bus charging through high power fast charging solutions, and the introduction of intelligent tools for smart charging and energy storage systems. Some of these solutions can be transferred to the BRT concept, focusing on the vehicle, charging infrastructure and management and connectivity with other transport modes. This section describes and highlights these solutions and how they can support the electrification of existing BRT systems.

5.1.1 ASSURED Interoperability Reference

Ensuring the standardisation and interoperability of the charging infrastructure is key to ensure successful deployment of electric bus fleets at scale. Both ZeEUS and ASSURED projects have extensively worked on this topic.

The EC issued in 2015 the mandate M533 to the standardisation bodies CEN-CENELEC to define European standards for the use of alternative fuels infrastructure. Concretely, for

¹³ This topic is identified as one of the priority topics of the Horizon Europe research (2ZERO SRIA).

electric buses the mandate requested standards for conductive and wireless charging. With the aim of addressing the topic and supporting the work of the standardisation bodies, within the ZeEUS project, UITP initiated an industry-led standardisation committee, which established the initial guidelines for standardisation, in collaboration with the CEN-CENELEC, and was released as CEN-CENELEC recommendation for standardisation of e-bus charging in 2018.

The work achieved in ZeEUS was taken over by ASSURED, launched in October 2017. At that moment, the standards on fast charging for e-buses were not yet finalised or were lacking definitions of some of the parts required for successful interoperability. Therefore, ASSURED identified the need for its own baseline specification when preparing for the conformance and interoperability testing.

Analogous to the work performed in ZeEUS, ASSURED organised a series of workshops led by VTT Technical Research Centre of Finland, consisting of three working groups from ASSURED industry partners, to plan and create the specification according to the intermediate versions of the standards. The working groups identified the standards and their versions related to be used for the ASSURED work; as well as the gaps still left by the standardisation. The results were consolidated in the specification “ASSURED 1.0 Interoperability Reference”, released in 2019. The document presents three fast charging solutions with ACDs, including infrastructure mounted, roof-mounted, and floor-mounted ACDs. These solutions are same as the fast-automated charging solutions that were presented in CEN-CENELEC recommendation.

The ASSURED 1.0 Interoperability Reference was used as a common framework for the charging infrastructure suppliers and e-bus manufacturers within and outside of ASSURED project, during the time that the standardisation of e-bus charging infrastructure was not finalized.

In the next step, to facilitate the conformance and interoperability testing, VTT, with support of IDIADA, produced a document on conformance and interoperable fast charging test protocol for chargers and vehicles. This test protocol is based on the standards and definitions outlined in ASSURED 1.0 Interoperability Reference and it contains an extensive list of possible conformance and vehicle-charger interoperability test cases for buses and trucks with infrastructure-mounted and roof-mounted ACDs. To ensure the quality of the ASSURED conformance and interoperability test protocol, the document was first reviewed by the ASSURED internal experts and then by ASSURED external stakeholders.

After the successful conformance and interoperability testing led by IDIADA, the interoperability of the ASSURED chargers and vehicles was tested in real operation in Barcelona and Osnabrück. The results of the real operation phase were the basis for the finalisation of the latest update “ASSURED 1.1 Interoperability Reference”¹⁴.

Based on the positive results, the ASSURED partners have agreed to keep the ASSURED Interoperability Reference as a living document after the project end. To do so, a new working group will be established, under the coordination of UITP and support of the involved partners. The next tasks of the working group could be a) to explore the possibility of upgrading the ASSURED Interoperability Reference to e-BRT bus fleet; and b) the adaptation/retrofit to bi-polar trolleybus charging infrastructure for e-BRT buses.

¹⁴ <https://assured-project.eu/news-and-events/news/assured-releases-new-milestone-with-interoperability-reference-1-1>

Finally, supporting the definition of the ASSURED Interoperability Reference, the ASSURED pre-normative technology roadmap provides an overview of the most popular charging technologies today and in the next future. A series of expert interviews were conducted to collect the views of the industry and the end users (cities, operators).

As part of the results in terms of technology development, the roadmap forecasts articulated buses to reach battery capacities of 400 to 500 kWh, while for solo buses battery capacity is expected to go beyond 700 kWh in 2022 and 1 MW charging capacity. This result is aligned with the foreseen charging approaches for the three main bus service types, stating that BRT and trunk lines would preferably rely on opportunity charging, while feeder lines are expected to rely on overnight depot charging beyond 2024.

In this light, the ASSURED solutions for interoperable, high power fast charging developed are ready to be fully transferred to the e-BRT concept and fulfil opportunity charging.

5.1.2 ASSURED Simulation tool

Today, the operation of electric-bus systems cannot be dissociated from the use of smart tools, from the intelligent planning of the e-bus system to the monitoring of vehicles' performance, or the charging process. The intelligent exploitation of this data is essential for the optimisation of operations, and the use of telemetry becomes crucial as e-bus fleets grow.

In the frame of ASSURED, VUB has developed a simulation tool to help plan and define electric fleet upscale. Using this tool, end users can better understand the role played by key parameters like battery size, required charging time, or the optimal charging power according to their specific boundary constraints.

Beyond single bus or single-line operations, the simulation platform also helps design vehicle fleets for multiple routes in any given city. The route can be designed with the actual operational and charging scenario, including seasonal, elevation, velocity, passenger, and charging profile to evaluate the impact on the daily grid and the TCO. Moreover, different chemistries-based electric buses can be easily selected.

The potential of the ASSURED simulation tool for e-BRT applications could be the development, modelling and integration in the current tool of (next) functionalities to support:

- Predictive maintenance (PM) strategies and battery state-of-health estimation: PM strategies attempt to forecast the health of the components inside an electric bus by periodically gathering and analysing relevant datasets for these components.
- Intelligent driver support systems and safety systems: the cooperation of e-BRT and the technological capabilities of ADAS can provide a cost-effective solution for an efficient and safe transport system.
- Optimized connected vehicle digital twin and monitoring system: while simulation has been widely applied for analysing the performance of transportation systems in the past¹⁵, its modern variant/extension – digital twinning – can efficiently replicate the actual operation of these systems, exploiting two-way real time data, which can be directly transferred by high-performance 5G technologies.
- Advanced vehicle energy (and thermal) management: a proper energy and thermal management of electric vehicles is an important factor to maximize the driving range and the thermal comfort for the passengers.

6.2. ASSURED BRT-LIKE SYSTEMS

6.2.1. BARCELONA

In Barcelona, TMB deployed between 2012 and 2018 a network redesign based on orthogonal (H, V and D) premium routes, on top of conventional trunk lines and local and feeder routes. Next, the high-capacity line H16 is already operated in a fully electric mode, using opportunity chargers at both ends of the line.



Figure 8. e-Bus performing tests on line H16 during ASSURED demonstrations. Source: TMB

Building on the ASSURED learnings, TMB launched in March 2022 the procurement of 83 battery-electric buses and the required fast-charging infrastructure. The tender includes the necessity to provide a certificate of ASSURED 1.1 Interoperability Reference compliance issued by a third-party. The buses will be partially devoted to electrifying two additional orthogonal lines, H12 and V15.

6.2.2. OSNABRUCK

Since March 2019, the city of Osnabruck (Germany) is operating several lines as MetroBus lines, following the introduction of a total of over 60 e-buses.

The first line operated with e-buses was launched in 2019. It is the MetroBus line 1, between Düstrup and Haste, and with a length of 13 km, is the longest all-electric bus line in

Germany. It is serviced by 13 e-buses, which covered almost 730,000 km in the first year of operation.

The second MetroBus line M2 started operation at the end of October 2020, with 8 e-articulated buses covering the route between Landwehrviertel and Hauptbahnhof.

Following M2, at the end of 2020, the M3 line between Schinkel-Ost and Sutthausen/Hagen aTW started operation with 14 articulated e-buses. The vehicles are charged at the SWO depot and at the end terminals of the lines.

In total, the three MetroBus lines M1 to M3 have 35 articulated e-buses and cover more than 7,000 kilometres on weekdays.

From summer 2021 on, the lines M4 (Belm - Hellern-Nord) and M5 (Dodesheide Waldfriedhof - Kreishaus/Zoo) started operation with additional 27 articulated e-buses.

At the end of 2021, a new MetroBus line network with fast, accelerated main axes into the city centre, high frequency, and comfortable buses, serving five MetroBus lines.

Since the beginning of 2022, 62 e-buses are operating in the Osnabrück network. This corresponds to over 60% of the transport service provided. The procurement of further e-buses is planned in the following years until achieving full fleet electrification.

For the municipality of Osnabrück, the complete electrification of the local transport is an important part of the 'Mobile Future' project, a joint undertaking of the city of Osnabrück and its municipal utilities. This includes sustainable mobility concepts, promotion of environmentally friendly local mobility, and further development of e-mobility, encouragement of bicycle use, and advancement of public transport.



Figure 9. SWO e-bus in operation. Source: SWO

6. Conclusions

If electric buses are the natural step in the evolution of urban bus systems, autonomous, electric, bus rapid transit (BRT) is the ultimate step into the future, combining the best of the electric technology (emissions-free, silent), BRT (segregated lanes, right-of-priority) and autonomous and connected driving (comfort, safety, efficiency).

The advantages of autonomous, connected e-BRT and autonomous e-bus are many, and very powerful. The autonomous driving and the electric powertrain components enable a gentle driving without rushed accelerations and brakes ensuring a comfortable ride. The bus sensors adapt speed accordingly to the route development and needs. Parking at the bust stop is automatized, keeping the same gap bus-stop platform, easing the entry and exit of the passengers. Also, dedicated, segregated lanes enable opportunity charging whenever needed at convenient bus stops. At the bus depot, vehicle handling is simplified as the bus can drive himself to the charging, washing lane and parking slot, releasing the staff who can focus on other maintenance and service tasks.

Autonomous e-BRT would add flexibility to the operation as it would enable adapting to demand and add capacity whenever needed. Bus platooning is currently being explored as in theory, it could scale up to as many vehicles as needed, which would help operators maintain bus headways (the time between consecutive buses) and adapt to demand peaks and rush and off hours.¹⁵

ASSURED has contributed to advance this vision with the development and demonstration of high power, (ultra) fast charging solutions. According to the surveys conducted in the frame of the ASSURED pre-normative roadmap, BRT lines will preferably rely on opportunity charging.

In this light, the combination of battery bus technology, supported by interoperable, high power fast charging (as developed in ASSURED), with automation and connectivity constitutes the next step for e-BRT innovation, and has been identified as one of the priority topics of the Horizon Europe research (2ZERO SRIA).

Building on the ASSURED legacy, UITP is leading a project proposal in cooperation with several ASSURED Partners.

¹⁵ <https://www.masstransitmag.com/article/12270117/is-autonomous-bus-rapid-transit-the-next-evolution-of-brt>

ASSURED at a glance

Coordinated by VUB (Vrije Universiteit Brussel), ASSURED aims to boost the electrification of urban commercial vehicles and their integration with high power fast charging infrastructure. The project develops and tests high-power solutions for full-size, urban, heavy-duty applications. The fundamental aim is that each of these solutions will be able to charge various types of vehicles, enabling operators to mix and match different brands of vehicles and chargers.

During the project, electric buses, trucks, and vans test different types of charging solutions. They are first tested in controlled conditions and later operated in real cities. Another element which ASSURED has investigated is the stability of the energy supply, essential for future uses when a larger number of vehicles will rely on the charging infrastructure.

The ASSURED consortium brings together relevant actors along the entire value chain of commercial electric vehicles. The consortium comprises OEMs, fast charging suppliers, electricity suppliers, grid operators, engineering and technology organisations, associations, as well as research and academic institutions.

Duration

October 2017 – March 2022 (54 months)

Budget

€ 18.65 million EU funded (total budget € 23.64 million).





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