ADVANCING PUBLIC TRANSPORT

POLICY BRIEF

IN MOTION CHARGING TROLLEYBUS SYSTEMS

SEPTEMBER | 2024

INTRODUCTION

The transition to zero-emission bus fleets is a critical component of the global effort to combat climate change and reduce urban air pollution. Governments and cities worldwide are increasingly setting ambitious targets to eliminate fossil fuel use in public transport, which, in turn, offers an opportunity to enhance the passenger experience, increase safety, optimise operations, and improve fuel economy.

Sustainable and efficient public transport systems are instrumental to achieving broader carbon-neutral goals, as they include renewable energy sources and sustainable practices and eliminate emissions generated by other public transport modes with higher negative externalities.

By adopting zero-emission bus fleets, cities and regions can significantly lower their carbon footprint and contribute to a cleaner, healthier and more energy-efficient environment, leveraging renewable energy sources to power public transport networks. There is a wide array of zero-emission bus technologies to consider when planning and implementing the energy transition, including hydrogen buses, battery electric buses (BEBs), and trolleybuses, just to mention the most popular applications.

Several hundred cities around the world operate conventional trolleybuses. They have electric powertrains and are zero-emission buses. Their power networks consist of substations, power cables, and overhead wires. In many cases, major parts of the electric feeding infrastructure can be shared by electric buses (e-buses) with different charging technologies or even rail modes, as these modes are often operated under the same public ownership. This makes this infrastructure a public asset of strategic importance.

Many cities nowadays are actively implementing zero-emission buses, but, unfortunately, in some cases, they are simultaneously dismantling existing operational trolleybus systems. A couple of the main arguments against conventional trolleybuses are that the overhead wire network is a form of visual pollution and trolleybuses have various disadvantages like

In motion charging trolleybus (Cagliari) *poor manoeuvrability on small radius turns. However, these drawbacks are being minimised through current technological developments, such as the application of in motion charging (IMC), and can ultimately be outweighed by the benefits and opportunities in this sector. IMC trolleybuses employ a zero-emission bus technology that equips vehicles with a small battery pack and uses an extensive and optimised overhead wire network as charging infrastructure. The current trend is to introduce new trolleybus systems or update existing ones with IMC-capable vehicles, extending the reach of the trolleybus network off-wire and expanding trolleybus fleets.*

Achieving sustainability and circularity[1] in public transport entails not only evaluating public transport vehicles' environmental impact but also implementing sustainable practices in other areas. These areas include material and natural resource usage, working conditions and human rights, energy and climate, and material reuse, recycling, and recovery. While some of these aspects can be easily assessed, others are not as tangible.

In 2024, the International Association of Public Transport (UITP) Policy Board approved a sector-wide policy brief on trolleybuses developed by the UITP Trolleybus Committee. ***This document advocates for the consideration of trolleybuses as one of the alternatives when developing strategies for the decarbonisation of urban and suburban public transport bus fleets, including existing and planned (zero-emission) bus rapid transit (BRT) systems.*** *It highlights the benefits of IMC trolleybuses as a very energy-efficient road vehicle and discusses the opportunities for using trolleybus (or even tramway/light rail) infrastructure through a summary of the technical content and global use cases. This policy brief followed a series of three other UITP knowledge briefs (2019-2021-2023) that examined technical aspects and other considerations related to IMC trolleybuses in detail.[2]*

MAIN BENEFITS OF IMC TROLLEYBUSES

IMC trolleybuses, or battery trolleybuses, are e-buses that draw power from overhead wires via trolleys and can also run on rechargeable batteries. Hence, they are the direct substitute for older generations of trolleybuses fitted with auxiliary diesel generators. Moreover, since IMC systems provide a continuous supply of electricity to vehicles in motion under overhead wires, battery trolleybuses can recharge onboard batteries to power the vehicles while off-wire, thus extending the zero-emission operations beyond the wired network. Furthermore, if the charging strategy for specific use cases requires it, trolleybus poles can also be used statically at termini for additional opportunity charging, enabling cities to expand/introduce trolleybus networks without the need for extensive new infrastructure, while simultaneously supporting zero-emission bus operations.

San Fransisco F-line Streetcar and 21-Hayes Trolleybus sharing overhead systems

This technology minimises or eliminates the need for prolonged stops for recharging, reducing the dependence between vehicle scheduling and electric charging while keeping reduced battery packs on board. This might be an additional asset in urban areas that lack efficient bus priority measures, where traffic congestion jeopardises reliability and can affect stationary charging plans and, ultimately, bus schedules. Furthermore, IMC reduces the overall length and complexity of the overhead wire network, reducing setup and maintenance costs compared to traditional trolleybus systems, and benefits historical or sensitive areas in cities by eliminating the need for visible infrastructure.

IMC trolleybus characteristics:

- **Continuous operation:** Enables charging while driving, ensuring uninterrupted service even in high-traffic conditions and for demanding bus services.
- **High efficiency:** Electricity transfer is significantly faster than with battery charging.
- **Seamless connection:** Automatic reconnection to overhead wires during passenger boarding takes 3-15 seconds.
- **Flexibility and range:** Battery capacity in IMC trolleybuses can be designed to enable off-wire operations for significant parts of the route, reducing the need for extensive overhead wire networks.

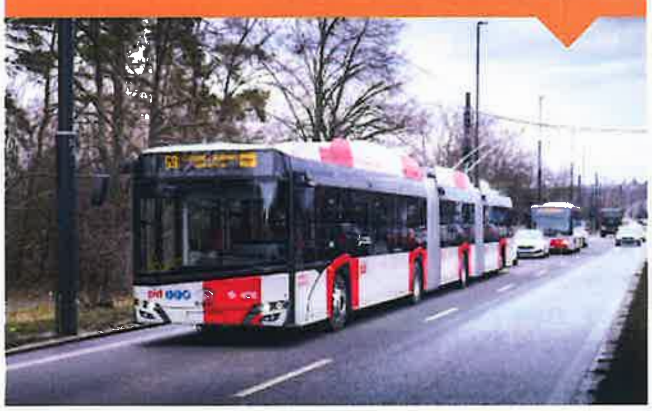
1 UITP Tender Structure Document 2023 – Annex VII on Sustainability and Circularity for Buses
2 The three knowledge briefs are accessible to UITP Members in UITP MyLibrary:
Knowledge Brief - In Motion Charging Innovative Trolleybus (2019)

- **Urban design integration:** Should it be a concern or requirement, off-wire operational capability can safeguard historical or sensitive areas from overhead wires.
- **Environmental benefits:** When infrastructure already exists, IMC trolleybuses facilitate the transition to zero-emission bus operations without significant infrastructure investment and can even significantly expand the reach of the original trolleybus network.
- **Open standard:** The two-wire overhead system is a long-lasting open standard, usable for decades and compatible with future developments.
- **Durability:** Trolleybus infrastructure lasts for decades.

USE CASE 1: PRAGUE

The dismantling of the trolleybus system in Prague in 1972 resulted from a political decision, not a technical assessment. After a comprehensive technical reassessment of electrification challenges and opportunities, Prague Public Transit Company (DPP) is integrating IMC-based zero-emission bus technology in various parts of Prague as part of its bus fleet decarbonisation plan. The deployment is aligned with other infrastructure projects and includes the coordinated modernisation of public lighting, combining lighting and overhead catenary system masts to save funds and minimise impact on public space.

Prague's IMC trolleybus electric BRT (eBRT) line was commissioned on March 6, 2024, featuring double articulated battery trolleybuses connecting Prague's Airport to the nearest metro station (Nadrazi Veleslavin). This enabled a 30% increase in transport capacity while reducing carbon dioxide (CO_2) emissions by approximately 1,300 tonnes per year through fuel savings. This service is one of the demonstration sites for the European Union (EU)-funded project eBRT2030, the aim of which is to support innovation in European eBRT systems.



IMC INFRASTRUCTURE WITHIN A CITY-WIDE ZERO-EMISSION TRANSPORT STRATEGY

IMC trolleybuses are part of the range of technologies and strategies to decarbonise bus fleets with e-buses and should be considered in associated feasibility studies. Failing to do so could result in suboptimal and/or more expensive solutions.

Every e-bus technology and charging strategy has advantages and disadvantages that need to be examined and weighed according to the local conditions, network and service needs, power availability, existing infrastructure, and depot conditions, among other aspects.

If your city has trolleybus infrastructure, consider keeping it.

Full-scale decarbonisation of a fleet does not require selecting one single technology; a combination of multiple options for different services could result in the most suitable and sustainable plan, especially when there is existing trolleybus infrastructure. Synergies between technologies and the required infrastructure should be carefully considered, including the use of tramway or light rail networks.

For instance, if there is an existing radial tramway network and favourable planning conditions, a circle or tangential trolleybus line could be envisioned, reusing some of the power available where the trolleybus network meets the rail infrastructure. This trolleybus corridor could, in turn, power other lines, partially overlapping the infrastructure with IMC technology and having opportunity charging at selected termini. This simplified example is an illustration of the potential of approaching the fleet decarbonisation challenge with strong technical leadership and without any preconceived ideas.

REUSE AND MULTIPURPOSE USE OF INFRASTRUCTURE

Upgrading existing trolleybus systems

Cities with existing trolleybus infrastructure can upgrade to IMC systems to maximise resource utilisation and reduce costs. As previously mentioned, existing tramway infrastructure can be used to facilitate the implementation of trolleybus networks to support the decarbonisation of urban bus fleets.

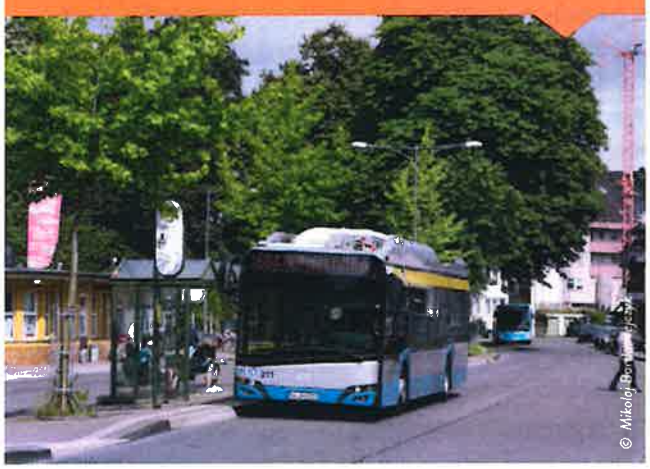
Advantages:

- **Cost-effective upgrades:** When trolleybus infrastructure already exists, transitioning to IMC requires minimal investment compared to the setup of infrastructure required by other zero-emission bus technologies. Existing infrastructure, such as poles and substations, can be reused with some straightforward modifications at a lower cost.

- **Reduced infrastructure complexity:** IMC systems simplify trolleybus infrastructure requirements by minimising the need for complex components such as switches and crossings. This leads to a more streamlined and efficient setup, lowering maintenance requirements and operating costs.
- **Environmental benefits:** Using existing infrastructure helps lower the carbon footprint associated with the production and installation of new equipment. Furthermore, the use of smaller onboard batteries recharged while in motion may reduce the environmental impact of battery production and disposal, contributing to the sustainability and circularity of the vehicle throughout its lifetime.

USE CASE 2: SOLINGEN, GERMANY

The Solingen case provides a notable example of successfully transforming a diesel bus line into an IMC trolleybus route. By converting the diesel buses on Line 695 to IMC500 e-buses, the city achieved nearly 80% wireless operation, with minimal overhead wire installation. The powerful IMC500 system allowed for efficient recharging along a small section of the route, demonstrating the practicality and efficiency of the IMC system.



PLANNING AND DEPLOYING IMC TROLLEYBUS SYSTEMS

In many cities, IMC trolleybuses are one of the solutions for decarbonising the bus fleet, along with other charging technologies and strategies for BEBs or even the use of hydrogen buses. In a sound and sustainable strategy, each technology is implemented for the routes and services it best fits. Furthermore, zero-emission technologies can achieve perfect harmony when synergies and opportunities in maintenance, energy supply, planning, asset management, etc. are fully exploited.

The key considerations for IMC trolleybus system planning and deployment are summarised below:

1. BUS NETWORK PLANNING AND SCHEDULING

Bus network planning is a core activity for public transport operators (PTOs) and public transport authorities (PTAs) and is key to guaranteeing citizens' access to public transport and ensuring efficient resource use[3].

When planning IMC trolleybus routes, existing trolleybus networks must be considered to identify the overlaps and opportunities where trolleybus infrastructure can provide electricity to IMC trolleybus vehicles to complete the routes. The IMC trolleybus has a high potential transport capacity due to its virtually infinite autonomy, which allows for optimised routes that maximise patronage at a higher energy efficiency level.

Extensions and modifications of the trolleybus network should be planned according to the current and planned network design to maximise the benefits. To achieve this, infrastructure and fleet managers should team up with operations and planning colleagues in the early stages to figure out how to optimise investments in infrastructure development and maintenance and fleet acquisition.

In scenarios where there is insufficient overlap between designed bus routes and overhead wires, opportunity charging at selected termini can be implemented, benefiting one or more lines terminating at these stops. With this strategy, IMC trolleybuses can operate off-wire for up to 80% of the line. A combination of trolleybuses with or without opportunity charging and BEBs with overnight depot charging, opportunity charging, or both can be used to operate the network efficiently and meet service requirements—a thorough analysis required to determine the optimal combination.

Especially when opportunity charging is needed to meet the energy demand, scheduling should account for charging stops and battery usage to ensure optimal performance and service continuity. By incorporating these elements into the scheduling process, PTOs and PTAs can ensure that energy-efficient vehicles are adequately charged while delivering consistent and timely public transport services.

2. THERMAL COMFORT AND ENERGY EFFICIENCY

Similarly to all zero-emission technologies, IMC trolleybuses must perform reliably in all weather conditions, including extreme cold and hot temperatures. This poses some challenges as HVAC can add up to 50% of the total energy consumption of the vehicle, hence any improvement in the efficiency of thermal comfort devices onboard will have a significant impact on energy consumption and charging infrastructure needed. In 2024, the UITP Bus Committee published a complete Thermal Comfort and Energy

Efficiency for Electric Buses Toolkit[4] to support operators and authorities tackling this challenge.

Although heating, ventilation, and air conditioning (HVAC) systems are increasingly being installed in e-buses, regardless of the charging technology, the connection to overhead wires enables the use of smaller batteries and greater use of onboard cooling and heating devices, even when dealing with extreme hot or cold temperatures. Trolleybuses are already in operation in a wide range of climates around the world.

3. DEPOT SPECIFICATIONS

The construction or adaptation of depots to accommodate zero-emission bus technologies is a crucial component of the overall strategy and an increasingly important issue for operators and authorities. In 2022 and 2023, the UITP Bus Committee released a series of factsheets for depot adaptations[5] to electric and hydrogen (H2) buses. Some of the considerations are applicable for IMC trolleybuses, such as safety recommendations, maintenance staff training requirements, location, and power supply, among others.

Because of the mix of technologies, depots should be suitable for storage, charging, maintenance, and all other routine activities of all vehicles in the fleet. The optimal depot layout and setup to accommodate the charging infrastructure for all technologies need to be determined.

IMC trolleybuses enable zero-emission operations to/from and within the depot without overhead wires, which reduces the infrastructure complexity—wires, crossings, and switches—and, thus, the depot setup and maintenance costs. Furthermore, they do not to rely on auxiliary combustion engines. IMC trolleybuses simply require short sections of electrified overhead wires or bars on top of the parking spots, equivalent to plugs or pantograph infrastructure for conventional BEBs.

Van Ness BRT - San Fransisco

IMC SYSTEM PROMOTION, PROCUREMENT, AND COMMISSIONING

Empirical evidence from cities that have implemented IMC systems provides valuable insights into the associated operational benefits and challenges. For instance, IMC technology deployment in Solingen, Germany and Zurich, Switzerland reportedly led to significant improvements in public transport reliability and efficiency. Public opinion has been predominantly positive in such cases, particularly when the environmental benefits and noise reduction advantages have been effectively communicated. The cases highlighted the importance of detailed planning, robust financial backing, and flexible management strategies that allow for iterative monitoring and optimisation.

INCLUSION OF IMC IN EARLY-STAGE PLANNING AND FEASIBILITY STUDIES

The integration of IMC technology into the early stages of public transport planning is critical. Feasibility studies are required to maximise the efficiency of this mode within the overall public transport system and enhance sustainability.

The energy source is always a crucial aspect in electrifying fleets. BEBs typically require more power from the electric grid at a single point, especially those charged overnight.

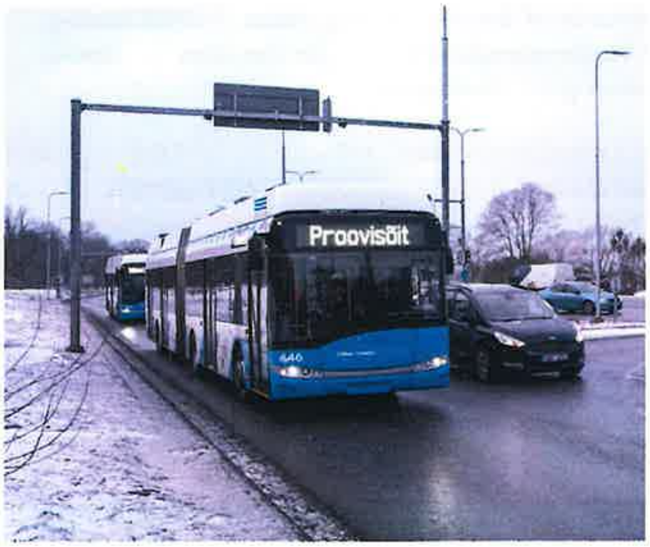
In the case of opportunity charging or flash charging, there is quite high demand for reserve power, which often makes up the most significant fraction of energy costs. In contrast, power networks designed for IMC can be cross-used with other electric modes such as light rail. Furthermore, in locations where overhead wires are available, a trolleybus network can be used as a power grid for electric vehicle charging stations. At the same time, it should be noted that such cross-use requires strong leadersWhip and political will to overcome any regulatory challenges.

Comprehensive assessment of technical requirements can enable the project team to strike a balance between building new infrastructure and ensuring interoperability with existing infrastructure, taking into account the electric grid's capacity and stability and the feasibility of incorporating renewable energy sources.

It is crucial to address all potential technical, environmental, and social concerns in the early stages, while simultaneously garnering support from municipal authorities, public transport operators, and the community. Infrastructure cross-use among different modes can enhance both community and authority support. Advanced simulation and modelling tools are available to predict system performance, optimise service design, and evaluate the proposed project's economic and environmental impact.

The implementation process often involves several challenges, especially when dealing with existing trolleybus systems.

As IMC often means fleet operation without overhead lines, this typically necessitates the purchase of new vehicles. However, existing trolleybuses can still be used on current routes fully running under overhead wires. It may also be possible to upgrade existing buses with larger batteries to enable IMC. For example, Tallinn's public transport operator Tallinna Linnatranspordi AS upgraded buses to provide proof of concept of IMC technology before deciding whether the city should proceed with it. Other challenges are related to infrastructure refurbishment, ensuring reliable power supply, and staff training on operation and maintenance.



In motion charging trolleybus (Tallinn)

A comprehensive total cost of ownership (TCO) analysis is always useful to compare different technologies; all currently available options should be considered, including BEBs with different charging strategies, hydrogen buses, and IMC trolleybuses. All key aspects must be taken into account, including capital and operating costs for both vehicles and infrastructure. It may seem that one transport mode would definitely be cheaper; however, hidden risks, mainly related to energy capacity and charging facilities, should be identified and checked.

TENDERING OF IMC TROLLEYBUS OPERATIONS

The tendering process for IMC trolleybus operations must be meticulously structured to ensure the selection of qualified and reliable service providers. Tender documents should specify detailed functional requirements, including battery performance metrics, vehicle compatibility standards, and energy efficiency benchmarks. As in the case of other zero-emission vehicle procurement, it is good practice to include the service details, including the route profiles, schedule, and demand, as part of the tender documentation to ensure optimal design of the battery capacity and other components for the specific service conditions.

It is advisable to follow the recommendations of the UITP Tender Structure Document, last updated in 2023[6], including assessment of bidders' experience with battery trolleybus technology. Furthermore, the tendering process should encourage innovation by allowing flexibility in the proposed technological solutions, fostering competition and ultimately leading to the selection of the most effective system.

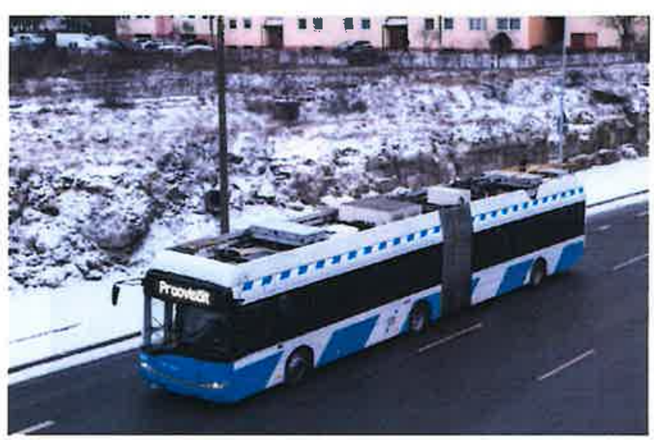
FINANCIAL CONSTRAINTS

The financial implications of adopting IMC technology represent a significant challenge. The substantial capital expenditure required for upgrading infrastructure, procuring IMC-compatible vehicles, and ensuring a stable and reliable power supply poses a barrier to widespread implementation. Municipal budgets are often constrained, necessitating project prioritisation based on detailed cost-benefit analyses and calculation of potential return on investment.

The use of existing trolleybus infrastructure or power supply infrastructure for light rail networks can significantly reduce the financial burden and may position this technology at the top of the cost-benefit analysis for transitioning towards zero-emission bus fleets.

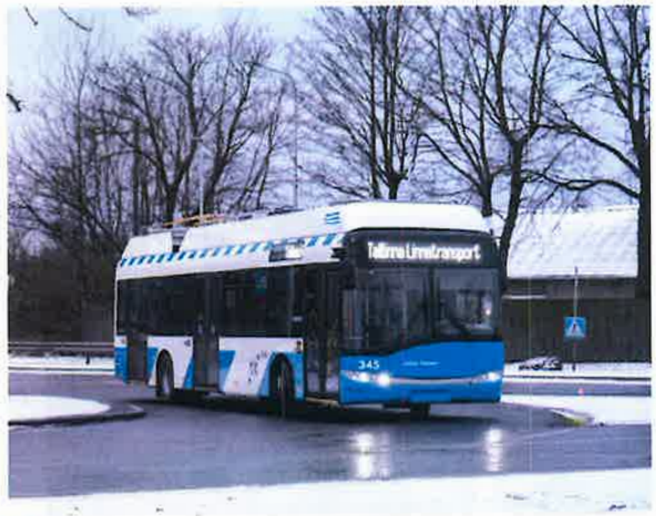
To mitigate the financial challenges, different types of funding mechanisms should be considered. Normally, there are a wide variety of grants and subsidies available from national and international organisations to support sustainable development in transport projects. Moreover, public-private partnerships can attract investors by highlighting the long-term environmental and social benefits of IMC projects. These strategies, among others, can enable municipalities to overcome financial barriers and advance towards more sustainable urban public transport solutions.

IMC trolleybuses represent a notable example of a circular economy solution in public transport.[7] By efficiently using recuperative braking energy, thus necessitating smaller battery packs onboard and, as a result, minimising the associated waste, IMC trolleybuses considerably **reduce the required amount of raw material and electronic waste.**

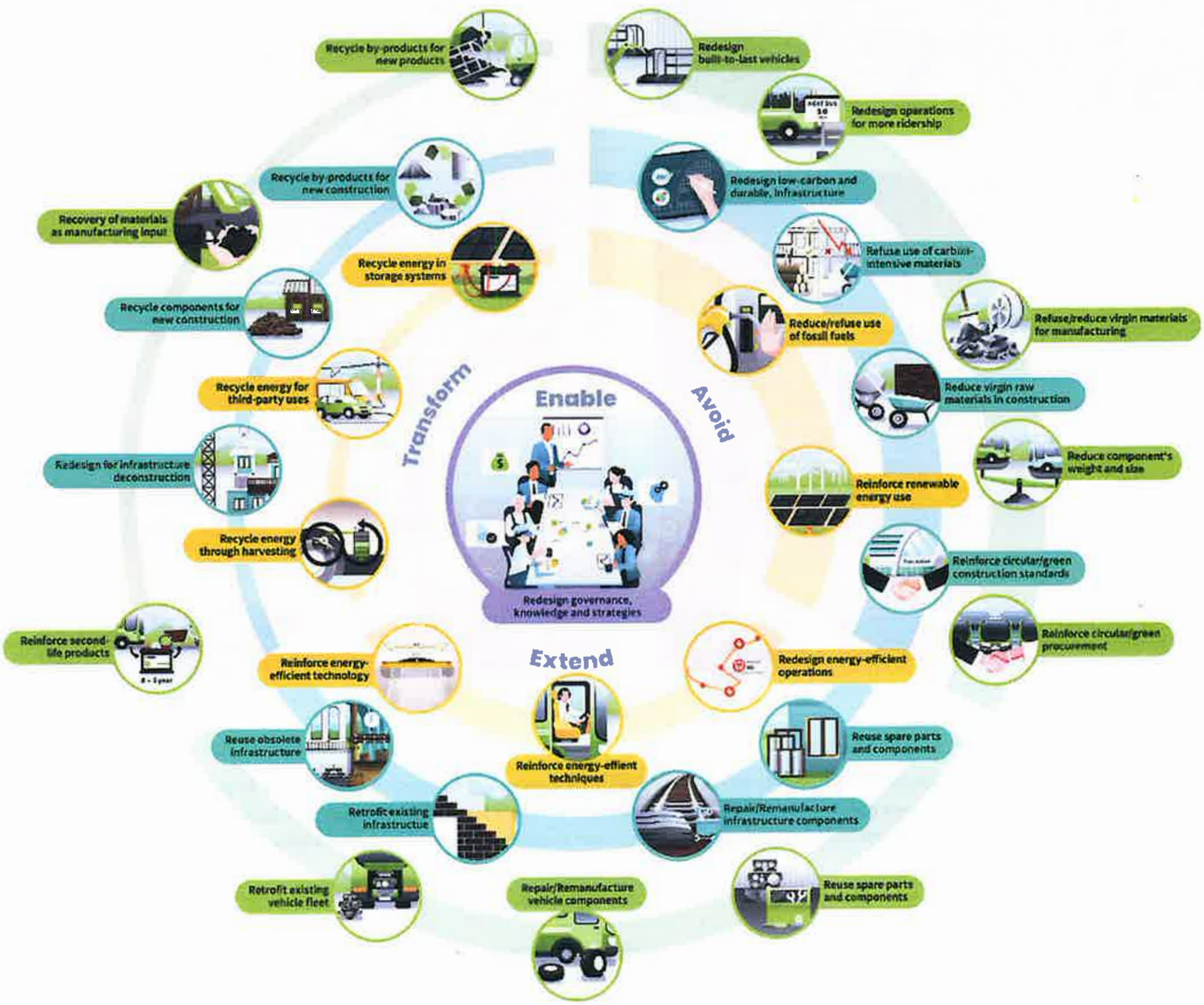


In motion charging trolleybus (Tallinn)

The CE4CE project, currently being implemented within and co-funded by Interreg CENTRAL EUROPE Programme, is focused on reducing the ecological footprint of public transport through adoption of circular economy system thinking in the public transport sector in Central Europe. The specific aim of the project is to limit waste and create value along new lifecycles of infrastructure, energy, and rolling stock and thus enhance circularity in public transport. CE4CE's partnerships cover the entire value chain and transport sector, with eleven project partners in six Central European countries (Austria, Italy, Germany, Hungary, Poland, and Slovenia), ranging from public transport authorities/operators to industry and research to interest groups. To facilitate the circular economy transition, these partners are using co-creation and peer reviews to jointly develop concrete, innovative, and state-of-the-art solutions, represented by the project's six pilots.



In motion charging trolleybus (Tallinn)



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In motion charging trolleybus (Cagliari)

RECOMMENDATIONS

IMC trolleybuses offer a highly efficient and effective solution for urban public transport, particularly when combined with existing trolleybus or light rail infrastructure and other e-bus technologies. They provide continuous service, reduce the need for extensive new infrastructure, and offer environmental benefits through reduced emissions and resource reuse. Their successful implementation in several cities highlights the potential for broader adoption of this technology.

POLICY RECOMMENDATIONS

- **Upgrade existing trolleybus systems:** Cities with existing trolleybus networks should consider keeping them and plan the needed updates to implement IMC technology to enhance efficiency and reduce costs.
- **Integrate IMC trolleybuses with eBRT systems:** Combining IMC trolleybuses with demanding routes such as eBRT routes can further optimise public transport operations, with infrastructure investment enabling high-capacity and continuous service.
- **Promote pilot projects:** Encourage pilot projects in cities drafting their fleet decarbonisation plans to evaluate the benefits of IMC technology in real-world conditions.
- **Fleet decarbonisation studies:** IMC trolleybus technology should be considered, along with other zero-emission technologies, in all fleet decarbonisation studies. Such studies must take into consideration all local constraints and specificities to objectively identify the optimal solution in technical, economic, and sustainability-related terms.
- **Urban design and infrastructure:** The design of the poles supporting the trolleybus infrastructure can be integrated into the urban landscape. If needed, an architecture competition for a city-specific design can reveal attractive ideas and improve community acceptance of the project.

IMC trolleybus systems support cities in advancing in their decarbonisation goals by contributing to zero-emission, energy-efficient, and reliable public transport.

This is an official Policy Brief of UITP, the International Association of Public Transport. UITP represents the interests of key players in the public transport sector. Its membership includes transport authorities, operators, both private and public, in all modes of collective passenger transport, and the industry. UITP addresses the economic, technical, organisation and management aspects of passenger transport, as well as the development of policy for mobility and public transport worldwide.

This Policy Brief was prepared by Trolleybus Committee. The working group included the following members: Charles Drane, Luigi Di Stasio, Grigori Parfjonov, and Marta Woronowicz.