From Santiago to Shenzhen

HOW ELECTRIC BUSES ARE MOVING CITIES

EXECUTIVE SUMMARY

ITDP
Institute for Transportation & Development Policy

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COVER PHOTO
A man with a disability entering an electric bus.
SOURCE:
94FM, Brazil.

LIST OF ACRONYMS

BEB	Battery electric bus
BRT	Bus rapid transit
BYD	Build Your Dreams (Chinese BEB company)
CO	Carbon oxide
CO_2	Carbon dioxide
CNG	Compressed natural gas
EV	Electric vehicle
FAME	Faster Adoption and Manufacturing of Hybrid and Electric Vehicles
GHG	Greenhouse gas
HVIP	Hybrid and Zero-Emission Bus and Truck Voucher Incentive Project (California, U.S.)
ICE	Internal combustion engine
ITDP	Institute for Transportation & Development Policy
kWh	Kilowatt hours
LFP	Lithium iron phosphate (battery type)
Li-S	Lithium sulfur (battery type)
LMP	Lithium metal polymer (battery type)
LTO	Lithium titanite (battery type)
N_2	Nitrogen (dinitrogen)
N_2O	Nitrous oxide
NEV	New energy vehicle
NO_x	Nitrous oxide
NMC	Lithium nickel manganese cobalt oxide (battery type)
LNG	Liquified natural gas
PEV	Private electric vehicle
PM	Particulate matter
TtW	Tank-to-Wheel
SOC	State of charge
SO_2	Sulfur dioxide
TCO	Total cost of ownership
VKT	Vehicle kilometers travelled
VOC	Volatile organic compounds
WtT	Well-to-Tank
WtW	Well-to-Wheel
ZeEUS	Zero-emission urban bus system


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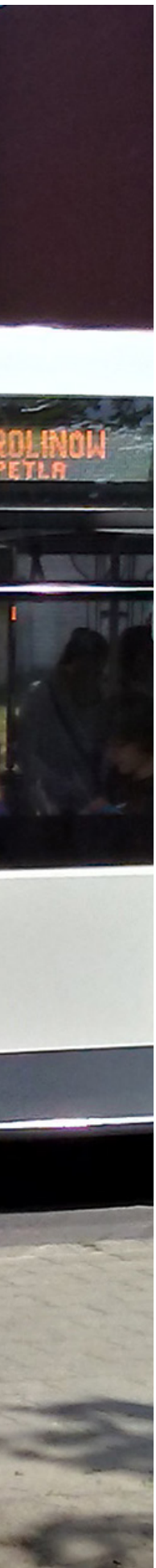
EXECUTIVE SUMMARY

Cities must significantly curb emissions and resource consumption in the next few years to prevent irreparable damage from climate change. Electrifying public transportation is imperative to achieving climate goals in the next decade and beyond. In particular, cities must electrify buses, as more people around the world depend on buses than any other mode of public transportation. As technology continues to scale and become more affordable, battery electric buses (BEBs) provide a timely solution for cities looking to significantly reduce their environmental impact. By electrifying public fleets, cities improve air quality, decrease noise pollution, reduce resource usage, lower GHG emissions, and reduce human-induced climate change, and they can improve bus service and increase community health. In light of the COVID-19 pandemic, it is clear that cities must invest in more resilient urban systems that reduce environmental and health impacts while facilitating healthy social interaction.

WHAT ARE BATTERY ELECTRIC BUSES AND WHY DO THEY MATTER?

Battery electric buses are fully electric buses with battery-powered, electric motor systems. While they are still a relatively new technology, particularly outside of China, a number of cities from Shenzhen (China) to Santiago (Chile) have already successfully grown the number of BEBs in their bus fleets. As technology and operations improve, the battery range and the total cost of ownership (TCO, the total cost of owning, operating, and maintaining the vehicle over its lifetime) of BEBs are increasingly competitive with diesel, hybrid, and compressed natural gas (CNG) buses.



OPPOSITE PAGE
Two cyclists safely bike alongside a hybrid electric bus in Poland.
SOURCE: WrS.tm.pl, Flickr.

A woman exits an e-bus in Medellin, Colombia. As in many cities, successful adoption of e-buses in Medellin was a multi-stakeholder process, including C40 (pictured on the bus).
SOURCE: Secretaría de Movilidad de Medellín, Flickr.

BEBs have enormous potential to improve urban transportation systems in a sustainable and equitable way. Successful public bus systems increase access to destinations, activities, goods, and services, and do so in a way that is **safe** and **equitable**, minimizes **environmental** harm, uses resources **efficiently**, and mitigates negative **health** impacts. Using this framework, we can evaluate the potential benefits of battery electric buses as opposed to diesel, hybrid, and CNG buses:

Environment. BEBs can reduce GHG emissions through more efficient energy use and replacing existing bus fleets.

Health and Safety. Battery electric buses decrease local air pollution and noise pollution, improving air quality and quality of life for all urban citizens.

Efficiency. BEBs use less energy than internal combustion engine (ICE) buses. BEBs with optimal conditions may reduce total cost of ownership in comparison to diesel and other bus types, thereby increasing financial efficiency.

Equity. Depending on route placement, BEBs can improve air quality and noise pollution in areas of higher bus frequency and population density—where air quality may be worse due to increased vehicle pollution. Often, vulnerable or disadvantaged communities are located in areas of cities with lower air quality.

Electric buses represent a growing segment of the electric vehicle market worldwide. BEBs are growing in popularity and scale due to several developments, including:

Longer distance ranges as battery technology and practices for driving, charging, and maintenance practices improve,

Falling purchase costs as the industry achieves economies of scale,

More informed decision-making with the increase of data and best practices for e-buses,

Improving understanding of how to use BEB technologies as more cities conduct pilots in geographically and economically diverse contexts, and

More financing opportunities through supportive grants and innovative financing schemes.

An e-bus in Vienna, Austria.
SOURCE:
Sandor Samkuti, Flickr.

AS MORE CITIES ADOPT BATTERY ELECTRIC BUSES, WHAT SHOULD THEY CONSIDER?

Planning for battery electric buses requires considering each of the following aspects: **existing technology, charging, pilots, contracts, financing, operations, maintenance,** and **supportive strategies.**

This publication provides an overview of each from an initial planning perspective. Creating a plan to adopt BEBs must also consider the relationship between all of these variables—BEB planning is a highly iterative process, and decisions for each variable below affect the others. It is critical that planning is focused on getting the replacement ratio of BEBs to diesel buses as close to 1:1 as possible: Doing so will save cities money and make systems more efficient. A focus on operations and the relationship between the service plan and charging infrastructure will ensure this happens.

To note the adoption and deployment of battery electric buses continue to change rapidly. Therefore, while the numbers and figures provided are current at the time of this release, the primary focus of this publication is the broader framework in which decision-making should be applied in adopting battery electric buses.

BUS AND BATTERY TECHNOLOGY.

Bus and battery technologies for BEBs are continually evolving, and there are many manufacturers competing globally. The largest BEB companies are based in China (such as BYD and Yutong), but manufacturers in other regions are growing (such as Proterra, New Flyer, and Solaris in North America and Europe). Battery electric buses are often significantly more expensive than other bus types, including diesel and CNG, sometimes costing twice as much as a diesel bus. While the upfront cost of battery electric buses is higher, over the total life-cycle of the vehicle, cities can now expect to recover those expenses. Batteries are the most expensive aspect of BEBs, and there are many battery technologies on the market. Lithium-ion (i.e., li-ion) batteries are the most popular type at present. There are regional preferences, with many manufacturers in China favoring lithium iron phosphate (LFP), while lithium nickel manganese cobalt oxide (NMC) and lithium titanate (LTO) batteries are often favored in North America and Europe. A typical battery life span is up to 12 years, with companies offering warranties ranging from six years (New Flyer) to 12 years (BYD and Proterra). However, it should be noted that few battery models have reached full life cycles, so estimates are often based on modeling. The type of bus and battery model selected for a given city will depend on the charging model chosen.

CHARGING AND INFRASTRUCTURE.

Electric charging is the biggest difference between diesel and battery electric buses. Getting the charging infrastructure right is as important as getting the buses right for electric bus adoption. There are multiple types of charging, including slow and fast plug-in charging (often in depots, generally 1 to 10 hours to reach full charge), overhead pantograph charging (typically on-route, 5 to 20 minutes for sufficient charge or a few hours in-depot), and wireless charging (seamless charging between the battery in the bus and underground charging infrastructure, ranging from 5 minutes to a few hours). Operators and/or other stakeholders that will manage and maintain charging infrastructure must analyze the city's demand, services, and existing grid infrastructure alongside feasible charging system options. Overnight plug-in charging is the most common, but other charging types can offer increased range and reliability (with increased capital costs). Operators need to collaborate with electricity companies to plan charging infrastructure, extend the grid (if necessary), ensure stable charging that does not overuse the grid, and identify ways to reduce charging costs.

PILOTS.

BEBs represent a large shift from traditional nonelectric buses for a variety of factors (fueling/charging, operations, maintenance scheduling, etc.), thus it is necessary to pilot a small number of electric buses and corresponding infrastructure. Pilots are an opportunity to trial buses, batteries, and charging infrastructure for a city's routes and services, enabling decision-makers and operators to collect information from real-world local conditions so they feel more comfortable with adopting a new technology. In addition, pilots are an opportunity to train personnel and collect data to improve operations and maintenance for fleets. While pilots should try to trial as much as possible to understand all opportunities and considerations, a pilot alone will not see all the benefits and considerations (particularly long-term ones) that cities will have once they adopt full BEB fleets. It is a step in the right direction, though, and will greatly improve the full transition, particularly when data is collected and used to improve planning and operations.

Passengers unload from an electric bus in Shenzhen, China.
SOURCE: Wahsaw, CC0, Wikimedia Commons.

CONTRACTS

Adoption of electric buses depends on the flexibility of existing contracts. If contracts are rigid and do not allow for the adoption of new technologies, this will make electrification under the existing contract challenging. Contracts for electric buses must ensure adequate performance of buses, batteries, and infrastructure. Financing and contracts are closely tied for public bus fleets in general, and as electric buses have a much higher capital cost than other buses, new financing schemes for them must be considered. Given the variability of e-bus performance, contracts must tie promised battery/bus lifetimes and performance to financing. In addition, contracts should include charging infrastructure and depot requirements, align with environmental legislation, establish frameworks for monitoring and evaluating operations for service quality and environmental impact, establish personnel training, and outline penalties for not meeting requirements. Electric bus operations and financing may have new stakeholders including utility companies and financing stakeholders, which must be taken into account in contracts.

FINANCING

Electric buses are more expensive than diesel, CNG, LNG, and hybrid buses, and sometimes double the initial cost. However, the total cost of ownership of battery electric buses is increasingly competitive with diesel, CNG, LNG, and hybrid buses. Capital costs and TCO competitiveness of electric buses varies significantly by region: For example, studies have found BEB TCO in Santiago, São Paulo, and Mexico City is competitive with diesel and CNG buses, while in Buenos Aires, TCO for BEBs is still more expensive. While the initial cost of the buses may be double that of diesel buses, the operations and maintenance over the vehicle lifetime offset these high investments. Supportive funding such as grants along with innovative financing schemes like battery leasing, financial leasing, and utility investment/ownership are popular means of spreading out electric bus costs across the vehicle lifetime. Financial incentives such as operational grants, land grants, preferential pricing for electricity, duty tax breaks, value-added tax reductions, and reduced tax on corporate profit can lower BEB costs.

OPERATIONS AND MAINTENANCE

Efficient operations along with charging are the key to getting the replacement ratio of electric to diesel buses as close to 1:1 as possible. Likewise, the cost efficiency of BEBs (often represented through the TCO) is dependent on achieving as close to a 1:1 replacement ratio as possible. Optimizing operations and ensuring adequate maintenance enable significant operations and maintenance savings annually with BEBs. This is due to the lower cost of fueling (charging) the vehicles and the propulsion system, which requires fewer parts and less maintenance than ICE buses. Route and operations planning must ensure sufficient battery charge for services and plan for new refueling (i.e., charging) requirements. Operations and maintenance planning should have personnel training specifically for BEBs to ensure the safety of operators, the longevity of the equipment, and the financial efficiency of the system.

ROUTE AND INFRASTRUCTURE PLANNING

Implementing charging infrastructure intelligently is imperative to the success of the system, as charging infrastructure is immobile and expensive. Planning stakeholders need to consider multiple stages of electrification when planning and modeling to enable the transition of full fleets to electric. As the transition will happen over many years, operators and maintenance personnel must plan to attend to a diverse fleet composition during the transition. Planning and modeling route infrastructure will depend on the BEB charging type selected and what is feasible given geographic constraints. The three main charging infrastructure types (traditional plug-in, pantograph charging, and wireless charging) all require different kinds of infrastructure and land area. Traditionally, bus routes are developed based on multiple factors, including: trip origin and destination needs of the public, ridership, urban expansion, and future demand. Route planning for BEBs should additionally center on route optimization—ensuring that all buses have sufficient charge to complete route services and return to depots or charging stations. Considering battery limitations, operators may adjust routes for optimal battery performance, operations, and system reliability. Cost efficiency is dependent on achieving as close to a 1:1 replacement ratio of fuel-based buses with electric buses, which is directly tied to optimized operation routes and scheduling.

SUPPORTIVE STRATEGIES

Electric buses can significantly reduce emissions and resource use, but they are even more powerful when combined with other strategies. These include: enacting policy to encourage adoption of zero-emission transportation, reducing traffic, transitioning to renewable energy production (i.e., greening the grid), integrating BEB planning with land use planning and improvements, and integrating bus services with other public transportation modes to create a sustainable transportation network.

A woman exits a bus station. **SOURCE:** ITDP, China.

SUMMARY OF RECOMMENDATIONS: WHAT SHOULD CITIES DO TO ENABLE THE ADOPTION OF BATTERY ELECTRIC BUSES IN THEIR PUBLIC TRANSPORTATION SYSTEM?

Informed decision-making (i.e., data- and best-practice driven), pilot testing, feasible financing, contracts that ensure performance, and sufficient operations and maintenance to elongate battery life are essential for enabling battery electric buses to reach as close to a 1:1 replacement ratio with diesel buses as possible. The key actions for success below summarize the report's findings for necessary steps for BEB adoption:

PROJECT GOAL	KEY ACTIONS FOR SUCCESS
Adequate battery range, bus type, and charging models for the urban area and existing grid	Survey available commercial technologies and infrastructure Assess charging options with existing utility providers on opportunities and constraints of BEBs Identify how travel demand, urban topography, and climate will affect bus battery life Conduct a pilot representative of local opportunities and challenges; collect data to improve procurement and operations; and adjust fleet planning based on the pilot
Well-designed infrastructure	Understand local geographic advantages and considerations Model charging infrastructure locations Use pilots to ensure sufficient land area and grid connections Outline depot and infrastructure requirements in contracts Involve different stakeholders in the infrastructure planning
Well-designed routes and services	Model bus routes and services. Check and compare operational data from cities that have similar conditions (fleet size, topography, climate, traffic conditions) Collect and monitor operational data. Inform decisions based on the data If services are to be changed, use participatory planning to improve routes and build community Add charging times to route schedules Adjust routes to improve BEB charging connectivity (if needed)

Supportive operations and maintenance	Include BEB-specific maintenance training requirements in contracts Set performance standards in contracts Assess different ownership and responsibility structures (detailed in contracts and financing) to choose the one that will lead to the best division of responsibilities for different stakeholder capacities Train operators and maintenance staff for battery electric buses specifically Practice operations and maintenance according to manufacturer guidelines
Supportive policy and strategies	Create new and/or update existing policy to incentivize zero-emission vehicle adoption as well as electric charging infrastructure and corresponding grid connections Align contracts with environmental legislation, incentivize emissions reduction and zero-emission technology adoption Align policy with the city's environmental and health agendas Use supportive strategies (reduce traffic, green the grid, engage and educate the community, integrate BEB planning with land use planning and improvement, integrate bus service with other modes) to create a sustainable transport network
Adequate funding and a viable financing scheme	Utilize local, state, and national funding resources and financial incentives Consider innovative financing schemes, such as battery-leasing, financial-leasing, and green loans/bonds. Consider new stakeholders for financing schemes, such as utility (energy) companies or investment companies Partner with utilities to extend grid, reduce charging costs, and install infrastructure for the least cost
Clear communication and adequate support from stakeholders	Build internal capacity through data collection and workshops Build external support by engaging the community and making electrification project information/data available to the public and civil society Meet with the utility early in the planning process Be clear with the challenges that governments will face and establish clear expectations from the public and private sectors

ELECTRIC BUSES ARE MOVING CITIES

Are you ready?

Design your pathway toward bus electrification

1 PLANNING

- Pilot routes to maximize battery charge and create a plan for full fleet transition
- Separate ownership and operations contracts to encourage competition and service quality, and align contracts with environmental legislation
- Establish contracts that require and/or incentivize new technology adoption

2 FINANCING

- Plan financing based on a total cost of ownership (TCO) model
- Consider innovative financing schemes such as battery leasing, and new financing stakeholders such as utility companies
- Leverage local, state, and national funding resources and financial incentives, such as fuel tax reform and EV subsidies

3 OPERATING

- Monitor performance of BEBs with local travel demand, right-of-way, topography, and climate
- Use participatory planning to improve routes and build community
- Optimize routes for typical BEB range (up to 300 km) and charging locations
- Ensure the electrical needs of the fleet are compatible with the local grid, as well as compatibility of hardware and software with the existing system
- Train staff, operators, and partners on new technology

4 CHARGING

- Standardize system equipment to connect to the grid
- Optimize battery charging through depot storage to accommodate hot/cold weather conditions
- Work with energy companies to optimize charging locations and electricity pricing
- Ensure a stable and sustainable energy source; plan for backup power
- Consider structuring preferential electricity tariffs to reduce costs
- Consider changes in operations that reduce impact on battery power

5 MAINTAINING

- Define maintenance duties of each stakeholder
- Train staff and drivers to maintain the fleet and charging infrastructure
- Consider additional software management requirements compared to traditional fleets
- Define maintenance duties of each stakeholder
- Set up a battery disposal or recycling plan with the manufacturer

6 SUPPORTING

- Use traffic reduction policies and road pricing to encourage transit use
- Set performance and monitoring standards for contracts
- Build support by engaging the community and making electrification project information/data available to the public
- Integrate bus routes with low emissions zones
- Integrate bus system with biking and walking opportunities

LET'S GET READY. VISIT ITDP.ORG TO LEARN MORE

BENEFITS OF GOING ELECTRIC:

- No tailpipe emissions
- Quieter, more comfortable ride
- Less maintenance
- Low operations & maintenance costs

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