From Santiago to Shenzhen

HOW ELECTRIC BUSES ARE MOVING CITIES

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SUPPORTED BY
ITDP would like to thank the Hewlett Foundation for its support of this research.

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JESTEM EKO
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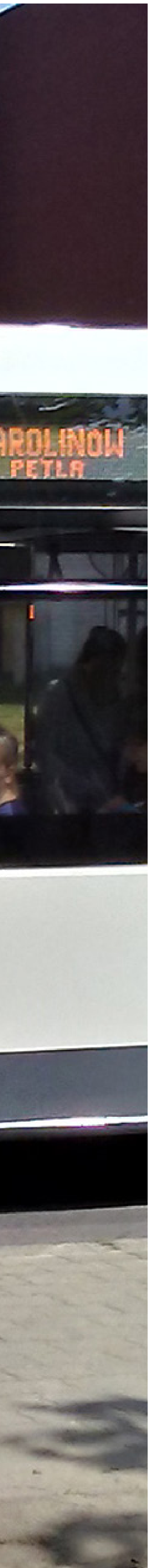
LIST OF ACRONYMS

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



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

ELECTRIC BUSES ARE MOVING CITIES

Are you ready?

Design your pathway toward bus electrification

BENEFITS OF GOING ELECTRIC:
- No tailpipe emissions
- Quieter, more comfortable ride
- Less maintenance
- Low operations & maintenance costs

ITDP

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

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INTRODUCTION

1

Electric buses have enormous potential to improve urban transportation systems. The rapid growth of BEB adoption signals increasing interest in this technology as a means to reduce greenhouse gas emissions and improve urban quality of life. Cities must electrify buses, as more people around the world depend on buses than any other mode of public transportation. Battery electric buses are growing in popularity and scale due to a number of developments, including:

- **Longer distance ranges** as battery technology and practices for driving, charging, and maintenance 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,
- **Increasing 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.

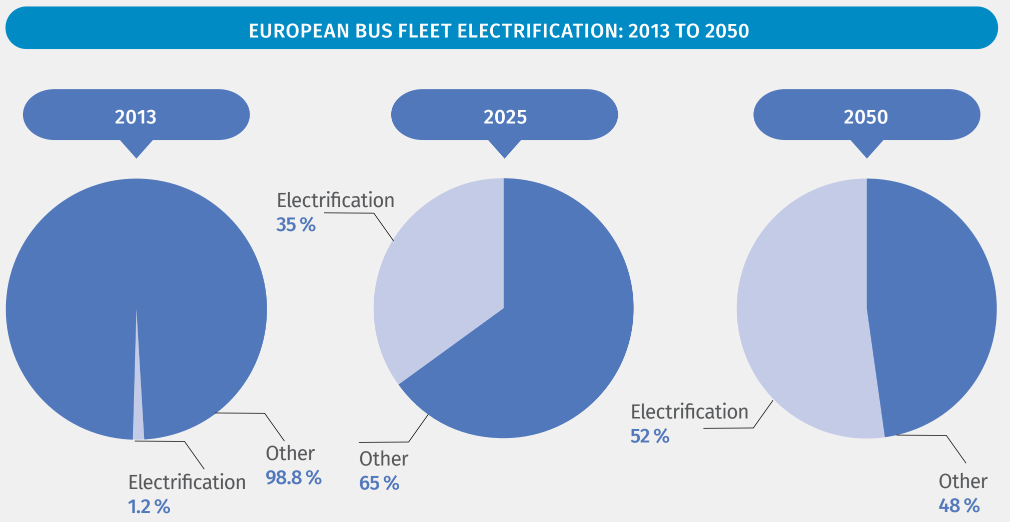
A number of cities, from Shenzhen to Santiago, have already successfully grown the number of BEBs in their bus fleets. Electric buses represent a growing segment of the electric vehicle market worldwide. While BEBs have a growing presence in Europe, Latin America, and North America, highly developed e-bus fleets are mainly contained to China.[7] This landscape is changing rapidly: For example, e-buses represented only 1.2 percent of total bus fleets in Europe in 2013[8], but that number is expected to reach 35 percent by 2025 and 52 percent by 2050.[9] In India, as of April 2020, there were about 400 e-buses, with another 1,650 contracted and paid for.[10] In Latin America, the mayors of many major cities—including Buenos Aires, Mexico City, Rio de Janeiro, and Santiago—have pledged net zero emissions by 2050, while Mexico City and Quito have pledged to procure only electric buses by 2025 and onward.[11] Currently, Santiago has the largest fleet outside of China, while Bogotá just confirmed a contract with BYD to secure 1,002 battery electric buses by 2022 (for more than 1,400 BEBs total), and São Paulo plans to adopt 2,600 e-buses by the end of 2021.[12 13 14]

> **By 2025, 35% of buses in Europe and 39% around the globe will be electric. By 2040, 67% of urban buses globally will be electric.[15 16]**

OPPOSITE PAGE
A woman walks alongside an electric bus and parked dockless bikeshare in Zhengzhou, China. Commons.
SOURCES: Windmemories, CC BY-SA 4.0, Wikimedia

7 Xu et al. 2019. Carbon Asset of Electrification: Valuing the Transition from Fossil Fuel-Powered Buses to Battery Electric Buses in Beijing.
8 UITP. 2016. ZeEUS eBus Report: An Overview of Electric Buses in Europe.
9 UITP. 2017. ZeEUS eBus Report #2: An Updated Overview of Electric Buses in Europe.
10 pManifold, March 2020 (presentation). Shifting the Gears—Towards Electric Buses: Basics of e-Buses—the Relevance and Possibilities.
11 Edwards et al. 2019. Charging Ahead: The Growth of Electric Car and Bus Markets in Latin American Cities.
12 BYD Motors LLC. 2021. BYD Wins Largest Pure-Electric Bus Order Outside of China.
13 Personal communication, ITDP Brazil, March 2021.
14 Sustainable Bus. 2021. BYD in Colombia, the Awarding of a 1,002 units Tender for Transmilenio (Bogotá).
15 International Finance Corporation (IFC, World Bank). 2020. Electric Buses: Why Now?
16 Sustainable Bus. 2020. Electric Bus, Main Fleets, and Projects Around the World.

FIGURE 1
While electric buses accounted for 1.2% of all European bus fleets in 2013, this number is expected to hit 35% by 2025 and 52% by 2050.



Beyond deployment, the geography of production is uneven, with many of the leading bus and battery manufacturers located in China. Yutong and BYD have been the Chinese e-bus manufacturers most successful at manufacturing e-buses for external markets, such as the U.S., Latin America, and Europe.[17 18] In general, there is a trend of regional manufacturing, with the U.S.-based company Proterra and the Canadian-based New Flyer having deployed buses in U.S. cities. This attention on national production is due in part to national policies, such as the "Buy America" requirement in the United States.[19] Similarly, in a 2019 pilot in Jakarta, the city procured buses from Indonesian manufacturer PT Mobil Anak Bangsa as well as BYD.[20] The Dutch company VDL Bus & Coach has delivered e-buses mainly to Dutch and German cities.[21]

As this technology continues to spread and become more affordable, BEBs may provide a timely solution for cities looking to reach social and environmental goals within the next decade and beyond. BEB benefits include reduced greenhouse gas emissions, noise pollution, and air pollution, as well as improved passenger comfort.[22] Cities that signed the C40 Cities Clean Bus Declaration—such as Cape Town, Jakarta, Los Angeles, Rio de Janeiro, and Mexico City—are committed to procuring only zero-emission buses from 2025 onward.[23] Electrification of buses is an important strategy for addressing climate goals in urban areas.

Passengers wait to load for an evening bus ride in Shanghai, China. **SOURCE:** ruich_whx, Flickr.

17 ITDP China. 2020. Research on Roadmap of Phasing Out Traditional Internal Combustion Vehicles in Public Sectors in Chinese Cities.
18 Deng et al. 2019. A Survey on Electric Buses—Energy Storage, Power Management, and Charging Scheduling.
19 Congressional Research Service. 2018. Buy America and the Electric Bus Market.
20 UN Environment Programme. 2019. World's Largest Public Bus System Begins Transition to Electric Vehicles.
21 Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Toward Cleaner Air and Lower CO2.
22 Horrox and Casale (U.S. PIRG). 2019. Cities in North America.
23 C40 Cities, n.d. Fossil Fuel Free Streets Declaration.

Cities - such as Cape Town, Jakarta, Los Angeles, Rio de Janeiro, and Mexico City - are committed to procuring only zero-emission buses from 2025 onward.

While a growing number of cities have deployed BEBs, there are a number of barriers to adoption. Challenges include: political support, high cost, range reliability (i.e., the distance an e-bus can go varies in changing conditions), concern with new technologies, a lack of operational data, new infrastructure partnerships and investments, delays with manufacturing, and vendor support. Many of these challenges are common for new technologies in transportation and will lessen as fleets grow, data becomes more wide reaching, and purchase costs fall.

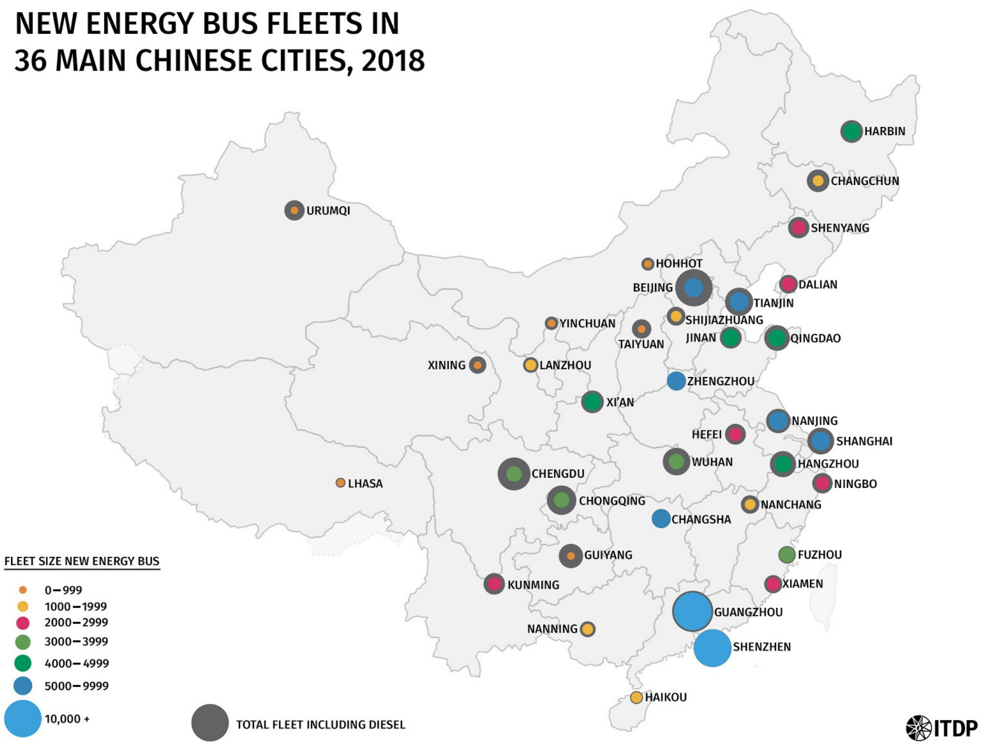


FIGURE 2
China remains the leader in transitioning to new energy buses broadly, which includes BEBs, hydrogen fuel cell, catenary, and hybrid electric buses. For battery electric buses only, in 2015 China had 170,000 BEBs, and the global total was approximately 173,000. In 2018, about 421,000 of the 425,000 electric buses globally were located in China, while Europe had about 2,250 and the United States owned around 300.

1.1
ABOUT THIS PAPER

This report focuses specifically on battery electric buses (BEBs). Other forms of electric buses, such as hybrid electric and electric trolley/catenary buses are not reviewed here. This paper focuses on BEBs, since not a lot is known about this rapidly growing new technology. Few BEBs have gone through a full life cycle, and new best practices are constantly emerging. BEBs are growing fast and now dominate the electric bus market (accounting for more than 75 percent of hybrid, electric, and fuel cell buses in China). Our focus on BEBs specifically stems from this rapid adoption, particularly in the cities in which ITDP works, spanning four continents, as well as the increasing dominance of the technology over other new energy technology types such as hydrogen fuel cell buses. BEB technology and its application is developing all the time, and this guide assesses the current landscape and identifies emerging best practices to serve as a resource for any city thinking about embarking on the transition to BEBs.

This first section examines the benefits of bus electrification impacts as they pertain to sustainable transport around Access, Environment, Equity, Efficiency, and Health and Safety. These benefits are then placed into context to give the reader a broad framing of the importance and issues associated with implementing BEBs. It is then followed by sections for each of the major aspects of transitioning a bus fleet to electric, which include understanding the bus and battery models, contracts for BEBs, pilots, costs and financing schemes, charging infrastructure and practices, operations, maintenance, and supportive strategies. 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.

PUBLICATION MAP

1. INTRODUCTION	
2. BATTERY ELECTRIC BUSES	→ Bus & Battery Models, Opportunities, Considerations
3. CHARGING	→ Infrastructure & Utilities Planning, Charging Types, Best Practices
4. PILOTS	→ Considerations, Best Practices
5. CONTRACTS	→ Stakeholders, Considerations, Best Practices
6. FINANCING	→ Costs, Financing Schemes & Incentives
7. OPERATIONS AND MAINTENANCE	→ Hardware & Software, Routes, Training, Battery Enf-of-life
8. SUPPORTIVE STRATEGIES	→ Networks, Green Grids, Reduced Traffic
9. CONCLUSION	

1.2
METHODOLOGY

ITDP examined and studied nearly 200 documents, including reports, articles, educational materials, background resources, and relevant literature (academic, gray, or peer-reviewed) related to BEBs, public fleet electrification, and electricity (production, infrastructure, and grids). For each topic we reviewed the latest developments from the literature and input from key international experts. In addition, the paper draws on real information about pilots and fleets that include, but are not limited to, projects involving ITDP regional offices, where the research draws on direct expertise from engagement at various stages of BEB implementation.

Passengers converse onboard a bus in Toronto, Canada.
SOURCE: NACTO, Flickr.

1.3
OPPORTUNITIES AND CONSIDERATIONS FOR BATTERY ELECTRIC BUSES

The transition to battery electric buses has significant environmental and social benefits for urban areas, including reduced greenhouse gas and local emissions, noise pollution, and air pollution, as well as improved passenger comfort.[24 25] We analyzed benefits and considerations for BEBs across four categories[26]: Environment, Health and Safety, Efficiency and Equity. Benefits and drawbacks for each goal are discussed in the following paragraphs. We do not include access, which is less impacted by the transition to electric goals than the other sustainable transportation goals.

ENVIRONMENT

Environmental benefits are often the primary motivation for electrifying public fleets, and with good reason. While urban buses represent only 1 percent of road vehicles globally, they make approximately 1.5 billion trips daily and are responsible for one quarter of black carbon emissions from road transportation.[27 28] Lifetime emissions for buses (sometimes referred to as well-to-wheel emissions, or WtW) can be broken down into well-to-tank (WtW) and tank-to-wheel (TtW) emissions. The former represents emissions created in the manufacturing of buses and fuel or energy to power them, while the latter represents emissions from the operation of the buses themselves. Figure 3 below demonstrates WtW emissions for diesel versus electric buses. The majority of BEB emissions are from their manufacture and the production of energy to power them, whereas diesel and CNG buses have emissions throughout the WtW process and use energy less efficiently. As such, BEBs reduce emissions through more efficient use of energy (thus they need less energy to be produced in the well-to-tank (WtW) stage) and negligible tank-to-wheel (TtW) emissions.

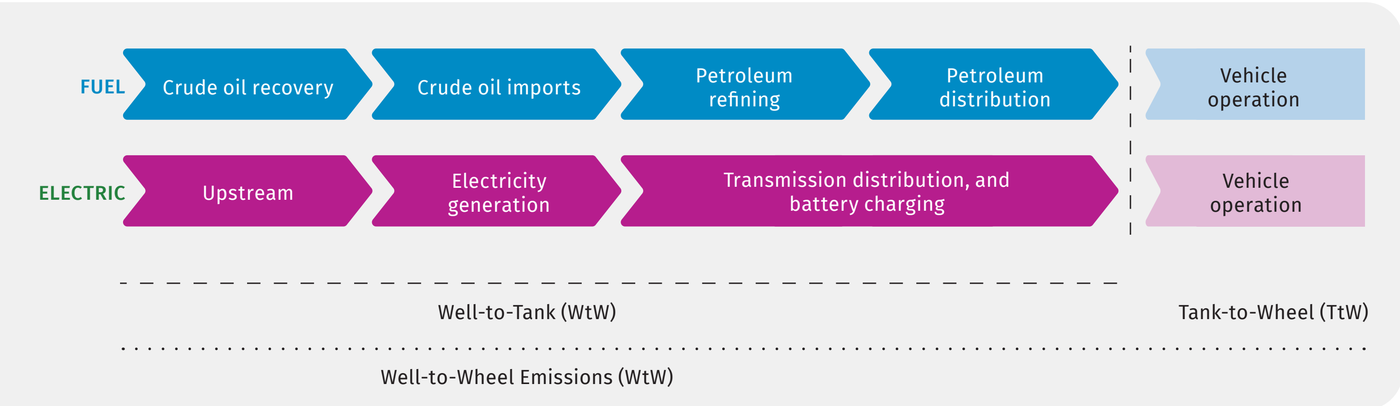


FIGURE 3 ABOVE
A breakdown of well-to-wheel emissions for fuel- vs. electric-based vehicles.
SOURCE:
Adapted from Jwa & Lim, 2017. Comparative Life Cycle Assessment of Lithium-ion Battery Electric Bus and Diesel Bus From Well to Wheel.

The potential scale of emissions mitigation with electrification is immense compared to business-as-usual diesel operations, particularly where electric grids are powered by renewable sources. Over a 12-year lifetime, using an electric bus instead of a diesel bus can save 1,690 tons of carbon and 10 tons of nitrogen oxides in operational emissions.[29 30] On average, over a vehicle lifetime battery electric vehicles in the U.S. emit 33 percent less GHG emissions, 93 percent less carbon monoxide, and 32 percent less black carbon than internal combustion engine vehicles.[31] These numbers vary widely based on local electricity generation and climate context.

24 Horrox and Casale (U.S. PIRG). 2019. Cities in North America.
25 Nordelof et al. 2019. Life Cycle Assessment of City Buses Powered by Electricity, Hydrogen Vegetable Oil, or Diesel.
26 Based on the sustainable transportation system goals outlined in High Volume Transport Programme. 2020. State of Knowledge Final Report on Urban Transport. Access was not included, as there is limited evidence showing that electrification of buses would increase urban access.
27 Three revolutions in urban transportation: How to achieve the full potential of vehicle electrification, automation, and shared mobility in urban transportation systems around the world by 2050. Unpublished data. 2017.
28 Miller et al. (ICCT). 2017. Financing the Transition to Soot-free Urban Bus Fleets in 20 Megacities.
29 While there are various methods to measure GHG emissions, we have found that the well-to-wheel (WtW) method is most apt as it breaks down emissions into two discrete stages: The first is well-to-tank (WtW), which looks at emissions from the production to distribution of fuel; the second is tank-to-wheel (TtW), which measures the emissions produced during operation.
30 Sierra Club, n.d. Zero Emission Bus Overview.
31 Congressional Research Service. 2020. Environmental Effects of Battery Electric and Internal Combustion Engine Vehicles.

Progress toward significant emission reductions is on its way. C40 estimates that when the 26 signatory cities of the Clean Bus Declaration replace 75 percent of their diesel fleets with electric vehicles, this will correspond to reducing 2.35 million tons of greenhouse gas emissions per year.[32] In the U.S., replacement of all diesel-power transit buses with electric-powered buses could reduce greenhouse gas emissions by 2 million tons per year.[33] In Latin America, replacing annual bus transit procurement with BEBs could save over 5.7 million tons of CO2 emissions and 124,000 tons of nitrogen oxides each year.[34] The table below highlights emissions savings data from European e-bus pilots.

FIGURE 4
Data adapted from the ZeEUS electric bus pilots by UITP in select cities in Europe.[35] Some pilots had data for a set period, not inclusive of the entire pilot. For example, in Bonn, Germany, the pilot time span ran from April 2016 to March 2018, while the data collected is from March 2016 to December 2017.

City, Country	Pilot Data Time Span*	Number of Buses	Kilometers Traveled	CO_2 Emissions Avoided (kg^2)	Emissions Avoided per 1,000 km Traveled (kg^2/1,000 km)
Bonn, Germany	March 2016–Dec. 2017	6	246,674	99,809	404.62
Barcelona, Spain	August 2014–August 2017	2	163,260	89,441	547.84
Eindhoven, Netherlands	December 2016–January 2018	43	3,417,331	1,167,054	341.51
Münster, Germany	November 2016–August 2017	5	118,012	49,047	415.61
Pilsen, Czechia	May 2015–April 2017	2	46,980	6,149	130.89

While converting to electric buses decreases greenhouse gas emissions, the amount of that reduction depends on local electrical grid resources and capacity. In particular, life cycle assessments for electric buses that trace emissions from well-to-wheel show increased greenhouse emission reduction with cleaner electricity sources.[36 37] If electrical grids are powered with nonrenewables that yield excessive emissions, hybrid electric or even diesel buses may outcompete battery electric buses.[38 39] As such, while there are clear benefits to electric vehicles, it is imperative that electricity grids also become greener, particularly where grids are coal-powered. This varies by geography. In Johannesburg, South Africa, modeling for battery electric buses showed reduced emissions with BEBs compared to the diesel buses in use even with the existing majority-coal-powered grid.[40] However, this modeling also showed Euro VI CNG and Euro VI hybrid crude oil buses similarly reducing emissions. Also, in many cities in China where electricity grids are in part powered by nonrenewables, studies have found environmental benefits and emissions savings when electrifying bus fleets.[41] BEBs reduce GHG emissions by 30 percent to 40 percent, even when the grid is unchanged.[42]

32 C40 Cities. 2015. C40 Cities Clean Bus Declaration.
33 Horrox and Casale (U.S. PIRG). 2019. Cities in North America.
34 Abramskiehn & Clark (The Lab). 2018. Pay as You Save for Clean Transport.
35 UITP, n.d. ZeEUS Demonstrations.
36 Cooney et al. 2013. Life Cycle Assessment of Diesel and Electric Public Transportation Buses.
37 Nordelof et al. 2019. Life Cycle Assessment of City Buses Powered By Electricity, Hydrogen Vegetable Oil or Diesel.
38 Nordelof et al. 2019. Life Cycle Assessment of City Buses Powered By Electricity, Hydrogen Vegetable Oil or Diesel.
39 Grauers et al. 2020. Total Cost of Ownership Model and Significant Cost Parameters for the Design of Electric Bus Systems.
40 Posada (ICCT). 2020. Development of a Strategy to Accelerate the Adoption of Soot-Free Buses in Johannesburg, South Africa (presentation).
41 Shen et al. 2014. Current and Future Greenhouse Gas Emissions Associated with Electricity Generation in China: Implications for Electric Vehicles.
42 Asian Development Bank. 2018. Sustainable Transport Solutions: Low-Carbon Buses in the People's Republic of China.

While BEBs reduce emissions and resource consumption, there are environmental considerations. As with other battery technologies, extractive mining is needed for battery manufacturing. EVs still produce air pollution and greenhouse gases from their manufacturing (WtW emissions), particularly of their batteries.[43] Batteries can also negatively impact the environment if they are disposed of improperly, and currently a common process for disposing of or recycling batteries is unclear and emerging. However, as opposed to diesel, CNG, and other fuel-based buses, the majority of emissions for BEBs come from the production and charging of buses rather than the operation of them.[44] Thus, local exposure to humans in the most densely populated urban areas can be reduced. Efforts, including through new policy, are being made to clean up the manufacturing, recycling, and disposal of BEB components.

Road transport significantly and dangerously adds to air pollution in cities globally. **Source:** Max Chen, Flickr.

43 Cooney et al. 2013. Life Cycle Assessment of Diesel and Electric Public Transportation Buses.
44 Nordelof et al. 2019. Life Cycle Assessment of City Buses Powered by Electricity, Hydrogen Vegetable Oil, or Diesel

SPECIAL ATTENTION TO THE FUTURE: MINING & EXTRACTIVES

An essential consideration in the implementation of BEBs is the source and method of production of battery materials, as well as their disposal. Just as oil and gas are extractive industries with significant upstream impacts, battery-powered buses will have upstream impacts as well. In light of growing environmental degradation and increasing awareness of environmental justice, cities should consider the upstream effects of battery production of electric buses.

The development of electric vehicles, especially BEBs, is enhanced by rapid improvements in battery technology. Before the wide adoption of rechargeable lithium batteries in the 1990s, batteries typically lost charge quickly and had recharging complications. Li-ion batteries allow for longer battery life and faster charging, and they have been applied to a wide range of new technologies. Production of li-ion batteries is expected to triple by 2025, as is the extractive mining to produce them.[45] The instability of the supply chain, including key minerals from low- and middle-income countries, poses a risk for workers' safety and an uneven sociopolitical burden for lower-income states, the local environment, and in the production of EVs. This has global environmental and sociopolitical ramifications, with rising political tensions between countries racing to hit environmental goals. Mineral extraction for battery production impacts the planet's geological landscape, and is happening at an increasing pace. While lithium can be extracted from hard rock, the vast majority (87%) is extracted using brine.[46] It is a labor-intensive, long process (extending 18 months) that requires large amounts of water and adversely affects nearby soil and water sources.[47] The majority is from the "lithium triangle"—Chile, Argentina, and Bolivia—which accounts for 75 percent of lithium produced.[48] Chile's Salar de Atacama has the highest brine concentration at almost 30 percent of the world's known lithium resources and accounted for 65 percent of the world lithium market in 2009.[49] In the United States, new momentum to mine lithium in Nevada (and multiple other states) has drawn resistance from Native American tribe members, environmental advocacy groups, and local agriculture workers who are protesting the use of enormous amounts of water for mining in an environment that is losing water levels annually.[50]

The mining of cobalt, a key component in lithium-ion batteries, has drawn international attention for concerns over workers' safety and treatment. The Democratic Republic of Congo is the source of over two-thirds of global cobalt production, and it faces criticism for reportedly using child labor and inadequate mining tools to remove the mineral. With both lithium and cobalt, there are environmental justice and equity concerns with the undue burden that middle- and lower-income countries—and particularly the poorer populations within them that experience the most direct health, economic, and environmental burdens—are forced into. This will become an even greater equity concern if attention is not paid to improving extraction methods as li-ion battery production increases. Rising concerns around the environmental, sociopolitical, and health impacts of the extraction and production of lithium batteries are leading to a rise in momentum to diversify methods. Several companies are developing alternative processes, with a particular focus on reuse. One example is "urban mining," or recycling used lithium-ion batteries to source new batteries.[51]

Cities should consider the upstream effects when implementing service or identify strategies to improve battery sourcing. The current options for minerals like lithium and cobalt have serious safety, environmental, and health impacts that may negate positive outcomes from BEBs if not properly sourced and managed.

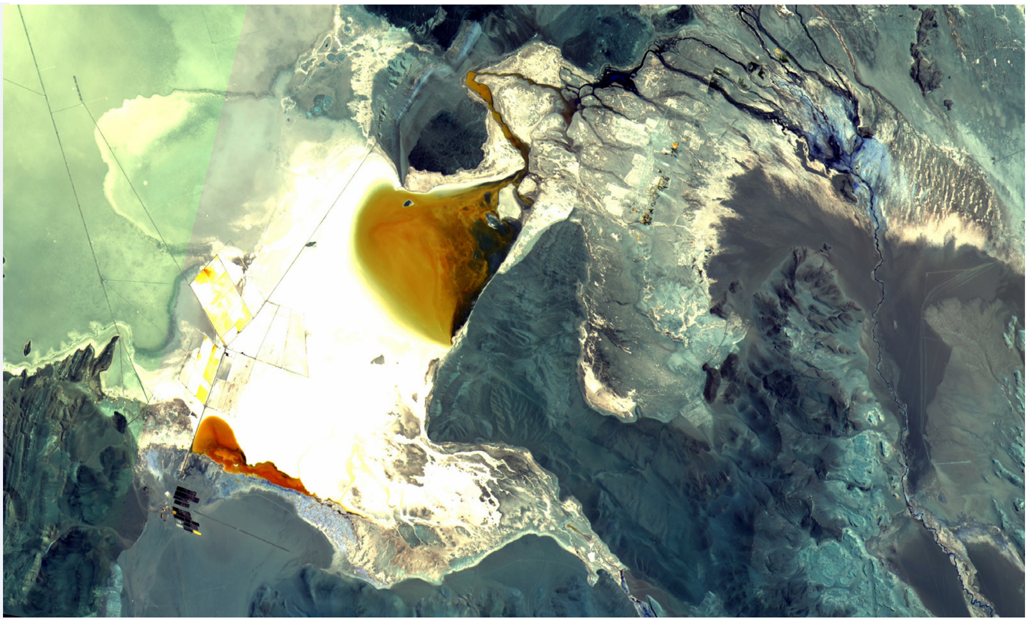
45 International Finance Corporation (IFC, World Bank). 2020. Electric Buses: Why Now?
46 Congressional Research Service. 2020. Environmental Effects of Battery Electric and Internal Combustion Engine Vehicles (R46420)
47 Institute for Energy Research (IER). 2019. The Environmental Impact of Lithium Batteries.
48 Congressional Research Service. 2020. Environmental Effects of Battery Electric and Internal Combustion Engine Vehicles (R46420)
49 Agusdinata et al. 2018. Socio-Environmental Impacts of Lithium Mineral Extraction: Towards a Research Agenda.
50 Penn and Lipton (NYT). 2021. The Lithium Gold Rush: Inside the Race to Power Electric Vehicles.
51 Shieber & Crichton (Tech Crunch). 2021. DuPont and VC's See Lithium Mining as a Critical Investment for the Electric Future

Electrifying transportation has a greater impact where electric grids are powered by renewable energy. Pictured, a wind turbine farm in Tunisia. **SOURCE:** World Bank Photo Collection, Flickr.

HEALTH AND SAFETY

Improving air quality is of utmost importance for safety and health around the world. The World Health Organization (WHO) estimates that outdoor air pollution is responsible for 4 million premature deaths each year and, 98 percent of children in low- and middle-income countries are exposed to particulate matter above WHO guidelines.[52 53] About 2.3 billion people in the Asia-Pacific region alone face air pollution levels several times those in the WHO's safe air guidelines.[54] Cities with millions of inhabitants that are located in valleys—such as Los Angeles, Mexico City, and Santiago—can have smog trapped for extended periods of time, which poses serious health threats. Reducing internal combustion engine (ICE) vehicle emissions has clear environmental and health benefits, and it must happen now.

> About 2.3 **billion people** in the Asia-Pacific region alone face air pollution levels **several times** those in the WHO's safe air guidelines.



An aerial image of lithium mining in Salar de Hombre Muerto, Argentina, a part of the lithium triangle. **SOURCE:** Flickr, Coordenação-Geral de Observação de Terra.

52 World Health Organization (WHO), n.d. Air Pollution.
53 Clean Air Fund. 2020. The State of Global Air Quality Funding 2020.
54 Climate & Clean Air Coalition, n.d. Air Pollution Measures for Asia and the Pacific.

Communities that electrify bus fleets significantly improve air quality and community health/comfort with cleaner air, lower noise pollution, and smaller benefits, such as higher passenger comfort from lower vibrations.[55] By removing ICE buses, cities reduce diesel exhaust emissions, particulate pollution, and ground-level ozone.[56] Electrification of bus fleets also helps prevent environmentally exacerbated respiratory illnesses such as asthma in children and adults.[57] **Diesel exhaust contains more than 40 pollutants that can cause and exacerbate respiratory and cardiovascular illnesses, including cancer.**[58] Lower socioeconomic and minority neighborhoods are often more exposed to dangerous air quality.[59] This results in **disproportionately high rates of respiratory illnesses such as asthma in less advantaged lower-income groups.**[60] In addition, babies and children are particularly vulnerable to pollutants, impacting the ability of youth to learn and grow.[61] **Poor air quality significantly affects the cognitive and mental development of babies and children, as they breathe more air per kilogram of body weight.**[62] As such, improving air quality in urban areas is particularly important for the most vulnerable and marginalized.

Noise pollution can negatively impact human health by causing loss of sleep, irritation, and negative cardiovascular and psychophysiological effects.[63] It is particularly an issue in urbanized areas, where heavy vehicles such as trucks and buses operate frequently. At low speeds, the majority of noise from buses is produced from engines, while at high speeds, noise is mainly produced from tire movement.[64] BEBs can reduce vehicle noise, particularly at low speeds in areas of high bus traffic and at bus stops.[65] Improving air and noise quality in cities through electrification is critical for cities to reach environmental justice and health for all—across all geographies, for all socioeconomic, racial, age, gender, identity, and occupational groups.

Battery electric buses have many positive safety and health benefits, with few drawbacks. However, it is important to consider safety training for operators and maintenance workers to avoid hazards with charging infrastructure. In addition, if unaddressed, quieter buses can result in increased risk for pedestrians and cyclists who may not hear e-buses approaching. Appropriate signage and visibility of buses is therefore necessary for electric vehicles. Artificial sounds may also act as a way to signal BEB presence.

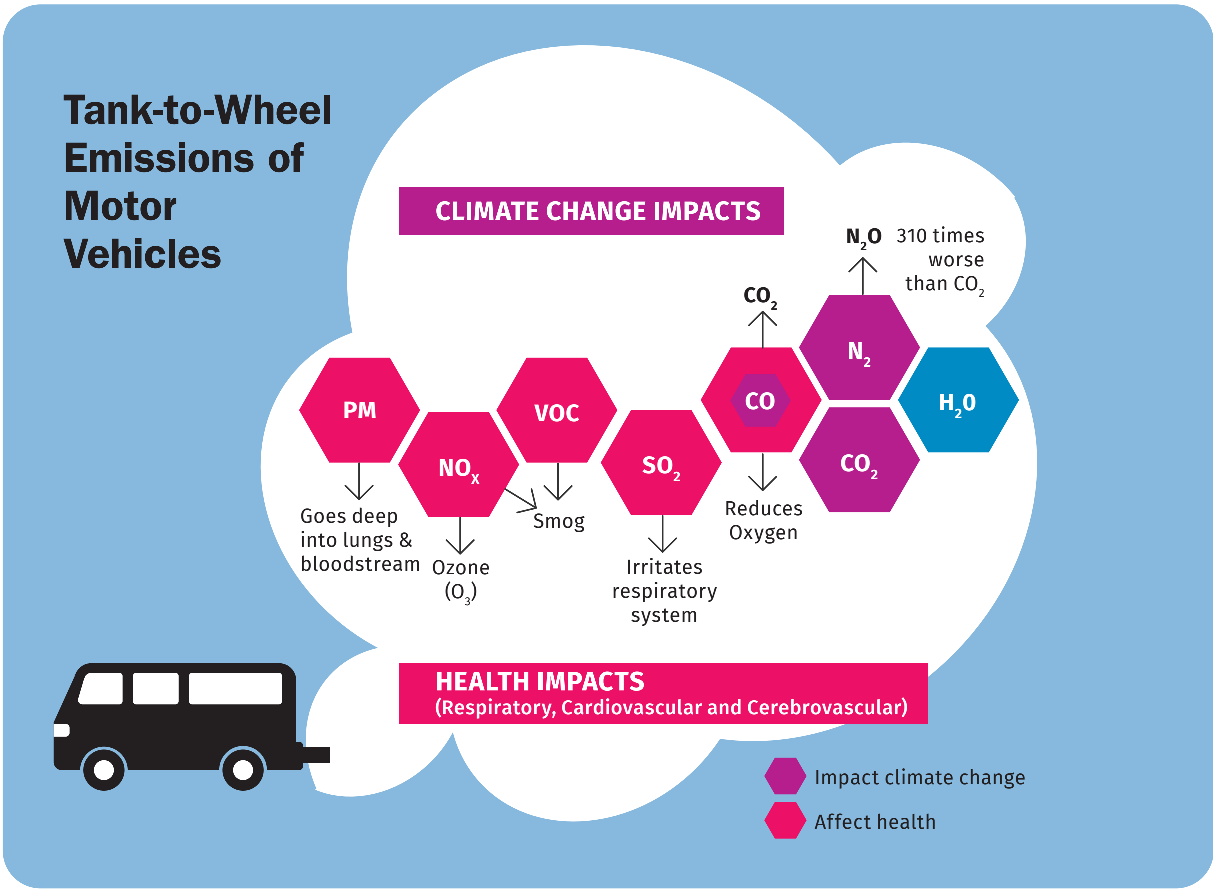
Pedestrians walk along a safe, wide footpath near a bus stop. **SOURCE:** ITDP India.

55 Varga et al. 2016. Electric and Hybrid Buses for Urban Transport: Energy Efficiency Strategies.
56 Horrox and Casale (U.S. PIRG). 2019. Cities in North America.
57 Miller et al. 2018. Electric Buses: Clean Transportation for Healthier Neighborhoods and Cleaner Air.
58 Occupational Safety and Health Administration (OSHA). 2013. Diesel Exhaust/Diesel Particulate Matter. In Sierra Club, n.d. Zero Emission Bus Overview.
59 Sierra Club, n.d. Zero Emission Bus Overview.
60 Landrigan et al. 2010. Environmental Justice and the Health of Children.
61 World Health Organization (WHO). 2018. Air Pollution and Child Health: Prescribing Clean Air.
62 Bernard van Leer Foundation. 2019. An Urban95 Starter Kit— Ideas for Action.
63 World Health Organization Europe, n.d. Noise.
64 Volvo Buses. 2019. How Electric Buses Can Address Noise Pollution.
65 Laib et al. 2018. Modelling Noise Reductions Using Electric Buses in Urban Traffic: A Case Study from Stuttgart, Germany.

Smog resting over Mexico City, Mexico. Electrifying transportation means reducing air pollution and lessening deadly effects of smog. **SOURCE:** Ilai A. Magun, Flickr.

Localized air pollution poses serious risks for human health including respiratory and cardiovascular diseases. **SOURCE:** FIA Foundation (ITDP Africa library), Flickr.

RIGHT
FIGURE 5
Bus transportation emissions affecting climate change and human health. It is important to note for particulate matter (PM) that the major contributor to combustion PM is buses, while the major contributors to abrasion PM are cars and motorcycles. Combustion PMs have significantly smaller particles than the abrasion PMs, which makes them even more harmful to the health.[66 67]



66 Congressional Research Service. 2020, Environmental Effects of Battery Electric and Internal Combustion Engine Vehicles (R46420).
6Z Adheesh et al. 2016. Air Pollution and Economics: Diesel Bus vs Electric Bus.

EFFICIENCY

Battery electric buses can improve resource and financial efficiency. Shifting from fuel-based to electricity-based vehicles is important for reducing nonrenewable resource consumption, particularly when electricity is powered from clean sources. In addition, energy resources can be used much more efficiently with battery electric bus operations, as BEBs use less energy per kilometer than diesel (when comparing energy and fuel equivalents).[68] One feasibility study for Monterrey (Mexico) found that for 50 kWh (the energy equivalent to 5 liters of diesel or 4.5 liters of gas), a battery electric bus can travel 30 km while a diesel bus can travel 12 km and a CNG can travel 8 km.[69] Energy savings with BEBs are from the more efficient transfer of energy into motion for electric motors as opposed to combustion engines, which lose a greater amount of energy to heat.

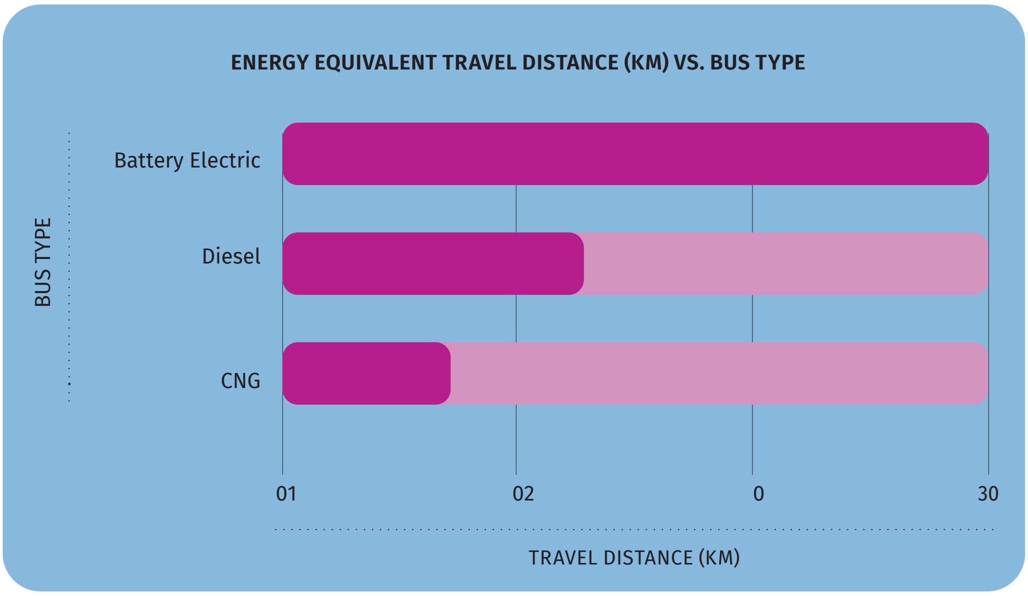


FIGURE 6
Battery electric buses can travel farther than diesel and CNG buses for an equivalent amount of energy (50 kwh), fuel (5 liters of diesel), and gas (4.5 liters of gas).

This also translates into financial efficiencies for operations between BEBs and diesel buses—transitioning to BEBs often significantly reduces maintenance and fuel costs.[70] While the cost of buying BEBs can be double that of diesel buses, BEB energy consumption costs are about half that of fuel buses per kilometer traveled. This is due in part to cheaper refueling (where energy prices are lower than fuel) and more efficient conversion of energy to motion. Maintenance costs of BEBs are significantly lower than those of diesel buses, as the electric propulsion system does not require the same maintenance or amount of replacement parts as a combustion engine does. While e-bus and/or battery warranty lengths vary, it is increasingly commonplace to have them. These warranties help to ensure financial competitiveness of BEBs with diesel and CNG buses.

While BEBs can reduce resource consumption and lifetime costs, there are considerations for charging and economic efficiency. BEBs rely on daily charging for power, which can potentially overdraw an area's electricity grid. Adding grid capacity can be expensive and logistically challenging. In addition, the driving range of bus batteries is not always consistent (depending on temperature, humidity, etc.), and the life spans of BEB batteries are still highly variable. This makes it challenging to accurately predict energy and cost savings from BEBs. When ranges are too small, the costs can jump dramatically if multiple buses are needed to operate when a single bus is anticipated. However, technologies and best practices are continually improving BEB efficiency.

68 Deliali et al. 2020. Transitioning to Zero-Emission Bus Fleets: State of Practice of Implementations in the United States.
69 ITDP México & Ulises Navarro Hernandez, personal communication, March 2021.
70 Horrox and Casale (U.S. PIRG). 2019. Cities in North America.

TOTAL COST OF OWNERSHIP

The total cost of ownership (TCO) is the lifetime costs of vehicle procurement, infrastructure, operations (including charging/fueling), maintenance (including regular maintenance, as well as major overhauls that happen during the lifetime), disposal, and financing costs. What is included in TCO may vary—for example, some cities and organizations may include charging infrastructure and/or financing costs, while others do not.[71][72] Charging infrastructure in particular may not be included in TCO, as diesel bus TCO does not include cost of fueling infrastructure. However, given that BEBs often require extending the grid and building charging infrastructure that does not exist prior to BEB adoption, it may be important for cities to include this cost to understand the full lifetime costs (and particularly upfront costs) for adopting BEBs. Battery electric buses are often significantly more expensive than other bus types, including diesel and CNG, and can sometimes be twice the cost of a diesel bus (see Section 6, Funding, Financing, and the Financial Model). While BEBs represent a large upfront investment, they have the potential for a lower TCO than traditional diesel or CNG buses over an average bus lifetime (10 to 15 years).[73] As such, when thinking about a total cost of ownership framework for battery electric buses, cities and operators will need to balance higher upfront capital costs with the lower operating costs through different approaches to financing and contracts. All BEB projects should aim for the TCO to be as close to (or less than) the TCO of a diesel or CNG bus as possible. As BEB models are continually evolving, and since the majority have not yet completed a full life cycle, it is not entirely clear how long life cycles will be, particularly over different battery types and in different conditions.

CATEGORY	ELEMENT	DESCRIPTION
Capital costs *(Bus, battery, and infrastructure purchase)*	Down payment/ equity financing	Initial payment, which may come from existing funds or grants. This does not include funding that needs to be paid back.
	Loan payment(s) /debt financing	Principal and interest payments over the specified loan timeline.
	Resale value	Applicable if the bus life extends beyond the system operations.
Operational costs *(operations and maintenance)*	Fueling/charging	Annual cost of fueling or charging the vehicle.
	Other operations	Annual cost of additional materials that are necessary for operations, such as coolant.
	Bus maintenance	Annual cost of regular bus maintenance.
	Infrastructure maintenance	Annual cost of maintaining charging infrastructure (both on-route and in depots).
	Bus overhaul	Costs of bus and battery overhauls, such as mid-life battery replacement (BEBs) or engine replacement (diesel, hybrid, CNG).
	Bus disposal	If the bus life does not extend past the system operations, this is the cost of vehicle and component disposal.
	Battery disposal	Cost of battery disposal. Batteries are expected to be replaced within the operational lifetime of the bus. If under warranty or under a designated disposal system, manufacturers may be in charge of disposal.

71 International Finance Corporation (IFC, World Bank). 2020. E-Bus Economics: Fuzzy Math?
72 World Bank. 2019. Green Your Bus Ride: Clean Buses in Latin America.
73 These studies are often based on models, as the market is continually evolving and many models have not yet completed full life cycles. Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.

EQUITY

People who are marginalized often have greater exposure to air pollution and bear the negative social and health impacts that accompany this exposure.[74 75 76] Replacing diesel with electric can reduce local noise pollution and improve air quality. Most lower-income communities rely on walking, cycling, or transit for daily mobility: By improving local emissions from transit in these neighborhoods, the environment is improved for all—pedestrians, cyclists, and transit users. Colocating clean routes in these areas means improving air quality and decreasing noise pollution for those communities.

In addition, poorer communities often experience higher rates of traffic injuries and emission-related illnesses/health complications, and prioritizing new safety features and cleaner technologies for bus routes in those areas would help to address those disparities.[77 78] Through this process, cities should seize these opportunities to benefit lower-income communities instead of merely passing on to them the potential increased expense and capital risk associated with improved transit.

There are two likely equity challenges with adopting electric buses that must be addressed and prevented: First, BEB adoption being concentrated in higher-income areas; second, increasing fare costs as a result of more expensive procurement. In both situations this would place an undue burden on the most vulnerable in urban areas, who are the most reliant on public transport for daily mobility, are often underserved by transportation locations, and pay a higher percentage of their income on mobility. To prevent these potential burdens, it is imperative that system planners consider how to best serve all riders, especially the most vulnerable. Fares should not be increased, given that affordability of fare is a prime consideration for many transit users. With the large structural changes that electrification entails, the process provides an opportunity to address existing gaps in public transportation services. For example, locating services in areas that are accessible to populations historically underserved by transit provides an opportunity to create a more equitable public transport network. See Section 7.2, Route Planning, for more information on community-oriented transit planning.

Women generally have different travel patterns than men, often carrying out multiple tasks and therefore taking multiple trips to multiple destinations. Having a diverse group of individuals from the community that represent different income levels, travel patterns, and interests is important for holistic community planning.
SOURCE: ITDP Indonesia.

74 Hajat et al. 2015. Socioeconomic Disparities and Air Pollution Exposure: a Global Review.
75 Landrigan et al. 2017. *The Lancet* Commission on Pollution and Health.
76 Li et al. 2018. Air Pollution and Environmental Injustice: Are the Socially Deprived Exposed to More PM2.5 Pollution in Hong Kong
77 Nantulya & Reich. 2003. Equity Dimensions of Road Traffic Injuries in Low- and Middle-Income Countries.
78 Martinez et al. 2020. Safe Mobility, Socioeconomic Inequalities, and Aging: A 12-Year Multilevel Interrupted Time-Series Analysis of Road Traffic Death Rates in a Latin American Country.

1.4
PERFORMANCE OBJECTIVES, CONSIDERATIONS, AND ACTIONS FOR SUCCESS

Electrifying public bus fleets is a necessary step in achieving sustainable transportation systems that maximize environmental, health, safety, efficiency, and equity benefits. Eight common overarching objectives, with corresponding considerations and solutions, are presented below. They include:

- Adequate battery range, bus type, and charging models for the urban area and existing grid,
- Well-designed infrastructure,
- Well-designed routes and services,
- Supportive operations and maintenance,
- Supportive policy and strategies,
- Adequate funding and a viable financing scheme,
- Significant emissions reduction, and
- Clear communication and adequate support from stakeholders.

PROJECT GOAL	PLANNING CONSIDERATIONS	KEY ACTIONS FOR SUCCESS	MORE INFO
Adequate battery, bus range, and charging models for the urban area	Inflated estimates of battery range Climate, traffic conditions, and topography Supply-chain challenges	Survey the latest technologies (bus, battery, and charging) for procurement. Compare benefits (e.g., improved range) to drawbacks (e.g., higher costs) with existing technologies.	Battery Electric Buses; Contracts; Charging; Pilots; Spotlight on ITDP Brazil
		Identify how travel demand, topography, and climate will affect bus battery life and charging options with utility providers.	
		Pilot feasible bus models for all routes and services (regular, BRT, etc.). Perform under different weather and topographical conditions. Collect data to use for full fleet transition.	
		Tie costs and (bus, battery) life cycle guarantees to bus and battery performance in contracts.	
Well- designed infrastructure	Poorly located infrastructure Limited knowledge of charging BEBs Concern with grid capacity	Collect pilot data to ensure sufficient land area and electrical grid connections for full fleet transition. Understand local geographic advantages and considerations, including land availability for implementing different types of charging infrastructure. Use this information to model infrastructure.	Pilots; Working with Utility Companies; General Infrastructure Planning; Contracts
		Model charging infrastructure locations and types with existing services to see how well existing infrastructure meets the needs of the system or how to adjust the operational plan to refuel.	
		Outline depot and infrastructure requirements in contracts, as well as who will be responsible for (ownership) and paying for upgrades to bus depots and other infrastructure requirements.	
Well- designed routes and services	Poor route planning can lead to underperformance of buses and batteries	Model bus routes and services against charging infrastructure. Adjust charging and services seasonally, as needed (such as elongating charging or charging while heating/cooling the cabin).	Pilots; Operations and Service; Route Planning
		Collect operational data to make decisions that optimize system functioning and community benefits.	
		If services are to be changed, use participatory planning to improve routes and build community buy-in.	
		Add charging times to route schedules. Set a bus battery minimum to return to the depot to recharge.	

Supportive operations and maintenance	Lack of familiarity with EVs Poor battery life due to poor ops and maintenance Supply chain challenges	Include BEB-specific maintenance training requirements in contracts.	Contracts; Spotlight on ITDP Brazil; Operations and Service Planning; Spotlight on ITDP China
		Set performance standards in contracts with manufacturers. Monitor BEBs performance, informed by collected data.	
		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 BEB-specific operations and maintenance (charging, schedules, battery minimums, driving style impact on battery life, etc.). Follow manufacturer guidelines.	
Supportive policy and strategies	Lack of supportive policy for or rigid contracts against adopting electric technologies Policies that encourage ICE travel	Create or update existing policy to incentivize zero-emission technology adoption, such as BEBs. Incentivize adoption of electric charging infrastructure and corresponding grid connections.	ITDP China Case Study; Contracts; Supportive Strategies
		Align policy with the city's environmental and health agendas.	
		Make contracts incentivize updating and adopting zero-emissions technology.	
		Use supportive strategies. Reduce traffic, green the grid, integrate BEB planning with land use planning, and integrate electric bus services into the sustainable transportation network.	
Adequate funding and a viable financing scheme	High capital cost (most frequently cited barrier)[79] High electricity pricing[80]	Utilize government funding resources and financial incentives (grants, subsidies, tax breaks). Consider adopting innovative financing schemes, such as battery-leasing, financial-leasing, and green loans/bonds.	Funding, Financing; Working with Utility Companies; General Infrastructure Planning
		Partner with utilities to extend the grid, reduce charging costs (i.e., charge during nonpeak hours, stagger bus deployment/charging), and install infrastructure for the least cost. Consider models that look at the total cost of ownership for financing as opposed to just the capital asset. Consider separating costs of charging infrastructure from TCO to make it more financially viable.	
Clear communication with and adequate support from stakeholders	Lack of collaboration, communication, and capacity/knowledge	Build internal capacity through data collection and workshops.	Spotlight on ITDP India; Spotlight on ITDP Mexico
		Build external support by making electrification project information available to the public and civil society. Communicate with communities, bring them into the transition process to help them understand the change and benefits to the community, and find out what they need from a transit service if service changes are being made.	
		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 sector.	

79 Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.
80 Gallo. 2016. Electric Truck & Bus Grid Integration, Opportunities, Challenges, & Recommendations.


City Centre
via
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BATTERY ELECTRIC BUSES

2

Battery electric buses (BEBs) are fully electric buses with battery-powered electric propulsion systems. The rapid growth of BEB adoption internationally signals growing interest in this technology as a means to reduce urban emissions and improve urban quality of life. The following sections identify common models for buses and batteries to help understand how variances in bus and battery technology may affect service design and operations. Currently, there are many competing manufacturers offering a variety of bus and battery models. Understanding the range in commercially available technology and how certain models may fit a given system's needs and parameters better than others is a foundational step toward creating transit systems using BEBs.

2.1 COMMON BUS MODELS

Sufficient bus capacity and battery range are fundamental to meeting transit demand and redeveloping service plans with electric buses. A given BEB's passenger capacity and travel range will depend on the bus length and interior design (e.g., sitting versus standing for passengers, placement of wheels and batteries), as well as the weight and energy storage capacity of the battery. Typically, a conventional bus (12 m) with a mix of sitting and standing can fit 60 to 80 passengers and an articulated bus (18 m) with a mix of sitting and standing can fit 120 to 160 passengers. This is generally true for electric buses as well, although maximizing passenger capacity can pose challenges for travel range and battery energy loss. How long a bus can run before it needs to recharge or refuel, also known as range, depends on the battery type and capacity. How long a bus is out of commission because it needs to recharge or refuel is based on the type of charging infrastructure. These are the main factors in deciding what bus is needed to meet the service plan.

The following table provides a brief overview of common BEB manufacturers globally. We include models that are most popular, use emerging technology (such as the LMP battery for Bolloré), or offer high capacity (such as the articulated Solaris bus and the double-decker BYD models) to show the diversity of BEB models available. Articulated models are less common at present, given challenges with higher weight, reduced range, and longer charging times than nonarticulated buses.

Passengers in a Nanning BRT bus station in Nanning, China. **SOURCE:** ITDP China.

OPPOSITE PAGE An electric bus runs through downtown Glasgow, UK. **SOURCE:** Ralf Roletschek, GFDL 1.2, Wikimedia Commons.

COMMON BATTERY ELECTRIC BUSES							
MANUFACTURER	**MODEL**	**LENGTH (M)**	**BATTERY TYPE AND CAPACITY (KWH)**	**COMPATIBLE CHARGING**	**MAXIMUM MANUFACTURER RANGE (KM)***	**PASS. CAPACITY ****	**MOST COMMONLY FOUND IN**
Bolloré	Bluebus	12	LMP	Plug-in depot (PD)	Up to 320	Up to 109	Europe
BYD	K9S	10.6	LFP, 352	PD	Up to 233 to 346	Seats 32	North America, Latin America, Europe, China, Asia
	K9 (multiple versions, see above and below)	12	LFP, 250 to 324 (most often 324)	PD	Up to 250 to 320	Up to 76	
	K9	12	LFP, 500	PD	Up to 255	Up to 61	
	K11 (versions include K11A)	18	LFP, 438	PD	Up to 350	Seats 47 to 55	Latin America
	C8MS (double-decker)	10.6	LFP, 313	PD	Up to 273	Seats 47 to 51	London
	C10MS (double-decker)	13.7	LFP, 446	PD	Up to 370	Seats 77	
New Flyer	XE35	11	Li-ion, 160 to 388	On-route charging (OC), PD	Up to 305	Up to 67	North America, Europe
	XE40	12.5	Li-ion 160 to 466	OC, PD	Up to 360	Up to 82	
	XE60	18.5	Li-ion 267, 320, 466	OC, PD	Up to 215	Up to 125	
Nova Bus	LFSe	12.2	Li-ion, 150	OC	--	Up to 80	North America
	LFSe+		Li-ion, 564	OC, PD	--	Up to 68	
Proterra	ZX5	10.6	Up to 450	PD, OC	Up to 386	Seats 29	North America
	ZX5	12	Up to 675	PD, OC	Up to 529	Seats 40	
Solaris	Urbino 8.9	8.9	LFP/LTO, 160	PD, OC	Up to 200	Up to 50	Europe
	Urbino 12	12	LFP/LTO, 160 to 300		Up to 266	Up to 65	
	Urbino 15	15	LFP/LTO, 470		--	Up to 65 seats	
	Urbino 18	18	LFP/LTO, 550		Up to 185	Up to 120	
VDL Bus & Coach	Multiple Models	10 - 18.75	85-288	PD, OC	--	Up to 60 to 135	Europe
Volvo Bus	7900 Electric	12	LFP, 198, 264, or 330	OC	--	Up to 105	Europe, North America, Latin America, Asia, Australia
Yutong	E-12	12	LFP, 295	PD	Up to 220	Up to 92	China, Europe, North America, Latin America, Australia
Zhong tong	LCK6122E VG	12	LFP, 230	PD	Up to 250	Up to 45 seats	China

81 **Sources:** MJB & A. 2020. Battery Electric Bus and Facilities Analysis, Lowell, 2019. Electric Bus 101: Economics, Politics, Myths, & Facts, Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2, BYD, n.d. The BYD K9: Battery Electric—Zero Emissions., BYD, n.d. The BYD K9S: Battery Electric—Zero Emissions, BYD, n.d. The BYD C8MS: Battery Electric—Zero Emissions, BYD, n.d. The BYD C10MS: Battery Electric—Zero Emissions, BYD, n.d. Bus Electrico K9G, BYD, n.d. Bus Electrico K11A, Sustainable Bus, n.d. More Than 100 Bluebus Electric Buses Ordered in Paris (with LMP batteries), BYD, 2020. BYD Delivers 10 Battery-electric Buses to Link Transit, BYD, n.d. The World's First 40-ft-Long Battery-Electric Bus, BYD, n.d. The BYD K11: Battery Electric—Zero Emissions, New Flyer, 2018. Xcelsior CHARGE XE35 Technical Summary, New Flyer, 2018. Xcelsior CHARGE XE40 Technical Summary, New Flyer, 2018. Xcelsior CHARGE XE60 Technical Summary, Nova Bus, n.d. LFSe, Nova Bus, n.d. LFSe+, Proterra, n.d. Revolutionizing Transit: The Proterra ZX5 Electric Transit Bus, VDL Coach & Bus, n.d., Aiming for Zero. Move Together. Citea. [Download on page], Solaris Bus, 2020. Zero Emission Powertrains: Product Catalogue 2020/2021, Green Car Congress, 2020. Szczytno Orders Two Solaris Urbino 8.9 Electric Buses, Sustainable Bus, 2020. All 90 Solaris Urbino 12 Electric Made It to Berlin, Solaris, 2020. Urbino 15 LE Electric, Sustainable Bus, 2019. Solaris Ready to Unveil a Solaris Urbino 18 Electric with 550 kWh Battery, Inside EVs, 2019. Solaris Introduces Urbino 18 Electric with 553 kWh Battery, Volvo, n.d. Volvo 7900 Electric, Volvo, n.d. Volvo 7900 Electric Data Sheet, Yutong, n.d. E12 Full Electric City Bus, Zhong Tong Bus, n.d. Electric Coach.

RIGHT: A double decker hybrid electric bus drives alongside a cyclist in Oxford, England. **SOURCE:** Martin Addison: Green Transport, CC BY-SA 2.0, Wikimedia Commons.

OPPOSITE PAGE TABLE 1[81] An overview of models for common BEB manufacturers globally.
*Range values were taken from manufacturer estimates, which may be higher than actual range recorded on the ground.
** Not all models offer data for passenger capacities, so some models in the table are marked with the maximum seating capacity (not including standing capacity).

2.2 COMMON BATTERY MODELS

Batteries can represent the most expensive aspect of battery electric buses, can be one of the heaviest components, and are the biggest factor affecting range (along with charging type). For example, a LFP battery can be up to 39 percent of total cost for a BEB, and a battery can represent up to 26 percent of total bus weight.[82] Understanding battery models is important, as battery type and charging type are dependent on each other and have a big impact on operations. This includes variance in travel range, battery capacity, and time needed for recharging. Manufacturers often list battery range as the upper limit of what is possible in ideal conditions, and the reality is that the actual average range of a service run of a bus, be it electric or diesel, will be much lower. Planners must understand this general overestimation so they can accurately plan for operations. In addition, the range and operational hours of electric buses is lower than for diesel. In China, while average operational hours for an electric bus nearly doubled from 4.9 hours in 2017 to 8.6 hours in 2019, having an operational hour limit continues to pose a challenge for urban bus systems.

A typical battery life span is six to 12 years, and companies offer warranties ranging from six years (New Flyer) to 12 years (BYD and Proterra).[83] Buses typically have two to six battery packs wired in them—the location of the battery packs depends on the battery type, battery safety considerations, and the manufacturer.[84] At present, multiple battery types are available, each with advantages and disadvantages. Lithium-ion (i.e., li-ion) batteries, including several variations shown in the table below, are the most popular battery type at present. There are regional preferences for batteries: Many manufacturers in China favor lithium iron phosphate (LFP), while lithium nickel manganese cobalt oxide (NMC) and lithium titanate (LTO) batteries are increasingly favored in North America and Europe.[85] Other non–li-ion battery technologies, including ZEBRA and Li-S, are less popular at present as companies continue to develop the technologies for heavy-vehicle use. Factors to consider include a battery's:

82 Bi et al. 2018. Integrated Life Cycle Assessment and Life Cycle Cost Model for Comparing Plug-in Versus Wireless Charging for an Electric Bus System.
83 Johnson et al. (NREL). 2020. Financial Analysis of Battery Electric Transit Buses.
84 JB & A. 2020. Battery Electric Bus and Facilities Analysis.
85 Carrilero et al. 2018. Redesigning European Public Transport: Impact of New Battery Technologies in the Design of Electric Bus Fleets. Bi et al. 2018.

An electric bus on route near Kyoto University, in Kyoto, Japan
SOURCE: hans-johnson, Flickr.

Weight. Heavier batteries are often less expensive and have better thermal stability (i.e., battery is less likely to be sensitive to and/or malfunction with high or low temperatures), but they will require more energy for heavier operations, while lighter batteries charge faster, have a longer life span, and allow buses to carry more passengers (due to decreased battery weight).[86 87]

Size. Battery size will depend on the type of charging system chosen—plug-in charging requires larger batteries that are often more stable, while on-route charging uses smaller batteries.

Safety. Batteries with longer operating lives may be more hazardous in manufacturing and operations. Hazardous in this case refers to the batteries' potential for leaking hazardous material or their explosive quality when the battery is being created or during operation, such as in the event of a crash. If a battery technology is more likely to be explosive in a collision, it may be necessary to place the battery away from the front or back of the bus (while more stable batteries' placement may be more flexible).[88]

Charging speed. A typical charging cycle can range from 5 minutes to 10 hours, depending on the charging method.

Range capacity. On-route charging can use smaller batteries (up to an optimal range of 200 km–300 km), while plug-in charging will use larger batteries with longer range capacities (up to an optimal range of 500 km).

Ability to charge in extreme temperatures. Different metal compounds have different sensitivities to extreme low and/or high temperatures, which can impact how fast a battery can charge and retain that charge.

Self-discharge. The capacity of a battery to retain a charge diminishes over time and varies across different battery types. Generally, when battery capacity falls below 70 percent to 80 percent it is considered ready for replacement (ideally, batteries will last until bus midlife maintenance, or around six to seven years).

Cost. Battery price will vary, largely based on the battery technology chosen (based on the above factors) as well as on the location of manufacturing and purchase. For example, the average cost of bus batteries in China is about $105 USD/kWh, while North American batteries are likely to average $300 to $500 USD/kWh.[89]

OPPOSITE PAGE
TABLE 2
Battery information from multiple sources.[91] Other battery technologies, such as lead acid (Pb-acid), nickel metal hydride (Ni-MH), lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium nickel cobalt aluminum oxide (NCA), lithium sulfur (Li-S), lithium air (Li-air), and zinc air (Zn-air) are not included in this table due to the popularity of other models. Darker tones represent particular advantages, while the boxes with "—" represent lack of data.

86 Integrated Life Cycle Assessment and Life Cycle Cost Model for Comparing Plug-in Versus Wireless Charging for an Electric Bus System.
87 Deng et al. 2019. A Survey on Electric Buses—Energy Storage, Power Management, and Charging Scheduling.
88 C40 Cities. 2020. How to Shift Your Bus Fleet to Zero Emissions by Procuring Only Electric Buses.
89 Scott (Forbes). 2020. Ever-Cheaper Batteries Bring Cost of Electric Cars Closer to Gas Guzzlers. Bolloré, n.d. Electricity Storage and Systems: Brittany.

The following table summarizes some of the available battery types and their advantages/ disadvantages, as well as companies that use each type. Some battery types may be used for multiple types of charging. Typically manufacturers will offer a few different battery types and sizes (capacities) for different charging methods.

SUMMARY OF BATTERY TYPES

BATTERY TYPE		WEIGHT	SAFETY	CHARGING SPEED	LIFE SPAN	PERFORMANCE	COST	DETAILS	USED BY	USED BY
Lithium- ion	Lithium iron phosphate (LFP, or LiFePO4)	↑	↑	↓	↑	↑	↓	+ Most common battery type	BYD, Volvo, Nova, Yutong, VDL Bus & Coach, Zhongtong, Solaris, Van Hool, Evopro, Bozankaya, Ebusco Proterra, New	BYD, CATL, Solaris, SAFT, Valence, BFFT, Bozankaya, Ebusco
	Lithium nickel manganese cobalt oxide (NMC, or (LiNiMnCoO2)	↓	↓	↑	↑	↑	↑	- Less safe (if a crash occurs, toxic and flammable materials can be produced)	Flyer, VDL Bus & Coach, ADL, Heuliez Bus, DCGT	LG Chem, Akasol, Durapower, Microvast, BMZ, Foresee, Mitsubishi, Solaris
	Lithium titanate (LTO, or Li4Ti5O12)	↑	↑	↑	↑	↑	↑	+ Charges at high kWh rates without reducing life cycle + Lasts 8,000+ more cycles than other li-ion technologies	Proterra, Solaris, Hybricon Bus System, Carrosserie Hess, DCGT	Toshiba, Solaris, Altair-Nano, ABB Group/ TOSA, Microvast
	Lithium metal polymer (LMP)	–	↑	–	–	–	↑	+ Higher operational safety than other li-ion batteries - Less common	Bolloré[90]	BlueSolutions
Sodium nickel chloride, or ZEBRA (NaNiCl)		↑	↓	–	↑	–	↑	+ Longer life cycle due to low self-discharge - Less common	Irizar	FIAMM

90 Bolloré, n.d. Electricity Storage and Systems: Brittany.

91 New Flyer, n.d. Xcelsior CHARGE, Carrilero et al., 2018. Redesigning European Public Transport: Impact of New Battery Technologies in the Design of Electric Bus Fleets, CALSTART, 2010. Energy Storage Compendium: Batteries for Electric and Hybrid Heavy-Duty Vehicles, New Flyer, 2017. Xcelsior CHARGE: Electric Bus Competitive Comparison, Tomaszewska et al., (2019). Lithium-Ion Battery Fast Charging: A Review. ETransportation, 1, 100011, Cano et al., 2018. Batteries and Fuel Cells for Emerging Electric Vehicle Markets., Shahan, 2020. Lithium-Sulfur Batteries to Help Electrify Brazil's Bus Fleets. Miao et al., 2019. Current Li-Ion Battery Technologies in Electric Vehicles and Opportunities for Advancements., Pelican and Yutong, n.d. E12 Electric Bus., Sustainable Bus, 2020. CATL to Equip VDL E-buses With Its LFP Battery (And Reveals a New European Dealer). Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2, Iclodean et al., 2017. Comparison of Different Battery Types for Electric Vehicles., Nair et al., 2019. Lithium Metal Polymer Electrolyte Batteries: Opportunities and Challenges. California Air Resources Board, 2016. Advanced Clean Transit Battery Cost for Heavy-Duty Electric Vehicles (Discussion Draft).


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CHARGING

3

To electrify fleets, getting the charging infrastructure right is as important as getting the buses right. Electric charging is the biggest fundamental change in transitioning fleets from diesel to electric buses. How long a bus can be in service is dependent on battery performance and charging time. BEBs average fewer kilometers per full charge than fully fueled diesel buses, particularly in scenarios where more energy from the battery is needed for challenging climate or topography. Electrifying fleets means that cities are replacing a bus system that used fuel stations to one with infrastructure that has not been built yet or deployed at scale the way diesel has. Charging locations, types of charging, and speed of charging will have major ramifications on a given bus system's operations. While refueling a bus could take 10 to 20 minutes, slow charging may take up to 10 hours (although five to eight hours is the typical upper time limit for plug-in charging).[92] As such, choosing the right mix of charging infrastructure and locations for them will be a critical step in the electrification of public bus fleets. It will also help to lower the replacement ratio if harmonized with the service plan and route design.[93][94] This is critical for cities that want to achieve as close to a 1:1 replacement of electric to diesel buses as possible.

The types of charging infrastructure, number of chargers and stations needed for each type, available space/land for installing charging stations (both in existing depots or along the routes), potential for new depot space, and capacity of the grid should be calculated, with the intent of piloting infrastructure for a full scale-up. Operators should collect data on the hard infrastructure and the system technology (software) in the pilot phase and use this to inform fleet hardware and software moving forward. Evaluating charging types must also be done in the context of the service plan, which delineates how many buses are needed over what routes and with what types of services to meet passenger demand. This evaluation also must consider projections of growth and demand, as most infrastructure generally has a planning horizon of 10 to 20 years at a minimum. Planners must understand what future ridership demand will be to adequately plan for the long-term installation of an electric system.[95]

The final consideration will be cost. The service plan will determine the number of buses to be procured, but the type of charging, the rate of charging, and the location of charging stations will affect how many buses are needed to provide the service. Decision-makers must have an idea of what charging scheme and infrastructure they will use to see how that influences the service plan and vice versa. The mix that is chosen will affect the costs. More expensive, rapid-charging infrastructure may mean fewer buses are required to provide the service. The amount of funding and financing available will influence the types of charging schemes and infrastructure as well as the number of buses that a city can afford. In addition, the limited knowledge and best practices for charging BEBs (as different cities opt for different types of charging) makes it harder to give clear guidance on what works best for different types of systems and conditions, which is a concern for decision-makers.[96] As such, surveying available technologies, understanding how they relates to the service plan, and understanding financing for charging types is critical.

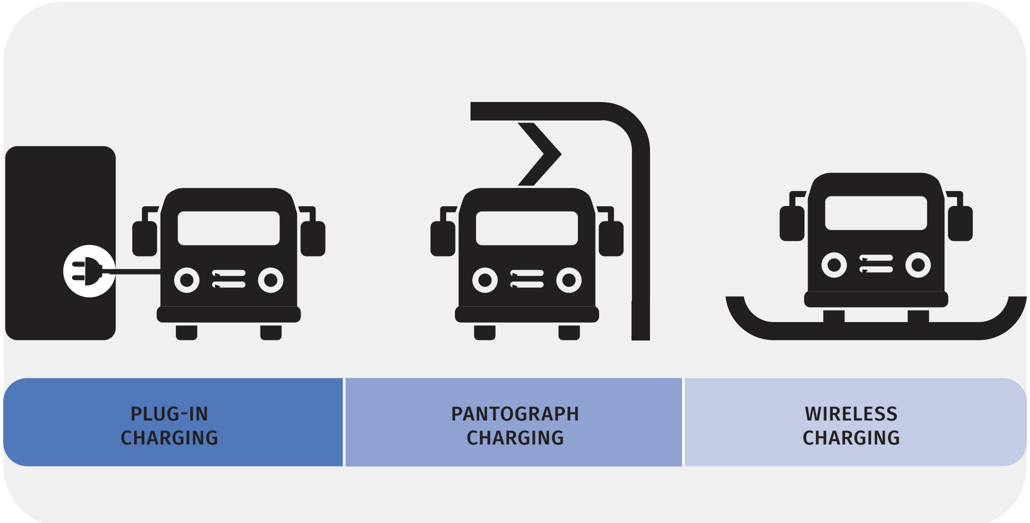
OPPOSITE PAGE
An electric bus and plug-in charger in Shenzhen, China.
SOURCE: ITDP China.

92 UITP. 2017. ZeEUS eBus Report #2: An Updated Overview of Electric Buses in Europe.
93 Eudy et al. (NREL). 2016. Foothill Transit Battery Electric Bus Demonstration Results.
94 Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.
95 Bouslog (Burns McDonnell). 2018. Electrifying the Nation's Mass Transit Bus Fleets.
96 Mohamed et al. 2018. What Hinders Adoption of the Electric Bus in Canadian Transit? Perspectives from Transit Providers.

3.1
TYPES OF CHARGING SYSTEMS

There are three main BEB charging types: traditional plug-in, pantograph charging, and inductive charging. Some types, such as plug-in and on-route pantograph charging, may be combined. Each charging type requires distinct infrastructure and presents different advantages and challenges, particularly in terms of space requirements and the time it takes to charge. Table 2 summarizes different aspects of these charging types. Other charging types, such as flash charging (similar to pantograph, but a few seconds instead of a few minutes) and battery swapping, are not included in this review, as they are not prevalent options at this time.[97]

BATTERY ELECTRIC BUS CHARGING TYPES



TRADITIONAL PLUG-IN CHARGING

Traditional plug-in, also referred to as depot or overnight charging, is the most common charging method globally. In China (the largest bus and charger market), traditional plug-in dominates the electric bus scene.[98] It is the least expensive charging option, with relatively low infrastructure investment costs, and the least intensive on the electric grid and batteries. The most common form of plug-in is overnight charging in the depot with a manual plug, which provides the bus with a range of 200 km to 300 km.[99] The number of chargers needed for a fleet will depend on the charger and battery size, capacities, rates of charging, and charging method, among other factors. Generally, one charger per one to two vehicles is needed for slow charging in depots.[100] However, new technologies are constantly emerging, and large-scale chargers such as the 1.5MW charger by Proterra can charge up to 20 vehicles simultaneously.[101] Decision-makers must work directly with vendors (for equipment availability) and electric utility companies (for electricity availability/limitations) to understand their system's charger-to-vehicle ratio.

Charging speed: Slow. Plug-in charging includes both slow charging, which can take up to 10 hours (although five to eight hours is the typical upper time limit), and fast charging, which can take 10 to 30 minutes but generally takes less than one to two hours. It is most common to have plug-in charging that takes around two to eight hours.[102]

Infrastructure location: Because of the time required to charge the buses, plug-in chargers will likely be at the end of routes or in bus depots, which may be new facilities or existing locations that are retrofitted. Depot construction and retrofitting must consider the extra area needed for electric chargers, which require more space than diesel refueling stations.

97 Flash charging can be highly draining for the electric grid, and battery swapping can be expensive (both for the purchase of the additional batteries and for the personnel to manage swapping).
98 Gohlich et al. 2018. Design of Urban Electric Bus Systems.
99 Gohlich et al. 2018. Design of Urban Electric Bus Systems.
100 Johnson et al. (NREL). 2020. Financial Analysis of Battery Electric Transit Buses.
101 Proterra, n.d. Charging for Electric Vehicles.
102 UITP. 2017. ZeEUS eBus Report #2: An Updated Overview of Electric Buses in Europe.

PANTOGRAPH CHARGING

Pantograph (overhead) charging is more expensive than plug-in charging, but it has a significantly shorter charging time. This enables longer operational distances, as buses can quickly recharge their batteries at these charging stations along their service routes. This type of charging also allows the use of smaller batteries that allow for more passengers. It can be combined with overnight charging to top up bus batteries throughout the day (as seen in Barcelona and Seattle) or be used by itself.[103 104] The chargers can be roof-mounted (where the charging arm is mounted to the bus and the bus connects to the charger) or pole-mounted (where the charging arm is mounted to the charging pole and the pantograph drops down to connect to the bus).[105] Pantograph charging is more common in Europe and North American than in other regions, but it is beginning to grow more popular in China.[106] Generally one charger can be used for eight to 20 vehicles on-route, but this varies.[107 108] The size of battery and the amount of charge needed depends on whether pantograph charging is combined with overnight charging, but often pantograph charging is most financially advantageous for large cities with high kilometers traveled per public bus.[109] The ZeEUS program in Barcelona found pantograph charging the most reliable system for operations, but high costs and delays in infrastructure construction pose significant challenges for adoption.[110] While charging with pantograph infrastructure can yield the greatest electric bus performance and route stability, financial and grid constraints (from high-volume charging within a short period as opposed to low-intensity charging over a longer period with plug-in) may slow adoption.[111]

Charging speed: Fast. While plug-ins may take anywhere from one to 10 hours, fast pantograph charging on-route takes about five to 20 minutes to reach sufficient charge to finish its daily service run before returning to the depot (around 40 percent to 80 percent).[112 113] Pantograph can also be used in-depot, and typically will charge more slowly, taking a few hours to reach full charge.[114]

Infrastructure location: Generally, the charging stations are placed along or near the route (sometimes at the end of routes or where multiple routes overlap), so that buses can be charged throughout the day. Can also be in depots.

A pantograph charging station in Warsaw, Poland. **SOURCE:** Wistula, Wikimedia commons.

103 King County Metro. 2020. Battery-Electric Bus Implementation Report: Interim Base and Beyond.
104 Endesa. 2019. Endesa and TMB Install 2 New Pantographs to Charge Electric Buses in Barcelona.
105 McKinsey & Company. 2018. The European Electric Bus Market Is Charging Ahead, but How Will It Develop?
106 Personal communication, ITDP China, April 2020.
107 Johnson et al. (NREL). 2020. Financial Analysis of Battery Electric Transit Buses.
108 Pelletier et al. 2019. The Electric Bus Fleet Transition Problem.
109 McKinsey & Company 2018. The European Electric Bus Market Is Charing Ahead, but How Will It Develop?
110 UITP. n.d. ZeEUS Demonstrations (Barcelona).
111 Mohamed et al. 2017. Simulation of Electric Buses on a Full Transit Network: Operational Feasibility and Grid Impact Analysis.
112 Endesa. 2019. Endesa and TMB Install 2 New Pantographs to Charge Electric Buses in Barcelona.
113 MJB & A. 2020. Battery Electric Bus and Facilities Analysis.
114 UITP. 2017. ZeEUS eBus Report #2: An Updated Overview of Electric Buses in Europe.

WIRELESS CHARGING

Wireless charging occurs from electromagnetic resonance between contactless coil plates located at the bottom of vehicles and in the roadway.[115] A section of wireless charging can be referred to as a pad and can be placed on-route or in bus depots. These pads could also be used in dedicated lanes or even in mixed-traffic lanes to charge passenger vehicles, taxis, and trucks, although this is less common currently. Benefits of wireless charging include the ability to charge during operation, energy efficiency, limited or no personnel needed to oversee charging, and ability to use lighter batteries. In addition, reducing the bus and battery weight combined with having the ability to continuously charge reduces life cycle energy consumption and emissions.[116] This type of charging requires significant construction along the system's bus routes, with approximately 5 percent to 15 percent of the route consisting of the installed charging infrastructure.[117] The maximum range is theoretically limitless (if inductive chargers are located throughout the routes), but other constraints (limited locations of charging pads) limit the daily range.[118] For example, in Wenatchee, Washington, U.S., on-route charging pads can fully charge an e-bus battery in three to four hours and can top up battery charge throughout the day.[119] As charging infrastructure is embedded in the route pavement, this charging type is the least common and the most expensive. It has been trialed in a few cities in high-income European countries, South Korea, and the United States.

Charging speed: Fast. Similar to pantograph charging, this type can take less than 20 minutes for a top-up or a couple of hours for full charge.

Infrastructure location: Can be on-route, at the end of routes, or in depots. Often the lane with the wireless charging embedded will be separate from traffic, but it can be in a mixed-traffic lane.

LEFT: A Proterra plug-in charging station in Washington, D.C.
SOURCE: BeyondDC, Flickr.

RIGHT: A wireless power charger.
SOURCE: Spsmiler, CC0, Wikimedia Commons.

115 Bi et al. 2018. Integrated Life Cycle Assessment and Life Cycle Cost Model for Comparing Plug-in Versus Wireless Charging for an Electric Bus System.
116 Bi et al. 2018. Integrated Life Cycle Assessment and Life Cycle Cost Model for Comparing Plug-in Versus Wireless Charging for an Electric Bus System.
117 Bak et al. 2018. Strategies for Implementing Public Service Electric Bus Lines by Charging Type in Daegu Metropolitan City, South Korea.
118 Gohlich et al. 2018. Design of Urban Electric Bus Systems.
119 Hill, 3030. Washington E-Buses Get 300kw Wireless Charging System.

For systems with electricity grid constraints, it will be important to consider charging methods that pull from the grid at off-peak times: For example, traditional plug-in with overnight charging can reduce grid impact during peak hours.[120] Additional tactics can be used to manage the grid while supporting electric fleets, such as the Volvo LIGHTS project, which partners utility companies and operators and gives utility operators real-time data to integrate EVs to prevent power outages or other complications from increased charging.[121] This highlights a good practice that planners should adopt, which is **offering accurate route and fleet information to utility partners** so that all necessary stakeholders can predict and prepare for peak fleet charging times (which may or may not align with peak energy demand hours).[122]

Alternatively, systems with grid constraints and ample financial stability may consider pantograph or wireless charging.[123] Local grid operators should be consulted for their knowledge and opinion, as they may have concerns about charging heavy vehicles, especially large fleets and those with fast charging (which drains the grid at a higher rate).[124] Limited knowledge of charging BEBs (as different cities opt for different types of charging) may limit knowledge and best practices available to decision-makers.[125]

TABLE 3[132]
Comparison of electric bus charging cost, type, and common geography. Battery swapping is one additional method, but it is very expensive and uncommon (for example, tested in Qingdao, China).[133] *Pantograph here is only fixed, not continuous

COMPARISON OF ELECTRIC BUS CHARGING TYPES							
CHARGING SYSTEM TYPE	COST LEVEL	CHARGER POWER (KW)	BATTERY SIZE (KWH)	CHARGING SPEED AND TIME[126]	PROS	CONS	COUNTRIES AND REGIONS OF USE
Traditional plug-in	Medium expense	40 to 125 (slow charging) 150 to 500 (fast charging)	300 to 450+ (some models up to 660)	Slow charging, ~ two to 10 hours Fast charging, can be 10 to 30 minutes, generally less than one to two hours	+ Lower infrastructure and electricity costs, thereby lower initial investment + Flexible layout + Fewer requirements for the power grid + Slow charging has least impact on battery life	- Longer time charging - Lower charging efficiency - Scattered infrastructure layout - Fast charging can reduce battery life and require more capacity from the power grid - More area required for infrastructure	China, Latin America, Europe, U.S., New Zealand
Pantograph (overhead)*	High expense	125 to 500 (on-route) Up to 600 (at depots)	60 to - 250+ (can use larger if desired)	Fast charging, five to 20+ minutes	+ Enables longer operation + Smaller batteries + Short charging time + Less area required	- More expensive infrastructure and electricity costs - Fast charging can reduce battery life and require more capacity from the power grid - Less data available for this mode as opposed to slow plug-in charging	China (although less common), South Korea, Europe, U.S., Canada[127]
Wireless	Highest expense	200[128] to 300[129]	60 to 125[130]	Fast, dynamic charging (i.e., infrastructure underground aligns with on-bus charging infrastructure)	+ Enables longer operation + Smaller batteries + Seamless charging	- Most expensive - Requires significant construction, both in terms of area used (all of the route designated for charging) and timing (longest installation timeline) - Less data available for this mode	Europe, South Korea, US[131]

Information on the costs for operations, including charging costs, are included in sections 6.3, Operational Costs, and 6.4, Funding Operational Costs. An overview of operational planning, including charging infrastructure planning, is included in Section 7, Operations and Service Planning. The following section summarizes considerations and best practices for piloting battery electric buses.

120 Mohamed et al. 2017. Simulation of Electric Buses on a Full Transit Network: Operational Feasibility and Grid Impact Analysis.
121 Volvo LIGHTS, n.d. About.
122 Singh. 2020. Alleviating Stress on the Grid with EV Fleet Adoption.
123 Mohamed et al. 2017. Simulation of Electric Buses on a Full Transit Network: Operational Feasibility and Grid Impact Analysis.
124 Singh. 2020. Alleviating Stress on the Grid with EV Fleet Adoption.
125 Mohamed et al. 2018. What Hinders Adoption of the Electric Bus in Canadian Transit? Perspectives from Transit Providers.
126 Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.
127 Vapor Bus International (Mass Transit). 2020. ETS Installs In-Depot Pantographs to Charge Electric Buses.
128 Shepard. 2020. 200-kW Charging System for Electric Transit Buses.
129 Hill, 3030. Washington E-Buses Get 300kw Wireless Charging System.
130 IPT Technology, n.d. Wireless Charging Buses.
131 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.
132 Sources: Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2, Strategies for Implementing E-Bus Lines by Charging Type—Daeku City, South Korea, Financing Hybrid Electric Buses. APTA, 2020. Resiliency for Battery Electric Buses: Best Practices & Future Strategies, Vapor Bus International (Mass Transit). 2020. ETS Installs In-Depot Pantographs to Charge Electric Buses. Carrilero et al., 2018. Redesigning European Public Transport: Impact of New Battery Technologies in the Design of Electric Bus Fleets. Houbaddi et al., 2019. Optimal Scheduling to Manage an Electric Bus Fleet Overnight Charging. Gao et al., 2017. Battery Capacity and Recharging Needs for Electric Buses in City Transit Services, MJB & A, 2020. Battery Electric Bus and Facilities Analysis.
133 Li et al. 2018. Planning of Electric Public Transport System Under Battery Swap Mode.

PILOTS

4

Electric bus pilots are an important first step to public fleet electrification. Pilots enable governments, transit agencies, operators, and other stakeholders to trial potential bus, battery, and charging infrastructure models; practice new operation and maintenance schedules; train personnel; and collect data to plan for a future fleet transition strategy. In doing so, they allow cities to test manufacturer-promised performance versus actual performance of BEB technologies.[134] The small nature of pilots gives the opportunity to master BEB-specific challenges and solutions before adopting full fleets.

Pilot project timelines will range significantly due to a variety of factors, such as prior experience, existing infrastructure, flexible financing, and stakeholder capacity. The California HVIP (Hybrid and Zero-Emission Bus and Truck Voucher Incentive Project) program estimates a deployment timeline as planning for three to 12 months, development (infrastructure upgrades and installation) for six to 48 months, and deployment (integration of BEBs in the transport system) for one to three months, for a range of one to four years from planning to deployment.[135] Timelines will vary, but planners must understand realistic project timelines within their region to provide ample flexibility and attain project success.

The BEB pilot must be on a small enough scale that financial and political risks are reduced and large enough to ensure that data collection may be sufficiently detailed to plan for a future fleet transition.[136] It may be that some routes will continue to be diesel-operated for a period of time. Planners should prepare not only for the pilot and full electrification of the fleet itself but also the time in transition, in which operations must account for a diverse fleet composition.

Considerations and Best Practices. As a trial, the pilot is designed to test routes and services reflective of the local challenges that a city may face as well as the operators' and utility services' capacity for electrification. Pilots should:

BUILD GOVERNMENT AND PUBLIC SUPPORT.
Pilots should be used to build internal support by communicating and/or visiting cities with successful e-bus operations, and strengthen internal capacity through consulting, data collection, and workshops. In addition, they should garner public support by establishing clear communication about e-bus benefits with the public and by making e-bus data publicly available. Cities should use pilots to build evidence of benefits with collected data and then link the findings to the concerns of communities and decision-makers.

EXPLORE THE LATEST TECHNOLOGY FOR PROCUREMENT.
Identify and test feasible (ideally multiple) bus models. Use charging infrastructure that is compatible with multiple manufacturers' bus models. Given the rapidly changing market and available models for buses, batteries, and charging infrastructure, planners must survey new technologies, which may have increased ranges, more reliable charging, and lower costs).[137]

OPPOSITE PAGE
An official pilot of an opportunity charge e-bus in Ontario, Canada.
SOURCE:
York Region, Flickr.

134 Bouslog (Burns McDonnell). 2018. Electrifying the Nation's Mass Transit Bus Fleets.
135 California HVIP, n.d. Infrastructure.
136 C40 Cities. 2020. How to Shift Your Bus Fleet to Zero Emissions by Procuring Only Electric Buses.
137 Singh. 2020. Alleviating Stress on the Grid with EV Fleet Adoption.

SPOTLIGHT ON INDIA: BUILD GOVERNMENT CAPACITY AND PUBLIC SUPPORT FOR BEB ADOPTION

The city of Pune is working with ITDP India to establish data collection standards, assist in expanding its fleet, and prepare technical documents for procurement and operations. In the past, ITDP India assisted with public education campaigns and media awareness for the original transition to electric buses. Lessons learned in India include:

- **VISIT CITIES WITH BEBs TO SEE ON-THE-GROUND ADVANTAGES**
  If possible, take decision-makers to cities where e-buses are in operation so that they can see the positive externalities that come with BEB adoption, such as improved service quality.

- **BUILD INTERNAL CAPACITY THROUGH PILOT DATA COLLECTION AND WORKSHOPS**
  Data should inform decisions. A lack of planning will manifest as system weaknesses, such as inadequate battery range. Capacity-building workshops and other knowledge-sharing events set up long-term internal government capacity.

- **MAKE PILOT AND FULL FLEET INFORMATION PUBLICLY ACCESSIBLE**
  Lack of public knowledge and the spread of misinformation regarding e-buses can significantly hinder BEB adoption. In Pune, a lack of understanding around the gross contract for e-buses led to public pushback. To mitigate this, ITDP helped the transit authority build awareness of electric bus benefits, including comparable TCO to CNG buses, low maintenance costs, and improved service.

An Olectra-BYD electric bus in Pune, India. **SOURCE:** ITDP India

SPOTLIGHT ON INDONESIA: GOVERNMENT SUPPORT, OPTIMAL BUS MODELS, AND DATA COLLECTION FOR SUCCESSFUL ADOPTION

After piloting BYD buses in 2020, ITDP Indonesia is assisting the city of Jakarta in adopting 30 e-buses in 2021. Lessons learned from the planning so far include:

- **STRONG GOVERNMENT SUPPORT IS NECESSARY**
  The push to adopt e-buses in Jakarta is part of a larger push by the Indonesian government to rapidly increase electric vehicle use in the country. Both the Presidential Regulation No. 55/2019 to accelerate electric vehicle adoption and the National Energy General Plan aim to reduce emissions and increase the rate of EV adoption within the next few years. While in 2021 there will be 220 e-buses, the Ministry of Energy and Mineral Resources estimates that Indonesia will have 8,264 e-buses by 2025.[138]

- **SELECT THE RIGHT E-BUS TECHNOLOGY**
  Choosing the appropriate e-bus model and battery technology is a crucial part of the planning process and will affect operational and financial aspects (and success) of the e-bus fleet. Great attention must be paid to available technologies and viable models for a given city's context.

- **COLLECT DATA**
  There is a general lack of reliable data sources and limited evidence of e-bus model performance. As such, it is necessary that pilots collect data and establish a strategy for how to collect fleet data when more buses are adopted.

- **CONSIDER A SENSITIVITY ANALYSIS**
  A sensitivity analysis is recommended for e-bus planning because it can mitigate the uncertainty of future changes in technology. As the e-bus technology market is continually developing at its relatively nascent stage globally, this is of particular relevance. Changes in technology may include a battery's density or range, bus prices, or charging prices, among other factors.

The Transjakarta BRT system in Jakarta, Indonesia is the largest BRT system in the world. Choosing the right e-bus technology will be particularly important for this system that carries over one million people each day. **SOURCE:** ITDP Indonesia, Flickr.

138 Kementerian Energi Dan Sumber Daya Mineral, Republik Indonesia, n.d. Dashboard Percepatan Program KBLBB (Kendaraan Bermotor Listrik Berbasis Baterai).

Operators should consider local travel demand needs, the public transportation system's parameters, different levels of bus infrastructure (e.g., painted or physically separated dedicated lanes), and existing technologies when determining feasible models for buses and charging infrastructure. Pilots should test a bus model's reliability and effective range for the given geographic context. Cities such as Seattle, U.S., and Nanjing, China, tested multiple models to find models compatible with their local requirements.[139 140] When it is not feasible to test multiple models, reach out to other cities to find out how different models have performed. When possible, charging infrastructure should be compatible with multiple bus models and vendors so that cities are not restricted to buying from only one vendor, which may or may not have the appropriate bus models for the city.[141]

TEST WHERE AND WHEN SUPPORTIVE POLICIES ARE FEASIBLE.

When planning and executing the pilot, planning stakeholders should consider where supportive strategies of reducing traffic, greening the grid, integrating BEB planning with land use planning, and integrating electric bus services into the sustainable transportation network are possible. See more in Section VIII, *Supportive Strategies.*

Electrifying BRT can be advantageous, due to the dedicated lane infrastructure and reduced congestion. The Transjakarta BRT system in Jakarta, Indonesia is in the process of electrifying. **SOURCE:** Flickr, ITDP Indonesia.

139 Horrox & Casale. 2019. Electric Buses in America: Lessons From Cities Pioneering Clean Transportation.
140 Gong et al. 2020. Road-Test-Based Electric Bus Selection: A Case Study of the Nanjing Bus Company.
141 C40 Cities. 2020. How to Shift Your Bus Fleet to Zero Emissions by Procuring Only Electric Buses.

Passengers ride in an electric bus in Białystok, Poland. **SOURCE:** Rakoon, CC0, Wikimedia Commons.

SPOTLIGHT ON MEXICO: CLEAR COMMUNICATION AND GREEN ADVOCACY FOR PLANNING PILOTS

The city of Monterrey ,with the support of ITDP Mexico, worked to identify appropriate financing, models, and infrastructure to electrify three bus lines. Lessons learned in Monterrey include:

- **BE CLEAR WITH THE CHALLENGES THAT GOVERNMENTS WILL FACE**
  While e-buses are an excellent opportunity, there will be significant investments (financial, institutional, political). Selling e-bus projects as cost-efficient in the long run is attractive, but the whole image needs to be shared to create a realistic partnership and allow for confident decision-making.

- **ESTABLISH CLEAR EXPECTATIONS FROM THE PUBLIC SECTOR AND DEVELOP REALISTIC TIME FRAMES**
  Understand existing limitations and opportunities for the governments and publicly funded agencies at the beginning of the project (such as for planning capacity, funding, and political support). Develop realistic time frames for each stage of the planning process so that all project planning aspects can be completed approximately at the same time. This can help prevent financial or personnel resources from being misused.

- **ADVOCATE FOR ADOPTING GREEN ENERGY SOURCES FOR THE LOCAL GRID**
  Clearly communicate the benefits and challenges of pursuing greener energy sources at the outset of the project planning. Demonstrating the difference in emissions reduction with different energy grid supply is important for cities to understand before implementing pilots, as the best opportunity for exploring cleaner options is prior to extending the electric grid for charging. While this may be a large undertaking, energy supply is critical to emissions reductions. In addition, cities can consider adding green energy sources at a smaller scale, such as solar panels for powering depots.

TEST ALL ROUTES AND SERVICES OF THE LOCAL BUS SYSTEM, AND DO THIS UNDER DIFFERENT WEATHER AND TOPOGRAPHICAL CONDITIONS.

The pilot is an opportunity to test, monitor, and record successes and considerations for each route in a bus system's daily offerings. Pilots should test different route conditions, such as speeds, rights-of-way, and grades, as well as service conditions, such as layovers between services, passenger loads, and charging schemes. In cities that offer multiple bus services (such as conventional and BRT), operators should test these various routes and services. While electrifying BRT may pose greater battery range challenges (with increased kilometers traveled and quantity of riders), it also offers greater emissions reductions, a higher percentage of electrified vehicle kilometers traveled, and more comfort for more passengers.[142] In addition, BRT systems may have unique opportunities with dedicated infrastructure that normal bus systems do not, such as dedicated depots and lanes, simple service design comparatively, and less congestion than normal bus services. Pilots should test the e-bus performance for different traffic conditions (high congestion, different levels of dedicated bus lanes). A BEB will consume much more electricity with stop-and-go conditions on a congested road. During the pilot, operators should find out how long it takes to charge the electric buses so they can understand how it will affect service planning.[143] All this will help inform a fuller understanding of how the service may need to change, how many buses will be required, and what type of charging infrastructure will be needed to charge those buses to meet the new service plan. Buses in cities that are hillier or have extreme temperatures (hot or cold) will often require more electric charge to travel a set distance. Temperature extremes may drain battery capacity significantly and worsen performance because of two main factors: the energy needed to heat or cool the bus and the leakage from batteries during extreme temperatures (thermal stability or instability). For example, in cities with hot temperatures, such as Shanghai and cities in Brazil, more energy is dedicated to air conditioning, which limits battery range performance since more energy is needed for cooling.[144 145] In Albuquerque, New Mexico, U.S., operators faced challenges with high temperatures that resulted in subpar battery life because of the battery's sensitivity to extreme heat.[146] A pilot should span all seasons a region would experience to test and collect data for all challenges in seasonal adjustments, including heavy rains. During the pilot, operations should find out how long it takes to charge the electric buses in different seasons.[147] If this is not possible, the pilot should be planned or account for the most battery-draining season (whether this be a high or low temperature extreme). Ideally, different topographical conditions are tested through the entire pilot so cities may evaluate how seasonal weather challenges and topography affect fleet performance.

ENSURE SUFFICIENT LAND AREA AND AVAILABLE ELECTRICITY GRID CONNECTIONS FOR NEW INFRASTRUCTURE. MAKE SURE HARDWARE AND SOFTWARE SYSTEMS ARE COMPATIBLE.

Charging infrastructure, available land for conversion to new depots or charging stations along the routes, potential for retrofitting existing depots, and the number of chargers necessary for the pilot phase should be calculated, with the intent of piloting infrastructure for a full scale-up. Operators and utility companies must collaborate to ensure that the charging infrastructure adequately charges the fleet, optimizes charging costs, and does not pose significant challenges to the electric grid. Piloting technology should ensure that the different components of the system (bus software and charging software) talk to each other and also to the scheduling and control (dispatch) software systems that may preexist these new systems. Scalability of the pilot relies on the technology for managing, charging, and dispatching fleets that links the components of the system together, and this must be considered when planning the pilot phase. This is also necessary for data collection and sharing.

142 National Academy of Sciences, Engineering, and Medicine. 2018. Battery Electric Buses State of the Practice.
143 C40 Cities. 2020. How to Shift Your Bus Fleet to Zero Emissions by Procuring Only Electric Buses.
144 Personal communication, ITDP Brazil, April 2020.
145 Li. 2016. Battery-Electric Transit Bus Developments and Operations: A Review.
146 Horrox and Casale (U.S. PIRG). 2019. Cities in North America.
147 C40 Cities. 2020. How to Shift Your Bus Fleet to Zero Emissions by Procuring Only Electric Buses.
148 ZEBRA & P4G. 2020. Accelerating a Market Transition in Latin America: New Business Models for Electric Bus Development.
149 C40 Cities. 2020. How to Shift Your Bus Fleet to Zero Emissions by Procuring Only Electric Buses.

TRAIN AND PREPARE OPERATIONS AND MAINTENANCE STAFF. SUPPORT INNOVATION AND RISK REDUCTION.

Electric buses have different propulsion and “fueling” systems. Pilots must train all personnel to identify context-specific challenges and best practices, as well as prepare personnel to train other staff for fleet transition. Data collected during the pilot phase about best practices should influence operations and maintenance planning as the bus fleet scales. During transitional phases such as pilots and fleet scaling, operators may suffer financial loss during a short period as operations, emergency, and maintenance personnel learn to use and optimize new electric technologies.[148] Helping to mitigate this loss may fall on the public sector, or incentives may be needed to help with the adoption of innovative methods.

MONITOR AND TRACK PERFORMANCE WITH DATA.

Cities should plan pilots so that they can use the data collected to revise future procurement contracts, operations, and maintenance based on pilot outcomes. Data for the existing fleet technology should also be collected so it’s possible to compare conventional bus and electric bus performance. Procuring buses and batteries, whether these are the same or different to the ones in the pilot phase, should be based on the successes and shortcomings found in the piloting. Data collected during the pilot phase will determine whether expected BEB performance compares to what was observed. Necessary adjustments to bus procurement, operations, and maintenance must be done in conjunction with utility companies to ensure that any changes to charging infrastructure can be completed. Operators should collect feedback from drivers and passengers regarding bus performance.[149] Data metrics to collect may include:

- Service data: daily ridership, bus frequency, vehicle occupancy, and operating speed.
- E-bus and battery performance data: power consumption (which will vary across vehicle types and sizes, bus manufacturers, season, topography, and road conditions), daily driving distance, daily operational time, charging time and frequency, and the replacement ratio
- Operational data: battery decay rate, major operational failures
- Cost data: vehicle with battery costs, charging infrastructure installation costs, charging costs, maintenance and replacement costs, personnel costs (all factors that will impact the TCO analysis)
- Environmental benefits: energy savings, greenhouse gas emission and pollutant reduction
- Rider perception data: user perspective on the quality of service and benefits felt

All of this data must be collected and disaggregated according to the manufacturer used, vehicle type, bus size, season, topography, and road conditions (for each route). In the Appendix, a table of recommended data collection elements from ITDP China is provided.

A cyclist rides next to an e-bus in Shanghai, China. Electric buses reduce local air pollution, benefiting local communities and improving immediate air quality for cyclists. **SOURCE:** Flickr, Ludger Heide.

CHINA CASE STUDY: NATIONAL POLICY AS KEY TO WIDESPREAD ELECTRIC UPTAKE

China is the largest producer and user of electric buses in the world.[150] From 2011 to 2017, the proportion of e-buses to total bus sales grew from 0.6% to 22%.[151] From 2013 to 2017, the government subsidized purchases of more than 350,000 BEBs.[152] In 2019, new energy vehicles (NEVs, i.e., electric, hybrid, and fuel cell buses) accounted for 59% of public buses in China, and 75% of these were battery electric buses. ***Policy support has played the most important role in promoting e-bus development since 2009.*** The Chinese government's support has been three-fold: economic support, preferential policies, and compulsory laws and regulations.[153] Key policy stages include:

- **STAGE I (2009–2013): Promoting pilots.**
  2009: Government launches the "Ten Cities and One Thousand Vehicles" project, with each city to launch 1,000 new energy vehicles. Aimed to have NEVs represent 10% of market by 2012.

  2012: Government releases a development plan for the NEV industry. Aims to have the production capacity of NEVs at 2 million vehicles and sales volume over 5 million vehicles by 2020.

- **STAGE II (2013–2018): Promoting pilots, fleets, and improvements.**
  2013: Vehicle procurement by public institutions must be 30% NEVs or higher.

  2013: From 2013 to 2015, the government provides awards to cities for annual procurement of NEVs, ranging from 10 to 120 million yuans (approx. 1.5 to 18 million USD).

  2014: Vehicle procurement from 2014 to 2016 for the central government and pilot cities must be no less than 30% of total vehicles.

  2015: By 2020, there must be 200,000 NEV buses for the public sector. Also, 30% of new or updated buses in the pilot cities must be NEVs, and 35% of those must be in Beijing, Tianjin, and Hebei.

  2015: Government issues an opinion that the priority for NEVs for public transportation, sanitation, and airport transportation should be creating charging infrastructure.

- **STAGE III (2018–2021): Promoting BEBs nationwide (more focus on operations).**
  2018: By the end of 2020, NEVs in urban public transport, taxis, and delivery should reach 600,000, and all buses in municipalities under the central government will be replaced with NEVs.

  2018: Government issues a notice to accelerate the use of new or clean energy vehicles for public transport and other sectors. Proportion of use in key urban areas should reach 80%.

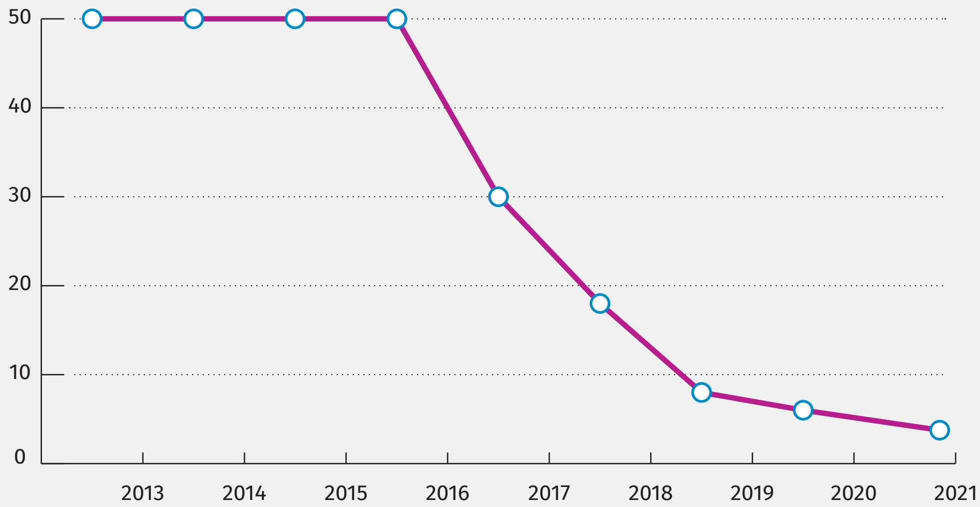
  2019: Local purchase subsidy is generally abolished, with the local government responsible for continued subsidies for new energy buses. The government exempts new energy buses from vehicle purchase tax and travel tax.

  2019: Government issues opinion to promote new and updated postal and express vehicles in urban built-up areas using new energy or clean energy, with key areas to reach 80% by the end of 2020.

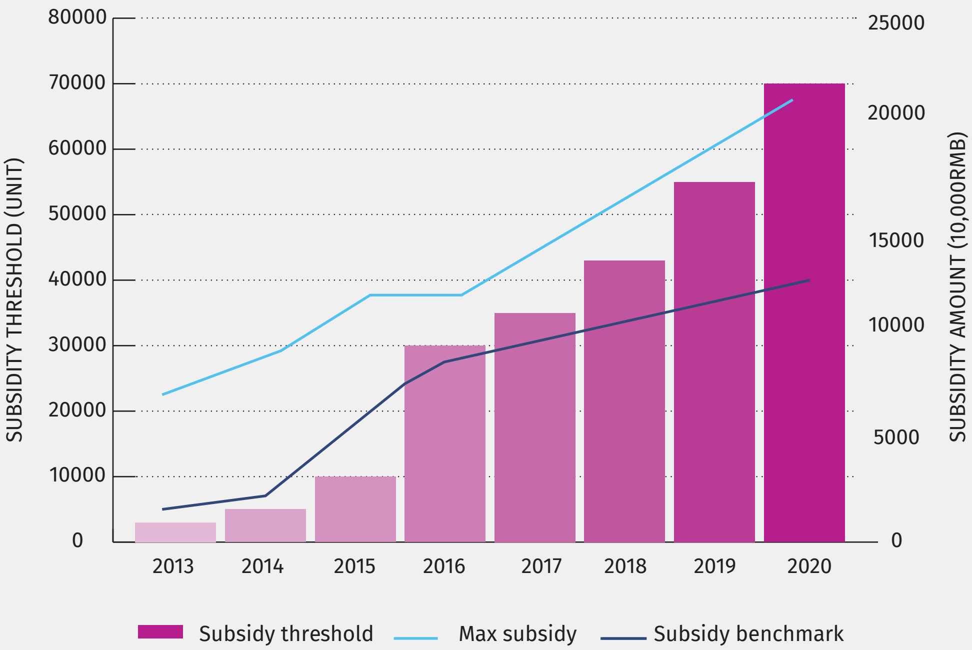
150 ITDP China. 2020. Research on Roadmap of Phasing Out Traditional Internal Combustion Vehicles in Public Sectors in Chinese Cities.
151 Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.
152 Roberts (Vox). 2018. China Made Solar Panels Cheap. Now It's Doing the Same for Electric Buses.
153 ITDP China. 2020. Research on Roadmap of Phasing Out Traditional Internal Combustion Vehicles in Public Sectors in Chinese Cities.

As the government moves away from initial procurement subsidies, it has been increasingly supporting charging and operations through charging infrastructure subsidies (which have steadily increased since 2013) and operational subsidies (since 2016) (represented in the graphs below). This shift toward improving operations is important, as both the operational distance and hours of operation of electric buses are lower than for diesel buses. While BEBs travel an average of 133 km per day, diesel buses are able to travel an average of 208 km. Even in Guangzhou, which has the highest daily average kilometers for BEBs, they are still able to reach only 185 km. These efforts to improve operations are yielding results: While the average operational time of electric buses was only 4.94 hours in 2017, it increased to 8.6 in 2019. Operational range and hours of operation are expected to continually improve as China continues to focus its efforts accordingly.

YEAR 2013-2021 NATIONAL SUBSIDY ON E-BUS PURCHASE (10,000 RMB/VEHICLE) (10m≤L<12m)



NATIONAL SUBSIDY FOR CHARGING INFRASTRUCTURE IN BEIJING-TIANJIN- HEBEI, PEARL RIVER DELTA AND YANGTZE RIVER DELTA



*The subsidy threshold represents the minimum number of buses a city needed to receive the subsidy, and the subsidy benchmark represents the minimum amount a city could receive.


Columbus Av
M86
ONE WAY
CEMUSA
"You dipped the chip, you took a bite... and you dipped again!"
Seinfeld
hulu

CONTRACTS

5

While electric bus contracts will share similarities with traditional public bus contracts, there will be new stakeholders and contract areas (such as charging operations and maintenance) to consider, for both ownership and operations contracts. Overall, the high upfront cost of BEBs requires a shift from purchase cost to a total cost of ownership (TCO) procurement model and new financing schemes.[154] Contracts have typically been structured to combine asset procurement and operations—including financial costs such as debt payments—and are often tied to the time it takes to get a return on investment (ROI) from those assets. Understanding new innovative financing schemes for electric buses—such as battery leasing, which may be more financially feasible—will be important for contract planning and may be a way to delink operating contracts from ROI. We first provide a brief overview of common bus contracts, and then we highlight best practices for BEB-specific contracting stemming from ITDP Brazil expertise. More information about this can be found in Section 6, Funding, Financing, and the Financial Model. Contracts are one element of an interconnected and iterative planning process for the electrification of public fleets, as demonstrated below.

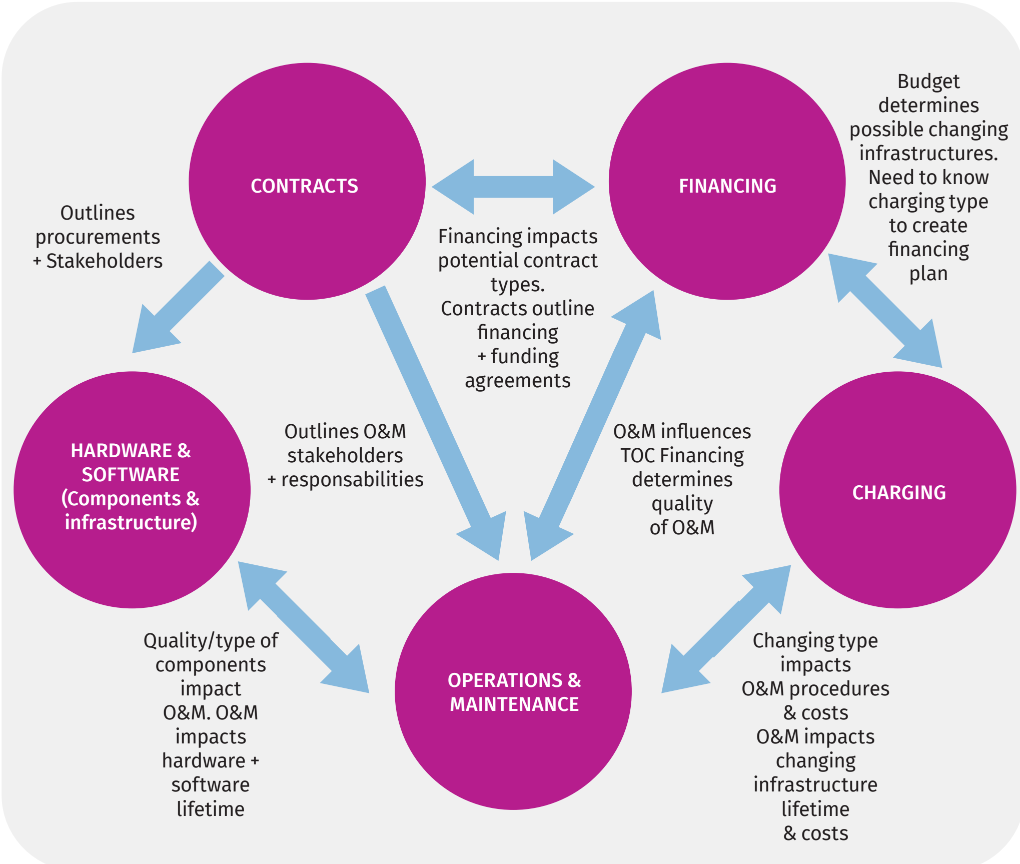


FIGURE 7. Battery electric bus planning is an iterative process, with contracts and financing tied to each other and determining possible charging systems; bus and batteries types; and corresponding hardware, software, maintenance, and operations.

OPPOSITE PAGE Passengers load onto an articulated bus in New York City. The bus stop features clear wayfinding signage, real time information, and shelter for passengers. **SOURCE:** NACTO, Flickr.

154 International Finance Corporation (ITF, World Bank). 2020. E-Bus Economics: Fuzzy Math?

For successful BEB procurement and operations, planners may consider separating the ownership/provision contracts from operation contracts. As research by C40 and the IFC highlights, when operators are responsible for both owning and operating the fleets, this has a couple of risk points: There is limited capacity to raise capital, and passenger demand fluctuations can lead to revenue loss, both of which can compound the financial risks of owning and operating the fleet.[155] ITDP Brazil's research found that separating contracts enables transit planners to have a longer contract with the fleet owner, allowing them time to recoup their investments, and a shorter contract with operators, which allows the city to change operators if quality of service is poor. This is a relatively new model, but it is being increasingly explored. However, there may be challenges with this separation. Research by ITDP Mexico found that separating provision and operations contracts may result in poor maintenance and certification:[156] For example, the operator may not be as diligent about driving and maintaining the vehicles if they are just renting them. This can increase costs, as now there are two contractors where there used to be one. However, a city should consider whether this separation could benefit it, if adequate incentives or agreements can prevent maintenance neglect and reduce financial risk to the system.

If separating contracts is chosen, contracts for ownership/provision will establish bus procurement and who owns them, while operations contracts will establish the responsible stakeholder for operations. If not separating, one contractor will be responsible for ownership and operations. In either case, best practices for contracts include:

TO INCENTIVIZE UPDATING AND ADOPTING NEW, ZERO-EMISSION TECHNOLOGIES: (1) ADD ADOPTION INCENTIVES IN CONTRACTS AND (2) CONSIDER CREATING DIFFERENT CONTRACT TIMELINES FOR DIFFERENT BUS TECHNOLOGIES TO ENCOURAGE ZERO-EMISSION TECHNOLOGIES.

Contracts should promote zero-emission goals through incentivizing adoption of improved technology as it becomes available. In particular, contracts should highlight the importance of adopting new technologies that reduce environmental emissions and increase community health. While existing long-term contracts may prevent adoption if too rigid, longer-term contracts with appropriate flexibility and incentivization for adopting new zero-emission technologies can help spread the cost over a longer time.[157] Establish vehicle ownership contracts that are longer for electric buses (such as up to 15 years) so that the financial benefits of electric buses with their total cost of ownership is over a full vehicle lifetime (ideally, 12 years or longer). Cities should consider establishing shorter contracts for non-zero-emission-buses (such as up to 10 years for diesel buses) to discourage their continued use and to avoid the issue of a long contract duration for heavily polluting bus technologies that makes switching to electric or other zero-emission bus technologies more challenging.[158]

TO GUARANTEE PROTECTION FROM UNDERPERFORMANCE: (1) TIE COSTS AND LIFE CYCLE GUARANTEES TO BUS AND BATTERY PERFORMANCE, (2) TIE BATTERY-LIFE DEGRADATION RATE TO VENDOR PAYMENT OR BATTERY REPLACEMENT, AND (3) STIPULATE DATA COLLECTION AND SHARING REQUIREMENTS.

It should be clear in contracts with vendors that vehicle underperformance may result in return of vehicles that will not penalize the public transportation agency.[159] Performance and battery life must be tied to costs and life cycle guarantees. Contracts must allow transportation agencies to hold manufacturers accountable and give flexibility for changing bus and/or battery models according to (under)performance and new technologies. Cities such as São Paulo have established fines as well as payment-with-performance incentives for reaching service quality and environmental standards (see the following infographic). Inconsistent rate of battery-life degradation can significantly impact the number of years a battery can be used, as well as the battery's range performance. Contracts must tie vendor promises for battery life to vendor payment to ensure that observed performance and life span meet what is promised.[160] C40, for example, recommends a battery replacement clause if batteries fall below 70 percent capacity under a given life cycle warranty period.[161] Other organizations typically recommend between 60 percent to 80 percent. To be able to track underperformance, operators must collect data. Cities should consider which data metrics they want to collect and outline these in contracts. In addition, it is important that data-sharing requirements are included to ensure that planning stakeholders can access and use the data collected.

155 Graham and Courreges (IFC & C40). 2020. Leading a Clean Urban Recovery with Electric Buses: Innovative Business Models Show Promise in Latin America.
156 Personal communication, ITDP Mexico with the BRT Centre of Excellence. May 2020.
157 Miller et al. (ICCT). 2017. Financing the Transition to Soot-Free Urban Bus Fleets in 20 Megacities.
158 January 2021. Personal communication, ITDP Brazil.
159 Horrox & Casale. 2019. Electric Buses in America: Lessons From Cities Pioneering Clean Transportation.
160 Personal communication with ICCT. February 2021.
161 C40 Cities. 2020. How to Shift Your Bus Fleet to Zero Emissions by Procuring Only Electric Buses.

LEFT: Passengers at a bus station in Pune, India.
SOURCE: ITDP India, Flickr.

RIGHT: Passengers wait for a bus in Rio de Janeiro, Brazil. ITDP Brazil is working with the city to electrify the bus fleet.
SOURCE: Stefano Aguilar ITDP Brazil, Flickr.

TO MEET ENVIRONMENTAL GOALS: (1) ALIGN WITH ENVIRONMENTAL LEGISLATION AND CREATE ENVIRONMENTAL REQUIREMENTS, (2) MONITOR AND EVALUATE ENVIRONMENTAL IMPACTS, AND (3) CREATE CLEAR PENALTIES FOR NOT MEETING ENVIRONMENTAL REQUIREMENTS.
Contracts should align with existing international and national environment legislation to ground the pilots or fleets in urban environmental goals. Operators should monitor vehicle emissions on a regular basis and inspect whether targets and standards for pollutant emission levels are being met during the contract period. Contracts should establish and apply fines or other penalties linked to meeting environmental requirements and improving the quality of service during the contract period. (See “Environmental Incentives” in the following infographic.)

TO GUARANTEE QUALITY INFRASTRUCTURE AND OPERABILITY: (1) INCLUDE CHARGING INFRASTRUCTURE INTEROPERABILITY REQUIREMENTS AND (2) OUTLINE BUS DEPOT REQUIREMENTS.
Contracts should state that charging infrastructure must be interoperable with multiple bus manufacturers’ models to ensure that cities are not stuck with one manufacturer.[162] Battery electric buses can be particularly sensitive to variable weather conditions. Contracts should ensure that depots are properly covered and ventilated to enable the best operational performance for BEBs.

TO ENSURE PROPER HANDLING OF BUSES THAT ELONGATES BUS AND BATTERY LIFE: INCLUDE BEB-SPECIFIC TRAINING REQUIREMENTS.
Driving style dramatically changes the battery performance of electric buses, and proper maintenance can elongate battery life spans. Contracts should include mandatory training for employees as well as maintenance incentives. Additional best practices for operations and maintenance are included in Section 7.

Common types of operations contracts are included in the table below.

162 C40 Cities. 2020. How to Shift Your Bus Fleet to Zero Emissions by Procuring Only Electric Buses.

COMMON TYPES OF OPERATIONS CONTRACTS			
CONTRACT TYPE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Service contract (gross cost)	The operator is paid to operate a minimum number of kilometers (km) of public transport services over the life of a contract anywhere directed by the municipality. Municipality owns revenues, though the operator may collect.	- Ensures good service coverage; - Makes off-board fare collection and free transfers compatible; - Ends dangerous competition at the curb; - Makes interzone routes and modifying services compatible; - Easier to have 2+ companies in the same zone, so the operator is less entrenched.	- Weak incentive to control costs; - Leads to ongoing increasing operating subsidies; - Requires diligent and competent municipal authority to supervise; - Weak incentive to attract new customers or enforce fare collection.
Area contract (gross cost)	An operator is paid to operate a set of services within a zone, anywhere instructed by the municipality, usually by the bus km or the bus hour. Fare revenue is owned by the municipality.	- Ensures good service coverage; - Makes off-board fare collection and free transfers compatible; - Ends dangerous competition at the curb.	- Poor service between zones; - Removes incentive to control costs, tends to lead to ongoing increasing operating subsidies; - Requires diligent and competent municipal authority to supervise; - Weak incentive to attract new customers or enforce fare collection; - Difficult to replace an entrenched operator.
Area contract (net cost)	A private operator provides a set of services determined by the municipal authority within a specified zone and owns all fare revenue in that zone.	- Reduces risk of open-ended subsidies; - Makes it easy for large companies to form; - Allows for good coordination and possible cross-subsidy within zone; - Mitigates destructive competition within zone	- Poor service between zones; - Harder to work with off-board fare collection and free transfer; - Leads to limited public control over operator; - Difficult to dislodge an operator for poor service; - Risk of dangerous on-street competition on corridors shared by zones.
Route contract (gross cost)	Operators have a license with a city authority to provide bus services specified by the municipality on a route or a particular route, but revenue is owned by the municipal authority.	- Gives the municipality greater control over the services; - Avoids dangerous competition for customers at curbside; - Makes for off-board fare collection and free transfers compatible.	- Disincentivizes operator to ensure secure fare collection; - Creates situation in which operator has weak incentive to improve efficiency of service; - Lowers responsiveness to needed service changes.
Route contract (net cost)	Operator has a license with a city authority to provide bus services specified by the municipality on a route or a particular route and all fare revenue is owned by the operator.	- Minimizes risk of ongoing open-ended subsidies, exposes operator to demand risk; - Operator has incentive to collect revenue and operate the route efficiently; - Gives municipality some control over services.	- Difficult to make changes to the network; - Disallows the cross-subsidizing of loss-making routes with more profitable routes; - Makes for fewer returns to scale; - Lacks compatibility with off-board fare collection; - Dangerous competition for customers on corridors with multiple routes.
Design-build-operate forms	Concessionaires are given a long-term contract to design, build, and operate a public transport system. Contractor owns fare revenue.	- Raises capital for infrastructure, can provide good project management for new services; - Can provide quality, coordinated services.	- Leads to the same problems as with gross cost service contracts, plus there is less government leverage (due to contract length) to change services or control quality.
Profit-sharing	Operator is paid a predetermined share of total system revenues, based on a pre-agreed formula (usually linked to bus kilometers, customers served, or a combination).	- Gives operators strong incentive to reduce costs and attract customers; - Causes large companies to form; - Removes destructive competition for customers; - Reduces risk of needed subsidies.	- Makes percentages difficult to negotiate in advance; - Sometimes one element of the system ends up with a disproportionate set of profits; - Makes it more difficult to ring-fence if the system is not profitable.

SPOTLIGHT ON ITDP INDIA: GROSS COST CONTRACTS AND FAME-II NATIONAL FUNDING

In India, gross cost contracts (GCC) were included as a mandatory condition for cities to get subsidies for electric bus procurement under the FAME-II scheme, beginning in April 2019. Since subsidies were important for cities to procure electric buses, this led to a large-scale shift from the net cost contracts to gross cost contracts throughout the country for electric bus operations. Subsequently, most e-buses in India are now being operated on GCC.

A dedicated busway in Pune, India.
SOURCE: ITDP India

OPPOSITE PAGE
TABLE 4:
This is an adjusted table from the ITDP BRT Planning Guide. Contract types that are incompatible with BEBs, such as unregulated entry (with or without quality control) in which private operators own their own vehicles, are not included.

Contracts for pilots and for fleets are essentially the management documents for the transit system and as such should define the particular duties of each stakeholder, including management, operational, and land ownership responsibilities, and also define the rights of each stakeholder, including compensation. Diagrams for different financial arrangements and their corresponding stakeholders are presented in Section 5, Funding, Financing, and the Financial Model. Stakeholder duties may include:

PLANNING.
Stakeholders in the planning process will likely include the local government, operator(s), manufacturers/vendors, utility companies, infrastructure construction companies, and/or consultants.[163] Planning will be iterative, and selecting technologies for buses, batteries, and charging infrastructure will not only depend on the technologies but on financing and stakeholder capacity too.

PROCUREMENT.
Given the high capital cost of BEBs, procurement of buses may be the responsibility of the operator, the government, or the utility company. Additional stakeholders may include manufacturers/vendors or third-party financiers. This will vary widely, according to the financing scheme (see Section 5, Funding, Financing, and the Financial Model). Procurement may be split between bus and battery. Procurement of charging infrastructure is similar, but it may not be done by the same people who buy the buses. Financing that procurement will involve other stakeholders too. Stakeholder willingness to collaborate will determine the financing schemes that are possible, which will, in turn, affect the contract structure. For example, operators should communicate with utilities very early in the planning process, as the feasibility of different charging schemes will depend on the utility company's willingness to collaborate, as well as on the existing electric grid capacity, extent, and pricing.[164]

OPERATIONS AND MAINTENANCE.
Operations and maintenance duties will depend on the type of charging, as well as the agreed upon ownership and/or leasing scheme for the given system. Contracts should specify level of service agreements between the government and the operator, as well as between the bus and charging infrastructure providers and operators. Duties may include reporting operations challenges, driving according to vendor warranties; monitoring operations, planning maintenance, ensuring replacement parts availability; reporting operational difficulties; financial responsibility; and supplying necessary materials.[165] It is also important to outline in procurement and/or contracts which stakeholder is responsible for end-of-life recycling or disposal, both financially and logistically.

SPOTLIGHT ON ITDP BRAZIL: ESTABLISHING CONTRACTS TO ENABLE ELECTRIFICATION

In Brazil, many cities' procurement and operations models, as well as existing rigid contracts, do not allow the adoption of electric bus fleets that could benefit urban residents. This is important, as the degree of flexibility or incentivization of electrification in contracts will significantly affect the pace of electric bus adoption for Brazil in the next few years and decades. Modeling by the National Platform for Electric Mobility (PNME) shows vastly different electric uptake for Brazil with conservative, moderate, and aggressive models, projecting 1,000, 3,925, and 18,000 buses adopted by 2030, respectively.[166]
To understand current gaps and best practices, as well as how concessions can encourage BEB adoption, ITDP Brazil conducted a review of electric bus contracts for major Brazilian cities. The results from this survey will develop knowledge and capacity in Brazilian cities for long-term electrification of public fleets. The recommendations from this study (summarized in the following infographic) are being applied directly to work with the city of Rio de Janeiro to procure e-buses.

163 Orbea et al. 2019. Adapting Procurement Models for Electric Buses in Latin America.
164 Horrox and Casale (U.S. PIRG). 2019. Cities in North America.
165 Wu (APTA), n.d. (presentation). Lessons Learned From Operating Battery Electric Buses in the Real World.
166 Plataforma Nacional de Mobilidade Eletrica. 2020. 1o Anuário Brasileiro Da Mobilidade Elétrica.

A TransOeste BRT bus moves freely in dedicated infrastructure in Rio de Janeiro, Brazil. **SOURCE:** Stefano Aguilar / ITDP Brazil, Flickr.

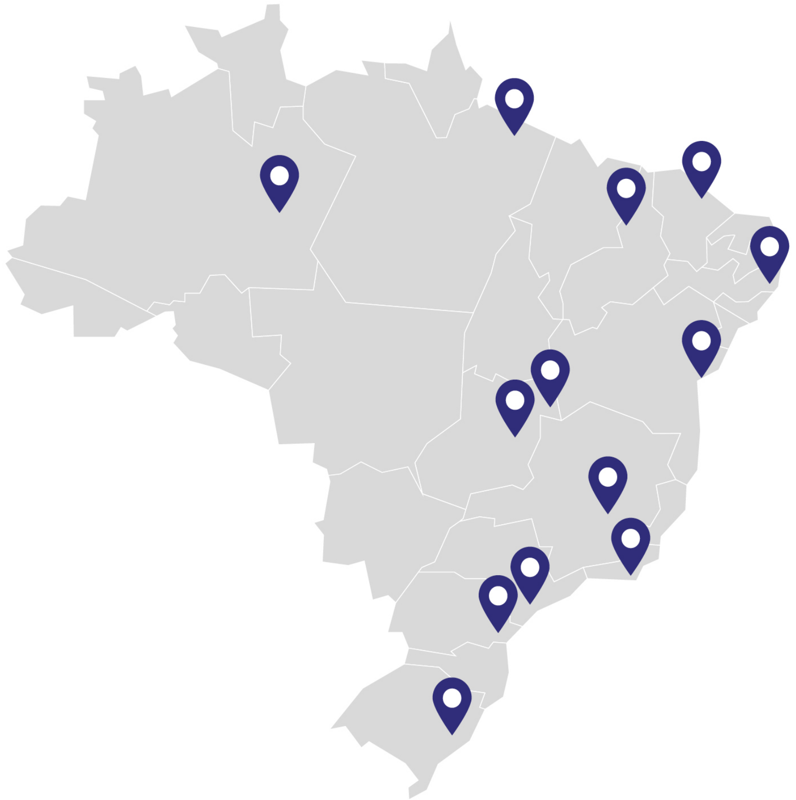
POLICY INCENTIVES: THE KEY TO ELECTRIFICATION

Rigid regulations create major barriers to electrification. Without enabling policy, electric buses may not be adopted. How can we change this?

To incentivize electrification, public bus contracts must:

- encourage competition;
- reduce harmful emissions;
- incorporate the latest technologies;
- improve the quality of service.

We surveyed how these goals are considered in 13 Brazilian capital cities' contracts, to either **encourage fleet electrification** or continue supporting **diesel-powered fleets**



EXISTING CONTRACTS IN 13 CAPITALS

CAPITAL	YEAR IMPLEMENTED
Belém	in bidding process*
Belo Horizonte	2008
Brasília	2012
Curitiba	2010
Fortaleza	2012
Goiânia	2008
Manaus	2011
Porto Alegre	2015
Recife	2013
Rio de Janeiro	2010
Salvador	2014
São Paulo	2019
Teresina	2014

**Among the cities analyzed, Belém is the only one without an active contract. As such, the bidding notice was analyzed.*

CONTRACT PERIODS

77% of the cities surveyed have contracts that extend for more than 15 years. When considering available contract extensions, this jumps to 92%.

Curitiba, Fortaleza, Recife, and Teresina have contracts that do not extend past 15 years; while the city of Belém is currently in the bidding process for a contract that would have a 6-year maximum extension.

ENVIRONMENTAL INCENTIVES

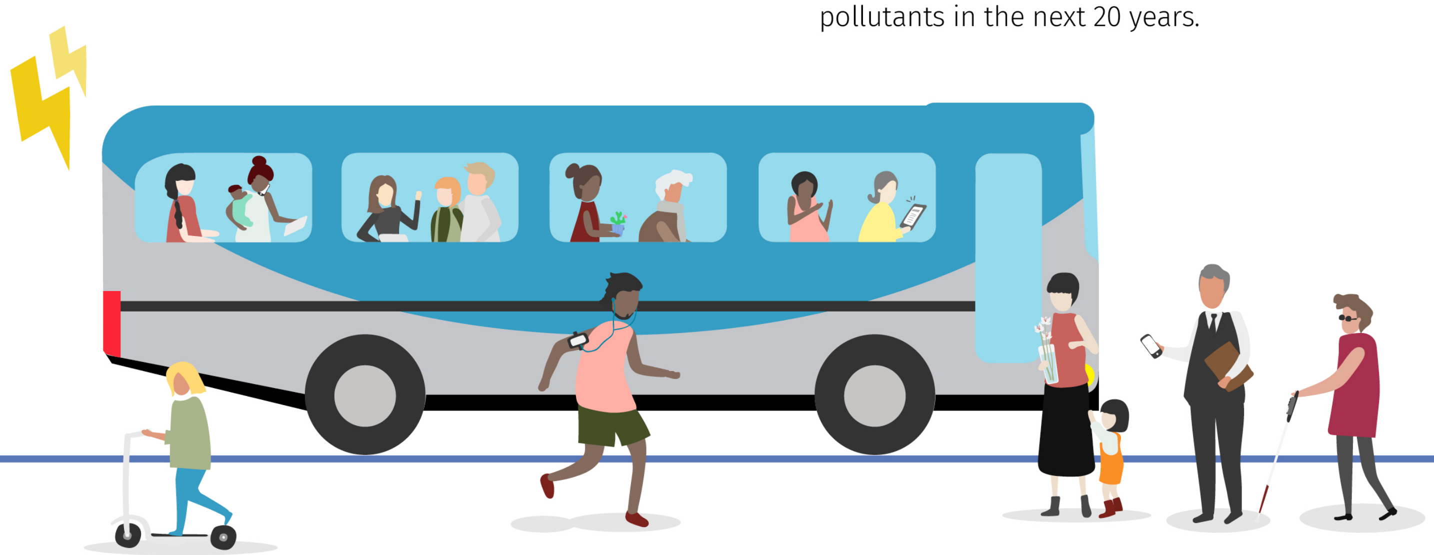
38% of contracts do not specify vehicle fuel types types to be used for the fleet (such as Euro III, Euro V, hybrid or electric);

61% do not establish monitoring or inspection standards for vehicle emissions;

77% do not identify monitoring standards for specific environmental pollutants.

Goiânia established an Environmental Responsibility Program to monitor the city's progress towards the goal of 20% greenhouse gas reduction in 5 years;

São Paulo created a Steering Committee for the Monitoring Program for the Replacement of Fleets with Cleaner Alternatives, which requires an annual emission report and establishes clear targets for reducing local and global pollutants in the next 20 years.



FINANCIAL INCENTIVES

62% of the contracts do not have penalties for operations that exceed emissions levels or do not meet environmental standards;

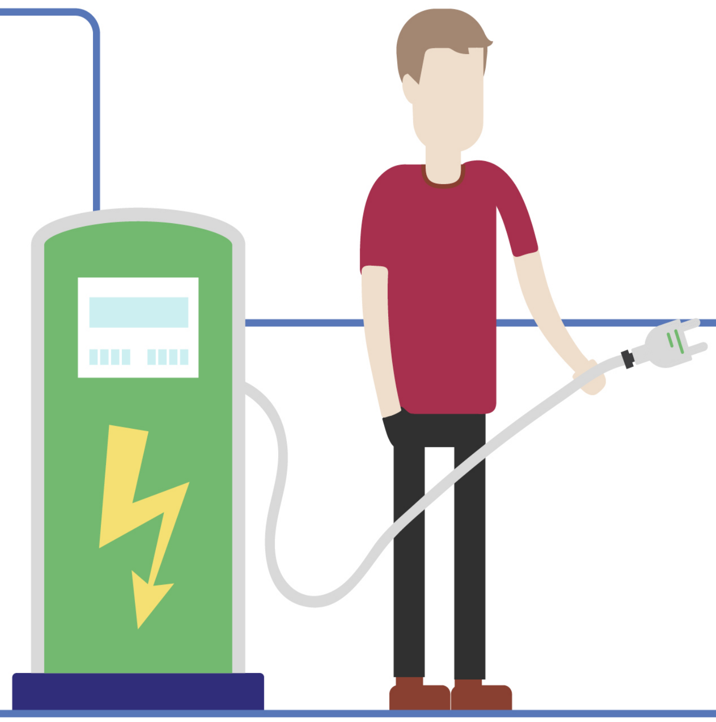
69% of contracts do not have fines for operations that do not meet minimum performance objectives (which are created to improve the quality of service for users);

61% do not have payment-with-performance critieria (which create incentives for operators to improve the quality of the system).

São Paulo established clear fines (negative reinforcement) and payment-with-performance criteria (positive reinforcement) for meeting environmental standards;

Fortaleza has penalties for operators that do not adopt technological innovations that would improve the quality of the system;

Belém, Curitiba, Porto Alegre, and Recife have payment-with-performance criteria that incentivizes improved quality of service for users.



TECHNOLOGY INCENTIVES

30% of contracts do not mention mandatory vehicle renovations or upgrades for vehicle equipment and technology;

77% do not mention standards for regular (i.e. scheduled) fleet renewal;

15% do not mention parameters that must be considered when renewing the fleet;

23% of the contracts do not establish a maximum or average vehicle age allowed during the concession period.

Contracts for Goiânia and São Paulo establish a minimum interval for fleet renewal, with the goal of reducing environmental impacts;

Contracts for Brasília, Porto Alegre, Salvador, and São Paulo identify electrifcation as a criteria for fleet upgrades;

Recife's contract prioritizes fleet renewal for older vehicles, and mandates that new vehicles must be clean vehicles (i.e. green technology).

OPERATIONAL ASPECTS

In order to safely and efficiently charge the electric vehicles, bus depots must have adequate space for buses to be covered and ventilated. In addition, buses should not be exposed to variable weather conditions.

54% of contracts do not mention vehicle coverage as a requirement for depots;

46% do not define a minimum area for fueling, which leaves area requirements tied only to the number and type of vehicles in the fleet.

Contracts for Brasília and Goiânia highlight the need for a covered and ventilated area to maintain the vehicles.

Electric vehicles must be operated differently than conventional vehicles. Specific requirements for training employees about new technologies must be included in the contracts.

53% of the contracts do not mention mandatory training for employees. This number jumps to 77% for contracts that specifically cite training for new technologies, quality of service, or emissions reduction.

São Paulo is the only city that has a specific training program for new technologies and best practices that reduce emissions;

Fortaleza and Belém mention the need for new electric bus-specific training to improve the quality of service provided.

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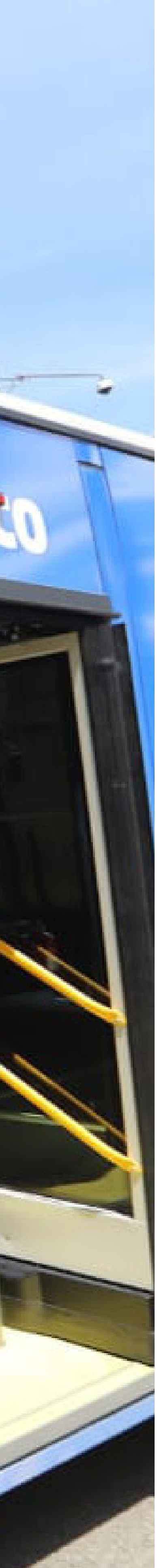
Alcaldía de Medellín



FUNDING, FINANCING, AND THE FINANCIAL MODEL

6

OPPOSITE PAGE
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.

Battery electric buses may need to have a different financial model than other existing bus technologies because of the differences in capital and operating expenditures for electric versus nonelectric buses. The financial model is the balance of the expenditures, capital and operations, against the potential sources of revenue. In general, capital expenditures are (often) one-time investments in assets like buses and depots, while operating expenses include costs associated with personnel, administration, debt financing fees, system maintenance, and (if involving the private sector) a return on investment. Taken together, these are the expense inputs for the financial model. Revenue inputs for the financial model may include ongoing revenue, such as farebox revenue or investments from the government for operating expenses. It may also include one-time revenue outlays, such as for capital expenses, through grants or capital subsidies.

Financing BEBs differs from diesel and CNG buses as the balance between capital and operational expenses shifts significantly. BEBs' capital costs may be two to three times more than those of diesel buses, while operating costs are lower, with a range of one-and-a-half to four times less. As such, financing the procurement of buses is often the most frequently listed challenge for cities in moving toward electrification. Despite the higher initial cost for electric buses, though, BEBs often have cost savings over the operational life of the bus. ***Capturing these financial advantages requires rethinking the traditional financial model for public bus operations through the total cost of ownership (TCO).*** The total cost of ownership is the lifetime costs of purchasing (capital costs) and maintaining (operational and maintenance costs) a bus, as well as the installation and maintenance costs of charging infrastructure. Understanding the changes in the TCO model is vital to the argument for BEBs. This will affect the financial model for electric buses, which will need to find a balance of expenses and revenues despite the higher upfront capital costs and lower operational costs than traditional ICE bus systems.

TOTAL COST OF OWNERSHIP

There is increasingly more research that while BEBs represent a large upfront investment, they have the potential for a lower total cost than traditional diesel or CNG buses over an average bus lifetime (10 to 15 years).[167] Estimates by Bloomberg New Energy Finance find that electric buses with smaller batteries (110 kWh) and slow depot (overnight) charging can reach TCO parity with diesel buses at an annual distance around 34,000 km for over 10 years, while electric buses with larger batteries (250 kWh and 350 kWh) with slow charging achieve parity over 10 years of use at around 44,000 km and 80,000 km, respectively.[168] For a 110 kWh electric bus using wireless charging, parity is reached around 60,000 annual kilometers traveled over 10 years of use.[169 170] The competitiveness of TCO for electric buses varies by city. For example, a World Bank study found that BEB TCO in Santiago is competitive with diesel and CNG buses, while in Buenos Aires TCO for BEBs is still more expensive.[171] São Paulo and Mexico City both conducted TCO analysis that found slight cost savings with BEBs.[172] However, many other studies indicated that while BEBs are to reach TCO parity with diesel and CNG buses within the next decade, they are yet to break even.[173] The timeline for BEBs' TCO breaking even with diesel and CNG buses ranges significantly by region and even country, with estimates showing some European countries reaching parity around 2025 to 2035, while North America is projected not to reach parity until 2050 or beyond.[174] The reasons for this variance include:

167 These studies are often based on models, as the market is continually evolving and many models have not yet completed full life cycles. Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.
168 Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.
169 Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.
170 It is important to note that few buses have gone through a full life cycle and thus these TCO parity timelines are estimates, so there is an accuracy risk with these estimates.
171 International Finance Corporation (IFC, World Bank). 2020. E-Bus Economics: Fuzzy Math?
172 C40 Cities. 2020. How to Shift Your Bus Fleet to Zero Emissions by Procuring Only Electric Buses.
173 Lowell (MJB & A). 2019. Electric Bus 101: Economics, Politics, Myths, & Facts.
174 Lowell (MJB & A). 2019. Electric Bus 101: Economics, Politics, Myths, & Facts.

TCO of electric buses may be lower where: fuel pricing is high, electricity pricing is low, local and national import taxes are low, BEB manufacturers are available and competitive, buses have high average annual kilometers traveled, and batteries/charging infrastructure are adequate for local climate and topography.[175]

TCO of diesel/CNG buses may be lower where: fuel pricing is low, utility service upgrades are necessary, imports for BEBs are high, buses have low average annual kilometers traveled, and electricity pricing and demand is high.[176]

Given the inversion of capital and operating costs from ICE buses to BEBs, cities will need to rethink investment in public transport buses, the role of and investment from operators, and the financial model more generally within the frame of total costs of ownership.

Supportive funding and innovative financing schemes can enable cities to electrify their fleets by achieving competitive TCO for BEBs. In many regions, such as China and Europe, government subsidies offer initial funding that allows cities to feasibly finance electrification of their bus fleets. In other regions, like Latin America, collaboration with capital providers such as multilateral development banks has provided innovative financing schemes for pilots and entire fleets that reduce initial costs and make electric bus costs comparable to those of diesel and CNG buses across the vehicle lifetime.[177] Common financial challenges include: high bus costs, high upfront costs for charging infrastructure deployment and land procurement, a lack of flexible and feasible financing schemes, unknown electricity costs, and poor replacement ratios (i.e., needing more than one electric bus to replace one diesel bus to maintain the same operations).[178] The next section looks at capital costs in more depth, focusing on funding and financing schemes, providing a brief overview of operating costs, and concluding with an explanation of how new e-bus capital and operational costs relate to the financial model. More research is needed to understand how best to fund and finance charging infrastructure. Also, since most diesel buses' TCO does not include refueling infrastructure, it is worth considering separating the costs of charging infrastructure from the TCO and using one-time grants or funding to cover these costs. Capital costs and operating costs are often covered by different revenue streams. As such, these costs are separated in the following sections.

Battery electric buses may have a more competitive TCO than diesel buses in cities where public buses travel a high number of kilometers annually. Pictured, buses operate along dedicated lanes in Guangzhou, China. **SOURCE:** NACTO, Flickr.

175 Johnson et al. (NREL). 2020. Financial Analysis of Battery Electric Transit Buses.
176 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.
177 ZEBRA & P4G. 2020. Accelerating a Market Transition in Latin America: New Business Models for Electric Bus Development.
178 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.

6.1 CAPITAL COSTS

The capital costs for piloting and adopting BEBs vary depending on the country, charging system selected, financing scheme selected, and funding options available. Capital costs will typically be covered by two main financing mechanisms: (1) equity, where money is raised in exchange for a stake in the venture and can include a down payment for a loan (initial payment put down for the above key components, with the remainder being funded over time with loans, leasing, or other financing scheme) and (2) debt financing, such as a loan or other long-term scheduled payments (initial and/or interest payments over time).[179] Other avenues for covering capital costs include funding mechanisms like grants and subsidies from the government. Key areas for capital costs of BEBs include:

- Bus and battery procurement,
- Charging infrastructure equipment and installation,
- Depot or station construction/retrofitting, and
- Personnel and training before operations begin and revenue starts coming in.

As mentioned, costs will vary significantly for a variety of factors. Infrastructure costs, including depot and/or charger installation, will vary significantly depending on the charging system type and land availability. While traditional plug-in charging will require bus depot retrofitting, opportunity and wireless charging along the route may require greater changes to the land uses along the bus system's routes and the environment may be more complex for construction. More than most factors, costs will vary significantly based on region. To give a sense of this regional variation, the table below shows average diesel bus price versus average electric for five geographies.

TABLE 5. Approximate diesel vs. electric bus cost comparison for nonarticulated bus models, based on 2012–2013 data and updated with more recent data in 2021. While based on older data, these numbers give an idea of the proportional difference between buses, and diesel data is relatively unchanged. For example, research published in 2020 identifies diesel cost of ~$450,000 and BEB cost of ~$550,000 to $750,000 in the U.S., reflective of the North American values above.[190] *Global average is not weighted by units sold but is an average of cost across regions. Main source: Grütter, 2014.[191] Other sources for country specific data are footnoted.

COUNTRY	INITIAL DIESEL BUS COST (USD)	INITIAL BEB COST (USD)	APPROXIMATE % INCREASE FOR ELECTRIC
China[180]	$ 60,000–$90,000	$ 140,000–$350,000	~ 250%
Europe[181 182]	$244,000–$420,500	$575,000–$807,000	~ 110%
India[183 184]	$30,000–$80,000	$105,000–$250,000	~ 220%
Latin America[185 186]	$200,000–$225,000	$260,000–$475,000	~ 75%
North America[187 188 189]	$300,000–$510,000	$550,000–$1,200,000	~ 115%
Global Average*	~ $210,000	~ $480,000	~ 155%

The cost of an e-bus ranges significantly by region. Electric buses in the U.S. can cost two to four times those in China. Passengers hop on a double decker 'Superlo' bus in New York City. **SOURCE:** Metropolitan Transportation Authority of the State of New York, Flickr.

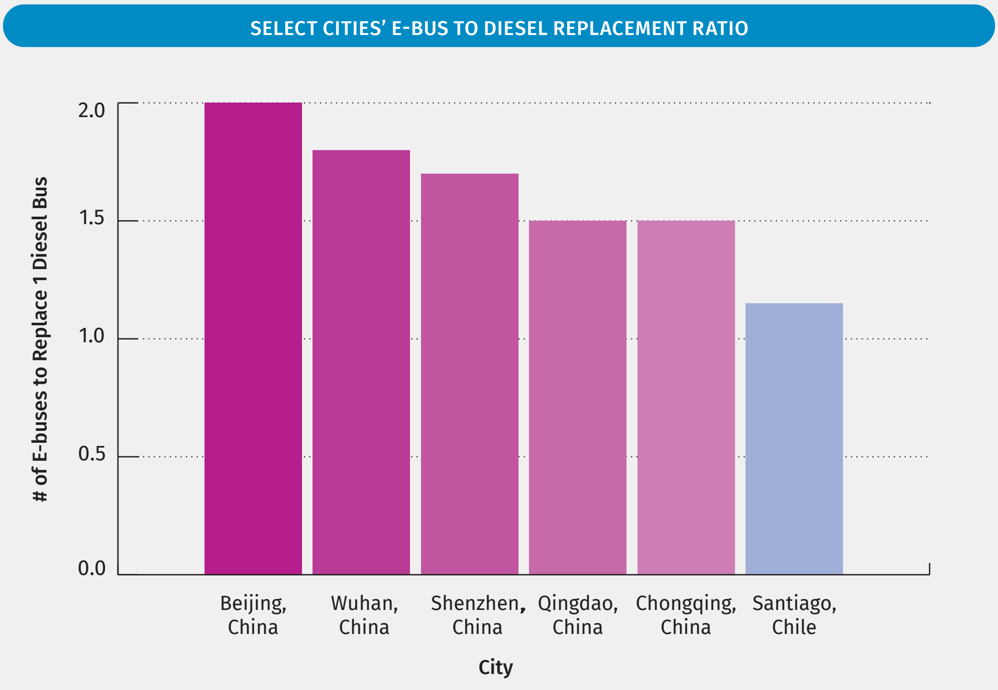
179 Miller et al. (ICCT). 2017. Financing the Transition to Soot-Free Urban Bus Fleets.
180 C40 Cities Finance Facility & Grutter Consulting. 2018. Evaluation of Electric Buses for Eje 8 Sur.
181 Assumes 1.1068 USD to EUR for 2016. Laizans et al. 2016. Economic Viability of Electric Public Buses: Regional Perspective.
182 Assumes 1.122 USD to EUR for 2019. Meishner & Sauer. 2019. Technical and Economic Comparison of Different Electric Bus Concepts Based on Actual Demonstrations in European Cities.
183 Khandekar et al. 2018. The Case for All New City Buses in India to Be Electric.
184 Personal communication, ITDP India, March 2021.
185 Lefevre et al. (Inter-American Development Bank). 2019. Bogotá Is a Pioneer in Acquiring Electric Buses by Tender.
186 World Bank. 2019. Green Your Bus Ride: Clean Buses in Latin America.
187 Quarles et al. 2020. Costs and Benefits of Electrifying and Automating Bus Transit Fleets.
188 C40 Cities Finance Facility & Grutter Consulting. 2018. Evaluation of Electric Buses for Eje 8 Sur.
189 MJB & A. 2020. Battery Electric Bus and Facilities Analysis.
190 Quarles et al. 2020. Costs and Benefits of Electrifying and Automating Bus Transit Fleets.
191 Grutter Consulting. 2014. Real World Performance of Hybrid and Electric Buses.

Similarly, costs of batteries range significantly based on region, battery type, battery size, and manufacturer. It is difficult to provide estimates for one electric bus given this variation in batteries as well as the battery price often being represented as cost ($) per kWh of battery capacity. The cost per kWh may range from around $100 to $500 USD, and cities may choose a range of battery pack sizes. To give a sense of regional variation, the average cost of bus batteries in China is about $105/kWh, while North American batteries are likely to average $300 to $500/kWh.[192 193] One North American study evaluating costs of BEBs estimated a battery price at $100,000 USD (assuming a $500/kWh cost for a 200 kWh battery) for a $550,000 USD bus, with another estimating $150,000 (250 kWh battery) for a total cost of a BEB ranging from $650,000 to $700,000 USD.[194 195] Another study valued batteries at $60,000 to $72,000 USD.[196] These prices are decreasing as technology continually improves.

As with other upfront costs, those of charging infrastructure range widely depending on the charging type selected, the region, and the existing local grid capacity/extent. A state of practice review for North America found that plug-in charging equipment itself may cost $19,000 to $50,000 USD, while the installation of the infrastructure can be an additional $5,000 to $55,000 USD.[197] The cost for on-route pantograph or wireless charging infrastructure jumps to $241,000 to $500,000 USD, with installation costs of $50,000 to $250,000 USD.[198] It is challenging to acquire estimates for other regions, but as with batteries and buses, these are expected to fluctuate based on import costs and local manufacturing capacity.

Given the limited range of BEBs (and lack of optimal operational efficiency), it is unlikely at this time for a city to achieve a replacement ratio of 1:1. At present, ratios between 1.5 and 1.1:1 are generally considered favorable (given current operations challenges, which prevent reaching a perfect 1:1 replacement rate). Some cities—particularly in the past decade, in which bus fleets were still very nascent–have had replacement ratios of 2:1 or higher. For example, in many Chinese cities, the replacement ratio was much higher than one to one: Beijing (2:1), Wuhan (1.9:1), Shenzhen (1.7:1), Qingdao (1.5:1), and Chongqing (1.5:1).[199] In Santiago, the city reached a replacement ratio of 1.1:1, which has set a best practice for cities to reach as close to a 1:1 ratio as possible.[200] Not only is the capital cost of the buses much higher upfront but high replacement rates further heighten upfront costs. It is imperative that planning, procurement, installation, and operations decrease the replacement ratio to achieve lower costs to the system.

FIGURE 8.[201]
The closer a city can reach to a 1:1 replacement ratio, the better the financial viability of BEB fleets. The chart shows the BEB replacement ratio for various cities. Generally, ratios of 1:1–1.5 are considered favorable at present. The current focus on improving operational efficiency to elongate e-bus usage and reliability should yield continually lower replacement ratios.



192 Scott (Forbes). 2020. Ever-Cheaper Batteries Bring Cost of Electric Cars Closer to Gas Guzzlers.
193 Quarles et al. 2020. Costs and Benefits of Electrifying and Automating Bus Transit Fleets.
194 Quarles et al. 2020. Costs and Benefits of Electrifying and Automating Bus Transit Fleets.
195 Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.
196 Deliali et al. 2020. Transitioning to Zero-emission Bus Fleets: State of Practice of Implementations in the United States.
197 Deliali et al. 2020. Transitioning to Zero-emission Bus Fleets: State of Practice of Implementations in the United States.
198 Deliali et al. 2020. Transitioning to Zero-emission Bus Fleets: State of Practice of Implementations in the United States.
199 Jin (ICCT). 2020. Preparing to Succeed: Fleet-Wide Planning Is Key in the Transition to Electric Buses.
200 Jin (ICCT). 2020. Preparing to Succeed: Fleet-Wide Planning Is Key in the Transition to Electric Buses.
201 Jin (ICCT). 2020. Preparing to Succeed: Fleet-Wide Planning Is Key in the Transition to Electric Buses.

ABOUT ESTIMATING COSTS

With increased BEB market growth and interest in lessening barriers to entry, multiple organizations have created tools for cities to estimate fleet costs. UN Environment created the eMob Calculator that allows users to estimate costs and emissions for cities and countries.[202] The California HVIP program created a total cost of ownership (TCO) tool, TCO Estimator.[203] Others exist, and cities may find regionally specific tools for their own planning.

6.2 COMMON FUNDING AND FINANCING SCHEMES FOR BUSES AND BATTERIES

The most common approach to capital investments for BEB systems is a combination of funding (such as grants and subsidies) and financing. Because of the higher costs of e-buses, some form of grant or direct budgetary funding may be needed in the beginning until costs reach more parity in the future. The following table provides an overview of different funding and financing options, followed with a description of the most common schemes in use today.

TABLE 6. Comparison of common financing schemes for BEBs.

SCHEME	ADVANTAGES	CONSIDERATIONS
Funding with existing funds or grants	+ Common, relatively simple model + Funding does not need to be reimbursed + Acts as a catalyst for transition	- High upfront burden - Ample funding or grants are needed, so it is not possible everywhere - Does not necessarily lead to large-scale fleet transition
Debt financing, including concessional loans and green bonds	+ Spreads out the costs over time, allowing for less upfront burden + Concessional loans may offer flexible lending and much lower interest rates, making it more affordable	- May not offer enough financial support - May require additional coordination between multiple stakeholders (if borrowing from national or international development banks)
Component (battery) lease arrangement	+ By moving some capital costs to act more like operational costs, this balances the upfront versus ongoing expenditure + Can sometimes be paired with better component maintenance or replacement from manufacturers + Enables large-scale fleet transition	- Involves more stakeholders and divided responsibilities - Must have willing stakeholders to be possible
Operating lease arrangement	+ Spreads out the financing, allowing for less total burden for one party + Enables large-scale fleet transition	- Involves more stakeholders and divided responsibilities - Must have willing stakeholders to be possible - May increase longer term as more parties are involved
Financial lease arrangement	+ Spreads out the financing, allowing for less total burden for one party + Can be a much more financially robust option + Enables large-scale fleet transition	- Involves more stakeholders and divided responsibilities - Must have willing stakeholders to be possible - May increase longer term as more parties are involved

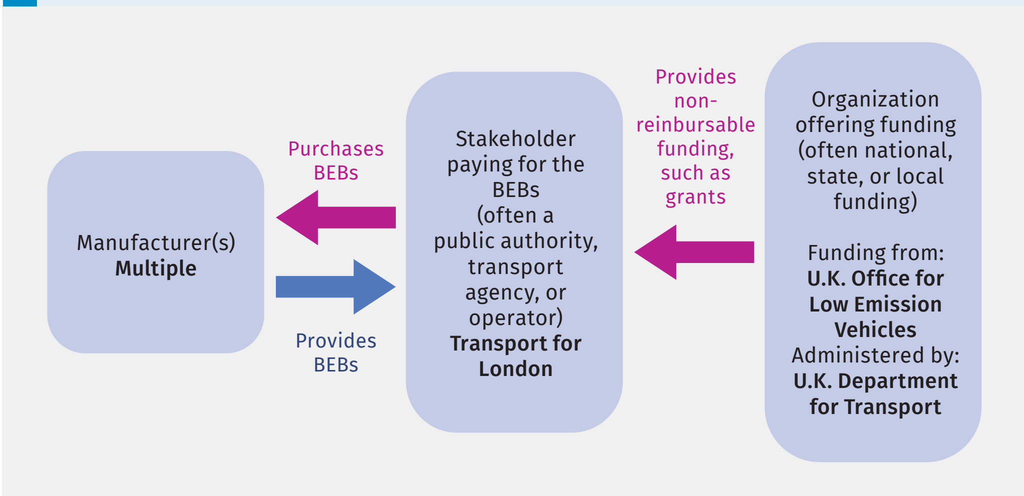
202 UN Environment, n.d. Electric buses.
203 California HVIP, n.d. HVIP Total Cost of Ownership Estimator.

FUNDING WITH EXISTING FUNDS OR GRANTS.

In this scheme, the public transportation agency/operator takes on capital costs through direct budgetary support or with grants.[204] Upfront purchases from public budgets are relatively common in Europe and the United States, where the transit operations are publicly operated.[205] However, in regions with limited funds, this option is often rendered infeasible. When operations are contracted out, some form of grant funding or support can also help reduce the need for financing, as governments often assist with risk mitigation for the private sector for the uptake of new technologies or innovations.[206] Whether outright purchase or combined with other financing schemes, grants or similar financial opportunities are common for the initial purchase of BEBs. Outright purchase with grants is of particular (albeit declining) importance in China, where government subsidies since 2009 have allowed the electric bus and new technology market to scale exponentially. Grant opportunities in India include federal grant programs such as the FAME I and II schemes, and in the U.S. they include state-led programs such as the California Hybrid and Zero Emission Truck and Bus Voucher project, federal grant programs such as the Low or No-Emission grant program, or others such as the Volkswagen Emissions Settlements Funds.[207] The FAME scheme should be viewed more as a catalyst to help with the transition and may not be scalable for the long term.

OWNERSHIP: Operator or transportation agency/government [208]
CITIES USED: Multiple cities in Europe and the U.K.,[209] the United States, and China.

OUTRIGHT PURCHASE WITH GRANT (LONDON, U.K. EXAMPLE)



DEBT FINANCING, INCLUDING CONCESSIONAL LOANS AND GREEN BONDS.

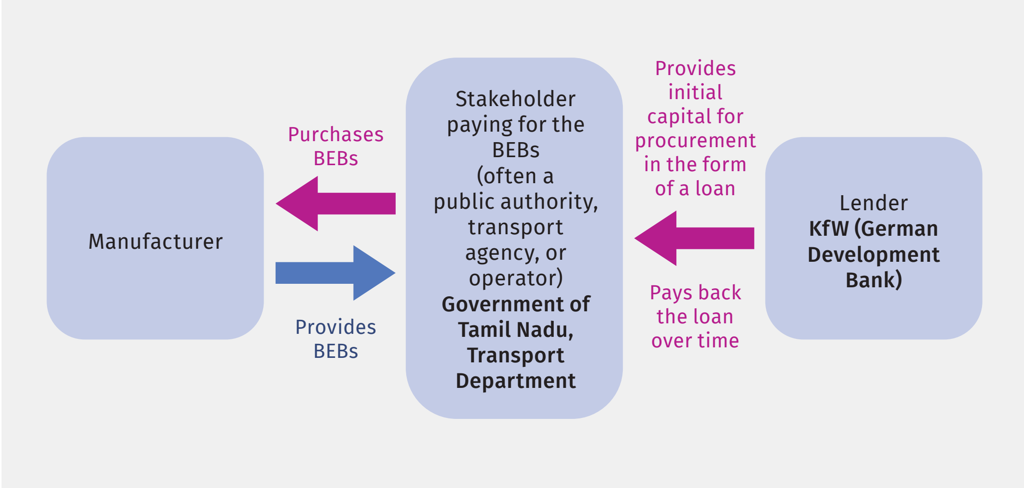
In this scheme, the public transportation agency or operator utilizes flexible loans for capital costs, repaying lender(s) over a given time period. Lenders may include national and international development banks or international environment funds, such as the Green Climate Fund or the Global Environmental Facility, who are motivated to reach urban development and climate change goals.[210] Concessional loans for operators offer flexible lending conditions—such as low interest rates or elongated repayment schedules—which give a more financially durable alternative to outright purchase. This scheme has been used in Curitiba (the operator purchased hybrid electric buses by Volvo with a flexible loan from BNDES, the Brazilian Development Bank) and Bogotá (similarly, operators received lending support from the Colombian bank, Bancoldex, which received support from the Inter-American Development Bank, the Brazilian Development Bank, and the Swedish Export Credit Agency).[211] With loans, a portion will be equity financing and a portion debt financing. The amount of equity financing will determine how much debt financing servicing fees will need to be covered in operational costs. This scheme is increasingly used as more and more development banks work on loans in this space and capital costs decrease with falling costs of batteries and charging infrastructure. Tamil Nadu, a state in southern India, is procuring electric buses under a KfW (German development bank) loan, with the majority to be deployed in Chennai, the capital city.[212] Similar to the concessional loans and grant schemes, green bonds are used

204 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.
205 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.
206 Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.
207 Liu. 2019. The U.S. Electric Bus Transition: An Analysis of Funding and Financing Mechanisms.
208 Miller et al. (ICCT). 2017. Financing the Transition to Soot-Free Urban Bus Fleets.
209 Gomez Jattin (GIZ). 2019. Financial Mechanisms for Electric Bus Adoption.
210 Gomez Jattin (GIZ). 2019. Financial Mechanisms for Electric Bus Adoption.
211 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.
212 Personal communication, ITDP India, November 2020.

to lessen initial financial constraints. This arrangement utilizes green bonds in which 95 percent of the bond proceeds contribute to environmentally beneficial projects—in this case, for electrifying public transportation.[213] This innovative financing has been used in Tianjin, China,[214] as well as increasingly in Sweden.[215]

OWNERSHIP: Operator or transportation agency/government[216]
CITIES USED: Tamil Nadu (Chennai), India; Curitiba, Brazil; Bogotá, Colombia;[217] Tianjin, China;[218] Sweden (multiple cities)[219]

OUTRIGHT PURCHASE WITH LOAN (CHENNAI, INDIA, EXAMPLE)



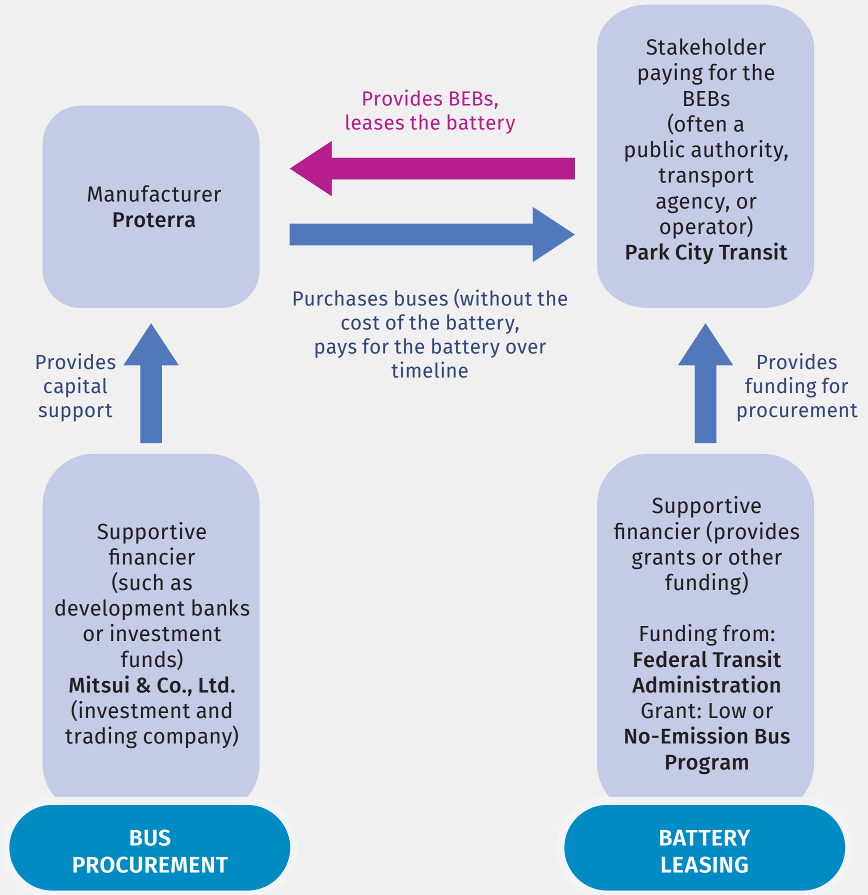
COMPONENT (BATTERY) LEASE ARRANGEMENT.

In this lease-to-own scheme, the transit operator or government leases the bus and/or battery from the manufacturer or vendor (often with support from a third-party financier such as development banks or niche financing companies[220]) to reduce the upfront financial risk. By separating the purchase of some components (such as infrastructure) and the leasing of others (such as the bus and/or battery), the upfront cost is comparable to that of diesel and CNG buses.[221] This benefits manufacturers by increasing the pool of transit operators who are interested and can afford electrification through this model, and it benefits operators by making BEBs a viable financial option both initially and over the vehicle lifetime. Third-party financiers such as development banks are motivated to support electrification projects to reach environmental and social goals. In addition, the lease arrangement is not always the only financial mechanism—it can be combined with grants or loans to further reduce upfront costs.[222] This agreement was used in Bogotá with Volvo, in conjunction with the loan to the operators to buy the hybrid electric buses,[223] as well as in Park City, Utah, U.S., with the company Proterra.[224] In addition to the benefit of reduced upfront costs, component-leasing arrangements that lease batteries may offer battery lifetime guarantees (12 years for Proterra), battery performance warranties, and/or new batteries at mid-life.[225] The latter is particularly beneficial, as operators can get the newest battery technology without exorbitant costs. Relatively limited information is available for best practices of battery leasing in Bogotá and other cities, but increasing interest in and use of this model should yield best practices in the upcoming years.

OWNERSHIP: Manufacturer may own the bus and/or battery, operator or transportation agency/government may own the bus, battery and/or infrastructure[226]
CITIES USED: Bogotá, Colombia; São Paulo, Brazil; Park City, UT, U.S.[227]

213 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.
214 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.
215 Soderlundh, (presentation) 2016. Fossil Free Sweden: Supporting Local Government Climate Action Through Green Loans & Green Bonds.
216 Miller et al. (ICCT). 2017. Financing the Transition to Soot-Free Urban Bus Fleets.
217 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.
218 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.
219 Soderlundh, (presentation) 2016. Fossil Free Sweden: Supporting Local Government Climate Action Through Green Loans & Green Bonds.
220 Miller et al. (ICCT). 2017. Financing the Transition to Soot-Free Urban Bus Fleets.
221 Blanco. 2019. Proterra Ready for Electric Bus Battery Leasing With $200-Million Credit Facility.
222 Gomez Jattin (GIZ). 2019. Financial Mechanisms for Electric Bus Adoption.
223 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.
224 Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.
225 Blanco. 2019. Proterra Ready for Electric Bus Battery Leasing With $200-Million Credit Facility.
226 Miller et al. (ICCT). 2017. Financing the Transition to Soot-Free Urban Bus Fleets.
227 Proterra. 2019. Financing EV Fleets with Proterra Battery Leasing Program.

BATTERY LEASING (PARK CITY, UT, UNITED STATES, EXAMPLE)



SPOTLIGHT ON BATTERY LEASING: BOGOTÁ AND SÃO PAULO

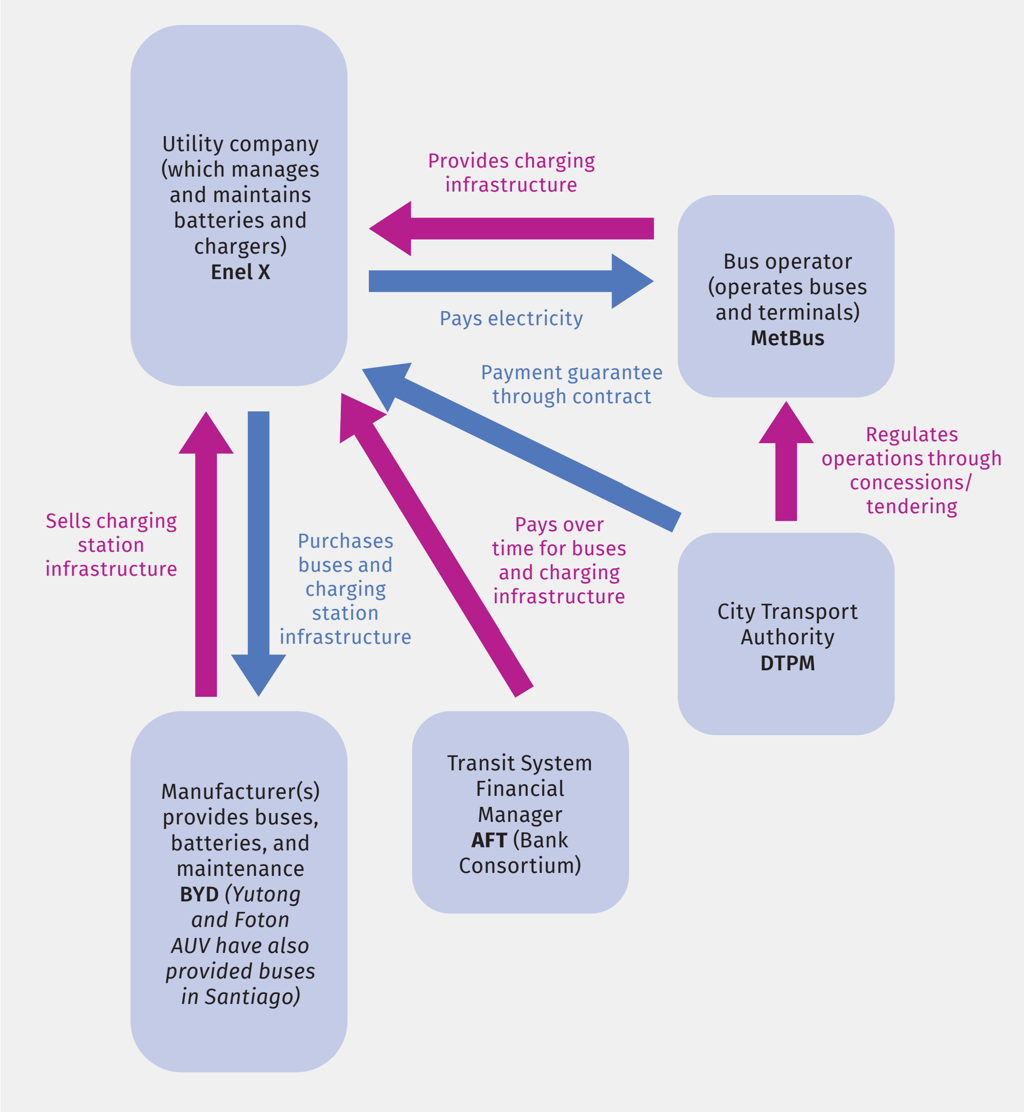
In Bogotá, Volvo's partnership with two private operators provided 300 hybrid electric buses for TransMilenio, the city's bus rapid transit system.[228] The cost of the buses was separated from the batteries, with the private operators buying the buses from Volvo, and the city agreeing to a 12-year leasing contract for the batteries. The contract involves a monthly installment fee to be paid by the city, which covers a five-year service agreement and 12-year protection contract.[229 230] Over this term, Volvo owns the battery until all installments are paid, after which the city of Bogotá owns the batteries of their buses. For the purchase of the buses, the private operators used concessional loans. The partnership reduced the upfront total cost of ownership and incentivized faster electric battery uptake.[231] Since these hybrid buses were adopted, Bogota has procured BEBs and will have over 1,400 by 2022.[232] Similarly, in São Paulo, battery leasing was used for 15 BEBs in 2018. For the pilot project, BYD helped finance the vehicles (with a 20% down payment and 60 months market rate). The city agreed to a battery leasing arrangement (R$ 9.500,00/month, equivalent to about USD $1,700/month) to be paid over 15 years. In this way, financing schemes can help reduce barriers for fleet financing but also for initial piloting.

228 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.
229 Welch et al. 2020. Moving Zero Emission Freight Towards Electrification.
230 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.
231 Automotive World. 2013. Volvo Sells 200 Hybrid Buses to Bogotá, Colombia.
232 Sustainable Bus. 2021. BYD in Colombia, the Awarding of a 1,002 Unit Tender for Transmilenio (Bogotá).

OPERATING LEASE ARRANGEMENT.
In this scheme, a third party purchases the agreed-upon assets (for example, buses) and leases the assets and/or infrastructure for operations. A utility ownership arrangement may be a form of an operating lease arrangement. Cities such as Santiago, Chile, and Portland, Oregon, U.S., have used this scheme with utility companies acting as the asset or infrastructure owners.[233] In Santiago, two separate utility companies own the buses and lease to the transportation operators.[234] Different variations of this scheme are increasingly popular. By separating the upfront costs among multiple stakeholders, this scheme can alleviate high capital cost challenges for the operator and provide stakeholders different benefits. For the manufacturer, this increases sales; for the operator, this speeds up electrification without incurring enormous financial responsibility; for the owner of buses/batteries (such as a utility company), this adds additional revenue and creates a stronger balance sheet; and for the capital provider, this expands their reach in the EV market while receiving steady pay back from the lessor.[235]

OWNERSHIP: Third party (such as a utility company)
CITIES USED: Santiago, Chile; Portland, Oregon[236]

UTILITY INVESTMENT AND OWNERSHIP (SANTIAGO, CHILE, EXAMPLE)



SOURCE:
Gomez Jattin (GIZ), 2019. Financial Mechanisms for Electric Bus Adoption.

233 Liu. 2019. The U.S. Electric Bus Transition: An Analysis of Funding and Financing Mechanisms.
234 Orbea (TheCityFix). 2018. How Santiago de Chile Became a Global Leader on Electric Buses.
235 Global Innovation Lab for Climate Finance. 2018. Pay as You Save for Clean Transport.
236 Liu. 2019. The U.S. Electric Bus Transition: An Analysis of Funding and Financing Mechanisms.

LEASING IN ACTION: PAY-AS-YOU-SAVE

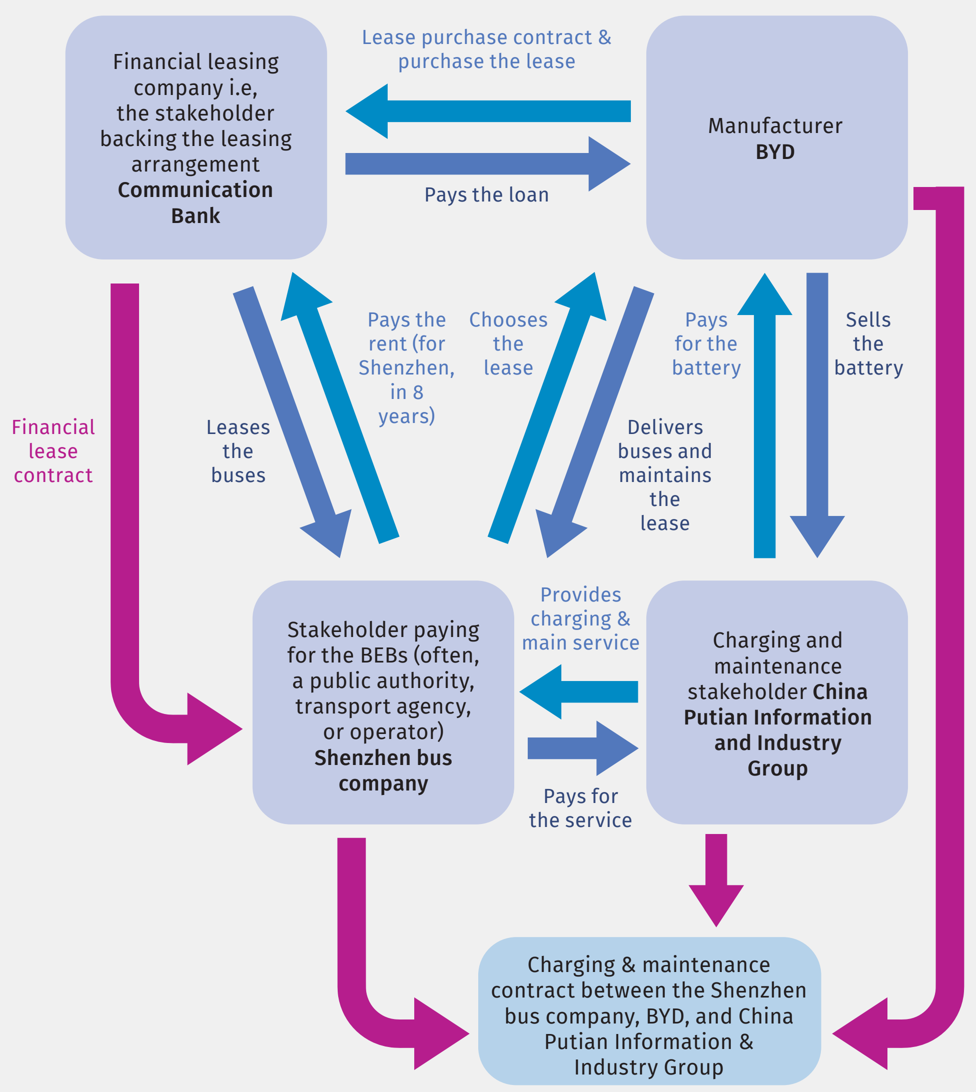
Similar to an operating lease arrangement, a PAYS program (pay-as-you-save) features a utility company (third party) that purchases the agreed-upon assets (batteries, charging infrastructure, buses, or others) and leases the assets and/or infrastructure for operations. The utility company may absorb the financial investment or lease batteries and buses to the public transportation agency. Capital investors may offer debt financing to the utility company if needed.[237] The utility company is paid back over time for its initial purchases of batteries or other infrastructure, and the operator may work toward owning the buses and batteries by the end of the lease.[238] PAYS is similar to an operating lease if the utility company owns the assets or to a financial lease if the operators eventually take ownership of the assets.

FINANCIAL LEASE ARRANGEMENT.
There are multiple types of financial lease arrangements, including direct leasing, after-sales leasing, and entrusted leasing. This scheme is similar to a loan, and it often involves multiple stakeholders. This differs from the component (bus/battery) lease and operating lease, as another stakeholder with capital for purchase then leases to the operators in this arrangement. Often the financial leasing company purchases the buses with or without batteries and leases the fleet to the bus operator, who pays the lease for a set time.[239] The contract must stipulate that the bus is rented with the battery for a certain period of time (for example, 15 years), and the lessor has to provide one change of battery after a certain period of time (seven or eight years) or when the batteries go beyond a certain threshold of their initial capacity. The bus operator pays both the initial cost and interest on the buses, while the financial leasing company is guaranteed income over time. The most notable example of a financial lease arrangement is in Shenzhen, China, where the city government, bus company, operator, financial leasing company, and electric bus production companies signed a BEB purchase and sales contract. In this case, the financial leasing company purchased only the buses (not batteries) and leased the fleet to the bus operator, who paid the lease for a set time (in this case, eight years).[240] The batteries were sold by BYD to the China Putian Information and Industry Group, which received payment for service from the Shenzhen bus company. In this scenario, the bus operator is guaranteed slow, longitudinal financial obligation, paying both the initial and interest on the buses. The financial leasing company is guaranteed income over time.[241] Iterations of this scheme have also been used in New York City and Warsaw.

OWNERSHIP: The financial lender owns the buses and batteries, and the public authority or transport agency signs a lease.[242] The operator may sign an asset care agreement with the lender(s). Alternatively, the public agency may prefer to sign the lease directly with the lender. In this case the termination of the operation contract does not involve the vehicles. It also opens the possibility of signing shorter operation contracts to create incentives for them to provide a better service. In this case, the transport agency can purchase the buses at the end of the leasing period.
CITIES USED: Shenzhen, China; New York City, U.S.; Warsaw, Poland

237 Global Innovation Lab for Climate Finance. 2018. Pay as You Save for Clean Transport.
238 Clean Energy Works, n.d. Tariffed On-Bill Finance to Accelerate Clean Transport.
239 Zhang. 2019. Analysis of "Shenzhen Model" for New Energy Vehicle Promotion in Public Transportation.
240 Zhang. 2019. Analysis of "Shenzhen Model" for New Energy Vehicle Promotion in Public Transportation.
241 Zhang. 2019. Analysis of "Shenzhen Model" for New Energy Vehicle Promotion in Public Transportation.
242 Miller et al. (ICCT). 2017. Financing the Transition to Soot-Free Urban Bus Fleets.

DIRECT LEASING (SHENZHEN, CHINA EXAMPLE)



ALTERNATIVE APPROACH TO REDUCING COST: BULK PROCUREMENT DISCOUNTS

In this arrangement, joint operators (such as transit agencies from different cities) aggregate their BEB purchase for larger fleet procurements that are then split among the various joined forces. This can be facilitated either through joint agreements or through larger state or regional-level procurement contracts that designate procurement for the given state or region.[243] San Francisco and Seattle used this model and jointly purchased BEBs from the Canadian company New Flyer.[244]

243 Liu. 2019. The U.S. Electric Bus Transition: An Analysis of Funding and Financing Mechanisms.
244 Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.

SPOTLIGHT ON FINANCIAL INCENTIVES FOR CAPITAL COSTS

The financing schemes above can be combined with financial incentives, which may reduce initial capital and operational costs. While financial risk and instability pose significant barriers to adoption, increasingly there are incentives for investment that the government can provide to mitigate risk for investment. These often center around public bodies incentivizing environmentally beneficial practices for the public and private sectors, or supporting the growth of industry. There are many kinds of financial investment incentives, including:

- Land grants (local, state, national levels),
- Duty tax breaks (national level),
- Value-added tax reductions (local and/or national level),[245] and
- Reduced tax on corporate profit (national level).[246]

A Solaris electric bus picks up passengers in Warsaw, Poland.
SOURCE: Janusz Jakubowski, Flickr.

6.3 OPERATIONAL COSTS

Operational and maintenance costs for e-buses will have similarities to ICE buses, such as administrative costs including taxes and insurance, personnel costs, as well as system upkeep (maintenance) and replacement costs. However, differences in operational costs include fuel costs (i.e., energy pricing for charging versus diesel), major maintenance (i.e., battery replacement versus engine overhauls), maintenance regimes, and end-of-life costs. ***Operational costs and maintenance for BEBs can offer significant cost reductions in comparison to diesel buses.*** A ZEBRA program study in Santiago found a 70 percent cost reduction for operations and maintenance.[247] Similarly, a 2018 European study found annual operational and maintenance costs for an electric bus were approximately one-third those of a diesel bus, at €12,600 EUR (approx. $15,100 USD) and €36,300 EUR (approx. $43,600 USD) respectively.[248] In Chicago, two pilot e-buses were estimated to annually save $24,000 (USD) in fuel costs and $30,000 in maintenance.[249]

245 Gomez Jattin (GIZ). 2019. Financial Mechanisms for Electric Bus Adoption.
246 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-electric Buses
247 ZEBRA, n.d. From Pilots to Scale: Lessons from Electric Bus Deployments in Santiago de Chile.
248 Potkany et al. 2018. Comparison of the Lifecycle Cost Structure of Electric and Diesel Buses.
249 Tigue. 2019. U.S. Electric Bus Demand Outpaces Production as Cities Add to Their Fleets.

BEBs may have lower operational costs due to lower energy (fuel) costs per kilometer and reduced costs of maintenance, but they will range depending on multiple factors, such as:

- Geographic area (which will change the cost of electricity as well as the battery performance depending on temperature, heating and cooling needs, and topography),
- Performance of physical assets (buses, batteries) and charging infrastructure, as well as performance of drivers and conditions of the service (i.e., congested, high demand),
- Debt financing costs,
- Energy demand (avoiding peak charging times can yield huge financial benefits over time),[250]
- Local policies (will hinder or enable a system when it comes to optimizing ongoing costs), and
- Financial incentives (tax breaks, etc.) available to a system.

People walk, cycle, and board a bus in Seattle, Washington, USA on a complete street. **SOURCE**: Green Lane Project, Flickr.

Operational and maintenance costs will include:

ELECTRICITY COSTS.
Generally, electricity costs per kilometer will average lower than diesel costs per kilometer. This depends greatly on the given urban area's energy demand and electricity costs, as well as the kind of charging. Energy costs vary by country and region, but they are likely structured as one of the following: fixed charge(s), which serve as a flat rate over time; energy usage charges, which fluctuate according to how much energy is used; or demand charges, which fluctuate according to when charging occurs (during peak or off-peak hours).[251] Pantograph or wireless charging may have greater costs given the higher capacity needed from the grid and the need to charge during on-peak electricity hours. Electricity consumption rates may vary according to: seasonal rates, time of use rates, or tiered rates (i.e., level of use).[252]

MAINTENANCE AND PREVENTATIVE MAINTENANCE COSTS.
While maintenance costs are likely lower given that less maintenance is needed for electric propulsion, the operator should plan for an adjustment period—especially in terms of building staff capacity to maintain an electric propulsion system versus an internal combustion propulsion system that is more mechanical. As electric buses do not require the same kind of upkeep as diesel buses because there is no engine to maintain and less wear on brake systems, it is likely that maintenance costs will be lower than those of ICE vehicles.[253] Electric buses are less intensive on brakes due to regenerative braking, in which the energy produced from braking goes back into the charging system.[254]

250 A study from Mobility House in Germany estimated that avoiding peak hours for charging a fleet of 15 BEBs would yield savings of $1.3 to $1.6 million USD (1.2–1.4 million euros) over 10 years. The Mobility House, n.d. Smart Charging for Your Electric Buses.
251 Edison Electric Institute. 2019. Preparing to Plug-in Your Bus Fleet: 10 Things to Consider.
252 Johnson et al. 2020. Financial Analysis of Battery Electric Transit Buses.
253 National Academy of Sciences, Engineering, and Medicine. 2018. Battery Electric Buses State of the Practice.
254 The University of Tennessee at Chattanooga, n.d. FAQs: Electric and Hybrid Buses.

COMPONENT REPLACEMENT AND/OR BUS OVERHAUL COSTS.
Of all ongoing costs, component replacement costs are the most difficult to predict, and likewise it is very difficult to determine if these costs would be more or less than those for traditional ICE vehicles. For this reason, Hanlin et al. (2018) recommend comparing costs based on mid-life overhaul expectations, as major components such as engines and batteries are created with the intent of replacement during a vehicle's lifetime.[255] For traditional diesel buses, the most expensive items associated with maintenance and upkeep are tires, oil, and engine overhauls. For BEBs, battery replacement represents the highest maintenance expense, along with tires and other technology replacements. Battery lifetimes are also uncertain, with warranties generally ranging from six to 12 years. Battery replacement for BEBs can be compared with engine overhaul for other fuel-based bus types.[256] While certain components (batteries) are more expensive than ICE vehicle components, there are fewer components in the BEB system and therefore less to replace.[257]

INFRASTRUCTURE IMPLEMENTATION AND MAINTENANCE COSTS.
Regardless of the charging infrastructure type (such as retrofitted depots with overnight charging, or opportunity and inductive charging along the route), it will require more costly maintenance than diesel refueling stations.

6.4 FUNDING OPERATIONAL COSTS

As operational costs for electric buses are often lower than those for ICE buses, operators or governmental agencies may be able to cover operational costs within the existing budget. However, as with funding for capital costs, it may be more financially sustainable for cities to consider innovative funding for operational costs. High upfront costs of BEBs leading to higher debt financing fees, decreased budgets in the wake of COVID-19, or concern with financial sustainability of adopting electric buses may mean that cities must turn to innovative funding schemes in which the operational costs are paid from other sources of revenue than just the farebox or by other stakeholders. While for many systems, fare revenues are used to pay operational costs. However, the COVID-19 pandemic has shown that this funding is not as resilient or as sufficient as cities may need in order to continue providing service.[258] The pandemic also showed how critical public transport is to the resiliency of the functioning of the city. New approaches to funding public transport service are needed to ensure that this critical service is provided. This includes more public sector investment in operations and looking at other revenue streams like advertising and congestion pricing. In some situations, costs for ownership and operations are separated between stakeholders so that the operator and/or government agency running the bus system does not face financial risk with both ownership and operations.[259] Cities will need to assess their ownership, financing, and funding options to find the best solution for their context.

Innovative financing for operational costs may include a financing stakeholder in charge of payment for charging, vehicle operations, and/or maintenance for buses and infrastructure. This may be a utility provider, such as in Shenzhen with the China Putian Information and Industry Group or in Santiago with Enel X. Alternatively, national or multilateral development banks, export–import banks, commercial banks, manufacturers, climate finance, or governments (through grants or incentives) may be financing stakeholders to consider.[260]

Governments and utility companies may offer financial incentives or preferential options that lower operational costs. These include:

- Operational expenditure grants (state or national government level) and
- Preferential pricing for electricity (from utility company).[261]

Operators and planning bodies should explore these possible incentives, such as preferential pricing for off-peak charging or limited demand charges from utility companies.[262] One-time incentives can trap municipalities into being on the hook for operations and maintenance that they can't afford without ongoing incentives (although BEBs often have significantly lower annual operating costs than traditional diesel buses). As such, consideration of the longer-term financial sustainability of this option should be considered by operators.

255 National Academy of Sciences, Engineering, and Medicine. 2018. Battery Electric Buses State of the Practice.
256 Miller et al. (ICCT). 2017. Financing the Transition to Soot-Free Urban Bus Fleets in 20 Megacities.
257 National Academy of Sciences, Engineering, and Medicine. 2018. Battery Electric Buses State of the Practice.
258 Graham and Courreges (IFC & C40). 2020. Leading a Clean Urban Recovery with Electric Buses: Innovative Business Models Show Promise in Latin America.
259 Graham and Courreges (IFC & C40). 2020. Leading a Clean Urban Recovery with Electric Buses: Innovative Business Models Show Promise in Latin America.
260 Miller et al. (ICCT). 2017. Financing the Transition to Soot-Free Urban Bus Fleets in 20 Megacities.
261 Seen in Vancouver, Canada. C40 Cities. 2020. How to Shift Your Bus Fleet to Zero Emissions y Procuring Only Electric Buses.
262 Horrox and Casale (U.S. PIRG). 2019. Cities in North America.

Financial incentivization through subsidies were critical to the incredible growth of electric buses in Chinese cities. Pictured, electric buses at a checkpoint in Shenzhen. The city's fleet has over 16,000 electric buses.
SOURCE:
Can Pac Swire, Flickr.

6.5 FINANCIAL MODEL

When planning financing for procurement and operations, it is critical to emphasize that the ***affordability and efficiency of transitioning systems to electric requires getting as close to a 1:1 ratio of electric bus to diesel/CNG bus as possible.***[263] Currently, bus providers may need 20 percent to 100 percent more electric buses than diesel/CNG buses to provide the same level of service. This is due to operational constraints from the charging requirements, which need to be further improved.[264] Achieving affordability for cities may require creativity, new stakeholders, and innovative financing schemes, such as component leasing, operating leasing, and financial leasing arrangements.[265]

The financial model for BEBs must address the differences in TCO for electric (higher upfront costs and lower operational costs) versus diesel buses (lower upfront costs and higher operational costs). When possible, planning bodies should leverage available funding and incentives for capital costs (procurement, infrastructure, and land grants; tax reductions) and operational costs (operational grants, preferential pricing). Cities will need to secure significant grants for capital costs or otherwise adopt a financing scheme that allows payment over time, payment assistance from third-party stakeholders (such as development banks, utility companies, environmental financiers, or manufacturers), and/or third-party ownership of system components (such as buses, batteries, or infrastructure).

For operational costs, cities may have sufficient funding to cover these reduced costs. In the event that they do not, grants or payment assistance from third-party stakeholders and/or third-party component ownership are common alternatives. The funding streams and financing stakeholders may differ between capital and operational costs.

BEBs require us to rethink the financial model for capital and operational costs, we must understand changes to the operational plan. The following section provides an overview of operations and maintenance planning for electric buses.

263 Miles and Potter. 2014. Developing a Viable Electric Bus Service: the Milton Keynes Demonstration Project.
264 Lowell (MJB & A). 2019. Electric Bus 101: Economics, Politics, Myths & Facts.
265 Graham and Courreges (IFC & C40). 2020. Leading a Clean Urban Recovery with Electric Buses: Innovative Business Models Show Promise in Latin America.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OPERATIONS AND SERVICE PLANNING

7

Operations and maintenance planning will need to change with the adoption and transition from diesel or CNG buses to BEBs. There will be changes in route planning, infrastructure, refueling/charging schedules, and maintenance practices. The lower range distances of BEBs means that there are ramifications for scheduling services, both in terms of how many buses are needed to perform the service and how to schedule refueling. Because of this, BEBs cannot just replace the existing services performed by diesel buses one to one; this approach will lead to a higher replacement ratio or higher costs with charging infrastructure. To analyze and select feasible models for charging, batteries, and financing, service planning needs to be done first—those inputs will form the basis for the financial model, and they may need to be revised because of that. Planning services for BEBs enables operators to better understand:

- What type of **charging infrastructure** fits the needs and considerations of the system and bus services,
- How much **power** each bus depot needs,
- Where and when to **charge each e-bus** during daily operation,
- What types and how many **batteries** are needed,
- How many **buses** will be needed to provide the new service, and
- How does this intersect with **demand and passenger loads**, and how should e-buses be allocated to different route configurations accordingly.

Given the differences in how battery electric and diesel or CNG buses operate, BEBs also afford an opportunity to review network design and route planning.[266] Planning services and schedules are often relics of decades-old planning decisions. BEBs can allow for larger system changes that transit agencies have wanted to implement but lacked the political will or capacity to do so. If some changes in service design are required, that can be a wedge to open the door to more changes, such as bus-only lanes, BRT, off-board fare collection, level boarding, or more equitable fare payment systems.

Operational success will be directly tied to battery range, stability, and maintenance. A multitude of factors may reduce battery range, including frequent stops, extreme temperatures (both hot and cold), challenging topography (hills, etc.), passenger loads, internal conditioning (heating, cooling), and heavy traffic (as discussed in Section 2, Battery Electric Buses). This section overviews planning for routes, hardware, software, operations, and maintenance and provides best practices.

OPPOSITE PAGE
An electric bus moves past pedestrians and parked bikes in Shenzhen, China.
SOURCE: Wiaauquaiu, CC BY-SA, Wikimedia Commons.

266 Hall et al. 2019. Adjustments to Public Transit Operations Planning Process for the Use of Electric Buses.

SPOTLIGHT ON ITDP CHINA: OPERATIONS AND MAINTENANCE BEST PRACTICES

Over the past few years, ITDP China has worked with other NGOs to develop policy and strategies to fully electrify bus fleets throughout the whole country. These studies were utilized by the Ministry of Industry and Information Technology to inform policy. Lessons learned in China include:

MEET WITH THE UTILITY EARLY IN THE PLANNING PROCESS
Stakeholders in charge of planning, financing, and managing, such as operators and/or government, need to meet with the utility company during the planning stage to consider local grid capacity and electricity pricing. This alters and defines plans for other e-bus specifications, such as bus route information, charging time, location, and daily electricity consumption.

ESTABLISH A PLAN FOR OPERATIONS AND CHARGING BEFORE PROCUREMENT
Cities need to have a concrete e-bus operational plan and charging plan prior to procurement to make sure that the e-bus configurations match the ridership, daily driving distance, and operational time of the designated bus routes. The experience in Chinese cities shows that not having this or some operational standards can lead to poor replacement ratios. A plan for what to do with the diesel buses that are being replaced is also important to maximize overall environmental benefits.

USE REAL WORLD OPERATIONAL DATA
Operators should use operational data from pilots and comparable cities to guide planning e-bus procurement, optimize operational plans, and establish a charging plan. In addition, collecting data regularly is important for evaluating and improving operations and services.[267]

OPTIMIZE OPERATIONAL EFFICIENCY WITH DATA
While there has been widespread adoption of electric buses in China, a lack of guidance on how to deploy them effectively on routes has frequently led to poor replacement ratios. This results in less frequent and more expensive operations. In response, ITDP China conducted a study on developing the schedule timetables and road maps for 75 major Chinese cities to phase out ICE buses. The 75 cities were divided into four levels, and all four city levels are projected to achieve full e-bus operation by 2028. ITDP identified the most important e-bus operational data metrics and built a matrix to evaluate BEB operations and improve efficiency. For example, evaluating bus fleet capacity by calculating passenger capacity and replacement ratio, and evaluating service level by calculating average operational hours and failure rate. These metrics and their associated calculations are listed in the Appendix.

267 ITDP China. February 2021. Personal communication.

An electric bus on route in Shanghai, China.
SOURCE: ruich_whx, Flickr.

OPERATIONS FOR PILOT TO FLEET TRANSITION: ANTICIPATING FLEET DIVERSITY

Cities must use pilots as an opportunity to learn about electrification and train personnel accordingly. From the outset, pilots should be informative and scalable, including the operations and maintenance transition to new hardware and software.[268] As the transition will happen over many years, operators and maintenance personnel must plan to attend to a diverse fleet composition during the transition.[269] This may include different practices on- and off-route, such as new parking schemes to accommodate charging infrastructure while holding buses out of service (waiting for disposal) or buses waiting for charging.[270]

Cities such as Washington, D.C. not only have a mixed fleet composition (they have electric, hybrid electric, and diesel buses present in the metropolitan area) but have multiple bus systems intersecting. Buses from WMATA, the operator for D.C. proper, and Ride-on, the operator for Montgomery county, Maryland, are pictured.
SOURCE: BeyondDC, Flickr.

268 [Bouslog (Burns McDonnell). 2018. Electrifying the Nation's Mass Transit Bus Fleets.]
269 [Hall et al. 2019. Adjustments of Public Transit Operations Planning Process for the Use of Electric Buses.]
270 [ChargePoint. 2020. What It Takes to Manage an EV Fleet.]

An electric bus charging station in Gothenburg, Sweden. **SOURCE:** Andrzej Otrębski, CC BY-SA 4.0, Wikimedia commons.

7.1 CHARGING INFRASTRUCTURE PLANNING

Implementing charging infrastructure intelligently is imperative to the success of the system. This will affect operations by determining how much time buses are out of service for recharging and how long their routes can be before they need to be recharged either through fast charging along the routes or returning to the depot.[271] Charging type, schedule, and operations will also affect how many buses need to be procured and the financial model. Moreover, procuring and implementing charging infrastructure will be a time-intensive aspect of the electric transition, as it will involve multiple stakeholders (city governments, transit operators, utility companies) and often requires electricity grid extensions, land use changes, and depot retrofitting or construction.

Planning stakeholders should consider multiple stages of electrification when planning and modeling to ensure long-term compatibility.[272] Infrastructure must be planned and installed prior to bus deployment and operations. Installing BEB charging infrastructure will be an extended process and should be planned at least 18 months before charging infrastructure is to be utilized.[273][274] Even before charging infrastructure, the installation of electric grid extensions alone can take up to two years.[275] Given the extended timeline, charging infrastructure installation can be highly challenging from an administrative perspective.[276] In the ZeEUS London pilot, the most difficult challenge throughout the process was installing the charging infrastructure.[277] In Washington, D.C., U.S., the BEBs for the pilot arrived before the depot had been fully retrofitted with charging infrastructure, requiring the city to buy generators in order to keep the batteries somewhat charged while they finished the upgrades. As with everything else for charging, the installation process will vary based on the charging infrastructure type. Specific attributes are necessary for different infrastructure:

271 Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.
272 Lin et al. 2019. Multistage Large-Scale Charging Station Planning for Electric Buses Considering Transportation Network and Power Grid.
273 UITP, n.d. ZeEUS Warsaw (PL).
274 UITP, n.d. ZeEUS Warsaw (PL).
275 California HVIP, n.d. Infrastructure.
276 UITP, n.d. ZeEUS Pilsen (CZ).
277 UITP, n.d. ZeEUS London (UK).

ON-ROUTE.

On-route charging—pantograph or inductive charging—should be well located in relation to routes and the infrastructure of the power grid. Often this will be at bus stations, bus route end-points, or stations or stops where multiple bus routes intersect. A key issue for deciding where these should be is whether there is adequate land available for charging infrastructure. It will usually take five to 20 minutes to charge, so buses will need to pull into a separate area for charging, like a docking bay at a station or a closed area off-route.[278] Passengers can be on board when charging is taking place.

DEPOTS.

Regardless of charging type, bus depots will need to be retrofitted or constructed for BEB infrastructure. Bus depots should accommodate and provide convenient access to charging infrastructure, which will likely demand 15 percent to 30 percent more floor space than an average depot.[279] How much storage room a given system requires is dependent on the type of charging mode (overnight plug-in, opportunity overhead). If operators are unable to create new depots or add more space to existing ones, one option is to construct a shell on top of existing depots.[280] In this scenario, the shell provides an additional area for charging equipment, which may reduce installation costs, as wiring is installed overhead not underground.[281] Because batteries may degrade more quickly in high temperatures or perform worse in colder temperatures (and buses will use more energy to heat or cool a bus), planners should ensure that battery charging is in an adequately covered and ventilated place and that there are sufficient facilities for heating or cooling electric hardware, taking into account sensitivity to local weather and seasonal fluctuations.

SMART CHARGING HARDWARE AND SOFTWARE

BEB-specific hardware and software play a particularly important role in electric charging, as charging is not as simple as fueling or plugging in a charger. Smart charging hardware that is managed with software becomes critical for understanding fleet state of charge (SOC), energy demand, and charging scheduling to minimize operational costs.[282] For efficiency and ease of use, BEB charging software should be integrated with other software, including routing and dispatching, as well as external services such as traffic management.[283]

ChargePoint stations in Santa Clara, California. **SOURCE:** Santa Clara Valley Transportation Authority, Wikimedia Commons.

278 Rogge et al. 2015. Fast Charging Battery Buses for the Electrification of Urban Public Transport—a Feasibility Study Focusing on Charging Infrastructure and Energy Storage Requirements.
279 UITP. 2019. The Impact of Electric Buses on Urban Life.
280 Bouslog (Burns McDonnell). 2018. Electrifying the Nation's Mass Transit Bus Fleets.
281 Bouslog (Burns McDonnell). 2018. Electrifying the Nation's Mass Transit Bus Fleets.
282 ChargePoint. 2020. What It Takes to Manage an EV Fleet.
283 ChargePoint. 2020. What It Takes to Manage an EV Fleet.

Planning and modeling route infrastructure will depend on the kind of BEB charging system a transit agency decides to utilize and what is feasible given geographic constraints.[284] The three main charging infrastructure types (traditional plug-in, pantograph charging, and inductive charging) all require different kinds of infrastructure and land area. When planning for capital costs of charging infrastructure, operators and related planning stakeholders should consider:

- Charging station hardware,
- Charging station construction and implementation,
- Available space and grid connections, including land acquisition costs,
- Labor costs for construction and implementation (including preconstruction costs such as personnel for on-site consultations), and
- Municipal permitting costs.[285]

BEST PRACTICE FOR CHARGING INFRASTRUCTURE PLANNING: WORK WITH THE UTILITY COMPANY

Planners should establish direct communication with electric companies to foster a partnership that yields benefits to public transportation and utility companies alike. The feasibility of different charging schemes (both financially and physically) will depend on the willingness of the utility company to collaborate.[286] This collaboration may include offering financing or infrastructure schemes that lessen the financial burden on transportation agencies as well as ensure that the fleet charging will not cause preventable strains on the energy grid.[287] Planners should understand the existing electrical service at depots early on, and utility companies will be a key resource for estimating if current service is adequate to support a program.[288] Electricity companies will have critical insight on:

- How electricity pricing fluctuates locally and what financing schemes are feasible for electric operations,
- Electricity pricing estimates for initial charging and long-term TCO,
- How to plan electrical upgrades for full fleet transition,
- What permitting is necessary for electric grid extensions, and
- Necessary service and infrastructure upgrades for creating or retrofitting bus depots (taking into account size of depot, as well as maximum number of buses charging at one time and at what power level).[289]

Understanding this will help operators estimate TCO, including the ongoing operational costs, while evaluating the feasibility of charging types and timing of charging infrastructure installation. If possible, transportation agencies should collaborate with local government and utilities to develop transportation-specific electricity rates, and they should use (offered or agreed upon) financing schemes in planning models to best prepare for ongoing costs.[290] This is an iterative process: As the charging infrastructure plan is developed, it needs to be tested against the financial plan and the operational plan. It is important to understand the operational implications of different styles of charging.

BEST PRACTICE FOR CHARGING INFRASTRUCTURE PLANNING: REDUCING ENERGY COSTS

While evaluating the operational costs for charging, planning stakeholders should consider tactics that may reduce charging costs, including:

- Distributing charging infrastructure to reduce demand at one location,
- Using lower-power charging over longer periods of time (such as overnight charging),
- Staggering bus deployment to stagger charging times,
- Reducing charging during peak hours (if electricity pricing will increase due to demand hours and usage),[291]
- Setting a charging cap on depot(s) or charging station(s), and
- Maintaining backup storage for emergencies or for use during peak charging hours.[292]

Additional optimization strategies for energy storage include adding decentralized storage (energy stored outside of the main electric grid, such as separate, smaller solar-powered grids or generators), constructing depots as smart buildings (equipped with their own form of capturing and storing electricity, such as solar panels), and maintaining a digitalized energy-management system, which can instruct operators when to charge based on demand, real-time energy pricing, and weather variance.

284 Bak et al. 2018. Strategies for Implementing Public Service Electric Bus Lines by Charging Type in Daegu Metropolitan City, South Korea.
285 National Academy of Sciences, Engineering, and Medicine. 2018. Battery Electric Buses State of the Practice.
286 Horrox and Casale (U.S. PIRG). 2019. Cities in North America.
287 Edison Electric Institute. 2019. Preparing to Plug-in Your Bus Fleet: 10 Things to Consider.
288 Bouslog (Burns McDonnell). 2018. Electrifying the Nation's Mass Transit Bus Fleets.
289 Edison Electric Institute. 2019. Preparing to Plug in Your Bus Fleet: 10 Things to Consider.
290 Horrox and Casale (U.S. PIRG). 2019. Cities in North America.
291 Horrox and Casale (U.S. PIRG). 2019. Cities in North America.
292 Edison Electric Institute. 2019. Preparing to Plug in Your Bus Fleet: 10 Things to Consider.

BEST PRACTICES FOR CHARGING INFRASTRUCTURE PLANNING: MODELING

Adequate charging infrastructure planning through modeling, research, and system analysis is of high importance, as charging infrastructure is immobile and expensive but will affect how services are deployed and how buses will be needed to perform those services. Investment in fast charging may reduce costs of operations in the long run by reducing the number of buses needed to provide service. Using modeling to bring together all the inputs from existing origin–destination trip models, the existing services and routes, existing depot locations, and grid connections can help identify the best routes for pilots, best infrastructure location (depots, charging infrastructure), and how existing routes and infrastructure can be adjusted for scaling the fleet. In addition, models can find the optimum routes for the estimated range of bus batteries if an agency is interested in changing routes to accommodate the greatest access for riders and the battery range.[293] This is important for charging types that require periodic charging throughout the day. If charging infrastructure is too far apart or too close together, or if seasonal fluctuations greatly change the BEBs' range, the fleet may not be able to complete normal service operations year-round. In this event, operators may need to purchase additional buses, reducing the possibility of having as close as possible to a 1:1 replacement ratio of diesel buses with BEBs. For the ZeEUS program in Münster, Germany, appropriate charging infrastructure was key to the reliability of buses.[294] Changing charging type from fast charging to overhead pantograph charging increased operational capacity in Münster and improved service.

In many cities, land use restrictions, as well as existing infrastructure that must be retrofitted, pose significant challenges to optimizing infrastructure locations while ensuring financial and logistical feasibility. For example, in the Foothill Transit pilot in Southern California, the use of overhead charging meant that the fast-charging stations along the route had to be placed where Foothill Transit had the rights to install the infrastructure.[295] This is a particular difficulty in complex urban areas with high density and limited land availability. In China, restricted land availability is cited by many cities as a significant barrier to the adoption of fast charging on-route.[296]

BEST PRACTICES FOR CHARGING INFRASTRUCTURE PLANNING: ENSURING STABILITY AND SUSTAINABILITY

Infrastructure planning should consider how to ensure a stable energy source and plan for resiliency strategies in the event of electrical grid failure. Stability of the electric grid is particularly important if the entire system requires electricity to run. When crises such as natural disasters occur, operators need to have a backup electric system to continue supporting the public. Redundancy is at the heart of resiliency for BEB systems.

As a strategy to both improve resilience of the system and increase environmental benefits, planners should consider integrating sustainable energy options into system infrastructure.[297] Some tactics that transit agencies may employ for resilience by lowering the risk of power outages include:

- Backup diesel, hybrid, or CNG buses,
  Backup generator (normally diesel or CNG),
- Adding renewable energy options to the grid, such as solar panels or wind turbines,
- Multiple connections to the grid (in the event that part of the grid is down, the operator
- may still charge the fleet with other connections), or
- Local or decentralized battery power generation and storage (such as solar panels, smart buildings, or microgrids).[298 299]

This movement toward energy-efficient buildings alongside electric vehicle adoption is underway in multiple cities. For example, New York City and Shanghai have incorporated solar panels into their electric bus depots.[300 301] By increasing the energy efficiency of the system by adopting energy-efficient technology and buildings—as well as transitioning to renewable energy through solar and wind—cities can use less energy and thereby increase the reliability of their electrical grids.[302]

293 Bak et al. 2018. Strategies for Implementing Public Service Electric Bus Lines by Charging Type in Daegu Metropolitan City, South Korea.
294 UITP, n.d. ZeEUS Munster (DE).
295 National Academy of Sciences, Engineering, and Medicine. 2018. Battery Electric Buses State of the Practice.
296 ITDP China. May 2020. Personal communication.
297 World Economic Forum. 2018. Electric Vehicles for Smarter Cities: The Future of Energy and Mobility.
298 Bouslog (Burns McDonnell). 2018. Electrifying the Nation's Mass Transit Bus Fleets.
299 APTA. 2020. Resiliency for Battery Electric Buses: Best Practices & Future Studies.
300 Sustania. 2019. Buses Go Truly Zero Emission With Solar Power.
301 Evarts. 2019. New York to Add Solar to Transportation Hubs.
302 APTA. 2020. Resiliency for Battery Electric Buses: Best Practices & Future Studies.

INCENTIVIZING CHARGING INFRASTRUCTURE INSTALLATION

Investments in charging infrastructure are critical, as a lack of infrastructure prevents BEB system success. In China, recent attention by the government to subsidizing charging infrastructure has been important to growth. However, land use restrictions (i.e., a lack of available land for charging infrastructure development) are a barrier for charging infrastructure in Chinese cities, as with many cities globally. In general, there are a few models for charging infrastructure, in which different actors act as the instigator(s) for charging infrastructure growth. Table 7 summarizes these different models:

MODEL	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Government-driven (i.e., public)	The government is the main investor for charging infrastructure and is responsible for its construction and operation	+ Conducive to well-organized and intensive development (assuming efficient government capacity and management) + May allow for overcoming barriers in beginning until costs lower due to scale + May relieve some stress on the financial model	- Depending on government funding, is less sustainable over the long term (if the initial investment is from government, this model can enable scaling over time until the private sector can catch up and/or costs reduce)
Enterprise (i.e., private) driven	Enterprise (i.e., manufacturers and others) is the main investor for charging infrastructure and is responsible for its construction and operation	+ More financing available + Higher-quality operations and management	- This model is not conducive for orderly market development - Cost will be passed on to the government or passengers through higher operational costs
Mixed model	Enterprise plays an important role under government supervision and support	+ High efficiency for operations + Avoids unsustainable development and/or operations that are in conflict with government's interest for the public	- Highly dependent on enabling policy

TABLE 7
Comparison of different charging infrastructure adoption and growth models.

In the United States, incentive programs have largely centered around reducing upfront capital expenditure. Yet programs such as the California HVIP Infrastructure Incentives have subsidized the installation of charging infrastructure in tandem with subsidies for zero-emission heavy-duty vehicles. This funding came from the State of California's cap and trade program, which has raised over $1 billion USD since 2013.[303] While the program is no longer in effect as of 2019, this kind of financial incentivization program for charging infrastructure should be pursued through public policy to enable BEB adoption.[304]

303 Tigue. 2019. U.S. Electric Bus Demand Outpaces Production as Cities Add to Their Fleets.
304 California HVIP, n.d. Infrastructure.

Careful planning of battery charge is important for high capacity routes.
SOURCE: ITDP China.

7.2 ROUTE PLANNING

Traditionally, routes are developed based on a few factors: trip origin and destination needs of the public, ridership, urban expansion, and future demand.[305] 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. With the more limited battery performance of BEBs (particularly in comparison with fuel-based buses), operators may need to adjust system routes because of battery performance. ***Cost efficiency of BEBs is dependent on achieving as close as possible to a 1:1 replacement of fuel-based buses with electric buses, which is directly tied to optimized operation routes and scheduling.***[306] Adequate route planning can help ensure that a system is financially optimized for planning and funding stakeholders as well as reliable for passenger stakeholders.

As with charging infrastructure, modeling routes allows for operators to optimize and improve service. E-buses will change route and operations planning given infrastructure and performance constraints such as the need to schedule time for charging of BEBs.[307] Charging infrastructure and battery performance are the two biggest factors that will affect operational planning. When route planning for BEBs, operators must consider:

EXISTING INFRASTRUCTURE AND GRID PARAMETERS.
Routes must best utilize existing charging infrastructure, ensuring that buses can complete services and return to depots or charging stations without running out of power. Evaluating the local grid capacity and estimated costs for different charging profiles (if applicable along routes) should be done with utility company expertise.

MAXIMUM RANGE, ROUTE LENGTHS, AND CHARGING SCHEDULE.
The maximum e-bus range is often around 200 km to 300 km for plug-in vehicles, although range is continually improving with evolving technology, and some batteries and conditions enable a range of up to 500 km. Each bus should have a battery minimum for returning to depots or other charging infrastructure, which will depend on the given city.[308] A general rule is having no less than 10 percent to 20 percent of battery charge, to both prevent stress on the battery and to ensure sufficient charge for returning to the depot. The specific BEB range limits how many times a BEB can perform a complete route. Systems with long routes, high kilometers traveled, or substantial financial support can consider on-route charging. If many buses arrive at the depot at the same time for charging, this may increase demand and thus overall charging costs for a system. By staggering the return times of buses to the depot(s), operators may optimize electricity costs by reducing the total number of buses charging concurrently.[309]

305 Bouslog (Burns McDonnell). 2018. Electrifying the Nation's Mass Transit Bus Fleets.
306 Lajunen. 2014. Energy Consumption and Cost-Benefit Analysis of Hybrid and Electric City Buses.
307 Hall et al. 2018. Adjustments of Public Transit Operations Planning Process for the Use of Electric Buses.
308 ITDP China. 2020. Research on Roadmap of Phasing Out Traditional Internal Combustion Vehicles in Public Sectors in Chinese Cities.
309 Edison Electric Institute. 2019. Preparing to Plug in Your Bus Fleet: 10 Things to Consider.

ROUTE TOPOGRAPHY AND CLIMATE.

While many pilots have found challenges in battery performance with hilly cities or those with temperature extremes, this varies from location to location. Pilots in Seattle found greater depletion for routes with ample hills.[310] Pilots in North American and Brazilian cities have found significant challenges with extreme hot weather. Similarly, pilots in North America and Europe have found significant battery depletion with extreme cold weather. However, for the ZeEUS Barcelona program, system operators found little energy consumption difference between hilly routes to flat routes and that energy consumed ascending is nearly recouped when descending (in part due to regenerative braking).[311] Topography and climate will have varying effects on BEB performance, so pilots are necessary for assessing local challenges.

HOW TO ACCOMMODATE HIGH-CAPACITY ROUTES (PARTICULARLY DURING PEAK HOURS) AND BUS WEIGHT CAPACITY.

BEB batteries are drained at a faster rate with heavier loads (i.e., higher capacity), particularly on challenging routes due to topography, climate, or peak hours. Batteries add weight to an e-bus and reduce the maximum capacity limit (when comparing similar electric and ICE models, to accommodate vehicle weight restrictions for a given city's roads). As a result, operators need to consider how to accommodate capacity during peak hours to accommodate all passengers in high demand corridors, such as whether to increase the number of buses.

Best practices for route planning include:

PLAN AND UNDERSTAND BATTERY PERFORMANCE THROUGH ROUTE SIMULATIONS.

In Los Angeles, Foothill Transit studied how to optimize routes for BEBs operations based on driving range, daily route characteristics (i.e., stops, charging speeds) , and charging opportunities. To do so, cities should conduct route analysis and route simulations, to determine how BEBs could meet range requirements while optimizing battery performance.[312] These analyses should consider how varying demand (weight of the bus), driving style, and number of stops affects battery performance.[313 314]

COLLECT DATA TO IMPROVE SERVICES.

When planning new or adjusted routes, system operators should monitor operational data for different routes in their system. For U.S. cities, pilots in King County, Washington and Albuquerque, New Mexico faced challenges with battery depletion from weather and topography (too cold and hilly for the former, too severely hot for the latter).[315] This data

Route planning for electric buses, if changing existing routes, should involve community planning. Passengers walk onto a bus in Rio de Janeiro, Brazil. **SOURCE:** ITDP Brazil / Stefano Aguilar, Flickr.

310 Horrox and Casale (U.S. PIRG). 2019. Cities in North America.
311 UITP, n.d. ZeEUS Demonstrations (Barcelona).
312 Eudy & Jeffers (NREL). 2017. Foothill Transit Battery Electric Bus Demonstration Results: Second Report.
313 Wilson. 2020. To Get More Electric Buses, We Don't Just Need a Better Battery, We Need a Better Grid.
314 Kunith et al. 2017. Electrification of a city bus network—an optimization model for cost-effective placing of charging infrastructure and battery sizing of fast-charging electric bus systems.
315 Horrox and Casale (U.S. PIRG). 2019. Cities in North America.

during early (or even mature) phases of electrifying bus fleets can help modeling efforts, as well as other forms of analysis that may adjust operator behavior, route requirements, and system planning.

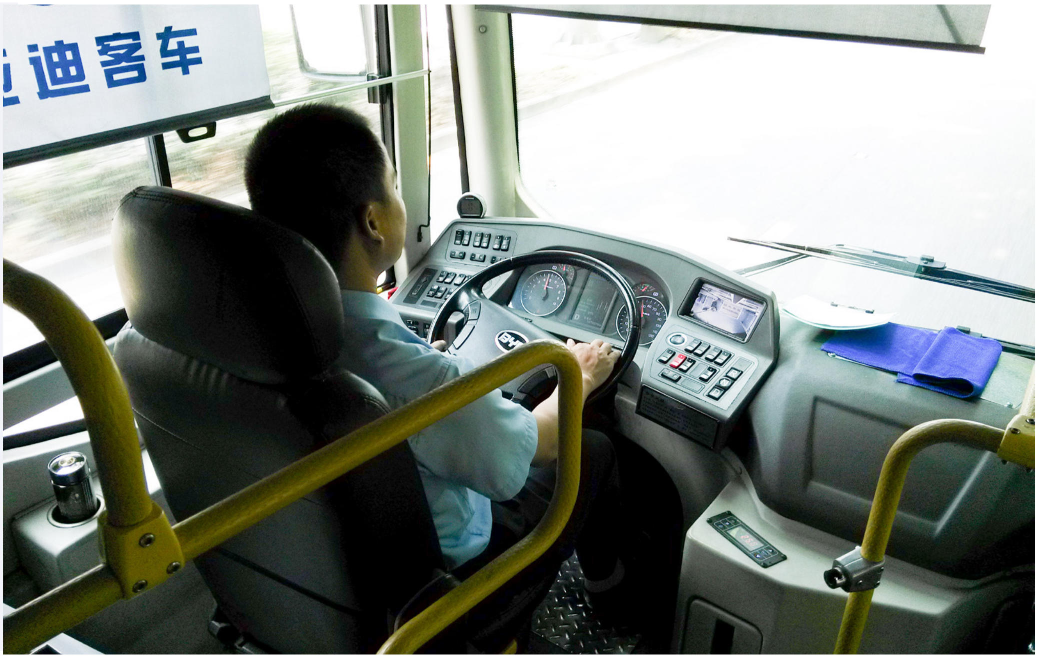
ADD CHARGING TIME TO THE ROUTE SCHEDULE, AND ADJUST ROUTES TO BE CLOSE TO CHARGING OPPORTUNITIES.

As BEB charging presents different requirements for when and how long to 'refuel' a given bus, the timetable for a system's routes must adjust. In Albuquerque, operators found that adding charging time to the route schedule (for pantograph charging) helped instill the necessary charging time requirements and set realistic expectations, which assisted in route performance.[316] Data collection during the pilot phase for charging time is necessary as well as how to best optimize this with the route schedule is important for accurately recasting route schedules. Operators should also consider adjusting the charging schedule around high traffic periods, particularly for vehicles on routes without dedicated lanes or during months with more challenging weather conditions, when BEBs will consume a lot of charge on congested roads. For infrastructure locations, when charging stations (whether at depots or on-route) are close to the starting and ending points of routes (i.e., 1 km or less), battery life over the course of the route can be optimized instead of wasting energy getting the bus to the route.

USE PARTICIPATORY PLANNING AND BUILD COMMUNITY.

System operators and planners should work to include passengers in route planning to ensure that changes are beneficial to users and to garner project support.[317] If changes are needed in route design or service planning, operators and planning stakeholders should create educational campaigns to inform the community of all upcoming changes. This will encourage community participation and feedback, and it will ensure that all community members are informed. Input to planning is a way to ensure that the changes are meeting the needs of the local communities, and cities should not use a top-down educational model. In addition, as the goal of electrification is often to achieve environmental targets, electric adoption is an opportunity to stop and understand how environmental justice is directly tied to equity. Through participatory planning actions, operators may be able to leverage other community-oriented changes for the transportation system, such as building a local constituency for transit, advocating for modal integration for improved service, and adopting complete streets redesign, including improvements to basic services if doing a street rebuild.

Other best practices that pertain to route planning are included in the operations best practices below.



Driving training is imperative for safe electric charging and extending the battery life for electric bus operations. **SOURCE:** Linuxthink, CC BY-SA 3.0, Wikimedia Commons.

316 Wu (APTA), n.d. (presentation). Lessons Learned From Operating Battery Electric Buses in the Real World.
317 Grengs. 2007. Community-Based Planning as a Source of Political Change: The Transit Equity Movement of Los Angeles' Bus Riders Union.

7.3
OPERATIONS AND MAINTENANCE PLANNING: CONSIDERATIONS AND BEST PRACTICES

BEBs require new technologies, infrastructure, operations, and maintenance. There are unique opportunities for BEBs to reduce cost as well as improve battery performance through operations and maintenance. Over a vehicle lifetime, operational costs of charging can yield significant savings over fueling (as mentioned in previous sections). In some areas of India, operations (fuel, tires, staff, etc.) and maintenance (preventative care and responsiveness to problems) of electric buses have been found to cost almost four times less than those of diesel buses, while other areas, such as Pune, have found electric bus operations to be just 1.5 times less than diesel buses.[318] This range is due to the huge variations in prices quoted by operators during bids as well as the variation in operating kilometers.[319] A major advantage of BEBs is that the propulsion system is less complex and has fewer parts; thus, BEBs require less frequent maintenance.[320] In addition, fewer components means that accessing and replacing them is quicker, resulting in lower maintenance labor costs.[321] For example, in the Foothill Transit pilot in Los Angeles, maintenance labor and tire costs represented the greatest proportion of maintenance costs for BEBs, while propulsion-related costs and maintenance labor were greatest for CNG buses.[322] Proper management can extend daily battery performance as well as the longevity of all physical assets, infrastructure, and technology of the new system. Considerations and best practices are reviewed below to explore how operators can optimize operations and maintenance to yield low annual costs and competitive total cost of ownership for BEBs.

OPERATIONS AND MAINTENANCE CONSIDERATIONS

BEB performance, while becoming increasingly more dependable with new technologies, remains a significant consideration for adoption as well as an ongoing challenge for operations and maintenance. System operators should anticipate a range in performance for a given vehicle fleet and prepare to collect data on an ongoing basis to track fluctuations in performance seasonally and per route. A ZeEUS BEB pilot in Bonn, Germany, found that it is not currently feasible to replace a diesel bus with an electric bus on a 1:1 ratio.[323] Current best practices show that a ratio between 1.1 to 1.5 : 1 is favorable. ***How close a system is able to reach 1:1 will depend on adequate planning and route scheduling, optimization and dependability of battery performance, and the actual (versus expected) performance of BEBs.*** As such, it is important to understand considerations and opportunities for optimizing operations and maintenance. New BEB-specific operations and maintenance challenges may include:

> **DOCKING FOR CHARGING.**
> Training drivers to dock buses for appropriate charging is crucial for successful operations. This will depend on the kind of charging technology and infrastructure layout. In the Foothill Transit pilot, operators had to relearn to dock, as fuel buses require deceleration while electric buses need acceleration.[324] The team concluded that detailed and ongoing driver training was an important step in successful operations. In Albuquerque, with pantograph (overhead) charging, the project team found training drivers to properly park and use the overhead style of charging was a challenge.[325]
>
> **TRAINING FOR NEW "FUEL" MINIMUMS AND CONSERVING BATTERY CHARGE.**
> BEBs will have a different range than conventional fuel buses, and it may vary from route to route. Drivers may be unfamiliar with how much charge is needed to complete a full route or to get the bus back to the depot.
>
> **FULLY SHUTTING DOWN THE BUSES.**
> The lack of noise emitted from electric buses may lead to drivers to not fully shut down a bus once it's back in the depot. Foothill Transit had to replace multiple low-voltage starter batteries due to multiple times when the battery was left running.[326]
>
> **MANAGING CHARGING.**
> Charge capacity for each bus may fluctuate in ways that are less familiar to bus operators who are used to conventional buses. Managing a fleet's charge capacity and ensuring that all buses are at optimized charge is a common challenge in electric bus pilots and scaling fleets.

318 pManifold. March2020 (presentation). Shifting the Gears—Towards Electric Buses: Basics of e-Buses: The Relevance and Possibilities.
319 Personal communication, ITDP India, March 2021.
320 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.
321 The University of Tennessee at Chattanooga, n.d. FAQs: Electric and Hybrid Buses.
322 Eudy et al. (NREL). 2016. Foothill Transit Battery Electric Bus Demonstration Results.
323 UITP, n.d. ZeEUS Bonn (DE).
324 Eudy et al. (NREL). 2016. Foothill Transit Battery Electric Bus Demonstration Results.
325 Wu (APTA), n.d. (presentation). Lessons Learned From Operating Battery Electric Buses in the Real World.
326 Eudy et al. (NREL). 2016. Foothill Transit Battery Electric Bus Demonstration Results.

AVOIDING HIGH ELECTRICITY COSTS.
Depending on the configuration, it may be logistically easier to charge during peak grid hours, but it is more expensive. When possible, operators should aim to charge buses when there are few others using the electric grid to reduce costs (especially for cities with demand pricing).

LACK OF SUFFICIENT COMMUNICATION WITH VENDORS, AND DIFFICULTY ACQUIRING SPARE AND REPLACEMENT PARTS.
As BEBs have different electrical and propulsion systems than ICE vehicles, there are new challenges and protocols to learn with electric bus hardware and software.[327] BEB-specific training is necessary, as is communication with manufacturers to solve new maintenance challenges. With the uneven geography of manufacturing—as well as the value-added taxes and related added total cost from importing parts—it may be challenging for operators to acquire BEB replacement components. The lack of standardization for batteries and buses (due to both the current variety and the continually emerging new technologies) creates further challenges. In addition, when replacement parts are secured, the delay in receiving them may slow system maintenance and operations.[328]

A BYD bus in operation in Bengbu, China. **SOURCE:** DKMcLaren, CC BY-SA 4.0, Wikimedia Commons.

327 Wu (APTA), n.d. (presentation). Lessons Learned From Operating Battery Electric Buses in the Real World.
328 Wu (APTA), n.d. (presentation). Lessons Learned From Operating Battery Electric Buses in the Real World.

The following section describes best practices for operations and maintenance, including training practices for addressing the considerations presented in this section.

OPERATIONS AND MAINTENANCE BEST PRACTICES

CHARGING

ADJUST SEASONALLY.
Case studies have found that in hotter and colder months, the bus schedule should accommodate longer charging times for slower charging in extreme temperatures, increased heating or air-conditioning, and lower battery performance.[329] In winter or summer months, more buses may be assigned to a route to compensate for lowered battery performance.[330] As a result of these temperature sensitivities, operators may choose to precondition (i.e., heat or cool) the buses in both summer and winter months while plugged in for charging to prolong full battery capacity.[331] In cities with hot climates, it is common to have air-conditioning as an obligation in contracts, and adjustments for BEBs should be considered. In addition, operators may adjust the heating or cooling temperature a few degrees to reduce battery usage: For example, in Washington, D.C., the operator lowered the heating temperature a few degrees in the winter to save battery. Operators should understand how battery temperature and performance will fluctuate based on charging and battery type.[332]

HAVE A SUPERVISOR MONITOR CHARGING AND PERSONNEL SCHEDULES.
Having a dispatcher or supervisor manage the charge capacity and levels of all BEBs in a system's fleet will ensure that charging is not uneven or overlooked.[333] In addition, this point of contact can maintain charging and personnel schedules in tandem, so that all BEBs have sufficient charging time and drivers are scheduled with enough time for properly finishing or beginning a charging cycle.

DO NOT CHARGE THE BATTERY TO 100 PERCENT.
Battery life is elongated when batteries are properly charged and maintained. BEB operators should keep state of charge for batteries between 20 percent and 95 percent (there should be a bit of wiggle room for energy recharging from regenerative braking).[334]

ENSURE ADEQUATE DEPOT SPACE AND COVERAGE FOR CHARGING.
To charge electric vehicles safely and efficiently, ensure that depots and charging areas are well covered and ventilated to avoid exposing vehicles and batteries to variable weather conditions. This should be stipulated in the contracts.

STAGGER CHARGING TIMES AND CHARGE DURING OFF-PEAK HOURS.
When bus routes are planned so that buses arrive at the depot(s) in a staggered manner, this can reduce high-demand fees. Staggering charging times to flatten the charging curve may reduce the electricity demand and overall costs.[335] Operators should consider the time of charging, ideally charging the buses during low power-consumption periods to avoid the high cost of charging at the peak period.

BATTERY PERFORMANCE

TRAIN DRIVERS ABOUT MINIMUM BATTERY TRAVEL DISTANCE AND SET A BATTERY MINIMUM FOR RETURNING TO CHARGING INFRASTRUCTURE.
Operators should understand the minimum battery charge required for all buses on all routes to return to the depot or other infrastructure. Going below this limit can negatively affect the lifetime of the battery.

TRAIN DRIVERS TO EXTEND BATTERY LIFE THROUGH DRIVING STYLE.
Training drivers in e-bus operations is important for extending the limited daily range.[336] Regenerative braking can preserve battery capacity, and battery range can vary by 20 percent due to a driver's braking style.[337] Drivers should be educated on the benefits of gentle acceleration and regenerative braking, as well as how an electric propulsion system functions, so they know how to optimize battery longevity.[339] Good driving behavior (i.e., slow acceleration and deceleration) can improve battery range by 30 percent.

329 Eudy & Jeffers (NREL). 2017. Foothill Transit Battery Electric Bus Demonstration Results: Second Report.
330 Wu (APTA), n.d. (presentation). Lessons Learned From Operating Battery Electric Buses in the Real World.
331 Wu (APTA), n.d. (presentation). Lessons Learned From Operating Battery Electric Buses in the Real World.
332 UITP, n.d. ZeEUS Eindhoven (NL).
333 Wu (APTA), n.d. (presentation). Lessons Learned From Operating Battery Electric Buses in the Real World.
334 Hill (Mass Transit). 2015. Battery Bus Range: It's All in the Math.
335 Edison Electric Institute. 2019. Preparing to Plug in Your Bus Fleet: 10 Things to Consider.
336 UITP, n.d. ZeEUS Eindhoven (NL).
337 Wu (APTA), n.d. (presentation). Lessons Learned From Operating Battery Electric Buses in the Real World.
338 The University of Tennessee at Chattanooga, n.d. FAQs: Electric and Hybrid Buses.
339 Li. 2016. Battery-Electric Bus Developments and Operations: A Review.

WORKING WITH VENDORS

PRACTICE MAINTENANCE AND OPERATIONS ACCORDING TO VENDOR GUIDELINES; ESTABLISH CLEAR COMMUNICATION WITH VENDORS; AND ENSURE THAT BEB REPLACEMENT PARTS CAN BE SECURED AND MAY BE EXPEDITED.

Operators and maintenance personnel should understand and follow vendor-instructed best practices to lengthen the lifetime of replaceable parts such as the battery, electric motor, and control system. This is important, as poor battery performance can mean BEB batteries have to be replaced two or three times within a 15- to 20-year life cycle.[340] Beyond following these vendor protocols, it is also important to maintain communication with vendors. Managing and learning new software system error codes is best facilitated when maintenance personnel have clear and timely communication with vendors for maintenance errors.[341] This communication is also important for repairs, as operators must work with manufacturers to ensure that spare parts are available can be expedited for repair.[342]

TRAIN OPERATIONS AND MAINTENANCE STAFF ON BEB TECHNOLOGY.

Training should include how staff, operators, and partners will interact with and manage new BEB-specific equipment and technology (such as driving, charging, first response, dispatching, and repairing).[343] In a ZeEUS pilot in Munster, the project team found that many frequent technical issues resulted from operational malpractice or vehicle malfunctions rather than the BEB hardware or software.[344] The team found that on-board training support during real-time operations increased driver confidence and operational expertise and reduced these issues.[345]

COLLECT DATA TO ENSURE FORECASTED RANGE ALIGNS WITH ACTUAL RANGE.

Data should be collected on an ongoing basis about battery range performance so operators can determine how close to the expected range the buses in their fleet perform.[346] This is important not only for instructing drivers about minimum range capacity for returning to the depot but also to ensure that the manufacturer's forecasted range aligns with the fleet's performed range, especially if tied to contracts and financing. Data collected can instruct decisions for bus and battery performance, fleet transition, route optimization, and best practices for maintenance and operations, among other factors.

A caretaker and child board a bus in Rio de Janeiro, Brazil. **SOURCE:** Stefano Aguilar / ITDP Brazil, Flickr.

340 Moon-Miklaucic (WRI). 2019. Financing Electric and Hybrid-Electric Buses.
341 Wu (APTA), n.d. (presentation). Lessons Learned From Operating Battery Electric Buses in the Real World.
342 Wu (APTA), n.d. (presentation). Lessons Learned From Operating Battery Electric Buses in the Real World.
342 Wu (APTA), n.d. (presentation). Lessons Learned From Operating Battery Electric Buses in the Real World.
344 UITP, n.d. ZeEUS Munster (DE).
345 UITP, n.d. ZeEUS Munster (DE).
346 Wu (APTA), n.d. (presentation). Lessons Learned From Operating Battery Electric Buses in the Real World.

7.4
END OF LIFE: BATTERY DISPOSAL

Batteries are considered "end-of-life" or needing replacement once they reach approximately 60 percent to 80 percent of original battery capacity.[347] A typical battery life should range from six to 12 years, with multiple manufacturers offering warranties for up to 12 years.[348] It is worth noting that few bus batteries have gone through a full life cycle, so many of these estimates are based on projections. Challenges with battery underperformance, such as low-voltage batteries, as seen with Foothills Transit in Los Angeles, may shorten the battery lifetime to a few years.[349]

End-of-life disposal presents a significant challenge for the electric bus market at present. Given the relatively new state of electric buses globally, the end-of-life practices for buses, bus batteries, and other system infrastructure will vary. While personal electric vehicle batteries may be more easily recycled and companies such as BMW, Nissan, Renault, Tesla, Volvo, and Yin-Long in the PEV market offer battery life reuse and recycling programs, this is much more challenging for BEBs.[350] This is both a result of the limited number of batteries reaching end of use (due to the new nature of BEBs) and the large, complex battery pack structure.[351] There is currently no standardized process for disposing of or recycling BEB batteries. However, recycling is likely to become increasingly easier as the BEB batteries currently in use reach the end of their life cycle and there is a greater supply of batteries to recycle. Likewise, competing battery technologies at present mean there are many types of battery pack structures and materials to recycle. As battery technology becomes more standardized in the future, this may also increase the popularity and ease of recycling.[352] The sector must move to address this, particularly with governments outlining requirements for safe battery disposal. Currently, inadequate disposal can lead to hazardous material contaminating land around the disposal site and add additional lifetime emissions to each BEB.[353] As such, it is important to outline in procurement and/or contracts which stakeholder is responsible for end-of-life recycling or disposal, both financially and logistically.

END OF LIFE: BUS DISPOSAL

As few BEBs have reached the end of life, there is little research available for bus disposal, resale, and recycling. In fact, due to the lack of data, many studies of life cycle assessments of BEBs do not include disposal.[354][355] In addition, there is not a clear resale market for BEBs, unlike with diesel buses. While planners may factor the disposal/resale value into TCO models, the market for this is likely to change dramatically in the next years as buses deployed in cities globally—and particularly in more mature Chinese cities—reach end of life.

347 Bloomberg Finance L.P. 2018. Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.
348 Johnson et al. (NREL). 2019. Financial Analysis of Battery Electric Transit Buses.
349 Eudy & Jeffers. 2019. Foothill Transit Agency Battery Electric Bus Progress Report.
350 Melin (Circular Energy Storage), n.d. The Lithium-Ion Battery End-of-Life Market—A Baseline Study.
351 ICCT. 2018. Effects of Battery Manufacturing on Electric Vehicle Life-Cycle Greenhouse Gas Emissions.
352 ICCT. 2018. Effects of Battery Manufacturing on Electric Vehicle Life-Cycle Greenhouse Gas Emissions.
353 Geuss. 2019. Electric Car Batteries Might Be Worth Recycling, But Bus Batteries Aren't Yet.
354 Gharaei et al. 2020. Comparative Lifecycle Assessment of Diesel, Hydrogen and Electric Buses in Real Driving Cycles in Tehran.
355 Jwa & Lim. 2017. Comparative Life Cycle Assessment of Lithium-Ion Battery Electric Bus and Diesel Bus From Well to Wheel.

One possible repurposing of bus batteries is for grid and backup storage, as well as for charging other technologies. In Spain, the electric bus company Irizar is experimenting with reusing bus batteries for electric vehicle charging stations.[356] Due to the more frequent charging of BEB batteries, the battery calendar life (approximately six to 12 years) is usually shorter than for personal electric vehicles (which can span 10 to 20 years).[357 358]

COLLABORATION WITH MANUFACTURERS

Operators should work with manufacturers to plan for end-of-life battery disposal or reuse (with the flexibility and incentivization to adopt a new end-of-life disposal method if new technology emerges). This may be included within lifetime warranties for buses and/or batteries. For example, BYD has created lifetime warranties that include the end-of-life disposal for the bus battery.[359] Operators can also pursue a battery lease model, in which the manufacturers retain ownership of batteries. For this model, battery and vehicle manufacturers may even be incentivized to retain control of the battery so as to get as much value as possible from each battery.[360] Battery leasing options may in particular reduce transactional waste by allowing manufacturers not to lose any of the BEB bus and/or battery price to a middle vendor.[361] This is a particular advantage of the battery leasing financing scheme, as discussed in Section 5, Funding, Financing, and the Financial Model.

PROMOTE POLICIES FOR REGULATION AND END-OF-LIFE

Requirements Given the current barriers around the of end-of-life battery handling, operators and planning stakeholders should work with local, regional, and national governments to promote policies for regulating end-of-life battery requirements. This is also useful for reducing the uncertainty around the residual value of the bus.[362] Promoting policies for regulation means stakeholders and duties are detailed clearly, which reduces uncertainty for end-of-life responsibilities.[363]

BELOW: New electric buses for the TransMilenio fleet in Bogota, Colombia. The city has 350 buses in operation, and is expecting to have over 1,450 delivered within the next year. **SOURCE:** BYD Colombia, CC BY-SA 2.5, Wikimedia Commons.

356 Shahan (Clean Technica). 2021. New Charging Station in Spain Uses 2nd-Life Electric Bus Batteries.
357 Enel X. 2020. How Long Do Car Electric Batteries Last?
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SUPPORTIVE STRATEGIES

8

In addition to the transition to public electric bus fleets, there are a variety of supportive strategies that operators and planning officials may pursue to further the environmental and social benefits that BEBs offer. First and foremost, electrification of public transportation should be seen as one part of a zero-emission mobility strategy moving toward creating more sustainable and resilient urban transportation networks.[364] Electrification alone does not make a transportation system more sustainable, nor does a move toward new technologies make it more resilient. In addition, a limitless number of green vehicles in itself does not constitute a sustainable transportation system.[365] City planners and operators must also employ strategies that improve community access, reduce environmental emissions, and increase socioeconomic benefits. These may include:

PROMOTE POLICY THAT ENCOURAGES ZERO-EMISSION TECHNOLOGY ADOPTION.
Vehicle emission standards, fuel quality regulations, fuel and vehicle tax reform, commitments to procuring zero-emission vehicles, and implementing low- or no-emission zones in cities are tactics that national, regional, or city governments may employ to encourage BEB adoption.[366]

TRAFFIC REDUCTION.
Cities should enable traffic reduction policies and road pricing strategies while incentivizing the use of public transit. This is important to encourage mode shifts to more sustainable modes of transport, including shared mobility, public transportation, cycling, and walking. Electric bus fleets are preferred over electric personal vehicles as BEBs reduce harmful emissions at a significantly higher rate per rider than the transition to personal electric vehicles.

GREEN THE GRID (INCREASE USE OF RENEWABLES AND CLEAN SOURCES FOR ENERGY PRODUCTION).
The environmental benefits of electric buses can fluctuate depending on the cleanliness and sustainability of the energy produced by the grid (which charges the buses). As such, there must be a concerted effort to update grids and shift to clean energy sources. The possibilities for this will vary by geography as well as financial contexts.

INTEGRATE BEB PLANNING WITH LAND USE PLANNING AND IMPROVEMENTS.
BEBs provide an opportunity to reduce emissions in cities. When electrification of transportation can be planned with compact, connected communities that encourage short walking and cycling trips (alongside low-emission public transport trips for longer distances), cities can significantly increase environmental, economic, and social benefits of land use and transportation planning.

INTEGRATE BUS SERVICE WITH OTHER MODES TO CREATE A SUSTAINABLE TRANSPORTATION NETWORK.
Cities should work to integrate bus routes with travel demand management and emissions schemes to create multimodal, sustainable transportation networks that enable diverse modes and offer urban citizens adequate travel options. Cities should likewise plan to integrate bus routes and the larger network with the cycling and pedestrian network.

OPPOSITE PAGE
Complete streets, like this one in Berlin, reduce traffic congestion and reclaim more street space for pedestrians and cyclists. **Source:** Eric Sehr, Flickr.

364 UITP. 2019. The Impact of Electric Buses on Urban Life.
365 UITP. 2017. ZeEUS eBus Report #2: An Updated Overview of Electric Buses in Europe.
366 Miller et al. (ICCT). 2017. Financing the Transition to Soot-Free Urban Bus Fleets.

SPOTLIGHT ON SUPPORTIVE POLICY

Adopting policy that enables electrification is an important supportive strategy a city can and often must take. China has developed the most advanced electric bus market and fleets through supportive policy (see the ITDP China Case Study). Many other cities and countries are following suit:

SANTIAGO, CHILE

In 2018, the Chilean government established the National Electromobility Strategy to drive the transition to clean buses. As of mid-2020, the city had more than 410 electric buses in circulation—at the time, the largest fleet in Latin America and the second largest in the world. The new bidding process for public transit buses in Santiago must include incentives for including and renewing clean vehicles for the fleet. These include:

- Providing temporary terminals for buses to park while charging after routes;
- New vehicles must be more energy efficient and have lower pollutant emissions.

LONDON, UNITED KINGDOM

In 2014, Transport for London established the CleanerAir Strategy for London to encourage the transition to clean buses.[367] In 2018, this strategy was driven by the municipal government with the creation of the Task Force for Electric Vehicles.[368] To achieve the objectives in the CleanAir Strategy, contracts must include concessions to:

- Adapt depots for electric buses, with adequate (increased) space for storing and charging vehicles;
- Require new vehicles to follow the European emissions standards system and ensure that old buses have filters to reduce emission levels;
- Provide driver training that focuses on reducing emissions.

BOGOTÁ, COLOMBIA

In 2019, President Iván Duque signed Law 1964, which promotes the adoption of clean energy vehicles and sets a goal of 100 percent of purchased vehicles for public transportation systems to be zero-emission by 2035.[369] In response, Bogotá established new criteria in 2019 to incorporate electric vehicles in procurement. Requirements included:

- Contracts must highlight the need to procure zero- or low-emission technologies;
- New contract models must separate vehicle provision and operation contracts;
- Contracts must ensure sufficient depot or on-route space for safely charging, operating, and maintaining the fleet;
- Mandatory regular training of drivers.

In December 2020, Bogotá received the first 120 buses out of a 470 BEB order.[370] In January 2021, BYD won another bid with Bogotá that will deliver 406 BEBs before the end of 2021, which will bring the city's fleet to 889 BEBs. services such as traffic management.[371]

Employing these strategies in tandem with the electrification of public transportation fleets will have multiplier effects on air quality, sustainable mobility, and urban health.[372]

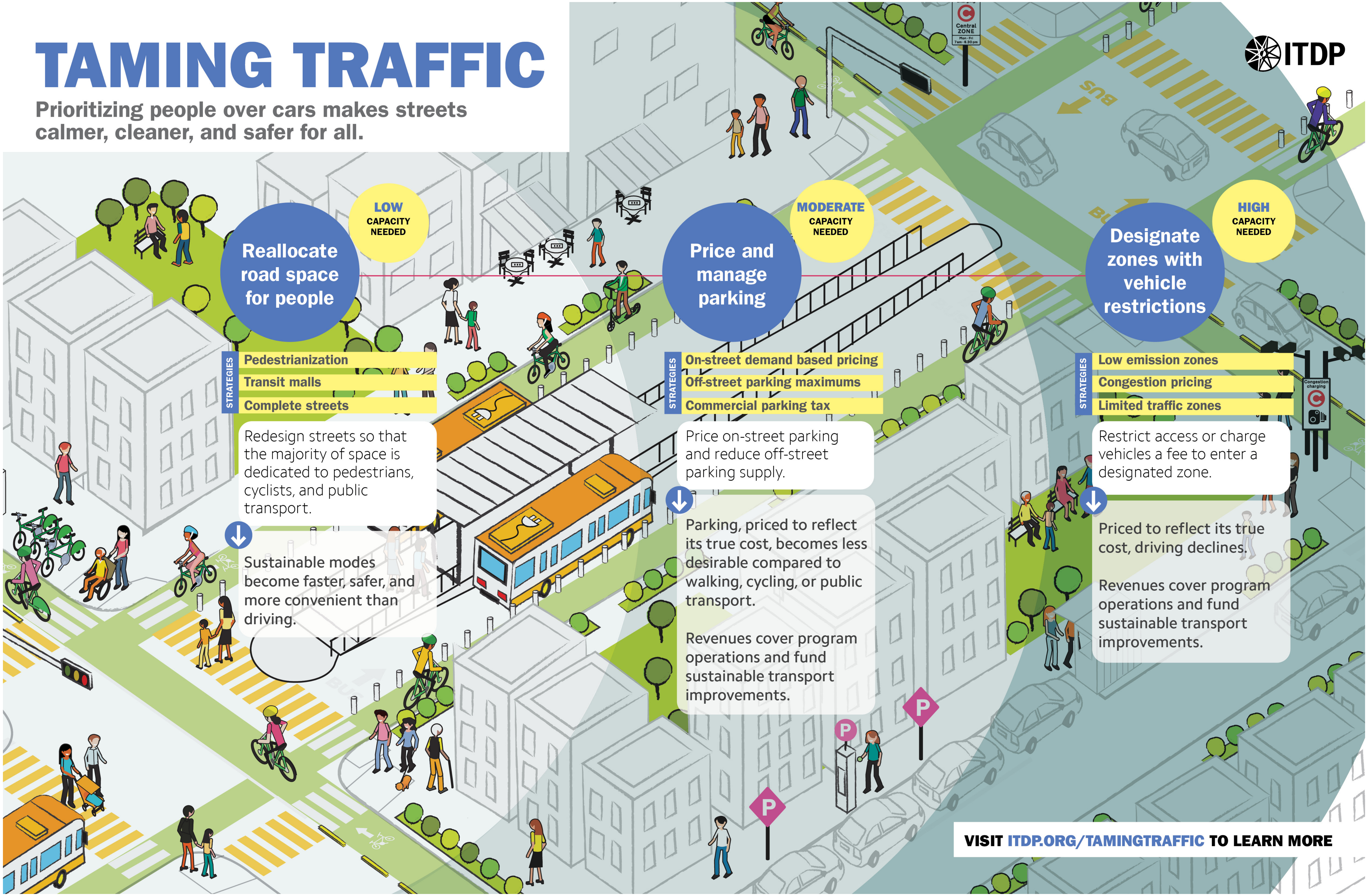
367 Transport for London, n.d. Improving Buses.
368 Mayor of London. 2018. Mayor Launches New Taskforce to Expand Electric Vehicle Infrastructure. Lefevre et al., (Inter-American Development Bank). 2019.
369 Bogotá is a Pioneer in Acquiring Electric Buses by Tender.
370 Sustainable Bus. 2020. BYD Has Delivered the First 120 E-Buses Out of 470 Unit Order in Bogotá (Colombia).
371 Sustainable Bus. 2021. Another Batch of 406 E-Buses for Bogotá (Colombia). Again with BYD's Logo.
372 UITP. 2019. The Impact of Electric Buses on Urban Life.

Walking, cycling, public transport, and private vehicles all safety come together at this intersection.
SOURCE:
City of St. Pete, Flickr.

TAMING TRAFFIC

Prioritizing people over cars makes streets calmer, cleaner, and safer for all.

ITDP



Reallocate road space for people

LOW CAPACITY NEEDED

STRATEGIES
- Pedestrianization
- Transit malls
- Complete streets

Redesign streets so that the majority of space is dedicated to pedestrians, cyclists, and public transport.

↓

Sustainable modes become faster, safer, and more convenient than driving.

Price and manage parking

MODERATE CAPACITY NEEDED

STRATEGIES
- On-street demand based pricing
- Off-street parking maximums
- Commercial parking tax

Price on-street parking and reduce off-street parking supply.

↓

Parking, priced to reflect its true cost, becomes less desirable compared to walking, cycling, or public transport.

Revenues cover program operations and fund sustainable transport improvements.

Designate zones with vehicle restrictions

HIGH CAPACITY NEEDED

STRATEGIES
- Low emission zones
- Congestion pricing
- Limited traffic zones

Restrict access or charge vehicles a fee to enter a designated zone.

↓

Priced to reflect its true cost, driving declines.

Revenues cover program operations and fund sustainable transport improvements.

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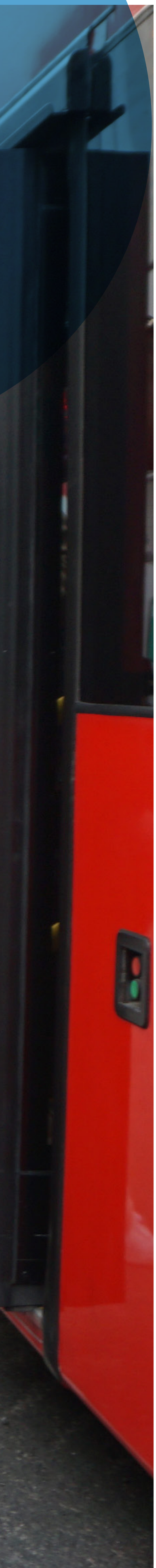
CONCLUSION

9

BEBs pose a significant opportunity for cities to reach time-sensitive environmental goals and avoid irreparable damage from climate change. By electrifying public fleets, cities can improve their sustainable transportation networks while reducing global and local emissions, as well as improving quality of life for urban residents. BEB technology improvements have increased reliability, while innovative financing schemes have increased adoption and the opportunity for public fleet electrification. By increasing market share and capturing a greater percentage of vehicle kilometers traveled (VKT) and emissions per capita than personal EVs, electric buses can enable cities to transition fewer total vehicles for a greater portion of electrified VKT and greater total emissions reductions. In doing so, BEB fleet adoption can improve local air quality and noise pollution while increasing energy efficiency in transport and urban networks.

Electric bus adoption and fleet expansion is dependent on how well cities can optimize BEB financing schemes, funding options, charging, operations, and maintenance. ***TCO for electric buses may rival that of diesel buses where a flexible, resilient financing scheme can be used and the operations and maintenance savings are secured***. Key goals and actions for success include:

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)



OPPOSITE PAGE Passengers step off of a Transjakarta BRT vehicle in Jakarta, Indonesia. **SOURCE:** ITDP Indonesia.

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 BEBs 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 have enormous potential to improve urban transportation systems. By executing these steps, cities can work toward achieving climate goals in the next decade and beyond.

9.1
AREAS TO EXPLORE

As the market grows and research continually develops, areas to explore include:

BEST CONTRACTING PRACTICES FOR BEBS
As BEBs have distinct financing compared to other bus types and there are multiple financing schemes available, it is challenging to identify best practices for contracts. In addition, contracts can be challenging to acquire and are often highly detailed.

IMPROVED OPERATIONS AND MAINTENANCE
As real world experience and lessons learned grow, improving operations and maintenance to achieve as close as possible to a 1:1 replacement ratio of battery electric to diesel buses will be critical for the success of large-scale BEB fleets. Getting the replacement ratio as close to 1:1 as possible will save money, and a focus on operations and charging infrastructure will ensure this happens.

IMPROVED UNDERSTANDING FOR THE INTERSECTION OF CHARGING, BATTERY TYPE, AND OPERATIONAL PLANNING
Research, application, and best practices for the existing popular battery and charging types as well as for the less-used battery and charging technologies will be important for the future of electric buses in cities. While LFP batteries continue to be the most popular type, there is rising interest in other batteries that can offer increased lifetime and reliability. Wireless charging could offer seamless operation and ample battery power for completing all bus services, there is little application to date due to high costs and significant infrastructure installation. Further technological advancements are needed for charging and battery technologies. It is also important to increase understanding of how these technologies intersect with the interest in improving bus operations to get as close as possible to a replacement ratio for electric to diesel buses of 1:1.

IMPROVED BATTERY LIFE, RELIABILITY, AND COST
Battery underperformance and unreliability continue to pose challenges for BEB services, battery lifetime, and total cost of ownership.

BATTERY RECYCLING, SECOND-LIFE, AND DISPOSAL
The current state of uncertainty for end-of-life for batteries poses a challenge to BEB adoption. In addition, inadequate disposal at present adds to overall lifetime emissions, which may be prevented. While PEV companies are developing recycling, upgrading, and reuse programs, there is much work to be done for BEB batteries. Research should focus on understanding how BEB batteries can be reused or repurposed, such as by using them for decentralized energy storage or as recycled materials for new batteries.

DIESEL BUS PHASE OUT AND DISPOSAL
As one of the greatest advantages to electric bus adoption is the environmental benefits of the vehicles used, it is important that the transition to electric buses is environmentally responsible. Further research should be conducted on best practices for diesel bus repurpose and disposal.

APPENDIX

10

10.1 ELECTRIC BUS OPERATION EVALUATION INDICATORS

The following table, created by ITDP China, lists metrics to evaluate BEB operations.

INDICATOR	DATA NEEDED	CALCULATION METHOD
Bus specifications (evaluate the bus fleet capacity)		
Passenger capacity	Bus card-swipe data and cash payment data	The total count of card and cash payment = the total passenger ridership of all bus lines
Replacement ratio (i.e., the ratio of the number of e-buses to the diesel buses for a given line)	Number of e-buses and diesel/gasoline buses on the line	$= \frac{\text{Number of BEBs for all routes}}{\text{Number of diesel/gas/CNG buses for all routes}}$
Operations and maintenance (evaluate the service level, operational efficiency, and the maintenance ability of the bus system)		
Frequency of bus departure in the peak hour	Bus service schedule from the bus company	Data from the bus company
Average speed during the peak hour	Vehicle GPS data	Data from the bus company
Peak-hour full-capacity rate	Number of passengers carried by cross-section of vehicles during peak hours	Data from field research
BEB use rate (i.e., how many of the buses are in daily operation)	Number of e-buses in operation	$\% = \left(\frac{\text{Number of BEBs in operation}}{\text{Total number of BEBs}}\right) \times 100$
Daily operation distance of e-buses	Total operation distance by e-buses	$= \frac{\text{Total operation distance by BEBs}}{\text{Total operating days}}$
Valid operation distance	Total traveling distance on the lines and total traveling distance	$= \frac{\text{Total traveling distance for all routes}}{\text{Total traveling distance}}$
Average operating time per day	Total operation time	$= \frac{\text{Total operation duration}}{\text{Total operating days}}$
Failure rate	Total failure times and total operation distance	$= \frac{\text{Total number of breakdowns}}{\text{Total operation distance}} \times 10{,}000$

OPPOSITE PAGE
Passengers sit comfortably in an electric bus in Kathmandu, Nepal.
SOURCE: Gaurav Dhwaj Khadka, CC BY-SA 4.0, Wikimedia Commons.

INDICATOR	DATA NEEDED	CALCULATION METHOD
Charging infrastructure and battery (evaluate the feasibility of the charging plan and battery performance)		
Average charging frequency per day	Total charging times	Total number of charging times = ---------------------------------- Total number of operating days
Average charging time per day	Total charging time	Total charging time = ---------------------------------- Total operating days
Actual power consumption per 100 km	Total power consumption and total operation distance	Total power consumption = (----------------------------) x 100 Total operating distance
Total charging queuing time	Total e-buses charging queuing time	Data from the bus company's investigation
Duration of the failure time	Duration of the failure time	Data from the bus company's investigation
Decay rate of the battery for every 10,000 km (also called self-discharge rate)	Stated battery endurance distance, actual endurance distance, and total operational distance	(Stated battery distance range - actual distance range) = (-----------------------) x 10,000 x 100% (stated battery distance x total operating distance)

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