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ELECTRIC BUSES IN MAHARASHTRA

LESSONS FROM INTERVIEWS AND RECOMMENDATIONS FOR FUTURE ROLLOUT IN INDIA

By Anuj Dhole and Pramoda Gode

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ABOUT THIS REPORT

Vehicle emissions are a concern worldwide, and heavy-duty vehicles are responsible for a disproportionate amount of these emissions in India. As a result, over the past decade, many bus transit authorities in India have shifted from diesel to compressed natural gas as fuel, as this reduces both tailpipe pollution and operating costs. But now electric buses are increasingly in focus, as they are even cheaper to operate and have the advantage of zero tailpipe emissions. Although only three new electric buses were registered in India in 2015, that grew to 1,176 new electric buses registered in the year 2021 alone. Additionally, there was a recent aggregated tender for 5,450 electric buses for five cities, and a separate 3,000 electric bus order by Mumbai.

Despite the momentum, there are certain challenges with electric buses, including higher upfront costs and longer refueling time than conventional combustion engine buses. To address these issues, innovative procurement models and schedules that accommodate the longer refueling time are already being developed and used. Indeed, some transit authorities in India have been operating electric buses for a few years now, and their experiences can provide crucial lessons for future electric bus rollout in peer transit authorities.

This report captures experiences from three Indian cities that adopted electric buses early: Mumbai, Pune, and Navi Mumbai. These cities represent about 42% of the electric buses already operating in India and they obtained these using both outright purchase and gross cost contract models. We interviewed 21 representatives from the transit authorities and their private bus operators, and this report identifies key experiences and lessons from the rollouts. Based on these and by drawing from international best practices, we also make specific recommendations for the future. This report is supplemented by a blog series at theicct.org that touches on a variety of the anecdotes from this research.

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ABBREVIATIONS

BEST	Brihanmumbai Electric Supply and Transport Undertaking
CNG	compressed natural gas
CPI	Consumer Price Index
FAME	Faster Adoption and Manufacturing of (Hybrid &) Electric vehicles in India
GCC	gross cost contract
ICE	internal combustion engine
KPI	key performance indicator
kWh	kilowatt hour
BMC	Brihanmumbai Municipal Corporation
DHI	Department of Heavy Industries
NMMT	Navi Mumbai Municipal Transport
OEM	original equipment manufacturer
PMPML	Pune Mahanagar Parivahan Mahamandal Ltd.
WPI	Wholesale Price Index

Also

Standard buses have lengths ranging from 10 to 12 meters

Midi buses have lengths ranging from 8 to 10 meters

Mini buses have lengths of less than 8 meters

INTRODUCTION

The number of electric buses registered in India rose from just three in 2015 to 3,130 as of June 2022.[1] The total number of registered buses in India also grew by about 38% from 2009 to 2019, and most of these were diesel buses.[2] Still, the share of electric buses in annual new bus registrations in India surpassed that of compressed natural gas (CNG) buses for the first time in 2021 (Figure 1). About 68% of all the electric buses ever registered through December 2021 were incentivized under the two phases of the national-level Faster Adoption and Manufacturing of (hybrid &) Electric vehicles in India (FAME) scheme, which was launched by the Department of Heavy Industries (DHI).[3]

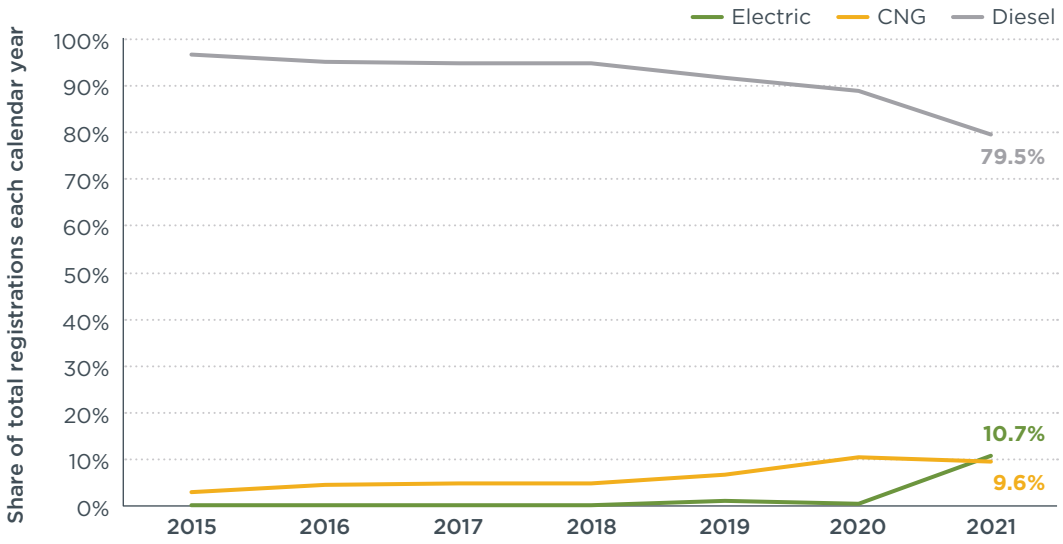

Figure 1. Annual registration of buses in India by fuel type.

Note: Data retrieved from Vahan Sewa Dashboard of the Ministry of Road Transport and Highways, Government of India; 80 electric buses operating in Hyderabad and Indore were added separately.

Given the increasing popularity, this qualitative study focuses on the experience of early adopters of electric buses in India. There is a learning curve for transit authorities when transitioning to a new bus technology and the lessons learned by early adopters can help other transit authorities planning electric bus deployment to set realistic expectations, have more confidence, and avoid or mitigate some of the impediments experienced by others.

1 Vahan Sewa Dashboard, Ministry of Road Transport & Highways, Government of India, "Battery Operated Medium and Heavy Passenger Vehicles," accessed June 27, 2022, https://vahan.parivahan.gov.in/vahan4dashboard/. Eighty electric buses operating in Hyderabad and Indore were added separately.

2 Transport Research Wing, Ministry of Road Transport & Highways, Government of India, *Road Transport Year Book (2017–18 & 2018–19)*, (2021, p. 52), https://morth.nic.in/sites/default/files/RTYB-2017-18-2018-19.pdf

3 Press Information Bureau, Ministry of Heavy Industries & Public Enterprises, Government of India, "Electric Vehicle Operational in Medium and Heavy Passenger Vehicle Category Register an Increase," August 5, 2021, https://pib.gov.in/PressReleasePage.aspx?PRID=1742666; Ministry of Heavy Industries, Ministry of Heavy Industries & Public Enterprises, Government of India, "Year-End-Review of Ministry of Heavy Industries – 2021," December 22, 2021, https://pib.gov.in/newsite/erelcontent.aspx?relid=228991

In particular, electric buses require special considerations for charging infrastructure, route planning, scheduling, operation, maintenance, and re-skilling of the workforce. At the same time, they offer multiple benefits such as zero tailpipe emissions, less maintenance overall, lower fuel cost, less heat in the driver's cabin, less noise, and many report a better driving experience.

India's stage-carriage fleet has 3.2 lakh (320,000) buses that are operated by public and private operators.[4] There is a big opportunity to electrify these because of their recurrent nature of operations, in other words, they operate on specified routes and schedules each day. India is rapidly deploying battery-electric buses and recently floated its largest-ever aggregated tender for 5,450 electric buses for five cities. The tender included buses divided into five lots based on their size, the presence (or not) of air conditioning (AC), and deck height. The original equipment manufacturers (OEMs) who are awarded the order were required to be a part of an agreement with the transit authorities to provide service throughout the lifetime of the buses. Additionally, the FAME incentive for eligible buses was expected to be calculated based on the lowest quoted rate for each of the lot. The lowest quoted rates for the electric buses in the tendering process were 36% to 48% cheaper than the operating costs for comparable diesel buses.[5] Electric buses have already been found to have at least 12% lower total cost of ownership than diesel buses at a high daily utilization of 200 km.[6]

"We have maintenance staff working in three shifts of 8 hours each. Thus, we have people working around the clock on maintenance activities of ICE buses. Interestingly, the operator has only seven technicians for maintaining about 100 electric buses, mostly working at night."

— DEEPAK WALUNJKAR, DEPOT MANAGER, PMPML

4 Amit Bhatt and Shilpa Kharwal, "Don't miss the bus," *Deccan Herald*, June 12,, 2020, https://www.deccanherald.com/opinion/in-perspective/dont-miss-the-bus-848580.html

5 Amber Banerjee, "World's Largest Electric Bus Tender for 5,450 Buses: How CESL Orchestrated This Deal," *The Times of India*, May 24, 2022, https://timesofindia.indiatimes.com/auto/worlds-largest-electric-bus-tender-for-5450-buses-how-cesl-orchestrated-this-deal/articleshow/91760385.cms

6 Parveen Kumar and Chaitanya Kanuri, "Total Cost of Ownership of Electric Vehicles: Implications for Policy and Purchase Decisions," *WRI India*, October 6, 2020, https://wri-india.org/blog/total-cost-ownership-electric-vehicles-implications-policy-and-purchase-decisions

METHODOLOGY

The steps we took to gather and analyze data for this report are illustrated in Figure 2 and each is described in more detail below.

Figure 2. Research methodology.

CITY SELECTION

India's electric bus fleet is concentrated in urban areas. Only 27% of the electric buses deployed under FAME I are being used for intercity operations, and only 7% of the 5,595 electric buses were sanctioned for intercity operations under FAME II.[7]

The Maharashtra State Electric Vehicle Policy 2021 set a goal of 25% electrification of public bus fleets in five cities by 2025, and 15% electrification of the state transport corporation's fleet.

Maharashtra is in the national spotlight because of its success in procuring a large number of electric buses. Notably, the Maharashtra State Electric Vehicle Policy 2021 set a target of 15% bus fleet electrification for the Maharashtra State Road Transport Corporation and 25% public bus fleet electrification by 2025 in five urban agglomerations: Greater Mumbai, Pune, Nagpur, Nashik, and Aurangabad. As the first serious mover in this space, the electric bus rollout experiences in Maharashtra can offer lessons for others.

Maharashtra accounted for about 42% of the electric buses operational in India as of February 2022, and the overwhelming majority of these, approximately 99%, have been registered in Mumbai, Pune, or Navi Mumbai.[8] We chose these three cities because they have fairly extensive experience with electric bus operations and each of them adds unique value to this study. Mumbai's oldest public electric buses were commissioned in 2017, while those of Navi-Mumbai and Pune were commissioned in 2018. Additionally:

» **Mumbai** has more than 4 years of operational experience and has been through four rounds of electric bus procurements, one round of outright purchase and three rounds under a gross cost contract (GCC) model.[9]

7 Press Information Bureau, "Electric Vehicle Operational in Medium and Heavy Passenger Vehicle Category Register an Increase"; Department of Heavy Industries, Ministry of Heavy Industries & Public Enterprises, Government of India. *Sanction of Electric Buses Under Phase-II of Faster Adoption and Manufacturing of Electric Vehicles in India Scheme (FAME India Scheme)*, 2019, https://heavyindustries.gov.in/writereaddata/fame/famepressrelease/1-E__didm_WriteReadData_userfiles_Press%20Release%20for%20Buses.pdf

8 Vahan Sewa Dashboard, Ministry of Road Transport & Highways, Government of India, "Battery Operated Medium and Heavy Passenger Vehicles," accessed February 7, 2022, https://vahan.parivahan.gov.in/vahan4dashboard/. Eighty electric buses operating in Hyderabad and Indore added separately.

9 A gross cost contract is a procurement model in which a transit authority hires a bus fleet from a private bus operator for an agreed-upon period and terms in a contract. The operator is responsible for the operation and maintenance of the buses according to the schedule set by the transit authority. In exchange, the transit authorities pay an agreed-upon fixed amount per unit distance operated (contract cost). In a dry lease, the operator provides buses without drivers and in a wet lease the operator also provides drivers.

» **Pune (Pune Metropolitan Region)** was the first city in India to procure electric buses without the FAME I incentive (150 buses). Pune also built two depots exclusively for electric buses and has recently commissioned six new depots exclusively for electric buses.[10]

» **Navi Mumbai** is one of the few cities in India that procured electric buses under outright purchase using the FAME I incentive (30 buses). Navi Mumbai's transit authority also represents the experience of a smaller transit authority.

Table 1 is a snapshot of the present bus fleets and charging infrastructure in the three cities in this study and their electric bus procurement plans.

Table 1. Bus fleet details and plans for Mumbai, Pune, and Navi Mumbai.

	Mumbai	Pune	Navi Mumbai
Number of buses per million population	250.7 [a]	228.3 [b]	483.9 [c]
Total number of buses	3,460	1,895	600
Number of electric buses in operation	386	220	180
Work order placed for electric buses	3,000	430	None
Number of electric buses planned	900 double decker	300 (7 meters long)	1 double decker
Current level of fleet electrification	11%	12%	30%
Plans for full electric operation by year	2027	25% by 2025 [d]	—
Types of chargers used	150 kW, 200 kW, and 240 kW	80 kW and 150 kW	120 kW and 240 kW

a. We estimated the population of Mumbai to be 13.8 million in 2021, based on an assumed 10.7% growth since 2011 and the 12.5 million population reported in the 2011 census. The population growth rate assumption for all three cities is taken from the estimated population growth in Maharashtra as per "Population projections for India and States 2011 – 2036," (July 2020), National Commission on Population. Available at https://main.mohfw.gov.in/sites/default/files/Population%20Projection%20Report%202011-2036%20-%20upload_compressed_0.pdf

b. Estimated population of the Pune Metropolitan Region in 2021 was 8.3 million, based on 10.7% growth since 2011 and the reported population of 7.5 million in the 2011 census.

c. Estimated population of Navi Mumbai in 2021 was 1.24 million, based on 10.7% growth since 2011 and the reported population of 1.12 million in the 2011 census.

d. As per the Maharashtra Electric Vehicle Policy 2021, MSEVP-2021/CR 25/TC 4, accessed May 6, 2022, https://maitri.mahaonline.gov.in/PDF/EV%20Policy%20GR%202021.pdf

INTERVIEWS

We conducted interviews from August 2021 to March 2022 with 21 individuals who can be grouped into three broad categories: *technical decision-makers* such as chief engineers, executive engineers, and junior engineers; *managers* of depots, operations managers, and traffic managers; and *others*, including private bus operators, drivers, bus maintenance staff, and site supervisors.

The *technical decision-makers* and *managers* in transit authorities work closely with the higher-level decision-makers such as the chairman, managing director, and general manager. Technical decision-makers are concerned with things related to bus specifications and fueling infrastructure, while managers look after decisions related to operations at the fleet and depot levels, such as route planning, schedules, revenue, and staff. Personnel in the *others* category work on the ground.

Our objective with the interviews was to record experiences through a semi-structured discussion rather than a fixed question-and-answer format. This was so the interviewees would not feel restricted, and we identified high-level topics for discussion for each interviewee in advance. Please see Appendix A for more details of these topics.

10 Dheeraj Bengrut, "PMPML to Construct 6 Mega Charging Stations for E-buses," *Hindustan Times*, December 2, 2021, https://www.hindustantimes.com/cities/pune-news/pmpml-to-construct-6-mega-charging-stations-for-ebuses-101638385281562.html

ELECTRIC BUS PROCUREMENT STORIES OF THE THREE CITIES

MUMBAI

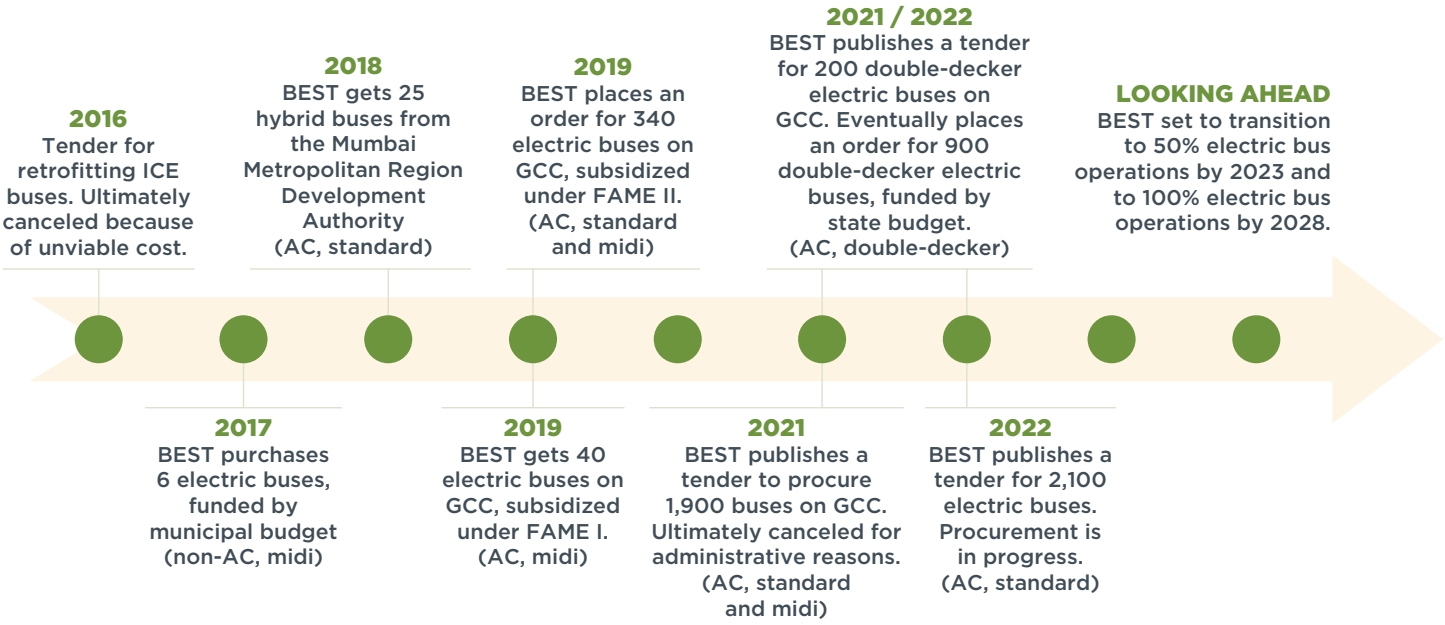

Figure 3. Timeline of electric bus procurements in Mumbai.

The Brihanmumbai Municipal Corporation (BMC) is the governing body of India's financial capital, Mumbai. BMC covers an area of 437.7 sq. km and had an estimated population of 13.8 million in 2021.[11] Brihanmumbai Electric Supply and Transport Undertaking (BEST) has been responsible for providing public bus services in Mumbai and the neighboring cities since 1926.[12] BEST has a fleet of 3,460 buses, including the iconic double-decker buses.

> **"Hybrid buses did not show promise. They have an internal combustion engine as well as a battery. They did not show enough tangible benefits in terms of emissions, operations, and maintenance costs. Thus, we decided to go for battery electric buses only."**
>
> **—CHANDRAKANT BIRAJDAR, EXECUTIVE ENGINEER, BEST**

BMC's working group for alleviating air pollution offered ₹ 100 crores (₹ 1 billion) to BEST for purchasing new buses in 2015, out of which they allotted ₹ 10 crores (₹ 100 million) for purchasing fully electric buses. According to BEST, electric buses made domestically were not available at that time. During that same time, though, Kirtaney Pandit Information Technologies (KPIT) and the Central Institute of Road Transport (CIRT) had plans to retrofit internal combustion engine (ICE) buses to electric, and BEST offered some of their buses for that. BEST also published a tender for retrofitting

11 Assumes a 10.7% growth rate since 2011. The population of Mumbai was reported to be 12.5 million in the 2011 census.

12 "Organization Information," BEST, accessed August 8, 2022, https://www.bestundertaking.com/in/page.asp?i=1

its ICE buses to electric in 2016, but it received very high bids of ₹ 2.5 crores (₹ 25 million) per bus, and this was considered financially unviable.

At the same time, Tata's hybrid buses were available, and the Mumbai Metropolitan Region Development Authority was procuring 25 of them. The FAME scheme was also being formulated, and it provided an incentive for both hybrid and electric buses. BEST tested a hybrid bus and an imported electric bus from two different manufacturers, and this experience convinced them to opt for electric buses only. Some more details of the electric bus procurements in Mumbai are available in Appendix B.

Pre-FAME I and FAME I bus procurement

Testing of electric buses began in Himachal Pradesh in 2016.[13] After that, BEST issued a tender for the outright purchase of electric buses using the ₹ 10 crores (₹ 100 million) fund allotted by BMC, and it was won by Olectra Greentech Pvt Ltd (previously known as Goldstone Infratech). The company delivered six non-AC midi electric buses in 2017.

Subsequently, FAME I offered an upfront purchase incentive of 60% of the bus cost to the transit authority, up to a maximum of ₹ 1 crore (₹ 10 million) if the OEM of the electric bus being purchased achieved 15% localization and a maximum of ₹ 1.5 crores (₹ 15 million) in cases where the OEM achieved 35% localization.[14] DHI invited an expression of interest in October 2017 from cities that wanted to procure electric buses under FAME I.[15] BEST submitted a proposal for 100 electric buses and out of that 80 buses were allotted in two phases of 40 buses each. BEST began procurement of electric buses on GCC. Evey Trans Pvt. Ltd., a subsidiary of Olectra Greentech Pvt. Ltd., won the first tender and the other tender was won by Volvo Eicher Commercial Vehicles (VECV).

BEST was looking for joint ownership of electric buses to safeguard its investment and ensure accountability from the OEM and the private bus operator. However, BEST settled for an equivalent bank guarantee from the private bus operator instead of joint ownership. A bank guarantee is a form of security provided by a lessee (in this case, the private bus operator) for the contractual obligations toward a lessor (here the transit authority). The lessor can access the funds in the bank guarantee to cover losses if the lessee fails to deliver the required services in case of bankruptcy or other reasons.

13 PTI, "Himachal Pradesh to Start Battery-Operated Electric Buses," *The Economic Times*, August 3, 2016, https://economictimes.indiatimes.com/news/politics-and-nation/himachal-pradesh-to-start-battery-operated-electric-buses/articleshow/53514988.cms?from=mdr

14 Abhay Khairnar, "Pune Smart City Pitches for 60 Electric Buses Under the National Electric Mobility Mission Plan 2020," *Hindustan Times*, November 29, 2017, https://www.hindustantimes.com/pune-news/pune-smart-city-pitches-for-60-electric-buses-under-the-national-electric-mobility-mission-plan-2020/story-THjn8Qx3mPb1DPbCHjubON.html

15 Department of Heavy Industries, Ministry of Heavy Industries & Public Enterprises, Government of India, *Expression of interest inviting proposals for availing incentives under FAME India scheme of Government of India from State Government departments/ undertakings/ municipal corporations for million plus cities*, October 31, 2017, https://heavyindustries.gov.in/writereaddata/UploadFile/EoI636662994025953960.pdf

According to BEST, three supply options were provided in the tender document and this was to encourage maximum participation and to get the most competitive rates for the two procurements under FAME I. These were:

- Option 1 – Range of 80 km on a single charge
- Option 2 – Range of 170 km to 200 km on a single charge
- Option 3 – Range of 50 km with battery swapping

BEST received the lowest bid for the second option. Meanwhile, DHI added two conditions to avail incentives under the FAME I scheme. The first was **benchmark prices**. Cities across India received varying bids for their tenders under FAME I. For example, bid prices for outright purchase of midi AC electric buses varied from ₹ 7.7 million to ₹ 9.9 million per bus.[16] As a result, DHI declared benchmark prices and decided to use them to calculate the maximum incentive. The benchmark prices were based on the lowest bid received in each bus category, and the categories were formed based on bus length, seating capacity, battery capacity, and floor height.[17] The second condition was **joint ownership**. Due to the large subsidy provided for the electric buses, DHI added the clause of joint ownership of buses between the transit authority and the OEM or private bus operator, which BEST had already tried to include in its contract.[18]

As a result of the above changes by DHI, interviewees shared that the subsidy for Evey Trans Pvt. Ltd. was reduced by about ₹ 24 lakh (₹ 2.4 million) per bus, but they decided to move ahead with the order and delivered the 40 midi non-AC electric buses. Also, per interviewees, VECV suffered a significant setback as their subsidy was reduced by about ₹ 55 lakh (₹ 5.5 million) per bus.[19] This made it economically unviable for them, and the contract was canceled. As a result, BEST only procured 40 out of the 80 electric buses approved under the FAME I scheme.

Notably, BEST had previously relied upon outright purchase of buses, and GCC was a shift in its procurement model. According to BEST, this change came after studying multiple tenders published by transit authorities across the country.

Procurement under FAME II

DHI launched the FAME II scheme in March 2019 and issued an invitation for expression of interest for availing incentive for electric buses in June 2019.[20] DHI mandated the GCC procurement model and declared ₹ 35 lakh (₹ 3.5 million), ₹ 45 lakh (₹ 4.5 million), and ₹ 55 lakh (₹ 5.5 million) as maximum incentives for mini, midi, and standard buses, respectively.[21] BEST submitted a proposal for 1,000 electric buses, out of which 300 were allotted.[22] DHI also re-allotted the 40 electric buses from FAME I to make up for the canceled contract. So, under FAME II, BEST procured 340 AC electric buses (200 midi buses and 140 standard buses) from Tata Motors in 2019, and this brought its total fleet of electric buses to 386.

16 Ravi Gadepalli et al., *Fiscal Incentives to Scale Up Adoption of Electric Buses in Indian Cities*, (UITP and Shakti Sustainable Foundation, 2019), https://shaktifoundation.in/wp-content/uploads/2020/01/Fiscal-Incentives-to-scale-up-electric-buses.pdf

17 Cabell Hodge et al., *Surat Municipal Corporation Bus Electrification Assessment*, (National Renewable Energy Laboratory/TP-5400-73600, 2019), https://doi.org/10.2172/1515398

18 During FAME I, OEMs also played the role of private bus operators because there were no private bus operators willing to operate electric buses in India.

19 The reduction in subsidy amounts has not been verified.

20 Department of Heavy Industries, Ministry of Heavy Industries & Public Enterprises, Government of India, *Publication of notification in Gazette of India (extraordinary) regarding Phase-II of FAME India scheme* (1(1)2019-AEI), (2019), https://heavyindustries.gov.in/writereaddata/fame/famedepository/2-notification.pdf

21 Department of Heavy Industries, Ministry of Heavy Industries & Public Enterprises, Government of India, *Expression of Interest Inviting Proposals for availing incentives under FAME India Scheme Phase II For Deployment of Electric Buses on Operational Cost Model basis*, (2019), https://heavyindustries.gov.in/writereaddata/fame/famedepository/13-E__didm_WriteReadData_userfiles_Final%20EOI%2004%20June%202019%20Published.pdf

22 Department of Heavy Industries, *Sanction of electric buses under Phase-II of Faster Adoption and Manufacturing of Electric Vehicles.*

Procurement of 3,000 electric buses in 2022

BEST scrapped 1,235 ICE buses between 2020 and 2022 and is planning to scrap 200 more ICE buses by 2023. The initial plan was to replace them with CNG buses, but BEST has decided to procure electric buses, instead. This is for two reasons. First, procuring CNG buses would postpone complete fleet electrification by at least a decade. Second, BEST had a positive experience with the performance of their 386 electric buses.

BEST published a tender in September 2021 for 1,900 AC electric buses (1,400 standard buses, 400 midi buses, and 100 mini buses). However, it was canceled in February 2022 due to administrative issues.[23] BEST published a fresh tender in April 2022 for procuring between 1,400 and 2,100 electric buses and the process is still ongoing as of August 2022.[24]

Additionally, with state government funding, BEST has placed an order for 900 double-decker electric buses which will be delivered by 2023.[25] Seven hundred of these buses will be delivered by Causis E-Mobility and 200 will be delivered by Switch Mobility (Ashok Leyland).[26]

Charging infrastructure

For 340 electric buses, BEST's private bus operator has installed 53 Tellus Power Green chargers with 200 kW capacity and 19 Exicom chargers with 240 kW capacity. The rest of the 46 electric buses are charged using 26 BYD chargers with 150 kW capacity.

Plans for expansion of the electric bus fleet

The Mumbai municipal commissioner announced that BEST would transition to 50% electric operation by 2023, and the Maharashtra state environment minister announced that BEST would fully transition to electric operation by 2028.[27] This is a more ambitious timeline than the Maharashtra State EV Policy.

23 Although this tender was eventually canceled, we have included the lessons learned from it in this report.

24 Manthank Mehta, "Mumbai: BEST Places Order for 2,100 Electric Buses," *The Times of India*, May 23, 2022, https://timesofindia.indiatimes.com/city/mumbai/mumbai-best-places-order-for-2100-electric-buses/articleshow/91749157.cms; Carrie Hampel, "2,100 Olectra Electric Buses Headed for Mumbai," *Electrive.com*, May 24, 2022, https://www.electrive.com/2022/05/24/2100-olectra-electric-buses-headed-for-mumbai/

25 Somit Sen, "BEST to Get 900 AC Electric Double-Decker Buses for Mumbai," *The Times of India*, January 26, 2022, https://timesofindia.indiatimes.com/city/mumbai/best-to-get-900-ac-electric-double-decker-buses-for-mumbai/articleshow/89133180.cms

26 Vinod Shah, Causis E-Mobility Plans to Revolutionise Green Public Transport in India," *Urban Transport News*, February 28, 2022, https://urbantransportnews.com/news/causis-e-mobility-wants-to-revolutionise-green-public-transport-in-india; "Switch Mobility Mulls 'Green' Plant to Make E-buses," *The Hindu*, June 14, 2022, https://www.thehindu.com/business/switch-mobility-mulls-green-plant-to-make-e-buses/article65526651.ece

27 PTI, "BEST's Entire Fleet Will Have Electric Buses by 2028: Aaditya Thackeray," *The Economic Times*, October 4, 2021, https://economictimes.indiatimes.com/industry/renewables/bests-entire-fleet-will-have-electric-buses-by-2028-aaditya-thackeray/articleshow/86760923.cms; Purva Chitnis, "Commuters, Come Back: Mumbai's Iconic BEST Double Decker Bus Returning in Electric, AC Avatar," *The Print*, February 6, 2022, https://theprint.in/india/commuters-come-back-mumbais-iconic-best-double-decker-bus-returning-in-electric-ac-avatar/821556/

PUNE

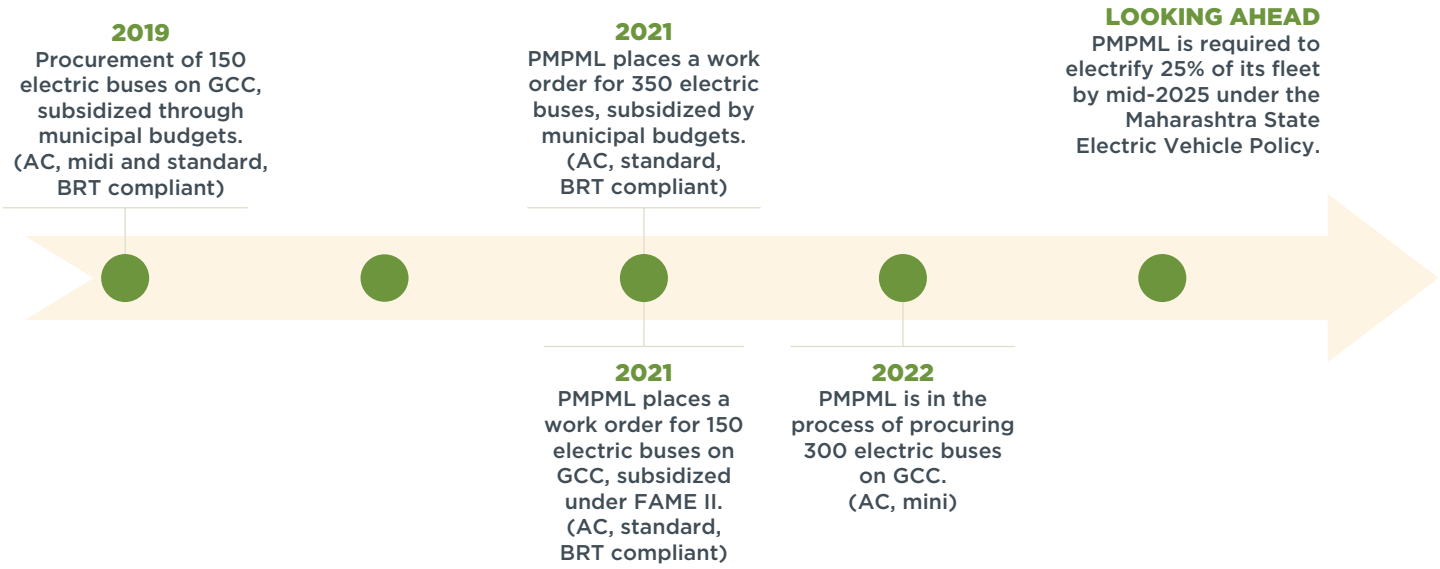

Figure 4. Timeline of electric bus procurements in Pune.

The twin cities of Pune and Pimpri-Chinchwad are a part of the Pune Metropolitan Region. Pune Mahanagar Parivahan Mahamandal Ltd. (PMPML) has provided the public bus transport service in the Pune Metropolitan Region (hereafter referred to simply as Pune) since 2007.[28] PMPML has a fleet of 1,895 buses that serve a population estimated to be 8.3 million in 2021, spread out across 7,257 sq. km.[29] PMPML scrapped all of its diesel buses and decided to operate only CNG and electric buses; currently 88% of PMPML's fleet is CNG buses and 12% is electric.[30]

Pune was considering procurement of electric buses in 2017 using Smart City funds.[31] According to PMPML, some experts were skeptical about electric vehicle technology, and they predicted prohibitive operating costs. But PMPML conducted several meetings with the OEMs to understand the market and ensure that the technology was mature enough. PMPML was also following the electric bus experiences in Himachal Pradesh and Mumbai. Eventually, they were convinced that the technology was sufficiently mature to serve their operational requirements.

Additionally, PMPML's erstwhile chairman and managing director favored electric bus procurement. The board of directors approved the chairman's proposal for procurement of 150 electric buses on GCC in 2018. It was then presented to the two municipal corporations of Pune and Pimpri Chinchwad, and the matter was debated in the standing committee meetings. PMPML organized a question-and-answer session to convince all stakeholders and ensure their support. After deliberation, both municipal corporations unanimously accepted the proposal. They decided to grant a lump sum

28 "History," Pune Mahanagar Parivahan Mahamandal Ltd., accessed August 8, 2022, https://www.pmpml.org/en/about-us/history/

29 Estimated population of Pune Metropolitan Region in 2021 is based on a 10.7% growth since 2011. The population of Pune Metropolitan Region was reported to be 7.5 million in the 2011 census. Pune Metropolitan Region Development Authority, Government of Maharashtra. "Background: Pune Metropolitan Region," accessed February 9, 2022, http://www.pmrda.gov.in/pmrda_background

30 FE Bureau, "Pune Scraps Diesel Buses in its Public Transport Fleet," *Financial Express*, April 15, 2022, https://www.financialexpress.com/express-mobility/vehicles/buses/pune-scraps-diesel-buses-in-its-public-transport-fleet/2493172/; The calculation is based on the bus age data provided by PMPML as of February 14, 2022, adding the 70 electric buses inducted in March 2022 and deducting 380 diesel buses scrapped in early April 2022.

31 Pune was selected as a Smart City under the National Smart Cities Mission by the Ministry of Housing and Urban Affairs, Government of India. Under this program, cities were allotted funds for promoting sustainable development; Abhay Khairnar, "Pune Smart City Pitches."

incentive of ₹ 50 lakh (₹ 5 million) per bus to the OEM for the first procurement, which consisted of 25 midi AC electric buses and 125 bus rapid transit (BRT) compliant standard AC electric buses.[32] Some more details of the electric bus procurements in Pune are available in Appendix B.

First procurement

Because people at PMPML did not have the necessary expertise in drafting electric bus specifications, they reached out to CIRT and jointly drafted a request for proposal with them.[33] According to PMPML, some special conditions and specifications in the request for proposal were:

1. Range of 225 km on a single charge, with a provision to accommodate one opportunity charging event during the day lasting 30 minutes.
2. Minimum of 225 assured kilometers per day.
3. BRT-compliant standard buses with a floor height of 900 mm.
4. Air suspension for better comfort.
5. Monocoque body because of the longevity and durability it offers. (AC is also more effective in a bus with a monocoque body because it prevents air leakage. A typical bus body built in the transit authority's workshop is different because it is composed of numerous joints, nuts, and bolts that start rattling with use and require frequent maintenance.)

During the pre-bid meeting, manufacturers requested that PMPML reduce the required range to 125 km on a single charge and allow opportunity charging for the rest of the 100 km. To keep the procurement process competitive, PMPML agreed to this request. However, PMPML ultimately only received one bid during the first round of the bidding process, from Evey Trans Pvt. Ltd. To invite other manufacturers to participate and support competition, PMPML extended the deadline of the bidding process twice, but to no fruition. Ultimately, PMPML went ahead with the procurement process with Evey Trans Pvt. Ltd.

PMPML conducted an elaborate proof of concept before procurement with an electric bus from Evey Trans Pvt. Ltd. (manufactured by Olectra Greentech Pvt. Ltd.). PMPML operated the bus on a variety of routes, both congested and non-congested, and over a variety of terrains, including hilly areas, for 7 days. This testing also mimicked actual operating conditions: daily operation for 18 hours in two shifts with AC switched on, three tons of sandbags loaded in the bus, and halts and door operation at each of the bus stops. The bus achieved a 150 km range in the first shift and a 100 km range in the second shift after a 30-minute opportunity charge using a 150 kW fast charger. PMPML was satisfied with the performance and went ahead with the procurement on a GCC model using the incentive provided by the municipal corporations.

32 The municipal corporation of Pune paid 60% of the incentive and the municipal corporation of Pimpri-Chinchwad paid 40% of it. Only OEMs or consortiums in which OEMs were lead members were invited to participate in the tendering process.

33 Central Institute of Road Transport (CIRT) is a joint initiative of the Ministry of Shipping and Transport and the Association of State Road Transport Undertakings, itself an association of transit authorities in India. CIRT provides training, consultancy, and automobile component testing services to the transit authorities. See http://www.cirtindia.com/About_History.html

Later, PMPML also issued a work order to Evey Trans Pvt. Ltd. for 125 standard BRT-compliant AC electric buses with similar specifications. The contract cost included buses, their maintenance, charging infrastructure, and driver; meanwhile, the cost of conductors and the electricity for bus charging were to be paid by PMPML. The buses are being operated by Evey Trans Pvt. Ltd.

Second procurement

PMPML has issued a work order for an additional 500 electric buses. Of these, 150 are under the FAME II scheme and 350 are being supported through municipal budgets; this support is in the form of upfront purchase incentives for the private bus operators, similar to the first procurement. Seventy out of the 500 electric buses were delivered as of March 2022 and rest were expected to be delivered by mid-2022.[34]

Charging infrastructure

PMPML's private bus operator has installed 42 BYD chargers with 80 kW capacity and two Delta chargers with 150 kW capacity at Bhekrainagar depot for the 90 electric buses stationed in that depot.

Plans for expansion of the electric bus fleet

Recall that Pune is one of the five cities in Maharashtra that is required to electrify at least 25% of its fleet by 2025, as per the Maharashtra State EV Policy 2021. The total tally of electric buses in Pune, after the expected delivery of the remaining 430 electric buses mentioned above, would be 650, and the total fleet size would be 2,325 if no buses are added or scrapped. That means that 28% of PMPML's fleet would be electric and Pune will have achieved the target of at least 25% electrification. Further, PMPML tested 7-meter long electric buses in July 2022 and plans to procure 300 such buses by the end of this year.[35] PMPML is also planning to add double-decker electric buses in the future.[36]

34 Joy Sengupta, "Pune: PMPML to Get 500 E-buses by May," *The Times of India*, January 8, 2022, https://timesofindia.indiatimes.com/city/pune/pmpml-to-get-500-e-buses-by-may/articleshow/88766031.cms

35 Joy Sengupta, "Pune Mahanagar Parivahan Mahamandal Limited Starts Trial Run of 7m-long E-bus," *The Times of India*, July 5, 2022, https://timesofindia.indiatimes.com/city/pune/pune-mahanagar-parivahan-mahamandal-limited-starts-trial-run-of-7m-long-e-bus/articleshow/92663939.cms

36 TNN, "Double-decker Buses May Run Again in Pune, as EVs," *The Times of India*, February 4, 2022, https://timesofindia.indiatimes.com/city/pune/double-decker-buses-may-run-again-in-pune-as-evs/articleshow/89334573.cms

NAVI MUMBAI

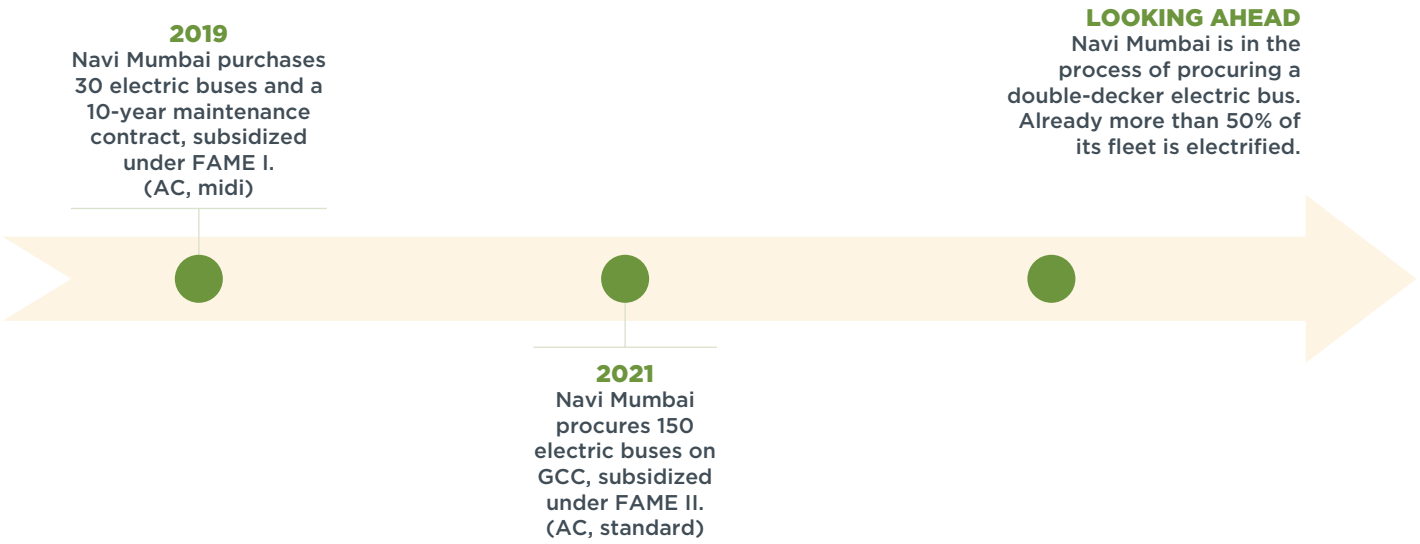

Figure 5. Timeline of electric bus procurements in Navi Mumbai.

Navi Mumbai has three administrative jurisdictions, and they are governed by Navi Mumbai Municipal Corporation, the City and Industrial Corporation of Maharashtra Ltd., and Panvel Municipal Corporation. Navi Mumbai also spans two districts, Thane, and Raigad. The total area of Navi Mumbai is around 344 sq. km.[37] The estimated population of Navi Mumbai in 2021 was about 1.24 million.[38] Navi Mumbai Municipal Transport (NMMT) provides public bus transport services to Navi Mumbai and connects the city to the Mumbai Metropolitan Region. NMMT has a total fleet of around 600 buses. Some more details of the electric bus procurements in Navi Mumbai are available in Appendix B.

Procurement under FAME I

NMMT procured its first set of electric buses on an outright purchase model by availing the incentive under the FAME I scheme at ₹ 1.28 crore (12.8 million) per bus (this was different from the GCC model used by BEST).[39] Navi Mumbai submitted a proposal for the outright purchase of 55 midi electric buses and DHI allotted the city 30 midi electric buses. NMMT published the tender for these buses in August 2018. According to NMMT, only two major specifications were included in the request for proposal, and this was to encourage maximum participation in the bidding process:

1. Range of 120 km on a single charge.
2. Minimum seating capacity of 34, including driver.

Out of many bidders, JBM Auto won the contract. As NMMT owns the buses, it must also maintain the buses. Thus, NMMT also purchased a 10-year comprehensive maintenance contract (CMC) from JBM Auto at ₹ 7.05 per km, and it includes regular

37 City & Industrial Development Corporation of Maharashtra Limited. *Navi Mumbai: The periphery*, December 19, 2017, https://cidco.maharashtra.gov.in/

38 Estimated population of Navi Mumbai in 2021 is based on a 10.7% growth since 2011. The population of Navi Mumbai was reported to be 1.12 million in the 2011 census. Navi Mumbai Municipal Corporation, *Environmental Status Report of Navi Mumbai Municipal Corporation 2018-19*, accessed February 9, 2022, https://www.nmmc.gov.in/navimumbai/assets/251/2020/02/mediafiles/ESR_2018-19_English.pdf

39 George Mendonca, "NMMT Gets Nod to Buy 30 Electric Buses, 18 Charging Stns at Rs 42cr," *The Times of India*, August 10, 2018, https://timesofindia.indiatimes.com/city/navi-mumbai/nmmt-gets-nod-to-buy-30-electric-buses-18-charging-stns-at-rs-42cr/articleshow/65358693.cms

bus maintenance, spare parts, labor cost, accidental damage insurance, and battery maintenance. In this way, NMMT was able to manage the technology and maintenance-related risks even in an outright purchase; this is otherwise an advantage of a GCC procurement model.

Procurement under FAME II

DHI initially allotted 100 electric buses to NMMT under FAME II, and then later on, allotted an additional 50 electric buses.[40] NMMT thus procured 150 electric buses under the scheme: 105 standard and 45 midi AC electric buses. These buses were procured on a GCC model as it was a requirement to qualify for the incentive under the FAME II scheme. NMMT increased the range requirement for this procurement and added a few more specifications to suit the GCC procurement, as shown in Table 2.

Table 2. Technical specifications for NMMT's second electric bus procurement

	Midi buses	Standard buses
Range (km)	160	200
Assured kilometers per day	199	223
Opportunity charging time (minutes/day)	75	90
Preferred seating capacity	More than 31	More than 37
Expected minimum daily operation in two shifts (km)	220	260

The second order was also won by JBM Auto, and it delivered the 150 electric buses by October 2021.

Charging infrastructure

NMMT had planned to set up 15 chargers in a depot and three chargers at terminals at the cost of ₹ 3.5 crore (₹ 35 million) for 30 electric buses in 2019.[41] In interviews, NMMT explained that 26 chargers had been installed so far: 20 Exicom chargers with 120 kW capacity, and two Exicom chargers and four Delta chargers with 240 kW capacity.

Plans for expansion of the electric bus fleet

NMMT has started procurement of one double-decker AC electric bus on an outright purchase model. The tender includes one electric bus, the charger, and a comprehensive maintenance contract for 12 years. NMMT is expecting a range of 120 km on a single charge, a minimum seating capacity of 65, and an energy efficiency of less than 1.4 kWh/km. Interestingly, NMMT prefers outright purchase over GCC because the capital cost of the electric bus is paid from the municipal budget; the transit authority has to bear only the costs of operation and maintenance. On the other hand, in a GCC, the contract cost is inclusive of the bus cost, and that would therefore increase NMMT's expenses. According to NMMT, the maintenance of electric buses can be streamlined by purchasing a comprehensive maintenance contract, as it did during its first electric bus purchase.

40 Department of Heavy Industries, *Sanction of electric buses under Phase-II of Faster Adoption and Manufacturing of Electric Vehicles*.

41 Local Press Co., "NMMT Takes Delivery of First Electric Bus, 30 Such Buses to Start Plying in Navi Mumbai Soon," August 27, 2019, https://localpress.co.in/mumbai/nmmt-takes-delivery-of-first-electric-bus-30-such-buses-to-start-plying-in-navi-mumbai-soon/

SUMMARY OF SELECT EXPERIENCES IN THE THREE CITIES

This section presents the lessons learned through the interviews in the three cities. We divided them into four categories—procurement, personnel and training, data collection and application, and bus operations—and have included our recommendations at the end of each category.

PROCUREMENT

Technical evaluation before bus procurement

"We chose to complete the proof of concept and technical assessment of the electric buses before opening bids. That way, we ensured that the electric buses were technically fit for our operational requirements"

—SUNIL BURSE, CHIEF MECHANICAL ENGINEER, PMPML

In its tendering process, PMPML decided to open the technical bids before opening the financial bids. This meant that preference was given to the performance and technical specifications of the buses over price, and prevented a process that would only select the lowest bidder. PMPML relied upon the expertise of CIRT to draft the specifications for the electric buses and to make sure that the products offered by the bidders fulfilled them. The chief mechanical engineer of PMPML stressed the benefits of this approach and suggested that transit authorities procuring electric buses for the first time should conduct a pilot for a minimum of 15 days to ensure that the buses meet their range requirements.

Prior to awarding a contract, NMMT also conducted a detailed inspection to verify bus range, battery capacity, bus quality, and workmanship.

Terms of bus procurement

The benefits of procuring buses on GCC for the transit authorities are well known, and it has been the most popular model for electric bus procurement. Only 320 electric buses have been outright purchased as of March 2021, and that is only 10% of the electric buses operating in India today.[42] GCC is attractive in part because it separates the costs and risks associated with bus operations and maintenance from scheduling and revenue. Additionally, the transit authorities we studied have used some strategies to reduce the contract cost and enable a smoother and faster rollout of buses:

1. **Contract length**: The contracts for BEST's procurements in 2018 and 2019 were 10 years. However, they subsequently realized that the private bus operators expect to replace the battery in 6 years, and thus a 12-year contract would enable full use of two battery cycles and BEST would get the most competitive rate. BEST has since included a provision to extend the 12-year contract further by 3 years, depending on the condition of the electric buses at the end of 12 years. NMMT's recent electric bus contract length is also 12 years. PMPML's contracts are 10 years, with a provision for a 2-year extension.

42 Number of buses purchased outright referred from: Anumita Roychowdhury and Sayan Roy, *Electric Bus Towards Zero Emission Commuting*, (Centre for Science and Environment: New Delhi, 2021), https://www.cseindia.org/electric-bus-10969

2. **The cost of electricity**: This is a key differentiator between the three transit authorities we studied. BEST has included the cost of electricity in the contract cost from the private bus operator, while PMPML and NMMT pay for the electricity required for bus charging separately. BEST has used a formula to revise the contract cost to account for the changes in the electricity tariff since its first electric bus procurement. For the latest procurement, BEST adjusted the formula to account for the real-world efficiency of the electric buses to offset the actual electricity cost to the private bus operator, as detailed in the section on Data collection and application, below.

PMPML pays the private bus operator for the electricity consumed by bus charging and each charger has a separate electricity meter. PMPML keeps track of the number of units of electricity consumed per kilometer operated at the end of each month at the fleet level (energy efficiency in kWh/km). If the number of units consumed is higher than 1.3 kWh/km (1.4 kWh/km in the latest tender) for standard AC buses and 1 kWh/km for midi AC buses, the private bus operator is expected to pay for the excess electricity.

Similarly, NMMT pays for the cost of electricity subject to the maximum energy efficiency of 1.4 kWh/km for standard AC buses and 1.2 kWh/km for midi AC buses.

Table 3. Terms for payment of electricity consumed for charging of electric buses in the three transit authorities

	PMPML	NMMT	BEST
Midi AC buses	Up to 1 kWh/km	Up to 1.2 kWh/km	Does not pay separately for electricity
Standard AC buses	Up to 1.3 kWh/km for first tender Up to 1.4 kWh/km for latest tender	Up to 1.4 kWh/km	

3. **Depot development**: The general practice has been that the transit authority provides land, upstream electrical infrastructure, and developed depots (which includes basic infrastructure like an office building, bus shelters, paving, and electrical connection), and the operator is responsible for purchasing, installing, and maintaining the chargers. However, PMPML has identified depot development as one of the potential risks for delay in bus rollout. Delays can happen because of interdependence between government departments and agencies and if there is a lack of coordination between them. Hence, PMPML has transferred the responsibility of depot development to the operators in its latest procurement; it still provides the land and upstream infrastructure.
4. **Opportunity charging**: BEST tried to operate its electric buses without providing opportunity charging in its FAME I procurement, but that meant the private bus operator had to deploy about 8% more electric buses than the number contracted, and this eventually led to a higher cost for BEST. Therefore, in the 2021 procurement, BEST provided an opportunity-charging window. See the section on Bus operations, below, for more details.
5. **Fleet availability**: The transit authorities mostly expect 100% fleet availability in their contracts for electric buses and penalize private bus operators if availability falls below 100%. However, BEST reduced its fleet availability requirement to 95% for peak hours in its latest procurement, and this gives the private bus operator some additional time to charge and maintain the buses.

"We have learned from our past tenders that it is important to minimize the financial risk perceived by the private bus operators to get the most competitive rates"

—CHANDRAKANT BIRAJDAR, EXECUTIVE ENGINEER, BEST

6. **Other price revision criteria**: The private bus operator can be expected to factor in the increasing operating cost over the contract period upfront if the transit authority does not enable regular escalation of the contract cost. BEST, which uses a formula to calculate regular price increases, updated the formula in its latest contracts to offset the increasing operational cost for the private bus operator more realistically by accounting for the following:

   - **Change in electricity tariff**. The contract cost is revised in accordance with the ratio of actual change in the electricity tariff to the bus energy efficiency in km per kWh, and this adjustment is made as and when the electricity tariff changes. BEST calculated the real-world energy efficiency of the electric buses they are already operating to use more realistic values of the energy efficiency in the tender. More details are in the section on Data collection and application, below.
   - **Change in labor cost**. Adjustment is equal to the product of the quoted contract cost and 20% of the relative change in the minimum wages for skilled laborers (drivers) as issued by the Government of Maharashtra from the second year onward. This was 15% in the previous contracts and this adjustment is made once every two months.
   - **Change in the cost of spare parts and other consumables required for bus maintenance**. Adjustment is equal to the product of the quoted contract cost and 5% of the relative change in the Consumer Price Index (CPI) from the third year onward. This adjustment is made every 2 months.

$$C_r = C_q + \left(\frac{T_r - T_p}{E}\right) + \left(Cq \times \frac{CPI_{month} - CPI_{base}}{CPI_{base}} \times 0.2\right) \times \left(C_q \times \frac{MW_{month} - MW_{base}}{MW_{base}} \times 0.05\right)$$

C_r	Revised contract cost (₹/km)
C_q	Quoted contract cost when the bid was submitted (₹/km)
T_r	Revised electricity tariff (₹/kWh)
T_p	Previous electricity tariff (₹/kWh)
E	Energy efficiency (km/kWh) based on the bus type
CPI_{month}	Revised consumer price index in that month
CPI_{base}	Consumer price index when the bid was submitted
MW_{month}	Minimum wages as published by the Government of Maharashtra

NMMT has a formula similar to that of BEST and it is based on the model concession agreement published by DHI for procurement of electric buses under FAME II.[43] The provision in the tender was to revise the contract cost every 6 months, and sooner if the electricity tariff varies by 10% and/or CPI and Wholesale Price Index (WPI) vary by more than 2%.

43 NITI Aayog, Government of India, *Public Private Partnership in Operation and Maintenance of Electric Buses in Cities (OPEX Model). Model Concession Agreement*. (2021). https://www.niti.gov.in/sites/default/files/2020-02/ModelAgreement-Operation-and-Maintenance-of-E-Buses.pdf

PMPML provides a fixed 1% escalation annually in the contract cost from the third year onward.

7. **Disputes and contract closure:** Transit authorities define key performance indicators (KPIs) in the contracts to monitor and manage the quality of service provided by private operators. KPIs of concern might include trip delay, trip cancellation, breakdowns, deviation from agreed-upon bus specifications, and violations of traffic rules. Transit authorities impose penalties in the case of any such infractions by private bus operators.

Officials from BEST said they were too risk-averse in the FAME I and FAME II tenders and heavily accounted for the risk of default by the operator, with a cap on total penalties for infractions in a month at 10% of the monthly bill and a fixed bank guarantee for 5 years. But in retrospect, BEST stated that it might not have been the best option for them because when operators bid for a tender, they quote a rate that would cover their costs even in the case of such a penalty. BEST has since reduced the cap on the penalty for infractions to 5% of the total monthly bill payable to the operator and incorporated a bank guarantee that reduces by 20% annually, to account for the services provided against the disbursed incentive and depreciating assets. [44]

RECOMMENDATION: WELL-DESIGNED TENDERS AND CONTRACTS CAN REDUCE COSTS, RISK, AND THE POTENTIAL FOR DELAYS IN ROLLOUT.

- **Minimize the financial risk to the private bus operator**. Including comprehensive cost revision provisions in the contracts recognizes and offsets operational cost increases for the private bus operator over the contract tenure. If this is not done by the transit authority, the operator will factor in these risks upfront and contract costs will be higher.
- **Align contracts with battery lifetimes**. The operational life of electric buses is dependent on the life of the battery and the motor, both of which are replaceable. In Santiago, Chile, battery life is assumed to be 7 years, and thus the electric bus contract tenure is 7 years, with a provision for another 7-year extension.[44] Provisions that allow for an extension of the contract also motivate operators to maintain service quality.
- **Identify and transfer responsibilities that are better served by the private bus operators**. Activities like depot development and installation of downstream electrical infrastructure can be handled efficiently by private bus operators. Transferring responsibility for paying for the electricity to the private bus operators can also save on administrative costs for the transit authorities. In the case of outright purchase, the transit authority can purchase a comprehensive maintenance contract to ensure adequate support from the OEM over the lifetime of the bus.

PERSONNEL AND TRAINING

Personnel requirement

PMPML appoints one timekeeper per shift per depot to document the electricity consumption for charging electric buses and other details mentioned in the section on Data collection and application, below. Each charger has a separate electricity meter, and the timekeeper records the unit reading before and after the charging event, along with the start and end time. The timekeeper also records the odometer reading of the bus at each charging event in a standard sheet (see Table 4, below) and communicates these details to PMPML's central office. Three timekeepers per depot per day are required for monitoring electricity consumption and this becomes four timekeepers if a reliever is also appointed for cases of absenteeism.

44 Red Metropolitana de movilidad, "Tender Process for Public Transport Operation [Webinar]," accessed August 8, 2022, https://www.dtpm.cl/descargas/licitacion20/Tender%20Process%20for%20PT%20Operation_ENG.pdf

Bus drivers are usually in high demand and private bus operators said they typically maintain a daily driver-to-bus ratio of 2.5:1 (for two shifts), including additional drivers to account for absenteeism.

Training requirements and priority

The focus of the transit authorities is on building the capacity of their electrical department, as it will play a crucial role in ensuring energy security in the future. However, many interviewees did not feel a pressing need for electric bus-specific training for their staff, as most of the responsibilities for charging and maintenance are handled by the private bus operators.

Some transit authorities feel the need to protect themselves by relying on high penalties when negotiating contracts with the operator. This is due to a lack of experience and expertise regarding electric buses, and they hope this will change as they get more experience and training.

According to the private bus operators, driver training is the most essential part of their hiring process. The drivers are given safety training and are trained to read and interpret the information that is specific to electric buses, such as the state of charge and the error codes on the dashboard that are displayed in cases of malfunction. Drivers are also taught best practices to achieve maximum efficiency from the battery and to leverage regenerative braking in electric buses. NMMT follows this kind of approach in training its drivers, and even organizes refresher courses for them regularly.

Range anxiety

Some depot managers and drivers stated that range anxiety remains a concern, but they think it is getting better with time as drivers gain confidence in electric buses. According to a depot manager at PMPML, the display that shows the remaining range is helpful because it helps drivers make better decisions before starting the trip. However, they have experienced hesitancy among drivers to drive the bus at a lower state of charge and have considered displaying reference charts inside electric buses that show the battery percentage required to complete one trip on various routes, to guide drivers. However, it became unnecessary as drivers became more confident with experience. We also observed a difference in perception of the actual range of the electric buses amongst the staff working in the transit agencies.

A driver from NMMT said that their electric buses automatically disable AC when the state of charge drops below 20%. This extends the bus's range, helps the driver overcome range anxiety, and makes breakdown due to insufficient charge unlikely.

RECOMMENDATION: RESKILL AND UPSKILL THE EMPLOYEES OF TRANSIT AUTHORITIES

» Transit authorities should provide training and regular refresher courses for their planners, decision-makers, and other staff, even if most of the responsibility of the technology is on the private bus operator.

» Transit authorities might opt for outright purchase of some electric buses in the future to avoid complete dependence on hired fleets and to utilize their permanent employees who will likely remain with them for several years. Such employees should be trained in electric bus operations before completing the transition to electric.

» Range anxiety is interfering with bus planning in some transit authorities. This affects scheduling and route planning and may lead to the underutilization of buses. Training and evidence-based planning can alleviate this concern.

DATA COLLECTION AND APPLICATION

Traditionally, transit authorities collect and store operational data from their bus fleets. Some key performance indicators (KPIs) tracked include the scheduled and operated kilometers, fuel consumption, revenue collection, material use, and breakdowns. In the case of electric buses, transit authorities keep a record of some additional data points, especially at the charger level. Table 4 is representative of data typically recorded by transit authorities.

Table 4. Format of the data traditionally collected by the transit authorities.

Duty supervisor name: **Shift:** **Date:**

Bus Number	Odometer reading	Driver name / Number	Charger Number	Start Time	End Time	Start SOC	End SOC	Meter reading before	Meter reading after	No. Of units consumed

Transit authorities do not typically have access to any information on battery health or energy efficiency from the on-board diagnostics of the electric buses. Some of the interviewees were skeptical as to whether they would ever have access to such data, as the OEMs consider it proprietary. They also reported that the private bus operators do not share the monthly operational and performance reports as agreed to in the contracts, let alone the real-time performance data.

Note, though, that BEST uses real-world electric bus energy efficiency to calculate the contract cost escalation in its latest tender. It calculates the real-world energy efficiency by taking the ratio of the number of units consumed for bus charging to the number of operated kilometers at the depot and fleet levels. The energy efficiency is based on assumptions in their previous contracts and is shown in Table 5, along with the revised values.

Table 5. The energy efficiency numbers used by BEST to calculate electricity consumption in two of its contracts.

Bus type	Energy efficiency assumed for FAME II contract (kWh/km) [a]	Revised energy efficiency (kWh/km) for 2021 procurement
6 to 8 meter AC (mini bus)	—	0.66
9 meter AC	0.94	1.05
12 meter AC	1.18	1.33

[a] BEST represents energy efficiency in kilometers traveled per unit of electricity (km/kWh). We have converted it to kWh/km for clarity.

RECOMMENDATION: MONITORING AND EVALUATION IS A MUST

- Mandate data sharing by the private bus operator on bus technology and operations in the contracts, especially regarding **energy efficiency, battery health, and maintenance cost**. This improves transparency and informs the true cost of operating electric buses. **Sharing this information between transit authorities can help identify potential outliers and improve critical assumptions** related to battery such as battery life and battery replacement cycles, both of which affect the cost of the electric buses directly or indirectly.
- **Transit authorities can monitor and estimate the energy efficiency and the state of health of the battery using telematics devices (real-world performance monitoring)**. Many ICE bus contracts already require that buses fit the Recommendatory Urban Bus Specifications II (UBS II), and the specifications for the Intelligent Transport System in UBS II include support for Vehicle Health Monitoring and Diagnostics (VHMD).[45] VHMD can report the health of the power train (engine for ICE buses), electrical system, electronics, safety features, and transmission. **Similar VHMD mandates can be standardized for and applied to electric buses, as well.** The **true costs of electric bus operation can inform future tenders** and can be leveraged to reduce the financial risk on the private bus operator as well as to negotiate better rates on future buses for the transit authorities.
- Transit authorities can include a clause for a penalty on the private bus operators in case they fail to share data.

BUS OPERATIONS

Charging and scheduling

BEST did not modify its existing ICE bus schedules to suit electric buses for its FAME I and FAME II procurements. Their strategy was to operate the maximum number of buses during morning and evening peak hours and about 80% of the buses during off-peak hours; the hope was to leverage this downtime to charge the buses. But this time was not sufficient for charging the buses to meet the operational requirements and the private bus operator had to deploy about 8% extra electric buses and keep on exchanging the charged buses with the discharged ones. Additionally, BEST realized that the additional buses deployed by the private bus operator were not eligible for the FAME II subsidy because they were over and above the number of electric buses sanctioned to them. Thus, this cost was eventually factored into BEST's contract cost.

As a result, in its latest procurement, BEST allowed opportunity charging for 45 to 60 minutes per day. Additionally, BEST reduced the required bus availability from 100% to 95% on weekdays and even lower on weekends, so that the private bus operator gets an opportunity to charge and maintain the electric buses. In its latest procurement, BEST procured electric buses with ranges varying from 160 km to 200 km. To manage charger use, the plan is to allot bus routes so that some of the buses with larger battery capacity will require minimum opportunity charging time during the day.

NMMT and PMPML had already provided an opportunity-charging window in their GCC contracts and the time varied from 45 minutes to 90 minutes. Both authorities informed us about changes in schedules to accommodate electric buses. NMMT has now adopted the Ahmedabad pattern where crew change takes place at the depot at the end of the shift; they previously followed the London pattern, with crew change at the terminal. This change was necessary because electric buses have to come back to the depot for charging, and that incurs additional dead kilometers between the terminal and the depot. PMPML did not face the problem of dead kilometers because it has bus depots at the city's fringes and it was possible to build terminals next to the

45 Ministry of Urban Development, Government of India. *Recommendatory Urban Bus Specifications II*, (2013), https://mohua.gov.in/upload/uploadfiles/files/Urban-Bus-Specifications-II.pdf

depots. Note, too, that some transit authorities find it challenging to accommodate opportunity charging in cases where buses turn up later than their scheduled time, and this causes trip cancellations.

Both PMPML and NMMT leverage the 30-to-40-minute crew break in both shifts for opportunity charging. However, ICE buses do not remain idle even during the crew breaks, and this is an adjustment to the schedule to accommodate time for opportunity charging.

A depot manager at PMPML stated that they have a few CNG buses in reserve and proactively deploy them at the beginning of the second shift to give some extra time for electric buses to charge, even though the private bus operator did not specifically request this.

According to the private bus operator in Pune, they assign buses to specific routes, and the current practice is to charge the electric buses as soon as they reach the depot. However, this comes at the cost of a higher energy bill, as it involves charging the buses even when the electricity tariff is higher. They did not have any immediate insights on the effect of frequent charging events on battery health.

Route selection

Route length and depot location were identified as essential criteria for route selection by all three transit authorities that we studied. PMPML plans the routes to/from/between electric bus depots where the charging infrastructure is located. The planners informed us that they try to allocate electric buses to as many areas of the city as possible to ensure that the benefits of lower pollution, noise, and better passenger experience are spread out geographically.

NMMT has assigned its midi electric buses with a smaller battery capacity to the routes operating solely within Navi Mumbai due to range constraints and frequent traffic congestion on roads leading to Mumbai. The new standard electric buses, meanwhile, can be operated on longer routes due to the longer expected range. Both PMPML and NMMT have installed a limited number of chargers at some terminals in the city, and these obviate the need to bring some electric buses back to the depot and provide some flexibility in route selection.

BEST assigned shorter routes to the electric buses initially, but then as they proved to be reliable, started using them on longer routes.

Minimizing energy bills

Interviewees described the importance of optimizing bus charging to minimize energy use during peak load periods. For example, Maharashtra State Electricity Distribution Co. Ltd. charges an additional ₹ 1.1 per unit of electricity between 6 pm and 11 pm, but provides a discount of ₹ 1.5 per unit between 11 pm and 6 am.[46] The impact of optimized charging is shown in Table 6 and the transit authority in this example would pay 65% less for electricity when charging at night compared to the peak load period in the evening.

46 Assuming power factor = 1, in other words, 1 kVAh = 1 kWh. Tariff retrieved from Maharashtra State Electricity Distribution Co Ltd., *Revision in Electricity Tariff w.e.f. 1st April 2020 and implementation thereof*, (2020, p. 60), https://www.mahadiscom.in/consumer/wp-content/uploads/2020/04/Commercial_Circular_for_MYT_Order-3.pdf

Table 6. Effect of charging optimization on the energy bill.

Electricity consumption	Electricity cost from 11 pm to 6 am (₹)	Electricity cost from 6 am to 9 am and 12 pm to 6 pm (₹)		Electricity cost from 6 pm to 11 pm (₹)	
	Total cost (A)	Total cost (B)	Additional cost (B-A)	Total cost (C)	Additional cost (C-A)
1 unit	4.0	5.5	1.5	6.6	2.6
10,000 units	40,000	55,000	15000	66,000	26,000
50,000 units	200,000	270,000	70,000	330,000	130,000
94,500 units	378,000	519,750	141,750	623,700	245,700

Note: Power factor assumed to be 1. Estimated daily electricity consumption is 94,500 units for 300 electric buses, 225 km of daily operation per bus, and energy efficiency of 1.4 kWh/km. The concessional electricity tariff charged by Maharashtra State Electricity Distribution Co. Ltd. for EV charging is from the order dated March 30, 2020, available at https://www.ciicovid19update.in/uploads/1/3/1/3/131362769/mahrashtra.pdf

RECOMMENDATION: ELECTRIC BUSES WILL REQUIRE A NUANCED APPROACH TO SCHEDULING AND ROUTE SELECTION

- Transit authorities have benefited from providing **dedicated opportunity charging time** for electric buses. All transit authorities have leveraged crew breaks for opportunity charging, while some also charge the buses during short layovers if the terminals are close to the depots. While the responsibility for electric bus charging strategy falls on the private bus operators, transit authorities must engage with them and **allow sufficient and dedicated time for charging**.
- Transit authorities should undertake technical studies to **identify and prioritize routes** on which the **existing ICE buses can be replaced by the same number of electric buses**. Prioritizing such routes can reduce the cost of operations and maintain service levels.
- Transit authorities can **leverage mixed fleets** by deploying some ICE buses as fillers during the opportunity-charging windows, if required and until they transition to 100% electric bus operation.
- Transit authorities can opt for **smart scheduling solutions** that optimize how buses in their fleets are deployed.
- Transit authorities can adopt **smart charging solutions** to manage the load on the grid and the energy drawn during peak tariffs. Such solutions can not only optimize infrastructure use, but also minimize charging cost.
- **It is important to plan for depots and routes of operation**. The route and depot allotment for electric buses should not be an afterthought. Transit authorities must identify depot locations for the electric buses before beginning the tendering process and start preparing the depot well in advance to avoid any delays in bus rollout.

WAY FORWARD: THE UNIFYING PIECE OF ELECTRIC BUS DEPLOYMENT

The experiences described above are varied, but a key imperative that emerges can be considered common to all: **electric buses are reliable**. Cities need not opt for transient technologies like hybrid buses and can instead transition to electric buses directly.

The findings complement both our prior work and the knowledge gleaned by others who have examined a variety of international experiences. From an overarching view, we can see that transit authorities are already experiencing the numerous benefits that electric buses offer, such as zero tailpipe emissions, lower maintenance requirements, better driving and passenger experience, and the lower operating costs than diesel buses that are consistent with international experience.[47] As a transition to full electric bus operations in India is somewhat likely to happen in the near future, to streamline this transition, we suggest that transit authorities prepare a **fleet-wide strategy for full electrification**. The strategy should include clear targets for both transitioning to electric-only new bus purchases and electric-only operations. Adopting these targets in the form of a policy will guide decision-making by future leadership.

Fleet-wide strategies can be based on fleet turnover, available technologies, models available in the market, and economics. These plans can be reviewed regularly to account for the development of the technology. Inclusion of **infrastructure planning**, especially identification of depot locations for future electric buses and terminals suitable for installing chargers would make fleet-wide strategies more comprehensive. It is also essential to engage with municipal corporations for land allotment and with power distribution companies to plan the upstream infrastructure, as the depots might be in areas where this infrastructure is not readily available.

Such strategies send a **market signal to OEMs** and enable them to be more confident in their estimates of future demand; from this they can make necessary investments and be prepared to supply products. State governments in India can encourage transit authorities to formulate such fleet-wide strategies via regulations like the Innovative Clean Transit Regulation in California. The Innovative Clean Transit Regulation requires all public transit agencies in the state to transition to 100% electric bus purchases by 2029, and to 100% electric bus operations by 2040. To achieve the same, they are required to formulate fleet-wide transition strategies to avoid premature retirement of their ICE buses.[48]

Transit authorities can opt for a phased implementation that starts with procurement of a relatively small number of electric buses and then expands later, as they gain confidence in and experience with electric bus operations. In the early stages, evidence-based route selection for electric buses can help transit authorities to select the most energy-efficient routes on which they can replace ICE buses without the need to deploy extra electric buses for the same schedule. Also, smart scheduling and smart charging solutions can help the transit authorities better manage their services to the benefit of their passengers.

47 Jairo Bedoya, "Latin America Can Inspire Electric Buses Adoption Worldwide," *World Bank*, March 23, 2021, https://www.worldbank.org/en/news/feature/2021/03/23/uso-de-buses-electricos-marcha-sobre-ruedas-en-latinoamerica; Peter Maloney, "Electric Buses for Mass Transit Seen as Cost Effective," *American Public Power Association*, October 17, 2019, https://www.publicpower.org/periodical/article/electric-buses-mass-transit-seen-cost-effective

48 California Air Resources Board, "Innovative Clean Transit Rollout Plans," accessed February 9, 2022, https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/ict-rollout-plans; California Air Resources Board, "Innovative Clean Transit (ICT) Regulation Fact Sheet," May 16, 2019, https://ww2.arb.ca.gov/resources/fact-sheets/innovative-clean-transit-ict-regulation-fact-sheet

APPENDIX A. DETAILS OF INTERVIEWS

The interviews were primarily done in person between August 2021 and March 2022, but in some cases, they were conducted over the phone. The plan was to select broad topics for discussion without adhering to a stringent question-and-answer format. The broad topics for discussion are presented in the table below. We divided the topics into high priority and low priority and discussed the low-priority topics only in cases where time permitted, or where interviewees were available for follow-up discussions. We tried to limit the conversations to 45-minute sessions and extend the conversations based on the interest and response of the interviewee. As a result, most of the interviews were 30 to 40 minutes long, but some extended to 2 hours.

TOPIC ALLOCATION FOR THE INTERVIEWS

High Priority Topic
Low priority Topic

Topics	Technical	Operations	Drivers and maintenance staff	Private bus operators
Planning and vision				
Procurement				
Infrastructure				
Training and personnel				
Partnerships, external conversations, and negotiations				
Data collection and application				
Contracts (GCC)				
Operation				
Maintenance				
Reliability				
Scheduling				
Charging performance				
Driving experience and challenges				
Range anxiety				

APPENDIX B. PROCUREMENT DETAILS

The following tables contain procurement details as reported by the transit agencies in each of the three cities.

BEST, Mumbai

	2017	2018 (FAME I)	2019 (FAME II)	2021*	2022 (Double Decker)	2022 (in process)
Procurement model	OP total: 6	GCC total: 40	GCC total: 340	GCC total: 1,900	GCC total: 900	GCC Total: 2100
Number of buses	Midi Non-AC: 6	Midi AC: 20 Midi Non-AC: 20	Midi AC: 200 Std. AC: 140	Mini AC: 100 Midi AC: 400 Std. AC: 1400	10 to 10.5 m AC- 900	Std. AC: 2100
Contract cost ₹/km	—	Midi AC: 55.17 Midi Non-AC: 51.75	Midi AC: 74 Std. AC: 83	Mini: 43.75 Midi: 44 Std.: 54.85	56	46.81
Maintenance cost ₹/km	2 to 3	—	—	—	—	—
Electricity included in the rate?	—	Y	Y	Y	Y	Y
Energy efficiency	1.1 to 1.3 km/unit	—	—	—	—	—
Contract period	—	10	10	12	12	12
Assured km	—	4,000 per month	4,750 per month	5,800 per month	5,000 per month	5,800 per month

Note: OP = outright purchase; GCC = gross cost contract; mini = buses of length less than 8 m; midi = buses of length between 8 m and 10 m; standard (Std.) = buses of length between 10 m and 12 m; DD = double decker (bus length usually 10 m to 10.5 m).

* This procurement was canceled for administrative reasons in February 2022 and a fresh tender was floated later; details of the subsequent tender are not included in this report.

PMPML, Pune

	2018/2019	2021 (FAME II)	2021
Procurement model	GCC	GCC	GCC
Number of buses	Midi AC: 25 Std. AC: 125 Total: 150	Std. AC: 150	Std. AC: 350
Contract cost ₹/km	Midi AC: 40.32 Std. AC: 58.5	63.95 (includes depot development)	67.4 (includes depot development)
Electricity cost included in the rate?	No Paid by PMPML Up to 1.3 kWh/km for Std AC and up to 1 kWh/km for midi AC	No Paid by PMPML Up to 1.4 kWh/km for Std AC	No Paid by PMPML Up to 1.4 kWh/km for Std AC
Energy efficiency	Actual efficiency not available	Actual efficiency not available	Actual efficiency not available
Contract period	10+2 years	10+2 years	10+2 years
Assured km	225	225	225

Note: Approximate electricity cost per km for PMPML = ₹ 8; approximate conductor cost per km for PMPML = ₹ 11.

NMMT, Navi Mumbai

	2018 (FAME I)	2021 (FAME II)
Procurement model	OP	GCC
Number of buses	Midi AC: 30	Midi AC: 45 Std. AC: 105
Contract cost ₹/km	Maintenance cost under comprehensive maintenance cover (CMC): 7.05	Midi AC: 52.2 Std. AC: 69.9
Electricity cost included in the rate?	—	No. Paid by NMMT up to 1.4 kWh/km for Std. AC and up to 1.2 kWh/km for midi AC
Energy efficiency	Actual efficiency not available	Actual efficiency not available
Contract period	CMC for 10 years	12 years
Assured km	—	6,780 per month for standard bus 6,050 per month for midi bus

Note: Approximate conductor cost per km for NMMT = ₹ 11.

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