Technical Assistance for BMTC Transitioning to an all-EV/Clean Fuel Public Transport Fleet

Electric Bus Technology and Infrastructure Planning Report

C40 Cities Finance Facility

September 2020
ABOUT THE C40 CITIES FINANCE FACILITY

The C40 Cities Finance Facility (CFF) is a collaboration of the C40 Cities Climate Leadership Group and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. The CFF supports cities in developing and emerging economies to develop finance-ready projects to reduce emissions to limit global temperature rise to 1.5°C and strengthen resilience against the impacts of a warming climate. The CFF is funded by the German Federal Ministry for Economic Cooperation and Development (BMZ), the Children’s Investment Fund Foundation (CIFF), the Government of the United Kingdom and the United States Agency for International Development (USAID).

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<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>BNEF</td>
<td>Bloomberg New Energy Finance</td>
</tr>
<tr>
<td>BESCOM</td>
<td>Bengaluru’s state-owned electricity company</td>
</tr>
<tr>
<td>BYD</td>
<td>Build Your Dreams (a Chinese EV manufacturer)</td>
</tr>
<tr>
<td>BMTC</td>
<td>Bangalore Metropolitan Transport Corporation</td>
</tr>
<tr>
<td>BMRCL</td>
<td>Bangalore Metro Rail Corporation Limited</td>
</tr>
<tr>
<td>CapEx</td>
<td>Capital Expenditure</td>
</tr>
<tr>
<td>C40</td>
<td>C40 Cities Climate Leadership Group</td>
</tr>
<tr>
<td>CFF</td>
<td>Cities Finance Facility</td>
</tr>
<tr>
<td>C40 KAPM</td>
<td>C40 Knowledge and Partnership Manager</td>
</tr>
<tr>
<td>CNG</td>
<td>Compressed Natural Gas</td>
</tr>
<tr>
<td>CO2</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DISCOM</td>
<td>Electricity Distribution Company</td>
</tr>
<tr>
<td>E-Bus</td>
<td>Electric bus</td>
</tr>
<tr>
<td>E-mobility</td>
<td>Electric mobility</td>
</tr>
<tr>
<td>EV</td>
<td>Electric Vehicles</td>
</tr>
<tr>
<td>FAME</td>
<td>Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles</td>
</tr>
<tr>
<td>GCC</td>
<td>Gross Cost Contract</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
</tr>
<tr>
<td>GiZ</td>
<td>German Development Agency</td>
</tr>
<tr>
<td>HEAT</td>
<td>Habitat, Energy Application and Technology (HEAT GmbH)</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>ICE</td>
<td>Internal Combustion Engine</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transport System</td>
</tr>
<tr>
<td>INR</td>
<td>Indian Rupee</td>
</tr>
<tr>
<td>IEA</td>
<td>International Energy Agency</td>
</tr>
<tr>
<td>IPCC</td>
<td>Inter-Governmental Panel on Climate Change</td>
</tr>
<tr>
<td>LFP</td>
<td>Lithium Iron Phosphate Battery</td>
</tr>
<tr>
<td>LTO</td>
<td>Lithium Titanate Battery</td>
</tr>
<tr>
<td>NMC</td>
<td>Lithium Nickel Manganese Cobalt oxide Battery</td>
</tr>
<tr>
<td>NMCA</td>
<td>Lithium nickel manganese cobalt aluminum oxide</td>
</tr>
<tr>
<td>NDC</td>
<td>Nationally Determined Contribution</td>
</tr>
<tr>
<td>NDE</td>
<td>National Designated Entity</td>
</tr>
<tr>
<td>NOx</td>
<td>Nitrous Oxide</td>
</tr>
<tr>
<td>ODS</td>
<td>Ozone Depleting Substances</td>
</tr>
<tr>
<td>OpEx</td>
<td>Operational Expenditure</td>
</tr>
<tr>
<td>PIU</td>
<td>Project Implementation Unit</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate Matter</td>
</tr>
<tr>
<td>SoC</td>
<td>State of Charge</td>
</tr>
<tr>
<td>UBS</td>
<td>Urban Bus Specification</td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

Background

BMTC has set a vision for 100% electrification of its fleet by 2030. Since the electric buses modal remains in nascent stages with several cities in India staging pilots, Bengaluru has been identified as one of the partner cities for Zero-Emission Public Transport by Cities Finance Facility (CFF).

Goal

The Electric bus is different from the internal combustion bus. It is not about choosing the perfect vehicle, but it is about designing the system according to the needs of the service and the technological features. The goal of the technical feasibility study is to provide technology inputs for a roadmap of full-transition to electric bus. The electric bus technology system has the following three key elements: Powertrain Technology, Charging Stations and the Infrastructure and Power supply.

Electric Bus Technology selection and its mix, for BMTC’s full transition, will be guided by its services and operational requirements (both present and future), technology availability and applicability (both in present and in future) alongside the financial implications and expected economic and social impacts of transition.

Findings

- It’s clear from a review of electric bus adoption by Indian cities that public bus operators are experimenting with different available technology (battery size, chemistry and charging) during these early days of embracing electric buses. The learnings curve is gradually moving which implies that more technology advancements and options will be welcomed in coming days. This will be necessitated by varying requirements for different bus services in different size cities, thereby potentially leading to demand for a vibrant Electric bus and infrastructure supply for different variants that can satisfy the specific requirements at reasonable price in the near future, as is the case for ICE technology vehicles.

- The Li-ion battery is likely to dominate the electric vehicles (EV) market for the next 10 years. This could be attributed to the fact that this technology is well established, it’s been commercially deployed across multiple geographies and it being scaled up in manufacturing also. There is a good understanding on the performance and its long-term durability. The supply chain has been well established.

- Based on learning from cities that have adopted electric buses, four major factors are listed below that will help in moving towards complete electrification of the buses in the BMTC network:
  - National and local subsidies;
  - Leases to reduce upfront (capital) investment;
  - Optimized charging and operations;
  - Lifetime warranty of batteries.
- Detailed road map for electrification, ideally at the city level with a long term view

- The depot selection and charging infratrure facilitations, if planned for the whole depot, will give better and economic charging solutions to electric bus adoption.

**Primary Technology Adoption Strategy**

A methodical approach is needed for the implementation of Electric bus induction by BMTC. Based on the successful deployment of Electric buses across the globe and in some parts of the country, following learnings are applicable to BMTC’s transitioning to Electric buses.

- Route Characteristics play an important role in rolling stock selection
- TCO needs to be calculated at the route level
- Infrastructure requirement cannot be an afterthought and needs to be planned at the very beginning with long term transition plan.
- Need to plan for regular maintenance of Electric buses to enable good value of money.
- Need to understand vehicle availability in the market to avoid customization

Allowing new actors, e.g., in Transantiago, Santiago, Chile, the implementation of Electric buses meant that the energy companies (ENEL & ENGIE) carried out the acquisition of the fleet and sublet it to the operators.

**Phased Transition to Electric bus technology**

Based on fleet age profile and scrappage policy, following phased transition plan for different bus types is identified and adopted for further detailing of technology adoption strategy and full transition-based business case development.

**Proposed BMTC’s Phased transition to Electric Bus**

<table>
<thead>
<tr>
<th>Phase Details</th>
<th>Midi</th>
<th>Standard</th>
<th>Air Conditioned</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1 (2021-25)</td>
<td>540</td>
<td>1206</td>
<td>418</td>
<td>2164</td>
</tr>
<tr>
<td>Phase 2 (2026-29)</td>
<td>505</td>
<td>1028</td>
<td>274</td>
<td>1807</td>
</tr>
<tr>
<td>Phase 3 (2030-32)</td>
<td>0</td>
<td>2558</td>
<td>168</td>
<td>2726</td>
</tr>
<tr>
<td>Total</td>
<td>1045</td>
<td>4792</td>
<td>860</td>
<td>6697</td>
</tr>
</tbody>
</table>

Source: Consultant Team
Power Consumption for Electric bus operations

The total daily electricity consumption for different scenarios have been calculated as shown in the Table below. The peak load time will be small percentage of the total daily consumption and will have very less impact on the overall peak-load of the city. With charging strategies in place, it can be very well-managed.

Estimated Daily electricity consumption, BMTC

<table>
<thead>
<tr>
<th>Fleet requirements</th>
<th>Fleet Size</th>
<th>Total daily electricity consumption</th>
<th>Number of Electric buses charged during Peak Demand (Assumed 15% of the total fleet)</th>
<th>Using a 100 kW Charger, Peak additional power demand from buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current fleet size in 2020</td>
<td>~6,500</td>
<td>1,690 MWh/day</td>
<td>975</td>
<td>97.5 MW</td>
</tr>
<tr>
<td>Minimum required fleet size in 2020</td>
<td>~9,500</td>
<td>2,470 MWh/day</td>
<td>1,425</td>
<td>142.5 MW</td>
</tr>
<tr>
<td>As per CMP, 2030 requirement</td>
<td>~16,500</td>
<td>4,290 MWh/day</td>
<td>2,475</td>
<td>247.5 MW</td>
</tr>
</tbody>
</table>

Source: Consultant Team

Recommendations

- Based on trial and error methodology, battery size for achieving the desired kilometer range of BMTC bus operations is estimated. Midi buses with a battery of 125 kWh and with one-hour of fast charging will result in range of up to 300 kms per day. For standard non-AC and standard AC buses, battery size of 150 kWh with one hour of fast charging will result in a range of about 280 kms per day.

- Based on the operational data, best practices, available technology and the market study, a strategic technology adoption road map has been prepared. The overall summary of the findings is included in the table below.

Roadmap of the electric bus technology adoption

<table>
<thead>
<tr>
<th>Parameters</th>
<th>2021-2025 yr</th>
<th>2026-2029 yr</th>
<th>2030-2032 yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Technology</td>
<td>LFP and NMC</td>
<td>LFP and NMC, testing with LTO and NMCA</td>
<td>LFP, NMC, NMCA &amp; LTO and other technologies evolving in</td>
</tr>
<tr>
<td>Battery Size</td>
<td>Bigger Battery: Daily utilization kms &gt;200kms</td>
<td>Medium size battery: Daily utilization kms 125kms-200kms</td>
<td>Small size battery: Daily utilization kms 75kms-125 kms (Feeder services)</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------------------------</td>
<td>----------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Electric Motor Ratings</td>
<td>120 kW (minibus) / 160 kW (midi-bus) / 200 kW (standard bus)</td>
<td>120 kW (minibus) / 160 kW (midi-bus) / 200 kW (standard bus)</td>
<td>120 kW (minibus) / 160 kW (midi-bus) / 200 kW (standard bus)</td>
</tr>
<tr>
<td>Charging Options</td>
<td>Combination of Depot Charging and Opportunity Charging: Based on range extension needed, headway and dead kms Thumb rule: 1 slow charger for three buses (1:3) 1 fast charger for five buses (1:5) (When the deployment is spread and there is not enough scale). However, needs to be determined based on actual operations.</td>
<td>Combination of Depot Charging and Opportunity Charging: Based on range extension needed, headway and dead kms Thumb rule: 1 charger for three buses (Slow chargers) 1 fast charger for ten buses (1:10) (As the electric buses scale-up across the city). However, needs to be determined based on actual operations.</td>
<td>Combination of Depot Charging and Opportunity Charging: Based on range extension needed, headway and dead kms Thumb rule: 1 charger for three buses (Slow chargers) 1 fast charger for ten buses (1:10) (As the electric buses scale-up across the city). However, needs to be determined based on actual operations.</td>
</tr>
</tbody>
</table>
### Next Steps

Based on the technology roadmap different scenarios will be developed for each phase and will help in preparing the business case. Every phase of transition should be considered based on the approach shared below.

#### Approach for Electric bus adoption and deployment

1. **Understanding/Survey the technologies**
2. **Route Selection**
3. **Preliminary Charging Strategy**
4. **Design of service schedules, Depot Selection**
5. **Technical Discussion with operators**
6. **Finalizing of charging Strategy, locations and Dimensioning**
7. **Finalizing of tender documents**

Source: Consultant Team
1 INTRODUCTION

1.1 Background

Bengaluru city is the capital of state of Karnataka, with a total population of over 14 million. Bengaluru is known as the “Silicon Valley” of India with rapid urbanization and economic growth. The public transport services in Bangalore include buses managed and operated by BMTC and metro services BMRCL. BMTC is the major public transport service provider in Bengaluru City, operates 11.71 lakhs Kms everyday catering to 35 lakh passengers daily. BMTC has set a vision for 100% electrification of its fleet by 2030. Since the electric bus technology is in nascent stages with several cities in India staging pilots, Bengaluru has been identified as one of the partner cities for Zero-Emission Public Transport by Cities Finance Facility (CFF).

1.2 Purpose of this Report

The purpose of the Report on Electric bus Technology and infrastructure is as follows:

i. To present a status of electric bus technology availability/penetration in Indian road transport sector

ii. Future technology mix and advancements expected to influence its adoption in coming 2-5 years vis-à-vis commercial availability, prices and performance

iii. Recommend a roadmap for technology transition/adopter for BMTC’s full transition to Electric bus-based fleet.

1.3 Data Collection

The data collection, for supporting above outcomes, focuses on the following aspects:

- Available literature on urban electric bus systems – Powertrain, Battery, Motor
- Preliminary market research around electric bus manufacturers and charging stations;
- Review of existing studies carried out for implementation of electric buses in Bengaluru;
- Bus Operations Data of BMTC;
- Assumptions for Total Cost of Ownership (TCO) calculations for ICE and Electric bus based operations
- Learning from around the world about the implementation of electric buses and Implementation and Procurement strategy recommended for BMTC

1.4 Structure of the Report

This report is primarily divided into three parts, covered through nine chapters.

Part 1 (Chapter 2 and 3) puts up the electric bus technology and infrastructure landscape - present and prospective advancements/growth/trends for future (2021-2025, 2026-2029, 2030-2032). The aspects on technology landscape includes a brief explanation of nuances, corresponding CapEx, OpEx and performance levels over lifetime. The findings from the Market Study are integrated here for what's available within India and any identified trends for
future (Chapter 3). Learnings, on how different cities across the globe have travelled the path to electric bus technology adoption, are presented in this chapter, alongside findings and recommendations from earlier studies undertaken for BMTC electric bus adoption.

Part 2 (Chapter 4 and 5) of the report covers and briefly discuss BMTC route operations (Chapter 4). The battery and charging infrastructure suitability for BMTC route operations is discussed in this chapter alongside a phased transition plan. Broad implications on power demand and impacts for the city of Bangalore are looked into in Chapter 5, towards preliminary level feasibility of this transition.

Part 3 (Chapter 6 and 7) elaborates the recommendations on Electric bus technology selection and road map for BMTC, suitable for a gradual transition over three phases (2021-2025, 2026-29, 2030-32). Finally, chapter 7 outlines the next steps to advance to the Business Case.

The following Annexures supplement the main report:

- Learning Different Motors for EV
- Available Charging Options in the market
- Few global experience of Electric Bus deployment
- Earlier studies for electric bus adoption by BMTC


2 ELECTRIC BUS TECHNOLOGY

2.1 Features required for Urban Electric bus

Following from the usual environment in which city buses operate in urban areas of India, technical requirements of an Electric bus are identified below:

- frequent stopping for traffic light and passenger,
- operating for several hours a day,
- operating at steady cruising speed for only few miles, and operating a low average speed,
- high power requirement of short duration for acceleration of large weight Electric bus,
- low drive range and regenerative braking,
- quick recharge time for the energy sources,
- high torque – low speed drive profile for start – stop movement, and
- minimum weight and volume of energy sources for efficiency and passenger capacity enhancements.

2.2 Technology mix requirements for urban area operation

The technology mix includes the relevant components of powertrain (battery and motor), charging station and infrastructure as well as power supply-based arrangements.

These need to be studied in detail to support selection of technology mix for above requirements for Electric bus induction into BMTC fleet, corresponding to an appropriate package of routes and depots. Other associated ancillary infrastructure and the impact on the grid can thereafter be assessed. This is particularly important for Electric bus procurements planned during different phases over the period of next decade (2021-30).

Technology aspects look at the powertrain (battery technology, motor etc.) charging stations and infrastructure, as well as electrical supply and the grid impact.

Figure 1: Components of Electric bus Technology

Source: Consultant Team
2.3 Powertrain of Electric bus

Powertrain refers to the set of components that generate the power required to move the vehicle and deliver it to the wheels. An EV powertrain has 60% fewer components than the powertrain of an Internal Combustion Engine (ICE) vehicle. The components are described below:

**Battery Pack** – The battery pack is made up of multiple Lithium-ion cells and stores the energy needed to run the vehicle. Battery packs provide direct current (DC) output.

**DC-AC Converter** – The DC supplied by battery pack is converted to Alternating current (AC) and supplied to the electric motor. This power transfer is managed by a sophisticated motor control mechanism (also referred to as Powertrain Electronic Control Unit) that controls the frequency and magnitude of the voltage supplied to the electric motor in order to manage the speed and acceleration as per driver’s instructions communicated via acceleration/brakes.

**Electric Motor** – Converts electrical energy to mechanical energy, that is delivered to the wheels. Many motor generators can perform regeneration as well.

**Charger** – Converts AC received through charge port to DC and controls the amount of current flowing into the battery pack.

The powertrain could be an overnight charging powertrain or an opportunity charging powertrain based on the requirement of an operator. Table below summarizes the difference between the two powertrains. The figure below indicates the powertrain of an Electric bus.

Table 1: Opportunity charging and Overnight Charging Powertrain

<table>
<thead>
<tr>
<th>Powertrain parts</th>
<th>Opportunity-Charging Powertrain</th>
<th>Overnight-Charging Powertrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive</td>
<td>Purely electric drive</td>
<td>Purely electric drive</td>
</tr>
<tr>
<td>Battery Capacity</td>
<td>Medium battery capacity (typically ~40-60kWh), Li-ion technology</td>
<td>Large battery capacity (typically &gt;200kWh), Li-ion technology</td>
</tr>
<tr>
<td>Range</td>
<td>Range (typically &lt;100km)</td>
<td>Range (typically 100-200km)</td>
</tr>
</tbody>
</table>
2.4 Battery Technology

Batteries have been the major energy source for EVs for a long time. Different battery technologies have been invented and adopted for different use. The most important criteria are to have high energy density and high-power density. High specific energy is required from a source to provide a long driving range whereas high specific power helps to increase the acceleration. The U.S. Advanced Battery Consortium (USABC) has set the performance for EV batteries as shown in the table below:

Table 2: Performance goal of EV batteries as set by USABC

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>Mid-Term</th>
<th>Long-Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Energy density (C/3 discharge rate)</td>
<td>Wh/L</td>
<td>135</td>
<td>300</td>
</tr>
<tr>
<td>Specific energy (C/3 discharge rate)</td>
<td>Wh/kg</td>
<td>80 ( Desired: 100)</td>
<td>200</td>
</tr>
<tr>
<td>Power density</td>
<td>W/l</td>
<td>250</td>
<td>600</td>
</tr>
<tr>
<td>Specific power (80% DoD/30s)</td>
<td>W/kg</td>
<td>150 ( Desired: 200)</td>
<td>400</td>
</tr>
<tr>
<td>Lifetime</td>
<td>year</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Cycle life (80% DoD)</td>
<td>cycles</td>
<td>600</td>
<td>1000</td>
</tr>
<tr>
<td>Price</td>
<td>USD/k Wh</td>
<td>&lt;150</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>°C</td>
<td>-30 to 65</td>
<td>-40 to 84</td>
</tr>
<tr>
<td>Recharging time</td>
<td>hour</td>
<td>&lt;6</td>
<td>3 to 6</td>
</tr>
<tr>
<td>Fast recharging time (40% to 80% SoC)</td>
<td>hour</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Secondary Self-discharge</td>
<td>%</td>
<td>&lt;15 (48 h)</td>
<td>&lt;15 (month)</td>
</tr>
<tr>
<td>Efficiency (C/3 discharge, 6 h charge)</td>
<td>%</td>
<td>75</td>
<td>80</td>
</tr>
<tr>
<td>Maintenance</td>
<td>-</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Resistance to abuse</td>
<td>Tolerance</td>
<td>Tolerance</td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td>Thermal loss</td>
<td>3.2</td>
<td>3.2</td>
<td></td>
</tr>
</tbody>
</table>

Source: USABC

Batteries used in EVs consist of several electrochemical cells that are coupled in parallel and in series to form a battery with a specific voltage and capacity. Batteries age over time as a result of multiple charging and discharging cycles. The ageing of a battery causes a higher internal resistance and a loss of storage capacity. A battery is deemed not suitable for EV/bus application, if the remaining storage capacity is 80 % of the initial capacity.

2.5 Battery Chemistry

Currently, lithium iron phosphate (LFP), lithium titanium oxide (LTO) and lithium nickel manganese cobalt oxide (NMC) are the most common cell types encountered in Electric buses.

- LTO permits the highest charging power of all technologies, however, owing to its comparatively low energy density, it has the lowest capacity. LTO is only applicable in opportunity-charging systems.
- NMC enables the largest capacity as well as high charging power and therefore lends itself useful to both the Opportunity Charging and Depot Charging.
- LFP is feasible only in slow-charging situations.

Figure 3: Capacity and Charging Power of different battery chemistry

2.6 Electric Motors

The core element of the EV, apart from EV-Batteries, which replaces the Internal Combustion engines is an Electric motor. The rapid development in the field of Power electronics and control techniques has created a space for various types of electric motors to be used in EVs. The electric motors used for automotive applications should have characteristics like high starting torque, high power density, good efficiency, etc. Various types of Electric Motors used in EVs are listed below with their brief description available in Annexure 1:

- DC Series Motor
- Brushless DC Motor
- Permanent Magnet Synchronous Motor (PMSM)
- Three Phase AC Induction Motors
- Switched Reluctance Motors (SRM)

2.6.1 Motor Drive Requirement for Electric City Bus

For Electric buses, the desired output characteristics of electric motor drives are illustrated in figure below. It can be observed that the EV motor drive is expected to be capable of offering a high torque at low speed for starting and acceleration, and a high power at high speed for cruising. At the same time as wide as possible speed range, under constant power, is desired. Ideally, eliminating the constant torque region would provide the minimum power rating of the motor, but this is not physically realizable.

Figure 4: Desired output of electric motor drive

Source: Selection of electric motor drives for EVs, X. D. Xue, K. W. E. Cheng, and N. C. Cheung, Department of Electrical Engineering, the Hong Kong Polytechnic University Hung Hom
2.6.2 Technology Features of Electric Motor for City Bus

The majority of bus suppliers have single traction central motors using asynchronous motor or permanent magnet synchronous motor. The power peak ranges from 100 kW to 480 kW for up to 24m buses. For system design, the crucial information is characteristic of the powertrain. In general, synchronous motors have high efficiency at low motor speed and high torque, whereas the asynchronous machine is more efficient at high speed and low torque. Currently, both types can be found in bus systems, because in actual system design packaging, motor control and cost are additional parameters that need to be examined. Permanent magnet synchronous motors have advantages in mass transport and have higher efficiencies in the nominal operating point, but are more costly due to permanent magnets and manufacturing issues (Neudorfer 2016).

2.7 Charging Equipment

Charging setup for Electric bus fleet comprise of charging solution (associated equipment) and associated power infrastructure. The charging solution for electric buses is an important part of transition due to complete reliance on commercial solutions for large battery sizes (generally more than 150kWh) and higher charger output ratings (50kW – 600 kW). This section explains different charging solutions and associated requirements.

2.7.1 Depot Charging and Opportunity Charging

Depot (Slow) Charging is typically done at Depots overnight while Opportunity (Fast) Charging is done at depots, terminals and major enroute points, accessible by the BMTC buses in the city. Fast Charging is prevalent more during the day time, when the operations are happening at maximum levels. The applicability of depot charging, however, is limited by the required availability of buses and the dead mileage involved in travel to depots for charging. On the other hand, if the ratio between Total mileage per day, Journey time, and Turn around or idle time at terminals with charging stations is kept within certain limits, opportunity charging can facilitate significantly higher mileages per day of operation without changing the mode of operation, i.e. additional drivers or buses are not necessary.

However, opportunity charging requires additional charging infrastructure outside the bus depots (charging stations with high charging power), which makes the implementation significantly more complex and difficult. Furthermore, opportunity charging is not applicable on bus routes where long delays frequently occur. On the other hand, opportunity charging significantly reduces the amount of energy requirement for recharging at a bus depot and the grid connection power that is required. A comparative view of slow and fast charging is available in Table below.
Table 3: Comparison between Depot Charging Only vs Depot + Opportunity Charging

<table>
<thead>
<tr>
<th>Depot Charging Only/Slow Charging</th>
<th>Depot + Opportunity Charging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larger batteries meaning lesser passenger capacity and higher rolling stock-based CapEx</td>
<td>Smaller batteries meaning more passenger capacity and lower rolling stock-based CapEx</td>
</tr>
<tr>
<td>Lesser cost of charging infrastructure</td>
<td>Need additional charging infrastructure. Cost may go up.</td>
</tr>
<tr>
<td>May need extra fleet to cover along high demand corridors</td>
<td>Adherence to service schedules with lesser fleet size</td>
</tr>
<tr>
<td>High upfront cost due to large battery requirement</td>
<td>Lower battery size can be used resulting in lower bus cost</td>
</tr>
<tr>
<td>Higher depth of charge (DoC), which accelerates the degradation of batteries.</td>
<td>Faster battery degradation on account of frequent charging of batteries</td>
</tr>
</tbody>
</table>

Source: Consultant Team

2.7.2 General design of Chargers

The charging technologies are directly linked to the applied charging strategy, that primarily defines the time availability for recharging, energy requirement and necessary charging power. Different charging powers are used to define slow and fast chargers. For the purposed of our study, charging technologies are divided into:

- AC Level 3 Charger
- DC Chargers- Plug-in
- DC Charger- Pantographs/Flash Charging
- Battery Swapping
A. AC 3 Charger
AC Level 3 considers vehicle charging at three-phase AC distribution voltage level. The minimum voltage level associated with AC 3 charging in the Indian context is 415 V. The AC Level 3 chargers are generally designed for wall-mount with minimal area requirement. However, those delivering high charging power require additional ancillary equipment including step down transformers, switchgear, cables, and protection system. BYD chargers are three-phase AC 80 KW chargers.

B. DC Plug-in Chargers
DC plug-in charging entails DC charging by a plug-in connection. The minimum voltage level associated with this type of charging is 415 V. Currently, range of DC plug-in chargers available in India are with power output of 50 kW-150 kW.

C. DC Pantographs
With typical charge times of 3 to 6 minutes the pantograph system can easily be integrated in existing operations. DC pantograph charging technology is expensive and requires auxiliary infrastructure. The 400kW chargers are placed at terminals where buses typically spend three to five minutes. These stops can add 20 to 30kWh of charge to the bus, nearly topping off the vehicle completely at each terminal point of their route operations. This facilitates longer running time for electric buses over the day as there is no need to go off operations for purpose of charging.

Flash charging is an extension of DC Pantographs. The flash-charging stations can deliver 600kW of power, adding two or three kWh of energy to the bus in just 15-20 seconds. This is the time, usually required by buses to stop for boarding and alighting of passengers enroute, during the route operations.

2.7.3 Battery Swapping
The core idea in battery swapping is to physically separate battery from the vehicle. This results in bringing down the upfront capital cost anywhere between 40%-50%. Smaller swappable batteries increase utilization as an asset and the business model is more centered around cost of energy. Typically, swap stations work on slow chargers and draw slow power for whole day. In comparison, the power requirement for fast charge stations would be high for some particular period of time and remain idle during other times.

Swap technology has certain limitations as well. It could become a challenge for longer routes requiring more than 50 kms at a stretch. In addition, a network of swap stations will be needed. The battery swapping model also introduces a new stakeholder, battery supplier in the supply chain. For every one Electric bus the requirement of batteries could be as much as 3-4 times in a battery swapping model.
In India, battery swapping has been tried in Ahmedabad with 18 Electric buses. The pilot project has been deployed on routes with roundtrip length of about 30 kms. The buses complete about 7-8 trips a day. At end of one circular trip, batteries of the bus are swapped. Swapping and charging of batteries are done at same location. Batteries can be charged in an hour.

In China, Beijing originally started on a battery swapping strategy. However, high investment cost, large space requirements and the duration of swapping procedures (approx. 20 min) turned out to be major obstacles. Therefore, Beijing introduced opportunity charging of battery buses. The buses need up to three recharging events per day (10 – 15 min), for which the regular driver breaks were used.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Charging Type</th>
<th>Estimated Cost (Equipment + Ancillary infrastructure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AC Level 3</td>
<td>Rs 3.5 Lakhs – Rs 10.4 Lakhs</td>
</tr>
<tr>
<td>2</td>
<td>DC Plug-in</td>
<td>Rs 16 Lakhs -Rs 26 Lakhs</td>
</tr>
<tr>
<td>3</td>
<td>DC Pantograph</td>
<td>Rs 38 Lakhs- Rs 1.38 Crores and more</td>
</tr>
<tr>
<td>4</td>
<td>Battery Swapping</td>
<td>Rs 3.2 Crores and more</td>
</tr>
</tbody>
</table>

Source: Charging India’s Bus Transport (Shyamasis Das, Chandana Sasidharan, Anirudh Ray 2019)

Given the high investment costs for flash charging and battery swapping in India. It is recommended that DC plug-in chargers be adopted. With technological advancement the charging powers in plug-ins will be enough to serve the requirements for BMTC.

### 2.7.4 Charger Standards

Electric bus and charging infrastructure are required to be tested, integrated and validated before operations for ensuring an optimum charging experience. **Standards followed by both chargers and buses need to be same. Hence, ensuring compatibility will be the major issue.** Charging infrastructure is a critical service for the operation of Electric buses. Hence by having a dedicated operator for this may ensure best services for compliance, specifically to full scale operational route planning requirement, that can vary for each Electric bus operator.
The charging power defines the technology for connecting Electric buses to the charging infrastructure. These are

- Plug-in systems, which consist of plugs and sockets or inlets (also referred to as “gun charging”)
- Automated contact systems, and
- Inductive charging systems.

Standardization concerns three major aspects, which are

- The physical design of the connecting components,
- The charging mode (e.g. slow or fast charging), and
- The communication between the vehicle and the charging infrastructure.

The standards are necessary to enable the recharging of Electric buses of different manufacturers at the same charging station or charging device. Currently, three standards compete globally, namely

- The Japanese CHAdeMO standard,
- The European Combined Charging Standard (CCS), which is also applied in North America, and
- The Chinese GB/T standard or protocol.

In addition, a new global standard called Chaoji is being developed, in collaboration between CHAdeMO Association (Japan) and China Electricity Council. Version 3.0 of the protocol was released on April 25, 2020. It is a 600-amp, 900-kW, bi-directional DC quick-charging standard.

The OppCharge standard is a non-official standard set-up by European bus and charging infrastructure manufacturers. It describes the DC charging of utility vehicles at charging stations with a charging power of more than 150 kW using automated contact systems.

### 2.7.5 Depot level Charging Infrastructure

**Load estimation at Depots**

The following assumptions have been made to calculate the load estimation at depots:

- A 120 kW DC charger with a maximum of 15-20 number chargers at each depot
- A 120 kW DC charger can charge two buses to full charging during overnight charging (5-6 hours)
- A parallel factor of 80%, i.e. during the peak load scenario a maximum of 80% of the capacity will get charged simultaneously.
- A power factor of 90%
- Input output efficiency of the charger of 90%
- The load has been estimated based on the formula = No. of buses (including idle buses) x 120 kW x parallel factor (80%) / power factor / efficiency
The load at the depot has been limited to 4MVA connection so that it can be accommodated under an 11 kV feeder.

Thus, it is envisaged that each depot will have a 4MVA 11 kV connection.

**Charging infrastructure Needs**

Connection of charging infrastructure to the electricity grid is highly dependent on local circumstances. For example, depending on charging power and local grid capacity, individual opportunity-charging stations may be connected directly to the low-voltage grid (400 V), or they may have a dedicated transformer substation connected to the medium-voltage grid (10-20 kV). An energy storage unit (batteries or capacitors) can be implemented within the charging station to reduce peak load. Electric bus depots usually require a dedicated substation connected to the medium-voltage grid; large depots (>200 vehicles) may even need a high-voltage grid connection (60-132 kV) with a distribution station.

**2.8 Key questions for consideration to effect technology transition**

Given the available battery technology and size, scheduled route km for the Electric bus can vary from 180 km/day to 240 km/day over 16-hour operation period. This poses challenge in term of selection of routes/services and corresponding charging strategy. Accordingly, some of the key questions that need to be answered for city operations include:

- How does the estimated range of battery-electric buses compare to the expected daily utilization of diesel or Compressed Natural Gas (CNG) buses for city operations/services?
- How do route and operational characteristics affect the bus energy consumption and the range of Electric buses?
- Which routes should be electrified first, based on the economic and operational assessment?
- Where and when should Electric buses be charged?
- What will be electrical power consumption and the impact on the grid?
- What infrastructure required at the depots to support the charging of Electric buses?
- How battery size, chemistry and charging infrastructure requirements vary for different size buses and for AC services.
3 ELECTRIC BUS OPERATIONS IN INDIAN CITIES

In addition to coverage of general discussions around Electric bus technology, in the previous chapter, a review of electric bus operations in India, products availability, and views of relevant players across the market, concerning technology, is taken up in this chapter.

3.1 Snapshot of Electric bus technology summary from operations of buses in Indian cities

The table below summarizes the technology mix explored by different Indian cities. The table indicates different models that have been explored.

Table 5: Electric bus technology snapshot from Indian cities

<table>
<thead>
<tr>
<th>Battery Size</th>
<th>Charging Options</th>
<th>Pros and Cons</th>
<th>Implementation in Indian Cities</th>
<th>OEM and Partners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Battery Size</td>
<td>Slow Charging (Maximum 80 KW)</td>
<td>Simple to Operate, Proven Technology, high bus weight</td>
<td>Pune, Hyderabad</td>
<td>Olectra &amp; BYD</td>
</tr>
<tr>
<td>(324 kWh, 12m bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>135 kWh, 9m bus)</td>
<td>Battery Chemistry: LFP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium Battery Size</td>
<td>Slow and Fast Charging (60 KW and 120 KW).</td>
<td>Requires re-charging during the day, additional space for chargers at terminals in addition to at depots</td>
<td>Kolkata</td>
<td>Tata Motors and Tellus Power</td>
</tr>
<tr>
<td>(188 kWh, 12m bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>125 kWh, 9m bus)</td>
<td>Battery Chemistry: NMC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small-Medium Battery</td>
<td>Battery Swapping (&lt;5 minutes)</td>
<td>Require re-charging during the bus operations, will help in understanding battery lease model, not all OEMs are exploring this technology,</td>
<td>Ahmedabad</td>
<td>Ashok Leyland and Sun Mobility</td>
</tr>
<tr>
<td>Size (70 kWh)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery Chemistry:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NMC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
It’s clear from above table that Indian cities are experimenting with different technology combinations (battery size, chemistry and charging) during these early days of embracing electric buses. The learnings curve is gradually moving which implies that more technology advancements and options will be welcomed in coming days. This will be necessitated by varying technology requirements for different bus services in different size cities, thereby potentially leading to demand for a vibrant Electric bus and infrastructure supply for different variants that can satisfy the specific requirements at reasonable price, as is the case for ICE technology vehicles.

### 3.2 Cost Estimates

The table below provides approximate cost estimates based on market study consultations with Electric bus manufacturers and DISCOMS for the CapEx and OpEx components.

**Table 6: CapEx and OpEx estimates**

<table>
<thead>
<tr>
<th>Component</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of 12 m Electric bus</td>
<td>1.3- 1.6 crores</td>
</tr>
<tr>
<td>Slow Chargers (&lt;100 KW)</td>
<td>7- 12 Lakhs</td>
</tr>
<tr>
<td>Fast Chargers (120 KW)</td>
<td>15- 20 Lakhs</td>
</tr>
<tr>
<td>HT- LT- Substation and Electrical Supply</td>
<td>Vary between 2-10 crores per depot</td>
</tr>
<tr>
<td>Maintenance cost per km</td>
<td>Rs 10- Rs 14 per km</td>
</tr>
<tr>
<td>Electricity Tariff in Bengaluru</td>
<td>Rs 5 per unit + 9 % Tax</td>
</tr>
</tbody>
</table>
3.3 Electric Bus Models as available

The following table summarizes the specification of Electric buses by various major manufacturers across the globe.
Table 7: Overview of 12 m Electric bus by various manufacturers

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Volvo 7900 Electric</th>
<th>Zhengzhou Yutong Bus Co., Ltd. (NEW E12LF)</th>
<th>Zhongtong Bus Holding Co., Ltd. (LCK6125EV)</th>
<th>Proterra Catalyst 40-foot E2 series</th>
<th>BYD (K9)</th>
<th>Tata</th>
<th>Ashok Leyland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger capacity /Seats</td>
<td>80-105</td>
<td>75+2 (wheelchair)</td>
<td>45+1</td>
<td>40+1</td>
<td>Up to 35 seats</td>
<td>40 + 1</td>
<td>44</td>
</tr>
<tr>
<td>Dimensions (Length, Width &amp; Height)</td>
<td>Length -12m Width – 2.55m Height – 3.28m</td>
<td>Length - 11.99m Width – 2.5m Height – 3.6m</td>
<td>Length - 12.95m Width – 2.55m Height – 3.4m</td>
<td>Length - 12.0m Width – 2.5m Height – 3.4m</td>
<td>Length – 12.0m Width – 2.58m Height – NA</td>
<td>Length – 11.08 m Width – 2.5m</td>
<td></td>
</tr>
<tr>
<td>Max Speed</td>
<td>80 kph</td>
<td>70-85 kph</td>
<td>90 kph</td>
<td>105 kmph</td>
<td>70 kmph</td>
<td>75 kmph</td>
<td>95 kmph</td>
</tr>
<tr>
<td>Power Train details</td>
<td>160kW Electric Motor</td>
<td>Not Available</td>
<td>Three-phase AC synchronous motor</td>
<td>220 kW peak permanent magnet drive motor</td>
<td>AC Synchronous 300 kW (150 kW×2) 180 kW (90 kW×2)</td>
<td>Integrated Motor Generator Max Power: 245 kW Continuous</td>
<td>Not Available</td>
</tr>
<tr>
<td>Parameters</td>
<td>Volvo 7900 Electric</td>
<td>Zhengzhou Yutong Bus Co., Ltd. (NEW E12LF)</td>
<td>Zhongtong Bus Holding Co., Ltd. (LCK6125EV)</td>
<td>Proterra Catalyst 40-foot E2 series</td>
<td>BYD (K9)</td>
<td>Tata</td>
<td>Ashok Leyland</td>
</tr>
<tr>
<td>---------------------</td>
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<td>-------------------------------------------</td>
<td>-------------------------------------------</td>
<td>-----------------------------------</td>
<td>----------</td>
<td>------</td>
<td>---------------</td>
</tr>
<tr>
<td>Details on Suspension system and braking system</td>
<td>Suspension system - Electronically controlled air Suspension with kneeling function Braking system - Electronic Braking System (EBS 5) with Brake Blending function</td>
<td>Not Available</td>
<td>Suspension system – Air suspension 2/4 Braking system – Electric air pumper; dual-circuit air brake; front disc and rear drum brake; air drier; ABS; and rear automatic adjustment arm</td>
<td>Suspension system – Air suspension 2/4 Braking system – Multi-Link Air Ride rear suspension Braking system – Front &amp; rear air disk brake</td>
<td>Suspension system – Air suspension 2/4 Braking system – Front and Rear Air Suspension with kneeling mechanism Braking system – Disc Brake with ABS</td>
<td>Power: 145 kW</td>
<td></td>
</tr>
<tr>
<td>Parameters</td>
<td>Volvo 7900 Electric</td>
<td>Zhengzhou Yutong Bus Co., Ltd. (NEW E12LF)</td>
<td>Zhongtong Bus Holding Co., Ltd. (LCK6125EV)</td>
<td>Proterra Catalyst 40-foot E2 series</td>
<td>BYD (K9)</td>
<td>Tata</td>
<td>Ashok Leyland</td>
</tr>
<tr>
<td>--------------------------</td>
<td>---------------------</td>
<td>--------------------------------------------</td>
<td>---------------------------------------------</td>
<td>-------------------------------------</td>
<td>----------</td>
<td>------</td>
<td>--------------</td>
</tr>
<tr>
<td>Gross Vehicle Weight</td>
<td>11,400-12,000 kg</td>
<td>19,100 kg</td>
<td>18,600 kg</td>
<td>15,000 kg</td>
<td>18,000 kg</td>
<td>17,800 kg</td>
<td>Not Available</td>
</tr>
<tr>
<td>Charging System</td>
<td>Opportunity charging, overhead, conductive, Pantograph on pole</td>
<td>Plug-in</td>
<td>Slow Charging</td>
<td>Utilizes standard J1772-CCS plug-in chargers</td>
<td>AC Charging</td>
<td>DC Charging</td>
<td>DC Charging</td>
</tr>
<tr>
<td>Charge Rate</td>
<td>300 kW</td>
<td>60 kW</td>
<td>120 kW</td>
<td>120 kW</td>
<td>80 kW</td>
<td>60-120 KW</td>
<td>Not Available</td>
</tr>
<tr>
<td>Charging time</td>
<td>3-6 min</td>
<td>5.5h</td>
<td>3-4 hrs.</td>
<td>3-4 hrs.</td>
<td>4-5 hrs.</td>
<td>2-6 hrs.</td>
<td>Not Available</td>
</tr>
<tr>
<td>Battery</td>
<td>High capacity 19 kWh Lithium-Ion battery</td>
<td>Lithium Iron Phosphate having energy of 324kWh</td>
<td>Lithium battery of 3.2V/20Ah</td>
<td>LTO having energy of 660 kWh</td>
<td>Lithium Iron Phosphate having energy of 324kWh</td>
<td>NMC having energy of 186 kWh</td>
<td>NMC</td>
</tr>
</tbody>
</table>
Source: Consultant Team
3.4 Technology Elements based on Market Study Consultations

More than 400 Electric buses have been deployed across 10 cities in India. The battery chemistry that have been used are LFP and NMC. Multiple battery sizes ranging from 135 kWh to 324 kWh have been deployed in the market.

This section includes the findings from the preliminary market research and consultations with the Electric bus manufacturers and charging infrastructure providers, under this study. The detailed set of information collected, discussion outcomes and suggestions from market players are available in the ‘Market Study Report’ of this single city contract of technical assistance to BMTC. The Based on 4 interviews with major OEMs, the following key points, covering technology aspects, are extracted from the Market study for ready reference below.

3.4.1 Bus Technology Related

- Schedule and route plan are key to Electric bus deployment
- Operators should not define the technology selection but rather focus on the performance requirements.
- Life and size of battery and type of battery chemistry don’t matter in a Gross Cost Contract (GCC) contract. Total cost of ownership (TCO) should be considered. However, in outright purchase the technology selection plays a very crucial role.
- Interoperability would be key rather than standardization for Electric buses
- At least 6 to 7 months are required for development and inspection of Electric buses
- Indian OEMs like Tata Motors Limited and Ashok Leyland Limited have deployed buses with NMC battery chemistry in Indian cities. For high power like 600 KW, LTO batteries are suitable and their replacement time is about 10 years.
- Intelligent transport system must be defined as per UBS-2 guidelines.
- Demand of 9m buses is on higher side compared to 12 m bus
- For 900mm floor height bus, cost would be 20 to 30% lower than that of low floor bus

3.4.2 Charging Infrastructure related

- EV-charging creates lot of challenges like managing peak demand, creation of harmonics at downstream. While many OEM’s are providing charging solutions, managing power from grid is crucial.
- Many aspects are to be considered in designing overall charging system. Flash charge requires high power for short time periods and overnight charging at depot requires slow and consistent power for long time period. In overnight charging, lot of power electronics are required for AC-DC chargers and space is required for installing chargers, transformers and large batteries.
- Flash charging is light and requires spread out power supply and charging infrastructure. Bus charges at few bus stops and buses have small batteries. It can
charge in 30 seconds with high power of about 600 KW. This application is mostly suitable for BRT systems having fixed bus stops and guide ways.

- Larger the number of buses, better is the economics and space saving which leads to cost saving. For a large fleet of 1,000 buses, adopting normal chargers will be bulky. The sequential grid solution is more suitable for large scale fleet adoption. In sequential charging, peak demand can be reduced through software control alternate charging.
- STU’s should provide minimum 440V point at one location in depot or 11 KV line.
- Power line availability and creation of charging infrastructure should be done considering future fleet increase and requirements. Planning should be based on the number of buses the depot can accommodate in total space and not for the current fleet size. This would help plan for complete load requirements.
- In Bengaluru there are 11KV or 66KV lines. Generally, less than 5MV load is there on 11 KV and max. up to 7.5 MV. For EV charging requirements, it may cater additional 2-3 MV with total around 10 MV depending on BESCOM.
3.5 Findings from Existing Electric bus Studies and global adoption experiences

This section includes the review of existing studies carried out for implementation of Electric buses in Bengaluru.

3.5.1 Implementation Plan for electrification of public transport in Bengaluru (2018) (By CSTEP)

Published in 2018, this report analyses the routes for Electric bus deployment and electricity distribution infrastructure in Bengaluru. 13 AC routes, 5 Metro feeders and 3 Non-AC routes were analysed. Criteria for route selection included: High Passenger density, Routes with a minimum length, Routes with higher number of scheduled stops per km, Routes converging at a common origin/or destination point Waiting time >= 5 hours.

Table 8: Route selection for Electric bus implementation, CSTEP Study

<table>
<thead>
<tr>
<th>Route Type</th>
<th>Routes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vayu Vajra</td>
<td>KIAS 8, KIAS 7A, KIAS 9, KIAS 5A, KIAS 5B</td>
</tr>
<tr>
<td>Metro-Feeder Services</td>
<td>MF-6, MF-13, MF-12, MF-1, MF-2</td>
</tr>
<tr>
<td>Ordinary Routes</td>
<td>KBS-1I, KBS-1K, SBS- 1K</td>
</tr>
</tbody>
</table>

Source: CSTEP Study

In addition to the routes identified the study also looked at 13 common charging locations listed below:

- Airport
- Electronic City
- Banashankari
- ITPL
- Central Silk Board
- Shivajinagar Bus Station
- KBS
- Yeshwanthpur Bus Station
- Depot 7, 13, 25, 28, 18
Supporting Infrastructure: Electricity load data from 11 kV feeders have been used to analyse the effects of electrification of the BMTC fleet on the existing electrical infrastructure. The feeders have been identified by the proximity of distribution transformers to bus depots. Further, the required battery size is estimated based on the range of the bus route, as determined by the route analysis. The energy rating of the battery would be 324 kWh, with a maximum charging time of approximately 330 minutes. 11 kV feeder lines have been considered for the electrical supply with the reference feeder rating considered as 11/11 kV, three-core, 400 mm², aluminum conductor, which is an XLPE insulated, armoured and ground-mounted cable with maximum available capacity of 4.12 MW.

TCO for Electric Bus: The study carried out a Total cost of ownership analysis for different standards bus types based on prevalent bus procurement, deployment, operations costs and its end of life salvage value. The TCO for electric bus was estimated at INR 137.0 for the electric bus against INR 107.0 for an airconditioned (AC) diesel bus. The TCO for non-airconditioned (non-AC) diesel standard size bus was estimated at INR 57.0.

Findings and recommendations from CSTEP study: The study initiated in 2015-16, focused on route selection and depot selection but does not provide any recommendation on the technology mix on either battery technology or charging options. However, the study looks at the overall TCO and the requirement of electrical supply from High Tension Cable to Low Tension cable at the depots.

The TCOs for diesel bus are observed to be lower than that of latest cost per kilometer (including only OpEx), estimated at INR 64, for BMTC operations of 2018-19. Present day diesel bus TCOs are expected to have increased for same operating and technology selection parameters, as adopted in CSTEP study. Similarly, the TCOs for electric bus are expected to have come down by now, on account of declining battery prices forming 50-60% of electric bus capital cost.

3.5.2 The Ins and Outs of Zero Emission Bus Deployment, Bengaluru (2020, UITP)

The analysis focused on depot and route selection in Bengaluru. The analysis looks at deployment plan for 800 Electric buses. The route selection is based on Buses per route, Daily Vehicle Utilization, Operational Feasibility, and Route Profitability. The study does not include the battery technology to be used or the range estimation.
Table 9: Route selection for Electric bus implementation, UITP Study

<table>
<thead>
<tr>
<th>Route Type</th>
<th>Routes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vayu Vajra</td>
<td>KIAS8, KIAS4, KIAS6, KIAS12, KIAS8E, KIAS14, KIAS7A and KIAS7</td>
</tr>
<tr>
<td>Ordinary Routes</td>
<td>KBS-1I, KBS-1K, SBS- 1K</td>
</tr>
</tbody>
</table>

**Depot Selection**: Depot selection is based on electricity infrastructure cost, depot area and geographic location. Out of the 45 depots that are functional and 6 depots that are under development, 13 depots were shortlisted. Furthermore, based on operational feasibility, 8 depots were shortlisted for electric bus operations. These depots include:

- Hebbal
- Hennur
- KR Puram
- Gunjuru
- HSR
- Surya City
- Deepanjalinagara
- Koramangala

**Findings and recommendations from UITP study**: The study focused on route selection and depot selection for Electric bus deployment but *does not provide any recommendation on the technology mix on either battery technology or charging options*.

### 3.5.3 Strategies for deploying zero-emission bus fleets: Development of real-world drive cycles to simulate zero-emission technologies along existing bus routes, 2020 (by ICCT)

In the study, vehicle simulation is used to determine the TCO at route level. The study looks at factors that influence Electric bus range including passenger load, AC and battery degradation that should be considered when determining route deployment. In addition, the analysis compares the estimated range and daily utilization to find out which routes
are most suitable for 1:1 replacement (diesel with Electric bus). Finally, for charging, schedule analysis was carried out to understand the break periods that can help to inform charging infrastructure buildout.

The following routes were selected for estimating the TCO and determining the replacement ratio.

**Table 10: Route selection for Electric bus implementation, ICCT Study**

<table>
<thead>
<tr>
<th>Route Type</th>
<th>Routes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vayu Vajra</td>
<td>KIAS9, KIAS8E, KIAS6, KIAS8C, KIAS4, KIAS12, KIAS7, KIAS7A, KIAS8</td>
</tr>
</tbody>
</table>

**Findings and recommendations from ICCT study:** Most of the routes selected are AC routes and long routes with daily utilizations greater than 200 kms. With the current available technology and products in the market, these routes would require bigger battery sizes and a combination of slow chargers (at Depots for overnight charging) and fast chargers (along the bus routes or at terminals for opportunity charging). The study focuses on TCO at route level and the impact on range estimation due to passenger loading and Air-conditioning.

ICCT study for Bengaluru indicated that the theoretical range of a 320 kWh battery is about 382 kms. With a 20% SoC reserve consideration it comes down to 306 kms, and furthermore if it is an AC bus with 100% passenger loading, the range is further reduced to 237 kms. Unless these are not taken into consideration the operational planning will not be accurate. It is important for a bus operator/transit agency to be aware of this irrespective of the contracting model.

**Table 11: Factors for estimating range of Electric buses under Bangalore city conditions**

<table>
<thead>
<tr>
<th>Reduction in Range</th>
<th>Factor to be considered for battery range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintain 80% depth of discharge</td>
<td>0.8</td>
</tr>
<tr>
<td>100% passenger loading</td>
<td>0.85</td>
</tr>
<tr>
<td>AC Bus</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Source: ICCT Simulation Study, Bengaluru
3.5.4 Assessment of the Phase 1: Electric bus Pre-Trial Results

Overview of Trial run

BMTC operated BYD Electric bus for a period of about 3 months in 2014. The average daily kms operated was 158 kms with ridership of about 218 daily passengers on Kempegowda Bus Station (KBS)–Kadugodi and KBS–ITPL routes. The route length is roughly about 25kms one way and the terrain is roughly flat between Kempegowda (3008 feet) and Kadugodi (2877 feet). There is about 30 feet elevation over 25 kms which would be considered as flat terrain. However, the corridor is one of the congested corridors specially around ITPL and Whitefield area with speeds dropping less than 10 kmph during peak hours.

Figure 5: BMTC Electric bus Trial Routes

As per BMTC, the cost per km on energy consumed was about Rs 15/km and battery cost was estimated to be about Rs 11.7/km with a one-time replacement. The average energy consumption from the trial run is 1.61 kWh/km.
### Table 12: Performance of Electric bus trial, BMTC

<table>
<thead>
<tr>
<th>S.No</th>
<th>Total kms operated</th>
<th>No. of units of power consumed (kWh)</th>
<th>Energy Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14,650</td>
<td>23,598</td>
<td>1.61 kWh/km</td>
</tr>
</tbody>
</table>

Source: BMTC, Cost-Benefit Analysis Calculations

However, energy consumption simulation for GPS data and drive cycle from ICCT study indicates energy consumption varying between 1.171 – 1.353 kWh/km for long routes and 1.174-1.554 kWh/km for short routes. The difference between the trial runs and the simulation can be explained to the fact that the trial was done almost 6 year and the technology has significantly improved for batteries. In addition, it is not very clear from the BMTC data if this was measured daily to clearly understand the performance.

#### 3.5.5 Learnings from BMTC Electric bus induction studies

The studies have focused on route and depot selection strategies for 500 to 800 electric buses. Three different types of routes (feeder, ordinary and airconditioned services) operated by BMTC are covered by these studies. A particular battery and charging infrastructure were adopted to understand implications of inducting above mentioned electric bus fleet, however full-scale conversion of the diesel fleet to electric fleet is not covered.

Being some of the initial studies that have looked into electric bus technology adoptions for BMTC, greater focus is imparted on overall policy framework in addition to recommendations on routes and depots to be adopted for electric bus operations.

Given the trial runs were done almost 6 years back, it will be good to include trials of different bus models from OEMs as part of the tendering process while evaluating the technical bid. It is important to understand the performance of the Electric buses in actual conditions along the selected routes, including the actual weather conditions. This will help in understanding the battery performance, available range and charging schedule. Based on this, the energy consumption and operations can be clearly understood.

Relevant findings from previous studies have been utilized towards building up of the Business Case of full transition to electric in this study. The recommendations on technology adoption strategy shall cover requirements of business case while accommodating the ongoing technology availability and learnings so far from past studies to best contextualised for BMTC case.
3.6 Global Electric bus adoptions

3.6.1 Selected Examples

Singapore city envisions to go fully electric by 2040 for its 5400 diesel buses. The initial batch of electric buses (28 seated, 52 standing) is supplied by one private sector consortium while power/charging supply (450kW flash charging) is managed by another private sector consortium.

Pune city, India has largest operational electric fleet in the country with 133 Electric buses deployed, with bus maintenance and charging managed through single all electric bus depot.

In Santiago city (Chile), the public bus operator Transantiago has launched 400 electric buses on the first electric bus corridor with upto 250 km range. The energy companies (ENEL & ENGIE) carried out fleet acquisition and sublet them to the private sector operator.

Los Angeles (USA) will receive 155 electric buses (fleet mix ordered from two OEMs) over next two years, with a plan to fully electrify its fleet (2300 Buses1) by the start of 2028 Summer Olympics.

Gothenburg city (Sweden) is going to procure 157 electric buses (7900 Volvo Electric Articulated model) with passenger capacity of 150 and to be charged with depot + opportunity charging (en-route using OppChargeTM interface).

Shenzhen city (China) started its all electric bus fleet plan from 2013 onwards. The city’s 16,000 Electric bus fleet, will be charged by 32 charging operators, with city having 8246 fast charging points and operations planned to be managed by three private sector companies. The charging stations and infrastructure is owned and built by power utility companies while the buses are fully charged at overnight.

3.6.2 Learnings from Indian and Global experiences

Based on the successful deployment of Electric buses across the globe and in some parts of the country, following learnings are applicable to BMTC’s transitioning to Electric buses.

- Route Characteristics play an important role in rolling stock selection
- TCO needs to be calculated at the route level
- Government fiscal incentives needed for the early push of Electric bus deployment. As China deployed a National Policy for Electric bus inductions with subsidies, state and central governments need to pan out a long-term policy and financial support with required program monitoring process.
- Infrastructure requirement cannot be an afterthought and needs to be planned at the very beginning with long term transition plan.

1 https://www.metro.net/news/facts-glance/
• Need to plan for regular maintenance of Electric buses to enable good value of money.
• Need to understand vehicle availability in the market to avoid customization

Allowing new actors, e.g., in Transantiago, Santiago, Chile, the implementation of Electric buses meant that the energy companies (ENEL & ENGIE) carried out the acquisition of the fleet and sublet it to the operators.
4  BMTC BUS ROUTE OPERATIONS AND TECHNOLOGY ADOPTION STRATEGY

4.1  BMTC Operations Pre COVID 19

4.1.1  Broad Profile of Operations

This section includes the following aspects: Bus Operations Data obtained from BMTC and analysis with a focus on routes and depots. Currently almost 6,700 buses operate on a daily basis in Bengaluru. All the buses are self-operated by BMTC. The fleet composition is dominantly BS III and BS IV (equivalent Euro III and Euro IV) technology fleet.

Figure 6: Bus Operations of BMTC

6,661 Buses
6,161 Schedules
35 Lakh Passengers Daily
2,262 Routes
67,115 Bus Trips
11.71 Lakh Service Kilometers Daily

Source: BMTC, March 2020
4.1.2 BMTC Fleet Mix

BMTC fleet comprise of a mix of non-AC standard size buses, AC standard size VOLVO buses and non-AC Midi buses. The non-AC standard size buses form a major share of BMTC fleet followed by an almost 850 VOLVO buses. BMTC has the highest fleet of VOLVO buses that is deployed on city services. The Midi buses primarily operate on metro feeder routes in the city of Bangalore.

4.1.3 Routes and Schedules

BMTC operates different routes across three types of service categories namely General non-AC, AC services and Special services:

- AS-series Atal Sarige (Inclusive bus services)
- G-series Trunk route services
- K-Connector
- KIAS- Airport link
- MF-Metro Feeder
- MBS-regular bus services
- CHAKRA- Circular services

A schedule is the daily time-table of a bus from the time it leaves the Depot till the time it comes back at the end of the day. It serves one primary route but may traverse multiple routes, portions/variations of routes and each schedule has a pre-defined bus type (AC/non-AC, Standard/Midi). Each depot caters to many routes and each route may be served by more than one depot i.e. there is no exclusive relation between depots, routes and schedules.

4.1.4 Operations Categorization by Daily Kms/Bus

The average mileage for the Electric buses in Bengaluru would range between 60,000 kms to 80,000 kms annually along different routes. There will be buses that would serve long distance and buses that would operate as feeder services. Since the cost parameters of a bus primarily depend upon the distance covered per day and charging time availability, a schedule is considered to be the primary unit of analysis.

Figure below indicates the distribution of BMTC bus operations’ daily schedules. The distribution is across range of daily distance coverage observed between the minimum and maximum. It can be further be observed that BMTC buses across all daily distance
ranges make more than 10 round trips over a day's operations, except the AC service route, due to their longer route lengths and lower frequency needs in comparison to ordinary routes.

**Figure 7: Operations distribution based on BMTC schedules daily distance coverage**

Source: Consultant based on BMTC data

It is important to understand the actual battery capacity available for the actual operations, will determine the exact range of the Electric bus. This is crucial in understanding the replacement ratio (number of Electric buses required to replace a diesel/CNG bus operating along a route), the need for opportunity charging and type of charging infrastructure.

### 4.2 Battery Size/Capacity range requirement

Understanding route length along with daily total kilometers and peak and off-peak headway for each route can help in determining the battery size and the required number of chargers at depots and terminals. In the absence of route level details around peak and off-peak operations, round trip times and so on, the study considers the following for operational needs and to support the business case of full transition of its fleet from ICE to Electric bus technology.

- broad route level data, as provided by BMTC,
- strategic guidance on technology mix, battery composition and size

Various battery sizes are recommended in the table below. However, these need to be verified based on actual daily utilization kms.
Table 13: Battery size choice for BMTC based upon route lengths

<table>
<thead>
<tr>
<th>Route Length</th>
<th>Battery Size</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5 kms</td>
<td>Small Battery Size (&lt;150 kWh)</td>
<td></td>
</tr>
<tr>
<td>5-10 kms</td>
<td>Small Battery Size (&lt;150 kWh)</td>
<td></td>
</tr>
<tr>
<td>10-15 kms</td>
<td>Medium Battery Size (150-250 kWh)</td>
<td>Smaller battery size with opportunity charging is also an option. TCO should be calculated for both cases i.e. Large battery with Slow charging Vs Smaller Battery with Slow/Opportunity Charging</td>
</tr>
<tr>
<td>15-20 kms</td>
<td>Medium Battery Size (150-250 kWh)</td>
<td></td>
</tr>
<tr>
<td>20-25 kms</td>
<td>Big Battery Size (&gt;250 kWh)</td>
<td></td>
</tr>
<tr>
<td>20-25 kms</td>
<td>Big Battery Size (&gt;250 kWh)</td>
<td></td>
</tr>
</tbody>
</table>

Source: Consultant Team Based on BMTC Route Details

4.3 Battery and Charging Combination for BMTC Operations

For the purposes of estimating the maximum operating range and charging strategy, an analysis was carried out for midi, standard non-AC and standard AC buses. To begin with the battery size were assumed to be 200 kWh for midi buses and 324 kWh for standard non-AC and AC buses (please note these are not the recommended battery sizes).

Four different charging strategies were used, Overnight charging only and one hour of opportunity charging with charging power of 120 KW, 150 KW and 200 KW.

As can be seen from the image below (refer Figure below), for mini buses with only overnight charging option the achievable range is only 160kms and this covers about 42% of the scheduled trips by BMTC. However, the range can be roughly increased to 295 kms with one hour of fast charging@ 120 KW resulting in 97% coverage of the schedules, to 329 kms with one hour of fast charging @ 150 KW and 385 kms with one of fast charging @ 200 KW resulting in 100% coverage of the schedules.

For the standard non-AC buses, with a 324-kWh battery, the achievable range with only overnight charging is 207 kms and will cover only 48% of the schedules. However, the range can be roughly increased to 315 kms with one hour of fast charging@ 120 KW resulting in 99% coverage of the schedules, to 342 kms with one hour of fast charging @ 150 KW and 387 kms with one of fast charging @ 200 KW resulting in 100% coverage of the schedules.

For the standard AC buses, with a 324-kWh battery, the achievable range with only overnight charging is 190 kms and will cover only 43% of the schedules. However, the
range can be roughly increased to 289 kms with one hour of fast charging@ 120 KW resulting in 87% coverage of the schedules, to 314 kms with one hour of fast charging @ 150 KW with a coverage of 87% and 355 kms with one of fast charging @ 200 KW resulting in 92% coverage of the schedules. Some of the airport bound buses cover more than 400 daily kms hence the coverage for standard AC buses is less than 100%. This indicates that one of fast charging is not enough but would require additional time.

It may however, be noted that above guideline is an upper limit to battery size and charging infrastructure related requirements for BMTC operations. Based on trial and error methodology by adjusting the battery size for achieving the desired range, it is estimated that for midi buses with a battery of 125 kWh and with one-hour of fast charging will result in range of up to 300 kms per day. For standard non-AC and standard AC buses, battery size of 150 kWh with one hour of fast charging will result in a range of about 280 kms per day.

These numbers have been used for the TCO analysis discussed in the later section of the report. The TCO analysis, for different types of buses and across different daily Km ranges, has been carried out for BMTC operations to support formulation of a technology adoption and transition roadmap over next decade.
Figure 8: Maximum operating range and proportion coverage of BMTC schedules

**Maximum Operating Range and %age of Schedules**

- **Midi (Non-AC)**: 42%, 97%, 100%
- **Standard (Non-AC)**: 48%, 99%, 100%
- **Standard (AC)**: 43%, 87%, 92%

- Purple: Night Charging only
- Green: 1 hour opportunity charging @ 120 kW
- Light Blue: 1 hour opportunity charging @ 150 kW
- Dark Blue: 1 hour opportunity charging @ 200 kW

**Midi Buses with 200 kW battery and Standard buses with 324 kWh battery**

**Opportunity charging is essential for achieving wider coverage of schedules**

Source: Consultant Team
4.4 BMTC’s Phased Transition to Electric Buses

4.4.1 Need and Strategy

Presently with 6700 odd diesel buses BMTC, may as a minimum, look at converting its existing fleet to electric fleet by 2030 (as per BMTC Vision 2030, it is 16500 clean fuel technology buses). The transition has to be a phased process over next ten-year period. Given the standard non-AC bus scrappage at 11 years or 8,50,000 kms (whichever is minimum), complete transition to electric bus technology will be achieved during year 2031. This implies that diesel bus fleet should undergo a regular replacement schedule, as per the bus scrapping policy, starting year 2021. The three phases are identified on basis of technology maturity, sector wide maturity and expected TCO parity achievement over time.

4.4.2 Phasing Plan for Adoption

Based on fleet age profile and scrappage policy, following phased transition plan for different bus types is identified and adopted for further detailing of technology adoption strategy and full transition-based business case development.

Table 14: Proposed BMTC’s Phased transition to Electric Bus

<table>
<thead>
<tr>
<th>Phase of Transition</th>
<th>Midi (Non-AC)</th>
<th>Standard (Non-AC)</th>
<th>Standard (AC)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1 (2021-25)</td>
<td>540</td>
<td>1206</td>
<td>418</td>
<td>2164</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>32%</td>
</tr>
<tr>
<td>Phase 2 (2026-29)</td>
<td>505</td>
<td>1028</td>
<td>274</td>
<td>1807</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>27%</td>
</tr>
<tr>
<td>Phase 3 (2030-32)</td>
<td>0</td>
<td>2558</td>
<td>168</td>
<td>2726</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>41%</td>
</tr>
<tr>
<td>Total</td>
<td>1045</td>
<td>4792</td>
<td>860</td>
<td>6697</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: Consultant Team Based on BMTC Route Details
5 ELECTRIC SUPPLY AND GRID IMPACT

5.1 Overview of Power Infrastructure in Bangalore

Connection of charging infrastructure to the electricity grid is highly dependent on local circumstances. For example, depending on charging power and local grid capacity, individual opportunity-charging stations may be connected directly to the low-voltage grid (400 V), or they may have a dedicated transformer substation connected to the medium-voltage grid (10_20 kV). An energy storage unit (batteries or capacitors) can be implemented within the charging station to reduce peak load.

Karnataka Power Transmission Corporation Limited (KPTCL) and Bangalore Electricity Supply Company Limited (BESCOM) are responsible for powering Bengaluru city. While KPTCL is responsible for transmission (up to and including 66kV lines), BESCOM is responsible for distribution and supply (below 66kV lines). Bengaluru is the largest power consumption centre in Karnataka with almost one third of state’s demand/consumption. With the rapid change and growth in Bengaluru the demand for power supply is also ever growing.

As per the Regional Master Plan, the total peak power demand for Bengaluru (BMAZ) stood at 2,579 MW (2015-16) and the energy consumption is at 13,885 MU. The average growth in peak demand during 2004 to 2015 has been 11.6% per annum (CAGR), while the Energy Demand has increased by 9.5%.

The power supply to Bengaluru is made through four 400/220kV power stations located at Hoody, Nelmangala, Bidadi and Somanahalli. Further, electric supply to different parts of the city is affected through 220/66kV sub stations, which are equally distributed to all parts of the city. Table below indicates the infrastructure employed for power supply distribution across the city. In addition, as per the RMP 2031, 18 sub-stations with different capacities (400kV, 220kV, 66kV substations) have been planned in the Bengaluru Zone.

Table 15: Existing grid infrastructure in Bengaluru Metropolitan Area Zone

<table>
<thead>
<tr>
<th>Power supply</th>
<th>Number of units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of 400/220 kV substations</td>
<td>4</td>
</tr>
<tr>
<td>Number of 220/66 kV substations</td>
<td>25</td>
</tr>
<tr>
<td>Number of 66/11 kV substations</td>
<td>52</td>
</tr>
<tr>
<td>Distribution transformers</td>
<td>2801</td>
</tr>
<tr>
<td>Total Capacity</td>
<td>13,245 MVA</td>
</tr>
</tbody>
</table>

Source: RMP 2031, Draft Master Plan
Based on the 19th Electricity Power Survey by Central Electricity Authority (CEA), requirement of power for Bengaluru in the year 2026, as projected by the KPTCL, is 3680 MW while the estimated peak demand for 2031 is 4288 MW (say 4300MW). To meet the additional requirement of 1720MW (Difference between peak demand in 2031 and the usage in 2015-2016), the KPTCL & BESCOM need to augment the power supply and improve the transmission and distribution system.

5.2 Power Demand in the Bengaluru City

Table below shows the power demand of the city at various instances of time in recent times. The peak load reached 5,690 MW during February 2019. However, the average load is about 4,800 MW in the city.

Table 16: Power Demand in BESCOM region

<table>
<thead>
<tr>
<th>Date</th>
<th>Power Demand</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 10, 2020 @ 10:30am</td>
<td>3,998 MW</td>
<td>KTPCL Website</td>
</tr>
<tr>
<td>July 10, 2020 @ 10:42pm</td>
<td>2,940 MW</td>
<td>KTPCL Website</td>
</tr>
</tbody>
</table>

Source: Consultant Team

Figure 9: Karnataka Power Transmission Corporation Limited, Loads on July 10, 2020
As per the BESCOM officials the city has achieved power surplus until 2023. (Source: https://www.deccanherald.com/city/bengaluru-infrastructure/power-in-surplus-bescom-says-no-outage-till-2023-755824.html). The surplus scenario has also stopped the utility company from mulling over any new generation projects for the time being. It is anticipated that at least till 2023, there will not be any threat of load-shedding, except for some technical glitches. The power utility is now chalking out plans to sell excessive energy. However, various stakeholder bodies including industry associations have complained about unscheduled plans. The transmission infrastructure needs to be upgraded in the city.
5.3 Electricity Consumption estimates for BMTC’s Electric bus Fleet

The total daily electricity consumption for different scenarios have been calculated as shown in the Table below. It is assumed that the average running kms is 200 kms/day and the efficiency is 1.3 kWh per km. The peak load time will be small percentage of the total daily consumption and will have very less impact on the overall peak-load of the city. With charging strategies in place, it can be very well-managed.

Table 17: Estimated Daily electricity consumption, BMTC

<table>
<thead>
<tr>
<th>Fleet requirements</th>
<th>Fleet Size</th>
<th>Total daily electricity consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current fleet size in 2020</td>
<td>~6,500</td>
<td>1,690 MWh/day</td>
</tr>
<tr>
<td>Minimum required fleet size in 2020</td>
<td>~9,500</td>
<td>2,470 MWh/day</td>
</tr>
<tr>
<td>As per CMP, 2030 requirement</td>
<td>~16,500</td>
<td>4,290 MWh/day</td>
</tr>
</tbody>
</table>

Source: Consultant Team

5.4 Peak Demand on the Grid

Assuming that 15% of the total Electric buses would be charged during peak load, this would result in anywhere, between 98 MW to 250 MW. Accommodating this demand should not be a challenge as understood from BESCOM details that the state has surplus generation. However, uninterrupted supply could be a challenge hence upgrading the transmission lines and supporting infrastructure at Depots would be extremely critical.

Table 18: Estimated impact on the peak demand, BMTC

<table>
<thead>
<tr>
<th>Fleet Size</th>
<th>Total daily electricity consumption</th>
<th>Number of Electric buses charged during Peak Demand (Assumed 15% of the total fleet)</th>
<th>Using a 100 kW Charger, Peak additional power demand from buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>~6,500</td>
<td>1,690 MWh/day</td>
<td>975</td>
<td>97.5 MW</td>
</tr>
<tr>
<td>~9,500</td>
<td>2,470 MWh/day</td>
<td>1,425</td>
<td>142.5 MW</td>
</tr>
<tr>
<td>~16,500</td>
<td>4,290 MWh/day</td>
<td>2,475</td>
<td>247.5 MW</td>
</tr>
</tbody>
</table>

Source: Consultant Team
6  RECOMMENDATIONS ON STRATEGISING TECHNOLOGY ADOPTION

6.1  Learnings from the International Experience

A methodical approach is needed for the implementation of Electric buses. Based on the successful deployment of Electric buses across the globe, the following learnings are made for transitioning to Electric buses.

6.1.1  Broad Level guidelines

- Government fiscal incentives needed for the early push of Electric bus deployment. As China implemented a National Policy for deploying Electric buses with subsidies, state and central governments need to plan out a long-term policy and financial support with required program monitoring process.
- Allowing new actors, e.g., in Transantiago, Santiago, Chile, the implementation of Electric buses meant that the energy companies (ENEL & ENGIE) carried out the acquisition of the fleet and sublet it to the operators.
- Infrastructure requirement cannot be an afterthought and needs to be planned at the very beginning with a long-term transition plan. The bus operator needs to be selected first, so that the charging infrastructure company understands what chargers to install.

6.1.2  Operational Guidelines

- Route specific analysis is required to understand the exact charging strategy and bus battery requirement and corresponding rolling stock needs. TCOs may be calculated at the route level to support this analysis. Various routes may need a redress and possible redesigning vis-a-vis battery range, charging infrastructure, space and power availability etc.
- The charging infrastructure should be inter-operable, in the absence of which problems could arise with different variants of buses procured in future.
- Regular maintenance of Electric buses and related infrastructure is essential to ensure good value of money.
- There are issues related to battery and bus de-gradation. A battery replacement clause is a must in the requirement (when battery goes below 80% efficiency) due to its degradation. Proper contracting terms and conditions need to be ensured while engaging with the manufacturer for replacement of buses and batteries.

6.2  Approach for Deployment

6.2.1  Overall Framework

The Electric buses fleet induction in BMTC would be either through the Gross Cost Contract (GCC) Model or with Outright Purchase alongside Annual Maintenance Contract (AMC), given that the bus operators may not have the requisite in-house skill and capacity. The figure below presents the overall approach for deploying Electric buses.
6.2.2 Depot Selection

For the initial procurement of the 300+90 buses under the FAME -II and the Bengaluru smart city program, not much assessment has been done for the charging devices or stations. However, assessment has been done by BMTC in collaboration with BESCOM for estimating infrastructure requirements at 13 depots. These depots are Depot-32 (SuryaCity), Depot-16 (Deepanjalinagara), Depot-07 (Subhashnagara), Depot-25 (HSR Layout), Depot-41 (Gunjuru), New Depot-Kodathi, New Depot-Sadarmangala, Depot-15 (Koramangala), Depot-04 (Jayanagara), Depot-10 (Kacharakahanhallli), Depot-22 (Peenya2ndStage), Depot-28 (Hebbala), Depot-29 (K.R.Puram).

These level 1 depots can be considered for roughly 2000 odd electric buses, to be procured under Phase 1 (2022-2025).
6.2.3 Route Selection strategy for transitioning to Electric Bus

Currently, the procurement of the ICE buses is solely based on the number of buses and viewed more as a rolling stock addition to the existing fleet. For Electric buses deployment it will be important to look at the routes and schedules as the starting point for any Electric bus deployment. This will help in determining the battery size and the rolling stock requirement. The table below present general guidance on route selection for Electric buses.

Table 19: Route selection criteria for Electric buses

<table>
<thead>
<tr>
<th>Route selection</th>
<th>General Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger ridership (pax/bus/day)</td>
<td>If pax/bus/day &gt; 500, select buses with bigger battery size</td>
</tr>
<tr>
<td></td>
<td>If pax/bus/day &lt; 500, select buses with medium/smaller battery size</td>
</tr>
<tr>
<td>Route Length</td>
<td>If &gt; 200 kms, select buses with bigger battery size if single charge is preferred.</td>
</tr>
<tr>
<td></td>
<td>For longer routes, smaller batteries could be appropriate if frequency is low and appropriate infrastructure is in place</td>
</tr>
<tr>
<td></td>
<td>If &lt; 200 kms, select buses with smaller/medium battery size</td>
</tr>
<tr>
<td>Frequency</td>
<td>Frequency of service will help in choosing the right charging strategy</td>
</tr>
<tr>
<td>CPKM vs EPKM (Cost per km vs Earning per km)</td>
<td>Select routes with % difference less than 5%-10% in the initial deployment preferably with EPKM&gt;CPKM</td>
</tr>
<tr>
<td>Replacement Ratio</td>
<td>Select routes with replacement ratio in the range of 0.85-1.15 in the initial deployment. The replacement ratio should be close to 1.0</td>
</tr>
</tbody>
</table>
### Route selection

<table>
<thead>
<tr>
<th><strong>TCO at Route Level</strong></th>
<th>General Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select routes with TCO for Electric buses &lt; TCO for diesel buses in the initial deployment, or the next best option is to ensure that the TCO of routes with Electric buses are on par/close to diesel buses</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Common origin/destination points</strong></th>
<th>General Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>In the early deployment it will be good to select buses operating out of common depots for optimizing the charging infrastructure</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Dead kms</strong></th>
<th>General Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consider routes with lesser dead kms to optimize access to charging points and location of chargers</td>
<td></td>
</tr>
</tbody>
</table>

**Source: Consultant Team**

### 6.2.4 Monitoring and Evaluation of Performance

With the initial deployment it will be important to monitor and evaluate the performance of the Electric buses. Table below provides a general outline of important data points to understand the Operation and Maintenance (O&M) and in decision making for future deployment.

**Table 20: Monitoring and Evaluation Form for BMTC**

<table>
<thead>
<tr>
<th>Data Item</th>
<th>Bus 1</th>
<th>Bus 2</th>
<th>Bus 3</th>
<th>--</th>
<th>--</th>
<th>--</th>
<th>--</th>
<th>Bus ‘N’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Period</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total mileage (in kms)-Daily</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability of the bus – How much time was it used for?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Consumption-Daily (kWh/km)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Speed including stops (kmph)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kms between road recalls for recharging</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.2.5 Electric bus Trial Runs

As BMTC is undergoing process of tendering out 300 Electric buses (with FAME-2 subsidy), it will be good to include trials of different bus models from OEMs as part of the tendering process while evaluating the technical bid. It is important to understand the performance of the Electric buses in actual conditions along the selected routes, including the actual weather conditions. This will help in understanding the battery performance, available range and charging schedule. Based on this, the energy consumption vis-à-vis operations can be clearly understood.

6.3 Technology Road Map for BMTC

The table below gives an overall guidance on the technology mix for full transitioning to Electric buses for BMTC. These details have been derived from the market study, learnings from the experience of different cities across the globe and research publication around EV deployment.

Table 21: Technology Roadmap for BMTC

<table>
<thead>
<tr>
<th>Parameters</th>
<th>2021-2025 yr</th>
<th>2026-2029 yr</th>
<th>2030-2032 yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Technology</td>
<td>LFP and NMC</td>
<td>LFP and NMC, testing with LTO and NMCA</td>
<td>LFP, NMC, NMCA &amp; LTO and other technologies evolving in the market for urban buses to be tested.</td>
</tr>
<tr>
<td>Bus Type, Battery Size and Range</td>
<td>Electric midi buses with 125 kwh battery size for range upto 150kms</td>
<td>Electric midi buses with 125 kwh battery size range upto 150kms with fast charging option</td>
<td>Electric midi buses with 125 kwh battery size range upto 150kms</td>
</tr>
<tr>
<td></td>
<td>Electric AC buses with 300 kWh battery size for distance upto 250kms and with fast</td>
<td>Electric AC buses with 300 kWh battery size for distance upto 250kms and with fast</td>
<td>Electric AC buses with 300 kWh battery size for distance upto 250kms and with fast</td>
</tr>
<tr>
<td>Parameters</td>
<td>2021-2025 yr</td>
<td>2026-2029 yr</td>
<td>2030-2032 yr</td>
</tr>
<tr>
<td>------------</td>
<td>--------------</td>
<td>--------------</td>
<td>--------------</td>
</tr>
<tr>
<td>charging range can be extended to 300+kms</td>
<td>charging range can be extended to 300+ kms</td>
<td>charging range can be extended to 300+ kms</td>
<td></td>
</tr>
<tr>
<td>Standard non-AC buses with medium size battery 150 kWh-200 kWh for distances 200-225 kms extendable to 275 kms</td>
<td>Standard non-AC buses with medium size battery 150 kWh-200 kWh for distances 200-225 kms extendable to 275 kms with fast charging option</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric Motor Ratings</td>
<td>120 kW (minibus) / 160 kW (midi-bus) / 200 kW (standard bus)</td>
<td>120 kW (minibus) / 160 kW (midi-bus) / 200 kW (standard bus)</td>
<td>120 kW (minibus) / 160 kW (midi-bus) / 200 kW (standard bus)</td>
</tr>
<tr>
<td>Combination of Depot Charging and Opportunity Charging: Based on needed range extension, headway and dead kms</td>
<td>Combination of Depot Charging and Opportunity Charging: Based on needed range extension, headway and dead kms</td>
<td>Combination of Depot Charging and Opportunity Charging: Based on needed range extension, headway and dead kms</td>
<td></td>
</tr>
<tr>
<td>Thumb rule: 1 slow charger for three buses (1:3)</td>
<td>Thumb rule: 1 charger for three buses (Slow chargers)</td>
<td>Thumb rule: 1 charger for three buses (Slow chargers)</td>
<td></td>
</tr>
<tr>
<td>1 fast charger for five buses (1:5) (When the deployment is spread and there is not enough scale). However, needs to be determined based on actual operations.</td>
<td>1 fast charger for ten buses (1:10) (As the electric buses scale-up across the city). However, needs to be determined based on actual operations.</td>
<td>1 fast charger for ten buses (1:10) (As the electric buses scale-up across the city). However, needs to be determined based on actual operations.</td>
<td></td>
</tr>
<tr>
<td>Charger rating for fast chargers to be 100 KW-150KW</td>
<td>Charger rating for fast chargers to be 100 KW-150KW</td>
<td>Charger rating for fast chargers to be 100 KW-150KW</td>
<td></td>
</tr>
</tbody>
</table>

Source: Consultant Team
The figure below gives a general guidance for selection of the charging strategy based on storage capacity of the battery and the distance travelled per day by an Electric bus.

Figure 11: Charging strategy based on battery capacity and daily distance travelled by Electric bus

Source: Manufacturers and UITP
7 NEXT STEPS FOR TECHNOLOGY TRANSITION

Electric buses are a fast-evolving technology as compared to Diesel/CNG buses, which directly impacts operational aspects. Both authorities and operators are still in a learning phase and battery buses are a paradigm shift in city bus operations. Standards, especially communication protocols are still under development and finalization. Any project and phasing structure must take into consideration the technical and operational challenges that come with the introduction of Electric buses. Based on the technology roadmap different scenarios will be developed for each phase and will help in preparing the business case. Every phase of transition should be considered based on the approach shared below.

Figure 12: Approach for Electric bus adoption and deployment

- Understanding/Survey the technologies
- Route Selection
- Preliminary Charging Strategy
- Design of service schedules, Depot Selection
- Technical Discussion with operators
- Finalizing of charging Strategy, locations and Dimensioning
- Finalizing of tender documents

OEMs+EVSEs + Operators

Requirement

Feedback
ANNEX 1: TYPES OF MOTOR

**DC Series Motor** - High starting torque capability of the DC Series motor makes it a suitable option for traction application. It was the most widely used motor for traction application in the early 1900s. The advantages of this motor are easy speed control and it can also withstand a sudden increase in load. All these characteristics make it an ideal traction motor. The main drawback of DC series motor is high maintenance due to brushes and commutators. These motors are used in Indian railways. This motor comes under the category of DC brushed motors.

**Brushless DC Motors** - It is similar to DC motors with Permanent Magnets. It is called brushless because it does not have the commutator and brush arrangement. The commutation is done electronically in this motor because of this BLDC motors are maintenance free. BLDC motors have traction characteristics like high starting torque, high efficiency around 95-98%, etc. BLDC motors are suitable for high power density design approach. The BLDC motors are the most preferred motors for the electric vehicle application due to its traction characteristics. BLDC motors further have two types:

i. **Out-runner type BLDC Motor:**
   In this type, the rotor of the motor is present outside and the stator is present inside. It is also called as Hub motors because the wheel is directly connected to the exterior rotor. This type of motors does not require external gear system. In a few cases, the motor itself has inbuilt planetary gears. This motor makes the overall vehicle less bulky as it does not require any gear system. It also eliminates the space required for mounting the motor. There is a restriction on the motor dimensions which limits the power output in the in-runner configuration. This motor is widely preferred by electric cycle manufacturers like Hullikal, Tronx, Spero, light speed bicycles, etc. It is also used by two-wheeler manufacturers like 22 Motors, NDS Eco Motors, etc.

ii. **In-runner type BLDC Motor:**
   In this type, the rotor of the motor is present inside and the stator is outside like conventional motors. These motors require an external transmission system to transfer the power to the wheels, because of this the out-runner configuration is little bulky when compared to the in-runner configuration. Many three-wheeler manufacturers like Goenka Electric Motors, Speego Vehicles, Kinetic Green, Volta Automotive use BLDC motors. Low and medium performance scooter manufacturers also use BLDC motors for propulsion. It is due to these reasons it is widely preferred motor for electric vehicle application. The main drawback is the high cost due to permanent magnets. Overloading the motor beyond a certain limit reduces the life of permanent magnets due to thermal conditions.
**Permanent Magnet Synchronous Motor (PMSM)** - This motor is also similar to BLDC motor which has permanent magnets on the rotor. Similar to BLDC motors these motors also have traction characteristics like high power density and high efficiency. The difference is that PMSM has sinusoidal back EMF whereas BLDC has trapezoidal back EMF. Permanent Magnet Synchronous motors are available for higher power ratings. PMSM is the best choice for high performance applications like cars, buses. Despite the high cost, PMSM is providing stiff competition to induction motors due to increased efficiency than the latter. PMSM is also costlier than BLDC motors. Most of the automotive manufacturers use PMSM motors for their hybrid and electric vehicles.

**Three Phase AC Induction Motors** - The induction motors do not have a high starting torque like DC series motors under fixed voltage and fixed frequency operation. But this characteristic can be altered by using various control techniques like FOC or v/f methods. By using these control methods, the maximum torque is made available at the starting of the motor which is suitable for traction application. Squirrel cage induction motors have a long life due to less maintenance. Induction motors can be designed up to an efficiency of 92-95%. The drawback of an induction motor is that it requires complex inverter circuit and control of the motor is difficult.

In permanent magnet motors, the magnets contribute to the flux density B. Therefore, adjusting the value of B in induction motors is easy when compared to permanent magnet motors. It is because in Induction motors the value of B can be adjusted by varying the voltage and frequency (V/f) based on torque requirements. This helps in reducing the losses which in turn improves the efficiency.

Tesla Model S is the best example to prove the high-performance capability of induction motors compared to its counterparts. By opting for induction motors, Tesla might have wanted to eliminate the dependency on permanent magnets. Even Mahindra Reva e2o uses a three-phase induction motor for its propulsion. Major automotive manufacturers like TATA motors have planned to use Induction motors in their cars and buses. Induction motors are the preferred choice for performance oriented electric vehicles due to its cheap cost. The other advantage is that it can withstand rugged environmental conditions.

**Switched Reluctance Motors (SRM)** - Switched Reluctance Motors is a category of variable reluctance motor with double saliency. Switched Reluctance motors are simple in construction and robust. The rotor of the SRM is a piece of laminated steel with no windings or permanent magnets on it. This makes the inertia of the rotor less which helps in high acceleration. The robust nature of SRM makes it suitable for the high-speed application. SRM also offers high power density which are some required characteristics of Electric Vehicles. Since the heat generated is mostly confined to the stator, it is easier to cool the motor. The biggest drawback of the SRM is the complexity in control and
increase in the switching circuit. It also has some noise issues. Once SRM enters the commercial market, it can replace the PMSM and Induction motors in the future.

Right Motor for your EV

For selecting the appropriate electric vehicle motors, one has to first list down the requirements of the performance that the vehicle has to meet, the operating conditions and the cost associated with it. For example, go-kart vehicle and two-wheeler applications which require less performance (mostly less than 3 kW) at a low cost, it is good to go with BLDC Hub motors. For three-wheelers and two-wheelers, it is also good to choose BLDC motors with or without an external gear system. For high power applications like performance two-wheelers, cars, buses, trucks the ideal motor choice would be PMSM or Induction motors.
## ANNEX 2: ELECTRIC BUS CHARGING DEVICES

Details of Electric bus Charging Devices are illustrated below.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Charging Devices</th>
<th>Charging Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Siemens</td>
<td>150/300/450 kW/600 kW</td>
</tr>
<tr>
<td></td>
<td>-Off-board top down Pantograph</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Charging via connector</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 kW to 150 kW</td>
</tr>
<tr>
<td>2.</td>
<td>BYD AC Charging Adapter</td>
<td>2 x 40 kW / 4 x 60 kW</td>
</tr>
</tbody>
</table>
3. Heliox Bus Depot DC Charger
   50 kW / 150 kW

4. Eko Energetyka Depot Charger
   40 kW / 60 kW / 80 / 100 / 120 kW or on request
5. Schaltbau Refurbishment EVA400-Depot 75 kW

6. Shenzhen Haipengxin Electronics Co., Ltd. – HPXIN 2 x 75 kW

7. ABB HVC 3 x 50 kW
8. Proterra Power Control System 60 / 125 kW

9. Tritium Veefil 50 kW (Fast chargers up to 475 kW)
10. ABB Terra HP  
   175 kW to 350 kW

11. Kempower C-Series  
   40-480 kW
12. Guangdong Kangdewei Electric Co., Ltd  120 kW intelligent DC EV charging for buses

13. Eko Energetyka Quick Point City Charger  Up to 1 MW
14. Heliox Opportunity Charger 300 kW

15. Proterra Power Control System 500 kW 500 kW

16. Xcharge Up to 360 kW
ANNEX 3: LESSONS LEARNED FROM ELECTRIC BUS ROLLOUT IN INTERNATIONAL CITIES

Introduction

This section includes the following aspects: Learning from around the world on the implementation of Electric buses.

Singapore

Singapore aims at having a fully Electric bus fleet by 2040. The first batch of 10 Electric buses has already started plying Singapore’s streets and 50 more vehicles will be added in 2020.

Public transport operators SMRT, Tower Transit and Go-Ahead Singapore were involved in the launch of these Electric bus services. BYD, Yutong and ST Engineering manufactured buses. Up to 80 passengers can be welcomed on board, 28 seated and 52 standing.

ABB is supplying power to these vehicles by providing 450kW fast charging stations based on the opportunity charging (OppCharge) platform, the solution will allow the Electric buses to be quickly partially recharged in less than ten minutes at key interchanges with an automated rooftop connection.

Pune, India

In January 2019, Pune became the first Indian city to adopt Electric buses and Bhekrai Nagar the country’s first all Electric bus depot. As of November 2019, up to 133 EVs have been deployed across the city in the first phase of its Electric bus programme. The buses are owned, operated, and maintained by their manufacturer, the Secunderabad-based Olectra Greentech and technical partner BYD.

The city has engaged with the operator Olectra to operate the Electric buses on a per-kilometre basis. Olectra is then responsible for running all operations, maintaining the bus, recruiting and training drivers.
**Santiago, Chile**

Chile has about 400 Electric buses launched in Latin America’s first Electric bus corridor in Santiago with a range of up to 250 km.

In Transantiago, Santiago, Chile, the implementation of Electric buses meant that the energy companies (ENEL & ENGIE) carried out the acquisition of the fleet and sublet it to the operators.

![Electric bus in Santiago, Chile](image)

**Los Angeles, USA**

The city of Los Angeles will receive the first of a total of 155 Electric buses to be delivered over the next two years starting in March 2020. The procurement is part of the California city’s plan to fully electrify its bus fleet by the start of the 2028 Summer Olympics. The Los Angeles Department of Transportation (LADOT) had ordered 130 Electric buses from BYD, another 25 from Proterra.

Proterra, a leading innovator in heavy-duty electric transportation, has been selected by the California Department of General Services as a vendor to supply Proterra® battery-electric buses and Proterra charging systems for the statewide contract.

![Electric bus in Los Angeles, USA](image)

**Gothenburg, Sweden**

Volvo Buses has received the largest single order for Electric buses in Europe. Volvo Buses will deliver 157 electric articulated buses to Transdev starting in 2020. The buses will operate on a number of routes in Gothenburg. All of the buses will be of the recently launched 7900 Volvo Electric Articulated model. The Volvo Electric Articulated bus can carry 150 passengers.

![Electric bus in Gothenburg, Sweden](image)
The buses will be charged at quick-charge stations along the route, using the industry common charging interface OppChargeTM.

**Shenzhen, China**

Shenzhen’s plan to create an all-electric public bus fleet began in 2013. To achieve the goal, a Shenzhen public bus operator is granted a total of 500,000 Yuan (US$72,150) worth of subsidies every year for each vehicle that it runs – 400,000 Yuan from Shenzhen authorities and 100,000 Yuan from the central government per vehicle to encourage the use of Electric bus nationwide.

With the city’s 16,000 Electric buses the total subsidy costs are at an unparalleled rate of 8 billion Yuan a year for the government. Shenzhen City has 32 charging operators, and by 2020, Shenzhen City is expected to have 8,246 fast-charging points for Electric buses, capable of charging between 16,500 and 24,738 pure Electric buses.

Shenzhen city has currently 3 operating companies namely Shenzhen Bus Group, Shenzhen East Bus Group and Shenzhen West Bus Group. Shenzhen Bus Group is the largest with around 6,000 Electric buses. The Shenzhen East and Shenzhen West have combined Electric bus strength of around 10,000 buses. In Shenzhen, the utility companies own most of the charging infrastructure. This partnership has resulted in charging stations built along bus routes. With *coordinated charging times* buses fully charge overnight, when electricity demand (and price) is lower.


CSTEP (2018): Implementation plan for electrification of public bus transport in Bengaluru

DIW Berlin (2016) Electrification of a city bus network: An optimization model for cost-effective placing of charging infrastructure & battery sizing of fast charging electric bus systems


Elsevier (2018). Estimation of the energy demand of electric buses based on real-world data for large-scale public transport networks


GIZ (2019): Impact assessment of large-scale integration of electric vehicle charging infrastructure in the electricity distribution system


Khandekar, A., Rajagopal, D., Abhyankar, N., Deorah, S., & Phadke, A. (2018, December 07). The Case for All New City Buses in India to be Electric. Retrieved February 12, 2019, from eScholarship - Open Access Publications from the University of California: https://escholarship.org/uc/item/7d64m1cd


Mäkinen, J. (2016). Fundamentals of electric bus charging. ABB.


US Department of Energy (2017). Challenges and opportunities of Grid modernization and electric transportation


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