ZERO-EMISSION BUS CHARGING SYSTEMS:
INSIGHTS FROM JAKARTA
The aim of this report is to provide city officials and practitioners with an understanding of the key elements and considerations in determining an appropriate and cost-effective charging system for the deployment of zero-emission buses.

This report is the first iteration, with a final version planned for early 2021.

**Jakarta, Indonesia**

Jakarta’s metropolitan area is home to 32 million people and Indonesia’s busiest transport network, at more than 10 million vehicles in total. In 2016, the city’s emissions, at 18MtCO2e, accounted for about 11% of Indonesia’s greenhouse gas (GHG) transport emissions. This is expected to double by 2030 under a business-as-usual scenario (Grutter Consulting, 2019). The city’s air quality is also a concern, with around 60% of the local population affected by air pollution-related diseases.

The City of Jakarta has identified steps to address its poor air quality and combat climate change, two of its top priorities. One of the key objectives is to expand and electrify public transport throughout the city. To this end, the C40 Cities Finance Facility (CFF) has supported Jakarta in realising the first 100 zero-emission buses of its planned full-fleet transition.

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**Objective of this report**

1. Bus technologies and their requisite charging strategies need to be analysed as a system. It is not necessarily true that shorter routes require smaller batteries and longer routes require larger batteries.

2. A strategy that replaces 100% of buses on a designated route with zero-emission vehicles rather than split over multiple routes can make it easier for operators to evaluate deployment and ensure reliable, high-quality information for analysis and decision-making.

3. It is necessary to understand the relationship between operational requirements, such as air conditioning, loading and distance, and measured battery range to develop an optimal charging strategy.

4. The preferred charging schemes and infrastructure must be considered within the context of local grid capacity and the potential to upgrade capacity in the future.

5. Bus depots are often ideal locations for installing distributed renewable energy generation, such as rooftop solar photovoltaic (PV) systems, which can reduce operational costs, improve air quality and deliver significant climate benefits.
Jakarta’s zero-emission transition

TransJakarta is a government-owned enterprise that runs the bus rapid transit (BRT) system across the Greater Jakarta area. It operates 13 main corridors of the 244km long BRT network with a total of 249 routes supported by a fleet of over 3,700 diesel, gasoline and CNG buses (Figure 1).

TransJakarta is progressively growing its fleet through partnership and collaboration with multiple bus operators under a gross cost contracting scheme. It is looking to expand it to more than 12,000 buses by 2030, while simultaneously switching to zero-emission buses in the medium and long term (Figure 2).

Based on data from TransJakarta’s ongoing zero-emission bus pilot, as well as zero-emission bus projects elsewhere, the city conducted feasibility studies to evaluate a selection of BRT and non-BRT routes and identify which ones were the most technically and financially viable. Full route transition was prioritised over mixed operation to facilitate analysis and inform future decision-making. Several key metrics were analysed, including ridership, number of buses, bus replacement ratio and total cost of ownership. Following the evaluation, one BRT route and two non-BRT routes were selected for full electrification.

Gross cost contract

Gross cost contract scheme is a contracting system whereby owners or operators of a private bus fleet are paid based on specific performance parameters. These typically include the number of buses provided and kilometres serviced.

Figure 1: Composition of TransJakarta’s bus fleet. Source: TransJakarta

Figure 2: TransJakarta’s electrification plan (2021-2030). Source: TransJakarta. N.B. Not intended to convey specific figures

Gross cost contract scheme is a contracting system whereby owners or operators of a private bus fleet are paid based on specific performance parameters. These typically include the number of buses provided and kilometres serviced.
The results of TransJakarta’s continuing zero-emission bus pilot suggest that a 324kWh battery pack can offer a total range of 239km (13–15kWh per km), taking into account route conditions, air-conditioning usage and passenger loading, and limiting the depth of discharge to 80%. The trials suggest that only 2 of Jakarta’s 13 BRT routes exceed the range of a single battery pack.

As a 324kWh battery pack can meet the operational requirements of the two non-BRT routes (including dead kilometres – the distance from the depot to the start of the route), overnight depot charging with this size of battery was deemed the optimal solution for those routes. However, as a 324kWh battery pack could not meet the daily power needs of a BRT route with over 240km per day, a 180kWh battery pack, with a combination of overnight depot and on-route or end-of-route opportunity charging, was determined to be more suitable for that service.

Daily energy demand can be estimated using the total distance travelled per day (including dead kilometres) and the total number of buses in operation. In Jakarta, the energy requirement for the first 100 buses is estimated at 31-36MWh. Most of this energy will be needed for overnight charging and the remainder for end-of-route or on-route opportunity charging. Assuming that about 15% of buses may need to be charged during peak load, the peak-loading power requirement will be about 2.25MW.

Understanding peak load is important, especially from the perspective of local grid capacity. If the peak load needed to charge the e-buses exceeds that of the local grid, costly upgrades will be necessary. Depending on the policies of the distributing utility, the costs may heavily influence the financial viability of the overall initiative. Thus, an appropriate charging scheme and infrastructure must be considered together with local grid capacity.

The buses on the BRT route need to travel a daily distance in excess of the measured range of a large 324kWh battery pack. This implies that a combination of overnight depot and opportunity charging will be required. Under this scenario, early analysis of the total cost of ownership (TCO) shows that using buses with a 180kWh battery pack is only 6–11% more expensive than the buses currently serving the BRT route, while buses with 324kWh battery packs cost 24–36% more.

The buses on the two non-BRT routes, in contrast, travel less than the measured range of a 324kWh battery pack each day (less than 180km). A 180kWh battery pack would offer cost savings of 10–15%, but this would be outweighed by the cost of installing opportunity chargers and the variability of daily operations on non-BRT routes. The optimal solution for the non-BRT routes, therefore, is to implement overnight depot charging.

Important considerations when selecting depots:

- Avoiding ‘dead kilometres’: In Jakarta, depots are typically owned by private operators. The average distance between depots and route starting points is 20–25km, so each bus will probably need to travel 40–50km per day on top of route requirements. Selecting routes with a lot of these ‘dead kilometres’ can reduce the operating range of zero-emission buses and limit the charging time available and thus alternative depots should be prioritised.

- Renewable energy generation: Municipal bus depots are an ideal location for rooftopsolar PV systems to generate renewable energy. Selecting a depot with the space and capacity to adopt zero-emission buses coupled with solar PV deployment can maximise the air quality and GHG benefits, reduce operational costs and minimise the need for local grid upgrades.

### Depth of discharge

Depth of discharge refers to the extent to which a battery is run down. To prolong battery lifespan, zero-emission bus manufacturers commonly specify that packs should undergo a maximum 80% depth of discharge, meaning that 20% of a battery’s capacity should be reserved. Charging and discharging, or ‘cycling’ a battery in this way protects it against over-discharge and generally increases its service life.

### Energy demand and peak load

Identifying the necessary charging infrastructure

### Overnight depot charging

Overnight depot charging is a charging strategy whereby electric buses are charged in depots when not in service, typically overnight. Such an approach means a typical e-bus will need a big enough battery pack to run continuously throughout the day. This system may require large up-front costs for e-buses, but will avoid the more costly infrastructure improvements of an opportunity charging system. However, local grids may require significant upgrades to cope with high localised electricity demand.

### Opportunity charging

Opportunity charging is a charging strategy whereby charging points are installed along or at the end of a service route. It may replace the need for overnight depot charging but, in practice, is often complementary. It typically uses fast charging units (150kW and above) to avoid disrupting the bus timetable in contrast to depot-only charging, opportunity charging allows smaller battery packs to be used and, potentially, energy demand to be distributed across multiple local grids.
By undertaking a structured analysis such as the one proposed above an operator can identify the most appropriate charging system and the required infrastructure for the selected route (Table 1).

<table>
<thead>
<tr>
<th>Routes</th>
<th>Charging system</th>
<th>Infrastructure required</th>
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<tbody>
<tr>
<td>Two non-BRT routes</td>
<td>A single overnight depot-charged 324kWh battery is sufficient to achieve the necessary range</td>
<td>Buses with 324kWh batteries 1 slow charger per two buses (50kW)</td>
</tr>
<tr>
<td>One BRT route</td>
<td>A 180kWh battery requires both overnight depot charging and opportunity charging at terminals</td>
<td>Buses with 180kWh batteries 1 slow charger per two buses (50kW) 1 fast charger per five buses (minimum of 150kW)</td>
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</table>

Table 1: Charging requirements for TransJakarta electrified routes. Source: C40 Cities Finance Facility (2020).

**Conclusion**

Acknowledgments

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Disclaimer: Due to the impending tender of Jakarta’s first 100 zero-emission buses, specific details have intentionally been left out of the report. These will be reflected in the final version of the report, which will be published in early 2021.

**Further reading**


**Bibliography**


