ACCELERATING ELECTRIC BUS ADOPTION IN THE NEW YORK MTA BUS SYSTEM

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This paper examines the Metropolitan Transit Authority’s (MTA) goal to transition its 5700-vehicle bus fleet from internal combustion engines (ICE) to a battery electric bus (BEB) fleet by the year 2040. This transition will bring two direct benefits: improved local air quality for New Yorkers and reduced greenhouse gas emissions from the New York City transportation sector.
EXECUTIVE SUMMARY

This paper examines the Metropolitan Transit Authority’s (MTA) goal to transition its 5700-vehicle bus fleet from internal combustion engines (ICE) to a battery electric bus (BEB) fleet by the year 2040. This transition will bring two direct benefits: improved local air quality for New Yorkers and reduced greenhouse gas emissions from the New York City transportation sector.

Meeting this ambitious goal requires thoughtful planning, analysis, and coordinating between policymakers, utilities, the private sector, and other key stakeholders across a broad range of complex topics. Thus, this study’s analysis and recommendations for NYC and MTA fall into four main areas:

• Regulating Emissions
• Managing Electricity Load and Rates
• Implementing and Operating Electric Buses
• Financing Fleet Transition and Supporting Infrastructure

Electric buses can yield significant economic, environmental, and social benefits for cities that choose to implement the technology. The question is not whether it’s possible for NYC to adopt electric buses, but will the city manage the implementation of electric buses in an effective manner that maximizes the benefits for all stakeholders by the target year of 2040. The following recommendations are actionable steps that decision-makers can take to ensure that NYC and the MTA realize this goal.

Key considerations in the evaluation of the available policy options include cost-effectiveness, technological availability, political viability, and operational integration. While many aspects of the MTA’s operating model may have to adapt to electric bus adoption, the MTA can still achieve its mission of delivering reliable, safe, and affordable surface transit services with the following recommendations.

MTA Electric Bus Pilot

In early 2018 the MTA initiated an electric bus pilot to test operational performance and gather data to support the agency’s long-term strategy to transition to a zero-emissions fleet by 2040.¹ In developing a scope for the pilot, the MTA engaged several leading electric bus manufacturers including Build Your Dreams (BYD), Proterra, New Flyer, and Novabus.

Ultimately, the MTA negotiated a vehicle leasing arrangement with Proterra and New Flyer for a 3-year testing period with 10 buses. 5 Proterra E2 models equipped with 440kW batteries² are serving the B32 and B39 routes in Brooklyn and Queens, and 5 New Flyer XE40 Xcelsior models equipped with 150 kWh batteries are serving the M42 and M50 routes in Manhattan. Proterra buses were selected to charge primarily through 50 kW depot chargers at Grand Avenue Depot along with a 500kW fast charging station at the Williamsburg Bridge plaza serving as a range extender and to provide for increased route flexibility. The first five New Flyer buses are supported by two on-route fast chargers (300 kW) located on the east and west side of Manhattan at East 41 Street and at Pier 83, Circle Line on West 43 Street, respectively. Two 50kW depot chargers were installed at MJ Quill Depot for maintenance and reliability.

The MTA’s initial capital program from 2015-2019 allocated $71m in funds to purchase 50 electric buses and eight charging stations.³ However, the capital plan goes through as-needed

amendments to account for actuals. In April of 2018, the third amendment to the plan increased NYCT’s electric bus funding from 50 all-electric buses to 60 vehicles, including; 45 standard electric, 15 articulated electric buses and additional charging infrastructure, including one additional high powered 500v DC opportunity charger which are being actively procured.4

REGULATING EMISSIONS

**Recommendation 1:** The NYC Mayor’s Office of Sustainability and State officials should align the MTA’s bus goal to a specific emissions reduction target to ensure progress is tied to environmental outcomes. Without a clear connection to the state-level and city-level emissions targets, MTA risks not making progress on goals and not timing procurement cycles for new BEBs to measurable emissions reductions.

**Recommendation 2:** The NYC Mayor’s Office of Sustainability should adopt additional performance-based environmental policies to drive action across transport sub-sectors and accelerate EV adoption. This could take the form of a low emissions zone(s) modeled after London’s implementation of a Low Emissions Zone and Ultra Low Emissions Zone. Proponents of congestion pricing in NYC have suggested that revenues from the new congestion charges will help fund the MTA bus and subway systems. While this is a positive step toward alleviating budget deficits and funding desperately needed system upgrades, it is unclear whether congestion pricing will have a real-world environmental impact.

MANAGING ELECTRICITY LOAD AND RATES

**Recommendation 3:** Electric bus advocates, operators and utilities should work with the NYPSC to develop a rate structure that sends a correct price signal to customers that helps to manage charging times and peak load. Demand charges should be eliminated for bus charging operations and be replaced with time-of-use rates. The time-of-use rate should include seasonal considerations, and be kept as stable as possible. The MTA must petition for separate rate classification and re-consideration for the grid services that it can provide to each customer by load shifting and placing several high-power draw resources onto the grid in the evening.

IMPLEMENTING ELECTRIC BUSES

**Recommendation 4:** The MTA should set specific vehicle procurement targets through 2040 that help ensure their fleet transition goal is met. This will serve to reduce stakeholder uncertainty and allow for planning and course correction if operational challenges arise. For example, if implementation or operational challenges were to arise the interruption would be considered a delay and allow for MTA leadership to update projections of the transition timeline and procurement volumes necessary to meet the 2040 goal. Procurement targets would establish accountability and elevate the importance of this effort with clear metrics.

**Recommendation 5:** Bus operators should initially focus on shorter routes and depots that have excess grid capacity that will not trigger major electrical infrastructure upgrades. Existing BEB technology options are well-equipped to handle simple operations, but are limited in cold/inclement weather or for longer routes without excess backup buses or frequent charging. To match the current

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use-cases that BEBs are well equipped for, the MTA should continue to implement BEBs on shorter routes.

**Recommendation 6:** Con Edison and the NYPSC should evaluate tariff modifications that allow for rate basing necessary infrastructure upgrades to service the interconnection of electric bus depots. Existing regulations require excess distribution facilities be paid for by customers. A tariff could be developed with specific regulations that dictate the scope and process of applying for and building out required interconnection facilities for fleets of public service vehicles. This DC Charging as a Service tariff would lay out rules for new service requests and allow utilities to coordinate directly with organizations like the MTA to rate base required infrastructure upgrades.

**FINANCING THE TRANSITION**

**Recommendation 7:** The MTA Board should take steps to link the Capital Budget and the Operating Budget in order to promote BEBs and other long-term cost-savings technologies with high upfront costs. Total Cost of Ownership (TCO) for buses must account for the higher upfront capital cost of the vehicle and the lower variable costs of fueling and maintaining the bus over its useful life.

**LESSONS FOR EVERY CITY**

The trend of electric bus adoption is largely being driven by cities around the world that are motivated by an urgent need to reduce carbon emissions and improve air quality simultaneously. While the technology is certainly promising, few models around the world exist for cities that have successfully implemented 100% electric bus fleets. Policies and programs that work – environmentally, economically and politically – have the potential to be adopted elsewhere. Thus, the learnings from NYC, London, Shenzen, and many other cities that are forging ahead can be extremely useful to every city.

While the recommendations of EVery City were developed with a focus on New York City, many lessons from this study can be applied to other cities. As cities gain more experience with electric buses and understand barriers and opportunities to implementation, continuous information sharing and the development of best practices is critical to the global growth of this market.

Based on the initial experience of NYC’s transition, the following lessons can be broadly applied to all cities:

- **Clear top-down policy regarding emissions and technology goals provides certainty to the market.** The transition to electric buses will be more successful if the relevant decision-makers have a clear mandate that ties bus procurement targets with emissions reductions at clear milestones. This alignment can help ensure transparency, accountability, and environmental benefits of electric bus adoption.
- **Grid capacity must be assessed, but can be managed with cooperative planning.** Places around the world that are challenged by transmission reliability, generation capacity, and load management should carefully evaluate the available capacity on the grid.
- **Rate design can make-or-break electric buses especially in early stages of implementation.** Utilities have the potential to benefit from electric vehicles given the potential for rate-based investments and higher utilization rates of existing capacity. It’s critical that transit authorities, electric utilities, and relevant regulators work together to evaluate rate design in order to mutually benefit fleet operators and utilities.
• Route and depot planning must consider the potential that 100% of a future fleet will be electrified even if initial time-bound procurement targets are lower than 100%. Fleet operators should attempt to proactively plan for 100% electric fleets due to the complex configuration of depot charging infrastructure and the possibility of insufficient or redundant infrastructure upgrades.

• TCO benefits are only realized when CapEx and OpEx of an investment are evaluated together over the life of an asset. Cities like NYC that have separate budget planning processes for capital budgets and operating budgets should consider taking steps to reorient their budgets to fully realize the lifetime savings of electric bus adoption.

• Proactive and transparent engagement between policymakers and implementers is critical. The electrified transportation trend means that previously unrelated industries, the power sector and the transport sector, and their respective government agencies and regulators must coordinate to set policy in unprecedented ways. While this may take some time, all parties involved will achieve better outcomes through coordinated efforts.

ADDITIONAL RESEARCH NEEDS

While this report addressed many practical aspects of implementing electric buses in NYC, more research is needed as NYC progresses steadily toward 2040. The following areas were out of scope for EVery City and are outstanding needs that require further investigation:

• **Route optimization for phases of electric bus implementation** – As the MTA makes progressively larger purchases of electric buses, more thoughtful planning must occur to transition routes and depots to all electric. The MTA or independent researchers should undergo a planning exercise to evaluate all route data to optimize routes for electric buses taking into consideration route distance, charging needs, off-peak charging hours, and battery range.

• **Siting of on-route opportunity charging** – Similar to the previous point, the MTA has indicated that it is interested in using on-route opportunity charging in addition to depot charging to help extend the range of electric buses in service. This is another strategic exercise that will require significant data analysis and joint planning with Con Ed to site and install on-route chargers.

• **Solutions for consumer responsiveness to time-varying rates** – EVery City recommends the elimination of demand charges and the implementation of time of use rates for electric buses to shift charging patterns to off-peak hours. However, rates are only as effective if customers have visibility and access to information to respond to price signals. Customer interface solutions are needed to ensure that customers respond to TOU rates.

• **Analysis for price-setting of a Low Emissions Zone charge** – Should a LEZ be considered by the city, analysis must be done to establish the economically efficient and effective price for entering the LEZ.
ELECTRIC BUS BACKGROUND

The emergence of new vehicle technologies – most notably electric vehicles (EVs) – has captured the public’s imagination as a cleaner and more exciting option for the next generation of transportation. Some estimates project that by 2040, 55% of all new car sales and 33% of the global fleet will be electric. This transition is being driven by declines in the total cost of ownership of EVs as well as policy goals aimed at improving local air quality and reducing greenhouse gas emissions. While the global bus market is still predominantly powered by diesel and natural gas, the electric bus market has continued to develop as cities look for ways to tackle local air pollution issues and reduce carbon emissions from the transportation sector.

Challenges for Electric Bus Deployment

Despite the growing appetite for electric vehicles, few cities and their electric utilities have taken significant steps to incorporate full transportation electrification into their municipal planning. Looming challenges for policymakers, utilities, and the private sector include the implementation of emissions regulations, identifying sources of capital to fund the required infrastructure and vehicle investment for transition, electricity rate design considerations that can maintain predictable fueling costs, and necessary operational changes to optimize bus company processes for electric vehicles.

NYC and the MTA face these same challenges as they begin to transition their own bus fleet electric by 2040. Thoughtful planning and analysis in partnership with other key stakeholders is critical for MTA to maximize the benefits of electric buses. Thus, this study’s analysis and recommendations for the NYC and MTA fall into four main areas to address these challenges:

• Regulating Emissions
• Managing Electricity Load and Rates
• Implementing and Operating Electric Buses
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METROPOLITAN TRANSIT AUTHORITY (MTA)

Governance and History

In May 1965, the New York State Legislature chartered the Metropolitan Commuter Transportation Authority (MCTA) under the New York State Public Authorities Law, and provided the entity with the authority to make contracts and arrangements with other commuter-railroad operators. Following a name change in 1968 and decades of expansion, the MCTA has become the Metropolitan Transportation Authority (MTA) we know today.

The complexity of MTA’s shared governance between New York State, New York City, and surrounding counties presents challenges to making major policy change. Chartering the MTA, Article 5 Title 11 of New York State’s Public Authorities Laws requires the governor to appoint the MTA board,
which consists of a chairperson, sixteen other voting members, two non-voting members, and four additional alternate non-voting members, with the advice and consent of the senate. While MTA bus service through New York City Transit (NYCT) nearly exclusively serves NYC, NYC only has 4 of the 17 voting rights on the board.

Funding Challenges

Because the MTA manages a large portfolio of transportation services including commuter-rail systems, a rapid transit system, bridges, tunnels, and more, the bus fleet may not always be a priority for the MTA. The complexity of MTA’s daily operation is a result of its history of consolidating private companies. The consolidation has created significant centralization of infrastructure and capital investment, but compromised planning and flexibility of certain aspects of the system. As an example, the MTA subway system has different train sizes for different lines, limiting the MTA’s ability to move its assets around.

Since its inception, the MTA has struggled to sustain itself financially. For example, the MTA’s first acquisition, the Long Island Rail Road (LIRR), has declared several bankruptcies. The MTA’s subsequent mergers with the New York City Transit Authority (NYCTA), the operator of buses and subways in New York City, and the Tri-borough Bridge and Tunnel Authority (TBTA), the operator of toll bridges and tunnels within New York City, have improved the financial situation of the MTA, as the mergers allow the MTA to subsidize subway and bus fares using the revenues generated from the TBTA tolls. Even with the additional operating revenues from the TBTA, the MTA has encountered challenges in financing major construction projects and capital expenses, and has required significant assistance from both the City and the State.

Coupled with the board’s reluctance to increase fares, the increase in maintenance costs and new capital expenses means that yearly deficits are the norm of the MTA’s operations.

11 The MTA Board composition is as follows:
- 1 chairperson (recommended by New York State Governor)
- 5 voting members (recommended by New York State Governor)
- 4 voting members (recommended by New York City Mayor)
- 1 voting member (recommended by Nassau County Executive)
- 1 voting member (recommended by Suffolk County Executive)
- 1 voting member (recommended by Westchester County Executive)
- 1 collective vote by 4 members (recommended by Dutchess, Orange, Putnam, and Rockland County Executives)
MTA does not recover its expenses from its operational revenues. Instead, the MTA relies on support from both NYS and NYC to balance its budget.\(^{20}\)

**MTA Bus Fleet**

The MTA is the largest public transit authority in the United States and operates a bus fleet of more than 5,700 buses.\(^{21}\) As of January 2019, almost half MTA’s fleet is diesel, and the planned deliveries of new buses from MTA’s 2010-2014 and 2015-2019 capital programs are also mainly diesel buses.\(^{22}\) In 2017, the average age of the bus fleet was 7.8 years, and 22% of the fleet had been in service for more than 12 years, well above the MTA’s twelve-year replacement cycle.\(^{23}\) Appendix I shows the current fleet mix in greater detail. While this aging bus fleet remains a major source of emissions in New York City, the age of the fleet presents a timely opportunity to adopt BEBs.

MTA’s main two bus operators, New York City Transit (NYCT) and the MTA Bus Company (MTABC), operate a combined 238 local routes, 18 select-bus services, and 74 express routes. The combined annual ridership of these routes is more than 700 million people, with 2.3 million riders on an average weekday.\(^{24}\) Since 2007, bus ridership has declined, while the residential population in the service area has increased. MTA attributes the decline to a large shift from bus ridership to subway ridership, stating that ridership on bus routes with good subway alternatives declined by 6%, while ridership on routes without good subway alternatives fell by only 4%. Past declines included large shifts from bus to subway.\(^{25}\) This claim highlights the complementarity of subway and bus services in MTA’s operations and management approach, which influences the organization’s budgetary decisions.

**MTA Electric Bus Pilot**

In early 2018 the MTA initiated an electric bus pilot to test operational performance and gather data to support the agency’s long-term strategy to transition to a zero-emissions fleet by 2040.\(^{26}\) In developing a scope for the pilot, the MTA engaged several leading electric bus manufacturers including Build Your Dreams (BYD), Proterra, New Flyer, and Novabus.

Ultimately, the MTA negotiated a vehicle leasing arrangement with Proterra and New Flyer for a 3-year testing period with 10 buses. 5 Proterra E2 models


equipped with 440kW batteries are serving the B32 and B39 routes in Brooklyn and Queens, and 5 New Flyer XE40 Xcelsior models equipped with 150 kWh batteries are serving the M42 and M50 routes in Manhattan. Proterra buses were selected to charge primarily through 50 kW depot chargers at Grand Avenue Depot along with a 500kW fast charging station at the Williamsburg Bridge plaza serving as a range extender and to provide for increased route flexibility. The first five New Flyer buses are supported by two on-route fast chargers (300 kW) located on the east and west side of Manhattan at East 41 Street and at Pier 83, Circle Line on West 43 Street, respectively. Two 50kW depot chargers were installed at MJ Quill Depot for maintenance and reliability.

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**STAKEHOLDER OVERVIEW**

While the MTA is primary institutional decision-maker for electric bus adoption in NYC, there is a crowded landscape of stakeholders who have a role to play in order to meet the MTA’s 2040 goal. The following stakeholder analysis identifies the scope of influence and likely position for each stakeholder involved in electric bus adoption. These stakeholders are also depicted in relation to one another in the following graphic.

**Secondary Stakeholders**

While lacking direct decision-making authority, companies, non-governmental organizations, regulators, and political bodies can make decisions about matters that can enable the transition to electric buses. These stakeholders may have different priorities from the MTA and can

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significantly accelerate or hinder progress.

**Consolidated Edison (Con Ed):** As the distribution utility serving MTA, Con Ed is nearly as critical to the decision making on electric bus adoption as MTA. A transition to electric buses means that MTA will have substantial demand for new power distribution to chargers located at depots and on routes across NYC. Con Ed has several ongoing projects related to EVs including a public charging demonstration funded through New York State’s Reforming the Energy Vision (REV). Con Ed also participated in launching MTA’s pilot of 10 electric buses and charging stations. Beyond physical infrastructure, Con Ed plays an active role in designing rates that could either positively or negatively impact electric bus adoption.

**New York Power Authority (NYPA):** NYPA is a state power organization that serves MTA as a public sector customer and helps to carry out key energy initiatives within the state. NYPA plans to deploy $250 million through 2025 for electric vehicle infrastructure, services, and consumer awareness efforts as a part of its Evolve NY initiative. Similar to Con Ed, NYPA must deliver power to MTA depots and on-route chargers cheaply and reliably. NYPA plays an active role in designing rates that could either positively or negatively impact electric bus adoption.

**NYC Mayor’s Office of Sustainability:** The Mayor of the City of New York, Bill De Blasio, has only partial control over the MTA governance. However, the Mayor’s Office of Sustainability has responsibility for setting broad environmental policies for the city, many of which directly impact transportation. For example, this office is responsible for collecting and publishing city-wide emissions inventories and issues the OneNYC sustainability plan that sets a number of transportation related emissions targets across city agencies and sectors.

**New York State Energy Research and Development Authority (NYSERDA):** NYSERDA is a state agency with the mission to accelerate energy efficiency and clean energy technologies. NYSERDA has specific goals related to clean vehicle and EV adoption including the ability to administer state incentives for clean vehicles such as the NY Truck Voucher Incentive Program.

**New York State Governor’s Office:** The Governor’s office has significant control over the MTA, both in terms of its leadership, budget process, and nomination of six of the seventeen members of the MTA’s board. The Governor’s office also proposes the annual budget to the New York State legislature. As the MTA relies in part on funding from the state government, the budgetary process shapes the MTA’s practices and available funding for the capital budget.

**New York State Public Service Commission (PSC):** The PSC is the regulatory body responsible for the oversight and rule-making for utilities operating in New York. The services under the PSC’s purview include electric utilities, natural gas, steam, telecommunications, and water. In terms of electric utilities, the PSC has oversight over Con Ed’s activities and investments, including submissions for their Integrated Resource Plans and electricity-rate structure requests. The PSC has final say over Con Ed’s infrastructure investment plans and demand charges for large customers.

**Influencers**

Influencers are companies, cities, non-governmental organizations, and groups of individuals that can affect the rate at which BEBs are adopted, the financial challenges that may be presented by implementation, the technological options available, and the political feasibility of BEB adoption.

**Model Cities:** Model Cities include metropolitan areas, such as those in the C40, that have a stake in finding sustainable solutions to environmental and energy-related challenges for major urban areas. These cities include London, which served as the model city for this study. Similarly, solutions
and key learnings found in NYC can provide a template for other cities that can be adopted to accelerate the transition to BEBs.

**Environmental Groups and NGOs:** Environmental groups and NGOs include organizations such as the Sierra Club, WE ACT for Environmental Justice, and other environmental groups. These entities promote policy and technology changes that will reduce carbon emissions and local air pollution through their advocacy work. These groups have no direct influence on the adoption rate or selected technology but exert strong grassroots and political influence over policy.

**Vehicle and Charging Manufacturers:** BEB manufacturers such as Proterra, NewFlyer, and BYD support a faster transition to BEBs due to their direct business interests. The manufacturers influence the rate of transition to BEBs in NYC by their technology performance, cost of equipment, and their reputation. As BEBs are a relatively new technology and require a premium compared to the incumbent technology, manufacturers shape the perception of electric buses and are not only responsible for selling their product, but also selling a new operating system to transit authorities.

Manufacturers also influence transit authorities in their selection of charging technology. Currently, some BEB manufacturers have their own proprietary plug shape. Brand-specific charging ports are part of each vehicle manufacturer’s strategy to maintain market share by promoting asset lock-in rather than interoperability. However, this strategy by individual manufacturers may hinder the rate of adoption as the MTA is reluctant to rely on a single manufacturer.

**Labor Union:** The MTA’s labor union can influence the process through its collective bargaining agreement. Due to the lower maintenance requirements for BEBs compared to diesel buses, the labor union may resist transition plans if jobs are threatened as part of the transition or significant retraining is required.

**General Public / Tax Payers:** Taxpayers provide revenue directly to the MTA through special levies for mass transit and through the State’s General Fund. Taxpayers may resist the high upfront cost of BEBs if New York raises taxes to fund the transition.

**Riders:** Bus rider approval is key to successful implementation. Rider dissatisfaction with the BEBs could result in backlash if the implementation of BEBs interrupts service. Additionally, any fare increases as a result of BEB adoption could create backlash for the transition plan.

### EMISSION AND POLLUTION REDUCTIONS GOALS

The clear benefits of electric bus adoption are the zero-tailpipe emissions of greenhouse gases and air pollutants. According to a previous Columbia University study, total electrification of the MTA bus fleet would yield GHG emissions savings of approximately 575,000 metric tons of CO2e per year. “The net savings, including the incremental power generation required for the electric buses is nearly 500,000 metric tons of CO2e assuming the current mix of power generation in New York City and Westchester (EPA).”

Additionally, conservative estimates put the healthcare savings as a result of improved air quality at roughly $100 per NYC resident per year.

The State of New York Reforming Energy Vision (REV) 2030 Goals call for a 40% reduction in greenhouse gas emissions from 1990 levels by 203 and New York City has launched multiple initiatives to improve its air quality and reduce its greenhouse gas emissions. NYC’s current targets

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for air quality and carbon emissions are incorporated under its OneNYC plan and include a commitment to reduce carbon emissions 80 percent by 2050 compared to its 2005 baseline. Approximately 30 percent of the City’s carbon emissions are from the transportation sector. While the majority of vehicle emissions are from private vehicles, fleetwide initiatives like the MTA’s goal to transition all electric by 2040 are critical because fleets can be more directly managed.

In the past, MTA and NYCT have demonstrated their ability to set ambitious goals and achieve them. As an example, NCYT became the first public agency in the world to have an 100% accessible bus fleet for customers on wheelchairs by equipping its buses with front or rear-door lifts. New procurements include buses with low floors and a ramp that connect the buses with the curbs. Nevertheless, MTA’s complex governance and finances pose challenges in meeting its 2040 bus electrification target. MTA’s 2040 BEB goal appears to be independent of state-level and city-level emissions targets that have been set and procurement cycles for new BEBs are not tied to specific emissions reduction targets.

MODEL CITY – LONDON CASE STUDY

Few cities in the world have made as much progress toward transportation electrification and decarbonization as London. London serves as an excellent point of comparison for NYC because of London’s similar policy objective to achieve a zero-emissions fleet by 2037 and focus on air quality improvement as it has the worst air quality in Europe. Additionally, London and NYC have similar population sizes and densities, comparable bus fleets, and similar socio-economic and political conditions. To observe this progress directly, the EVery City team traveled to London in March, 2019 to meet with stakeholders and decision makers from the London city government, transit authority, bus fleet operators, and electric utilities.

Transportation Strategy and Policy

In 2017, the Mayor of London, Sidiq Khan, and Transport for London (TfL) announced that by 2037, London would have an entirely zero emission fleet. This goal is largely motivated by persistent poor air quality in London and the need to reduce GHG emissions to address climate change. London experiences some of the worst air quality in Europe and as many as 2 million people in London live in areas that regularly experience levels of ground-level ozone above the legal limits. Additionally, Mayor Khan has set a goal of making London a net-zero carbon emission city by 2050.

London’s stated commitments include:

- All new double deck buses procured in London will be hybrid, electric or hydrogen from 2018. All new single deck buses will be electric or hydrogen from 2020. This procurement plan means the entire bus fleet will be zero emission by 2037.
- All new cars and vans in Greater London Authority group fleets, including emergency response vehicles, will be zero emission capable from 2025. London has committed that all public heavy-duty fleets will be “fossil free” by 2030.

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In the interim, more than £300 million will be dedicated to retrofit the existing diesel-powered fleet to meet the tightest possible emission standards (Euro 6) by 2020 as it transitions to a zero-emission fleet by 2037.

London’s commitment is bolstered by key environmental policies. Since 2003, London has enforced a Congestion Charge for vehicles entering the Congestion Charge Zone (CCZ), which corresponds to the area of Central London. The Congestion Charge is an £11.50 daily charge for driving a vehicle within the charging zone between 7:00am and 5:00pm, weekdays. In reaction to acute air quality in 2017, Mayor Khan implemented an additional Toxicity Charge (T-Charge) of £10 on top of the Congestion Charge for vehicles entering the CCZ that do not meet the Euro 4/IV emissions standard. Overlaid with the Congestion charge are two emissions-control zones. The first is a Low Emission Zone (LEZ) that was introduced in 2008 to target reductions in vehicle emissions from larger vans, commercial vehicles, and trucks. The LEZ roughly maps the London metropolitan area bounded by the M25 motorway and only allows vehicles that meet the Euro 4/IV emissions standard. In April 2019, a new Ultra-Low Emissions Zone (ULEZ) will be implemented in Central London that requires diesel vehicles to meet the Euro 6 emission standard or pay a daily charge to enter the zone. Petrol vehicles will have to meet the Euro 4/IV emission standard. The ULEZ will be in effect 24 hours a day and 7 days a week and is expected to be expanded to other areas of London.

Governance and Operation of Fleets

While TfL and the Mayor of London have a significant amount of control over transportation, TfL does none of its own operation or maintenance of the bus system. Instead TfL contracts private operators on a competitive basis to procure, operate, and maintain the 9000 buses, 700 bus routes, and 98 depots. TfL issues a tender for the operation of each route every 5 years. Contractors who win a bid for a 5-year contract have the potential to extend their contract two additional years, making the turnover of routes, associated vehicles, and depots happen as frequently as every 5-7 years.

One of the largest private operators serving TfL’s bus routes is Go-Ahead London, which operates nearly 25% of the buses in London. Go-Ahead is responsible for deploying the first all-electric bus garage in the UK, making it an important case study for the rest of London and for other cities. In 2016, the contract for the Waterloo Bus Garage in Central London was expiring and was bid competitively by TfL. Given London’s pending ULEZ, Go-Ahead made the strategic decision to transition the Waterloo Bus Garage zero emissions or all-electric to ensure eligibility for the tender. In anticipation of the pending tender cycle, Go-Ahead began a trial of electric buses from the Chinese company Build Your Dreams (BYD), which did not have a manufacturing presence in Europe at the time. BYD initially faced some challenges meeting the EU vehicle specifications and eventually partnered with the Scottish bus builder Alexander Dennis to meet the specs for Go-Ahead. Today, Go-Ahead is operating 50 BYD buses out of the Waterloo Bus Garage, which serve 2 routes in Central London. By the end of 2019, Go-Ahead will have logged 2.5 million miles of BYD battery electric bus operations.

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35 The Euro 4/IV emissions standard was effective from 2006 onward and defines emissions limits for particulate matter and NOx emissions from various vehicle classes in the EU.
Depot Redesign Considerations: Lessons from the Waterloo Garage

Each depot will require a unique design that considers existing obstructions in order to optimize space. Uncovered, outdoor depots face limitations on the amount of available square footage particularly in Central London, while indoor depots have to account for building support beams and other immovable features of the building/depot. Trial and error prior to the installation of chargers is crucial to determine the order of parking, charging and departure from a depot.

Run-in / Run-out Scheduling

Parking and exit planning will allow the depot to maximize the use of its space with the placement of chargers. However, the capacity of a depot will be diminished slightly by the arrangement, as buses can no longer be parked nose-to-tail. The depot may choose to maintain nose-to-tail parking, but must then potentially rely on overhead, drawdown cables to charge the buses, which adds a layer of complexity to the operations and potential safety hazards.

Parking Design and Vehicle Cycling

In order to site charging infrastructure efficiently and maximize available space, Go-Ahead had to re-imagine the run-in/out and parking configuration of the depot. Vehicles could no longer enter the depot, refuel, and then stack in rectangular parking pattern as they once did. Instead, Go-Ahead experimented with different parking configurations to arrive at an ideal layout. Experimentation was conducted by parking the existing diesel fleet as if the vehicles were electric, and marking out parking configurations that could maximize available space given the location of the chargers and ensure safety.

Driver Retraining

Once the parking configuration had been finalized, drivers started to proactively practice the logistics of the new parking layout with the diesel fleet. A few additional common-sense additions were made to the depot such as wheel chocks for parking spots that require a driver to back the bus into position as well as rail guards that were installed to protect the chargers during parking. Additionally, the BYD buses that Go-Ahead procured came with rearview cameras to further aid drivers in correctly parking the vehicles and small LED lights by charging plugs to ensure ease of plug-in at night.
Technology Integration Challenges and Solutions

London bus operators have steadily learned from the initial challenges identified during the early roll-out of BEBs and are looking to incorporate learning into their strategy moving forward.

HVAC on Buses

A main issue with BEB technology is the Heating, Ventilation, and Air Conditioning (HVAC) system, particularly during winter months. Because the HVAC system draws power from the same batteries used for vehicle propulsion, the range of a BEB can vary significantly depending on the climate. BEBs use electric resistance-based heating systems, which can reduce the total mileage range by as much as 40-60 percent. Cooling is a significant energy draw during summer months. Given London’s climate, cooling requires less energy than heating and is less of a concern for London bus operators. This is primarily due to the relatively inefficient heating technology. However, multiple options exist to reduce the power draw and total energy consumption used for heating.40

Two strategies to overcome the current heating issues for BEBs involve lower temperature setpoints, and improved BEB design based on these constraints. The lower temperature setpoint can be mandated by Transport for London as part of the procurement tenders that are issued, and combined with heating control specifically for the bus operator. As an energy conservation strategy, lower setpoints with zone heating for the driver would allow for lower total energy consumption from HVAC, while keeping the bus driver and riders comfortable. Anecdotally, bus operators also believe that this could improve rider experience. As many riders wait for the bus wearing warmer winter layers, the high temperature setpoint in the bus means that riders are uncomfortably warm while riding and may actually prefer less heating on the bus.41

The second option to improve HVAC energy consumption requires manufacturers address current inefficiencies in vehicle design. Improving the air sealing of the vehicle frame, as well as replacing current electric resistance heating technology with heat pumps can reduce energy consumption and improve efficiency. Energy efficiency improvements may reduce energy consumption by up to two-thirds if efficiency levels equivalent to residential heat pumps can be achieved. Both of these strategies can reduce the range limitations imposed by current technology. For the purposes of an all-electric fleet, these improvements are considered vital by London’s bus operators. If they cannot be implemented, many bus operators suspect that they will need to use fossil-fuel fired booster heaters as the route distance required with BEBs increases.42

Depot Conversion and Planning

The second integration challenge that was reported by Go-Ahead is the need to prepare the entire depot for electrification at the beginning of the fleet conversion. As the charging operations and schedule takes several hours, re-fueling needs for BEBs are significantly longer than the few minutes it takes to refuel a diesel or CNG bus. At low levels of penetration, the placement of charging infrastructure is relatively inconsequential, even for depots with significant space constraints. However, there is a tipping point at which full reconfiguration of the depot is necessary and it may no longer be feasible for the depot to be operating both liquid fuel and electric buses. This tipping point may include the complexity of reorganizing the entry and exit from the depot and the parking arrangement in order to allow charging for each bus. Each depot will require its own unique arrangement in order to park each bus and allow for charging. It should also be anticipated that there

40 Mandel, Ben Interview by Lauren Kastner, Andy Catania, Michael Woods, and Eugene Tseng. CALSTART. February 18, 2019.
41 Ibid.
will be a slight reduction in the number of buses that can park at a given depot, as buses will not be able to continue to park nose-to-tail unless overhead chargers are used.

**Selection of Charging Technology**

The final integration problem is the selection of AC charging or DC Fast Charging (DCFC). Go-Ahead reported that they selected AC charging infrastructure due to the excess heat generation that would be created from DCFC, which was potentially problematic for maintaining the integrity of BYD’s battery performance at the time. DCFC requires that the batteries be cooled in order to protect the chemical integrity of the battery. This concern also reduced the amount of additional grid capacity that the depot needed, as smaller capacity sizes were required for each charger. The limitations of DCFCs makes the use of AC charging favorable, which optimizes charging to shift to long periods of off-peak charging overnight.

**Grid Capacity Planning**

London’s grid challenges are not dramatically different from the constraints imposed on every electric grid. These issues include capacity constraints for the end-use customer and concerns over grid congestion. As the addition of substations at bus depots in order to add electric vehicle charging.

A given location for a bus depot is generally assigned a power capacity by the local utility, limiting the amount of infrastructure for the depot that is reliant on the grid. In order to be able to draw more power, additional infrastructure must be added on site. The Waterloo Bus Garage in London reported that an additional 2.5 MW of power capacity was added to the location through the build of new infrastructure to support bus charging. Of the additional 2.5 MW of capacity, it was estimated that only 1.6 MW of the additional capacity are actually utilized. This indicates that with proper scheduling, additional substation capacity needs can be minimized. Additionally, the cost for capacity charges is prescribed by the maximum capacity draw for customers. This provides certainty to bus operators about what their electricity costs will be rather than experiencing potentially severe price spikes for demand charges.

UK Power Networks (UKPN), the local grid operator in most of London, reported that the focus for their business has shifted to non-wires solutions as TfL looks to electrify their fleet. This has meant primarily focusing on partnering with customers and generators to increase or decrease generation, or to increase or decrease end-use consumption, to match load. The utility regulatory structures between the United States and the United Kingdom are similar. Cost-of-service recovery, prudency, and stranded assets are common terms in the vernacular of utilities in both countries.

**Rate Design**

Utilities are allowed to recover what their regulating bodies consider a reasonable rate of return for infrastructure build-outs. Rates are then apportioned based on the costs accrued in delivering electricity to customers, and the reasonable return on investment applied to the capital assets accrued by the utility. Utilities are disincentivized from making imprudent investments by having assets that are retired before the end of their useful life that were not reasonable at the time are disallowed from cost recovery. Using these determinants, regulators set prices based on the cost-of-service-recovery.43

UKPN confronts similar issues in building capacity at bus depots that Con Ed does in New York City. If capacity is overbuilt at a given depot due to improvements in bus ranges and charging

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infrastructure, UKPN may be disallowed from recovering the cost of building the infrastructure. Overall, this increases the cost of BEB adoption given new construction needs, and likely significant disruptions including digging up streets to add power lines.

UKPN has an additional constraint that Con Ed does not share in the ability to include new customer connections in the rate base. UKPN customers must pay fully for the upfront cost of adding capacity on site, while Con Ed can include these costs in the rate base. TfL depot operators face higher upfront cost in fleet conversion than the MTA due to the connection charge to increase capacity on-site.44

FUNDING ELECTRIC BUSES

Cost of Electric Buses

A recent report from BNEF identified the largest challenge faced by electric bus technology as the high upfront cost as compared to operationally proven diesel opportunities.45 The sentiment was validated in discussions with the MTA and TfL as the organizations look to meet pollution and electrification goals, while maintaining an affordable service for their customers.

While upfront costs are an important consideration for capital allocation for bus operators and transit agencies, the real cost saving benefits of electric buses can only be realized with a total cost of ownership (TCO) calculation. Depending on battery size (a significant factor in BEB cost) and bus utilization, electric buses research from BNEF demonstrates that from a TCO perspective, electric buses are competitive with diesels buses today. Therefore, it is critical that organizations evaluate future operational expenditures in tandem with expected capital expenditures in order to better evaluate true costs during asset procurements.

The Federal Transit Administration estimates the “expected or planned useful life” of a transit bus to be between 12 and 15 years. Diesel buses have an approximate upfront cost of $450,000 per unit, but are significantly more expensive to maintain and fuel than an electric bus. Upfront costs of electric buses vary based on battery capacity, but estimates range between $750,00046 for vehicles with 350 kWh of battery capacity to $530,000 for buses equipped with 110 kWh47. These higher upfront costs are mitigated by lower maintenance and fuel costs as compared to diesel. A Columbia University study found that “annual savings are estimated at $39k per year over the 12-year lifetime of the bus, excluding health care cost benefits.”48 This estimate does not include the costs associated with upgrading depots because the conditions at a particular depot can vary significantly.

BNEF produced the graph below to illustrate the cost savings associated with a TCO approach. Appendix III shows likely configurations of electric buses on a TCO basis. As bus utilization increases, electric buses can be cheaper to operate than diesel today. The BNEF analysis also evaluates the cost of various charging infrastructure configurations which all result in a net savings or

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TCO parity with diesel. Additionally, as the EV market continues to grow, battery costs are expected to continue down the cost curve with manufacturing scale up and technology improvements.

In addition, bus operators are also developing innovative ideas to further reduce upfront costs. Greentech Media recently reported on Proterra has introduced a battery leasing program with financing provided from Mitsui that brings the upfront cost of an electric bus equal to that of diesel. Bus operators then make lease payments for the batteries over the 12-year operating life of the bus. Appendix IV shows declining battery costs in greater detail.

![Figure 1: Total cost of bus ownership comparison with different annual distance](image)

Metropolitan Transit Authority Budget Process

In 2017, the MTA collected a total operating revenue of $8.7-billion, while incurring total operating expense of $15.5-billion. With $6.4-billion in dedicated taxes and state and local subsidies, MTA still had a budget deficit of $300-million. The deficits continue to grow in MTA’s 2018 mid-year forecast, 2019 financial plan, and plans for the future. The growing deficits serve as MTA’s justification for additional state and local subsidies through dedicated revenue streams, including a congestion pricing that will take effect in 2021. Nevertheless, tensions exist between who should bear the burden of new revenue streams through fare increase, dedicated city taxes, or state taxes as sources of funding to meet MTAs budget needs going forward.

Due to the complexity of its funding sources, the MTA adopts its financial plan in December, and prepares four-year projections that allow New York State and New York City to understand MTA’s

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50 Ibid

upcoming funding needs. In January, the governor of New York State proposes the state budget that includes the State’s contributions to the MTA, and the New York State Legislature votes on the budget before the end of March. The mayor of New York City also considers the MTA’s financial plan in the City’s budget proposal, and New York City Council holds several hearings on the MTA before voting on the city budget that includes the City’s contributions to the MTA. As the MTA continues to request more funding, state and city legislators criticize the inefficiencies of the MTA, and are reluctant to increase funding until the MTA demonstrates improvements in its performance metrics.

Operating Budget vs. Capital Budget

Similar to other public entities, the MTA’s budget is segmented into an operating and capital budget. The operating budget includes expenses related to the daily operation such as payroll and fuel costs. The capital budget includes major investments such as new subway lines or new bus procurements. The MTA issues bonds to finance its capital projects and pays off the bonds through the lifetime of the financed projects. Debt service represents the annual payment toward the capital projects. Appendix II shows the breakdown of MTA’s budget in greater detail.

MTA’s expenses related to bus operations in New York City include the expenses of New York City Transit (NYCT) and MTA Bus Company (MTABC). Fuel expenses are approximately $112-million in the 2018 estimate, a fraction of the electric power expenses used by the subway system as a point of comparison. In the same estimate, NYCT collects approximately $926 million in revenue from its bus operations. Meanwhile, MTABC collects approximately $240 million in operating revenue, but incurs approximately $1,001 million in expenses, resulting in a deficit of approximately $761 million. These budget deficits may seem significant, but only represent a small percentage of MTA’s total operating expenses.

Electric bus procurement and associated infrastructure upgrades represent capital investments that reduce fuel costs in the operating budget, but may result in an increase in the line item of “electric power.” An increase in capital investments also results in an increase debt service. Currently, debt service constitutes 16% of MTA’s total expenses. The level of debt service has implications on whether the MTA has the ability to procure electric buses and upgrade existing infrastructure, as the MTA board may limit the level of total debt service and annual debt service, with the understanding that annual debt service may crowd out other operating expenses.

Credit Ratings

MTA’s debt service level also impacts its credit ratings and its ability to borrow in the future. Amidst declining projections of MTA ridership, in 2018, S&P Global Ratings downgraded MTA’s credit ratings twice within five months.

Kroll Bond Rating Agency also has a negative outlook on MTA’s

References:


Every City
transportation revenue.\textsuperscript{62} Coupled with the lack of available public information for investors, the declining investor confidence increases financial risks and MTA's cost of borrowing.\textsuperscript{63} To stabilize its finances, the MTA has long advocated for a congestion pricing proposal, allowing the MTA to leverage the new revenue-generating mechanism that would support increased borrowing.\textsuperscript{64}

As of March 2019, the MTA has a total outstanding debt of more than $40-billion.\textsuperscript{65} With New York State Governor Andrew Cuomo's five-year, $29.5 billion capital program, the New York State Comptroller claims that the MTA could face $42 billion in outstanding debt by 2022.\textsuperscript{66}\textsuperscript{67} The State can restore investor confidence by earmarking funding for capital projects, or by paying down long-term liabilities, but it does not always do so.\textsuperscript{68}

Other Revenue Streams

State and local legislators are always looking for other revenue streams in financing both the MTA's operating and capital expenses, as the current revenue streams, including the Metropolitan Commuter Transportation Mobility Tax levied on employers in the jurisdictions serviced by the MTA, are inadequate in covering even the operating expenses.\textsuperscript{69} In 2019, the New York State Legislature approved a congestion pricing proposal that would take effect in 2021, and requested the MTA to propose the implementation of congestion pricing, with the endorsement of New York City Mayor Bill de Blasio.\textsuperscript{70}

Although proponents estimate that the congestion pricing plan will generate an annual revenue of $1 billion, there is still much uncertainty. Many stakeholders are requesting exemptions, including New Jersey Governor Phil Murphy, who is negotiating with Governor Cuomo on three crossings into Manhattan.\textsuperscript{71}

State legislators are facing political pressure and are considering

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure6.png}
\caption{The MTA Collected $6.5 Billion in Tax and Subsidy Revenues in 2014: NYC vs. Commuter Counties vs. NY State}
\end{figure}

\begin{itemize}
\item \textsuperscript{62} “MTA Investor Information, Metropolitan Transportation Authority Credit Ratings” Metropolitan Transportation Authority. Accessed March 12, 2019. http://web.mta.info/mta/investor/new/credit-ratings.htm
\item \textsuperscript{69} “Metropolitan commuter transportation mobility tax.” New York State Department of Taxation and Finance. https://www.tax.ny.gov/mctmt/default.htm
\end{itemize}
different treatments for different stakeholders. With many possible exemptions, revenue generated from congestion pricing may fall short of the proposed target today.

Another consideration is that congestion pricing will discourage driving, while encouraging transit usage. Thus, the suggested $1 billion in annual revenue is under the assumption that the toll base will remain constant, but the assumption is unlikely to hold, as fewer commuters choose to drive into Manhattan. The MTA may be able to adjust the congestion pricing rate to offset the decline in toll utilization, but it faces the same political considerations of fare increases. While congestion pricing may not be the solution to solving all of MTA’s financial problems, it can help. More importantly, bus electrification requires reassessment of priorities and earmarking of funding for new bus procurement.

GRID CONSTRAINTS

A primary concern for load-serving entities and distribution utilities relates to the problem of BEB charging schedules. Notably, these concerns are related to load-matching and time-of-use.

Large commercial and industrial power consumers are highly sensitive to the existing rate structures, but do not make marginal decisions based on real-time electricity pricing. Rate structures for large electricity consumers are oriented towards maximum power draw. As a large power consumer itself, the MTA is aware of the additional costs that increased power demand for charging infrastructure would impose. The existing rate structure and its focus on a customer’s total maximum capacity and capacity outside of peak power demand windows limits the enthusiasm of energy managers within the MTA for BEB adoption.

This section of the report will explore the twin problems of grid design and rate structure as a barrier to connectivity. As the MTA develops its plan to transition to a fully-electric bus fleet, the MTA, Con Ed, and NYPA must continue to collaborate as problems with load and rate structure arise or impede progress as explored below.

Grid Implications

Initial concerns for utilities and the New York Public Services Commission on the integration of electric buses to the electricity grid relates to the transmission and distribution network. In place of rapid refueling from fossil-fuels, BEBs require charging infrastructure that draws significant power to “fuel” the BEB. The New York Independent System Operator (NYISO) has assessed the reliability of the electricity grid through 2028, and does not anticipate issues with reliability.

EVs have the greatest impact on electricity distribution in terms of capacity, managing demand, and physical infrastructure including substations, transformers, and chargers. The best way to look at distribution capacity is by estimating seasonal peak capacity. Con Ed estimates summer peak capacity at approximately 14,500 MW of power, with a winter peak capacity of approximately 8,300 MW. This means that except on the hottest day of the year, there is approximately 6,200 MW of flexibility in the distribution system’s capacity overall. Evidence from NYISO’s analysis further supports the potential for electricity delivery constraints to be eased. NYISO estimates that New York’s peak demand will

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decrease by an “average rate of 0.13% from 2018 through 2028.” This means that the growth in electric buses will not necessarily constrain the distribution system in NYC purely from a capacity standpoint.

However, physical constraints do still exist and solutions may still need to be integrated to mitigate capacity constraints on the proverbial “peakiest day” of a hot summer. For example, even if overall capacity is largely unaffected, the so-called “last mile” of distribution, or the connection from a substation or transformer to the final point of use can become overloaded. Suppose that multiple depots or other EV charge points are clustered and using the same substation. Simultaneously using the same distribution transformer may cause damage or outages from overloading. This can lead to degradation of power quality and necessitate costly replacement of equipment.

As stated earlier, BEBs shift the load profile for power demand and EV charging often coincides with existing peak demand making it the most expensive and capacity-constrained time of the day. This problem makes demand management an imperative for utilities and utility regulators. Solutions exist to smooth demand with physical additions such as the use of battery storage during peak times and through the use of differentiated pricing to send signals to fleet operators to change their charging behavior during peak hours.

NYISO has expressed concern over potential power and energy transmission constraints to NYC in coming years. These concerns are compounded by the increase in supply that is necessary to support various electrification efforts in the City, including by the MTA. Although NYC and the surrounding regions consumed 66 percent of electricity produced in 2017, these regions only produced 50 percent of the state’s electricity. The calculations and transmission and distribution infrastructure investment planning requires further in-depth evaluation to avoid transmission constraints, but it does not appear to be a prohibitive factor for Con Ed and the MTA.

There is a clear plan regarding infrastructure upgrades needed for electricity transmission. Recently, NYISO announced a plan to build an additional 900 MW of transmission capacity from upstate New York and Ontario to support the state’s renewable energy ambitions. While reliant on final approval from the PSC, capital planning for renewable energy proliferation and transportation electrification is ongoing that will allow the MTA to move forward with fleet electrification.

**Electric Buses and Charging Technology - Charging Voltage**

As charging technology advances, higher voltage chargers for electric vehicles with great speed continue to be a market focus. That said vehicle charging is application specific, and the premium price of high voltage equipment is not necessarily needed for all applications. Additionally, high voltage charging will require moving from 400V battery pack designs to materials and design that supports 1000V.

Bus operators need to understand route requirements and tailor charging infrastructure to meet fueling requirements. For example, Go-Ahead in London was able to transform their London based Waterloo depot by adding 43, 80kW chargers (composed of two 40kW plugs - per local electricity regulations) that service a fleet of 50 buses at the depot. The buses can complete all operational demands with overnight charging at the depot and no additional on-route DC fast charging.

A typical grid interconnection for Direct Current Fast Charger (DCFC) interconnections is depicted in Appendix V.

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The image to the right shows a re-imagined depot design that utilizes overhead pantograph charging to maximize depot space available for return-to-base charging. In this scenario, a driver would be able to pull into a designated spot within a depot where a pantograph arm would reach down from its overhead mount to automatically recharge the battery. Appendix VI shows various charging options in greater detail.

Additionally, regardless of an operator’s preference, there are two key considerations that must be evaluated for optimal equipment selection. First, selected technology must be compatible with all major bus manufacturer equipment. Second, “smart chargers” can be programmed to evaluate both grid constraints and operational route requirements in order to optimize charging accordingly.

**Technology Agnostic**

As bus operators like the MTA begin to procure increasing numbers of electric buses, they must be mindful of the potential for manufacturer lock in. For example, if charging infrastructure is installed that is specific to a single bus manufacturer, it could preclude competitive bidding for bus procurements which may inhibit price reductions. Additionally, the electric bus market is still developing and it is important that chargers not preclude flexibility for future bus procurements.

**Smart Charging Controls**

Charger technology has become increasingly sophisticated and is critical for efficient management of the more complex charging demands associated with fleet operations. Bus operators must balance charging needs accordingly for weather and route demands that can affect seasonal and even day to day operational range. At the same time, local utility tariff regulations have significant cost implications as to when vehicles should be optimally charged. If demand charges are in place, chargers must be optimized to schedule charging at a level that minimizes costs while still meeting operational requirements. Chargers must also be able to adapt for future regulatory changes such as movements toward time of use of real time electricity pricing.

**Rate Structure**

Current rate design does not allow for price discovery, and is inflexible. Any alteration of a rate structure or price must be approved by the PSC. Additionally, once a demand charge has been set for a given billing cycle, the MTA does not have an incentive to reduce demand for the remainder of a billing cycle. Rate structures are only effective once after receiving approval by the New York State Public Service Commission. Any alterations to the existing rate structure has to be made by Con Ed.

Current visions of the charging schedules that will be used for BEBs are not compatible with the current infrastructure. The initial conception involves dedicated chargers for each bus at
approximately 60 kW per BEB. Some expect that each BEB will be charged simultaneously. With the demand charges associated with commercial and industrial accounts, this model is cost prohibitive.

The demand charge for high-tension service for Con Ed’s Large customers under Rate I is $13.91 per kW for non-summer months, and $19.71 per kW during summer months. If charging is timed poorly in a non-summer month, a depot could add $834 to that month’s bill for each bus. If the depot makes a similar mistake during the summer, the mistimed use of the BEB chargers could add $1,180 per bus. Without the specific rate structure for the MTA, these numbers are high-level estimates. However, the provided calculations show that the total cost of ownership of BEBs compared to diesel or natural gas buses can rapidly erode if not well monitored.

Two California utilities have implemented rate structures related to electric fleet charging. These rates attempt to prevent large fleet owners from charging vehicles during peak hours and reduce the penalties associated with increased power demand. Southern California Edison’s recently approved rate structure removes the demand charge for the next five years, and only recovers cost on a time-of-use rates basis. Pacific Gas & Electric’s rate structure permanently eliminates demand charges in favor of a subscription fee that is lower than the cost of demand charges.\textsuperscript{79} The rate structure also relies on time-of-use rates for much of the cost. Both of these options alleviate the concerns over unpredictable, expensive demand charges, and treat the time of charging as a partnership between the utility and the customer. As such, the MTA and Con Ed can learn from California utilities as to how to effectively meet the fueling requirements for BEBs while not straining the grid.

**OPERATIONAL CONSIDERATIONS**

**Electric Bus Implementation Strategies**

As bus operators like the MTA and Go Ahead-London transition from diesel to electric fleets two factors have an outsized impact on operations scale up. First is the need for operational testing at low levels of implementation. Testing allows for operators to gather information on bus performance such as battery capacity, charge scheduling, maintenance and depot logistics required to scale up operations. Second, large fixed costs associated with the interconnection upgrades needed to service a fully electrified depot are a significant cost barrier to implementation. Therefore, it is important that an operator has gained some initial experience with new technology before scaling investments. That said, interconnection upgrades needed to support smaller scale “pilot implementation” can be minimal in some depot locations. Therefore, operators can gain initial experience with limited interconnection cost risk.

The diagram on page 24 demonstrates an example of a bus operator pilot implementation where a hypothetical 10 electric buses have been commissioned for testing. Given the low number of buses in a testing phase, charging can occur with minimal upgrades to existing depot electrical service. To gain additional cost certainty, the MTA has coordinated directly with Con Ed to identify depots locations with sufficient capacity to easily accommodate 5-10 buses. This allows the MTA to proceed with pilot implementation at the lowest cost possible. Operators are then able to gather data on bus performance, experiment with different route distances and gather valuable information that will allow for an efficient and well planned operational scale-up.

After the pilot phase has provided sufficient operating data, bus operators can begin to scale up procurement. Bus operators must continue to coordinate with utilities to understand interconnection upgrades and construction timelines to install electrical infrastructure capable of supporting a fully electric depot. Even with smart charging to manage power flow, depots containing several hundred electric buses will require significant infrastructure upgrades. This involves planning and coordination between a bus operator and utility to understand power draw of the new equipment that will be added to their system. Potential upgrades could include installation of new depot switchgear, transformers, multiple cable runs to distribution service, upgraded distribution feeders, and other location specific requirements. It is important that utilities and bus operators actively coordinate during interconnection phases to implement the most efficient and lowest cost design for a given depot.

**Funding Interconnection Upgrades**

A key question in the overall affordability of electric bus implementation is the cost of interconnection upgrades associated with the full scale up of electric bus depots. In the Con Ed 2020 rate case, the company requested $35 million in funds for “make ready” charging infrastructure. In its request, Con Ed cites that “when customers or developers seek to install EV charging facilities that require a second service, the charging facilities are characterized as Excess Distribution Facilities (EDF).” Con Ed states that “the dense urban environment” of its service territory “can require extensive trenching and construction to extend service, which translates to high EDF costs for the customer.” The company points to interconnection costs required to support EDF-related work for EV Direct Current Fast Charging as ranging $700,000 to $2.5 million, with a median cost of approximately $900,000 for a station consisting of six 150 kW DCFC plugs. Additionally, Con Ed states that maintenance fees for this EDF infrastructure can nearly double the typical cost to customers over ten years.

The fact that the MTA may be solely responsible for the costs to extend excess distribution infrastructure is a highly problematic regulatory constraint for electric bus depot upgrades. This utility rule is intended to prohibit rate basing of unnecessary customer specific upgrades but warrants an exception in the case of public transportation modernization, as is clearly the intent of Con Ed’s make ready infrastructure proposal.

However, the MTA faces a significant obstacle in accessing the benefits of Con Ed’s make ready program as the funding is only available for “publicly accessible charging infrastructure.” The NYPSC has broadly defined “publicly accessible” as charging stations that allow access without physical access restrictions, but notes that “additional refinement as to what constitutes a publicly accessible charging station is necessary to ensure the largest possible pool of public benefits.”

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85 NY - PSC. CASE 18-E-0138 - Proceeding on Motion of the Commission Regarding Electric Vehicle Supply Equipment and Infrastructure. ORDER ESTABLISHING FRAMEWORK FOR DIRECT CURRENT FAST CHARGING INFRASTRUCTURE PROGRAM. February, 7 2019. (44)
**Fig. 1 Electric Bus Depot Schematic - Initial Procurement**

*Bus Depot (10 Electric – 190 Diesel Buses)*

Initial Bus Procurement

Existing Depot Electrical Service and Account (Minimal Upgrades Needed)

Charging at 480v (losses in stepping down to 120v and then back up to 480v)

Existing 13kV Distribution Feeder

Local Utility Substation

- Existing Depot Schematic - Initial Procurement

**Fig. 2 Electric Bus Depot Schematic - Scale-Up**

*Dedicated Depot Substation (Potential DC load Center)*

“DC Fast Charging as a Service Tariff” – Public Service Infrastructure

Allow utilities to rate base Excess Distribution Facilities / Secondary Service upgrades that support comprehensive MTA depot electrification

480v or 1000v charging (reduced transformer losses)

Charging at 480v (losses in stepping down to 120v and then back up to 480v)

Existing 13kV Distribution Feeder

Local Utility Substation

- Existing Depot Schematic - Scale-Up

EVery City
RECOMMENDATIONS

Framework and Criteria for Recommendations

Electric buses are viable today and can yield significant economic, environmental, and social benefits for cities that choose to adopt the technology. The question is not whether it's possible for NYC to adopt electric buses, but will the city manage the implementation of electric buses in an effective manner that maximizes the benefits for all stakeholders by the stated target date. The following recommendations are actionable steps that decision-makers can take to ensure that NYC and the MTA successfully adopt 100% electric buses by 2040.

Key criteria used in the evaluation of the available policy options include cost-effectiveness, technological availability, political viability, and operational integration. While many aspects of the MTA’s operating model may have to adapt to electric bus adoption, the MTA can still achieve its mission of delivering reliable, safe, and affordable surface transit services with the following recommendations.

REGULATING EMISSIONS

Recommendation 1: The NYC Mayor’s Office of Sustainability and the State should align the MTA’s bus goal to a specific emissions reduction target to ensure progress is tied to environmental outcomes.

While NYS and NYC have set emissions reduction targets for their jurisdiction that apply to transportation emissions, MTA’s bus goal is disconnected from those targets. Without a clear connection to the state-level and city-level emissions targets, MTA risks not making needed progress on goals and not timing procurement cycles for new BEBs to measurable emissions reductions.

Recommendation 2: The NYC Mayor’s Office of Sustainability should adopt additional performance-based environmental policies to drive additional action across transport sub-sectors and accelerate EV adoption.

NYC should consider implementing a low emissions zone(s) using London’s implementation of the LEZ and the ULEZ as a model. Proponents of congestion pricing in NYC have suggested that revenues from the new congestion charges will help fund the MTA bus and subway systems. While this is a positive step toward alleviating budget deficits and funding desperately needed system upgrades, it is unclear whether congestion pricing will have a real-world environmental impact.

To specifically target air quality improvements from transportation related emissions in NYC, the City should consider implementing a low emissions zone on top of the congestion charge to restrict the most polluting vehicles from entering sensitive areas. The benefit of a policy like this is that it drives low emission technology across all classes of vehicles including MTA buses. A LEZ could accelerate the deployment of electric buses in critical places in NYC, help drive adoption for commercial fleets and private car owners, and it would create a new revenue stream for MTA that could be reinvested in the transition to electric buses. Politically it may be difficult for NYC to enact a LEZ like this at the same time that it is introducing congestion pricing. However, NYC can set a future target for implementation that aligns with the interim goals for electric bus adoption that this report recommends and in alignment with other NYSERDA targets for EV penetration.

NYS should also expand upon its participation in the Northeast states Transportation and Climate Initiative (TCI) and help design the proposed cap-and-trade market for vehicle emissions that TCI has proposed. Not only would this drive greater emissions reductions and accelerate EV adoption, but the market would create new revenue streams that could be reinjected into the MTA to fund the transition to electric buses and take even more cars off the road.
MANAGING ELECTRICITY LOAD AND RATES

**Recommendation 3:** Electric bus advocates, operators and utilities should work with the NYPSC to develop a rate structure that sends a correct price signal to customers that helps to manage charging times and peak load.

In order to make the transition to BEBs, the issues surrounding cost-effectiveness as currently constrained under rate structures must be eased. Demand charges should be eliminated for bus charging operations and be replaced with time-of-use rates. The time-of-use rate should include seasonal considerations, and be kept as stable as possible. We find that issues surrounding summer peak demand are a key chokepoint in keeping the TCO for BEBs low. This recommendation recognizes the need to prevent additional demand growth during periods of peak constraint during the grid, but allows for greater price discovery by the MTA.

Popular support is required for this recommendation to be feasible. Advocates for electric buses must emphasize the health benefits and environmental justice gains from the transition to BEBs in their campaigns to encourage electrification. The MTA must petition for separate rate classification and reconsideration for the grid services that it can provide to each customer by load shifting and placing several high-power draw resources onto the grid in the evening. The additional stability provided by smoothing demand will also support intermittent resources in the evening, such as offshore wind, as deployment progresses. An ongoing partnership and transparent prices will allow the MTA to maintain the cost-effectiveness of a transition to a BEB fleet while not creating a perverse incentive that will lead to increased demand during peak periods.

As any rate changes must be approved by the NYPSC, the commitment of advocacy groups to this goal is crucial to support the cost-effectiveness of BEBs. If the NYPSC is not adequately convinced of the benefits of time-of-use rates and price exposure for the MTA, rate redesign is unlikely to proceed. By utilizing grassroots pressure, advocacy groups may be able to persuade Commissioners of any TOU agreement reached between Con Ed and the MTA.

IMPLEMENTING ELECTRIC BUSES

**Recommendation 4:** The MTA should set specific vehicle procurement targets through 2040 that help ensure their fleet transition goal is met.

The MTA board should establish specific interim procurement goals that lay out a proposed roadmap of the transition to an all-electric fleet by 2040. Any detailed documentation of these goals that may exist is not public facing and therefore lacks accountability. This recommendation has the additional benefit of reducing stakeholder uncertainty and allowing for planning and course corrections if operational challenges arise. For example, if implementation or operational challenges were to arise the interruption would be considered a delay and allow for MTA leadership to update projections of the transition timeline and procurement volumes necessary to meet the 2040 goal. Without transparent and definitive targets, delays or setbacks may not be taken as seriously. Interim procurement targets would establish additional accountability and elevate the importance of this effort with clear metrics.

**Recommendation 5:** Bus operators should initially focus on shorter routes and depots that have excess grid capacity and will not trigger major electrical infrastructure upgrades.

Existing BEB technology options are well-equipped to handle simple operations, but are limited in cold/inclement weather or for longer routes without excess backup buses or frequent charging. To match the current use-cases that BEBs are well equipped for, the MTA should continue to implement BEBs on shorter routes.

Second, the MTA should transition its fleet to BEBs to the extent that depots have existing capacity for charging infrastructure. To meet its interim goals, the MTA should focus on rapid
implementation where possible, while waiting for technological improvements to expand range and HVAC capabilities. While there could be cost benefits to waiting for BEBs to become mainstream, the early transition will provide valuable operational experience for management, drivers and maintenance employees to become familiar with BEBs, and should reduce anxieties that may be held by fleet over fleet transition.

Implementing charging infrastructure to the extent allowed by current connection capacity and local grid capacity provides another trial as to the maximum demand needed at significant penetrations of BEBs. Typically, capacity increases are based on the total interconnected capacity of the end-use application - in this case, the nameplate capacity of the charging stations and the number of charging stations. If the MTA successfully begins to integrate BEBs into its fleet, the MTA will be able to test the percentage of capacity needed for expansions. This in turn will provide the MTA with significant cost savings compared to building infrastructure for the power draw of each individual charger operating at maximum capacity.

**Recommendation 6:** Con Edison and the NYPSC should evaluate tariff modifications that allow for rate basing necessary infrastructure upgrades to service the interconnection of electric bus depots.

Existing regulations require excess distribution facilities to be paid for by customers. In the case of public transportation infrastructure such as electric bus infrastructure, this requirement is owed careful consideration and the possibility for waiver. Alternatively, a tariff could be developed with specific regulations that dictate the scope and process of applying for a building out required interconnection facilities for fleets of public service vehicles.

One potential solution to address large interconnection upgrades for transportation fleets is the implementation of a testing and development program that could inform the design of a tariff permitting utilities to fully rate base required infrastructure upgrades. However, it is important that this proposal be analyzed and debated to ensure infrastructure has broad public benefits and does not act as a direct subsidy to private businesses. This *DC Charging as a Service* tariff would lay out rules for new service requests and allow utilities to coordinate directly with organizations like the MTA to rate base required infrastructure upgrades.

**FINANCING THE TRANSITION**

**Recommendation 7:** The MTA Board should take steps to link the Capital Budget and the Operating Budget in order to promote BEBs and other cost-savings technologies with higher upfront costs.

While electric buses are cost competitive today on a total cost of ownership (TCO) basis, challenges still remain for MTA to fully realize the TCO benefits of electric buses. TCO for buses must account for the higher upfront capital cost of the vehicle and the lower variable costs of fueling and maintaining the bus over its useful life. MTA faces a challenge in realizing the TCO benefits because the larger capital expenditure for new vehicles and necessary depot upgrades is allocated from MTA’s capital budget. Operational expenses including lower fuel costs and lower maintenance costs occur in MTA’s operational budget.

Given the 5-year planning cycle for capital budget programs separate from the distinct, annual plans for operational expenses, the savings on maintenance would only be realized in an annual budget. In order to emphasize the value of the transition to BEBs for MTA riders, there should be a valuation of future benefits of the procured buses. To properly account for the financial benefits, future savings must be discounted by the MTA’s discount rate. In the MTA’s case, the annual savings from BEB adoption should be discounted by the bond issuance rate. Correcting the disconnect between the operational and capital budgets will allow the MTA to realize the long-term benefits of a BEB transition, and may promote additional cost-saving synergies in future capital expenditures.
REFLECTIONS

Additional Research Needs

While this report addressed many practical aspects of implementing electric buses in NYC, more research is needed as NYC progresses steadily toward 2040. The following areas were out of scope for EVery City and are outstanding needs that require further investigation:

- **Route optimization for phases of electric bus implementation** – As the MTA makes progressively larger purchases of electric buses, more thoughtful planning must occur to transition routes and depots to all electric. The MTA or independent researchers should undergo a planning exercise to evaluate all route data to optimize routes for electric buses taking into consideration route distance, charging needs, off-peak charging hours, and battery range.

- **Siting of on-route opportunity charging** – Similar to the previous point, the MTA has indicated that it is interested in using on-route opportunity charging in addition to depot charging to help extend the range of electric buses in service. This is another strategic exercise that will require significant data analysis and joint planning with Con Ed to site and install on-route chargers.

- **Solutions for consumer responsiveness to time-varying rates** – EVery City recommends the elimination of demand charges and the implementation of time of use rates for electric buses to shift charging patterns to off-peak hours. However, rates are only as effective if customers have visibility and access to information to respond to price signals. Customer interface solutions are needed to ensure that customers respond to TOU rates.

- **Analysis for price-setting of a Low Emissions Zone charge** – Should a LEZ be considered by the city, analysis must be done to establish the economically efficient and effective price for entering the LEZ.

Lessons for EVery City

The trend of electric bus adoption is largely being driven by cities around the world that are motivated by an urgent need to reduce carbon emissions and improve air quality simultaneously. While the technology is certainly promising, few models around the world exist for cities that have successfully implemented 100% electric bus fleets. Policies and programs that work – environmentally, economically and politically – have the potential to be adopted elsewhere. Thus, the learnings from NYC, London, Shenzen, and many other cities that are forging ahead can be extremely useful to every city.

While the recommendations of EVery City were developed with the unique characteristics of NYC in mind, many lessons from this study can be applied to other cities. As cities gain more experience with electric buses and understand the barriers and opportunities, continuous information sharing and the development of best practices is critical to the global growth of this market.

Furthermore, the experience in cities can accelerate the shift of other vehicle classes to battery electric power. Sub-national governments and cities in particular hold a unique position and their governments are more nimble than state and national elected officials to take decisive action, often with immediate and impactful results. To this extent, cities are a powerful test-bed for larger action and there are already emerging examples of urban demonstrations of other heavy-duty vehicles that were previously assumed to be difficult to electrify.

Additionally, by 2050, two-thirds of the world’s population is expected to live in cities, meaning the conditions are ripe for local governments to play a more prominent role in shaping policy with
greater impact. For example, organizations like the C40 Cities emerged as an influential and well-funded network of city leaders to connect more than 90 of the world’s cities in every region. These cities represent over 650 million people, one quarter of the global economy, and 70% of the world’s GHG emissions. The potential emissions reductions captured by city-level pledges of another influential network, the Compact of Mayors, may be enough to close one-quarter of the gap between the current national pledges made to the Paris Agreement and the Paris Agreement’s 2°C target.

Based on the initial experience of NYC’s transition, the following lessons can be applied to every city that intends to adopt electric vehicles:

- Clear top-down policy regarding emissions and technology goals provides certainty to the market. The transition to electric buses will be more successful if the relevant decision-makers have a clear mandate that ties bus procurement targets with emissions reductions at clear milestones. This alignment can help ensure transparency, accountability, and real-world environmental benefits of electric bus adoption.

- Grid capacity must be assessed, but can be managed with cooperative planning. Places around the world that are challenged by transmission reliability, generation capacity, and load management should carefully evaluate the available capacity on the grid. NYC likely will not face these challenges, but many cities particularly in developing markets may struggle with rapid EV deployment.

- Rate design can make-or-break electric buses especially in early stages of implementation. Utilities have the potential to benefit from electric vehicles given the potential for utilities to rate-base investments and experience higher utilization rates of existing capacity. It’s critical that transit authorities, electric utilities, and relevant regulators work together to evaluate rate design in order to mutually benefit fleets and utilities.

- Route and depot planning should assume that 100% of a future fleet will inevitably be electrified even if initial time-bound procurement targets are lower than 100%. Fleet operators should proactively plan for 100% electric fleets due to the complex configuration of depot charging infrastructure and the impact of on-route charging to route planning.

- TCO benefits are only realized when CapEx and OpEx are funded together. Cities like NYC that have separate budget planning processes for capital budgets and operating budgets should consider taking steps to reorient their budgets to fully realize the lifetime savings of electric bus adoption.

- Proactive and transparent engagement between policymakers and implementers is critical. The electrified transportation trend means that previously unrelated industries, the power sector and the transport sector, and their respective government agencies and regulators are required to set policy together in unprecedented ways. While this may take some time, all parties involved will achieve better outcomes through coordinated efforts.
APPENDICES

Appendix I

<table>
<thead>
<tr>
<th>Fleet / Procurement</th>
<th>Current Fleet</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>NYCT DOB</td>
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<tr>
<td>Standard 40'</td>
<td>3,114</td>
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<tr>
<td>Diesel</td>
<td>1,409</td>
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<tr>
<td>CNG</td>
<td>431</td>
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<tr>
<td>Hybrid</td>
<td>1,264</td>
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<tr>
<td>All Electric*</td>
<td>10</td>
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<tr>
<td>Articulated 60'</td>
<td>858</td>
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<tr>
<td>Diesel</td>
<td>753</td>
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<tr>
<td>CNG</td>
<td>105</td>
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<td>Express 45'</td>
<td>497</td>
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<td>TOTAL</td>
<td>4,469</td>
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<table>
<thead>
<tr>
<th>Fleet / Procurement</th>
<th>2018/2019 Deliveries</th>
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<tr>
<td></td>
<td>Root</td>
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<tr>
<td></td>
<td>Proterra Dist. All Electric Bus (Lease)</td>
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<tr>
<td></td>
<td>Nova LFS-60 Clean Diesel</td>
</tr>
<tr>
<td></td>
<td>New Flyer XN-60 CNG</td>
</tr>
<tr>
<td></td>
<td>New Flyer XD-40 Clean Diesel / Hybrid</td>
</tr>
<tr>
<td></td>
<td>Nova LFS-40 Clean Diesel</td>
</tr>
<tr>
<td></td>
<td>Nova LFS-60 Clean Diesel</td>
</tr>
<tr>
<td></td>
<td>New Flyer XD-60 Clean Diesel</td>
</tr>
<tr>
<td></td>
<td>New Flyer XD-60 Clean Diesel</td>
</tr>
<tr>
<td></td>
<td>New Flyer All Electric Bus</td>
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<td></td>
<td>Total</td>
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MTA 2019 Preliminary Budget
Baseline Expenses After Below-the-Line (BTL) Adjustments
Non-Reimbursable

Where the Dollars Come From …

By Revenue Source
($ in millions)

<table>
<thead>
<tr>
<th>Revenue Source</th>
<th>Amount $</th>
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<tbody>
<tr>
<td>Farebox Revenue</td>
<td>6,422</td>
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<tr>
<td>Toll Revenue</td>
<td>2,027</td>
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<tr>
<td>Other Revenue</td>
<td>665</td>
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<tr>
<td>Dedicated Taxes</td>
<td>5,961</td>
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<tr>
<td>State &amp; Local Subsidies</td>
<td>1,261</td>
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<td><strong>Total</strong></td>
<td><strong>16,335</strong></td>
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Where the Dollars Go …

By Expense Category

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<tr>
<th>Category</th>
<th>Amount $</th>
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<tbody>
<tr>
<td>Payroll</td>
<td>5,456</td>
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<tr>
<td>Overtime</td>
<td>813</td>
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<tr>
<td>Health &amp; Welfare</td>
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<tr>
<td>Pension</td>
<td>1,352</td>
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<tr>
<td>Non-Labor</td>
<td>456</td>
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<tr>
<td>Debt Service</td>
<td>2,731</td>
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<tr>
<td>Other Labor</td>
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By MTA Agency

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<tr>
<th>Agency</th>
<th>Amount $</th>
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<tr>
<td>NYCT/SIR</td>
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<tr>
<td>LIRR</td>
<td>1,701</td>
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<td>MNR</td>
<td>1,340</td>
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<tr>
<td>MTABC</td>
<td>818</td>
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<tr>
<td>HQ/MTAC</td>
<td>490</td>
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<tr>
<td>BAT</td>
<td>568</td>
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<tr>
<td>Debt Service</td>
<td>2,731</td>
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</tbody>
</table>

By Expense Category

1. Totals may not add due to rounding.
2. Expenses exclude Depreciation, OPEB Obligation, GASB 68 Pension Adjustment and Environmental Remediation. MTA Capital Construction is not included, as its budget contains reimbursable expenses only.
3. These below-the-line adjustments impact expense dollars and have not been allocated to specific Agencies as yet.

Appendix III

Figure 23: TCO comparison for the most likely e-bus configurations in a large city

TCO, $ per km

<table>
<thead>
<tr>
<th>Configuration</th>
<th>TCO 1.03</th>
<th>TCO 0.92</th>
<th>TCO 0.86</th>
<th>TCO 0.84</th>
<th>TCO 0.81</th>
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</thead>
<tbody>
<tr>
<td>CNG bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow depot charging</td>
<td>0.07</td>
<td>0.10</td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
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<tr>
<td>Wireless charging</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td>Fast charging on-route</td>
<td>0.58</td>
<td>0.44</td>
<td>0.48</td>
<td>0.48</td>
<td>0.48</td>
</tr>
<tr>
<td>Fast charging at terminal</td>
<td>0.00</td>
<td>0.00</td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Source: Bloomberg New Energy Finance, AFLLET, Advanced Clean Transit – Cost Assumptions and Data Sources (California Air Resources Board) Note: Diesel price at $0.66/liter ($2.5/gallon), CNG price at $15 per MMBtu, electricity price at $0.10/kWh, annual distance traveled – 60,000km.

Appendix IV

Figure 12: Lithium-ion battery pack price forecast

Lithium-ion battery pack price ($/kWh) vs. Demand for lithium-ion batteries (GWh/year)

- 2025 implied price: $95/kWh
- 2030 implied price: $70/kWh
- Observed price
- 18% learning rate

Source: Bloomberg New Energy Finance. Note: ESS is stationary energy storage applications.

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Appendix V

Source: Yong, Ramachandaramurthy, Tan, and Mithulananthan

---

Appendix VI

<table>
<thead>
<tr>
<th>Product</th>
<th>Proterra* Power Control System 60kW</th>
<th>Proterra* Power Control System 120kW</th>
<th>Proterra* Power Control System 300kW</th>
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</thead>
<tbody>
<tr>
<td>Max Power Available (kW)</td>
<td>60</td>
<td>120</td>
<td>300</td>
</tr>
<tr>
<td>PCS Location</td>
<td>Depot</td>
<td>Depot</td>
<td>Depot / Onroute</td>
</tr>
<tr>
<td>Dispenser Type</td>
<td>Plug in / Overhead</td>
<td>Plug in / Overhead</td>
<td>Overhead</td>
</tr>
<tr>
<td>Connection Standard</td>
<td>J1772 CCS plug in</td>
<td>J1772 CCS plug in</td>
<td>J3105 Inverted PANTOGRAPH</td>
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<tr>
<td>VEHICLES</td>
<td>FC</td>
<td>FC+</td>
<td>E2</td>
</tr>
<tr>
<td>E2+</td>
<td>XR</td>
<td>E2</td>
<td>E2+</td>
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</table>

* Efficiencies based on DuoPower driversin FC series charges at max overhead power limit; XR/E2 series charges at continuous power limit for plug-in; all charge times are approximate.

Appendix VII

<table>
<thead>
<tr>
<th>Stakeholder Interviews</th>
<th>Organization Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build Your Dreams - BYD</td>
<td>Private Company - Electric Bus Manufacturer</td>
</tr>
<tr>
<td>CALSTART</td>
<td>NGO</td>
</tr>
<tr>
<td>City of New York - Office of Sustainability</td>
<td>Government Agency</td>
</tr>
<tr>
<td>Consolidated Edison - Customer Energy Solutions</td>
<td>Private Company - Utility</td>
</tr>
<tr>
<td>Go Ahead London</td>
<td>Private Company - Bus Operator</td>
</tr>
<tr>
<td>HEVO</td>
<td>Private Company - Charging Equipment Manufacturer</td>
</tr>
<tr>
<td>London Mayoral Office - Air Quality</td>
<td>Government Agency</td>
</tr>
<tr>
<td>MTA - Chief Maintenance Office</td>
<td>Public Transit Agency</td>
</tr>
<tr>
<td>MTA - Innovation and Technology Office</td>
<td>Public Transit Agency</td>
</tr>
<tr>
<td>NY Green Bank - Consultant</td>
<td>Government Agency</td>
</tr>
<tr>
<td>NYC DCAS - Energy Management</td>
<td>Government Agency</td>
</tr>
<tr>
<td>NYC DCAS - Fleet Management</td>
<td>Government Agency</td>
</tr>
<tr>
<td>NYSERDA</td>
<td>Government Agency</td>
</tr>
<tr>
<td>Proterra</td>
<td>Private Company - Electric Bus Manufacturer</td>
</tr>
<tr>
<td>Sierra Club</td>
<td>NGO</td>
</tr>
<tr>
<td>Transport for London</td>
<td>Public Transit Agency</td>
</tr>
<tr>
<td>UK Power Networks</td>
<td>Private Company - Utility</td>
</tr>
<tr>
<td>Union of Concerned Scientists</td>
<td>NGO</td>
</tr>
</tbody>
</table>

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